TRAVAUX

International Association of Geodesy

Volume 32

General and technical reports.

1999 - 2003

Established at the XXIII General Assembly,

Sapporo, Japan, July, 2003

Editor: O. B. Andersen

INTERNATIONAL ASSOCIATION OF GEODESY - TRAVAUX 2003

TABLE OF CONTENTS

Foreword O.B. Andersen

SECTION I: POSITIONING

Report by the President A. Dodson

Commissions of Section I:

Comm. X : Global and Regional Geodetic Networks C. Boucher

Special Commisions

SC4: Applications of Geodesy to Engineering H. Kahmen

Special Study Groups

SSG 1.179: Wide Area Modelling for Precise Satellite Positioning S. Han

SSG 1.180: GPS as an atmospheric remote sensing tool H. van der Marel

SSG 1.181: Regional Permanent Arrays R. Weber

SSG 1.182: Multipath Mitigation M. P. Stewart

SECTION II: ADVANCED SPACE TECHNOLOGY

Report by the President C. K. Shum

Commissions of Section II:

Comm VIII: Int Coordination of Space Techniques for Geodesy and Geodynamics (CSTG) H. Drewes

Special Commissions

SC7: Satellite Gravity Field Missions K.-H. Ilk

Special Study Groups

SSG 2.162: Precise Orbits Using Multiple Space Techniques R. Scharroo

SSG 2.183: Spaceborne Interferometry Techniques R. Hanssen

SSG 2.192: Spaceborne GNS Atmosphere Sounding R. Kursinski

SSG 2.193: Gravity field missions: calibration and validation P. Visser

SSG 2.194: GPS Water Level Measurements G. Mader

International Services of Section II:

IGS : International GPS Service R. Neilan

ILRS: The International Laser Ranging Service M.R. Pearlman

IVS: International VLBI Service for Geodesy and Astrometry N.R. Vandenberg

SECTION III: DETERMINATION OF THE GRAVITY FIELD

Report by the President — **M. G. Sideris**

Commissions of Section III:

Comm XIII: International Gravity and Geoid Commission — **M. Vermeer**

Special Study Groups

SSG3.167: Regional Land and Marine Geoid Modelling — **I.N. Tziavos**

SSG 3.177: Synthetic Modelling of the Earth's Gravity Field — **W. Featherstone**

SSG 3.184: Use of Remote Sensing Techniques for Validating Heights and Depths — **P. Berry**

SSG 3.185: Merging data from dedicated satellite missions with other gravimetric data (NO REPORT) — **N. Sneeuw**

SSG 3.186: Altimetry data processing for gravity, geoid and sea surface topography determination — **C. Hwang**

International Services of Section III:

BGI - International Gravimetric Bureau (NO REPORT) — **J-P. Barriot**

IGeS - International Geoid Service (NO REPORT) — **F. Sansò**

SECTION IV: GENERAL THEORY AND METHODOLOGY

Report by the president — **B. Heck**

Special Commissions of Section IV:

SC1: Mathematical and Physical Foundations of Geodesy — **P. Holota**

Special Study Groups of Section IV:

SSG 4.187: Wavelets in Geodesy and Geodynamics — **W. Keller**

SSG 4.188: Mass Density from Joint Inverse Gravity Modelling — **G. Strykowski**

SSG 4.189: Dynamic theories of deformation and gravity fields — **D. Wolf**

SSG 4.190: Non-probabilistic assessment in geodetic data analysis — **H. Kutterer**

SSG 4.191: Theory of Fundamental Height Systems (ONLY PDF) — **C.Jekeli**

SECTION V: GEODYNAMICS

Report by the president — **C. Wilson**

Commissions of Section V:

Comm V: Earth tides — **S. Takemoto**

Comm XIV: Crustal Deformation — **S. Zerbini**

Special Commissions of Section V:

SC3: Fundamental Parameters	**E. Groten**
SC8: Sea Level and Ice Sheets	**M. Bevis**

Joint Working Groups of Section V:

IAG/IAPSO: Joint Working Group Geodetic Effects of Non-Tidal Oceanic Processes	**R. S. Gross**

International Services of Section V:

IERS: International Earth Rotation Service	**B. Richter**
PSMSL: Permanent Service For Mean Sea Level	**P. L.Woodworth**
BIPM: Bureau International des Poids et Mesures - Time Section	**E.F. Arias**
ICET: International Center for Earth Tides	**B. Ducarme**

OUT OF SECTION

GALOS: Geodetic Aspects of the Law of the Sea	**B. G. Harsson**
IAG WG: Working Group on Eduction	**C. C. Tscherning**
IAG-CDC: Committee for Developing Countries (CDC)	**D. Blitzkow**
SIRGAS: Geocentric Reference System for the Americas	**H. Drewes**

MEETINGS

EC - Meetings	**O. Andersen**
IAG Sponsores Meetings	**Various**

NEW IAG STRUCTURE

Executive Summary (ONLY PDF)	**G. Beutler et al.**
New IAG Structure: Status March 2003	**G. Beutler**
Proposal to Establish the "Integrated Global Geodetic Observing System (IGGOS)" as IAG's First Project	**G. Beutler et al.**

Foreword

Every four year the International Association of Geodesy (IAG) publishes its reports for the past four year period, called the "Travaux de l'Association Internationale de Geodesie".
The "Travaux " is published shortly after the General Assembly of the International association of Geodesy held as a part of the General Assembly of the International Union of Geodesy and Geophysics (IUGG) which took place this year in Sapporo, Japan between the 30th June and the 12th of July, 2003.

The Travaux is the complete collection of all the reports of all the bodies constituting the Association. Each of the 5 sections within the IAG reports on their commissions, services, special commissions, special study groups and working groups. A number out of sections reports are found, and the reporting on the work leading/preparing the new structure is documented in this version of the Travaux. This version of the Travaux is volume 32 and it contains more than 34 reports.
It is an instantaneous picture of the work performed the last four years by a large number of individuals and groups through international corporation under the auspices of the International Association of Geodesy. The "Travaux" is published in a short timetable after the General Assembly, so that scientific information can be disseminated rapidly throughout the geodetic community.

I would like to thank all the contributors who did their best to provide their report prior to the Sapporo IUGG General Assembly.

The IAG has established a homepage on the Internet (www.gfy.ku.dk/~iag) as an open up-to-date forum for communication. Through this electronic address, all members of the IAG are now able to have almost real time access to all information related to the IAG. An electronic version of the "Travaux" can also be found here.

As the communication and outreach branch will shortly be transferred to the Hungarian Academy of Sciences. The official internet address of the IAG will also change to www.iag-aig.org.

Ole B. Andersen

SECTION I:

“POSITIONING”

REPORT OF THE PRESIDENT FOR THE PERIOD 1999-2003

A. Dodson

The structure of Section I in the period 1999-2003, was established during the IUGG General Assembly in Birmingham, and was similar to that for the previous four-year period, in that it consisted of one Commission, one Special Commission and four Special Study Groups. These were:

- Commission X "Global and Regional Geodetic Networks"
  President: Claude Boucher

- Special Commission 4 "Application of Geodesy to Engineering"
  President: Heribert Kahmen

- SSG 1.179 "Wide Area Modelling for Precise Satellite Positioning"
  Chair: Shaowei Han

- SSG 1.180 "GPS as an Atmospheric Remote Sensing Tool"
  Chair: Hans van der Marel
  Co-Chair: (ionosphere) Susan Skone

- SSG 1.181 "Permanent Regional Arrays"
  Chair: Robert Weber

- SSG 1.182 "Multipath Mitigation"
  Chair: Mike Stewart

The Commissions and SSGs have all been productive during the period 1999-2003, and full details of their activities are reported below. I will therefore only highlight a few of the more significant aspects of the progress that has been made.

There has been some progress towards realizing the AFREF project, aimed at establishing a continental geodetic reference frame for Africa. Although steady progress has been made, with the support of IAG, there is still a considerable way to go before such a frame is fully implemented. I hope that developments will continue, and the project will repeat the success of the SIRGAS project in South America.

There has been substantial activity in the topic of GPS as an Atmospheric Remote Sensing Tool, as GPS is proving to be of significant importance in a number of atmospheric research and operational applications. In terms of meteorology, there is now considerable development of GPS networks for near real-time forecasting, and growing interest in long time-series data sets for climate studies. The activity in ionospheric studies has been considerable, not least due to the recent period of maximum solar activity.

Signal multipath is still a considerable problem in many environments, but significant progress has been made over the last four years through improved hardware solutions, novel data analysis techniques and sophisticated approaches to system modeling. Interestingly, as with propagation delay, multipath is turning out to be of interest in its own right, not just as a nuisance factor. It is also of growing importance as indoor GPS positioning becomes more available.

Improvements in stochastic and functional modelling have led to substantial improvement in both the accuracy and reliability of precise kinematic positioning solutions. The multiple reference station approach to providing corrections for RTK positioning has led to much improved performance. However, there is still a way to go before long-range sub-centimetre accuracy is achieved.

A growing area of research in the application of geodesy to engineering, has been the use of pseudolites to augment GPS signals, as well as for sole use, and integrated with other sensors. This promises to be an area of continuing interest, particularly in terms of aiding indoor GPS measurement, or providing a "seamless" positioning solution..

Section I has also played a major part in numerous scientific meetings during the last four years, including for example the Mobile Mapping Technology workshop in Cairo, Egypt in January 2001, the symposium on Vertical Reference Systems in Cartagena, Colombia in February 2001, and the workshop on GPS Meteorology in Tsukuba, Japan in January 2003. In addition the Section played a full role in the very successful IAG Scientific Assembly in Budapest, Hungary, in 2001 and will be contributing to many of the symposia, in addition to the specific Section 1 meeting, at the forthcoming IUGG General Assembly in Sapporo, Japan.

It is increasingly apparent that there has been growing interaction and overlap between the Sections of the IAG (Section I and Section II in particular) as well as between the Sections and the IAG services. This is no more apparent than in Section I with for example the subject of global and regional networks being of primary importance to both Commission X and the IGS. For these reasons, the IAG review of its structure, presented and approved at the Scientific Assembly in Budapest, addressed the growing importance of the IAG Services, whilst also redefining the Section/Commission structure in an attempt to recognise the changing geodetic scene.

In the new structure the present five sections and their associated commissions and special commissions will be abolished, to be replaced by four topic-related Commissions (each with a sub-structure of sub-commissions and SSGs). Under this structure a new Commission 4 on "Positioning and Applications" will be established, following the Sapporo General Assembly. This new Commission will encompass much of the role of the current Section I, whilst also recognising the growing involvement of geodesists in the application of geodesy. The exact sub-structure is still to be confirmed but I hope it will enable a much better recognition for the substantial activities of geodesists in the ever growing applications market. This includes not only engineering but also navigation and a wide range of scientific fields, where geodesy is often implicitly involved, but often not explicitly visible. Furthermore the IAG Services, such as the IGS, will have a more explicit role in IAG activities in the future as they will be better integrated with the new Commissions.

Finally, I would like to express my sincere thanks to everyone who has contributed to the Section's activities over the last four years, notably the Section officers, and in particular my Section Secretary, Prof Chris Rizos, for his tremendous efforts. I wish him every success in his role as President of the new Commission 4.

Commissions of Section I

Commission X

“Global and Regional Geodetic Networks (GRGN) “

Report for 2000-2003

C. Boucher

with contributions of

Z. Altamimi, M. Craymer, W. Gurtner, B.G. Harsson, H. Hornik, J. Ihde, W. Kearsley, P. Knudsen, D. Milbert, R. Snay, T. Soler, J.A. Torres, M. Unis, R. Wonnacott

The purpose of the IAG Commission X on Global and Regional Geodetic Networks (GRGN) is to focus on the variety of existing control networks (horizontal or vertical, national or continental, global from space techniques) as well as their connections and evolutions.

The Commission X has two types of subdivisions:

(1) Subcommissions for large geographical areas:

Such subcommissions will deal with all types of networks (horizontal, vertical and threedimensional) and all related projects which belong to the geographical area.

(2) Working Groups for specific technical topics

Several countries has appointed national representatives to the Commission. Details can be found in the Travaux de l’Association Internationale de Géodésie and Geodesist’s Handbook or in the GRGN web page.

Most of the activities was done in the frame of the subcommissions and some in the Working groups. The activities are presented hereafter following this structure.

Report on regional activities

Africa

(Prepared by Richard Wonnacott, South Africa and Mufta Unis, OACT)

The concept of unifying regional or continental geodetic references systems is not new as shown by EUREF, SIRGAS and the Asia and Pacific Regional Geodetic Project. Previously the ADOS (Africa Doppler Survey) project of the 1980's attempted to fulfill this requirement in Africa but, for various reasons, was not entirely successful. The technology at the time required that all stations be occupied simultaneously which made the implementation of the project very difficult indeed from a logistic point of view.

With the increased use of GNSS, and in particular GPS, the prospects of fulfilling the primary objective of unifying the geodetic datums in Africa has become much more feasible and a lot less difficult from a logistic point of view. In addition the activities and services of the IGS have improved the prospects of the successful completion of the project more feasible.

Broad Outline of project

The concept of AFREF is to establish a network of permanent GPS base stations at approximately 1000km spacing which will be connected to stations of the IGS including the Hartebeesthoek Radio Astronomy Observatory (HartRAO).

As the establishment of the primary network of base stations progresses a further break down and densification of the network will take place at the national level. The concept of unifying the vertical datums of Africa will be run in parallel and in conjunction with the Africa Geoid project. A key element in the AFREF project is that the NMO's of participating countries must be actively involved at all stages from the planning to the management and execution stages. A major difficulty lies in the lack of suitable and appropriate expertise in Africa; hence it is suggested that international experts assist in achieving the goals and objectives of AFREF but that the project must remain an African initiative. The resulting transfer of technology will enable African countries to carry out similar projects and to densify national geodetic networks to meet national requirements. The objectives of AFREF are thus:

1. Define the continental reference system of Africa. Establish and maintain a unified geodetic reference network as the fundamental basis for the national 3-d reference networks fully consistent and homogeneous with the global reference frame of the ITRF.
2. Realize a unified vertical datum and support efforts to establish a precise African geoid, in concert with the African Geoid project activities.
3. Establish continuous, permanent GPS stations at approximately 1000km spacing and that each nation or each user has free access to the data derived from such stations.
4. Provide a sustainable development environment for technology transfer, so that these activities will enhance the national networks, and numerous applications, with readily available technology.
5. Understand the necessary geodetic requirements of participating national and international agencies.
6. Assist in establishing in-country expertise for implementation, operations, processing and analyses of modern geodetic techniques, primarily GPS.

There are 54 countries in Africa which will make the project extremely difficult to implement on a continental basis. For this reason it has been proposed that implementation must be at the regional level such as North (NAFREF), West (WAFREF), East (EAFREF), Central (CAFREF) and Southern (SAFREF) before the entire project can be "pulled" together to create the continental geodetic reference frame for Africa – AFREF.

Broad Outline of Overall Project Activities 1999 - 2003

EGS, Nice, France, April 2000

This meeting was held during the European Geophysical Society meeting held in Nice, France, in April 2000 and was called by Dr C. Boucher, chairman of IAG Commission X "Global and Regional Networks", also head of the ITRF and the representative of the International Earth Rotation Service (IERS) to the International GPS Service (IGS). The meeting was attended by representatives from a number of organizations including EUREF, IGS, NIMA, and Africover. Unfortunately no representatives from African countries were able to attend.

The meeting was called to discuss the possible organisation of a project to establish a common geodetic reference system throughout Africa (AFREF) compatible with the International Terrestrial Reference System (ITRF). The meeting also discussed ways to involve the international geodesy community to work with African nations to develop a single, uniform, continental geodetic reference system meeting international standards to replace the myriad national reference systems, many of which have not been maintained, and are out of date and inaccurate.

This meeting and earlier ad-hoc discussions highlighted the importance of a renewed effort to realize a reference system for this continent through international collaboration directly with the African nations. It was emphasized that this must truly be a joint effort with Africans to be successful and that it must focus on the transfer of appropriate technology to sustain the references with modern instrumentation, e.g. GPS and other satellite techniques. It is also noted that resources will be required to enable organizational participation and project activities (e.g. travel, equipment, technical support, etc.). The meeting attendees agreed to further explore and pursue a joint project AFREF with the Africans and other international partners

CONSAS, Cape Town South Africa, March 2001
During the Conference of Southern African Surveyors (CONSAS) held in Cape Town in March 2001, a meeting of the representatives of 8 Southern African countries was convened to gauge the level of interest and support for AFREF in the region. Also at the meeting were representatives from the IAG/IGS, EUREF and NIMA. The group supported the project and its goals and objectives and requested that it be organized under the auspices of the IAG. As a result of the latter request, Prof F. Sanso, the President of IAG, sent a letter of support to the represented countries urging their continued commitment to the project and offering the support and commitment of the IAG.

4th UN/USA GNSS Workshop, Lusaka, Zambia, July 2002
The United Nations Office for Outer Space Affairs (UNOOSA) and the United States of America co-sponsored a GNSS Applications Workshop in Lusaka Zambia in July 2002. The workshop was attended by representatives from many African and Middle Eastern countries including the IGS, US Dept of Agriculture, US Dept of Trade, ICAO and so on. One of the topics for discussion included surveying and mapping applications of GNSS. Among the resolutions resulting from the workshop a strong statement was made to create a uniform modern geodetic reference for Africa and gave the AFREF project its fullest support.

The outcomes of this workshop were taken forward to a final UNOOSA workshop held in Vienna in December 2002 where the outcomes of all four workshop were further worked and a final list of priority projects or actions was selected of which AFREF featured prominently.

RCMRD Workshop, Windhoek, Namibia, December 2002
An AFREF Planning Workshop was held in Windhoek in Namibia in December 2002. This workshop was co-sponsored by the Regional Centre for Mapping of Resources for Development (RCMRD) based in Kenya and the Surveyor General Namibia. 8 Countries from Southern and East Africa were represented as well as the United Nations Economic Commission for Africa (UNECA). There were a number of outcomes resulting from the workshop including:

- A declaration of intent on AFREF was prepared which will be forwarded to the UN ECA Committee for Development Information (CODI), IAG, UN OOSA and other International organizations for acceptance and adoption. AFREF is being justified through NEPAD, the outcomes of the WSSD and other projects requiring a uniform continental geodetic reference system to support consistent spatial geo-information in order to win support from African governments and development partners. Countries which are members of international organizations such as IAG, etc. should lobby or continue lobbying for support for AFREF within those organizations.
- AFREF will be implemented on a sub-regional basis for ease of logistics with the sub-regional groupings being made according to established UN sub-regions for Africa. National Surveying and Mapping organizations must be represented throughout the proposed organizational structures for implementation of AFREF. It is expected that new structures will be set up to take over AFREF activities during the CODI III meetings to be held in Addis Ababa in May 2003
- The RCMRD, together with UN ECA will make efforts to bring aboard other regional groupings and countries not represented at this workshop. In this respect the RCMRD has an important unifying role to play in AFREF.
- Besides the permanent GPS base stations already functional in East and Southern Africa a further 14 possible station sites were selected. The proposals were made taking into consideration, among others, an approximate 1000km spacing of the stations, availability of facilities such as power, telecommunication links, security of equipment and cost efficiency. The1000km spacing is such that any user, irrespective of the country in which they are operating should be within 500km of the nearest permanent GPS base station.

Conclusion
For the period 1999 to 2003 slow but steady progress has been made with the implementation of AFREF. Africa is a large continent with many countries each with its own difficulties and priorities. It will be very difficult to get all countries involved with project from the outset but even at this early stage new countries are showing interest and the number of countries wishing to participate is growing. Of major concern is the sourcing of sufficient funding to support the project in all its stages. Of lesser concern is the comfort in knowing that the IAG and its associates and service organizations such as the IGS will give the project its fullest support.

Antarctica

A sub commission for Antarctica was established as a formal link of the SCAR activities to the GRGN. This subcommission is co-chaired by John Manning (Australia) and Reinhard Dietrich (Germany).

Europe

(Prepared by Werner Gurtner, Switzerland, Helmut Hornik, Germany and Joao Agria Torres,Portugal)

Introduction
The present report covers the period August 1999 – April 2003 and is focused on the following topics:

- Overview and Organisation
- EUREF Permanent Network (EPN)
- Improvements and extensions of ETRS89
- European Vertical Reference System (EVRS)
- European Combined Geodetic Network (ECGN)
- Symposia
- Communication layer
- External interfaces
- Publications

Overview and Organisation
The purpose of EUREF, the Sub-Commission for Europe of IAG's (International Association of Geodesy) Commission X on Global and Regional Geodetic Networks, is the establishment and maintenance of the European Reference Frame. This is being achieved by means of a number of space geodetic reference stations (SLR and VLBI), an array of GPS permanent sites - the EUREF Permanent Network (EPN) -, a network of high-precision geodetic reference sites determined by various GPS campaigns, and the combination of the Unified European Levelling Network (UELN) and the European Vertical GPS Reference Network (EUVN).

The forum where the activities are discussed and decisions are taken is the annual symposium. The Technical Working Group (TWG) has the task to govern current activities, such as:

- to evaluate and classify results of campaigns presented to the TWG for acceptance as EUREF densification or extension and to prepare the respective recommendations for the EUREF plenary meeting
- to organise and coordinate European-wide GPS campaigns for the improvement of the European reference frame
- to implement and co-ordinate a European network of permanent GPS stations, the EUREF Permanent Network (EPN)
- to prepare recommendations for the definition and realisation of a European height system to the EUREF Sub-commission
- to set up the working groups to run the projects defined by the plenary.

The TWG is composed by 19 members. It met 11 times in the period covered by this report; one more meeting is already scheduled to take place during the Toledo Symposium (June 2003). The working groups established in order to run the projects during the period 1999-2003 are the following:

- Unified European Levelling Network (UELN)
- European United Vertical Network (EUVN)
- EUREF Internet Protocol (EUREF-IP)
- European Combined Geodetic Network (ECGN)
- EUVN Densification Action (EUVN_DA)

It must also be mentioned the initiative to present an Expression of Interest for an Integrated Project submitted under the Framework Program 6 entitled "SCIGAL - Earth Science Applications using GALILEO". SCIGAL aims to establish an operational European GNSS network infrastructure exploring the full potential of the GALILEO and GPS systems serving high precision users in Geodesy, Geophysics, Meteorology, Timing and Navigation, superior to the existing science-driven infrastructure for GPS, taking advantage of the expertise in GNSS data communication and analysis within the EUREF group.

EUREF Permanent Network (EPN)
The EUREF Permanent Network (EPN) consists presently of 137 permanent GNSS (Global Navigation Satellite System) stations. All sites have been installed following IGS standards, and about 50% of the EPN stations are also part of the IGS network. Due the enormous amount of tasks, a re-organisation of the permanent network was done in the period 2000-2001. Taking into account new technical evolutions, the EPN guidelines for the inclusion of new stations as well as for the routine operation and date flow where updated at regular intervals during the last 4 years. One of the results is that 58 % of the stations is now providing data on a near-real time basis.

The whole network is weekly processed on a routine basis, making use of the IGS precise orbits. Multi-year solutions of the EPN have been and will be submitted to IERS as contributions to the realisation of the International Terrestrial Reference Systems (ITRS), namely ITRF2000.

The EPN also runs two special projects using the installed infra-structure: 'Monitoring of the EPN to produce coordinate time series suitable for geokinematics' and 'Generation of a EUREF-troposphere product'. The goal of the first one is to support the use of the EPN products for geokinematics by establishing an interface between geodesists and geophysicists. The activity involves the following basic tasks:

- time series monitoring and correction, preparations for kinematic analysis;
- quality assessment and monitoring of site configuration;
- identification of stations with unreliable behaviour.

Within the second project tropospheric parameters are derived as part of the EPN estimation. Longer series of the zenith path delays, for example, support climate research. The basic task within this activity is to produce a combined troposphere solution with input from the individual troposphere solutions of all Analysis Centers, which contribute to the coordinate solution. Presently, the EUREF troposphere solution is recognized as the European reference solution for the troposphere and it is part of the global IGS troposphere solution.
In recognition of the growing need for European-wide improved real-time positioning and navigation, and using the recent developments in the interconnection of mobile communication and the Internet, a new EUREF initiative, the EUREF-IP Pilot Project, was set up during the last year. It aims to distribute differential GNSS data based on the EPN network.

Further information about the EPN can be found at http://www.epncb.oma.be.

Improvements and extensions of ETRS89
Besides the EPN, the establishment and maintenance of the European Reference Frame is also achieved by a network of high-precision geodetic reference sites determined by various GPS campaigns. In the last 4 years, the following campaigns have been validated by the TWG and accepted as class B standard (about 1 cm at the epoch of observation):

- EUREF-FIN-96/97 campaigns in Finland (sub-set of points)
- EUREF-Estonia-1997 campaign in Estonia (sub-set of points)
- EUREF-Balkan-98 campaign in Albania, Bosnia and Herzegovina, and Yugoslavia (final selection of points and publication of the coordinates pending)
- EUREF-Moldavia-99 campaign in Moldavia (sub-set of points)
- EUREF-SWEREF-99 campaign in Sweden (sub-set of points)
- EUREF-Balear-98 campaign on the Balearic islands (Spain) (sub-set of points)
- EUREF-CRO-94/95/96 (re-computation)
- EUREF GB2001

Three more campaigns have been already validated by the TWG as class B and are waiting for approval by the plenary at the Toledo Symposium:

- EUREF campaigns in Slovenia in 94/95/96 (re-computation)
- EUREF-SK 2001 campaign in Slovakia
- HUNREF2002 campaign in Hungary

Further information about the EUREF campaigns and the data base of stations can be found at http://www.geo.tudelft.nl/mgp/euref/

European Vertical Reference System (EVRS)
As result of the UELN and EUVN projects the IAG Sub-commission EUREF defined the European Vertical Reference System 2000 (EVRS), including a European Vertical Datum and related parameters as realisation, and for practical use as a static system. A document with the definition of EVRS was produced.

The UELN network is being densified and extended with new levelling observations. The existence of repeated observations in some areas presents the chance to take a first step on the way to a geokinematic height network. Some computations are being carried out in order to achieve this goal.

The EUVN has the objective to connect different kinds of height related observations as a contribution to a unified European height system, the European geoid determination consistent with the existing geodetic reference network EUREF/ETRS89 and the most recent realisation of UELN, and the monitoring of the sea level variations. The EUVN network consists of about 200 UELN sites observed with GPS. This project has been successfully finalised and the final report has been already published (see Publications).

Meanwhile, an action for the densification of the existing EUVN network (EUVN_DA) was initiated, in cooperation between EUREF and the IGGC ESc (International Gravity and Geoid Commission, European Sub-commission). The purpose is to separate gross errors in the levelling data and long wave biases in the geoid and/or levelling, at those areas where the greatest discrepancies between the current gravimetric geoid (EGG97) and the point-wise EUVN geoid have been found.

Further information about the European Vertical Reference System, UELN and EUVN can be found at http://evrs.leipzig.ifag.de/.

European Combined Geodetic Network (ECGN)
Another important issue for EUREF is to ensure the long time stability of the terrestrial reference system, including more gravity field related data in the evaluation models. So, a new project for the realisation of the European Combined Geodetic Network (ECGN) was launched.

The ECGN aims at the combination of geometric and gravity-related techniques for reference frame refinement, and will be developed in close cooperation with the International Gravity and Geoid Commission, European Sub-commission (IGGC Esc) of the IAG and the International Hydrographic Organisation (IHO).

Besides its scientific and practical implications, providing a better knowledge of the link between the geo-spatial and the vertical components, the ECGN project represents an important step ahead in the improvement of the European Reference Frame, and it is expected to be a remarkable contribution to the Integrated Global Geodetic Observing System (IGGOS) that is under development by the IAG.

Symposia
Following the symposium held in Prague in June 1999, three other symposia took place in Tromso (Norway) in June 2000, in Dubrovnik (Croatia) in May 2001 and Ponta Delgada (Portugal) in June 2002.

These meetings have been attended by more then 100 participants, representing more than 30 countries in Europe.

The next symposium is under preparation and will be held in Toledo (Spain) in June 2003.

Communication layer
A new web page has been installed at http://www.euref-iag.org. This page links to all the EUREF structures and projects. The main contents are:

- What is EUREF?
- Technical Working Group
- ETRS89 (European Terrestrial Reference System)
- Permanent Network
- GPS Campaigns
- European Vertical Reference System (EVRS)
- European Coordinate Reference Systems
- Symposia
- Documentation
- Links

In response to the interest demonstrated by the managers of the Framework Program 6, an article explaining SCIGAL and the role of EUREF in the geo-referencing activities in Europe was published in the 29th April's issue of the Parliament Magazine.

It must also be mentioned the running process for the trademark of the 'EUREF' name in all the European countries where this process is applicable; it is expected that the results will be presented during the Toledo Symposium.

External interfaces
The relationship with other organisations, the external interfaces of EUREF, has been growing. The liaison with EuroGeographics, the consortium of the National Mapping Agencies (NMA) in Europe, through its Expert Group on Geodesy (ExG-G) continues. A special reference has to be made to the financial support to EUREF for the organisation of the symposia.

Another result of the cooperation between EUREF and EuroGeographics is the publication of the description of national coordinate reference systems (CRS) in Europe and the transformation parameters between CRS and ETRS89 for practical purposes, following the ISO 19111 Spatial referencing by coordinates standard. This information is available at http://crs.ifag.de.

Presently, the cooperation has been extended to the definition of the geodetic components to be included in a project to be submitted by EuroGeographics to the INSPIRE initiative of the EU.

Following the initiative of the Northern African Countries to define and implement a common geodetic reference frame, EUREF was invited to participate in workshops held in TUNIS in May 2000 and Alger in 2001, in order to start a co-operation on this subject in the frame of the AFREF initiative within Commission X.

Publications
The proceedings of the EUREF symposia are the main source of information concerning the EUREF activities. In the period covered by this report were published:

- Publication No. 8 of the Sub-commission for Europe (EUREF), 1999
- Report on the Symposium of the IAG Sub-commission for Europe (EUREF) held in Prague, 2 – 5 June 1999.
- Reports of the EUREF Technical Working Group. Bayerische Kommission für die Internationale Erdmessung, No. 60, München 1999; ISBN 3 3 7696 9622 0.
- Publication No. 9 of the Sub-commission for Europe (EUREF), 2000
- Report on the Symposium of the IAG Sub-commission for Europe (EUREF) held in Tromso 22 – 24 June 2000.
- Reports of the EUREF Technical Working Group. Bayerische Kommission für die Internationale Erdmessung, No. 61, München 2000; ISBN 3 7696 9623 9.
- Publication No. 10 of the Sub-commission for Europe (EUREF), 2001
- Report on the Symposium of the IAG Sub-commission for Europe (EUREF) held in Dubrovnik 16 – 18 May 2001.
- Reports of the EUREF Technical Working Group. Mitteilungen des Bundesamtes für Kartographie und Geodäsie, Band 63, Frankfurt am Main 2002; ISBN 3 89888 860 6.
- Publication No. 11 of the Sub-commission for Europe (EUREF), Volume I and II, 2002

- European Vertical Reference Network (EUVN) Final Documentation. Mitteilungen des Bundesamtes für Kartographie und Geodäsie, Band 63, Frankfurt am Main 2002; ISBN 3 89888 869 X, ISBN 3 89888 870 3.

The proceedings of the symposium held in Ponta Delgada, 2002, are under preparation. The web page contains the papers presented at the symposia held in Tromso, Dubrovnik and Ponta Delgada. This procedure will be followed in the subsequent symposia, in order to have a faster diffusion of the information.

Conclusions
The Permanent Network is still developing and increasing its contribution to international projects. The GPS campaigns continued, extending and densifying the terrestrial GPS network and improving existing solutions. The EUVN project was finalised, and UELN is being densified and extended to countries in eastern Europe. Other projects have been launched (ECGN, EUVN-DA), aiming at the refinement of the existing solutions for the European Reference Frame, providing a better link between the geo-spatial and the vertical components.

The future situation of EUREF within the next IAG structure was also discussed, and the EUREF group looks forward to continue its activities in the frame of the new Commission I - Reference Frames.

The importance of the activities of EUREF is demonstrated by the involvement of more and more organisations and countries, covering almost all the map of Europe. The ETRS89 (European Terrestrial Reference System), defined more than 12 years ago, is being adopted by several countries and organisations in Europe as the official system for geo-referencing. The European Community will use ETRS89 and EVRS as conventional reference systems as well to promote widespread use as a de facto standard for future pan-European data products and services.

North America

(Prepared by Michael Craymer,Canada, Dennis Milbert, USA and Per Knudsen, Denmark)

Operating on a informal basis since 1997, the Sub-Commission for North America was formally created in 1999, immediately following the IUGG General Meeting in Birmingham, U.K. The purpose of the Sub-Commission is to provide international focus and cooperation for issues involving the horizontal, vertical, and three-dimensional geodetic control networks of North America, including Central America, the Caribbean and Greenland (Denmark). Some of these issues include:

- Densification of the ITRF reference frame network in North America (the North American Reference Frame) and promotion of its use.
- Maintenance and future evolution of vertical datums (ellipsoidal and orthometric), including NAVD88 and the International Great Lakes Datum.
- Collocation of different measurement techniques such as VLBI, SLR, DORIS, GPS, etc.
- Effects of crustal motion, including tectonic motions along, e.g., the western coast of N.A. and in the Caribbean, and post-glacial rebound.
- Standards for the accuracy of geodetic positions.
- Outreach to the general public through focused symposia, articles, workshops and lectures and technology transfer to other groups, particularly in N.A.

The membership of the Sub-Commission presently consists of:

Michael. Craymer (NRCan/GSD, Canada, co-President)
Dennis Milbert (NOAA/NGS, U.S., co-President)
Per Knudsen (KMS, Denmark)

No members have yet been identified for Mexico and the Caribbean, although contacts have been made with Mexico and the appointment of a representative is expected soon.

The members of the Sub-Commission are largely responsible for identifying the issues to be addressed and for forming working groups (WGs) to actively resolve these issues. The follow working groups have already been created:

- North American Reference Frame (NAREF)
- Reference Frame Transformations
- International Great Lakes Datum (IGLD)

Most recently, a new Stable North American Reference Frame (SNARF) Working Group is being formed in collaboration with UNAVCO Inc. to develop a highly accurate, stable North American Reference Frame fixed to the North American tectonic plate. Such a reference frame is required for the high accuracy studies of intraplate crustal motion being contemplated by, e.g., the Earthscope project (http://www.earthscope.org/).

Activities within each of these working group are discussed below.

North American Reference Frame (NAREF) Working Group

This is the most active working group of the Sub-Commission. The primary purpose of the WG is to densify the ITRF reference frame in the North American region by organizing the computation and combination of weekly coordinate solutions and associated accuracy information for continuously operating GPS stations that are not part of the IGS global network. Cumulative solutions for coordinates and velocities will also be determined on a regular basis once a sufficiently long series of weekly solutions is obtained. The WG organizes, collects, analyzes and combines solutions from individual agencies, and archives the results. These results are available on the NAREF web site and, since mid-2002, weekly combinations are also being submitted to the IGS Global Data Centers.

The goals of the WG and some of it's work have been promoted at various conferences over the past year and a half, beginning with the special session "Densification of the ITRF in North America" at the American Geophysical 2000 Spring Meeting (Craymer and Milbert, 2000; Craymer et al., 2000). More recent results from this work group are available at www.naref.org.

The current contributing members of the WG are:

Michael Craymer (NRCan/GSD, Canada – Chairman)
Bill Dillinger (National Geodetic Survey, USA)
Mike Cline (National Geodetic Survey, USA)
Mieczyslaw Piraszewski (NRCan/GSD, Canada)
Caroline Huot (NRCan/GSD, Canada)
Brian Donahue (NRCan/GSD, Canada)
Herb Dragert (NRCan/GSC/PGC, Canada)
Scripps Institution of Oceanography (USA)
Finn Bo Madsen (KMS, Denmark)
Remi Ferland (NRCan/GSD, Canada – IGS representative)

These members have been active in providing regional solutions and assistance in combining them. A plot of the current network is given in Figure 1. The addition of the US CORS network solutions by NGS has significantly filled out the coverage and made the densification network truly North American in scope. No success has been made thus far in soliciting weekly solutions for permanent stations in Mexico, although attempts will be made to contact some researchers in US that are computing solutions in this region for their own purposes.

Reference Frame Transformations Working Group

The purpose of this WG is to determine consistent relationships between international, regional and national reference frames/datums in North American, and to maintain (update) these relationships as needed. The WG has been very active on an informal basis since 1997 and includes the following memebers:

Michael Craymer (NRCan/GSD, Canada – Chairman)
Richard Snay (NOAA/NGS, U.S.)
Tomas Soler (NOAA/NGS, U.S.)
Remi Ferland (NRCan/GSD, Canada – IGS representative)

The primary focus of the WG has been on maintaining the relation between the North American Datum of 1983 (NAD83) and the International Terrestrial Reference Frame (ITRF). In fact, NAD83 has now been defined in terms of a 7 parameter Helmert transformation from ITRF96 (Craymer et al., 2000). Transformations to/from other ITRF realizations are determined by adding the incremental transformations between ITRFs, as adopted the IERS and/or the IGS.

This work has unified the fundamental definition of NAD83 in both the U.S. and Canada. Software tools have also been provide for users in both countries to make access to the NAD83 and ITRF reference frames easier than ever.

The North American Datum of 1983 (NAD 83) is currently defined in terms of a 14-parameter Helmert transformation from ITRF00 (Soler and Snay, 2003) in such a way that stations located within the non-deforming part of the North American plate will have little or no horizontal motion relative to this plate. This transformation, denoted (ITRF00 --> NAD 83), equals the composition of three separate transformations

(ITRF00 --> ITRF97) + (ITRF97 --> ITRF96) + (ITRF96 --> NAD 83)

where (ITRF00 --> ITRF97) represents the Helmert transformation from ITRF00 to ITRF97 adopted by the International Earth Rotation Service, (ITRF97 --> ITRF96) represents the Helmert transformation from ITRF97 to ITRF96 adopted by the International GPS Service, and (ITRF96 --> NAD 83) represents the Helmert transformation from ITRF96 to NAD 83 adopted by Canada and the United States (Craymer et al., 2000).

International Great Lakes Datum (IGLD) Working Group

The purpose of this working group is to consider problems related to the maintenance of the vertical datum for the management of the Great Lakes water system, including post-glacial rebound, the use of GPS/geoid techniques, lake level transfers through hydrodynamic models, comparisons with NAVD88 and the possible implementation of a revised height system.

The Coordinating Committee on Great Lakes Basic Hydraulic and Hydrologic Data recently released their report, "Apparent Vertical Movement Over the Great Lakes - Revisited," in which they documented apparent vertical motion as derived from decades of water-level data, in combination with deglaciation models (see, e.g., Mainville and Craymer, 2003). Further cooperation with this Subcommission (especially, the NAREF WG) in the area of GPS monitoring of crustal motion is expected as more GPS data is gathered for the accurate and reliable estimate of crustal movements over the region.

Other Activities

In addition to the formal activities of the Subcommission’s working groups, all countries of the Subcommission have been very active in the past couple of years maintaining and enhancing their own geodetic networks.

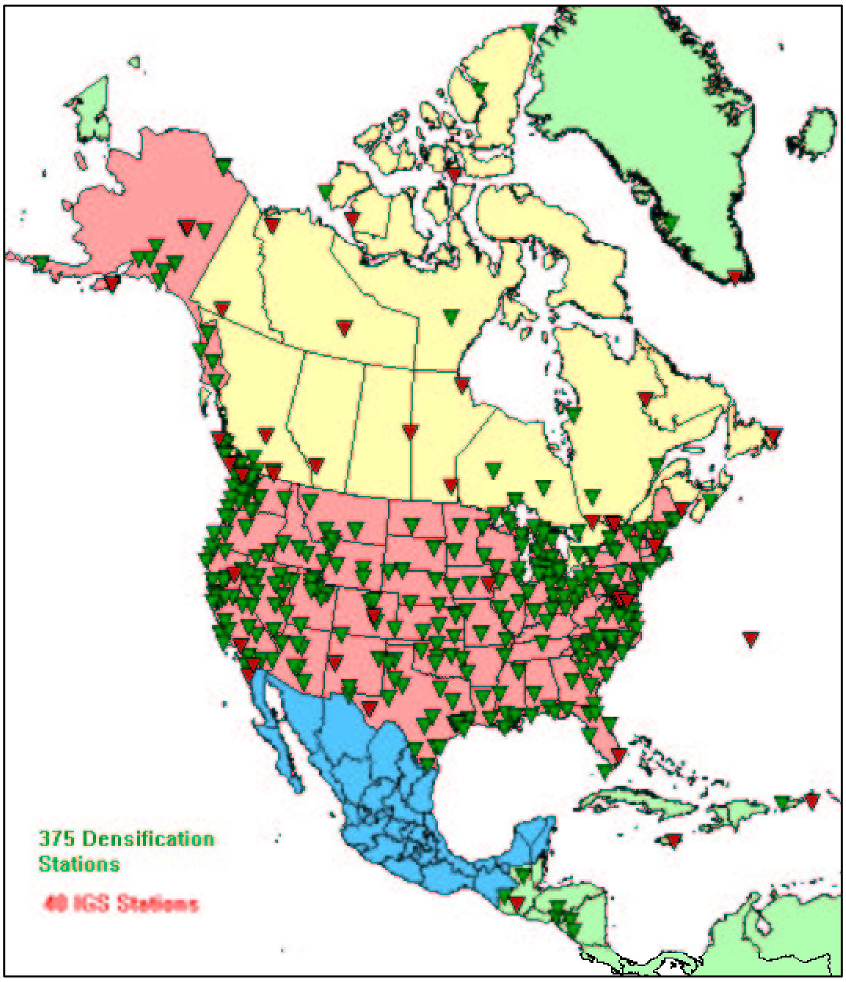


Figure 1*: Current NAREF densification network. Red symbols represent IGS global solutions and green symbols the NAREF densification stations. Note that three regional densification stations in the Arctic have now become global stations.*

US report

CORS Newtorks

More than 80 organizations in the United States have collaborated to establish the U.S. National and Cooperative Continuously Operating Reference Station (CORS) networks. Stations typically are part of the National CORS network, the Cooperative CORS network, or both. The National CORS network is comprised of stations whose GPS data are archived at the U.S. National Geodetic Survey. The Cooperative CORS network is comprised of stations whose GPS data are available directly from the organization that operates the station. A station whose GPS data are distributed both by NGS and by a cooperating organization is designated as a Combo CORS. Data and information about CORS can be obtained at: http://www.ngs.noaa.gov/CORS/

The National CORS currently (March 2003) contains more than 360 sites and the Cooperative CORS has over 43 sites. Most notable among the partners is the California Spatial Reference Center (CSRC) which provides data from more than 250 CORS in California; bringing the total number of CORS to well over 600 stations. Other organizations that distribute GPS data for Combo CORS include the International GPS Service (IGS), the Pacific Northwest Geodetic Array (PANGA), and state agencies in Florida, Ohio, Michigan, North Carolina, Pennsylvania, South Carolina, Texas, and Vermont. A listing with web links to organizations and their GPS CORS networks is maintained at: http://www.ngs.noaa.gov/CORS/links1/

The CORS network also contains stations in several U.S. territories, in Central America, and in the Caribbean. With this coverage, more than 96 percent of the coterminous United States is located within 200 km of a CORS, and more than 60 percent within 100 km. And, the CORS network is currently growing at a rate of about 6 stations per month.

In addition to data archival and dissemination, National CORS operations include daily coordinate solutions to quality control the GPS receiver data. Stations in the CORS network are operated for a variety of applications, including high accuracy positioning, navigation, remote sensing, GIS development, geophysics, atmospheric science, satellite tracking, and timing. The geophysics community is planning to install several hundred additional stations in the United States during the next few years to monitor the crustal motion associated with plate boundary interactions. Also, organizations in Canada and the United States are collaborating to establish about 20 stations at selected water-level sites located on the Great Lakes.

ITRF00 Positions and Velocities

The U.S. National Geodetic Survey (NGS) delivered two separate GPS contributions towards the realization of ITRF00 in year 2000 (Marshall, 2000). NGS has adopted ITRF00-compatible positions and velocities for all stations in the CORS network. Approximately every year, NGS validates adopted ITRF positions and velocities for all CORS. In particular, NGS uses every third day of CORS data in its archives to compute provisional positions and velocities for all CORS relative to the then current ITRF realization, call it ITRFxx. If for any station, these provisional ITRFxx positional coordinates differ from the currently adopted ITRFxx positional coordinates by more than 1 cm in the north-south dimension or by more than 1 cm in the east-west dimension or by more than 2 cm in the vertical dimension, then NGS adopts the provisional position and velocity to supercede the previously adopted ITRFxx position and velocity.

North American Datum of 1983

In March, 2002, NGS upgraded NAD 83 positions and velocities for all CORS sites, except those located on Pacific islands, so that they equal the transformed values of recently computed ITRF00 positions and velocities. This upgrade removed inconsistencies among previously published NAD 83 positions and velocities which are detectable with modern high accuracy GPS surveys. In addition, the NAD 83 coordinates are referred to an epoch date of 2002.00. (Previously, NAD 83 positions for the CORS sites were published for an epoch date of 1997.00). The use of the more current epoch date reduces those systematic errors occurring when points are positioned relative to CORS sites without applying appropriate site velocities. This more current epoch date benefits those involved in positioning activities in areas of crustal motion, like western CONUS and Alaska.

In October, 2002, NGS updated NAD 83 positions and velocities for all CORS located on Pacific islands to epoch 2002.0. Stations on the Hawaiian Islands, the Marshall Islands, and American Samoa now refer to the spatial reference frame called NAD 83 (PACP00). Stations on the Mariana Islands (GUAM and CNMI) now refer to the spatial reference frame called NAD 83 (MARP00). The "datum tags", PACP00 and MARP00, indicate that adopted positions and velocities were transformed from ITRF00 positions and velocities, respectively. Stations located in the interior of the Pacific tectonic plate are to have little or no horizontal velocity relative to NAD 83 (PACP00). Stations located in the interior of the Mariana tectonic plate are to have little or no horizontal velocity relative to NAD 83 (MARP00). Note that points located on Pacific islands have velocities in excess of 50 mm/yr relative to the standard NAD 83 reference frame.

OPUS

In 2001, NGS introduced a Web-based utility, called the Online Positioning User Service (OPUS), which will quickly and automatically calculate an accurate 3D position for a location corresponding to a user-supplied file of appropriate GPS data. In particular, this file must contain dual-frequency carrier phase observations at a single location. OPUS then automatically retrieves GPS data for three suitable CORS for use in calculating the positional coordinates associated with the user-supplied data. OPUS then emails the calculated coordinates to a user-specified email address. The computed coordinates are provided in each of two different reference frames: NAD 83 and the pertinent ITRF realization. For details see: http://www.ngs.noaa.gov/OPUS/

Network Re-Observation and Readjustment

Over the past several years the National Geodetic Survey has been re-observing the Federal Base Network (FBN) and Cooperative Base Network (CBN) to complete the ellipsoidal and orthometric height components of the FBN and CBN; see: http://www.ngs.noaa.gov/PROJECTS/FBN/

Project requirements for the FBN and CBN observations are to ensure 2-centimeter local accuracy in the horizontal component, as well as 2-centimeter local accuracy for the ellipsoid heights. By the end of 2003 the observations in the 48 contiguous states and the District of Columbia should be complete. Currently, observations for 44 states and the District of Columbia have been completed. Of these, the vector reductions and adjustments have been completed for 39 states and the District of Columbia. By the end of 2004 the vector reductions and adjustments for all 48 contiguous states should be complete. At this time, a comprehensive readjustment of NAD 83 will be completed in cooperation with the Geodetic Survey Division of Canada. Areas outside the contiguous United States (e.g., Alaska, American Samoa, Guam, Hawaii, Puerto Rico, Virgin Islands, etc,) will be included as resources permit their re-observations.

Comprehensive Everglades Restoration Plan

The Comprehensive Everglades Restoration Plan (CERP) is a major project to achieve ecological restoration of the Florida Everglades. The strategy is to restore the ecology by restoring the hydrologic characteristics of the historic Everglades. Hence, extremely accurate heights were needed to control water flow over long distances. Beginning in 2001, NGS has been assisting the U. S. Army Corps of Engineers in a comprehensive effort to establish both leveling and GPS control for the CERP. The leveling portion consisted of over 1500 km of new, First-Order, Class II leveling covering over 1100 bench marks in the region. The GPS portion, completed in July 2002, consisted of a primary (1:1,000,000) network of 64 stations and a secondary (1:100,000) network of 1051 stations. Most of the stations occupied by GPS were also bench marks from the leveling portion. The final product is a combined GPS and optically-leveled network having ellipsoid heights with a nominal 2 cm (95%) network relative accuracy and a similar orthometric height network relative accuracy in a region of about 175 km by 175 km. For general information on the CERP: http://www.evergladesplan.org/

Magnitude 7.9 Denali, Alaska Earthquake

A magnitude 7.9 earthquake occurred near Denali National Park, AK on November 3, 2002. The geographic coordinates of the epicenter are 63.520N and 147.530W and its depth is 5.0 km. The CORS Data Analysis Team has determined 3-dimensional displacements associated with this earthquake at several CORS located in Alaska. For details, see: http://www.ngs.noaa.gov/CORS/denali.html

Horizontal Time Dependent Positioning

NGS recently released version 2.7 of the HTDP (Horizontal Time-Dependent Positioning) software (Snay, 1999) for transforming positional coordinates and/or positioning observations across time and between spatial reference frames. Users may also apply HTDP to predict the velocities and displacements associated with crustal motion in any of several popular reference frames.

Version 2.7 expands the list of permissible reference frames to include the new realization of the World Geodetic System of 1984, called WGS 84(G1150), as well as two new reference frames related to the North American Datum of 1983; one called NAD 83(PACP00) in which most points located on the Pacific tectonic plate (Hawaiian Islands, Marshall Islands, American Samoa, etc.) experience little or no horizontal velocity, the other called NAD 83(MARP00) in which most points located on the Mariana tectonic plate (Guam, Saipan, etc.) experience little or no horizontal velocity.

Version 2.7 incorporates a more accurate model than previous HTDP versions for the 3D displacements associated with the magnitude 7.1 Hector Mine, CA earthquake of October 16, 1999.

Users may execute HTDP_2.7 interactively at: http://www.ngs.noaa.gov/TOOLS/Htdp/Htdp.html

One may also download the HTDP software and related information from this web site.

CORS Supports Crustal Motion Study

Gan and Prescott (2001) analyzed GPS data observed between 1996 and 2000 for 62 CORS distributed throughout the central and eastern United States. Their results suggest that no significant horizontal crustal motion occurs in this part of the country, except possibly in the region encompassing that part of the Mississippi River which is located south of Illinois. Here, points appear to be moving southward relative to the rest of the continent at an average rate of 1.7 mm/yr, with a standard deviation of 0.9 mm/yr. While this rate is not statistically significant, the fact that the motion occurs near New Madrid, MO--where earthquake risk is considered to be high--argues that the motion may be real.

Canadian report

Recent Highlights

Geodetic Survey Division (GSD) completed another year highlighted by continued improvements to the Canadian Spatial Reference System, strengthened collaboration in global geodetic services and leadership/support for national geodetic initiatives.

GSD continues to be present, active, and well recognised in national and international arenas. At the national level, GSD relies on it's partnership with the provincial geodetic agencies and territories through the Canadian Geodetic Reference System Committee (CGRSC) to deliver, maintain and enhance the Canadian Spatial Reference System (CSRS), including the Canada-wide Differential GPS (CDGPS) initiative, which is a primary project of the CGRSC. GSD's continued involvement in the GEOIDE National Centres of Excellence program has maintained the collaboration across Canada between the various universities, government departments and private companies. Scientific collaboration with Canadian Hydrographic Service (CHS) of DFO, and Geological Surveys of Canada (GSC) also continue.

At the international level, GSD plays a defining role in international standards and the shape of the future of all geodetic activities. This is achieved through direct product contributions, and chairing of International Association of Geodesy (IAG) committees, working groups, special study groups, workshops, commissions, sub-commissions and others. Canadian representation to the UN Action team on GNSS reporting to the UN Committee on Peaceful Uses of Outer Space (COPUOS) is through GSD. Other examples of international collaboration include work with GeoForschungsZentrum (GFZ) of the Republic of Germany on Sea Level change, and with the Ohio State University (OSU), National Geodetic Survey (NGS) and Forecast Systems Laboratory for water level studies in the Great Lakes region.

The Division is recognized as a leader and significant contributor to the International GPS Service (IGS), the International VLBI Service (IVS), the International Earth Rotation and Reference System Service (IERS), the International Gravity and Geoid Commission (IGGC), and the Global Geodynamics Project (GGP) among others. GSD continues to be actively involved in the IAG Subcommision 10 for North America which is concentrating on developing an integrated North American Reference Frame (NAREF) solution, and a member of a federal government working group overseeing Canada's involvement in the European Union's GALILEO program and continues to monitor progress of this initiative.

Activities continue to be consistent with the long-term strategic focus toward space-based positioning. The following are highlights of this effort that relate to the activities of IAG Commission X.

International GPS Service (IGS)

GSD continues to collaborate and exchange GPS data and products from its network of Active Control Points through its many roles within the IGS, which include Analysis Centre, Coordination for the IGS Reference Frame, and co-chair of the Real-Time Working Group, among others. Norman Beck is also an elected member of the IGS Governing Board.

Global Reference Frame

Regular Very Long Baseline Interferometry (VLBI) operations continue at fiducial stations Algonquin Park Radio Observatory (ARO) and Yellowknife (YELL) as part of GSD's contribution to the International VLBI Service (IVS), in order to relate the national and global terrestrial reference frames to the fixed Celestial reference frame. ARO has maintained it's designation as a primary site of the International Space Geodetic Networks of the Committee for Space Techniques in Geodesy because of it's long history of stability, continuous operation and the multiple geodetic techniques employed, which provides scale and long term control for other techniques including GPS.

International VLBI Service (IVS)

Dr. Bill Petrachenko was recently elected to the IVS Governing Board.

Global Integration
Norman Beck has taken part in a working group tasked with implementing the charter project of the IAG called Integrated Global Geodetic Observing System, that is expected to formally kick off during IUGG this July. Remi Ferland and Jan Kouba participated in reviewing and charting the direction of the IERS.

Activities Supporting Geodynamics/Crustal Motion Studies
GSD has been collaborating with several agencies (both internationally, and nationally) on the measurement of crustal motions in various regions of Canada.

Together with the Ohio State University, the U.S. National Geodetic Survey and Forecast Systems Laboratory, GSD has contributed to the establishment of the Great Lakes Continuously Operating Reference Stations Network with the aim of enhancing national vertical datum monitoring, safe navigation, weather forecasting, precision farming, geodynamics, shoreline environmental monitoring and recreational boating and tourism. For it's part, GSD has established 5 regional GPS active control points at Kingston, Port Weller, Parry Sound, Rossport and Hearst. All but the latter are co-located at CHS water level gauges.

Collaboration continues with Geological Surveys of Canada on the project "Relative Sea-level and Associated Climate Impacts on Northern Coasts and Seaways". With the goal of determining relative vertical crustal motion in the western Arctic, GSD has established and operates 3 regional active control points at Inuvik, Resolute and Sachs Harbour, as well as periodically re-occupying several non-permanent stations in the region.

As part of another collaborative project with GSC to conduct crustal deformation measurements across Vancouver Island under the "Natural Hazards" envelope, GSD managed a special order levelling contract along a profile across Vancouver Island.

Other field measurements conducted this past year for GSC included absolute gravity, and GPS at collocated sites. Through the use of these independent observational techniques, a more accurate estimate of present-day uplift rates across the coastal margin will be determined.

GSD has also been collaborating with Fisheries and Oceans Canada (DFO) on the establishment of permanent GPS stations at newly established tide gauges in the Arctic as part of Canada's contribution to the international Global Ocean Observing System (GOOS), an initiative to establish an global array of tide gauges about 1000 km apart along the world's coastlines to determine long-term changes in sea level due to climate change. GPS active control points have been co-located with tide gauges at Alert, Holman and Nain. Two more will be established in 2003 at Qikiqtarjuaq (Baffin Island) and Tuktoyuktuk. These GPS stations are also being contributed to the IGS GPS Tide Gauge Benchmark Monitoring (TIGA) Pilot Project, another effort to establish a global network of tide gauges co-located with permanent GPS stations.

Through a tri-lateral (GSD, GFZ of Germany, and GSC Pacific) MOU for cost-shared development of an infrastructure aimed at monitoring the vertical movement of the Earth’s crust in the broad region around Hudson Bay, six new regional GPS active control points have been established and integrated to the Active Control System network. Results of a N-S absolute gravity survey east of James Bay were presented at the Fall AGU. The presentation showed the correspondence of GPS-measured uplift rates with those of GSD’s JILA-2 absolute gravimeter at selected sites.

Canada-Wide DGPS (CDGPS) Service
CDGPS is the CCOG sponsored initiative to broadcast GSD’s GPSoC as a means to enable GPS positioning through coordinates consistent with the Canadian Spatial Reference System. Service Launch is scheduled for the 2003 field season. NRCan has provided extensive engineering support to the CDGPS project to ensure the success of the project, especially as Beta Trials approach. This work included the implementation of a fully managed infrastructure for provision of GPSoC corrections to CDGPS since November 2002, GTIS liaison for issues related to MSAT power and bandwidth, systems management, and the implementation of a verification and validation system at MSV. A revised Service Agreement between NRCan and GTIS reflecting the MSAT arrangement has been prepared.

Canadian Active Control Infrastructure
Over the past year, two new ACP sites have been established, at Fredericton, New Brunswick (FRED), and National Research Council in Ottawa, where the original site (NRC2) was decommissioned and a new site (NRC3) established.

GPS-C Testing
Successful testing and operational use of GPSoC was carried out by the Canadian Hydrographic Service (CHS) in the Eastern Arctic and Lake Temiscaming areas during the 2002 field season. CHS has again requested access to GPS∑C for the 2003 season, making this their 6th year using real-time positioning for Arctic operations.

Canadian Base Network
The Canadian Base Network (CBN) was completed in 2000 with the addition of 6 new stations in the Arctic. This completed the Canada-wide network of 154 monuments that provide a more traditional but very high accuracy control network for further densification by individual provinces. Remeasurement of the entire network took place in 2001 and 2002 in order to monitor monument stability and to determine the effects of post-glacial rebound. Remeasurements are expected to occur on a 4-5 year basis or as needed to provide a more accurate determination of post-glacial reboud and thus more accurate, up-to-date coordinates.

Greenland report

Five geodetic permanent GPS stations are now in operation in Greenland. The Geodetic Department of the National Survey and Cadastre of Denmark operates and maintains the stations at the Thule Airbase (THU1 and the newly established THU2) and in Scoresbysund (SCOB). Stations KELY and KULU in Kelyville and in Kulusuk, respectively, are operated by the University of Colorado. The stations THU1 and KELY are included in the IGS global network. THU2 was established in 1998 as a long-term stable station to complement the THU1 station. THU2 is equipped with a GPS/GLONASS receiver and has contributed to the IGEX and the IGLOS campaigns. Recently, THU2 was accepted for the IGS LEO network. A new station in southern Greenland is being established in Julianehaab to complete the coverage in the region.

Activities associated with the upgrading of the geodetic network in Greenland have been going on for several years. In 1996, the REFGR reference frame for Greenland was defined and includes eight globally positioned reference points. Since then, GPS points have been established throughout the populated parts of Greenland. In 2000, a special effort was made to complete this task. Sixty-seven settlements were visited and 171 new points established. Most new points were established at old reference points so that the classic geodetic triangulation measurements can be used together with the GPS coordinates in the computation of the new coordinates. The software for the combined adjustment of the new and the classic measurements was developed and new coordinates for most of the ice free parts of Greenland have been computed during 2001.

References
Craymer, M. and M. Piraszewski (2002) Canadian Contributions to the NAREF Initiative to Densify the ITRF in North America. AGU 2002 Fall Meeting, San Francisco, December 6-10.

Craymer, M. and M. Piraszewski (2002) Densification of the ITRF: The NAREF Experience in North America. IGS Network, Data and Analysis Center Workshop, Ottawa, April 8-11.

Craymer, M., M. Piraszewski and C. Huot (2002) Current Status to Densify the ITRF in North America. IGS Network, Data and Analysis Center Workshop, Ottawa, April 8-11.

Craymer, M.R. The North American Reference Frame (2002) Densification of the ITRF in North America. Plate Boundary Observatory US/Canada Workshop, Seattle, March 5.

Craymer, M.R. and M. Piraszewski (2001) The NAREF Initiative to Densify the ITRF in North America. IAG 2001 Scientific Assembly, Budapest, Hungary, September 2-7.

Craymer, M.R. and M. Piraszewski (2001) The North American Reference Frame (NAREF): An Initiative to Densify the ITRF in North America. Proceedings of KIS 2001: International Symposium on Kinematic Systems in Geodesy, Geomatics and Navigation, Banff, Canada, June 5-8, 2001. Revised July 13.

Craymer, M.R. and M. Piraszewski (2001) The North American Reference Frame (NAREF): An Initiative to Densify the ITRF in North America. KIS 2001: International Symposium on Kinematic Systems in Geodesy, Geomatics and Navigation, Banff, Canada, June 5-8.

Craymer, M.R. and M. Piraszewski (2001) The NAREF Initiative to Densify the ITRF in North America. Proceedings of the EUREF Permanent Network Third Local Analysis Centres Workshop, Warsaw University of Technology, Warsaw, Poland, May 31 - June 1.

Craymer, M.R., R. Ferland, R. Snay (2000) Realization and Unification of NAD83 in Canada and the US via the ITRF. In R. Rummel, H. Drewes, W. Bosch, H. Hornik (eds.), Towards an Integrated Global Geodetic Observing System (IGGOS), IAG Section II Symposium, Munich, October 5-9, 1998. International Association of Geodesy Symposia, Volume 120, Springer-Verlag, Berlin.

Craymer, M.R., D. Milbert (2000). NAREF: Densification of the ITRF in North America. IGS Analysis Center Workshop, Washington, September 25-29.

Craymer, M.R., M. Piraszewski, C. Huot (2000) Canadian Regional Solutions for NAREF: Initial Results. Presented at the AGU 2000 Spring Meeting, Washington, June 3.

Craymer, M.R., M. Piraszewski (2001a) The NAREF Initiative to Densify the ITRF in North America. Presented at the CGU Annual Scientific Meeting, Ottawa, May 14-17.

Craymer, M.R. and M. Piraszewski (2001b). The NAREF Initiative to Densify the ITRF in North America. Proceedings of the EUREF Permanent Network Third Local Analysis Centres Workshop, Warsaw University of Technology, Warsaw, Poland, May 31 - June 1.

Craymer, M.R. and M. Piraszewski (2001c). The North American Reference Frame (NAREF): An Initiative to Densify the ITRF in North America. Proceedings of KIS 2001: International Symposium on Kinematic Systems in Geodesy, Geomatics and Navigation, Banff, Canada, June 5-8. Revised July 13.

Eckl, R. Snay, T. Soler, M. Cline, and G. Mader (2001) Accuracy of GPS-Derived Relative Positions as a Function of Interstation Distance and Observing-Session Duration, Journal of Geodesy, vol 75, 633-640.

Ferland R., Z. Altamimi, C. Bruyninx, M. Craymer, H. Habrich and J. Kouba (2002) Regional Networks Densification. Proceedings of the IGS Network, Data and Analysis Center Workshop, Ottawa, April 8-11.

Gan, W., and WH Prescott (2001) Crustal deformation rates in central and eastern U.S. inferred from GPS, Geophysical Research Letters, 28, 3733-3736.

Henton, J., M.R. Craymer, J.O. Liard, T.S. James, C. Gagnon and E. Lapelle (2002) Absolute Gravity and GPS Measurements of Uplift in the James Bay Region, Quebec, Canada. AGU 2002 Fall Meeting, San Francisco, December 6-10.

Mader, G and F Czopak (2002) The Block IIA Satellites: Calibrating Antenna Phase Centers. GPS World, 13(5), 40-46.

Mader, G.L. & M.L. Morrison (2002). Using Interpolation and Extrapolation Techniques to Yield High Data Rates and Ionosphere Delay Estimates from Continuously Operating GPS networks, Proc. ION-GPS 2002, Portland, OR, September 24-27, 2342-2348.

Mainville, A. and M.R. Craymer (2003) Present-day tilting of the Great Lakes region based on water level gauges. Submitted to Geological Society of America Bulletin.

Marshall, J (2000) Estimating North American CORS coordinates in a consistent fashion within the framework of a global solution, Spring 2000 American Geophysical Union Conference, Washington, D.C.

Marshall, J., M. Schenewerk, R. Snay, and S. Gutman (2001) The Effect of the MAPS Weather Model on GPS-Derived Ellipsoidal Heights, GPS Solutions, Vol 5, pp 1-14.

Mazzotti, S., P. Flueck, R.D. Hyndman, H. Dragert, M. Craymer, M. Schmidt (2002) Tectonics of Western Canada From GPS Observations. AGU 2002 Fall Meeting, San Francisco, December 6-10.

Milbert, D. and M. Craymer (2000) NAREF: An Initiative to Densify the ITRF in North America. AGU 2000 Spring Meeting, Washington, DC, 3 June.

Piraszewski, M., M. Craymer and C. Huot (2000) Preliminary Results of the NAREF Densification. International GPS Service (IGS) Analysis Center Workshop, U.S. Naval Observatory, Washington, DC, 25-29 September.

Prusky, J. (2001). The Cooperative CORS Program, Professional Surveyor, 21(1), 14, 16, 22.

Schenewerk, M., J. Marshall, W. Dillinger, and N. Weston (1999) Vertical ocean loading deformations derived from a global GPS network, EOS, Trans., Amer. Geophys. Union, 80(46), 262.

Schenewerk, M.J., J. Marshall & W. Dillinger (2001). Vertical ocean-loading deformation derived from a global GPS network, J. Geodetic Soc. of Japan, 47(1).

Sella, GF, TH Dixon, and A. Mao (2002) REVEL: A model for Recent plate velocities from space geodesy, Journal of Geophysical Research, 107, ETG 11, 1-30.

Snay, R (1999) Using the HTDP software to transform spatial coordinates across time and between reference frames, Surveying and Land Information Systems, 59, 15-25.

Snay, RA (2003) Introducing two spatial reference frames for regions of the Pacific Ocean, Surveying and Land Information Science, in press.

Snay, R., M. Chin, D. Conner, T. Soler, C. Zervas, J. Oyler, M. Craymer, S.I. Gutman, C.K. Shum, K.-C. Cheng and C.-Y. Kuo (2002) Great Lakes Continuous GPS (CGPS) Network For Geodynamics, Meteorology and Safe Navigation. Weikko A. Heiskanen Symposium in Geodesy, The Ohio State University, Columbus, OH, October 1-4.

Snay, R.A. and T. Soler (1999). Part 1 - Modern Terrestrial Reference Systems. Professional Surveyor, 19(10), 32-33.

Snay, R.A. and T. Soler (2000). Part 2 - The evolution of NAD83. Professional Surveyor, 20(2), 16, 18.

Snay, R.A. and T. Soler (2000). Part 3 - WGS 84 and ITRS. Professional Surveyor, 20(3), 24, 26, 28.

Snay, R.A. and T. Soler (2000). Part 4 - Practical considerations for accurate positioning. Professional Surveyor, 20(4), 32-34.

Snay, R.A., T. Soler and M. Eckl (2002). GPS precision with carrier phase observations: Does distance and/or time matter?, Professional Surveyor, 22(10), 20, 22, 24.

Snay, R., G. Adams, M. Chin, S. Frakes, T. Soler and N. Weston (2002). The synergistic CORS program continues to evolve, Proc. ION-GPS 2002, Portland, OR, September 24-27, 2630-2639.

Soler, T. (2001). Densifying 3D GPS networks by accurate transformation of vector components, GPS Solutions, 4(3), 27-33.

Soler, T., R.E. Johnson, L.F. Thormahlen, R.H. Foote (2001). Parting the waters of the Western Gap: The U.S./Mexico Coastline Survey, GPS World, 12(5), 28-30, 33.

Soler, T. (2001). Transformaciones rigurosas de vectores GPS al marco de referencia SIRGAS, Revista Cartográfica, 72(1), 139-147.

Soler, T., N.D. Weston, H. Han (2002). Computing NAD 83 coordinates using ITRF-derived vector components, Proceedings XII FIG International Congress, ACSM/ASPRS Annual Conferences, April 19-26, Washington, D.C.

Soler, T., J. Marshall (2002). Rigorous transformation of variance-covariance matrices of GPS-derived coordinates and velocities, GPS Solutions, 6(1-2), 76-90.

Soler, T., R.A. Snay (2003). Equations for transforming positions and velocities between ITRF00 and NAD 83, J. Surveying Engineering, ASCE, in press.

Soler, T., J. Marshall (2003). A note on frame transformations with applications to geodetic datums, GPS Solutions, in press.

Soler, T., R.H. Foote, D. Hoyle and V. Bocean (2000). Accurate GPS orientation of a long baseline for neutrino oscillation experiments at Fermilab, Geophysical Research Letters, 27(23), 3921-3924.

Vanicek, P., M.R. Craymer and E.J. Krakiwsky (2001) Robustness Analysis of Geodetic Horizontal Networks. Journal of Geodesy, 75(4).

Vaníček, P., P. Novak, M. Craymer and S. Pagiatakis (2002) On the Correct Determination of Transformation Parameters of a Horizontal Geodetic Datum. Geomatica, Vol. 56, No. 4.

South America

South America is very well covered by the SIRGAS project, for which Hermann Drewes (Germany) acted as liaison to GRGN. See references for further informations.

South East Asia and Pacific

This is a report to Commission X on Geodetic activities in the Asia Pacific from the Sub Commission on SE Asia which was reformed in 1998 with John Manning (Australia) and Junyong Chen (China) as co-chairs.
International cooperation in Geodesy at the national level is coordinated through the Regional Geodetic Networks Working Group of the Permanent Committee for GIS Infrastructure in the Asia Pacific (PCGIAP)
As the objectives of Commission X are close to the aims of the Regional Geodetic Networks Working Group it was sensible to reform the sub commission from Working Group representatives.

Report of Commission X Working groups

Working Group 1 on Datums and Coordinate Systems

(Prepared by Bjorn Geirr Harsson, Norway and Johannes Ihde, Germany)

The Working Group Datum and Coordinate systems has mainly been done its activities in relation to ISO standards. In January 2003 the standard ISO 19111, Geographic information — Spatial referencing by coordinates was accepted as an international standard. This standard defines the conceptual schema for the description of spatial referencing by coordinates. A coordinate reference system is defined by one datum and by one coordinate system. The standard describes the minimum data required to define one-, two- and three-dimensional coordinate reference systems. It allows additional descriptive information to be provided. It also describes the information required to change coordinate values from one coordinate reference system to another. A set of coordinates on the same coordinate reference system requires one coordinate reference system description.
In addition to describing a coordinate reference system, this standard provides for the description of a coordinate transformation or coordinate conversion between two different coordinate reference systems. With such information, geographic data referred to different coordinate reference systems can be merged together for integrated manipulation.

In the standard 33 geodesy related terms are defined.

Another standard is under preparation, ISO 19127, Geographic information/Geomatics - Geodetic Codes and Parameters. This standard provides for creation and maintenance of a publicly available list of geodetic codes and parameters that is in compliance with ISO 19111, and that provides guidance on applicability and appropriate use. It provides guidance for proposals for additions or modifications to the list, validation of proposals, inclusion of data, and maintenance.

With the Spatial Reference Workshop 1999 and the Cartographic Projection Workshop 2000 in Marne-la-Vallee the foundations were laid for the definition of uniform European coordinate reference systems in position and height for the spatial referencing of geo-data of the European Commission and for future specifications of products to be delivered to the EC and the promotion of wider use of the system within all member states by appropriate means. The information system for coordinate reference systems (CRS) is a common initiative of EUREF and EuroGeographics (http://crs.ifag.de). The CRS information system orientates on the international standard ISO 19111. The Information System contains at present: The descriptions of pan-European Coordinate Reference Systems, the descriptions of national Coordinate Reference Systems of European countries and the descriptions of transformations to European Terrestrial Reference System ETRS89.

Working Group 3 on the Worldwide Unification of Vertical Datums

(Prepared by H. W. Kearsley, Australia)

The Goal
To investigate the possible actions to be undertaken to realize a global vertical datum, and to determine its connection to various existing vertical datums.

Significance
To bring the many height-related data sets around the globe onto the one common reference surface - the global geoid;
To enable the scientific study of departures of the regional vertical datums (both inter-regional and intra-regional) from the global geoid;
To ensure all height-related data, and results derived therefrom, relate to the global geoid. For example, to ensure that gravity reductions or terrain effects for global geopotential models based upon national height datums relate to the common global geoid.
To assist the study of distortions in the National Height Datums, and the study of oceanographic phenomena (SST) at tide gauges.

Meetings
1 IAG, Rio (Sept, 1997)
After an informal meeting of the Working Group in IAG, Rio, the following email was circulated:
Those of you who I originally circulated will remember my proposal to adopt a system for this purpose (for those not on the original circulation list, I have included this original proposal at the end of this email.) I was told that it was NOT possible to propose any resolution such as the one below at the IAG meeting in Rio. In any case, at the informal meeting of some members of the working group, it was felt to do this would be premature. Instead, it was proposed that

I. (say) four study groups be set up to carry out research into the operational and theoretical aspects of vertical datum connections,
II. using selected regions for pilot studies. Such regions would include those which already had extensive experience in datum unification, eg EUVN for Europe, NAVD for Nth America; and those areas where there were or are to be extensive regional high-precision GPS campaigns (eg SIRGAS - Sth America, and the Asia-Pacific Space Geodynamics Project (APSG - Pacific and SE Asia; or its subset GEODYSSEA)),
III. that the results be presented in 2 years at the IUGG in the Birmingham, UK meeting, commenting on such matters as

a) preferred height systems
b) preferred geometric reference
c) preferred tide model, and
d) preferred geopotential model.

This can be used as the basis for a resolution at IUGG which proposes the method to be used in the unification of the vertical datums.

Comments:

I. A meeting of the Regional Geodetic Network Working Group was held between the dates of 2-4 July 1998 in Canberra Australia, hosted by AUSLIG. A this meeting a number of important objectives and strategies directly related to the vertical datum unification were devised (see http://www.gmat.unsw.edu.au/final_year_thesis/p_epstein/campag.htm)
II. Unfortunately there is no special session specifically set aside at IUGG 1999 for the discussion of the matters above. However, a number of papers touching on these matters are being presented at session G6.

2. IERS Workshop, Paris, 14 -18 October, 1996
A meeting entitled Vertical References, and chaired by C. Boucher and W. E. Carter, produced a very useful report canvassing various theoretical and practical impediments to the realization of a unified vertical datum. It also made four recommendations specifically dealing with this problem, addressing both housekeeping and operational matters to overcome these difficulties (IERS 1997, Technical Note No 22).

World Wide Web Page
A summary of recent developments, the problems of unification, recent papers, and links to other relevant scientific groups and campaigns (eg EUVN, NAVD) is now available at HYPERLINK http://www.gmat.unsw.edu.au/final_year_thesis/p_epstein/main.htm .

Conclusions

We can conclude that the topic of the GRGN commission has shown during the last quadriennium a tremendous development of activities, in particular on

- the generalized use of GPS and the emerging role of Global Navigation Satellite Systems (GNSS) where new systems such as Galileo are under development in addition to GPS

- and the rapid unification of reference systems through the use of ITRF.

We hope that GRGN has played a role of stimulation and coordination by helping the dissemination of information, standardization, cooperation and education. We can also appreciate that the regional cooperation is active almost everywhere.

IAG has adopted a new structure in which the GRGN actiivities will obviously continue, especially in the new Commissions 1 and 4.

SPECIAL COMMISSION SC4:

"APPLICATION OF GEODESY TO ENGINEERING 1999 – 2003"

H.Kahmen

Introduction

Rapid developments in engineering, microelectronics and computer sciences have significantly changed both instrumentation and methodology in geodesy and geotechnics. To build higher and longer, on the other hand, have been key challenges for engineers and scientists since ancient times. Now and in the foreseeable future, engineers confront the limits of size, not merely to set records, but to meet the real needs of society minimizing negative environmental impact. Highly developed techniques are needed to meet these challenges for the 21st century.

The objectives of IAG Special Commission 4, influenced by these challenges, are on the one hand, to document the body of knowledge in the fields "Geodesy, Geotechniques and Engineering" and, on the other hand, to encourage new developments and present them in an consistent framework.

To fulfil these tasks Working Groups (WGs) have been established. To give the members of the WGs chances to come together, present their work and discuss the results, two International Workshops and two International Conferences were organized.

Objectives

To meet some of the challenges, engineering geodesy is confronted with at the beginning of the 21st century, the following goals of SC4 were defined:

a) studying of the newest developments of mobile multi sensor systems
b) development of dynamic monitoring and data evaluation systems for buldings
c) development of monitoring- and alert systems for local geodynamic processes
d) documentation of geodetic methods used on large construction sites
e) studying of pseudolite applications in engineering geodesy
f) studying of the application of knowledge-based systems in engineering geodesy

Working Groups (WGs)

Six WGs were proposed by the president, four worked successfully during the whole period and sent a report, two only during the International Syposium in Berlin, May 2002. The names of the WGs conform with the objectives of SC4.

i) SC4 WG1: Real time Mobile Multi-sensor Systems and their applications in GIS and Mapping
Chair: Dr. Naser El-Sheimy (Calgary);
20 members
To fulfil the need for up-to-date inventory and geometric data along roads, railways, rivers, pipelines, etc. Mobile Multi-sensor Systems (MMS) are being operated. MMS have in common that they integrate a set of sensors mounted on a common platform and synchronized to a common time base. They are typically used in cinematic mode. Systems of this type

- can be immediately deployed everywhere on the globe without the need for identifying existing ground control.
- employ a task-oriented system design through integration at the measurement level.
- can be equiped with real-time quality control features by including data redundancies in the system design and by using expert knowledge.
- use software to transform the time-dependent measurement process into a sequence of georeferenced images which can be considered as independent geometric units in post-mission processing.

The members of WG1 met at International Conferences (January 2001 in Cairo, Egypt and October 2001 in Vienna, Austria) and witnessed development activities by many universities and companies on almost all continents. Land-based systems continue to demonstrate the power promised at the early time of the development, for example in road and railway survey, utility survey and others. The takeover of part of such traditional surveying markets is believed to be only a start. Meanwhile the concept could also be transferred to air borne and backpack systems where positional and oriental sensors are integrated with imaging sensors to approach real time mapping that is not restricted to where only land vehicles can reach.
More details can be found under: http://www.ensu.ucalgary.ca/~nel-shei/iag.htm

ii) SC4 WG2: Dynamic Monitoring of Building and Systems Analysis

Chair: Dr. Gyula Mentes (Hungaria)
14 members

Worldwide local geodynamic processes (landslides, mudflows, rockslides, etc.) belong to the major types of natural hazards killing or injuring a large number of individuals and creating very high costs every year. Besides direct costs local geodynamic processes are also reason for even higher indirect costs like interruption of important infrastructure facilities or losses for the tourist industry etc. This implies that there is urgent need to be involved in research in these fields to develop multi sensor systems for monitoring and analytical models for the evaluation of the processes. In future knowledge based systems will be an important tool.

During the last four years new scientific results were achieved on the following fields:
Multi-sensor systems were developed for monitoring the processes
Environmental related effects, influencing the strain and tilt measurements were studied in order to remove them from the measured data in order to get the real signals of the mass movements. In this case environmental sources of influence are barometric pressure, wind humidity, temperature, ground water level etc.

To get a deeper insight into the processes an international consortium was organized to study the nature and behaviour of landslides and to develop fundamental methodes for alert systems. Knowledge based systems shall play an important role. The consortium consists of 12 institutes from 6 different countries. The research is sponsored by the 5th frame program of the European Union.
More details can be found under: http://info.tuwien.ac.at/ingeo/sc4/sc4_99-03.htm

iii) SC4 WG5: Pseudolite Application in Engineering Geodesy

Chair: Dr. Jinling Wang (Australia)
Co-Chairs: Dr. Gethin Roberts (UK)
Dr. Dorota Grejner-Brzezinska (USA)
26 members

The more satellites that are tracked for positioning, the more reliable results can be achieved. However, in some situations, such as in downtown urban canyons, engineering construction sites, and in deep open-cut pits and mines, the number of satellites occasionally is not sufficient. In worst situations, such as in underground tunnels and inside buildings, the satellite signals are completely lost. These problems with existing GNSS systems can be addressed by the inclusion of additional ranging signals transmitted from ground-based “pseudo-satellites” (pseudolites). As the research during the last years showed this technology can be used for a wide range of positioning and navigation applications, either as a substantial augmentation tool of spaceborne systems, or as an independent system for indoor positioning applications. Major objectives of the activities of the WG were:

a) Applications of pseudolites in engineering geodesy
b) Pseudolite augmentation of GPS
c) Pseudolite-only positioning scenarios
d) Integration of pseudolites with other sensors, such as INS
e) Setting up a WG website providing a focous for pseudolite research and applications with the relevant links. http://www.gmat.unsw.edu.au/pseudolite.

More details can be found under: http://info.tuwien.ac.at/ingeo/sc4/sc4_99-03.htm

In general the research of the WG showed that a greater number of applications is possible today, the main limiting factors, however, are multipath errors. Different methods were tested to overcome these problems.

iv) SC4 WG6: Application of Knowledge-Based Systems in Engeneering Geodesy

Chair: Dr. Klaus Chmelina (Austria)

4 members

The research of the WG showed that by now there is an extended field of applications in geodesy and other geo-sciences. Typical examples are: control of measurement- and guidance systems, deformation analysis, control of alert systems, control of multi-sensor systems and the evaluation of their complex data stream, etc. In many projects in geo-sciences data must be regarded incomplete and uncertain, that means additional heuristic knowledge has to be added to the evaluation processes. In knowledge-based systems expert knowledge (as well as its uncertainty) can get inserted, represented, stored, accessed and applied by using different techniques coming from the field of Artificial Intelligence. With knowledge-based systems the above mentioned tasks can be solved automatically, fast and with a minimum of human interaction. The members could show that mainly with contributions about deformation analysis and measurement system control.

More details can be found: http://info.tuwien.ac.at/ingeo/sc4/sc4_99-03.htm

International Conferences and Workshops

Two international conferences and two workshops were organized in cooperation with the WGs and other national and international organizations.

1. 3rd International Workshop on Mobile Mapping Technology Cairo, Egypt, January 3 - 5, 2001 organized by: IAG Special Commission 4, FIG Commission 5, ISPRS Commission II. For more information see: http://info.tuwien.ac.at/ingeo/sc4/sc4_99-03.htm

2. Workshop on Monitoring of Constructions and Local Geodynamic Processes Wuhan, China, May 22 - 24, 2001 organized by: IAG Special Commission 4, WG2 and WG3. For more information see: http://info.tuwien.ac.at/ingeo/sc4/wuhan01.htm

3. 5th Conference on Optical 3-D Measurement Techniques Vienna, Austria, October 1 - 3, 2001 organized by: ISPRS Commission II, IAG Special Commission 4. For more information see: http://info.tuwien.ac.at/ingeo/optical3d/o3d.htm

4. 2nd Conference on Geodesy for Geotechnical and Structural Engineering Berlin, Germany, May 21 - 23, 2002 organized by: IAG Special Commission 4, WG1, WG2, WG3, WG4, WG5, WG6, FIG Commission 5
For more information see: http://info.tuwien.ac.at/ingeo/sc4/berlin.html

5. Proposals for the future of SC4. My experience over the last eight years has been that the progress of our research work required both the detailed work of study groups and the integrating effects of the Special Commission. A larger structure, such as SC4 was essential in organizing meetings where research of special working groups could be presented and discussed. These meetings also provided a forum for the interaction between different international organizations as ISPRS and FIG. I would therefore propose that a subcommission for “Application of Geodesy to Engineering” becomes part of the new structure of IAG.

SPECIAL STUDY GROUP 1.179:

"WIDE AREA MODELLING FOR PRECISE SATELLITE POSITIONING"

S.Han

Introduction

Precise satellite positioning requires that carrier phase data be used and that the integer ambiguities associated with the carrier phase measurements be resolved in some way. However, the distance from the user receiver to the nearest reference receiver may range from a few kilometres to hundreds of kilometres. As the receiver separation increases, the problems of accounting for distance-dependent biases increase, and reliable ambiguity resolution for carrier phase-based satellite positioning becomes an even greater challenge.

'Wide area modelling' for precise satellite positioning requires either long observation spans to estimate all biases in the functional model, or multiple reference stations. For the first approach, all error sources, such as orbit bias, atmospheric parameters, receiver inter-channel biases, along with the user's trajectory, should be estimated simultaneously. This is the approach used for geodetic static positioning (e.g., IGS-based site coordinate determination, and precise GPS orbit determination). The second approach provides more opportunities to either estimate the different biases individually and then apply interpolated biases (at the user location) to the measurements, or generate a so-called 'virtual reference station', by using the data from a multiple reference station network. Some of the concepts have been studied in the past by previous IAG SSGs, both separately and in combination, and with respect to various applications. In 1999 the IAG established SSG 1.1.79 to focus on investigations of the GPS functional model, the stochastic model, and ambiguity resolution procedures. The website of the Special Study Group 1.179 is http://www.gmat.unsw.edu.au/snap/gps/iag_section1/ssg1179.htm.

Objectives of the SSG 1.179

1. Error modelling through the improvement of functional models for medium-range, and long-range high precision satellite positioning using multiple reference stations, including:
- multipath mitigation algorithms,
- troposphere model refinement,
- regional ionosphere modelling algorithms,
- orbit bias modelling,
- parametric modelling algorithms (for each error source), and
- integer bias estimation and validation, e.g. cycle slip detection/repair and ambiguity resolution.

2. Error modelling through stochastic model refinement, including:
- correlation analysis of carrier phase measurements from satellite positioning systems,
- stochastic modelling algorithms suitable for post-processing applications, and
- stochastic modelling algorithms suitable for real-time applications.

3. The continued study of ambiguity resolution techniques in order to develop:
- more efficient means of searching integer ambiguities, and
- validation procedures for ambiguity resolution.

4. The application of these improvements to:
- short-range satellite positioning applications,
- differential correction generation from multiple reference GNSS receiver network, in support of medium-range high precision navigation,
- precise long-range GPS kinematic positioning, and
- sub-centimetre engineering applications, e.g. construction deformation monitoring, volcano monitoring, etc.

Members and Corresponding Members

Members: Shaowei Han (Chair, USA), Oscar Colombo (USA), Paul Cross (UK), Liwen Dai (U.S.A.), Paul de Jonge (U.S.A), Hans-Jürgen Euler (SWITZERLAND), Yanming Feng (AUSTRALIA), Yang Gao (CANADA), Yongil Kim (KOREA), Donghyun Kim (CANADA), Dennis Odijk (THE NETHERLANDS), Günter Seeber (GERMANY), Dariusz Lapucha (USA), Jingnan Liu (CHINA), Nigel Penna (AUSTRALIA), Rock Santerre (CANADA), Julia Talaya (SPAIN), Jinling Wang (AUSTRALIA), Xinhua Qin (USA), Peiliang Xu (JAPAN).

Corresponding Members: Changdon Kee (KOREA)

Activities of the SSG1.179

Error Modelling Through Improvement of Functional Models

Single-based real-time kinematic GPS positioning systems over medium-range, e.g. 10-50km have been investigated. The distance dependent errors, e.g. ionosphere and troposphere, have been included into the functional model. The capability of long-range RTK system has been reported to extend to 35km from Leica and 40km from Thales Navigation.

Error modelling through the improvement of functional models for medium-range, and long-range high precision satellite positioning using multiple reference stations includes the study of topics such as multipath mitigation, troposphere modelling, regional ionosphere modelling, and orbit bias modelling. These biases could be estimated individually through some special approaches, or by setting different parameters in the functional model for the different error biases.

Absolute field calibration of GPS antennas is based on the controlled antenna motion of a robotic arm, and is now a mature calibration technique. The technique can be used to calibrate all antennas in a multiple reference station network. With (absolutely) calibrated antennas it is possible to separate phase centre variations and multipath. An approach for multipath calibration based on controlled antenna motion was proposed.

Investigations into the use of 'semi-parametric least squares' for the mitigation of systematic errors in GPS processing have been conducted. Current focus is the lumping together of all systematic errors as a single smoothing function, estimated over the processing session. Initial results from a 'short' 30km baseline are encouraging, and tests have commenced on more data sets.

An adaptive Finite-duration Impulse Response filter, based on a least-mean-squares algorithm, has been developed to derive a relatively noise-free time series from continuous GPS results. This algorithm is suitable for real time applications. Numerical simulation studies indicate that the adaptive filter is a powerful signal decomposer, which can significantly mitigate multipath effects.

Increased use has been made of ionospheric regional modelling to improvement on-the-fly ambiguity resolution over long distances, as part of initiatives within the GEOIDE project (website: www.scg.ulaval.ca/gps-rs/). In order to characterize the ionosphere's vertical profiles and subsequently further improve the ionosphere modeling accuracy, a three-dimensional ionosphere modeling method has also recently been developed based on tomography techniques. Preliminary research results based on carrier smoothed code observations have indicated that over 90% ionosphere delays in GPS measurements could be recovered by the proposed 3D tomographic model. Ionospheric tomography has also been used to help resolve GPS ambiguities on-the-fly at distances of hundreds of kilometres during increased geomagnetic activity. An approach, referred to as the "grand solution", which estimates orbit, refraction, and local bias error states, along with the uer's trajectory, was proposed. The modelling and estimation of the tropospheric zenith delay, both for more accurate real time and post-processed navigation, and for rapid and precise meteorological updates, has been implemented. Also numerical weather prediction has proven to contribute to the estimation of the tropospheric delay.

With respect to Real-Time Kinematic (RTK) positioning using multiple reference stations, the results of a survey conducted by Dr. Euler, Chair of the RTCM SC104 Working Group "Network RTK", of working group members found:

- The expected RTK accuracy could be at sub-decimetre to centimetre level (one sigma).
- The reference station distances should be of the order of 50-70 km for centimetre accuracy, or about 200 km and above for decimetre accuracy.
- The size of a reference station area should be of the order of 500 km x 500 km. However, target could be nationwide to continentwide coverage.
- The medium for distribution of data could be unidirectional techniques (Broadcast like UHF, VHF, TV, DARC, etc) or bi-directional techniques (GSM, UTMS, etc.).
- The baud rates for transmission are from 2400 Baud upwards, including 1Hz observation data.
- The tolerated latency is up to 10 seconds without SA, or up to 2 seconds with SA. However, the orbit information can be delayed by up to 120 seconds, ionosphere by up to 10 to 60 seconds, troposphere by up to 30 seconds. The real-time positioning output is expected within 100 milliseconds.
- The requirement for reference station equipment is dual-frequency receivers with clear sky view.

With regards to GPS/Glonass surveying and navigation applications using multiple reference stations, a new method was proposed, in which the distance-dependent biases have been separated into the frequency-dependent errors (ionospheric bias) and frequency-independent errors (e.g. troposphere bias and orbit bias). The separate estimates of the two types of errors, which are generated from the carrier phase measurements using the multiple reference stations, can be used to model the user distance-dependent biases for L1, L2 carrier phase and pseudo-range measurements in different ways.

Another new development is the carrier phase-based positioning system without requiring base receiver. It differs from current RTK systems since the positioning is based on the processing of un-differenced carrier phase observations from a single receiver. Although it does require the support of precise GPS orbit and clock data, it doesn't requires the use of any base stations so that no longer limited by the vicinity requirement of a rover receiver to the base receiver as the case in current RTK positioning. The results have already demonstrated position accuracy at 10cm-level after the convergence of the float ambiguities or fixing of the integer ambiguities. Fast un-differenced ambiguity convergence and resolution is a challenge to develop this type of high precision positioning systems and it requires strong collaborations among international researchers in the field.

Error Modelling Through Stochastic Model Refinement

High quality estimation results using least squares require the correct selection of the functional and stochastic models. The stochastic model should represent the statistical characteristics of the modelling errors. It is dependent on the choice of observation functional model, hence for a different choice of functional model, a different stochastic model may be needed. For example, if the ionospheric delay is considered an unknown parameter in the functional model, the modelling errors will not include the residual (double-differenced) ionospheric bias, and hence they will more likely have random properties.

The SIGMA-□ model has been developed for stochastic modelling of GPS signal diffraction errors in high precision GPS surveys. The basic information used in the SIGMA-□ model is the measured carrier-to-noise power-density ratio (C/N0). Using the C/N0 data and a template technique, the proper variances are derived for all phase observations. Thus the quality of the measured phase is automatically assessed and if phase observations are suspected of being contaminated by diffraction effects they are downweighted in the least-squares adjustment. An extended weight model for GPS phase observations was also proposed which the user does not require calibrated templates.

Mathematical and statistical modelling has also been investigated. Using a multipath estimation method based on the signal-to-noise ratio and an elevation-dependent stochastic model, the height accuracy of a typical RTK session has been improved by approximately 44% and the fidelity of quality measures has been increased.

A stochastic assessment procedure has been developed to take into account the heteroscedastic, space- and time-correlated error structure of the GPS measurements. Test results indicate that by applying the stochastic assessment procedure developed, the reliability of the estimated positioning results is improved. In addition, the quality of ambiguity resolution can be more realistically evaluated.

Magellan's new product Instant-RTK™ has reportedly overcome the functional and stochastic modelling problem through empirical knowledge and a real-time learning procedure which can used to adapt the model when the environment is changing.

On the other hand, the stochastic modelling approach has been applied to the parameters in the functional model. For example, the residual ionospheric delay after applying ionospheric delay corrections could be accounted for through processing the residual ionospheric delay correction as stochastic observables. The stochastic model to be applied for the corrections could be provided by multiple reference stations. First results show indeed an enormous improvement in the success rate of ambiguity resolution.

The stochastic behaviours of the residuals in un-differenced carrier phase observations using single GPS receiver without a base receiver has been investigated. The correlation analysis results indicated high correlations among the receiver clock, the height position component and the tropospheric parameter. The residual error influence on the point determination has also been assessed and different stochastic processes have been implemented for positioning under different environments from static to highly dynamic situation.

Continued Study of Ambiguity Resolution Techniques

GPS ambiguity resolution (AR) techniques have been intensively investigated. The integer ambiguity searching techniques have been dramatically improved over the last decade, especially by the contribution of the LAMBDA method. Moreover an inverse integer Cholesky decorrelation method and the Lenstra, Lenstra and Lovasz (LLL) method have also been proposed. However, it has to be recognised that all search algorithms are likely to result in identical integer ambiguity candidates under comparable setups, e.g. using like search windows/volumes and similar parameters. Continued study is now focused on AR in integrated systems: GPS, Glonass, pseudolite or other systems, and more powerful validation criteria to ensure correct ambiguity resolution.

For example, Magellan's new product Instant-RTK™ appears to have successfully addressed the functional and stochastic modelling problem through empirical knowledge and a real-time learning procedure. A series of validation criteria have been implemented, in addition to the commonly used ratio test, which can be adapted based on the reliability requirements, number of satellites, observation time and baseline length. The Instant-RTK validation criteria have successfully traded off the requirements of observation span on the one hand, and RTK solution reliability on the other. Moreover, the algorithm to detect, identify and adapt the outliers to guard against incorrect integer ambiguity determination has been implemented, and the success rate of AR has been increased significantly.

Leica Geosystems' System 500 has implemented a repeated search processing technique to shorten ambiguity initialisation time and to improve AR reliability, especially in difficult environments. This method repeats its internal determination of the integer ambiguity using significantly shorter observation times. Once the AR algorithm has verified that they are identical, the system can output its coordinates.

On the theoretical side, a method was proposed to evaluate the probabilities of correct integer estimation based on the variance matrix of the (real-valued) least-squares ambiguities. These success rates are given for the ambiguity estimator that follows from integer bootstrapping. Although less optimal than integer least-squares, integer bootstrapping provides useful and easy-to-compute approximations to the integer least-squares solution. In a similar manner, the bootstrapped success rates provide bounds for the probability of correct integer least-squares estimation.

Fast ambiguity convergence and resolution for high precision single GPS receiver positioning system has been investigated. Since un-difference carrier phase contains various residual errors including a non-zero initial phase bias, the ambiguity resolution problem becomes much more difficult compared to the traditional double difference ambiguity resolution. A pseudo ambiguity fixing algorithm has been developed based on a partial ambiguity search and fixing strategy and more research is currently underway.

New Development and Future Trends

In the next few years, more commercial system will be developed to generate corrections from multiple reference stations for surveying and precise navigation applications. RTCM SC104 Working Group "Network RTK" will propose a new format to transmit correction information from multiple reference station networks. This is not only beneficial to RTK systems, but also to single-frequency, low-cost GPS systems.

The high precision positioning system using one dual frequency GPS receiver without base receiver has been developed, in which the precise orbit and precise satellite clock are required. The commercial products or development reports have been released from NAVCOM, Thales Goesolution and Fugro. However the long converge time to 10cm centimeter is an obstacle for some applications and

With the new development of GPS modernization, Galileo and Glonass systems, the wide area error modelling for precise satellite positioning will be significantly improved.

SPECIAL STUDY GROUP 1.180:

"GPS AS AN ATMOSPHERIC REMOTE SENSING TOOL"

H. van der Marel

Introduction

Using networks of ground-based GPS receivers it is possible to observe the integrated water vapour (IWV) and the total electron content (TEC) of the Earth's atmosphere. While at first these parameters were considered a mere nuisance, it is nowadays considered to be an important signal for atmospheric sciences.

Water vapour is one of the most important constituents of the atmosphere. It plays a crucial role in many atmospheric processes covering a wide range of temporal and spatial scales. Furthermore, it is also the most important greenhouse gas and highly variable. Climate research and monitoring, as well as operational weather forecasting, need accurate and sufficiently dense and frequent sampling of the water vapour, to which existing GPS networks could contribute significantly. In order to be of any use for operational weather forecasting, firstly GPS networks must be able to provide integrated water vapour in near real-time (NRT) (with a typical delay of one hour), and secondly GPS observations must be assimilated into Numerical Weather Prediction (NWP) models.

Dual-frequency GPS receivers enable the estimation of total electron content (TEC) along a given satellite-receiver signal path. By combining observations from regional and global networks of continuously operating dual-frequency receivers, parameters describing the spatial and temporal distribution of total electron content can be derived. Such observations of TEC, available globally on a near real-time basis, allow an excellent opportunity for monitoring ionospheric signatures associated with space weather. For example, the development of ionospheric storms can be observed in global patterns of TEC, while small-scale irregularities in electron density (associated with scintillation) can be observed in short-term variations of TEC and/or spectral analysis of GPS phase observations. The website of the Special Study Group 1.180 is http://www.gmat.unsw.edu.au/snap/gps/iag_section1/ssg1180.htm.

Objectives of the SSG 1.180

The focus of the SSG is to explore the issues related to the derivation of water vapour and TEC in NRT using GPS, the assimilation of GPS water vapour data into weather forecasting models, use of GPS water vapour data for climate applications and the integration of GPS-derived TEC estimates and scintillation indices into space weather applications. The main objectives of the special study group are:

Identify key signatures observed in GPS-derived estimates of TEC, as associated with phenomena such as ionospheric and geomagnetic storms, scintillation, travelling ionospheric disturbances, magnetospheric substorms and auroral activity.

Assess methods to quantify the level and nature of ionospheric activity, based on TEC estimates.

Explore key issues related to the feasibility of integrating TEC estimates, and TEC-based indices, into space weather forecasting and nowcasting - such issues include real-time requirements, and the temporal and spatial resolution necessary for reliable detection and prediction of ionospheric phenomena.

Identify key problems in GPS-derived integrated water vapour, as associated with phenomena related to the near field of the antenna, such as multipath and phase centre variations, and local weather (gradients, mapping to the vertical), reprocessing and archiving of data, in relation to climate applications.

Explore key issues related to the assimilation of GPS-derived integrated water vapour observations into NWP models - such issues include real-time requirements, temporal and spatial resolution, slant or vertical delays, temporal and spatial correlation and quality insurance issues.

Assess the potential impact of tropospheric tomography using GPS-estimated slant delays.

Members

Hans van der Marel (Co-chair, THE NETHERLANDS), Susan Skone (Co-chair, CANADA), Helen Baker (UK), Michael Bevis (USA), Steven Businger (USA), Galina Dick (GERMANY), Mark Falvey (NEW ZEALAND), Manuel Hernandez-Pajares (SPAIN), Per Hoeg (DENMARK), Tetsuya Iwabuchi (JAPAN), Mark Knight (AUSTRALIA), Tony Mannucci (USA), Christian Rocken (USA), Akinori Saito (JAPAN), Peter Stewart (CANADA), Rene Warnant (BELGIUM). [1]

Activities of the SSG1.180

Solar Cycle 23

Solar Cycle 23 reached a peak in April 2000, with a secondary peak observed in late 2001. Enhanced solar flux values, and increased geomagnetic activity, were observed throughout the period of solar maximum. While a significant decrease in sunspot number has been observed recently, larger values of the planetary geomagnetic indices have persisted through early 2003 – indicating the continued presence of enhanced ionospheric activity associated with storm events. There have been approximately 50 major geomagnetic storms during Solar Cycle 23 (with the largest storm events occurring July 15-16, 2000 and March 31-April 1, 2001). In early 2003, it was noted that only one-half of the predicted geomagnetic storm events had occurred in recent years. It is anticipated that 45 additional major geomagnetic storms may occur during the remainder of the current solar cycle. This is consistent with previous solar cycles, where larger numbers of geomagnetic storms tend to be observed in the 2-3 years following solar maximum. The next solar minimum will likely occur in 2006 and Solar Cycle 24 is predicted to peak in 2010.

TEC Estimation and Monitoring

Networks of permanent GPS receivers are an excellent tool to compute the Total Electron Content (TEC) of the ionosphere. The International GPS Service (IGS) has set up an Ionospheric Pilot Project in June 1998, involving several International Associate Analysis Centers (CODE, EMR (NRCAN), ESA, JPL, UPC). Estimates of TEC are available on a daily basis in the form of IONEX files. Special campaigns were organised during the solar eclipse in August 2000 and during the solar maximum in 2001 involving high-rate (1ssec) observations of many GPS receivers.

The precise determination of TEC in real-time is important for DGPS and GPS-RTK applications with the closest reference station at several hundred kilometres. Several improvements of ionospheric models with GPS have been made involving tomographic and adaptive approaches. The University of Calgary has deployed a network of sixteen closely spaced dual frequency receivers in Southern Alberta (baselines of 50-70 km) for development of real-time regional ionosphere models based on a carrier phase-based double difference approach

A real-time ionospheric TEC model for the Australian region, based on a network of semi-codeless receivers extending from Northern Australia to the Antarctic, has been developed by the Ionospheric Prediction Services (IPS) in Australia. The purpose of this work is to provide broadcast corrections for single-frequency users as part of a proposed Wide Area DGPS system. More recent work has involved the use of GPS to monitor ionospheric disturbances during magnetic storm events, for ionospheric TEC and scintillation monitoring in low, mid and high (Southern) latitudes, including the Antarctic, and the use of GPS to measure the Earth's plasmasphere.

In Canada an ionospheric warning and alert system for Canadian Coast Guard DGPS users has been developed. The Canadian marine DGPS system operates in the sub-auroral region, where significant degradations in positioning accuracy are associated with storm-enhanced densities and gradients near the main trough. The impact of such effects has been quantified using long-term data sets, and a warning

[1] ***Mark Knight, Peter Stewart and Helen Baker have moved on to other jobs and are not anymore active in this field.***

system is based on predicted K indices provided by the NOAA Space Environment Center for the North American Sector.

The Canadian GPS Network for Ionosphere Monitoring (CANGIM) was initially deployed in 2001-2002. This network consists of (nominally) six dual frequency GPS receivers at various latitudes and local times in Canada. The receivers are equipped with precise oscillators and specialized firmware to provide observations of scintillation parameters, absolute TEC values and rates of TEC. Three sites are currently operating in near real-time. The rates of TEC are used to detect the presence of irregularities in electron density associated with auroral substorms. The extent and magnitude of auroral effects is monitored, and the spatial and temporal characteristics of local ionospheric effects are quantified for GPS users. Warnings are provided to users, with estimates of the impact on precise positioning applications.

Ionospheric Scintillation Monitoring and Effects of Scintillations on GPS

The Australian Defence Science & Technology Organisation (DSTO) has been developing models of the effects of ionospheric scintillations on GPS with the intention of quantifying losses in navigational accuracy and acquisition performance. The scintillation model they use is essentially a stochastic model in which the amplitude and phase distribution functions are assumed to be Nakagami-m and Gaussian respectively, and the power spectral densities are assumed to follow an inverse power-law relationship. This is based on measurements taken from numerous sources, in particular the Defense Nuclear Agency Wideband satellite experiment from the 1970s. It is also consistent with the Wide Band Scintillation Model, WBMOD, which was developed by Northwest Research Associates and enables key scintillation parameters such S_4 and σ_ϕ to be predicted. By linking WBMOD with the receiver performance models, predictions can be made about the likely impact of scintillations on a GPS receiver at a given time and location under a specified set of solar and geomagnetic conditions. In parallel with this work it has been attempted to validate the WBMOD model for the Northern Australia / South East Asia region using a network of Ionospheric Scintillation Monitoring receivers (ISMs which provide S_4 and σ_ϕ measurements etc.) and semi-codeless NovAtel Millennium receivers (used to measure TEC). These receivers have been in place for several years in locations close to both the magnetic equator and the crests of the equatorial anomaly in Indonesia, Malaysia and Papua New Guinea. This work has compared WBMOD predictions with regional measurements of the diurnal, seasonal and solar cycle variations in S_4 and σ_ϕ. Various groups within these countries have been actively involved with DSTO in this effort.

The CANGIM (previous section) is being used to develop a scintillation-monitoring service for near real-time operation. Receivers deployed in the CANGIM make simultaneous observations of raw GPS data, in addition to phase and amplitude scintillation parameters. Stochastic models are being developed to describe the impact of scintillations on receiver tracking performance and availability of regional RTK corrections. The CANGIM receivers are WAAS-capable, and current studies also focus on evaluating availability of the WAAS signal at high Northern latitudes during scintillation events. Continuity and reliability of WAAS corrections are also being investigated.

Space weather Applications

The growth of GPS infrastructure worldwide, in the form of wide area and regional GPS networks (many with real-time and near real-time capabilities), has allowed the development of scientific applications based on ionosphere products derived using GPS. Space weather applications include monitoring the ionospheric gradients and irregularities associated with geomagnetic storms and auroral substorms, and identifying TEC variations during ionospheric storm events. Significant progress has been made in understanding the processes associated with storm-enhanced densities by considering TEC signatures observed in GPS TEC maps. The SuomiNet has been developed for scientific applications, which include monitoring space weather in the United States and southern regions of Canada.

The USC/JPL team of the GAIM consortium (Global Assimilative Ionosphere Model) has made significant progress in inputting ground GPS data routinely into GAIM, a numerical weather prediction model for space weather. This model uses techniques similar to tropospheric weather forecast models, combining optimization mathematics with a physics-based model of the ionosphere. A model prototype is currently running on a daily basis using data from the global GPS network (IGS). Early indications are that the model predictions of global vertical TEC are close in accuracy to the semi-empirical Global Ionosphere Maps (GIM) produced by the IGS (see earlier section). Achieving parity between two models that differ in complexity is an important milestone. We expect that GAIM will eventually be more accurate than GIM because it can input a wider variety of data types that are expected from satellite instruments over the coming years.

Use of Ground-Based GPS for Meteorology

GPS Zenith Total Delay (ZTD) has become an important product from ground-based networks of GPS receivers. Over the last years the quality and availability of the estimated ZTD continued to improve as a result of refinements to the GPS analysis procedures, and more and denser GPS networks. Meteorologists are becoming more and more interested in using GPS derived ZTD for meteorological applications, and started to study several cases to assess the impact of ZTD on numerical weather predictions (NWP) and forecasting applications.

User requirements and standardized data formats for the use of ground-based GPS for meteorological applications have been formulated by the European COST-716 project "Exploitation of Ground Based GPS for NWP and Climate Applications" (http://www.oso.chalmers.se/geo/cost716.html/). The main impact on NWP is expected from very dense networks of GPS receivers, with inter-receiver distances of 100 km or shorter, but also data from less dense GPS networks can be used. The present accuracy of ZTD is sufficient for NWP and forecasting applications, but the biases are still to large for climate applications and need further investigation. Also, meteorologists have developed observation operators for ZTD, so that ZTD can be assimilated directly into weather models without having to convert ZTD into Integrated Water Vapor (IWV) first. This means that pressure sensors are not strictly required for GPS sites, except for climate applications, where well-calibrated pressure sensors at the GPS sites are recommended. Since IWV is still considered to be a very useful quantity for comparison purposes and for forecasting applications, several groups have started to use pressure (interpolated) from nearby synoptic stations or NWP models for the conversion of ZTD into IWV.

Many comparisons of GPS IWV with radiosondes and water vapour radiometers have demonstrated GPS-IWV has achieved an accuracy of about 1 kg/m^2 and relative uncertainty of 5-10%. This means that GPS-IWV already has sufficient accuracy for practical use in data assimilation and nowcasting of weather. The high quality of GPS IWV also allows it to be used for climate studies.

Near real-time networks for GPS-ZTD estimation

In order to be useful for NWP the ZTD should be available within 1-2 hours. A number of projects were started in Europe and USA to demonstrate the feasibility of a near real time GPS analysis.

In the USA NOAA/FSL operates a large network in near real-time using GPS data from a number of different sources, such as the FAA WAAS, SOPAC, CORS and SuomiNet networks, and many other data sources. Specific for meteorology, in the USA a network of over 100 GPS stations with a real-time analysis facility, called the SuomiNet, was established. NOAA/FSL has developed a GPS-Met data processing facility for this data, and has performed many impact studies using a research version of the RUC2 NWP model.

The European COST-716 action began in 2001 a near real-time demonstration trial, which now includes 250 stations in Europe, and involves 7 analysis centers using different softwares and analysis strategies. COST-716 has brought together several European (national) initiatives, such as the German GASP project of GFZ and the MAGIC project of the European Union, at the same time involving several new geodetic groups and meteorological institutes. The COST-716 network demonstrated that, using already existing resources, it is possible for many of the stations to deliver ZTD within 1h 45m to a gateway at one of the meteorological institutes, meeting the requirements set at the beginning of the project. The COST-716 NRT demonstration network continues to grow, including some very dense national Virtual Reference Station (VRS) networks.

The accuracy and timeliness of near real time GPS analyses is good enough for practical use in operational meteorology. The performance is mainly influenced the availability of (hourly) GPS data, the accuracy and availability of near real time orbits and, depending on the analysis strategy, satellite clocks solutions. Most groups are now using IGS Ultra Rapid orbit predictions, but for the best results and increased reliability the accuracy and timeliness of the orbits can still be improved. Several groups compute now their own real time orbits, and satellite clock solutions, in order to handle relative dense GPS networks using the precise point positioning concept. Further improvements in near real time orbit analysis are expected, together with the addition of satellite systems Galileo and GLONASS, the prospects for the future are good.

Impact of GPS-ZTD on operational meteorology

Proving that ZTD can be delivered in time is not enough. More important it has to be shown that GPS-ZTD can have a positive impact on NWP and forecasting applications. This activity is by no means limited to the NRT networks, because as a research activity it has not to be carried out in real-time.

Many GPS observation networks have already been established worldwide, in Europe, USA, Asia, New Zealand and Japan that are used for this purpose. In particular, very impressive results from the huge Japanese GEONET network, along with results from USA and Europe, were presented at the "International Workshop on GPS Meteorology", held in Tsukuba, Japan, 14-17 January 2003. The proceedings of this symposium give the best overview of activities in this area to date; and a large part of this report is also based on this information.

Various types of assimilation strategies, i.e., optimal interpolation, nudging, 3DVAR, and 4DVAR, were used. Several studies showed, under certain conditions, positive impacts of GPS-ZTD on short-range rainfall forecasts, but some others did not. Statistical scores indicate that GPS has a small positive or neutral impact on the forecast of precipitation, and a positive impact on water vapour analyses and forecasts. This is not very optimistic picture. Unless meteorologists are convinced of a positive impact of GPS in certain situations, there may be not much use for GPS-ZTD data. However, there are a couple of reasons for the relatively small impact at present, such as the very small amount of GPS-ZTD data compared to the total number of observations, some remaining biases in the GPS-ZTD, and problems related to the data assimilation itself. One of the main problems is that GPS-ZTD provides no information on the vertical profile of water vapour. On the other hand, the time resolution of GPS is very good, but this is hardly exploited in the present NWP models, which have difficulties in modelling water vapour, which varies on very small temporal and spatial scales. A practical problem with NWP arises in mountainous areas where the topography of a NWP model does not coincide with the real topography because of limited resolution of the model. Also, it must be said that GPS is a relatively new technique, and meteorologists are just beginning to understand its properties and benefits. With the advent of GPS atmospheric scientists now have the opportunity to investigate the detailed mesoscale to large-scale water vapour behaviour.

In order to be useful for meteorology the ground-based networks must be rather dense, but must also cover geographically interesting area's. Weather forecasts in coastal areas and on global scales could be improved with GPS-IWV measurements over the oceans, from e.g. buoys or ships, and radio occultation techniques. Also, GPS observations in Antarctica have been used to estimate IWV. Since IWV can be as small as a few kg/m^2 in Polar Regions, the practical use of GPS sensed IWV in the Polar Regions the accuracy of the GPS sensed IWV is very critical. The tropics on the other hand, are a major source of global water vapour, with IWV reaching several tens of kg/m^2. The tropics are an important region for climate studies. Unfortunately, there are at present very few GPS IWV observations in the tropics, and although the accuracy of GPS IWV has not been fully investigated in the tropics, GPS sensed IWV could become an important source of information.

Many GPS sites have now been operated for more than 5 years. Long-term stable time series of IWV will make it possible to study regional patterns in water vapour. Trends showing increasing IWV have been reported from the US and Swedish GPS networks. The worldwide IGS networks, and regional EUREF Permanent GPS Network (EPN), routinely produce combined estimates of ZTD that could be a valuable source of data for a variety of studies.

Improvements in GPS Analysis for IWV estimation

Considerable progress has been made in GPS analysis leading to significant improvements in the accuracy of IWV and positions. In Japan residual stacking is used to correct for antenna phase center variation and multi-path, with good results. Another area of research has been the mapping function. Until recently, mapping functions are produced statistically from radiosonde observations and are applicable to elevation angles greater than 3-5 degrees. Space and time dependent - dynamic - mapping functions, computed from a NWP, can substantially reduced the errors at low elevation angles. Also, new approaches using a stochastic model or a NWP model to model the slant delays have been proposed.

There is a strong need for further reduction of the errors in atmospheric delay. One of the substantial errors for geodetic purposes is the annual variation in the positioning error, and it is possible that the atmosphere generates the error. Also, monitoring of long-term trends in the IWV also requires a stable error, or bias, over time scales of decades. Thus, efforts to improve the accuracy of GPS analysis should be continued.

Slant-Delay Estimation and GPS Water Vapour Tomography

UCAR has initiated the development of ground-based GPS slant delay measurement techniques. The slant delay (SD) is the total delay along individual GPS ray paths, and is computed by adding the least-squares residuals to the slant delay computed from the estimated zenith delay and mapping function. This topic is still somewhat controversial, as several researchers doubt whether it is possible to estimate anything more from GPS besides zenith delays and horizontal gradients.

Dense network GPS observations have been performed in the USA and Japan, to test estimation methods for SD, using both zero and double differencing analysis strategies. It has been determined by comparison with pointed water vapour radiometers that the accuracy of slant water vapour is 1.4 kg/m^2 above 10 degrees elevation. Below 2 degrees elevation, the estimated accuracy of slant delay measurements is less than or equal to 1%. Slant delays definitely contain more information on the spatial and temporal variability of water vapour than zenith delays. Also, in combination with multipath stacking techniques, it is possible to obtain slant delays for very low - even negative - elevation angles. Although the noise on the GPS observations at low elevation angles grows, this is outweighed by the increase in the signal (water vapour) itself. In standard GPS analysis the elevation angle is limited to between 7 and 10 degrees because of problems with the mapping function and multipath at low elevation angles.

Slant delays from dense GPS networks have been used in several tomographic experiments. In Oklahoma a dense 25-site GPS network for water vapour tomography is operating (ARM-Tomography). Similar tests have been performed in Japan, France and Sweden. The goal of tomography is to estimate the three-dimensional distribution of water vapour. The results were reasonable, although it was not easy to verify the tomography results. A Tomography Comparison Project, which compares different mathematical methods with the same verification slant delay data, was started.

Groups in Japan, USA and Europe have also started to develop methods for assimilating slant delays into NWP. It is believed that assimilating SD instead of ZTD can retrieve better information on the vertical structure of water vapour. This is indeed seen as one of the reasons for the relatively poor performance of ZTD assimilation. Several Observing System Simulation Experiments in Japan showed that 3DVAR and 4DVAR of SD succeeded in obtaining more realistic vertical structures of water vapour than ZTD assimilation and in improving in the rainfall forecast.

GPS/LEO Radio Occultation Measurements

GPS and LEO satellites are used to carry out radio occultation studies of the ionosphere, for ionospheric tomography to reveal vertical density profiles, and for estimation of temperature and water vapour profiles.

The GeoForschungsZentrum (GFZ) has commenced, together with other research centres of German Helmholtz Society, a new strategic project GASP ("GPS Atmosphere Sounding") using ground-based and space-based GPS techniques for applications in numerical weather predictions, climate research and space weather monitoring. This included the launch of the CHAMP satellite in 2000. Development of a 6-satellite constellation for GPS occultation and space weather measurements (COSMIC) has commenced in the USA. An occultation data analysis centre is being developed at UCAR (COSMIC Data Analysis and Archive Center), for the processing of data from COSMIC and other occultation missions, such as CHAMP and SAC-C.

The GPS/MET experiment and recent results from CHAMP and SAC-C have proven that GPS/LEO occultation data can derive vertical profiles of temperature and water vapour from the surface boundary layer to the upper stratosphere and electron density in the ionosphere with high vertical resolution all over the globe. Thus GPS/LEO occultation is an important system for monitoring temperature and water vapour variation associated with climate change. Comparison of refractivity profiles with ECMWF global analyses indicate a good agreement in the stratosphere and upper troposphere. However, in the lower troposphere at mid and low latitudes the observations exhibit a negative bias due to the effect of super-refraction. Several methods were proposed to reduce the errors, and are currently under investigation.

For more information see also the activities of IAG/SSG 2.192 “Spaceborn GNS Atmosphere Sounding”.

List of Meetings Relevant to the SSG 1.180

XXII General Assembly IUGG, July 18-30, 1999 Birmingham, UK

COST 716 Workshop, Soria Moria, Oslo, 10-12 July 2000.

COST 716 Management Committee and Working Group Meetings.

ION-GPS'99, Nashville, USA, September 1999.

GPS'99, Tsukuba, Japan, October 1999.

PLANS 2000, San Diego, USA, March 2000.

EGS'2000, Nice, France, April 2000.

IRI workshop 2000, Warsaw, Poland, July 2000.

ION-GPS'2000, Salt Lake, USA, September 2000.

AMS meeting Albuquerque Jan 2001. Special session on GPS slant and Special session on SuomiNet

COSPAR meeting, Green Bay, Taiwan, Sept. 27-29 2001. Special meeting on COSMIC mission.

URSI meeting Boulder, CO, Jan 2001. Special Session on GPS remote sensing.

IAIN World congress, San Diego, June 2000.

ION National Technical Meeting, Anaheim, USA, January 2000.

URSI National Radio Science Meeting, Boulder, USA, January, 2000.

S-RAMP Conference (Solar-Terrestrial Energy Program for Space Weather), Sapporo, Japan, October, 2000.

Fall Meeting of the American Geophysical Union, San Francisco, California, December, 2000.

EGS'2001, Nice, France, March 2001. Special session on GPS Meteorology.

GNSS'2001, Seville, Spain, May 2001.

Beacon Satellite Symposium 2001, Boston, USA, June 2001.

IEEE AP-S International Symposium and USNC/URSI National Radio Science Meeting, Boston, Massachusetts, July 8-13, 2001.

ION meeting SLC, Sept. 2001. Session on GPS meteorology.

IAG Scientific Meeting, September 2001 Special session on GNSS meteorology.

CHAMP workshop, 22-25 Jan 2002, Potsdam, Germany

COST-716 Workshop, 28-29 Jan 2002, Potsdam, Germany

IGS Network, Data and Analysis workshop, 8-11 April 2002, Ottawa, Canada

EGS, XXVII General Assembly, 22-26 April 2002, Nice, France

ION GPS 2002, 24-27 September 2002, Portland, OR, USA

International Workshop on GPS Meteorology, 14-16 January 2003, Tsukuba, Japan

EGS-AGU-EUG Joint Assembly, 6-11 April 2003, Nice, France

SPECIAL STUDY GROUP 1.181:

„REGIONAL PERMANENT ARRAYS“

R. Weber

Introduction

The SSG 1.181 has been established by Section I of the IAG at the 22nd General Assembly (Birmingham) in August 1999. The basic idea was to pay attention and take advantage of the increasing number of GPS reference stations which were set up on both global and regional scales in recent years. Ideally, the latter should represent local densifications of the ITRF polyhedron. While, at the outset, these stations were built up in most cases to monitor active tectonic regions, recently the augmentation of real time surveying and probing the atmosphere have become more important tasks.

Objectives

The work of this study group aims at the tie of regional GPS networks to the ITRF as well as to study ambiguity resolution within a network of multiple reference stations at baselines with a length of up to several tens of kilometres. Especially the appropriate modelling of ionosphere and troposphere path delays as the limiting factors for ambiguity resolution and the influence of antenna phase centre variations should be discussed. Concepts and realisations of virtual reference stations will be compared. RTK solutions within active reference station networks, the benefits of using combined GPS/GLONASS receivers as well as the use of predicted IGS orbits are also subject of the investigations.

Members & Corresponding Members

The membership-list comprises 15 regular and 7 corresponding members (including chair-persons of the remaining Special Study Groups within Section I)

Members:
R. Weber (Austria) Chair
R. Bingley (UK)
H. Bock (Switzerland)
C. Bruyninx (Belgium)
P. Clarke (UK)
H. Dragert (Canada)
H. Hartinger (Austria)
T. Herring (USA)
J. Johansson (Sweden)
P. de Jonge (USA)
T. Kato (Japan)
A. Kenyeres (Hungary)
J.F. Galera Monico (Brasil)
E. Ostrovsky (Israel)
L. Wanninger (Germany)

Corresponding Members
S. Han (Australia)
M. Hernandez Pajares (Spain)
H. van der Marel(Netherlands)
L. Mervart (Czech Republic)
S. Skone (Canada)

M. Stewart (Australia)
H. Titz (Austria)

SSG 1.181 Research

Primarily for communication and information exchange between the Special Study Group Members a Web-Site has been established which is accessible via http://luna.tuwien.ac.at/ssg1181/ssg1181.htm . This Web-site summarizes the Working Programme which has been decomposed in a couple of work-frames (WF) discussed below. Basic assumption for all work-frames was the existence of a regional reference station network, equipped with dual frequency GPS (or combined GPS/GLONASS) receivers. The distance between the network stations should not be less than 20km and should , which was an outcome of our work, not exceed 100km. In order to determine rover coordinates we take advantage from the apriori knowledge of reference station coordinates at the +/-2mm level.

WF1: Reference Frame

Regional reference station networks are usually tied to realizations of the ITRS (ITRFxx). The tie may be established by regularly (weekly) processing station coordinates with respect to the closest ITRF stations using precise IGS orbits. Mean coordinates calculated over a 3 weeks span are of sufficient accuracy to be fixed for a subsequent modelling of the remaining error sources within the network area. Satellite orbits are provided in the most recent ITRS realization (e.g. ITRF2000), valid at the epoch of issue t_i. Regional networks, operated by local companies or national surveying authorities, are advantageously embedded in the ITRFxx as well, but at a stable reference epoch t_0. In order to calculate rover coordinates with respect to the regional frame the user has to transform the ITRFxx coordinates by means of a valid velocity model and the conformal similitude transformation into ITRF2000 (parameters provided by IERS) at the current epoch t_i. After baseline processing the new station coordinates have to be transformed back to ITRFxx at epoch t_0. Another option is to transform the satellite coordinates to the appropriate frame and epoch before baseline processing.

In order to serve the user community which is usually not pleased to work with frequently updated frames and changing coordinates one might ignore horizontal velocities and freeze the station coordinates at a given epoch (e.g. ETRF2000, epoch 1989.0). But keep in mind that caused by plate motion, this regional frame can deviate from ITRF2000 by a couple of centimetres per year.

The link of ITRFxx coordinates to a local geodetic datum is performed again by means of a similitude transformation. Transformation parameters are provided by local surveying authorities.

WF 2: Impact of the Atmosphere (Ionosphere, Troposphere)

The Ionosphere is an inhomogeneous (it consists of a number of horizontal layers in an altitude between 60 – 1000km with varying density of charged particles), anisotrop (the refractive index depends on the propagation direction of the wave) and dispersive (the phase velocity of a wave is frequency dependent) medium. The impact of varying ionospheric conditions within the area of the permanent station network is still the most restricting factor in view of reliable and precise (near) real time point positioning. We may separate the ionospheric refraction in a large scale and a medium scale part. The large scale part (absolute electron content) may be sufficiently described by a single layer model with a model height of about 450km in which all free electrons are assumed to be concentrated. The medium scale part is dominated by medium scale ionospheric disturbances which can be recorded by regional permanent networks. Small scale ionospheric disturbances with wavelengths of a few hundred meters (ionospheric scintillations) cannot be captured by observations of such a network.

On basis of a single layer model the phase propagation effect at the single station P can be described by

$$I = -0.5\frac{A}{f^2}\left(\frac{VEC_P}{\cos z}\right)$$

where VEC denotes the Vertical Electron content, z is the zenith distance of the satellite, f the frequency of the wave and A=constant= 80.6 m^3s^{-2}. If we convert this equation in order to describe the differential effect between stations P and Q we find

$$\Delta I_{PQ} = -0.5\frac{A}{f^2}\left(VEC_P \left(\frac{1}{\cos z_Q} - \frac{1}{\cos z_P} \right) + \Delta VEC_{PQ}\frac{d}{\cos z_Q} \right)$$

This formula separates the absolute (first term) from the relative ionospheric propagation error. Both terms are in first approximation proportional to the baseline length d which allows for a linear interpolation between the reference stations.
Vertical delays almost cancel out in single difference observations over baselines smaller than 100km but horizontal gradients, which might reach up to 10mm/km at solar maximum (VEC = 100* 10^{16} m^{-2}), do not. Unfortunately double differencing the observations does not reduce first order ionospheric effects, but their single difference effects are added.

The hydrostatic part of the tropospheric delay can be modelled with sufficient accuracy by well-known standard models. In relative positioning these models usually account for the height difference of the stations. The delay in zenith direction can be mapped afterwards by means of more or less experienced mapping functions (e.g. Niell mapping function) to the satellites elevation. Residual tropospheric refraction may stem from the wet delay component and from small scale local disturbances. We distinguish between an error in modelling the tropospheric delay at the starting point P of our baseline (absolute) and the relative tropospheric delay between P and Q. We can state that the relative tropospheric delay is again proportional to the distance between the reference stations and can be interpolated properly. Satellite specific interpolation errors might reach up to 1cm (at 10 degree elevation angle). Besides this satellite specific interpolation scheme more general models describe the residual zenith delay for all satellites as a whole. This allows for a clear separation of tropospheric from orbital errors. In general large height differences (> 1000m) within the reference station network should be avoided.

WF 3: Satellite Orbits

Three kinds of freely available satellite orbits have been investigated: Broadcast ephemeris, IGS precise orbits and IGS Ultra Rapid orbits. Broadcast ephemeris are part of the navigation message and currently of a quality of about +/- 2 meters. Deviations up to 80 meters for specific satellites are possible. Real time applications are also served by the IGS Ultra Rapid Orbits (IGU) which provide 48 hours satellite ephemeris comprising a 24 hours observed and a 24 hours predicted part. The IGU orbits are of a high quality for most of the given satellites (< 25 cm) but usually 2-3 satellites are missing. IGS precise ephemeris are the most accurate choice. They provide satellite orbits with an accuracy of a few centimetres and corresponding clock corrections at the 0.1 ns level. Due to the delayed availability of 2 weeks their use is restricted to post processing applications.

To discuss the impact of errors in orbit representation we may decompose the whole error vector (vector between calculated and true satellite position) in 3 components. The first component ξ points from the satellite towards the first site of our baseline, the second component η is parallel to our baseline and the third component ζ is perpendicular to ξ and η. A good approximation for the difference in pseudorange measurements at the start and end point of our baseline Δr then reads: $\Delta r = \eta\, d \sin\alpha / D$, where d denotes the baseline length, D is the rough distance between satellite and receiver and α is the height angle of the satellite. Thus, in relative point determination the effect of orbital errors is obviously proportional to the baseline length. In view of a given reference station network these errors are easy to interpolate between the reference sites at the mm –level if the distance between reference sites does not exceed 100km and the orbital errors do not exceed 80 m.

In summary orbital errors are satellite specific and usually of long-periodic character. A change between sets of broadcast ephemeris might introduce unpredictable jumps in the orbital representation of several tenth of meters. Currently standard rover software is not well suited for handling IGU orbit information, which restricts their use for precise positioning in real time.

WF 4: Concept of Virtual Reference Stations

Calculating the position of a rover receiver which is located close to one or more reference stations in post-processing mode is a well-known task and widely documented in literature. We may distinguish between models restricted to baseline lengths up to 15 km which solely need short period observation data (Fast Static) and ambiguity resolution techniques valid over large baselines which expect 60 minutes or more observation data to achieve cm-accuracy.

More recent concepts take full advantage of observations obtained at permanent stations of a regional network to provide cm position accuracy in real-time within the covered area. These concepts are based on a two dimensional modelling of distance and azimuth dependent error sources as listed in the previous sections. The models in use allow to separate ionospheric refraction on the one hand from orbital deviations and tropospheric refraction by means of the geometry-free and ionospheric-free linear combinations. Parameters of the satellite specific two-dimensional models are fitted advantageously on basis of zero difference residuals. A further separation of orbital and tropospheric errors is also possible but demands a common modelling of residual zenith path delays. Basic assumption for calculating correction models is that all ambiguities within the reference network have to be solved correctly in advance. Model parameters should vary very slowly to reduce the effort of frequent updates. The gain of correction models obviously diminishes with increasing baseline lengths. A current suggestion concerning the distance between the reference sites is 50-70km.

Calculations are usually carried out at the computer center of the reference station provider. In existence of a two way data-link between rover and computer center the provider simulates on basis of the approximate position of the rover and the obtained error models observation data of a so-called Virtual Reference Station (VRS). Station dependent corrections like antenna phase center variations are also accounted for. The VRS observation data can be distributed via GSM, GPRS or radio link in RTCM format. The VRS concept is clearly superior to usual network adjustment at the rover due to the smaller of amount of data which has to be transferred between reference and rover (basically the VRS data plus correction models) and the quality check already performed at the computer center. Last, but not least, point positioning can be carried out with standard software at the rover.

The VRS concept is able to supply a huge number of users within the covered area with correction data. Networks supporting this concept are under construction or were already established e.g. in Switzerland, Norway, Austria and Germany. A slightly different concept which also models the main error sources within the area of interest and applies these models to a code and phase data based single point position of the rover is the well-known Precise Point Positioning (PPP). This concept of precise positioning is successfully realized e.g. in Canada and Sweden.

WF 5: GPS/GLONASS integration

Due to the renaissance of the GLONASS system the number of reference sites equipped with dual frequency-dual system receivers is steadily rising. The use of GLONASS satellites, in addition to GPS, improves in various cases the ability to fix the rover position within the reference station network. Moreover it allows for an improved monitoring of the troposphere and ionosphere. These advantages stem from the increased number of active satellites (currently 27 GPS + 10 GLONASS satellites), the slightly improved geometry and slightly different center frequencies. On the other hand, positioning with GLONASS suffers from a number of disadvantages which have to be tackled. The still low number of active GLONASS satellites leaves periods with less than 2 satellites above horizon of the permanent station network. This harms or even prevents ambiguity resolution within the network. Moreover inter-system ambiguity resolution is more complicated than ambiguity fixing within one system. The PZ90 broadcast ephemeris provide state vectors which have to be updated more frequently compared to osculating elements. Precise GLONASS orbit predictions are still not in view. The impact of the mentioned drawbacks will continuously decrease as the number of active GLONASS navigation satellites will, according to plans of the Russian Federation Ministry of Defense, increase to about 18 till 2006.

A more detailed discussion of topics covered by the SSG would go beyond the scope of this summary. Thus, the interested reader is referred to the large number of publications provided by the SSG members over the past 4 years.

Robert Weber
(Chair of SSG 1.181; rweber@luna.tuwien.ac.at)

Below is a reference list of recent publications of the SSG members related to the topics of this study group.

References:

R M Bingley, A H Dodson, N T Penna, F N Teferle, S J Booth and T F Baker. "Using a Combination of Continuous and Episodic GPS Data to Separate Crustal Movements and Sea Level Changes at Tide Gauges in the UK." Book of Extended Abstracts of the WEGENER 2000 Conference, San Fernando, Spain, September 2000.

A H Dodson, R M Bingley, N T Penna and M H O Aquino. "A National Network of Continuously Operating GPS Receivers for the UK." Geodesy Beyond 2000, The Challenges of the First Decade, Edited by Schwarz, International Association of Geodesy Symposia, Vol 121, Springer-Verlag, 2000, ISSN 0939-9585, ISBN 3-540-67002-5, pp 367-372.

Adam J., W. Augath, C. Boucher, C. Bruyninx, P. Dunkley, E. Gubler, W. Gurtner, H. Hornik, H. van der Marel, W. Schlüter, H. Seeger, M. Vermeer, J.B. Zielinski, 2000,"The European Reference System Coming of Age", International Association of Geodesy Symposia, IAG Scientific Assembly, Springer, ed. K.-P. Schwarz, Vol. 121, pp. 47-54

Bruyninx C., 2001, "Overview of the EUREF Permanent Network and the Network Coordination Activities", EUREF Publication, EUREF Publication, eds. J. Torres, H.Hornik, Bayerische Akademie der Wissenschaften, München, Germany, No 9, pp. 24-30 Bruyninx C. and M. Yseboodt, 2001, "Frequency Analysis of GPS time series from the ROB EUREF analysis", EUREF Publication, EUREF Publication, eds. J. Torres, H. Hornik, Bayerischen Akademie der Wissenschaften, München, Germany, No. 9, pp. 37-42

Becker M., C. Bruyninx, D. Ineichen (2001) "The EUREF RNAAC: 1999 Bi-Annual Report", IGS Technical Reports, eds. I. Mueller, R. Neilan, K. Gowey, Pasadena, JPL, Pasadena (in press)

Bruyninx C., M. Becker and G. Stangl, (2001) "Regional Densification of the IGS in Europe Using the EUREF Permanent GPS Network (EPN)", submitted to special issue of Physics and Chemistry of the Earth, Proc. IGS Network Communications Workshop, Oslo, Norway, July 2000 (in press)

G. Blewitt, D. Lavallee, P.J. Clarke, K. Nurutdinov, W.E. Holt, C. Kreemer, C.M. Meertens, W.S. Shiver and S. Stein (2000). “GPSVEL project: towards a dense global GPS velocity field”. In 10th General Assembly of the WEGENER Project, extended abstracts book, Boletin RAO 3/2000.

A. Sehmisch, O. Boehme, S. Canan, P.J. Clarke, G. Taylor and S. Twynholm (2001). Integration of GPS and GIS in vehicle tracking systems. GISRUK 2001 abstracts volume.

G.A.Milne, J.L.Davis, J.X. Mitrovica, H.G. Scherneck, J.M. Johansson, M.Vermeer, H.Koivula (2001), “Space Geodetic Constraints on Glacial Isostatic Adjustment in Fennoscandia”. Science, Vol.291, pp.2381-2385.

Monico J. F. G. (2000),Precise Point Positioning: Using GPS: A solution for Geodynamics,Brazilian Journal of Geophysics Vol.17, 2000 (In portuguese) S.M. Alves Costa; E.S. Fonseca Junior; J. A. Fazan, J.F.G. Monico, P. O. Camargo. (2001), “Preliminary Results of SIRGAS 2000 Campaign” - IBGE Analysis Center: IAG Workshop - Cartegena.

Ostrovsky E. (2001), “The G1 GPS geodetic-geodynamic reference network in Israel”, Israel Journal of Earth Sciences, Issue on Geodetic Studies in Israel and the Eastern Mediterranean Region. Titz H. (2000), “Regionale GPS/GLONASS Echtzeitsysteme in Österreich”, Geowissenschaftliche Mitteilungen Vol.50, pp.11-20, TU-Vienna.

Wanninger, L. (1999): “The Performance of Virtual Reference Stations in Active Geodetic GPS-networks under Solar Maximum Conditions”, Proc. of ION GPS '99, Nashville, pp 1419-1427. Wanninger, L., May, M. (2000): “Carrier Phase Multipath Calibration of GPS Reference Stations”, roc. of ION GPS 2000, Salt Lake City, pp 132-144.

Wanninger, L., (2000): “Präzise Positionierung in regionalen GPS-Referenzstationsnetzen” Deutsche Geodätische Kommission , Series C, Volume 508, Munich.
Weber R., Fragner E. (2001) „The Quality of Precise GLONASS Ephemerides“, Proceedings of the 33. COSPAR Assembly, Warsawa , July 2000

Weber R. (2001) The International GLONASS Service – Pilot Project GPS Solutions, Vol.4 No.4, pp.61-67,2001

Böhm J., Schuh H., Weber R. (2001) „Comparison of troposheric gradients determined by VLBI and GPS“, Physics and Chemistry of the Earth, Part A, Vol. 26/6-8, pp. 385-388.

REPORT OF SPECIAL STUDY GROUP 1.182:

"MULTIPARTH MITIGATION"

M.P. Stewart

Introduction

The precision of raw carrier phase observations recorded by modern GNSS receivers is generally at the sub-millimetre level. However, in all but the most benign environments, the achievable resolution of GNSS positioning is one or more orders of magnitude worse. This discrepancy between the theoretical hardware-dependent precision of the raw observations and the practical accuracy of GNSS position solutions can, in part, be attributed to the effects of site-dependent electromagnetic scattering of incoming GNSS signals. If millimetre level (or better) GNSS accuracies are to be routinely achieved in the future, these electromagnetic scattering effects (commonly referred to as multipath and diffraction) must be eliminated.

Objectives of SSG 1.182

The goal of SSG 1.182 is to study GNSS multipath detection and mitigation techniques with the aim of improving existing high precision positioning accuracies. In the context of this SSG, multipath is loosely defined as the systematic errors in raw GNSS observations that are due to any signal scattering effect caused by the local environment surrounding an antenna. Furthermore, this SSG will focus on carrier phase and code-based multipath in terms of effects on receiver operation for high precision applications. Finally, within the scope of the group, the term GNSS is defined to encompass any type of global positioning system (for example, GPS, GLONASS-GPS and Galileo-GPS), or systems simulating GNSS signals (such as in the case of pseudolites).

The objectives of the group can be summarised as:

- Evaluate and compare existing and developing algorithms and techniques for multipath detection and mitigation.
- Quantify and document the effectiveness of commercial receiver-based multipath mitigation techniques for high precision positioning.
- Investigate and document the properties of multipath in a variety of environments (particularly high risk environments).
- Provide information and guidelines for multipath detection and elimination for high precision applications.

Group membership

Full Members:
Mike Stewart, Curtin University of Technology, Australia (chair)
Penina Axelrad University of Colorado, USA
David Bétaille. University College London, UK
Mike Braasch, Ohio University, USA
Luisella Giulicchi, European Space Agency, Netherlands
Cynthia Junqueira, UNICAMP, Brazil
Guillermo Ortega, European Space Agency, Netherlands
Jayanta Kumar Ray, The University of Calgary, Canada
Angela K. Reichert, Jet Propulsion Laboratory, USA.
Rodney Walker, Queensland University of Technology, Australia.
Andreas Wieser, Graz University of Technology, Austria
Linyuan Xia, Hong Kong Polytechnic University, Hong Kong

Corresponding members:
Paul A. Cross, University College London, UK
Xiaoli Ding, Hong Kong Polytechnic University, Hong Kong
Horst Hartinger, Graz University of Technology, Austria
Minghai Jia, Curtin University of Technology, Australia

Domenico Sguerso, Universitá di Trento, Italy

Review of Group Activities from 1st May 2001 – 31st May 2003

For a summary of group activities up to 1st May 2001, the reader is referred to the IAG mid-term Travaux 2001, which can be found at: http://www.gfy.ku.dk/~iag/Travaux/contents.htm.

The current period from 1st May 2001 to 31st May 2003 has been one of little organised activity within the group. Instead, group members have reported back to the chair individually on relevant developments in multipath mitigation within their core research areas. The following technical summary represents a compilation of recent feedback from group members, focussing on work published since the previous report was submitted. Some earlier work is quoted, mainly referring interesting or significant developments which were published during the first two years of the group and for which no subsequent references are available. References quoted are not exhaustive and a more complete reference list can be found on the SSG1.1.82 website at: http://www.cage.curtin.edu.au/~mike/ssg1.182/biblio.htm

Technical Summary of Recent Developments in the Field of Multipath Mitigation

As with much modern technology, the GPS user segment has moved along considerably in the past four years. It would be safe to say that most progress has been made in hardware development, with the latest receivers offering raw code measurements at a precision level of 10cm and raw carrier phase measurement at a precision level of 0.1mm. Similarly, all manufacturers now boast of some form of multipath mitigation technology within their receivers and much progress has been made in this field. Much information remains proprietary however. It is noteworthy that such hardware improvements have, generally, failed to translate into improvements in positional accuracy. The quality of GPS solutions in non-ideal observing environments continues to be highly variable. All high precision GPS positioning techniques, (and precise rapid positioning methods in particular), remain susceptible to environmental signal degradation. A wide range of data processing techniques have been proposed to mitigate multipath from the analysis of raw pseudoranges and carrier phase observations. However, it has to be said that no 'silver bullet' has yet been found to sufficiently reduce multipathing effects to allow precise GPS solutions to even approach 1mm precision levels. Part of the reason for the lack of definitive progress in this area is due to the fact that multipath characteristics can vary considerably in different environments and, significantly, can vary over time in the same environment. A better understanding of the characteristics of the GPS multipath environment may well lead to insights which allow for the development of more generic multipath mitigation algorithms.

In the following sections, recent developments in multipath mitigation are reviewed from the point of view of hardware, data analysis and modelling/ signal characterisation. A brief outlook to the future of multipath research is given in section 6.

i) Hardware developments for multipath reduction

In this section, hardware developments are defined as modifications to antenna design, GPS processor design and in-field receiver and antenna configurations.

Antenna design continues to receive considerable attention and a number of papers on this subject have been published in the interim period. Many developments tend to be designed for specific applications, with, for example, Boccia et al (2001) and Junqueira el al (2002) concentrating on patch antenna design for attitude determination on space vehicles. Of interest to the geodetic community is the proposal of McKinzie et al (2002) to use artificial magnetic conductors as lightweight, inexpensive alternatives to choke rings on geodetic antenna.

Developments in the GPS processor tend to be closely guarded by manufacturers. A typical example is the discussion of a multipath mitigation technique for the urban environment by Agarwal et al (2002). Here the authors propose a technique called 'anti-multipath triangulation' but give little technical detail. However, some insight into the mechanics of signal processing inside the receiver is provided by Braasch (2001) and, more recently, by Zhdanov et al (2002). Papers such as de Escobar et al (2002), which documents how superconducting filters can reduce both out-of-band and in-band interference on L1 and L2 frequency, and Fante and Vaccaro (2002), whose multipath reduction approach uses early-late gate processing of an objective function derived from a cross-correlating FIR filter, give the geodetic community insight into the latest developments in the electronics area. Such developments will have an impact on the quality of the signal geodesists can expect from future GPS receivers. Most recently, Betaille et al (2003) report on a GPS phase multipath mitigation technique based on information from a separate dedicated correlator that enables the direct correction of the multipath-biased phase output from the measurement correlator. The technique is based on sampling the received signals together with their possible multipath components before and immediately after code transitions.

A number of researchers have proposed multipath mitigation techniques based on multiple hardware arrays. Notable in this area is the work of Ray et al (2001), who propose a multiantenna system for multipath mitigation. An interesting alternative is proposed by Racquet (2002), who proposes a multiple receiver approach. Both these approaches have been primarily tested in GPS reference station scenarios. However, greatest benefit may be gained if such methods can be applied to kinematic situations.

ii) Data Analysis Techniques

Multipath mitigation research within the geodetic community tends to focus on analysis of raw pseudoranges and carrier phase observations, prior to, during or after computation of the receiver's position. Techniques may be broadly divided into three groups: those which utilise the nature of repeating satellite geometry to correlate then extract the multipath signature from repeat observations eg Bock et al, 2000; Wubbena et al, 2001;Wanninger and May, 2001; those which apply various mathematical filtering techniques to mitigate multipath-like features present in the data eg Ge et al, 2000 (adaptive filters); Kim and Langley, 2001 (parametric estimate), Jia et al, 2000 (semi-parametric estimation), Kaindl and Niklasch, 2001 (non-linear equation systems); Xia, 2001 (wavelet analysis); those which use signal properties (particularly signal-to-noise ratio) to reweight observations in the least squares position solution, based on their perceived level of multipath contamination eg Wieser and Brunner, 2000.

The types of techniques proposed above have all been successfully demonstrated on specific of data sets. However, it is striking to note that, of all the different approaches proposed, none has been adopted by the geodetic community as being the 'solution' to the multipath problem. The main problem is that in all but the simplest environments, multipath characteristics can be extremely variable, both spatially and temporally. For example, whilst day-to-day correlation may reduce multipath at sites stations situated in benign multipath environments, day-to-day GPS signals have actually been found to decorrelate in severe environments (eg Forward, 2002). Many authors publish work based on algorithms relatively few data set or simulated data. These algorithms rarely translate well to environments where the multipath signature is significantly different to the test data sets, hence the lack of a unified approach to multipath mitigation by the community.

Intuitively, it is logical to use the extra environmental information provided by SNR data for multipath mitigation. In the geodetic community, such approaches have been hampered by the fact that the RINEX format does not support raw signal-to-noise measurements. However, all geodetic GPS receivers can routinely output SNR values. The majority of published work has concentrated on using SNR information to reweight satellite observations in a least squares solution. Whilst moderately successful in some cases (satellites badly contaminated by multipath can effectively be removed), the variability of such techniques can be attributed to the fact that when poor satellites are downweighted an inherent worsening of satellite geometry occurs. Furthermore, a philosophical objection may be raised to attempts to mitigate systematic biases in the raw data through least squares stochastic processes. Providing a range correction based on SNR would, in principle, make a more consistent and productive use of SNR. Reichert and Axelrad (2001) proposed a technique developed by aerospace engineers for spacecraft attitude determination, which does just this. This technique has been recently followed up in Bilich et al (2003) and appears to be an extremely promising development.

It may be observed that there are still many questions to be answered in this area. Until recently, a general lack of understanding of the truly complex nature of GPS multipath has limited what can achieved. However, algorithm developers will benefit from a better understanding of the characteristics of the multipath signature in all environments derived from the type of research reviewed in the subsequent section.

iii) Modelling the multipath environment, multipath signal characterisation and simulation

The variability of GPS multipath signal characteristics in a variety of environments has led to some interesting recent work aimed at deeper understanding of the nature of the signal, simulation of multipath signals, and modelling of different multipath environments. Work by Kelly et al (2003) and Kelly and

Braasch (2001) has developed and tested theoretical GPS multipath signal characteristics, whilst Brown et al (2001) and Ma et al (2001) provide a different approachs to the characterisation problem. Meanwhile, Agarwal et al (2002) have performed a statistical study of GPS data in urban environments from major cities worldwide, concluding that 'urban environments pose a form of multipath entirely different from that accounted for by conventional methods'. Unfortunately, no other details are given of a potentially significant study.

Simulation is becoming an increasingly useful tool in the development of multipath mitigation techniques, with main developments being driven by studies into multipath effects on space missions. The main players in this field are JPL, who provide an extensive description of their multipath simulator and its application in a spaceborne simulation in Byun et al (2002a) and (2002b), the Queensland University of Technology, from which Hannah (2001) provides the most recent summary of developments, and ESA, whose Multipath Virtual Laboratory was described in the previous report of this group. The modelling of the relationship of the physical environment to the multipath signature remains of critical importance if GPS is ever to become fully functional in environments, which might nowadays be classed as 'difficult'. Cannon et al (2003) discuss a number of multipath models and relate them to results from a simple elevation and azimuth profile of obstructions around a test site. It is possible in the future that terrestrial laser scanning instruments, which allow the rapid pickup of full three dimensional information around a control point, will be able to provide a level of 3D information about the surrounding environment which will allow explicit modelling of multipath effects at particular locations.

Finally, it is interesting to note two studies recently published on the effect of power lines on GPS signals (Silva et al, 2002), and the characterisation of GPS signals under tree canopies (Koh and Sarabandi (2002). The former paper concludes power lines should have little effect on GPS performance, although the ensuing lively discussion on this subject in IEEE Transactions on Antennas and Propagation indicate that the final word is yet to be spoken on this topic.

Multipath Research – looking to the future

i) Multipath in other systems – GLONASS/GALILEO and pseudolites.

Researchers are beginning to consider the multipath issues that will be associated with the GALILEO system. Examples of such work are in the papers of Bischoff et al (2002) and Fu et al (2002). Clearly, study of the characteristics and multipath signature of the GALILEO signal will require a major research effort as the system comes online.

Study of pseudolite systems is continuing (eg Bartone (1999)) and the impact of multipath on indoor GPS positioning will surely become a major issue as better indoor GPS positioning techniques (either aided or unaided) become available. The reader is referred to the report of IAG Working Group 1.4.5 on pseudolite applications in engineering geodesy for an up to date assessment of pseudolite capabilities.

ii) Multipath – signal or noise?

In the early 1990s, GPS researchers began to realise that noise on GPS signals could actually be used to extract useful information about the atmosphere, thus founding the new research field of GPS meteorology. There are some indications that we could be on the verge of a similar revolution when considering GPS multipath. Previously considered as a noise term to be 'mitigated' in order to improve the quality of position solutions, it is becoming apparent that backscattered GPS signals can themselves contain valuable information.

One of the earliest suggests for treating GPS multipath as a signal rather than simply a nuisance parameter was from Ding el al (1999) who proposed using changes in the multipath signature over time to detect deformation in the environment close to a GPS antenna. This work was followed in by Chen (2001). More recently, the concept of using reflected GPS signal in a satellite altimetry-type mode over the oceans has been introduced by a number of groups, including Martin-Neira et al (2001), Zuffada et al (2001) and Elfouhaily et al (2002). The possibility of treating GPS multipath as a signal which contains useful information is certainly worthy of further study.

Acknowledgments

The chair of this group would like to thank the members of SSG1.182 for their timely contributions to this report.

Multipath Mitigation – Selected Bibliography (1999-2003)

Agarwal N, J Basch & 13 others (2002). Algorithms for GPS operation indoors and downtown. GPS Solutions, Vol 6, pp149-160.

Bartone C G (1999). Multipath considerations for ground based ranging sources. Proc. GPS ION-99, Nashville, Tennessee, 14-17 Sept., 1491-1498.

D Betaille, J Maenpa, H-J. Euler and P A Cross (2003). A New Approach to GPS Phase Multipath Mitigation. Proceedings of ION National Technical Meeting, Anaheim, California.

Bilich A, K Larson and P Axelrad (2003). Observing and Correcting the Effects of Multipathed GPS Signals Using the Signal-to-Noise Ration (SNR). Geophysical Research Abstracts, Vol. 5, 07835, European Geophysical Society. (presented at EGS-AGU-EUG Joint Assembly, Nice, 6 – 11 April).

Bischoff R, R Umbach, W Schulz and G Heinrichs (2002). Employment of a multipath receiver structure in a combined GALILEO/UMTS receiver. Proc. IEEE Vehicular Technology Conference, Vol.4, pp1844-1848.

Boccia L, G Amendola, G di Massa and L Giulicchi (2001). Shorted annular patch antennas for multipath rejection in GPS-based attitude determination. Microwave and Optical Tech. Lett., Vol. 28, no. 1, pp47-51.

Bock Y, R M Nikolaidis, P de Jonge and M Bevis (2000). Instantaneous Geodetic Positioning at Medium Distances with the Global Positioning System. Journal of Geophysical Research, Vol. 105, B12, pp 28223-28255.

Braasch M S (2001). Performance comparison of multipath mitigating receiver architectures. Proc IEEE Aerospace Conference, Vol. 3, pp1309 –1315.

Brown A, N Geirin and L Savage (2001). Multipath characterization using digital phased arrays. Proc. ION 57th Annual Meeting 2001, Albuquerque, NM, June.

Byun S H, G A Hajj and L E Young (2002a). Assessment of GPS signal multipath interference. Proceedings ION GPS-2002 National Technical Meeting, San Deigo California, January 28-30. pp 694-705.

Byun S H, G A Hajj and L E Young (2002b). GPS signal multipath: A software simulator. GPS World, July 2002, pp40-49.

Cannon M E, G Lapachelle, G MacGougan, R Klukas, P Boulton and A Read (2003). Testing a high sensitivity GPS receiver in weak signal environments. GPS World, Vol. 14, no. 3, pp24-32.

Chen Y Q, D F Huang, X L Ding, Y L Xu. And J M Ko (2001). Measurement of vibrations of tall buildings with GPS: a case study, Proc. of International Symposium on NDE for Health Monitoring and Diagnostics, 6-8 March 2001, Newport Beach, California, USA. pp.477-483.

Ding, X L Y Q Chen, J J Zhu, and D F Huang (1999) Surface deformation detection using GPS multipath signals, Proc. ION GPS-1999, Nashville,Tennessee, USA, 14-17 Sept., pp. 53-62.

De Escobar A L, W C McGinnis, M J Pulling, H J Whiltehouse (2002). SAW filters for Global Positioning (GPS) receivers. Proc. IEEE Position, Location and Navigation Symposium, pp4-11.

Elfouhaily, T, D R Thompson, L Linstom (2002). Delay-Doppler analysis of bistatically reflected signals from the ocean surface: theory and application, IEEE Transactions on Geoscience and Remote Sensing, Vol. 40, pp560-573.

Fante R L and J J Vaccaro (2002). Reduction of multipath-induced bias of GPS time-of-arrival. Proc. IEEE Position, Location and Navigation Symposium. pp74-76.

Forward, T A (2002). Quasi-continuous GPS steep slope monitoring: A multi-antenna array approach. PhD Thesis, Curtin University of Technology, Australia. 211pp.

Fu Z, A. Hornbostel, J. Hammesfahr and A. Konovaltsev (2003). Suppression of multipath and jamming signals by digital beamforming for GPS/Galileo applications. GPS Solutions. Vol. 6, pp 257-264.

Ge L, S. Han and C. Rizos (2000). Multipath mitigation of continuous GPS measurements using an adaptive filter, GPS Solutions, Vol. 4, no. 2, pp19-30.

Hannah B M (2001). Modelling and simulation of GPS multipath propagation. PhD Thesis, Queensland University of Technology, Australia. 375pp.

Jia M, M Tsakiri and M P Stewart (2000). Mitigating multipath error using semiparametric models for precise positioning. in: Geodesy beyond 2000: The Challenges of the First Decade. International Association of Geodesy Symposia, Ed. K P Schwarz. Vol. 121, pp393 – 398.

Junqueira, C, J Destro-Filho, A Romano; J M T Romano (2002). A Joint Blind-Neural approach for adaptive antenna array in GPS Interference Mitigation. Proc. Int. Telecommunication Symposium, ITS 2002, Natal, 2002.

Kaindl K and N Niklasch (2001). Attacking multipath problems by solving non linear equations. Proc. ION GPS-2001, Salt Lake City Utah, 11 –14 September.

Kelly J M, M S. Braasch and M F DiBenedetto (2003). Characterization of the effects of high multipath phase rates in GPS. GPS Solutions, Published online: 7 March 2003.

Kelly J M and M S. Braasch (2001). Validation of theoretical GPS multipath bias characteristics. Proc. IEEE Aerospace Conference, Vol. 3, pp1317 –1325.

Kim D and R B Langley (2001). Mitigation of GPS carrier phase multipath effects in real-time kinematic applications. Proc. ION GPS-2001, Salt Lake City, Utah, 11 –14 September.

Koh I and K Sarabandi (2002). Polarimetric channel characterization of foliage for performance assessment of GPS receivers under tree canopies. IEEE Transactions on Antennas and Propagation, Vol. 50, no. 5, pp713 –726.

Ma C, G Jee, G MacGougan, G Lapachelle, S Bloebaum, G Cox, L Garin and J Shewfelt (2001). GPS signal degradation modelling. Proc. ION_GPS-01, Salt Lake City Utah, 11 –14 September, pp882-893.

Martin-Neira M, M Caparrini, J Font-Rosello, S Lannelongue and C S Vallmitjana (2001). The PARIS concept: An experimental demonstration of sea surface altimetry using GPS Reflected Signals. IEEE Trans. Geosci. Remote Sensing, Vol. 39, no. 1, 142-150.

McKinzie W.E., R B Hurtado, B K Klimczak and J D Dutton (2002) Mitigation of multipath through the use of an artificial magnetic conductor for precision GPS surveying antennas. Proc. IEEE Antennas and Propagation Society International Symposium, Vol. 4, pp 640–643.

Raquet, J.F. (2002) Multiple GPS receiver multipath mitigation technique. IEE Proceedings-Radar, Sonar, and Navigation, Vol. 149, no. 4, pp195-201

Ray J, M E Cannon and J Fenton (2001). GPS code and carrier multipath mitigation using a multiantenna system. IEEE Tran. Aerospace and Electronic System, Vol. 37, pp183-195.

Reichert A K and P Axelrad (2001). Carrier-phase multipath corrections for GPS-based satellite attitude determination. Navigation, Vol. 48, no. 2, pp77-88.

Silva, J.M and R G Olsen (2002). Use of Global Positioning System (GPS) receivers under power-line conductors. IEEE Transactions on Power Delivery, Vol. 17, no. 4, pp938 –944.

Wanninger L and M May (2001). Carrier-phase multipath calibration of GPS reference stations. Navigation, Vol. 48, no. 2, pp113-124.

Wubbena G, A Bagge, G Bettcher, M Schmitz and P Andree (2001). Permanent object monitoring with GPS with 1mm accuracy. Proc. ION GPS-2001. Salt Lake City, Utah, 11-14. September.

Xia L (2001) Theoretical research and numerical results regarding multipath in GPS observations. PhD Thesis, Wuhan University, China.

Zhdanov A, M Zhodzishsky, V Veitsei and J Ashjaee (2002). Evolution of multipath error reduction with signal processing. GPS Solutions, Vol. 5, no. 3, pp19-28.

Zuffada, C; A Fung, M Okolicanyi, E Huang and J Parker (2001). The collection of GPS signal scattered off a wind-driven ocean with a down-looking GPS receiver: polarization properties versus wind speed and direction, Proc. IEEE Geoscience and Remote Sensing Symposium (IGARSS '01), Vol. 7, pp3335 – 3337.

SECTION II:

"ADVANCED SPACE TECHNOLOGY"

http://geodesy.eng.ohio-state.edu/iag_sectionII

REPORT OF THE PRESIDENT FOR THE PERIOD 1999-2003

President: C.K. Shum (USA), ckshum@osu.edu
Secretary: Pascal Willis (France), pascal.willis@ensg.ign.fr

Summary

Section II, Advanced Space Technology of the International Association of Geodesy, is engaged in new space techniques for geodesy, geophysics, geodynamics, atmosphere, oceanography and other areas of Earth science studies. Its objectives include the participation and promotion of the research and applications using the modern space technologies for a wide variety of interdisciplinary studies in Earth and planetary sciences. Section II organizes Commissions and Special Commissions, Special Study Groups and various Services to fulfill its objectives. This report summarizes the progress for the four-year term (1999-2003) of Section II activities. Specifically, the progress include the following activities:

- Study of innovative space technology for Earth science research and applications, including SAR Interferometry, gravity field mission mapping sensors (gradiometer and satellite-to-satellite microwave tracking), GPS water level, GPS Navigational System (GNSS) atmosphere sounding, and precision orbit determination for LEOs using various tracking techniques
- Coordination of space geodetic techniques for geodesy and geodynamics, including intercomparison of analysis techniques for geodynamic studies, new studies for microwave tracking system including DORIS and interdisciplinary applications using multi-mission radar altimetry
- Promotion of studies to improve mean and time-varying gravity field using advanced gravity mission sensors, including CHAMP, GRACE and GOCE
- Promote and coordinate improved scientific community use of services including IGS, and newly organized services such ILS and IVS; possibility of an International DORIS Service (IDS) and an International Altimeter Service (IAS) have been studied
- Participated and help the transition of IAG components into the new structure, and support the creation of the IGOOS Project

Commission, Special Commissions, and Special Study Groups

The structure of Section II during 1999-2003 has been organized at the IUGG General Assembly in Birmingham in 1999. It consists of:

1. Commission VIII, International Coordination of Space Techniques for Geodesy and Geodynamics (CSTG), http://www.dgfi.badw.de/~cstg/, Chair: Hermann Drewes (Germany), Secretary: Wolfgang Bosch (Germany). The Final report of CSTG is on: http://geodesy.eng.ohio-state.edu/iag_sectionII/CSTGmid-termreport.htm.
   Sub commissions are:
   (i) Coordination and Combination of the Analysis in Space Geodesy, Chair: Tom Herring (USA), http://bowie.mit.edu/~tah/cstg_comb/.
   (ii) Precise Satellite Microwave Systems, Chair: Pascal Willis (France).
   (iii) Multi-mission Satellite Altimetry, Chair: Wolfgang Bosch (Germany), http://dgfi2.dgfi.badw-muenchen.de/cstg/SCOMMSA/.
   (iv) Precise Orbit Determination for Low Earth Orbiting Satellites, Chair: Markus Rothacher (Germany), http://ww.iapg.bv.tum.de/cstg/index.html.

(v) Project on DORIS, Chair: Gilles Tavernier (France).

2. Special Commission VII, Satellite Gravity Field Missions, Chair: Karl-Heinz Ilk (Germany), Scientific Secretary: Jürgen Kusche (Germany), http://www.geod.uni-bonn.de/SC7/index.html. The Final report is on: http://www.geod.uni-bonn.de/SC7/index.html.

3. Special Study Groups. There are five Special Study Groups (SSG), two could be considered as continuation from the previous 4-year period, three SSGs are newly established. They are:

   (i) SSG 2.162, Precise Orbits Using Multiple Space Techniques, Chair: Remko Scharoo (The Netherlands), http://www.deos.tudelft.nl/~remko/ssg2.162
   (ii) SSG 2.183: Spaceborne Interferometry Techniques, Chair: Ramon Hanssen (The Netherlands), http://www.geo.tudelft.nl/fmr/research/insar/ssg/ssg2183.html
   (iii) SSG 2.192: Spaceborne Atmospheric GNS Soundings, Chairs: Rob Kursinski (USA), Klemens Hocke (Germnay), http://www.gfz-potsdam.de/pb1/IAG/SSG_RO/SSG_RO.htm
   (iv) SSG 2.193: Gravity Field Mission: Calibration and Validation, Chairs: Pieter N.A.M. Visser (The Netherlands), Christopher Jekeli (USA), http://www.deos.tudelft.nl/~pieter/IAG.SSG The Final report is on http://www.deos.tudelft.nl/~pieter/IAG.SSG/REPORTS/ReportSSG2.193_2000.htm.

4. SSG 2.194: GPS Water Level Measurements, Chairs: Gerry Mader (USA), Tilo Schone (Germany), Doug Martin (USA), http://op.gfz-potsdam.de/altimetry/SSG_buoys/index.html

5. Services. There are three Services under Section II:

   (i) International GPS Service (IGS), Chair: Christopher Reigber, Director of the Central Bureau: Ruth Neilan, http://igscb.jpl.nasa.gov. The Final report is on http://geodesy.eng.ohio-state.edu/iag_sectionII/ruthiag.html.
   (ii) International Laser Ranging Service (ILRS), Chair: John J. Degnan, Secretary: Mike Pearlman, Director of the ILRS Central Bureau: John M. Bosworth, http://ilrs.gsfc.nasa.gov. The Final report is on http://geodesy.eng.ohio-state.edu/iag_sectionII/ilrs.htm
   (iii) International VLBI Service for Geodesy and Astrometry (IVS), Chair: Wolfgang Schlueter, Director of the Coordinating Center: Nancy Vandenberg, http://ivscc.gsfc.nasa.gov. The Final report is on http://geodesy.eng.ohio-state.edu/iag_sectionII/IVS-midterm.htm.

Progress

July 2000 marked the first satellite gravity mission launch in the decade, CHAMP, for the beginning of a series of spaceborne gravity measurement sensors, followed by GRACE launch in March 2002 and GOCE launch in 2006. For the first time ever, high-low GPS-LEO tracking, low-low LEO-LEO Doppler ranging, spacebrone gradiometer and with 3-axis accelerometers will be flown and represent new space technologies at the frontier of geodetic measurements. SAC-C (2000), CHAMP, GRACE and COSMIC (2005) represent new and abundant missions using GPS limb-sounding or occultation for measuring atmospheric water vapor (integrated water vapor and precipitable water vapor profiles). Together with ground based GPS, spaceborne GPS occultation measurements are beginning to have a major impact on space weather, meteorology and climate studies. Use of GPS on buoys for water level measurements represents another innovative use of GPS. GPS reflection or GPS altimeter measurements, which are being tested (e.g., using CHAMP), represents another new space technology to be potentially promising. Synthetic Aperture Radar interferometry (InSAR) is continuing to be studied as another cutting-edge space geodetic technology. Special Commission and SSGs under Section II have made progress in studying in each of these new space geodetic techniques. IGS has grown significantly during 1999-2003. New services now include IVS and ILRS. Potential new services such as the International DORIS Service (IDS) and the International Altimeter Service (IAS) are being considered. The near future challenges include the smooth integration of current Section II elements efficiently into the new IAG structure.

Conferences

During 1999-2003, Section II contributed to various scientific conferences including the following partial list:

- ION GPS/GNSS 2003, Portland, Oregon, USA, September 9-12, 2003.
- IUGG Symposia, Sapporo, Japan, June 30-July 11, 2003.
- GNSS 2003, Graz, Austria, 22-25 April, 2003.
- GNSS Workshop, Wuhan, China, November 6-8, 2002.
- Weikko A. Heiskanen Symposium In Geodesy: Celebrating 50 years in Geodetic Science at the Ohio State University, Ohio State University, Columbus, Ohio, USA, 1-5 October 2002.
- ION GPS 2002, Portland, Oregon, USA, September 24-27, 2002.
- International Workshop on Satellite Altimetry, Wuhan, China, September 8-13, 2002.
- Joint EGS-AGU-EGU General Assembly, Nice, France, April, 2002.
- American Geophysical Union Fall Meeting, San Francisco, California, USA, December 2002.
- American Geophysical Union Spring Meeting, Washington DC, USA, June 2002.
- 27th General Assembly of the EGS in Nice, France, April, 2002.
- ION GPS 2001, Salt Lake City, Utah, USA, September 11-14, 2001.
- American Geophysical Union Fall Meeting, San Francisco, California, USA, December 2001.
- IAG Scientific Assembly, Vistas for Geodesy in the New Millennium, Budapest, Hungary, September 2-7, 2001.
- American Geophysical Union Spring Meeting, Boston, Massachusetts, USA, June 2001.
- Fifth Symposium on Integrated Observing Systems, American Meteorological Society Symposium, Albuquerque, New Mexico January 15-19, 2001.
- 26th General Assembly of the EGS in Nice, France, March 25-30, 2001.
- GNSS-2001, Sevilla, Spain, 2001.
- American Geophysical Union Fall Meeting, San Francisco, California, USA, December, 2000.
- ERS-ENVISAT Symposium, Gothenbury, Sweden, October 2000.
- COSPAR Symposia, Taipei, Taiwan, Sept., 2000.
- 14 th International Symposium on Earth Tides, Mizusawa, Japan, August 8-Septemeber 1, 2000.
- IAG International Symposium on Gravity, Geoid, and Geodynamics 2000, July 31-August 4, Canada, 2000.
- COSPAR Symposia, Warsaw, Poland, July 16-23, 2000.
- IGARSS 2000, Honolulu, July 2000.
- Spring AGU Meeting, Washington D.C. May 30-June 3, 2000.
- ERIM 2000, Remote Sensing for Marine and Coastal Environments, Charleston, May 1-3, 2000.
- Pacific Islands Conference on Climate Change, Rarotonga, Cook Islands, April 2-7, 2000.
- 25th General Assembly of the EGS in Nice, France, April 24-29, 2000.
- ISRSE, Cape Town, 27-31 March 2000.
- 6th International Conference on Applications of High-Performance Computers in Engineering, 26-28 January, 2000, Maui, Hawaii, 2000.
- American Geophysical Union Spring meeting, Washington, USA, 2000.
- TOPEX/POSEIDON/Jason-1 Science Working Team Meeting, Miami, USA, 2000.
- ION GPS 2000, Salt Lake City, Utah, USA, 2000.
- Sixth International Symposium on Land Subsidence,volume CNR, 2000.
- Fall AGU Meeting, San Francisco, December 13-17, 1999.
- Second International Workshop on ERS SAR Interferometry, `FRINGE99', Belgium, 10-12 Nov 1999.
- TOPEX side B altimeter calibration campaigns, Jason SWT Meeting, St. Raphael, France, October 25-27, 1999.
- EGS' First Vening Meinesz Conference on Global and Regional Sea-Level Changes and the Hydrological Cycle, Loiri-Porto San Paolo, Sardinia, Italy, October 4-7, 1999.
- GPS99 meeting, Tsukuba, Japan, October, 1999.
- IUGG Symposia, Birmingham, UK, July, 1999.
- EGS 24th General Assembly, The Hague, The Netherlands, April 1999.
- ALT-B Calibration Workshop, Goddard Space Flight Center, Greenbelt, Maryland, USA, 1999.
- The Ocean Observing System for Climate, OCEANOBS 99, St Raphael, France, 1999.

Conclusions

On the eve of the evolution of the IAG structure, Section II would be in its last 4-year term under the current organization. While mathematics and technology may considered by many as the foundation of Geodesy, the new IAG structure would reflect the prominence of applications and services in terms of Commissions (Reference Frame, Gravity Field, Earth Rotation and Geodynamics, and Positioning and Applications). It is envisioned that the development and studies of space technologies, while no long would be at the highest level of the IAG new structure, would and should still be playing a critical part in its evolved role to continue to contribute as one of the foundations of contemporary geodesy.

COMMISSION VIII:

"INTERNATIONAL COORDINATION OF SPACE TECHNIQUES FOR GEODESY AND GEODYNAMICS (CSTG)"

http://www.dgfi.badw.de/cstg/

H. Drewes
drewes@dgfi.badw.de

Objectives and Structure

The objectives of the Commission on International Co-ordination of Space Techniques for Geodesy and Geodynamics (CSTG) are to develop links between various groups engaged in the field of space geodesy, to co-ordinate the work of these groups, and to elaborate, propose and follow projects implying international co-operation. CSTG is the Commission VIII of the International Association of Geodesy (IAG) and simultaneously the Sub-commission B2.1 of the Scientific Committee on Space Research (COSPAR) of the International Council for Science (ICSU).

CSTG is structured into five sub-commissions (SC) and one Project:

- SC on the International Space Geodetic Network (ISGN),
- SC on Co-ordination and Combination of the Analysis in Space Geodesy (CASG),
- SC on Precise Satellite Microwave Systems (PSMS),
- SC on Multi-Mission Satellite Altimetry (MMSA),
- SC on Precise Orbit Determination for Low Earth Orbiting Satellites (POD LEOS),
- Project on DORIS.

While the sub-commissions were designed for long-term activities, the project has an objective limited in time and should serve only for one elective period.

CSTG operates through the Executive Committee (EC). It is composed by the commission's president and past-president, the chairpersons of the sub-commissions and the project, as well as each one representative of the relevant IAG Services and of COSPAR. These were during the period 1999 – 2003

- Hermann Drewes, Germany, President,
- Gerhard Beutler, Switzerland, Past-President,
- John Bosworth (since 2001 James Long), USA, Chair SC ISGN,
- Thomas Herring, USA, Chair SC CSAG,
- Pascal Willis, France, Chair SC PSMS,
- Wolfgang Bosch, Germany, Chair SC MMSA,
- Markus Rothacher, Germany, Chair SC POD for LEOS,
- Gilles Tavernier, France, Chair Project on DORIS,
- Claude Boucher, France, IERS Representative,
- Ruth Neilan, USA, IGS Representative,
- John Degnan (since 2002 Mike Pearlman), USA, ILRS Representative,
- Wolfgang Schlüter, Germany, IVS Representative,
- John Dow, Germany, COSPAR Liaison.

Publications, Symposia and Meetings

CSTG disseminates information about ongoing international activities and research results in the field of space geodesy by publishing the CSTG Bulletins. In the period 1999 – 2003 the following volumes were issued:

- Bulletin No. 16: Status and Program 1999 – 2003, Munich 2001, 86 pp.

- Bulletin No. 17: Progress Report 2001, Munich 2002, 95 pp.
- Bulletin No. 18: Final Report, Munich 2003 (in press).

CSTG organised two International Symposia during the last four years together with the COSPAR Panel on Satellite Dynamics (PSD):

- Symposium "New Trends in Space Geodesy", 33rd COSPAR Scientific Assembly, Warsaw, July 2000.
  Proceedings published in "Advances in Space Research", Vol. 30, No. 2, Pergamon Press 2002 (editors H. Drewes and J. Dow).
- Symposium "Integrated Space Geodetic Systems and Satellite Dynamics", 34th COSPAR Scientific Assembly, Houston, Texas, October 2002.
  Proceedings in print in "Advances in Space Research".

There were seven meetings of the CSTG Executive Committee during the period:

- Birmingham, 26 July 1999 (IUGG General Assembly),
- San Francisco, 14 December 1999 (AGU Fall Meeting),
- Warsaw, 18 July 2000 (COSPAR Scientific Assembly),
- Nice, 29 March 2001 (EGS General Assembly),
- Budapest, 5 September 2001 (IAG Scientific Assembly),
- Nice, 25 April 2002 (EGS General Assembly),
- Nice, 9 April 2003 (EGS/EUG/AGU Joint Assembly).

The minutes of all the EC meetings are published in the CSTG Bulletins.

Major General Achievements in the Period 1999 – 2003

In fulfilment of its objectives, CSTG continued its role of co-ordinating IAG activities in space geodesy. During the past elective period, 1995 – 1999, two new services had been installed upon the initiative of CSTG, the International Laser Ranging Service (ILRS) and the VLBI Service for Geodesy and Astrometry (IVS). Two other services, the International Earth Rotation Service (IERS) and the International GPS Service (IGS) had developed from CSTG sub-commissions before. The co-ordination of specific activities of these services and the co-operation with CSTG sub-commissions were continued. In the following we mention some of the major joint efforts.

- A joint initiative of CSTG (Sub-commission on the ISGN), the IERS (ITRS Product Centre) and the IAG Services was started to identify discrepancies in the local ties of co-located observation stations of different techniques (see SC ISGN report below).
- The combination of space geodetic observations, studied by the corresponding CSTG sub-commission, was included into the new structure of the IERS since January 2001 in the form of Combination Research Centres (CRC).
- The study of precise orbit determination of those low Earth orbiting satellites carrying GPS receivers was done by the CSTG sub-commission in close co-operation with the corresponding IGS Working Group (see SC POD for LEOS report below).

The CSTG Executive Committee decided in April 2003 to support the Project on DORIS in its application to become an official IAG Service. The intention was immediately forwarded to the IAG EC. The final decision will be made during the IUGG General Assembly in Sapporo, July 2003.

Activities of the Sub-commissions

The activities of the CSTG sub-commissions are summarised in the following in very short abstracts. For more details we refer to the reports in the CSTG Bulletin No. 18.

Sub-commission on the International Space Geodetic Network (ISGN)
The ISGN Sub-commission reviewed all the existing space geodetic observation stations with respect to its fulfilment of the CSTG/IERS criteria set up in 1998 (CSTG Bulletin No. 15, 1999). A list of candidate sites to become official ISGN stations and invitation letters to the station managers were prepared. The

issue came to a standstill because the technique-specific services also started the classification of their network stations. A common tuning seemed to be indispensable. Later on, the proposal of the IAG Project on an Integrated Global Geodetic Observing System (IGGOS) seemed to require a quite similar selection of sites which should not be predetermined.

A major problem of co-located space geodetic sites is the precise determination of relative positions of observation stations of different techniques (eccentricities, local ties). The ISGN Sub-commission is in charge of a list of local ties since several years. The ITRS Product Centre of the IERS also uses an own eccentricity file. In a joint effort of the ISGN Sub-commission and the ITRF Product Centre and several working meetings, a list of discrepancies between local surveys and differences of technique-specific station coordinates was prepared. The organisation of an international team of geodetic surveyors to assist in outstanding site survey omissions was begun.

In a regular way, the ISGN Sub-commission publishes the “Active Global Space Geodetic Site Information Summary” in the CTSG Bulletins. It includes approximately 300 sites with coordinates, host or managing agencies and available space techniques. The chart is continuously being updated and may be accessed by internet: http://cddisa.gsfc.nasa.gov/ggs/sgp_chart.html.

Sub-commission on Co-ordination and Combination of Analysis in Space Geodesy

The Sub-commission started its activities by combining mainly GPS processing results of different analysis centres. In the following, a main issue was the updating of the SINEX format to include information appropriate for all space geodetic systems and to enable the easy integration of different techniques. This was done in very close co-operation with the IGS and the IERS.

In 2001, the IERS started its new structure including an Analysis Co-ordinator (AC) and Combination Research Centre (CRC). The chairman of the CSTG Sub-commission, Tom Herring, became the interim AC and brought the CSTG Sub-commission and the CRCs together. The analysis is thus done in an integrated manner, co-ordinated by the IERS AC (since 2002 Markus Rothacher.

The principal objective is to investigate and develop strategies for combining results of geodetic data processing in a consistent and strict way. Approaches of combination at the level of observation equations, normal equations or complete solutions are studied. A main issue is the elimination of (direct or indirect) constraints, the estimation of relative weights, and the definition of a common datum.

Sub-commission on Precise Microwave Systems

The role of this Sub-commission was foreseen in supporting new and emerging techniques other than GPS than are not yet organised as IAG Service-oriented structure, namely GLONASS, DORIS, PRARE and Galileo.

Concerning GLONASS, a decision has been made after the final workshop of the IGEX-98 campaign to include GLONASS within the IGS organisation through an IGS project, called IGGLOS (International GLONASS Service). In early 2003, 36 GLONASS tracking stations are currently observing 7 available GLONASS satellites. All these stations are collocated, and most are equipped with combined GPS/GLONASS receivers. Russia has launched few new GLONASS satellites to replace part of its still incomplete constellation. Several analysis groups process GLONASS data using the same strategy as for GPS data within the IGS. Current performances are now closer to GPS results (10 cm radial for orbit and sub-cm accuracy for point positioning). At the end of the 4 years, the GLONASS data collection, analysis and information are joined with GPS.

DORIS has started activities as a Pilot Project. In 1999, a general call for participation has been issued and several groups proposed to serve as analysis centres (see Project on DORIS below). In 2002, 3 additional satellites have been launched by NASA, CNES and ESA. The DORIS constellation jumped from 3 to 6 satellites, including satellites with a new generation of receiver (on-board orbit determination, improved accuracy, autonomy and multi-channel). DORIS data and products can presently be found at CDDIS (cddisa.gsfc.nasa.gov) and at IGN (ftp://lareg.ensg.ign.fr/pub/doris/). DORIS results have improved in the last 4 years, showing orbit accuracy at 1 to 2 cm for TOPEX and JASON satellites, point positioning accuracy at 1 to 2 cm for weekly solutions, or 1 cm and 2 mm/year, respectively, for global solutions (over the 10 year period).

The PRARE system is only operating on the ERS-2 satellite. There are presently no plans to extend its activity to new satellites. Several groups process the PRARE/ERS-2 data. It is not foreseen to organise the PRARE community in an IAG-Service oriented structure.

The future European satellite navigation system Galileo has been decided and the first satellites should be launched before 2006, first a demonstration mode. As new actual Galileo data are available, the work of the sub-commission has been to start contact with Galileo (through the European Commission and ESA) and to prepare a possible geodetic use of the future Galileo satellites through the IGS structure. A few initiatives led to the future use of ITRF as the Galileo reference coordinates frame. In parallel, discussion with ESA could bring a co-operation between EUREF and the EGNOS system (first development phase of Galileo) concerning the monitoring EGNOS tracking stations coordinates. Within the IGS, a working group has been created in order to prepare a future inclusion of the geodetic applications of Galileo in the frame of the IGS (chairman: J. Dow). In the IGS strategic planning recommendation it is clear that Galileo has some specific interest for the IGS community and that, following the example of GLONASS, future steps should be taken in the future to incorporate Galileo data collection and data analysis in the frame of the IGS structure.

Sub-commission on Multi-Mission Satellite Altimetry

The main objectives of the Sub-commission are to promote free access to all available altimeter data for scientific investigations, to study synergies among different altimeter missions with different space-time sampling and with other remote sensing techniques, to set up the requirements for unified multi-mission long-term records of altimeter data (structure, standards, formats), to study new techniques and application areas, and to investigate the establishment of an international altimeter service.

A concept for a multi-mission altimeter data base was developed in terms of the organisation, functionality, contents, and structure. A prototype of such a system, an Open Altimeter Data Base (OpenADB) with a generic data format was prepared and tested. It allows the quick actualisation of parameters, i.e., adoption to actual gravity field models, different physical correction models and new algorithms. It is also possible to extract data in a user defined format or to add results from external groups.

The amount of altimeter data will grow tremendously in the next future due to new missions and increasing sampling rates. It will be beyond the normal storage capacities. A scaling into integer units and binary codes was developed for the compression of data. A decoder program allows the selection and formatting of data. The goal is to provide data of different missions for selected regions and time intervals for the users.

Sub-commission on Precise Orbit Determination for Low Earth Orbiting Satellites

Primary goals of the Sub-commission are the studies of different LEO orbit modelling approaches, the impact of global parameters on LEO orbits, mission-dependent data structures and standards, and the analysis of LEO orbits obtained from data of different observation techniques.

Various data sets of LEO observations were made available to interested groups for this purpose. The Sub-commission collected and distributed also information on ongoing LEO satellite missions and data sets. Exchange formats are defined and described. The activities are closely co-ordinated with the IGS Working Group on LEOS and the Special Study Group 2.162 of IAG. While the IGS WG is focussing more on the data formats and standards, the CSTG Sub-commission pays to the orbit analysis, in particular using data from different techniques.

Besides the TOPEX, GPS/MET and SAC-C orbits, emphasis is laid on the new satellite missions, CHAMP, GRACE and JASON-1. The orbits determined from GPS and SLR observations and the obvious offset of 5 cm were analysed.

Project on DORIS

DORIS was developed for precise orbit determination and precise positioning of ground tracking stations on Earth. In 1999 it was decided at the IAG General Assembly to create a DORIS Pilot Experiment. Such a Pilot Experiment would give time to all engaged groups to co-ordinate and improve their operation in order to create on the long term an International DORIS Service (IDS). A Steering Committee manages the DORIS Pilot Experiment with the help of a Central Bureau responsible for the co-ordination, communication, meetings, workshops etc.

Two Data Centres support DORIS data and products archiving and distribution for the space geodesy and geodynamics community. The Central Bureau started a Station Coordinates Analysis Campaign in November 2001 which was extended to new products in March 2002. The DORIS Station Selection Committee defines site criteria and analyses proposals for new sites. There are eleven Analysis Centres willing to process DORIS measurements, four of them regularly contributing to an Analysis Campaign and delivering products.

For three years, a network renovation action has been conducted: today more than half of the stations meet the new stability requirement. In the same period, third generation beacons were developed. Deliveries and deployment started in December 2001. Presently 56 stations are installed at the end of 2002. Three new satellites recently joined the three satellites already flying with a DORIS receiver. They carry an improved second generation DORIS receiver including two channels and DIODE navigator.

The Future of CSTG

During the last CSTG EC meeting in Nice, 9 April 2003, the future of scientific activities performed at present by CSTG were discussed. There is a general consensus that the new IAG Commission 1 “Reference Frames” should integrate the main CSTG objectives, i.e., the co-ordination of space geodesy in IAG and among the services. Commission 1 should also represent the COSPAR Sub-commission B2.1. The CSTG sub-commissions should go to the new Commission I or to the relevant IAG Services.

The sub-commissions on the IGSN and on the Combination of Space Geodetic Analysis should be integrated into the new IERS structure. The sub-commissions on Precise Satellite Microwave Systems and on Precise Orbit Determination for Low Earth Orbiting Satellites should completely continue in IGS. The sub-commission on Multi-Mission Satellite Altimetry should become a Project in the new Commission 1 with the goal of establishing a service. The DORIS Project should become an IAG Service in 2003.

SPECIAL COMMISSION 7:
"SATELLITE GRAVITY FIELD MISSIONS"

http://www.geod.uni-bonn.de/SC7.html

K.H. Ilk (chair), P. Visser (co-chair), J. Kusche (scientific secretary)

Abstract

This final report describes the activities of the Special Commission VII "Satellite Gravity Field Missions" during the past four years since the IAG General Assembly 1999 in Birmingham, UK. There was a tremendous progress in preparing and realizing satellite-borne gravity field missions in the past four years. In July 2000 the CHAMP mission had been launched and after a commissioning phase and an International Announcement of Opportunity the data of various product levels are accessible. The results achieved during the past years proofed the expectations of the scientific community. The first CHAMP progress meeting held in Potsdam in January 2002 documented the progress in gravity and magnetic field and in atmosphere research as well as in the techniques of orbit determination. In March 2002 the two GRACE satellites had been brought in nearly circular orbits. First results confirmed the expectations of the scientific community expected from satellite-borne gravity measurements and its value for unprecedented views of the earth's gravity field. The preparation of ESA's satellite gradiometry mission GOCE is under way. Together with complementary geophysical data and precise measurements of the surface of the oceans and ice regions, satellite gravity data represent a "new frontier" in studies of the System Earth. Scientific programs to take full advantage of these new information are in preparation. It can be expected that the work of Special Commission VII with a slightly modified task can be more successful in the coming years than in the past. Indeed, the data available in the next future will attract many groups with different analysis concepts and with various ideas to investigate scientific and commercial applications of a very precise high resolution gravity field. This is the reason that SCVII has the chance to support the international exchange of ideas and to draw the greatest possible benefit out of these new innovative data.

Introduction and background

SC VII is a continuation of a Special Commission that existed already during the four years period before 1999 and had been established occasional the IAG General Assembly in Boulder, USA, in the year 1995. The task at that time was to create a platform that integrates all international activities related to gravity field determination by satellite gravity gradiometry and to prepare the conditions for a future mission. Around the year 1995 the common opinion was that only a dedicated satellite gravity gradiometry mission could provide a gravity field which meets the demands of the community. In the upcoming years since 1995 the situation changed in so far as the cheaper satellite-to-satellite tracking concept gained again more interest. This situation is also reflected in the change of the subject of SCVII. Before 1999 it was dedicated to the "Gravity Field Determination by Satellite Gravity Gradiometry" and in the follow-on period to the more general topics of "Satellite Gravity Field Missions". The last eight years since 1995 showed a tremendous progress in preparing satellite-borne gravity missions: today we not only have an accepted satellite gravity gradiometry mission, GOCE, additionally, two satellite-to-satellite gravity missions, CHAMP and GRACE are already realized and the scientific data partly accessible to the interested community. The multi-purpose high-low satellite-to-satellite mission, CHAMP, has been launched in July 2000, the low-low satellite-to-satellite mission GRACE followed in March 2002 and the satellite gravity gradiometry mission GOCE, at present in the scientific and industrial preparation phase, will be realized in 2006. CHAMP, GRACE and GOCE have the potential to revolutionize the knowledge of the system earth. Not only the static part of the gravity field can be determined with unattained accuracy also an eventual time dependency can be derived. The coming years, sometimes defined as the "Decade of Geopotential Research" will represent an enormous challenge for the geo-scientific community. During the present decade additional satellite altimetry missions are already launched or will be realized. The satellite altimetry missions Jason-1 and ENVISAT are already in orbit since 2001 and 2002 respectively, and the cryosphere satellites ICEsat (in orbit since 2003) and CryoSat (envisaged for 2004) will supply the gravity field with important data of the geometry of the oceans and the ice regions. The combination of these data will open new vistas for the geo sciences.

Objectives

The Special Commission VII was envisaged to act as a platform of discussion and information exchange related to the various missions mentioned above. Three main problem areas had been defined; each of them consisted of several sub topics. It is indicated whether specific problems are treated within a Special Study Group.

- Analysis of the observation system:

  (i) on the flight validation and calibration of satellite data of various mission types – connections to SSG 2.193 "Cal/val of new gravity mission instruments" (P. Visser, C. Jekeli) and the Working Group "Preparation of Standard Procedures for Global Gravity Field Validation" (Th. Gruber),
  (ii) integrated sensor analysis - connections to SSG 2.162: Precise orbits using multiple space techniques,
  (iii) new sensors (laser interferometers, alternative gradiometers and accelerometers),

- Modeling and data analysis aspects:

  (i) comparison of analysis techniques (global and regional),
  (ii) gravity field modeling aspects with view to the time dependency of the gravity field – connections to SSG 4.187: Wavelets in geodesy and geodynamics (W. Keller),
  (iii) combination of satellite data and (inhomogeneous) terrestrial data – connections to SSG 3.185: Merging data from dedicated satellite missions with other gravimetric data (N. Sneeuw),
  (iv) calibration of satellite derived data – connections to SSG 2.193 "Cal/val of new gravity mision instruments" (P. Visser, C. Jekeli) and the Working Group "Preparation of Standard Procedures for Global Gravity Field Validation" (Th. Gruber),
  (v) downward continuation aspects,

- Applications in geo sciences, oceanography, climate change studies and other interdisciplinary research topics in earth sciences:

  (i) oceanographic aspects - connections to SSG 2.194: GPS water level measurements (C. Jekeli),
  (ii) inversion of the gravity field,
  (iii) structure of atmosphere and ionosphere - connections to SSG 2.192: Spaceborne atmospheric GNS soundings (R. Hanssen),
  (iv) temporal variations of the gravity field and the cryosphere,
  (v) temporal variations of the gravity field and the hydrosphere.

Besides these topics the Special Commission was created also to act as a brain pool for ideas of future developments in gravity field research. This encompasses not only applications to various fields of geo sciences but also developments of future satellite borne techniques to measure the gravity field.

Members

SC VII has 55 members and corresponding members, respectively, including the chair, co-chair and scientific secretary. The names of the members and corresponding members that expressed their interest in the work of SCVII are given in the following list.

Chair/co-chair/scientific secretary: Karl Heinz Ilk, Pieter Visser, Jürgen Kusche

Members/corresponding members: Dimitri Arabelos (Greece), Georges Balmino (France), Srinivas Bettadpur (USA), Johannes Bouman (The Netherlands), Ben F. Chao (USA), Jean Dickey (USA), René Forsberg (Denmark), Willi Freeden (Germany), Yoichi Fukuda (Japan), Martin van Gelderen (The

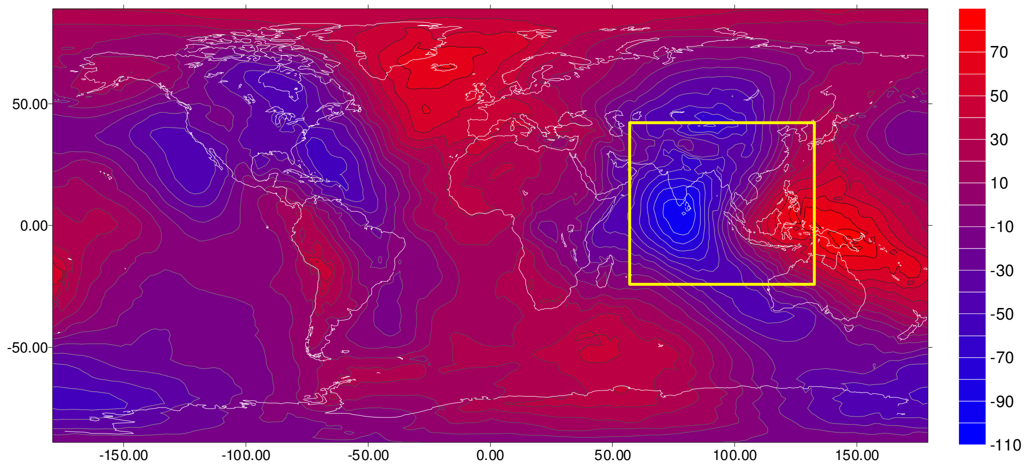
Netherlands), Erik Grafarend (Germany), Richard S. Gross (UK), Thomas Gruber (Germany), Roger Haagmans (Norway), Bernhard Heck (Germany), Cheinway Hwang (Taiwan), Chris Jekeli (USA), Steve Kenyon (UK), Wolfgang Keller (Germany), Roland Klees (The Netherlands), Rolf König (Germany), Radboud Koop (The Netherlands), Ulrich Meyer (Germany), Federica Migliaccio (Italy), Jerry X. Mitrovica (USA), Philip Moore (UK), Jürgen Müller (Germany), Steve Nerem (USA), Helmut Oberndorfer (Germany), Erricos Pavlis (USA), Margarita Petrovskaya (Russia), Dan Roman (USA), Reiner Rummel (Germany), Fernando Sansò (Italy), E.J.O. Schrama (The Netherlands), Wolf-Dieter Schuh (Germany), Avri Selig (The Netherlands), Abdel Sellal (Algeria), Peter Schwintzer (Germany), C.K. Shum (USA), Martijn Smit (The Netherlands), Dru Smith (USA), Nico Sneeuw (Germany), Hans Sünkel (Austria), Byron Tapley (USA), Pierre Touboul (France), Christian C. Tscherning (Denmark), Illias Tziavos (Greece), John Wahr (USA), Michael Watkins (USA), Martin Vermeer (Finland), Peiliang Xu (Japan).

Specific accomplishments

A first step of the activities of SCVII was to establish a web site integrated into the IAG home page. National and international activities related to the gravity field missions hade been distributed to the interested community. Links to the most important addresses related to these missions were given. Concerning the list of objectives of SCVII only a view aspects could be worked off. The idea to establish a forum of discussion could not be realized. There was only a minor feedback from the members. Looking back we can say that this is understandable in so far as the groups involved in the preparation and execution of the gravity satellite missions have to work under competitive conditions and are to a certain amount independent from the input of a broader community. Therefore, it remained the service of SCVII for those who are not directly involved in a mission proposal or a mission project. This is the reason that one initiative of SCVII related to the generation of data sets of simulated CHAMP, GRACE, GOCE and 24 GPS satellite orbits turned out to be quite successful. The generated data sets cover a time period of 30 days and include the velocities, accelerations, and for GOCE the tensor components for specified gravity fields and reference frame specifications. As a first step, the mission scenarios were generated based on very simple models concerning the reference systems and the noise models. In 2001 SRON, the Netherland's Space Agency, provided various error models for the tensor components of GOCE. Details were given in readme-files and additional information material on mathematical details were included. It took some iteration steps until the material was adapted to the needs of the users. The data sets were planned to be used for investigations related to satellite borne gravity field missions, especially to compare

- global and/or regional recovery techniques,
- spherical harmonics (each parameter and degree variances) and gravity functionals in (geographic) blocks (center point and mean block values),
- gravity functionals in (geographic) blocks (center point and mean block) values in the region specified in the data sheet.

In the starting phase the simulation material was available in packed form on two CD-roms. It could be received after demand or downloaded together with additional information material from the SCVII web page. Later a FTP-server was created, where the simulation material could be downloaded. The computation comparisons should be done for global and regional analysis techniques. As regional example an area with a rough gravity field in the South-East-Asian area has been selected (fig, geoid heights in m):



The response to the offer to provide the simulation scenarios was very encouraging. The CD-roms have been sent to 21 members of various institutions and countries on demand. Because of the fact that the simulation material could be downloaded from the SCVII FTP-server the detailed number of those who downloaded the material is not known. But it seems that many used the data for comparisons and simulation computations. Besides this activity the bibliography of SGG and SST related references had been moderately improved. Unfortunately, there was not much response to report all papers and articles to the SCVII chair to be included in the publication list. This is the reason that the bibliography is not up-to-date by far, especially concerning the huge number of papers published during the last years. Nevertheless, the bibliography gives an overview of references from the early days of SGG and SST activities. In 2001 a SC VII-meeting had been held occasional the IAG General Assembly in Budapest.

Conclusions and outlook

The realization of the missions CHAMP and GRACE and the fact that the real data are (partly) available made the simulation material of these missions unnecessary, at least for most of the applications. Nowadays, there are many groups around the world involved in the development of software for analyzing satellite born gravity field observations, as satellite gravity gradiometry observations, satellite-to-satellite tracking data, either in the high-low or in the low-low mode. To provide a simple platform for any scientist or for groups of scientists of the international community with the task to check and to improve his/their own developments or to compare the effectiveness of their procedures to the procedures of others it seems still to be useful to use a unique data set. For comparisons the simulated mission scenarios might be useful even nowadays where real data are already available. It would be very useful to compare the various approaches for global and regional gravity recovery procedures, space-wise, time-wise, based on spherical harmonics, wavelets, covariance functions or any other space-localizing gravity field representation. More sophisticated simulation scenarios would be helpful together with a selected set of real data. Another problem closely related to the recovery procedure are the topics "calibration" and "validation", but also data combination with terrestrial data or alternative data sets. These topics should be important points for a task list of a follow-on SC VII.

SPECIAL STUDY GROUP 2.162:

"PRECISE ORBITS USING MULTIPLE SPACE TECHNIQUES"

R. Scharroo (chair)

Abstract

During the years 2001-2002 the IAG Special Study Group 2.162 ``Precise Orbits Using Multiple Space Techniques'' has been mainly busy assessing the capabilities of new techniques and tracking systems on satellites. Several new satellites have been launched, such as Envisat, Jason-1, CHAMP and GRACE. This spun up a renewed effort in orbit determination based on GPS and DORIS.

Introduction and background

Modern satellites that require precise positioning are equipped with several independent tracking devices. The ERS satellites were the first to combine Satellite Laser Ranging (SLR) and Doppler tracking with the Precise Range And Range-rate Equipment (PRARE) for precise orbit determination in support of the radar altimeter (RA). It was soon shown that the RA itself proves an important tracking device. Interferometric Synthetic Aperture Radiometry (InSAR) has recently developed to become another demanding consumer of precise satellite orbits.

TOPEX/POSEIDON (T/P) carries, apart from its RA, four independent tracking systems including SLR, Doppler Orbitography and Radio Positioning Integrated by Satellite (DORIS), Global Positioning System (GPS), and the Tracking and Data Relay Satellite System (TDRSS). For the first time, the force model errors, especially gravity, have been reduced to a point where a comparison of the various satellite tracking systems at or near their noise level is possible.

Results, as expected, show that each system has its own strengths and weaknesses. Therefore, recent precise orbit determination improvements for ERS-2 and T/P have been obtained using a combination of multiple tracking techniques. With PRARE on ERS-1 and GPS on Geosat Follow-On (GFO) on the limb, orbits for these satellites will likely remain to be based partly on altimeter tracking data.

The new generation of altimeter satellites, including the recently launched Jason-1, Envisat and Icesat, and future satellites like Cryosat and Jason-2, are or will be equipped with several tracking systems to support their altimeter, either DORIS or GPS in combination with SLR. There are great expectations for achieving orbits with sub-centimetre precision with a latency of about a month. Operational near real-time orbit determination is rapidly gaining interest and precision. The capabilities of the DIODE on-board real-time orbit determination package are currently still under investigation and are being tuned. The real-time localisation of the satellite with this add-on to the DORIS system is expected to reach sub-decimetre level in radial direction.

In the future navigation and tracking satellites (GPS, GLONASS, and TDRSS) will start demanding higher precision orbit determination, because they are and will be used as reference for Low Earth Orbiters (LEOs) in high-low satellite-to-satellite tracking configurations (cf. IAG Subcommission on Precise Orbit Determination for Low Earth Orbiting Satellites). Some of these navigation satellites are equipped with more than one tracking system. An important aspect is also to assess the respective tracking station coordinate solutions and evaluate misfits between the solutions.

GRACE is now providing precise satellite-to-satellite tracking in a low-low configuration. The results of the orbit computations are referenced against the readings of the accelerometers. This is a joint research topic with SSG 2.193 (chaired by Pieter Visser)

The focus of this study group will be to further evaluate and characterise the various tracking systems, develop and assess new tracking techniques, and apply the products to improve the state-of-the-art in precision orbit determination.

SSG 2.162 members

The IAG Special Study Group 2.162 consists of 23 members, including the chair and 1 corresponding member. The names and affiliation of the members is listed below:

Chair: Remko Scharroo (TU Delft, The Netherlands)

Members: Boudewijn Ambrosius (TU Delft, The Netherlands), Per-Helge Andersen (FFI, Norway), Jean-Paul Berthias (CNES, France), Willy Bertiger (JPL, USA), Eelco Doornbos (TU Delft, The Netherlands), John Dow (ESA, Germany), Ramesh Govind Coleman (AUSLIG, Australia), Bruce Haines (JPL, USA), Jaroslav Klokocnik (Czech Academy of Sciences, Czech Republic), Scott Luthcke (GSFC, USA), Franz-Heinrich Massmann (GFZ, Germany), François Nouel (CNES, France), Erricos Pavlis (UMD, USA), John Ries (UT/CSR, USA), Markus Rothacher (AIUB, Switzerland), Ernst Schrama (TU Delft, The Netherlands), Ladislav Senhal (Czech Academy of Sciences, Czech Republic), C.K. Shum (OSU, USA), Tim Springer (AIUB, Switzerland), Mike Watkins (JPL, USA), René Zandbergen (ESOC, Germany), Shengyuan Zhu (GFZ, Germany)

Corresponding member: Pieter Visser (TU Delft, The Netherlands)

The members have all been active in satellite orbit determination and have contributed to the improvement of orbit precision in various ways: by the development of accurate measurement models and techniques to combine various types of tracking data, by the comparison of orbits based on different tracking data, and mainly by calibrating and validating the tracking systems on the recently launched satellites (CHAMP, GRACE, Jason-1, Envisat and Icesat). Some results of these activities have been presented at various international conferences and symposia like those of EGS, AGU, and IAG, and satellite-specific symposia and workshops like the T/P Science Working Team meetings. Unfortunately, the data sharing has not been optimal. All five above mentioned satellites are still considered to be in their ``Commissioning Phase''. During this period data distribution is minimal.

Specific results and outlook

During the last two years, most efforts have focused on the calibration and validation of the tracking data and the orbits of new satellites. Little time was available to actively research the combination strategies.

Operational, near real-time orbit determination is now feasible using only SLR and altimeter tracking data. Accuracies of near realtime ERS-2 orbits are in the neighbourhood of 10 cm in radial direction. In the near future when Jason-1 and Envisat are commissioned, we will be seeing the advantage of having an on-board orbit determination package like DIODE. The realtime positioning system will provide accurate orbits for the near realtime altimeter products.

Next studies will have to identify to which extend DORIS and SLR tracking data are compatible or complementary. The same holds for these tracking types with respect to GPS. Unfortunately, the later issue is still under-researched.

More work expected when the recent satellite missions of concern (CHAMP, GRACE, Jason-1, Envisat and Icesat) are all commissioned. There will be significant cross-talk between gravity field modelling, satellite tracking calibration, development of new combined tracking techniques, and atmospheric modelling.

SPECIAL STUDY GROUP 2.183:
"SPACEBORNE INTERFEROMETRY TECHNIQUES"

R.F. Hanssen

Introduction

The basic principles of Synthetic Aperture Radar Interferometry (InSAR) date back to the early 1970s and are well understood. Moreover, since the launch of the ESA satellites ERS-1 and ERS-2 enormous amounts of SAR data became available and many groups started to develop potential applications of InSAR in topographic mapping and surface deformation analysis, and to assess the main limitations of InSAR. In numerous studies it has been demonstrated that InSAR is an extremely powerful tool for topographic mapping of the Earth's land and ice surface and for detecting surface deformation with high accuracy and spatial resolution. However, most of the very exciting results have been obtained under `optimal' environmental conditions such as moderate topography, poor vegetation, and arid climate conditions. As such, these results had a rather opportunistic nature.

During the active period of SSG 2.183, techniques and algorithms were developed and validated, which allow the application of InSAR under much less favourable conditions such as severe temporal decorrelation, atmospheric signal contribution, and layover. Progress was also made in the geodetic description of the process of InSAR, in terms of geodetic model formulation. In addition, the technological improvements of data processors and the design of new airborne and spaceborne SAR systems evolved rapidly, triggering the development of new data processing strategies and analysis methods in order to optimally exploit this technology.

Apart from the new developments and techniques, there was also a considerable consolidation of the existing techniques, which became more mature. The technique became accessible for many non-expert scientists, leading to an explosion in InSAR related publications. Mainly the field of geophysics benefited from this expansion. Another development articulating this maturity is the growth of commercial initiatives to process and advise in the field of radar interferometry. At least ten companies worldwide claim expertise and capabilities in the field, which is a very good development to make the technique known to a larger audience.

Research objectives

The work of SSG 2.183 focussed on identifying practical procedures as well as mathematical techniques that can be applied to describe the quality of the interferometric products and push the application of the technique to more difficult circumstances. By publishing these results in journals and reports, members of the SSG contributed actively to advocate the technique as a standard geodetic tool. Results were also communicated during various conferences and symposia, such as IGARSS, AGU, and EGS.

The objectives of the SSG are:

- to develop techniques and algorithms that allow extracting unambiguously topographic, deformation, and atmospheric signal from spaceborne repeat-pass radar interferometry,
- to develop methods that allow describing the quality, in terms of accuracy and reliability, of the interferometric products taking the most significant error sources into account, and
- to validate topographic and deformation maps for various applications and under various environmental conditions.

These objectives result into a series of tasks:

- Develop phase unwrapping methodologies. Description of the quality of each pixel, quality measures, proper choice of the norm,
- Quality description of the unwrapped phases, phase unwrapping strategies in highly decorrelated interferograms (patch unwrapping).

- Investigate the atmospheric signal. Role of weather radar data, synergy of various sensors on board of future satellite missions (e.g.,MERIS on board ENVISAT), role of permanent GPS tracking networks, assessment of the spatial and temporal characteristics of the ionosphere on short spatial scales (below 100 km). Statistical (model) based approach to the atmospheric signal (Atmospheric Phase Screen).
- Evolve applications of water vapor mapping using InSAR.
- Develop a quality description of interferometric products
- Develop methods for integrated deformation analysis using InSAR, GPS, levelling, and geophysical data.
- Analyze the effects of temporal decorrelation: further assessment of the relation between temporal decorrelation and various types of terrain, expected decorrelation due to weathering, effect of ground cover, phase stability of man-made and natural permanent scatterers.
- Define data and instruments requirements of science users for orbiting and planned SAR instruments.
- Exploiting the potential of InSAR in the commercial and industrial sector (near real-time data processing, continuous data flow, mosaicking).

Membership:

Full members (alphabetical order): Falk Amelung (University of Miami, USA) amelung@pgd.hawaii.edu, Richard Bamler (German Aerospace Center (DLR), Germany) Richard.Bamler@dlr.de, Alessandro Ferretti (Politecnico di Milano, Italy) aferre@elet.polimi.it, Satoshi Fujiwara (Geographical Survey Institute), Japan, Linlin GE (University of New South Wales, Australia) l.ge@unsw.edu.au, Rick Guritz (Alaska SAR Facility, USA) rguritz@images.alaska.edu, Ramon Hanssen (Delft University of Technology, The Netherlands) hanssen@geo.tudelft.nl, Johan Mohr (Technical University of Denmark) jm@emi.dtu.dk, David Sandwell (Scripps Institution of Oceanography) sandwell@geosat.ucsd.edu, Andrew Wilkinson (University of Cape Town, South Africa) ajw@eng.uct.ac.za, Howard Zebker (Stanford University, USA)

Missions (1999-2003)

Several satellite missions were active or planned during the working period of this special study group.

ERS-1 performed well over its designed life time of 3 years, between 1991 and 1999. It was the first satellite that enabled co-seismic deformation maps with an unsurpassed resolution, coverage and accuracy. The ESA archive filled with ERS-1, ERS-2, and Envisat data is perhaps the most valuable product produced. Easy access to the archive enables many future studies, systematically combining the different data

ERS-2 delivered high quality data, with an uninterrupted repeat orbit, 35 day repeat period. It also extended its nominal life time of 3 years. Starting in 1995, it is still active and acquiring data. In the period after 2000, problems with the internal gyroscopes lead to errors in the positioning and attitude control. This lead to large deviations in the Doppler centroid frequencies which made many images practically useless for interferometry. Nevertheless, although not optimal, the instrument is stil gathering data, currently in a 30 minute tandem mission with Envisat.

The Shuttle Radar Topography Mission (SRTM) mapped in a period the entire world between latitude 60N and 60 S. Both from a scientific and an engineering point of view, the single-pass concept proved to be very well suited to deliver a global DEM with homogeneous quality. The X-band system produced a network of small swaths, but with a high resolution. The C-band system delivered full topographic coverage. Processing the data acquired with the 60 m long boom proved to be a challenging task, as movements and vibration of the antenna resulted in an anomalous signal that had to be subtracted from the data.

After significant delays, Envisat was launched early 2002, starting a new time series of radar acquisitions. Envisat is one of the last multi-instrument monsters, which influences the acquisition requests. Especially the advanced SAR (ASAR) has various polarimetric modes and can operate in 7 image swaths. Since for interferometry it is optimal to choose one set of parameter settings and keep it unaltered, it remains uncertain whether the mission will be optimal for radar interferometry.

Interesting concepts of new missions were introduced. The interferometric cartwheel is one of the spectacular ideas, in which three 'parasite' satellites with passive (receive-only) antennas record the scattered radar pulses of the 'master' satellite, with an active (send and receive) antenna. By giving the three satellites a different perigeum, they will 'roll' respective to each other in their orbital plane, like a cartwheel rolling over an imaginary sphere in space, concentric with earth. This concept results in large (km-sized) spatial baselines between the satellites, in single-pass configuration, yielding high topographic sensitivity. Global accuracies of 2 m are expected to be feasible. (Massonnet, 2001)

First results of cross-interferometry between different sensors (ERS-2 and ENVISAT) were shown. This was remarkable, since the center frequencies of both sensors are slightly different, so that no spectral overlap between the data exists in normal situations. However, in the case of a large baseline (about 1.5 km, depending on the terrain slope) the ground reflectivity spectrum overlaps in the data spectra of both sensors. The large baseline also introduces a very high height sensitivity, which has potential for accurate DEM generation. It has been shown, however, that volume decorrelation has a deteriorating effect on the potential of cross-interferometry.

Deformation monitoring

Deformation monitoring still is one of the key applications of repeat-pass interferometry, mainly due to the high accuracy in relation with the spatial resolution and coverage and the temporal repeat frequency. The main deformations studied are due to tectonic movement, volcano deformation, (urban) subsidence due to groundwater or hydrocarbon extraction, and land slides.

Tectonic movement. Although coseismic motion has lead to spectacular and visually appealing interferograms, the most important challenge is the unambiguous observation of inter-seismic strain-accumulation, due to its direct relation to earthquake hazards. This requires a large swath and mm-accuracies over long wavelengths. Wright (2000) and Wright et al. (2001) showed that it is possible to measure such subtle deformations by stacking different independent interferograms, hereby reducing the atmospheric noise component.

For volcano deformation InSAR may be the cheapest and sometimes the only available source of information. Studies of eruptions on the Galapagos Islands Amelung et al. (2000) showed that it is possible to derive several potential source parameters of a certain deformation phenomenon. The real challenge for volcano monitoring lies in revisit times of only a few days, using different look directions. Such goals can only be achieved by a dedicated satellite.

Subsidence and uplift phenomena require a temporally long-coherent region or sufficient permanent scatterers within and outside the subsidence region. Several studies have been performed, see Amelung et al. (1999), Crosetto et al (2002), Ferretti et al (2000, 2000a), Hoffmann et al (2001)

Permanent scatterers

Undoubtedly, the development of the permanent scatterer technique by the radar group of the Politecnico di Milano is one of the most spectacular developments by members of the SSG (Ferretti et al, 2000, 2000a). Although the principle of time series analysis of many radar images was already introduced earlier, it is the systematic processing of the data in the Permanent Scatterers technique that makes it so versatile. Some of the key principles of the technique are

- The selection procedure of the potential points (reflections). Temporal decorrelation renders conventional (contiguous) interferometry impossible over regions with changing scattering characteristics, such as fields, urban development, vegetation, etc. This leads to the well known noisy appearance of interferograms over such regions. Estimation of the phase noise per point was possible by the parameter of coherence. Coherence estimation in a complex interferogram was only possible assuming ergodicity in the signal. This enables the estimation using a spatial estimation window possible. The main limitation is that single, isolated point scatterers, located amidst a decorrelated region, will not be detected. The concept of the permanent scatterer method is that instead of spatial correlation, temporal correlation is used as a selection criterium. Instead of analysing this for all of the millions of pixels in an image, a first subset is used, characterized by constant high reflection amplitudes which have limited dispersion.

- Focussing the first order analysis on only a limited number of selected points, the parameters to be estimated are orbital trends, the height of the reflection, its possible (linear) behavior in time, the atmospheric signal per acquisition, and the integer phase ambiguities per point in time. Topography scales linearly with the perpendicular baseline independent of time, while deformation is considered linear in time (1^{st} order) and independent of baseline. This enables the estimation of both parameters. Phase ambiguities are estimated on-the-fly, by searching the solution space. The residual signal consists of the orbital trends and atmospheric signal, the so called atmospheric phase screen.
- Interpolation of the estimated atmospheric phase screen per interferogram, and averaging over the whole stack leads to the estimation of the atmospheric phase screen of the master image only. Subsequently, this is subtracted from all interferograms, yielding the atmospheric phase screen of the slave images.
- After the elimination of the atmospheric phase screen from every SAR image, it is possible to verify every pixel in the stack (or a subset with specific conditions if desired) and estimate height and deformation. Remaining residues can be analysed for potential non-linear deformation signal.

The permanent scatterers technique has been demonstrated on many case studies, concerning land subsidence, deformation due to infrastructural works, tectonics, volcanoes, effects of ground water pumping, etc. Results show that, depending on the number of images available, height estimates with accuracies of a few meters can be reached, while the velocity for a linear deformation can be estimated with accuracies less than 1 mm per year. For subsidence bowls with sufficient spatial correlation, official standard deviation can reach a level of a few micrometers per year, if averaging over hundreds of permanent scatterers is possible.

Bio- and geophysical parameter retrieval.

One man’s noise is the other man’s signal is a credo that became applicable during the working period of this study group. Atmospheric phase delay, wave penetration into snow and ice, and vegetation are considered to be nuisance signals in the estimation of topographic height and deformations. However, it is evident that in many, if not most, of the archived radar acquisitions are over regions where topography is sufficiently well known (especially with the SRTM data available) and deformation is minimal or absent. The residues in the interferometric data, either phase or coherence, reflect mainly other types of signal. For example, residual phase signal over snow regions can used to compute snow water equivalent, a parameter to describe the amount of fresh snow between the two acquisitions. For vegetation purposes, biomass estimates and tree heights can be derived using polarimetric radar interferometry. Using multi-baseline and multi-incidence angle interferometry, even tomographic methods were demonstrated. Tropospheric water vapor distribution could be accurately monitored by combining interferograms over the Netherlands with a short time interval.

Conclusions and outlook

Part of the traditinal craftmanship of geodesists is the notion of systematic model formulation and quality analysis (precision, reliability). Potential errors are traditionally (i) avoided by using high-quality equipment, (ii) made detectable by designing measuring networks with sufficient redundancy. In this optimised design of networks the skills of trained geodesists was evident. With the advent of GNSS systems, their relatively cheap equipment, and the sheer amount of data that is gathered every second, surveying, navigation and the related fields of science became accessible to non-expert users. Current developments in radar interferometry suggest a development in the same direction. Radar data are routinely acquired over large areas of the world, and the amount of data is not likely to decrease. Some parts of the world are currently measured with a revisit interval of a few days. This data stream is largely archived and available to scientific, institutional, and commercial users. As processing software will become easily accessible, deriving high accuracy measurements over a period of tens of years, with a monthly sampling, and a spatial resolution of several meters will be possible for non-expert users as well. The geodetic discipline will need to adapt quickly to these developments.

Dedicated satellites for radar interferometric deformation measurements have been proposed several times during the last years. However, often these proposals have been rejected based on the financial constraints. It is evident that an active instrument with large energy requirements, such as radars, will be more expensive than passive sensors that are in the same competition for funding. Mission proposal invitations will need to be more flexible in order to get future missions up in space. Nevertheless, it has become evident that spaceborne radars are unsurpassed in their capacities for e.g. hazard monitoring related to deformation analysis. European initiatives such as Terrasar-L, dedicated to radar and interferometry are therefore still worthwile to pursue. Especially L-band missions with Scansar possibilities and short repeat periods could provide new insights.

In any case, the direct future shows the launches of the Japanese ALOS satellite and the Canadian Radarsat-2, in L-band and C-band respectively.

Although techniques such as permanent scatterers interferometry have resolved some of the main problems such as temporal decorrelation and atmospheric noise, they can only be applied with a large archive of data available. This means that new missions would need to be in orbit for several years before such a technique could be applied. Furthermore, there are areas such as vegetated slopes of mountains over which it is not possible to identify permanent scatterers. Therefore, research on optimizing the conventional interferometric approach is still necessary, regarding phase unwrapping, atmospheric error reduction, etc.

References 1999-2003

R. Abdelfatta, J.M. Nicolas. Topographic SAR interferometry formulation for high-precision DEM generation. IEEE Transactions on Geoscience and Remote Sensing, 40(11):2415-2426, 2002.

N. Adam,B.M. Kampes. Permanent scatterer: Software documentation. Internal technical notes, 2002.

N. Adam, M. Eineder, H. Breit, S. Suchandt. Quality of the D-PAF ERS orbits before and after the inclusion of PRARE data. In Second International Workshop on ERS SAR Interferometry, `FRINGE99', Liège, Belgium, 10-12 Nov 1999. ESA, 1998.

N. Adam, M. Eineder, H. Breit, and S. Suchandt. Shuttle radar topography mission: DLR's interferometric SAR processor for the generation of a global digital elevation model. In Second International Workshop on ERS SAR Interferometry, `FRINGE99', Liège, Belgium, 10-12 Nov 1999. ESA, 1999.

N. Adam, M. Eineder, and H. Breit. SRTM X-SAR motion compensation: Concept and first assessment of the interferometric observation geometry. In International Geoscience and Remote Sensing Symposium, Sydney, Australia, 9-13 July 2001, pages cdrom, 3 pages, 2001.

D Alsdorf, C Birkett, T Dunne, J Melack, and L Hess. Water level changes in a large Amazon lake measured with spaceborne radar interferometry and altimetry. Geophys. Res. Lett., 28:2671-2674, 2001.

F Amelung and S. Day. InSAR observations of the 1995 Fogo, Cape Verde, eruption: Implications for the effects of the collapse events upon island volcanoes. Geophys. Res. Lett., 29(12):47-1/4, 2002.

F. Amelung, D.L. Galloway, J.W. Bell, H.A. Zebker, and R.J. Laczniak. Sensing the ups and downs of Las Vegas: InSAR reveals structural control of land subsidence and aquifer-system deformation. Geology, 27(6):483-486, June 1999.

F. Amelung, S. Jonsson, H. Zebker, and P. Segall. Prospects of volcano geodesy with ERS radar interferometry. In Second International Workshop on ERS SAR Interferometry, `FRINGE99', Liège, Belgium, 10-12 Nov 1999, p 1-9. ESA, 1999.

F Amelung, C Oppenheimer, P Segall, and H Zebker. Ground deformation near Gada 'Ale volcano, Afar, observed by radar interferometry. Geophys. Res. Lett., 27(19):3093-3097, 2000.

F. Amelung, S. Jónssen, H. Zebker, and P. Segall. Widespread uplift and trap door faulting on Galápagos volcanoes observed with radar interferometry. Nature, 407(6807):993-996, October-26 2000.

A. Arnaud, N. Adam, R. Hanssen, J. Inglada, J. Duro, J. Closa, and M. Eineder. ASAR ERS interferometric phase continuity. In International Geoscience and Remote Sensing Symposium, Toulouse, France, 21-25 July 2003, pages cdrom, 3 p, 2003.

A Ashok and A J Wilkinson. Topographic mapping with multiple antenna SAR interferometry: A Bayesian model-based approach. In International Geoscience and Remote Sensing Symposium, Sydney, Australia, 9-13 July 2001, pages cdrom, 3 pages, 2001.

A Avallone, A Zollo, P Briole, C Delacourt, and F Beauducel. Subsidence of Campi Flegrei (Italy) detected by SAR interferometry. Geophys. Res. Lett., 26(15):2303-2306, aug 1999.

G. Baer, D. Sandwell, S. Williams, Y. Bock, and G. Shamir. Coseismic deformation associated with the November 1995, Mw=7.1 Nuweiba earthquake, Gulf of Elat (Aqaba), detected by synthetic aperture radar interferometry. J. Geophys. Res., 104(B11):25221-25232, November 1999.

I Baran, M P Stewart, Z Perski, and B M Kampes. A modification to Goldstein's radar interferogram filter. In AGU Fall meeting, Dec 6-10, San Francisco, USA, 2002.

M Barbieri, J Lichtenegger, and G Calabresi. The Izmit earthquake: A quick post-seismic analysis with satellite observations. ESA Bulletin, 100:107-110, December 1999.

S. Bard. Synthetic aperture radar mission study report. Technical Report JPL D-18558, Jet Propulsion Laboratory, Pasadena, California, February 2000.

F B J Barends, F Kenselaar, and F H Schröder, editors. Bodemdaling meten in Nederland. Hoe precies moet het? Hoe moet het precies. Nederlandse Commissie voor Geodesie, Delft, 2002.

F B J Barends. Technisch-wetenschappelijke beschouwing van het rapport `schriftelijk commentaar mijnbouwet' (wetsontwerp 26 219) van m j van dunné, november 1998, met name pagina's 10 t/m 13. Technical report, Technische Universiteit Delft, Delft, March 1999.

A. Barka. The 17 August 1999 Izmit earthquake. Science, 285:1858-1859, Sep-17 1999.

A. Barka. Enhanced: The 17 August 1999 Izmit earthquake. Science Online, 285, September-17 1999.

M Battaglia, C Roberts, and P Segall. Magma intrusion beneath long valley caldera confirmed by temporal changes in gravity. Science, 285(5436):2119-2122, September-24 1999.

F Beauducel and F H Cornet. Collection and three-dimensional modeling of GPS and tilt data at Merapi volcano, java. J. Geophys. Res., 104(B1):725-736, January 1999.

F Beauducel, P Briole, and J-L Froger. Volcano wide fringes in ERS synthetic aperture radar interferograms of Etna. J. Geophys. Res., 105(B7):16391-16402, July 2000.

P. Berardino, G. Fornaro, R. Lanari, and E. Sansosti. A new algorithm for surface deformation monitoring based on small baseline differential SAR interferograms. IEEE Transactions on Geoscience and Remote Sensing, 40(11):2375-2383, 2002.

M Berberian, C Baker, E Fielding, J A Jackson, B Parsons, K Priestley, M Qorashi, M Talebian, R Walker, and T J Wright. The 14 March 1998 Fandoqa earthquake (Mw 6.6) in Kerman province, SE Iran: re-rupture of the 1981 Sirch earthquake fault, triggerring of slip on adjacent thrusts and the active tectonics of the Gowk fault zone. Geophysical Journal International, submitted, 2000.

J.P. Bobak and C.S. Ruf. A new model for the structure function of integrated water vapor in turbulence. Radio Science, 34(6):1461-1473, November 1999.

G. Bosman, R. Hanssen, and M. Tuttle. Advances in deformation measurements from spaceborne radar interferometry. Shell EPNL, 7025:34-36, October 2001.

H Breit, W Knöpfle, N Adam, M Eineder, S Suchandt, and B Rabus. SRTM X-SAR DEM of Europe --- results and algorithmic improvements. In International Geoscience and Remote Sensing Symposium, Toronto, Canada, 24-28 June, 2002.

H. Breit, M. Eineder, Juergen Holzner, Hartmut Runge, and Richard Bamler. Traffic monitoring using SRTM along-track interferometry. In International Geoscience and Remote Sensing Symposium, Toulouse, France, 21-25 July 2003, pages cdrom, 3 pages, 2003.

R Bürgmann, P.A Rosen, and EJ Fielding. Synthetic Aperture Radar interferometry to measure earth's surface topography and its deformation. Annual Review of Earth and Planetary Sciences, 28:169-209, 2000.

R Bürgmann, D Schmidt, R M Nadeau, M d'Alessio, E J Fielding, D Manaker, TV McEvilly, and M H Murray. Earthquake potential along the Northern Hayward Fault, California. Science, 289:1178-1182, 2000.

E Carminati and G Di Donato. Separating natural and anthropogenic vertical movements in fast subsiding areas: the Po plain (N. Italy) case. Geophys. Res. Lett., 26(15):2291-2294, aug 1999.

C Carnec and H Fabriol. Monitoring and modeling land subsidence at the Cerro Prieto geothermal field, Baja California, Mexico, using SAR interferometry. Geophys. Res. Lett., 26(9):1211-1215, May 1999.

WE Carter, MS Carter. The Newcomb-Michelson velocity of light experiments. EOS, Transactions, American Geophysical Union, 83(37):405-410, September 2002.

CW Chen, HA Zebker. Network approaches to two-dimensional phase unwrapping: intractability and two new algorithms. Journal of the Optical Society of America A., 17(3):401-414, March 2000.

CW Chen and A Zebker. Two-dimensional phase unwrapping using statistical models for cost functions in nonlinear optimization. Journal of the Optical Society of America A., 18:338-351, February 2000.

CW Chen and HA Zebker. Phase unwrapping for large sar interferograms: Statistical segmentation amd generalized network models. IEEE Transactions on Geoscience and Remote Sensing, in press, 2002.

CW Chen. Statistical-cost network-flow approaches to two-dimensional phase unwrapping for radar interferometry. PhD thesis, Stanford University, June 2001.

M Ciuc, E Trouvé, P Bolon, and V Buzuloiu. Amplitude-driven coherence filtering in complex interferograms. In International Geoscience and Remote Sensing Symposium, Toronto, Canada, 24-28 June 2002, 2002.

C Colesanti, A Ferretti, F Ferrucci, C Prati, and F Rocca. Monitoring known seismic faults using the Permanent Scatterers (PS) technique. In International Geoscience and Remote Sensing Symposium, Honolulu, Hawaii, 24-28 July 2000, pages 2221-2223, 2000.

C Colesanti, A Ferretti, C Prati, and F Rocca. Full exploitation of the ers archive: Multi data set permanent scatterers analysis. In International Geoscience and Remote Sensing Symposium, Toronto, Canada, 24-28 June 2002, 2002.

C Colesanti, R Locatelli, and F Novali. Ground deformation monitoring exploiting SAR permanent scatterers. In International Geoscience and Remote Sensing Symposium, Toronto, Canada, 24-28 June 2002, 2002.

M Costantini, P Rosen. A generalized phase unwrapping approach for sparse data. In International Geoscience and Remote Sensing Symposium, Hamburg, Germany, 28 June-2 July 1999, pages cdrom, 3 pages, 1999.

M Costantini, F Malvarosa, F Minati, L Pietranera, and G Milillo. A three-dimensional phase unwrapping algorithm for processing of multitemporal SAR interferometric measurements. In International Geoscience and Remote Sensing Symposium, Toronto, Canada, 24-28 June 2002, 2002.

M Crosetto, B Crippa, and R Barzaghi. Quantitative subsidence monitoring using SAR interferometry. In International Geoscience and Remote Sensing Symposium, Toronto, Canada, 24-28 June 2002, 2002.

M Crosetto, CC Tscherning, B Crippa, and M Castillo. Subsidence monitoring using SAR interferometry: Reduction of the atmospheric effects using stochastic filtering. Geophys. Res. Lett., 29(9):xxx, 2002.

GW Davidson, R Bamler. Multiresolution phase unwrapping for SAR interferometry. IEEE Transactions on Geoscience and Remote Sensing, 37(1):163-174, Jan 1999.

J L Davis. Atmospheric water-vapor signals in GPS data: Synergies, correlations, signals and errors. Physics and Chemistry of the Earth, 26(6-8):513-522, 2001.

M Debao, L Ming, D Yi-qun, and L Yi. A piece-wise polynomial fitting method to filter the interferogram phase noise. In International Geoscience and Remote Sensing Symposium, Toronto, Canada, 24-28 June 2002, 2002.

M Debao, L Wugao, and W Fuming. The relative and absolute geometric algorithm for the ERS baseline estimation. In International Geoscience and Remote Sensing Symposium, Toronto, Canada, 24-28 June 2002, 2002.

M Di-Bisceglie, A Fusco, C Galdi, and E Sansosti. Stochastic modelling of atmospheric effects in sar differential interferometry. In International Geoscience and Remote Sensing Symposium, Sydney, Australia, 9-13 July 2001, pages cdrom, 3 p, 2001.

JMB Dias, JMN Leitao. A discrete/continuous minimization method in interferometric image processing. In ?, page 19 pages, 2000.

JM B Dias, JMN Leitao. InSAR phase unwrapping: A Bayesian approach. In International Geoscience and Remote Sensing Symposium, Sydney, Australia, 9-13 July 2001, pages cdrom, 3 pages, 2001.

GS Doyle, RJ Stow, and MR Inggs. Satellite radar interferometry reveals mining induced seismic deformation in South Africa. In International Geoscience and Remote Sensing Symposium, Sydney, Australia, 9-13 July 2001, pages cdrom, 3 p, 2001.

GS Doyle, AJ Wilkinson, and MR Inggs. Major conclusions relating to the Katse Dam differential InSAR study. In International Geoscience and Remote Sensing Symposium, Sydney, Australia, 9-13 July 2001, pages cdrom, 3 pages, 2001.

MV Dragosevic , B Plache. Doppler tracker for a spaceborne ScanSAR system. IEEE Transactions on Aerospace and Electronic Systems, 36(3):907-924, July 2000.

D Dzurisin, C Wicks, and W Thatcher. Renewed uplift at the Yellowstone caldera measured by leveling surveys and satellite radar interferometry. Bulletin of Volcanology, 61:349-355, 1999.

M Eineder, J Holzner. Phase unwrapping of low coherence differential interferograms. In International Geoscience and Remote Sensing Symposium, Hamburg, Germany, 28 June-2 July 1999, pages cdrom, 4 pages, 1999.

M Eineder, B Schättler, M Hubig, W Knöpfle, N Adam, and H Breit. Operational processing large areas of interferometric SAR data. In Second International Workshop on ERS SAR Interferometry, `FRINGE99', Liège, Belgium, 10-12 Nov 1999, pages 1-6. ESA, 1999.

M Eineder, N Adam, H Breit, S Suchandt, J Holzner, B Rabus, and W Knöpfle. Results from the SRTM calibration phase. In ISPRS Workshop, High Resolution Mapping from Space, 19-21 Sept, Hannover, Germany, pages 55-60. ISPRS Workshop, High Resolution Mapping from Space, Hannover, Germany, 19-21 September 2002, September 2001.

M Eineder, B Rabus, J Holzner, S Suchandt, and W Knöpfle. Filtering of interferometric SRTM X-SAR data. In International Geoscience and Remote Sensing Symposium, Toronto, Canada, 24-28 June 2002, 2002.

M Eineder. Interferometric DEMs in rugged terrain. In International Geoscience and Remote Sensing Symp, Sydney, Australia, 9-13 July 2001, cdrom, 3 p, 2001.

T Ragne Emardson and HJP Derks. On the relation between the wet delay and the integrated precipitable water vapour in the European atmosphere. Meteorological Applications, 7(1):61-68, 2000.

TR Emardson and POJ Jarlemark. Atmospheric modelling in GPS analysis and its effect on the estimated geodetic parameters. J. Geod., 73:322-331, 1999.

TR Emardson, G Elgered, and JM Johansson. External atmospheric corrections in geodetic very-long-baseline interferometry. J. Geod., 73:375-383, 1999.

KL Feigl and E Dupre. Rngchn: a program to calculate displacement components from dislocations in an elastic half-space with applications for modeling geodetic measurements of crustal deformation. Computers and Geosciences, 25(6):695-704, 1999.

AJ Feijt. Quantitative Cloud Analysis using Meteorological Satellites. PhD thesis, Wageningen University, 2000.

A Ferretti, C Prati, and F Rocca. Non-uniform motion monitoring using the permanent scatterers technique. In Second International Workshop on ERS SAR Interferometry, `FRINGE99', Liège, Belgium, 10-12 Nov 1999, p 1-6. ESA, 1999.

A Ferretti, C Prati, and F Rocca. Permanent scatterers in SAR interferometry. In International Geoscience and Remote Sensing Symposium, Hamburg, Germany, 28 June-2 July 1999, pages 1-3, 1999.

A Ferretti, C Prati, and F Rocca. Multibaseline InSAR DEM reconstruction: The wavelet approach. IEEE Transactions on Geoscience and Remote Sensing, 37(2):705-715, March 1999.

A Ferretti, F Ferrucci, C Prati, and F Rocca. SAR analysis of building collapse by means of the permanent scatterers technique. In ?, pages 1-3, 2000.

A Ferretti, C Prati, and F Rocca. Analysis of permanent scatterers in SAR interferometry. In ?, pages 1-3, 2000.

A Ferretti, C Prati, and F Rocca. Measuring subsidence with SAR interferometry: Applications of the permanent scatterers technique. In L Carbognin, G Gambolati, and A I Johnson, editors, Land subsidence; Proceedings of the Sixth International Symposium on Land Subsidence, volume 2, pages 67-79. CNR, 2000.

A Ferretti, C Prati, and F Rocca. Monitoring of terrain motion using the ps technique. In European Conference on Synthetic Aperture Radar, München, Germany, 22-25 May 2000, pages 115-118, 2000.

A Ferretti, C Prati, and F Rocca. Nonlinear subsidence rate estimation using permanent scatterers in differential SAR interferometry. IEEE Transactions on Geoscience and Remote Sensing, 38(5):2202-2212, September 2000.

A Ferretti, C Prati, and F Rocca. Permanent scatterers in SAR interferometry. IEEE Transactions on Geoscience and Remote Sensing, 39(1):8-20, January 2001.

Y Fialko and M Simons. Deformation and seismicity in the Coso geothermal area, Inyo county, California: Observations and modeling using satellite radar interferometry. J. Geophys. Res., 105(B9):21781-21794, 2000.

Y Fialko, M Simons, and D Agnew. The complete (3-D) surface displacement field in the epicentral area of the 1999 m_w 7.1 Hector Mine earthquake, California, from space geodetic observations. Geophys. Res. Lett., 28(16):3063, 2001.

E Fielding, T Wright, B Parsons, P England, P Rosen, S Hensley, and R Bilham. Topography of northwest Turkey from SAR interferometry: Applications to the 1999 Izmit earthquake geomorphology and co-seismic strain. EOS Transactions, AGU, 80(46):F663, 1999.

G Franceschetti, G Fornaro. Synthetic aperture radar interferometry. In Franceschetti and Lanari [Franceschetti and Lanari, 1999], chapter 4, pages 167-223.

G Franceschetti , R Lanari, ed. Synthetic Aperture Radar processing. CRC Press, 1999.

G Franceschetti, A Iodice, and D Riccio. An electromagnetic model for scattering from buildings. In International Geoscience and Remote Sensing Symposium, Sydney, Australia, 9-13 July 2001, pages cdrom, 3 pages, 2001.

J-L Froger, O Merle, and P Briole. Active spreading and regional extension at Mount Etna imaged by SAR interferometry. Earth and Planetary Science Letters, 187:245-258, May 2001.

B Fruneau and F Sarti. Detection of ground subsidence in the city of paris using radar interferometry: isolation of deformation from atmospheric artifacts using correlation. Geophys. Res. Lett., 27(24):3981-3984, 2000.

B Fruneau, J-P Rudant, D Obert, and D Raymond. Small displacements detected by SAR interferometry on the city of Paris (france). In International Geoscience and Remote Sensing Symposium, Hamburg, Germany, 28 June-2 July 1999, pages cdrom, 3 pages, 1999.

B Fruneau, E Pathier, D Raymond, B Deffontaines, C T Lee, H T Wang, J Angelier, JP Rudant, and C P Chang. Uplift of Tainan Tableland (SW Taiwan) revealed by SAR interferometry. Geophys. Res. Lett., 28(16):3071-3074, 2001.

S Fujiwara, T Nishimura, M Murakami, H Nakagawa, M Tobita, and PA Rosen. 2.5-D surface deformation of M6.1 earthquake near Mt Iwate detected by SAR interferometry. Geophys. Res. Lett., 27(14):2049-2052, 2000.

M Ge, E Calais, and J Haase. Reducing satellite orbit error effects in near real-time GPS zenith tropospheric delay estimation for meteorology. Geophys. Res. Lett., 27(13):1915, 2000.

L Ge, T Tsujii, and C Rizos. Troposheric heterogeneities corrections in differential radar interferometry. In International Geoscience and Remote Sensing Symposium, Toronto, Canada, 24-28 June 2002, 2002.

R Gens, M Jirousek, R Guritz, and J Conner. The alaska dem project: Repeat-geometry approach for generating accurate InSAR DEMs. In International Geoscience and Remote Sensing Symposium, Toronto, Canada, 24-28 June 2002, 2002.

R Gens. On phase unwrapping based on minimum cost flow. In Second International Workshop on ERS SAR Interferometry, `FRINGE99', Liège, Belgium, 10-12 Nov 1999, pages 1-6. ESA, 1999.

R Gens. Quality assessment of interferometrically derived digital elevation models. International Journal of Applied Earth Observation and Geoinformation, 1(2):102-108, 1999.

R Gens. SAR interferometry: Software, data format, and data quality. Photogrammetric Engineering and Remote Sensing, 65(12):1375-1378, December 1999.

R Gens. Two-dimensional phase unwrapping for radar interferometry: developments and new challenges. submitted to Journal of the Optical Society of America A, 2000.

DC Ghiglia and LA Romero. Minimum lp-norm two-dimensional phase unwrapping. Journal of the Optical Society of America A., 13:1999-2013, 1996.

LP Gradinarsky and G Elgered. Horizontal gradients in the wet path delay derived from four years of microwave radiometer data. Geophys. Res. Lett., 27(16):2521-2524, August-15 2000.

L Gray, K Mattar, and N Short. Speckle tracking for 2-dimensional ice motion studies in polar regions: Influence of the ionosphere. In Second International Workshop on ERS SAR Interferometry, `FRINGE99', Liège, Belgium, 10-12 Nov 1999, pages 1-8. ESA, 1999.

AL Gray, K E Mattar, G Sofko. Influence of ionospheric electron density fluctuations on satellite radar interferometry. Geophys. Res. Lett., 27(10):1451-1454, May 2000.

J S Groot, D van Halsema, P J L Blommaart, G J Husti, G A M Kruse, D van Loon, J Samson, E J O Schrama, A J Striegel, and J M P C M Visser. Repeat pass interferometry with PHARUS, volume NRSP-2, 00-23. Beleidscommissie Remote Sensing, Delft, December 2000.

J S Groot, D van Halsema, R A van Maarseveen, P J L Blommaart, G A M Kruse, D van Loon, R F Hanssen, J Samson, A J Striegel, and J M P C M Visser. 2-D deformation measurements with ASAR and PHARUS, volume USP-2, 01-21. Beleidscommissie Remote Sensing, Delft, June 2001.

A Monti Guarnieri, P Guccione. Optimal focusing for low resolution ScanSAR. IEEE Transactions on Geoscience and Remote Sensing, 39(3):479-491, March 2001.

A Monti Guarnieri, F Rocca. Combination of low- and high-resolution SAR images for differential interferometry. IEEE Transactions on Geoscience and Remote Sensing, 37(4):2035-2049, July 1999.

A Monti Guarnieri, P Biancardi, D D'Aria, and F Rocca. Accurate and robust baseline estimation. In Second International Workshop on ERS SAR Interferometry, `FRINGE99', Liège, Belgium, 10-12 Nov 1999. ESA, 1999.

A Monti Guarnieri, F Rocca, P Guccione, and Ciro Cafforio. Optimal interferometric scansar focusing. In International Geoscience and Remote Sensing Symposium, Hamburg, Germany, 28 June-2 July 1999, 1999.
R Hanssen, R Bamler. Evaluation of interpolation kernels for SAR interferometry. IEEE Transactions on Geoscience and Remote Sensing, 37(1):318-321, January 1999.

R Hanssen, A Ferretti. Deformation monitoring by satellite radar interferometry: Design parameters and environmental factors affecting feasibility. GIM International, 16(9):52-57, September 2002.

RF Hanssen and A Ferretti. Parameter estimation in PS-InSAR deformation studies using integer least-squares techniques. EOS Trans. AGU, Fall Meet. Suppl., Abstract G62A-06, 83(47):F37, 2002.

R Hanssen and B Kampes. On the treatment of radar interferometry in terms of geodetic adjustment and testing theory. In International Geoscience and Remote Sensing Symposium, Honolulu, Hawaii, 24-28 July 2000, 2000.

R Hanssen, R Klees. Accuracy assessment of repeat-pass radar interferometry for topographic mapping and deformation analysis. VMSG Symposium, Utrecht, the Netherlands, November-19 1999.

R Hanssen, R Klees. Development of a stochastic model for repeat-pass SAR interferometry. In Second International Workshop on ERS SAR Interferometry, `FRINGE99', Liège, Belgium, 10-12 Nov 1999, pages 1-5. ESA, 1999.

R Hanssenm, R Klees. An empirical model for the assessment of DEM accuracy degradation due to vertical atmospheric stratification. In Second International Workshop on ERS SAR Interferometry, `FRINGE99', Liège, Belgium, 10-12 Nov 1999, pages 1-5. ESA, 1999.

R Hanssen and F van Leijen. Modeling and spatial interpolation of tropospheric signal delay for space-geodetic observations based on GPS time series analysis. In EGS XXV General Assembly, Nice, France, 21-26 April 2002, Geophys. Res Abstracts, 2, 2002.

RF Hanssen, TM Weckwerth. Evaluation of spatial moisture distribution during CLARA 96 using spaceborne radar interferometry. In Remote Sensing of cloud parameters: retrieval and validation. 21-22 Oct 1999, Delft, The Netherlands, pages 15-20, 1999.

R Hanssen, A Feijt, and R Klees. Evaluation of water vapor observations using SAR, GPS, and Meteosat. In IUGG XX General Assembly, page B.63, 1999.

R Hanssen, B Vermeersen, R Scharroo, B Kampes, S Usai, R Gens, and R Klees. Deformation pattern of the Ms 7.5, 17 August 1999, Kocaeli earthquake observed by satellite radar interferometry. VMSG Symposium, Utrecht, the Netherlands, November-19 1999.

R Hanssen, B Vermeersen, R Scharroo, B Kampes, S Usai, R Gens, and R Klees. Deformation pattern of the 17 August 1999, Turkey earthquake observed by satellite radar interferometry. Web publication, December 1999.

RF Hanssen, TM Weckwerth, HA Zebker, and R Klees. High-resolution water vapor mapping from interferometric radar measurements. Science, 283:1295-1297, February-26 1999.

R Hanssen, R Riva, B Vermeersen, K Aoudia, and R Sabadini. Coseismic deformation of the 17.8.1999, izmit, turkey earthquake from spherical and half-space modeling and satellite radar interferometry (sar) imaging. In AGU Fall meeting, San Francisco, USA, 2000.

R Hanssen, B Vermeersen, R Scharroo, B Kampes, S Usai, R Gens, and R Klees. Deformatiepatroon van de aardbeving van 17 augustus 1999 in Turkije gemeten met satelliet radar interferometrie. Remote Sensing Nieuwsbrief, 90:42-44, February 2000. In Dutch.

R Hanssen, I Weinreich, S Lehner, and A Stoffelen. Tropospheric wind and humidity derived from spaceborne radar intensity and phase observations. Geophys. Res. Lett., 27(12):1699-1702, June-15 2000.

RF Hanssen, P J G Teunissen, and P Joosten. Phase ambiguity resolution for stacked radar interferometric data. In Int Symposium on Kinematic Systems in Geodesy, Geomatics and Navigation, Banff, Canada, 5-8 June 2001, pages 317-320, 2001.

RF Hanssen, AJ Feijt, and R Klees. Comparison of precipitable water vapor observations by spaceborne radar interferometry and Meteosat 6.7- mum radiometry. Journal of Atmospheric and Oceanic Technology, 18(5):756-764, May 2001.

R Hanssen, D Moisseev, and S Businger. Resolving the acquisition ambiguity for atmospheric monitoring in multi-pass radar interferometry. In International Geoscience and Remote Sensing Symposium, Toulouse, France, 21-25 July 2003, pages cdrom, 4 pages, 2003.

RF Hanssen. An improved stochastic model for multi-pass radar interferometry. In 2nd International Symposium on Operationalization of Remote Sensing, Enschede, The Netherlands,, page 9 pages, August-16 1999.

RF Hanssen. Radar Interferometry: Data Interpretation and Error Analysis. Kluwer Academic Publishers, Dordrecht, 2001.

R Hanssen. Geodetische toevalsnetwerken: ontwikkelingen in deformatiemetingen met satelliet-radarinterferometrie en de permanent-scatters-methode. Jaarverslag 2001 Nederlandse Commissie voor Geodesie, pages 45-55, September 2002.

R Hanssen. SAR interferometry for bio- and geo-physical retrievals. literature review - atmosphere. Technical report, Delft University of Technology, Delft, the Netherlands, 2002. Report for the European Space Agency.

O Hellwich. SAR interferometry: Principles, processing, and perspectives. In C Heipke and H Mayer, editors, Festschrift für Prof. Dr.-Ing. Heinrich Ebner zum 60. Geburtstag, pages 109-120. Technische Universität München, 1999.

O Henriot, T Villemin, and F Jouanne. Long period interferograms reveal 1992-1998 steady rate of deformation at Krafla volcano (North Iceland).:1-4, 2001.

A Herique, L Phalippou, S Ramongassie, and C C Lin. High resolution SAR constellation for risk management. In CEOS SAR Workshop, ESA-CNES, Toulouse, France, 26-29 October 1999, pages dig.1-6, 1999.

E Weber Hoen and Howard A Zebker. Penetration depths inferred from interferometric volume decorrelation observed over the Greenland ice sheet. IEEE Transactions on Geoscience and Remote Sensing, 38(6):2571-2583, November 2000.

E Weber Hoen. A correlation-based approach to modeling interferometric radar observations of the Greenland ice sheet. PhD thesis, Stanford University, 2001.

J Hoffmann, HA Zebker, DL Galloway, and F Amelung. Seasonal subsidence and rebound in Las Vegas Valley, Nevada, observed by synthetic aperture radar interferometry. Water Resources Research, 37(6):1551-1566, June 2001.

J Holzner, S Suchandt, M Eineder, H Breit, and N Adam. Co-registration - geometrical analysis and verification for SAR interferometry under SRTM data conditions. In International Geoscience and Remote Sensing Symposium, Sydney, Australia, 9-13 July 2001, pages cdrom, 3 pages, 2001.

A Hommels, K H Scholte, J Munoz-Sabater, R F Hanssen, F D van der Meer, S B Kroonenberg, E Aliyeva, D Huseynov, and I Guliev. Preliminary ASTER and INSAR imagery combination for mud volcano dynamics, Azerbaijan. In International Geoscience and Remote Sensing Symposium, Toulouse, France, 21-25 July 2003, pages cdrom, 4 pages, 2003.

Y Huangyin, G Huadong, H Chunming, L Xinwu, and W Changlin. A SAR interferogram filter based on the empirical mode decomposition method. In International Geoscience and Remote Sensing Symposium, Sydney, Australia, 9-13 July 2001, pages cdrom, 3 pages, 2001.

M Hubig, N Adam, and S Suchandt. MCF-homomorphisms of cost functions for minimal cost flow InSAR phase unwrapping. In International Geoscience and Remote Sensing Symposium, Sydney, Australia, 9-13 July 2001, pages cdrom, 3 p, 2001.

S Jónsson, H Zebker, P Cervelli, P Segall, H Garbeil, P Mouginis-Mark, and S Rowland. A shallow-dipping dike fed the 1995 flank eruption at Fernandina volcano, Galápagos, observed by satellite radar interferometry. Geophys. Res. Lett., 26(8):1077-1080, April 1999.

S Jónsson, H Zebker, P Segall, and F Amelung. Fault slip distribution of the 1999 Hector Mine, California, earthquake, estimated from satellite radar and GPS measurements. Bull of the Seism Society of America, 92(4):1377-1389, 2002.

I Joughin, L Gray, R Bindschadler, S Price, D Morse, C Hulbe, K Mattar, and C Werner. Tributaries of West Antarctic ice streams revealed by RADARSAT interferometry. Science, 286(5438):283-286, October 1999.

BM Kampes and N Adam. Velocity field retrieval from long term coherent points in radar interferometric stacks. In International Geoscience and Remote Sensing Symposium, Toulouse, France, 21-25 July 2003, pages cdrom, 4 pages, 2003.

B Kampes, R Hanssen. Delft public domain radar interferometric software: processing considerations and future strategies. EOS Transactions, AGU, 81(19):S162, May-9 2000.

B Kampes, R Hanssen, and R Swart. Deformation monitoring with radar interferometry, analysis of permanent scatterers in Tianjin, China. VMSG Symposium, Utrecht, the Netherlands, November-19 2001.

BM. Kampes, RF. Hanssen, and KM.Th. Swart. Strategies for non-linear deformation estimation from interferometric stacks. In International Geoscience and Remote Sensing Symposium, Sydney, Australia, 9-13 July 2001, pages cdrom, 4 p, 2001.

B Kampes. Delft Object-Oriented Radar Interferometric Software: Users manual and Technical Documentation. Delft University of Technology, Delft, 1.2 ed, 1999.

B Kampes. Deformation at point scatterers in radar interferometry. VMSG annual report, Utrecht, the Netherlands, May-19 2003.

H Kimura and Hiroaki Kinoshita. Effect of tropospheric range delay corrections on differential SAR interferograms. In International Geoscience and Remote Sensing Symposium, Sydney, Australia, 9-13 July 2001, pages 1-3, 2001.

M Kircher, A Roth, N Adam, BM Kampes, and HJ Neugebauer. Remote sensing observation of mining induced subsidence by means of differential SAR-interferometry. In International Geoscience and Remote Sensing Symposium, Toulouse, France, 21-25 July 2003, pages cdrom, 3 pages, 2003.

R Klees, R Hanssen. Basics of synthetic aperture radar interferometry and applications. In Nordic Geodetic Commission (NKG) Autumn School ``Nordic Geodesy towards the 21st century'', 28 August - 2 September 2000, Fevik, Norway, pages 169-211, August 2000.

R Klees, D Massonnet. Deformation measurements using SAR interferometry: potential and limitations. Geologie en Mijnbouw, 77:161-176, 1999.

R Klees, R F Hanssen, and F Amelung. Geothermal field deformation monitoring using radar interferometry. In General Assembly European Geophysical Society, The Hague, The Netherlands, 19-23 April 1999, 1999.
R Klees. SAR interferometry technology. Final report, IAG Special Study Group 2.160, July 1999.

Y Klinger, R Michel, and J-P Avouac. Co-seismic deformation during the Mw 7.3 Aqaba earthquake (1995) from ERS-SAR interferometry. Geophys. Res. Lett., 27(22):3651-3655, 2000.

W K Lee. Analytical investigation of urban SAR features having a group of corner reflectors. In International Geoscience and Remote Sensing Symposium, Sydney, Australia, 9-13 July 2001, pages cdrom, 3 pages, 2001.

Z Lu, WR Danskin. InSAR analysis of natural recharge to define structure of a ground-water basin, San Bernardino, Calif. Geophys. Res. Lett., 28(13):2661-2664, 2001.

Z Lu and JT Freymueller. Synthetic aperture radar interferometry coherence analysis over Katmai volcano group, Alaska. J. Geophys. Res., 103(B12):29887-29894, December 1999.

Z Lu, D Mann, JT Freymueller, and DJ Meyer. Synthetic aperture radar interferometry of Okmok volcano, Alaska: Radar observations. J. Geophys. Res., 105(B5):10791-10806, May 2000.

P Lundgren, S Usai, E Sansosti, R Lanari, M Tesauro, G Fornaro, and P Berardino. Modeling surface deformation observed with SAR interferometry at Campi Flegrei caldera. J. Geophys. Res., 106:19355-19367, 2001.

S Lyons and D Sandwell. Fault creep along the southern San Andreas from InSAR, permanent scatterers, and stacking. J. Geophys. Res., submitted(?):?, 2002.

SN Madsen, W Edelstein, LD DiDominico, and J LaBrecque. A geosynchronous synthetic aperture radar; for tectnoci mapping, disaster management and measurements of vegetation and soil moisture. In International Geoscience and Remote Sensing Symp, Sydney, Australia, 9-13 July 2001, cdrom, 3 p, 2001.

J J Mallorqui, I Rosado, and M Bara. Interferometric calibration for DEM enhancing and system characterization in single pass SAR interferometry. In International Geoscience and Remote Sensing Symposium, Sydney, Australia, 9-13 July 2001, pages cdrom, 3 pages, 2001.

F Martinerie, S Ramongassie, B Deligny, E Thouvenot, and D Massonnet. Interferometric cartwheel payload: Development status and current issues. In International Geoscience and Remote Sensing Symposium, Sydney, Australia, 9-13 July 2001, pages cdrom, 3 pages, 2001.

D Massonnet and F Sigmundsson. Remote sensing of volcano deformation by radar interferometry from various satellites. In Mouginis-Mark et al. [Mouginis-Mark et al., 2000], pages 207-221.

D Massonnet, E Thouvenot, S Ramongassie, and L Phalippou. A wheel of passive radar microsats for upgrading existing SAR projects. In International Geoscience and Remote Sensing Symposium, Honolulu, Hawaii, 24-28 July 2000, 2000.

D Massonnet. Capabilities and limitations of the interferometric cartwheel. In CEOS SAR Workshop, ESA-CNES, Toulouse, France, 26-29 October 1999, p 13, 1999.

D Massonnet. The interferometric cartwheel, a constellation of low cost receiving satellites to produce radar images that can be coherently combined. International Journal of Remote Sensing, 22(12):2413-2430, 2001.

K E Mattar, A L Gray, D Geudtner, and P W Vachon. Interferometry for DEM and terrain displacement: Effects of inhomogeneous propagation. Canadian Journal of Remote Sensing, 25(1):60-69, March 1999.

R Michel, Jean-Philippe Avouac, and Jean Taboury. Measuring ground displacement from SAR amplitude images: application to the Landers earthquake. Geophys. Res. Lett., 26(7):875-878, April 1999.

M Migliaccio and F Bruno. Coherence loss minimization in SAR interferometric registration. In International Geoscience and Remote Sensing Symposium, Toronto, Canada, 24-28 June 2002, 2002.

JJ Mohr and SN Madsen. Geometric calibration of ERS satellite SAR images. IEEE Transactions on Geoscience and Remote Sensing, 39(4):842-850, 2001.

D Moisseev and Ramon Hanssen. Influence of hydrometeors on InSAR observations. In International Geoscience and Remote Sensing Symposium, Toulouse, France, 21-25 July 2003, pages cdrom, 4 pages, 2003.

D N Moisseev, R F Hanssen, and F J van Leijen. Water vapor observations with SAR, microwave radiometer and GPS: comparison of scaling characteristics. In Second European Conference on Radar Meteorology (ERAD), Delft, pp 190-194, 2002.

D Moisseev, R Hanssen, and J Munoz Sabater. Towards and atmosphere-free interferogram; first comparison between ENVISAT's ASAR and MERIS water vapor observations. In International Geoscience and Remote Sensing Symposium, Toulouse, France, 21-25 July 2003, pages cdrom, 4 pages, 2003.

A Monti Guarnieri and C Prati. An interferometric quick-look processor. IEEE Transactions on Geoscience and Remote Sensing, 37(2):861-866, 1999.

O Mora, J J Mallorqui, J Duro, and A Broquetas. Long-term subsidence monitoring of urban areas using differential interferometric SAR techniques. In International Geoscience and Remote Sensing Symposium, Sydney, Australia, 9-13 July 2001, pages cdrom, 3 pages, 2001.

O Mora, R Lanari, J J Mallorqui, P Bernadino, and E Sansosti. A new algorithm for monitoring localized deformation phenomena based on small baseline differential SAR interferograms. In International Geoscience and Remote Sensing Symposium, Toronto, Canada, 24-28 June 2002, 2002.

O Mora, J J Mallorqui, and J Duro. Generation of deformation maps at low resolution using differential interferometric SAR data. In International Geoscience and Remote Sensing Symposium, Toronto, Canada, 24-28 June 2002, 2002.

A Moreira and R Schreiber. Coregistration of interferometric SAR images using spectral diversity. IEEE Transactions on Geoscience and Remote Sensing, 38(5):2179-2191, 2000.

PJ Mouginis-Mark, JA Crisp, and JH Fink, ed. Remote sensing of active volcanism. Geophysical Monographs 116. Amer Geophysical Union, Washington, DC, 2000.

J Mu noz Sabater, R Hanssen, BM Kampes, A Fusco, and N Adam. Physical analysis of atmospheric delay signal observed in stacked radar interferometric data. In International Geoscience and Remote Sensing Symposium, Toulouse, France, 21-25 July 2003, pages cdrom, 4 pages, 2003.

R Nutricato, F Bovenga, and A Refice. Optimum interpolation and resampling for PSC identification. In International Geoscience and Remote Sensing Symposium, Toronto, Canada, 24-28 June 2002, 2002.

R Pedersen, F Sigmundsson, KL Feigl, and T Árnadóttir. Coseismic interferograms of two Ms= 6.6 earthquakes in the South Iceland Seismic Zone, June 2000. Geophys. Res. Lett., 28(17):3341, 2001.

G Peltzer, F Crampé, and G King. Evidence of the nonlinear elasticity of the crust from Mw7.6 Manyi (Tibet) earthquake. Science, 286(5438):272-276, October 1999.

F Posa, editor. SAR Image Analysis, Modelling, and Techniques IV, volume 4543. SPIE, Bellingham, 2001.

EJ Price. Coseismic and Postseismic Deformations Associated With the 1992 Landers, California Earthquake Measured by Synthetic Aperture Radar Interferometry. PhD thesis, University of California, San Diego, 1999.

ME Pritchard and M Simons. A satellite geodetic survey of large-scale deformation of volcanic centres in the central Andes. Nature, 418:167-171, July 2002.

C S Purry, K Dumper, G C Verwey, and S R Pennock. Resolving Doppler ambiguity for ScanSAR data. In International Geoscience and Remote Sensing Symposium, Honolulu, Hawaii, 24-28 July 2000, pages 2272-2274, 2000.

Radarsat. Radarsat specifications. (Accessed 2 Nov, 1999), , 1999.

K S Rao and S M Phalke. Analysis of dem derived from SRTM for the assessment of geo-coding and height accuracy. In International Geoscience and Remote Sensing Symposium, Sydney, Australia, 9-13 July 2001, pages cdrom, 4 pages, 2001.

M Rast, J L Bézy, and S Bruzzi. The ESA medium resolution imaging spectrometer MERIS--- a review of the instrument and its mission. International Journal of Remote Sensing, 20(9):1681-1702, 1999.

A Refice, F Bovenga, S Stramaglia, and D Conte. Use of scaling information for stochastic atmospheric absolute phase screen retrieval. In International Geoscience and Remote Sensing Symposium, Toronto, Canada, 24-28 June 2002.

R E Reilinger, S Ergintav, R Bürgmann, S McClusky, O Lenk, A Barka, O Gurkan, L Hearn, K L Feigl, R Cakmak, B Aktug, H Ozener, and M N Töksoz. Coseismic and postseismic fault slip for the 17 August 1999, M = 7.5, Izmit, Turkey earthquake. Science, 289(5484):1519-1524, September 2000.

E Rignot, RH Thomas. Mass balance of polar ice sheets. Science, 297:1502-1506, 2002.

EJM Rignot. Effect of Faraday rotation on L-band interferometric and polarimetric synthetic-aperture radar data. IEEE Transactions on Geoscience and Remote Sensing, 38(1):383-390, January 2000.

R Riva, R Hanssen, L L A Vermeersen, K Aoudia, and R Sabadini. Coseismic deformation of the 17 Aug 1999, Izmit, Turkey earthquake from normal mode modeling and satellite radar interferometry (SAR) imaging. In EGS XXV General Assembly, Nice, France, 25-29 April 2000, Geophys. Res Abstracts, 2, 2000.

G Fornaro A Monti Guarnieri F Rocca. Optimal, space-varying spectral filtering of IFSAR data. In International Geoscience and Remote Sensing Symposium, Honolulu, Hawaii, 24-28 July 2000, 2000.

P Rosen, S Hensley, IR Joughin, FK Li, S Madsen, E Rodríguez, R Goldstein. Synthetic aperture radar interferometry. Proc of the IEEE, 88(3):333-382, March 2000.

H Rott, B Schechl, A Siegel, B Grasemann. Monitoring very slow slope movements by means of SAR interferometry: A case study from a mass waste above a reservoir in the ötztal Alps, Austria. Geophys. Res. Lett., 26(11):1629-1632, June 1999.

SK Rowland, ME MacKay, Garbeil. Topographic analyses of K overlineilauea volcano, Hawai'i, from interferometric airborne radar. Bull of Volcanology, 61:1-14, 1999.

H Runge, M Werner, M Eineder, H Breit, and S Suchandt. Advanced synthetic aperture RADAR observations with clusters of SAR satellites. In ISPRS Workshop, High Resolution Mapping from Space, Hannover, Germany, 19-21 September 2002, pages 179-188. ISPRS, September 2001.

DT Sandwell, L Sichoix. Topographic phase recovery from stacked ERS interferometry and a low resolution digital elevation model. J. Geophys. Res., 105(B12):28211-28222, 2000.

David T Sandwell, Lydie Sichoix, Duncan Agnew, Yehuda Bock, and Jean-Bernard Minster. Near real-time radar interferometry of the Mw 7.1 Hector Mine earthquake. Geophys. Res. Lett., 27(19):3101-3104, 2000.

R Santer, V Carrere, P Dubuisson, and J C Roger. Atmospheric correction over land for MERIS. International Journal of Remote Sensing, 20(9):1819, 1999. 1840.

M Shimada, M Minamisawa, and O Isoguchi. Correction of atmospheric excess path delay appeared in repeat-pass SAR interferometry using objective analysis data. In International Geoscience and Remote Sensing Symposium, Sydney, Australia, 9-13 July 2001, pages cdrom, 3 pages, 2001.

M Shimoni, F van der Meer, R F Hanssen, E Ben-Dor, and B M Kampes. Monitoring of salt diapir movements using SAR interferometry. International Journal of Remote Sensing, submitted, 2002.

M Shimoni, R Hanssen, F van der Meer, B Kampes, and E Ben-Dor. Salt diapir movements using SAR interferometry in the Lisan Peninsula, Dead Sea rift. In Proc. SPIE Vol. 4543, SAR Image Analysis, Modeling, and Techniques IV, pages 151-160. International Society for Optical Engineering, 2002.

F Sigmundsson, P Durand, and D Massonnet. Opening of an eruptive fissure and seaward displacement at Piton de la Fournaise volcano measured by RADARSAT satellite radar interferometry. Geophys. Res. Lett., 26(5):533, 1999.

D Small, S Biegger, and D Nüesch. Automated tiepoint retrieval through heteromorphic image simulation for spaceborne SAR sensors. In ERS/ENVISAT Symposium, Gothenburg, Sweden, Oct. 16-20 October 2000, pages 479-491, March 2001.

L C Smith, D E Alsdorf, F J Magilligan, B Gomez, L A K Mertes, N D Smith, and J B Garvin. Estimation of erosion, deposition, and net volumetric change caused by the 1996 Skeidararsandur jokulhlaup, iceland, from synthetic aperture radar interferometry. Water Resources Research, 36(6):1583-1594, 2000.

N F Stevens, G Wadge, and C A Williams. Post-emplacement lava subsidence and the accuracy of ERS IfSAR digital elevation models of volcanoes. International Journal of Remote Sensing, 22(5):819-828, 2001.

N F Stevens, G Wadge, C A Williams, J G Morley, J.-P Muller, J B Murray, and M Upton. Surface movements of emplaced lava flows measured by synthetic aperture radar interferometry. J. Geophys. Res., 106(B6):11293-11315, 2001.

S Stramondo, M Tesauro, P Briole, E Sansosti, S Salvi, R Lanari, M Anzidei, P Baldi, G Fornaro, A Avallone, M F Buongiorno, and G Franceschetti E Boschi. The September 26, 1997 Colfiorito, Italy, earthquakes: modeled coseismic surface displacement from SAR interferometry and GPS. Geophys. Res. Lett., 26(7):883-886, April 1999.

S Suchandt, H Breit, N Adam, M Eineder, B Schättler, H Runge, A Roth, and E Mikusch. The shuttle radar topography mission. In ISPRS Workshop, High Resolution Mapping from Space, Hannover, Germany, 19-21 September 2002, pages 235-242. ISPRS, September 2001.

L M Th Swart. Spectral filtering and oversampling for radar interferometry. Master's thesis, Faculty of Geodetic Engineering, Delft Univ of Technology, Dec 2000.

A ten Katen, B M Kampes, R F Hanssen, L M Th Swart, R J P van Bree, J Youliang, and L Xu. TILSO - Tianjin Insar Land Subsidence Observation - Demonstration Project, volume NRSP-2, 01-36. Beleidscommissie Remote Sensing, Delft, 2001.

M Tesauro, P Berardino, R Lanari, E Sansosti, G Fornaro, and G Franceschetti. Urban subsidence inside the city of Napoli (Italy) observed by satellite radar interferometry. Geophys. Res. Lett., 27(13):1961, 2000.

T Toutin, L Gray. State-of-the-art of elevation extraction from satellite SAR data. ISPRS Journal of Photogrammetry and Remote Sensing, 55:13-33, 2000.

R Touzi, A Lopes, J Bruniquel, and PW Vachon. Coherence estimation for SAR imagery. IEEE Transactions on Geoscience and Remote Sensing, 1(37):135-149, Jan 1999.

S Usai and R Klees. SAR interferometry on very long time scale: A study of the interferometric characteristics of man-made features. IEEE Transactions on Geoscience and Remote Sensing, 37(4):2118-2123, July 1999.

S Usai, R Klees. On the interferometric characteristics of anthropogenic features. In International Geoscience and Remote Sensing Symposium, Hamburg, Germany, 28 June-2 July 1999, 1999.

S Usai, C Del Gaudio, S Borgstrom, and V Achilli. Monitoring terrain deformations at Phlegrean Fields with SAR interferometry. In Second International Workshop on ERS SAR Interferometry, `FRINGE99', Liège, Belgium, 10-12 Nov 1999, pages 1-5. ESA, 1999.

S Usai. An analysis of the interferometric characteristics of anthropogenic features. IEEE Transactions on Geoscience and Remote Sensing, 38(3):1491-1497, May 2000.

S Usai. A New Approach for Long Term Monitoring of Deformations by Differential SAR Interferometry. PhD thesis, Delft University of Technology, 2001.

S Usai. A least-squares approach for long-term monitoring of deformations with differential SAR interferometric. In International Geoscience and Remote Sensing Symposium, Toronto, Canada, 24-28 June 2002, 2002.

PW Vachon, JWM Campbell, A Laurence Gray, and Fred W Dobson. Validation of along-track interferometric SAR measurements of ocean surface waves. IEEE Transactions on Geoscience and Remote Sensing, 37(1):150-162, January 1999.

R J P van Bree, R Gens, J S Groot, D van Halsema, R F Hanssen, P van den Hout, R Klees, E J de Min ans E J O Schrama, S Usai. Deformation measurements with SAR, volume USP-2, 99-16. Beleidscommissie Remote Sensing, Delft, Jan 2000.

A G A van der Hoeven and R F Hanssen. Cross-validation of tropospheric water vapor measurements by GPS and SAR interferometry. In General Assembly European Geophysical Society, The Hague, The Netherlands, 19-23 April 1999, 1999.

A van der Hoeven, R Hanssen, and B Ambrosius. Cross-validation of tropospheric delay variability observed by GPS and SAR interferometry. GPS Nieuwsbrief, 15(2):2-7, November 2000.

A van der Hoeven, RF Hanssen, and B Ambrosius. Tropospheric delay estimation and analysis using GPS and SAR interferometry. Physics and Chemistry of the Earth, 27:385-390, 2002.

M van der Kooij, ALambert. Results of processing and analysis of large volumes of repeat-pass InSAR data of Vancouver and Mount Meager (B.C.). In International Geoscience and Remote Sensing Symposium, Toronto, Canada, 24-28 June, 2002.

M van der Kooij. Production of DEMs from ERS tandem data. In Second International Workshop on ERS SAR Interferometry, `FRINGE99', Liège, Belgium, 10-12 Nov 1999. ESA, 1999.

N Vanpuymbroeck, R Michel, R Binet, J P Avouac, J Taboury. Measuring earthquakes from optical satellite images. Applied Optics, 39(20):3486-3494, 2000.

D. Vasco, C Wicks, and K Karasaki. Geodetic imaging: High resolution reservoir monitoring using satellite interferometry. Geophysical Journal International, in press, 2000.

G Wadge, B Scheuchl, and N F Stevens. Spaceborne radar measurements of the eruption of Soufriere Hills volcano, Montserrat during 1996-99. Submitted to J. Volcanology and Geothermal Research, 1999.

G Wadge, P W Webley, I N James, R Bingley, A Dodson, S Waugh, T Veneboer, G Puglisi, M Mattia, D Baker, S C Edwards, S J Edwards, and P J Clarke. Atmospheric models, gps and insar measurements of the tropospheric water vapour field over mount etna. Geophys. Res. Lett., 29(19):11/1-4, October 2002.

P W Webley, R M Bingley, A H Dodson, G Wadge, S J Waugh, and I N James. Atmospheric water vapour correction to insar surface motion measurements on mountains: results from a dense GPS network on Mount Etna. Physics and Chemistry of the Earth, Parts A/B/C, 29(4-5):363-370, 2002.

CA William, G Wadge. An accurate and efficient method for including the effects of topography in three-dimensional elastic models of ground deformation with applications to radar interferometry. J. Geophys. Res., 105(B4):8103-8120, April 2000.

L S Wray, A J Wilkinson, and M R Inggs. Synthetic aperture radar image simulator for interferometry. In ISRSE, Cape Town, 27-31 March 2000, 2000.

T Wright, B E Parsons, J A Jackson, M Haynes, E J Fielding, P C England, and PJ Clarke. Source parameters of the 1 October 1995 Dinar (Turkey) earthquake from SAR interferometry and seismic bodywave modelling. Earth and Planetary Science Letters, 172:23-37, 1999.

T Wright, E Fielding, and Barry Parsons. Triggered slip: observations of the 17 August 1999 Izmit (Turkey) earthquake using radar interferometry. Geophys. Res. Lett., 28(6):1079-1082, March 2001.

T Wright, B Parsons, E Fielding. Measurement of interseismic strain accumulation across the North Anatolian Fault by satellite radar interferometry. Geophys. Res. Lett., 28(10):2117-2120, May 2001.

TJ Wright. Remote monitoring of the earthquake cycle using satellite radar interferometry. Phil. Trans. R. Soc. Lond. A, 360:2873-2888, 2002.

Y Xia, Hermann Kaufmann, and Xiaofang Guo. Differential SAR interferometry using corner reflectors. In International Geoscience and Remote Sensing Symposium, Toronto, Canada, 24-28 June 2002, 2002.

W Xu and Ian Cumming. A region-growing algorithm for InSAR phase unwrapping. IEEE Transactions on Geoscience and Remote Sensing, 37(1):124-134, Jan 1999.

H Xu, J Dvorkin, and Amos Nur. Linking oil production to surface subsidence fro satellite radar interferometry. Geophys. Res. Lett., 28(7):1307-1310, April 2001.

Y Yagi and M Kikuchi. Source rupture process of the Kocaeli, Turkey, earthquake of August 17, 1999, obtained by joint inversion of near-field data and teleseismic data. Geophys. Res. Lett., 27(13):1969, 2000.

Y Yong, W Chao, Z Hong, L Zhi, and G Xin. A phase unwrapping method based on minimum cost flows method in irregular network. In International Geoscience and Remote Sensing Symposium, Toronto, Canada, 24-28 June 2002, 2002.

HA Zebker, F Amelung, S Jonsson. Remote sensing of volcano surface and internal processes using radar interferometry. Mouginis-Mark et al., 2000, pages 179-205.

SPECIAL STUDY GROUP 2.192:

“SPACEBORNE GNS ATMOSPHERE SOUNDING”

R. Kursinski and K. Hocke

Report from the members (in alphabetic order):

Georg Beyerle (GFZ)

Summary of activities during the last two years:

1) Analysis of GPS signal reflections in CHAMP data

Radio holographic analyses of CHAMP occultation events revealed that in about one-third of the observations the received signal contains contributions from components reflected at Earth's surface. On the basis of geometrical ray tracing and multiple phase screen calculations characteristic frequency shifts in the radio holograms' power spectral densities were analyzed quantitatively. These frequency shifts were found to be dominated by surface elevation at the reflection point location and ground-level refractivity.

2) Simulation study of RO measurements

Atmospheric propagation of GPS signals under multipath conditions and their detection were simulated. The propagated signals are tracked by GPS receivers implemented in software and converted to refractivity profiles by the canonical transform technique and the Abel inversion. In the mid-troposphere down to altitudes of about 2 km a Costas-type phase-locked loop tracking induces negative refractivity biases on the order of -1 to -2%. Modifications to the receiver tracking algorithm significantly improves the retrieval results.

Dasheng Feng, Rob Kursinski, Stig Syndergaard (University of Arizona)

We have been developing the ATOMS (Active Tropospheric Ozone and Moisture Sensor) LEO-LEO occultation concept supported by the NASA Instrument Incubator Program utilizing atmospheric absorption by water vapor and ozone. We have been developing the ATOMS H_2O and O_3 computer retrieval codes and assessing the water vapor, temperature and geopotential accuracy in clear and cloudy air (Kursinski et al., 2002, 2003a). We have extended the original concept to retrieving water isotopes. We have also been developing instrument design concepts together with JPL. A Science Report for the NASA Instrument Incubator Program on the ATOMS LEO-LEO occultation concept has been finalized and is available upon request. We also developed an analogous Mars Scout weather and climate mission concept called the Mars Atmospheric Constellation Observatory (MACO) which we unfortunately could not get under the cost cap (Kursinski et al. 2003b). We continue developing the concept for the next Mars Scout opportunity.

We have been working on an alternative method for deriving the ionospheric TEC between GPS and LEO satellites (Syndergaard 2002). It consists of a linear combination of the L1 and L2 phases eliminating most of the refractive bending and dispersion using precise orbits, thereby giving a better estimate of the straight-line TEC than other methods.

We have been examining atmospheric stability in the upper troposphere and lower stratosphere as captured by GPS, global analyses and atmospheric GCMs. The diffraction limited GPS results are very similar to the ECMWF analyses. We have assessed the ~200 m vertical resolution Canonical Transform (CT) results in terms of stability and found that they reveal far more variability than the global analyses similar to high resolution radiosondes.

We have been working with researchers at JPL to develop and assess the ability to characterize the Planetary Boundary Layer (PBL) with GPS from LEO. The 200 m CT retrievals show significant promise

for many cases but, as Sergey Sokolovskiy has convinced us, the problem continues to be quite challenging.
We have been examining the water vapor derived from the CHAMP and SAC-C GPS receivers and comparing the results with the ECMWF analyses. We have found significant moisture biases between the GPS and ECMWF results in the free troposphere up to 30% and the ECMWF are very smooth vertically missing much of the variability in comparison with the GPS results. The GPS results tend to be more moist in the tropics and drier in the subtropics.

We have assessed the errors of refractivity and absorption profiles due to horizontal gradients near a weather front (Syndergaard et al. 2003a,b). We found that especially errors in water vapor absorption profiles can be quite (too) large when interpreted as vertical profiles (or profiles along the tangent points). This pushed us to develop a fast linear mapping of the horizontal structure into a 1D profile, mimicking the observation geometry and the data inversion process. We found that the mapping compares extremely well with retrieved profiles from accurate 3D raytracing and inversion simulations. We soon realized that the mapping would be valuable for data assimilation.

We are currently working on describing this forward-inverse mapping operator for data assimilation of refractivity and absorption profiles. Together with Gottfried Kirchengast's group at University of Graz, we are going to assess the error covariances (mapping operator errors) for ECMWF high-resolution refractivity fields using the forward model and inversion software in EGOPS.

We have also been studying propagation limitations on active microwave occultation remote sensing, and working on a general theory to formulate a complete forward study of active atmospheric occultation remote sensing based on wave nature of radiation and its propagation in the inhomogeneous and turbulent atmosphere. This theory in its full scope will account for turbulence effects of the atmosphere and partial coherence effects of the radiation. This includes cooperative research with Steve Dvorak and Xinyu Ye in Electrical Engineering to develop a wave-propagation model that will eventually include absorption.

Michael Gorbunov (DMI,…)

I was investigating the application of the theory of Fourier Integral Operators for the development of different types of CT-like techniques of inversion of radio occultation signals. Together with DMI team, we have performed the comparison of CT and Full Spectrum Inversion (FSI), developed by A. Jensen (DMI). The results show that FSI provides very high retrieval quality, practically identical with CT. I showed that both methods are specialization of general FIO approach to signal processing. I have elaborated a CT-FSI inversion algorithm, which eliminates some approximations used in FSI method. I designed a very fast forward modeling algorithm that can be used for LEO-LEO occultation simulations for high frequencies (10-30 GHz). This algorithm eliminates the coordinate transform used for stationarizing the transmitter.

Sean Healy (The Met Office)

The Met Office has been running its first impact trials with CHAMP measurements. Preliminary results are very encouraging. We see a clear and significant improvement in the NWP forecast fit to radiosondes at 300hPa in the SH, over the 24-72 hour forecast range. Given the small quantity of CHAMP data (~160) this is a very impressive result.

Norbert Jakowski (DLR)

Ionospheric radio occultation (IRO) measurements are carried out onboard the German CHAMP satellite since 11 April 2001 on a routine basis. At present about 100-150 vertical profiles of electron density are derived by an operational CHAMP data processing system. The achieved accuracy of the retrieved electron density profiles is estimated in particular by comparing the IRO results with independent data obtained from vertical sounding stations on Earth and from the Langmuir probe onboard CHAMP. The GPS navigation data received with the topside antenna are used to reconstruct the 3D electron density structure of the ionosphere by data assimilation techniques.
First results of ionospheric radio occultation measurements agree with vertical sounding based F2 layer height and electron density estimations within 13% and 17% RMS deviation, respectively.

A systematic comparison of more than 15000 IRO derived electron density profiles with corresponding IRI 2000 estimations revealed systematic deviations indicating that IRI generally overestimates the upper part of the ionosphere whereas it underestimates the lower part of the ionosphere under high solar activity conditions.

To improve the model assisted retrieval technique, studies concerning the development of a more accurate topside ionosphere/plasmasphere model were performed.

Gottfried Kirchengast (University of Graz)

We in the ARSCliSys Research Group of the University of Graz, Austria, have continued over the past two years work on GNSS occultation algorithm advancements, both in the stratosphere and troposphere and on preparations for an occultation-based global climate monitoring system. Foci in these areas have been theoretical - based on optimal estimation theory - and empirical - based on simulated and real-data profile ensembles – error analyses for all levels of retrieved profiles and for different kinds of error sources (instrumental, upper boundary, horizontal variability,...).

Linked to this, retrieval algorithm advancement work was on-going, especially on improved upper boundary initialization to minimize residual (upper) stratospheric biases and on tropospheric representativity errors to mitigate impacts of horizontal variability. In close collaboration with Michael Gorbunov (IAP Moscow), included hosting several research visits in Graz, also the advancement of wave-optics based retrieval methods and algorithms was importantly supported.

Furthermore, the work on the integrated end-to-end GNSS occultation performance simulation tool EGOPS was continued with dedication, to our knowledge the most advanced end-to-end occultation simulation tool currently available. EGOPS is employed by about two dozen user institutions worldwide; the latest released version is EGOPS4.2. Work on EGOPS5, including also LEO-LEO capabilities besides GNSS-LEO, is on-going.

A very successful workshop was hosted in Graz in September 2002 - OPAC-1 (Occultations for Probing Atmosphere and Climate) - where also discussion of latest advancements in GNSS occultation played a prominent role. Finally, it is to mention that we are involved in a leading role in the preparation of the ACE+ GNSS-LEO and LEO-LEO occultation mission of ESA, which is currently in phase A (up to early 2004, full approval foreseen in spring 2004).

Further detailed information on-line: ARSCliSys Research Group web: http://www.uni-graz.at/igam-arsclisys (includes detailed group publication list, many on-line as pdf files) Int. EGOPS Maintenance Center web: http://www.uni-graz.at/igam-iemc (basic information on the EGOPS end-to-end software tool) OPAC-1 web: http://www.uni-graz.at/OPAC1Workshop-Sep2002 (includes all abstracts and many presentations on-line as pdf files) ACE+ web: http://www.aceplus-mission.org (launch May 2003, significant extension foreseen over year 2003)

Yuei-An Liou[1] and Alexander Pavelyev[1,2] (CSRSR, IRE RAS)
Center for Space and Remote Sensing Research, and Institute of Space and Sciences, National Central University, Chung-Li 320, Taiwan. yueian@csrsr.ncu.edu.tw.
Institute of Radio Engineering and Electronics of Russian Academy of Sciences, (IRE RAS), Fryazino, Vvedenskogo sq. 1, 141191 Moscow region, Russia. pvlv@csrsr.ncu.edu.tw.

Progress was made toward opening new perspectives for radio holographic remote sensing of the Earth atmosphere, ionosphere and surface from space using high- precision radio signals of GPS/GLONASS satellites.

Three dimensional vector radio holographic equations were presented [Pavelyev et al., 2002a].
The 3D equations connect the electromagnetic field inside an inhomogeneous volume in space with the electromagnetic field at its boundary. Under the assumption of local spherical symmetry the 3D equations can be reduced to the 2D scalar diffractive integrals. These integrals connect the field measured along some line in the space (e.g. along the orbital trajectory of the receiver of the GPS/GLONASS signals) with the field in the space between the transmitter and receiver. The distinctive property of the vector and the corresponding scalar diffractive integrals is their applicability to the case of the inhomogeneous

media. The existing scalar diffractive integrals are applicable to the homogeneous media. The obtained diffractive integrals give the theoretical justification to the radio holographic method, based on the focused synthetic aperture approach first introduced early in our publications with co-authors (e.g., [Pavelyev et al., 2002b]) and can be used for reconstruction of the reference signal for solving the inverse radio holographic problem: to retrieve the spatial distribution of the physical parameters of the atmosphere and ionosphere (and, also, the parameters of the terrestrial surfaces) using the radio holograms registered at the near Earth orbit.

An amplitude method is elaborated for the analysis of the RO data [Liou et al., 2002].
This method gives simultaneously detailed vertical profiles of the temperature and its gradient in the atmosphere in the height interval 5-40 km and the vertical gradient of electron density in the lower ionosphere (heights interval 60-120 km) [Pavelyev et al., 2003, Igarashi et al., 2002]. This demonstrates that the GPS radio holography can be used for simultaneous observation of the processes in the atmosphere, stratosphere, and mesosphere and opens new perspectives to study interconnections between meteorological and ionospheric processes, as a part of the general problem of the investigation of the space weather phenomena and their influence on the Earth atmosphere.

Bill Randel (NCAR)

GPS/MET data have been utilized to study the thermal structure and variability of the tropical tropopause region, and study coherence with tropical deep convection. Results show that the tropical tropopause is characterized by a high degree of transient variability related to wave-line structures (such as Kelvin waves or gravity waves), with typical magnitudes of +/- 2-3 K. Our analyses furthermore show that the GPS/MET temperature fluctuations are significantly correlated with tropical deep convection (based on outgoing longwave radiation measurements), with the temperatures exhibiting coherent wave-like patterns over ~12-18 km, spanning a hemisphere in longitude. The GPS/MET temperatures also show clear evidence of the stratospheric quasi-biennial oscillation (QBO) over altitudes ~16-40 km.

C. K. Shum (Ohio State University)

Here is a list of relevant publications/presentations/conference papers for SSG 2.192. One of the papers (Ge et al., 2002) discusses how GPS occultations can be used to improve our estimates of the surface pressure field over Antarctica which is needed for time variable gravity recovery

Manuel de la Torre Juárez and Chi Ao (JPL)

An end-to-end GPS occultation simulation system has been developed at JPL that incorporates realistic simulation of the BlackJack receiver tracking loop. Extensive simulation studies have enabled us to quantitatively identify the causes of the negative refractivity bias (N-bias) in the lower troposphere observed in CHAMP and SAC-C data retrievals. Even with use of the canonical transform (CT) retrieval method, substantial N-bias was observed in the tropics and below 2 km altitude. Simulations suggest that this bias was predominately caused by tracking errors in the data. However, even in the absence of tracking errors, a small negative bias was found in the simulated CT retrievals. We showed that this was caused by errors in the Abel inversion when ducting (or critical refraction) of the GPS signals occurred. Ducting often takes place near the top of the planetary boundary layer where the vertical refractivity gradient can be so large that the curvature of ray trajectories exceeds the local radius of curvature of the Earth [Ao et al., 2003].

We have also developed a fast, FFT-based implementation of the CT method that does not require backpropagation. This enables order-of-magnitude improvement in CPU time over standard implementation and is ideally suited for near real-time CT processing of radio occultation data.

These steps are already proving useful to provide better data for assimilation purposes at NASA's Data Assimilation Office [Poli et al., 2003]

We have assesed the quality of using single frequency ionospheric corrections for occultation retrievals. This work enables to expand the historical database of GPS/MET to cover over 1996, and parts of 1995 and 1997 beyond the prime-time periods [de la Torre et al. 2003].

Advances have been shown also in solving the dry-wet ambiguity of low tropospheric occultation retrievals. It was shown that deviations of an exponential refractivity decay are mostly due to changes in specific humidity and this property was used to obtain moisture profiles without using ancillary data. The accuracy approached retrievals with good ancillary data and improved over retrievals with bad ancillary data
[de la Torre & Nilsson, 2003].

An application of occultation profiles to infer the air mass budget conducive to Polar Stratospheric Cloud formation showed that, in months with large wave activity, ECMWF analyses predict 40% less than occultations. This result may have important implications for both the application of occultation profiles by HALOE to detect conditions consistent with Polar Stratospheric Cloud formation (instead of relying on the model), and the understanding of the physical mechanisms driving the cloud formation [de la Torre et al., 2003].

A comprehensive preprint database for occultation-related works has been created under http://genesis.jpl.nasa.gov where the above cited references and many more can be downloaded.

Tobias Wehr (ESA/ESTEC)

There is a (very brief) web page on ACE+, if you wish to include this in the report: http://www.esa.int/export/esaLP/ESAILYJE43D_ace_0.html.

Also of interest could be the Metop page (Metop will fly GRAS):
http://www.esa.int/export/esaME/ESAD38VTYWC_gras_0.html

Jens Wickert (GFZ)

I want to summarize some key results regarding occultation progress (CHAMP) from my point of view:

Demonstration of continuous and precise atmospheric (occultation) sounding by CHAMP, independent of SA mode, providing about 200 profiles daily, this is a chance for the first long term occultation data set (hope at least 5 years) from CHAMP

Demonstration of continuous "near-real-time" occultation processing, with average delay of 5 hours between measurement and excess phase provision for each occultation event

Demonstration of the feasibility of space-based single difference processing using 5 minute GPS clock solutions for precise occultation analysis using CHAMP data (after termination of AS)

Larry Young (JPL)

Tom Meehan, Brooks Thomas, and Larry Young developed (US Patent 6,061,390) a new means of tracking the encrypted GPS signals. Along with improved occultation antennas on CHAMP and SAC-C, this processing as used on the BlackJack receiver recovers dual-frequency observables with better SNR than the GPS/MET mission obtained during periods when the GPS signals were not encrypted. A feature of this enhanced codeless processing is that the L1 and L2 signals are recovered independently. This means that scintillations affect only a single frequency, which is an important requisite for use of canonical transform processing.

References

Ao, C. O., T. K. Meehan, G. A. Hajj, A. J. Mannucci, "Lower-Troposphere Refractivity Bias in GPS Occultation Retrievals", JGR-atmospheres, accepted for publication, 2003.

Beyerle, G., K. Hocke, J. Wickert, T. Schmidt, C. Marquardt, and C. Reigber, GPS radio occultations with CHAMP: A radio holographic analysis of GPS signal propagation in the troposphere and surface reflections, J. Geophys. Res., Vol. 107, No. D24, 4802, doi:10.1029/2001JD001402, 2002.

Beyerle, G., M. E. Gorbunov, C. O. Ao, Simulation studies of GPS radio occultation measurements, submitted to Radio Science, 2003, preprint available at http://genesis2.jpl.nasa.gov/archive/200212007/01/GPSRecSim-20021017.pdf)

Chao, B., C. Hwang, C. Shum, M. Yang, and C. Cox, White Paper on Space Geodesy with ROCSat-3/COSMIC, COSMIC Workshop, UCAR, Boulder, CO, August 21-23, 2002, November 23, 2002.

Ge, S., C. Shum, C. Zhao, S. Gutman, and K. Hocke, GPS limb-sounding retrieval of water vapor using ground based network and spaceborne data, IAG Scientific Assembly, Vistas for Geodesy in the New Millennium, Budapest, Hungary, September 2-7, 2001.

Ge, S., C. Shum, S. Han, B. Chao, and C. Cox, Contributions of COSMIC to climate change studies: Improvement of the Antarctic pressure field, COSCIC Workshop, Boulder, Colorado, August 21-23, 2002.

Ge, S., C. Shum and J. Wickert, Contributions of GPS occultations to Antarctica ice sheet mass balance studies, proc. First International workshop on Occultation for Probing Atmosphere and Climate (OPAC-1), Graz, Austria, 16-20 September 2002.

Ge, S., and C. Shum, GPS meteorology using GPS limb-sounding with low-Earth orbiters, Proc. Weikko A. Heiskanen Symposium In Geodesy: Celebrating 50 years in Geodetic Science at the Ohio State University, Ohio State University, Columbus, Ohio, 1-5 October 2002.

Ge, S., C. Shum, J. Wickert, and C. Reigber, Atmospheric limb-sounding using GPS occultation, Proc. GNSS Workshop, Wuhan, China, November 6-8, 2002.

Ge, S., and C. Shum, Improvement of Antarctic pressure field using GPS occultation mission data, IUGG2003, Sapporo, Japan, June 30-July 11, 2003.

Heise S., N. Jakowski, A. Wehrenpfennig, Ch. Reigber, H. Lühr, Sounding of the Topside Ionosphere/Plasmasphere Based on GPS Measurements from CHAMP: Initial Results, Geophysical Research Letters, 29, No. 14, 10.1029/2002GL014738, 2002

Heise S., N. Jakowski, A. Wehrenpfennig, Ch. Reigber, and H. Lühr, Initial Results on Ionosphere/Plasmasphere Sounding Based on GPS Data Obtained Onboard CHAMP, First CHAMP Mission Results for Gravity, Magnetic and Atmospheric Studies (Eds. : Reigber, Lühr, Schwintzer), Springer-Verlag Berlin Heidelberg 2003, pp 408- 414

Igarashi, K., A. Pavelyev, J. Wickert, K. Hocke, D. Pavelyev, 2002: Application of radio holographic method to observation of altitude variations of the electron density in the upper atmosphere using GPS/MET radio occultation data. J. Atmos. Solar-Terr. Phys., 64, P. 959-969.

Jakowski N., A. Wehrenpfennig, S. Heise, Ch. Reigber, H. Lühr, Initial GPS Radio Occultation Measurements of the Ionosphere onboard CHAMP , Acta Geod. Geoph. Hung., 37(2-3), 221-226,2002 .

Jakowski N., A. Wehrenpfennig, S. Heise, Ch. Reigber, and H. Lühr, GPS Radio Occultation Measurements of the Ionosphere on CHAMP: Early Results, Geophysical Research Letters, 29, No. 10, 10.1029/2001GL014364, 2002

Jakowski N., I. S. Kutiev , S. Heise and A. Wehrenpfennig, A topside ionosphere/plasmasphere model for operational applications, Prceedings XXVIIth General Assembly of URSI, 17-24 August 2002, Maastricht, Netherlands, CD edition, p2174

Jakowski N., A. Wehrenpfennig, S. Heise, Ch. Reigber, H. Lühr, Status of ionospheric radio occultation CHAMP data analysis and validation of higher level data products, First CHAMP Mission Results for Gravity, Magnetic and Atmospheric Studies (Eds. : Reigber, Lühr, Schwintzer), Springer-Verlag Berlin Heidelberg 2003, pp 462-472

Kursinski, E. R., D. Feng, D. Flittner, G. Hajj, B. Herman, S. Syndergaard, D. Ward and T. Yunck, A microwave occultation observing system optimized to characterize atmospheric water, temperature and geopotential via absorption, J. Atmos. Oceanic Technol., 19, 1897-1914, 2002.

Kursinski, E. R. et al., An Active Microwave Limb Sounder for Profiling Water Vapor, Ozone, Temperature, Geopotential, Clouds, Isotopes and Stratospheric Winds, Submitted to Proceedings of 1st International Workshop for Occultations Probing the Atmosphere and Climate (OPAC-1), Springer-Verlag, 2003a.

Kursinski, E. R. et al., The Mars Atmospheric Constellation Observatory (MACO) Concept, Submitted to Proceedings 1st International Workshop for Occultations Probing the Atmosphere and Climate (OPAC-1), Springer-Verlag, 2003b.

Liou Y.A., A.G. Pavelyev, C.Y. Huang, K. Igarashi, K. Hocke, 2002: Simultaneous observation of the vertical gradients of refractivity in the atmosphere and electron density in the lower ionosphere by radio occultation amplitude method, Geophys. Res. Letters, V. 29, No.19, 43-1–43-4.

Marquardt, C., K. Schollhammer, G. Beyerle, T. Schmidt, J. Wickert, and Ch. Reigber: "Validation and Data Quality of CHAMP Radio Occultation Data" In First CHAMP Mission Results for Gravity, Magnetic and Atmospheric Studies, Springer Series, 384-396, 2003

Pavelyev A.G., Y.A. Liou, C. Y. Huang, C. Reigber, J. Wickert, K. Igarashi, K. Hocke, 2002a: Radio holographic method for the study of the ionosphere, atmosphere and terrestrial surface from space using GPS occultation signals. GPS Solutions, 2002, No. 6, P.101-108.

Pavelyev A., K. Igarashi, C. Reigber, K. Hocke, J. Wickert, G. Beyerle, S. Matyugov, .A. Kucherjavenkov, D. Pavelyev, O.I.Yakovlev, 2002b: First application of the radio holographic method to wave observations in the upper atmosphere. Radio Science, V. 37, No. 3, P. 15-1–15-11.

Pavelyev A.G., T. Tsuda, K. Igarashi, Y.A. Liou, and K. Hocke, 2003: Wave structures in the electron density profile in the ionospheric D and E-layers observed by radio holography analysis of the GPS/MET radio occultation data, J. Atmos. Solar-Terr. Phys. V. 65, No.1, 59-70.

Poli, P., C.O. Ao, M. de la Torre Juarez, J. Joiner, G.A. Hajj, R.M. Hoff, Evaluation of CHAMP Radio Occultation Refractivity using Data Assimilation Office Analyses and Radiosondes. Geophysical Research Letters. accepted for publication, art. no. 2003GL017637, 2003.

Randel, W.J., F. Wu and W. Rivera Rios, 2003: Thermal variability of the tropical tropopause region derived from GPS/MET observations. J. Geophys. Res., January 2003, doi10.1029/2002JD002595.

Schlüter S., C. Stolle, N. Jakowski, C. Jacobi, Monitoring of 3 Dimensional Ionospheric Electron Density Distributions Based on GPS Measurements, First CHAMP Mission Results for Gravity, Magnetic and Atmospheric Studies (Eds. : Reigber, Lühr, Schwintzer), Springer-Verlag Berlin Heidelberg 2003, pp 521-527

Schmidt, T., J. Wickert, C. Marquardt, G. Beyerle, Ch. Reigber, R. Galas, and R. Konig, 2003: GPS Radio occultation with CHAMP: An innovative remote sensing method of the atmosphere, Adv. Space Research, in print

Shum, C. and B. Chao, Contributions of COSMIC to Geodesy and Geodynamics, Proc. Workshop on Low Earth Orbiter Missions: Developing and Integrating Ground and Space Systems for GPS Applications, held at GeoForschungsZentrum Potsdam (GFZ), Potsdam, Germany, March 9-11, 1999.

Shum, C., C. Zhao, B. Chao, C. Cox, S. Klosko, and E. Pavlis, Space Geodesy and Climate Change Studies Using COSMIC Mission, Proc. COSMIC Workshop, COSPAR Symposia, Taipei, Taiwan, Sept., 2000.

Shum, C., B. Chao, and C. Cox, Space Geodesy and Climate Change Studies Using COSMIC Mission, Proceedings of the COSPAR Colloquium on Space Weather Study Using Multi-point Techniques, Taipei, Taiwan, September 27-29, 2000, 335-339, 2002.

Spalla P., N.Jakowski, A. Wehrenpfennig, Paul S. Spencer, and C.N. Mitchell, Verification of CHAMP radio occultation observations in the ionosphere using MIDAS, First CHAMP Mission Results for Gravity, Magnetic and Atmospheric Studies (Eds. : Reigber, Lühr, Schwintzer), Springer-Verlag Berlin Heidelberg 2003, pp 545- 550

Stankov, S., I. Kutiev, N. Jakowski, and S. Heise (2002): Electron density profiles deduced from GPS TEC, O^+-H^+ transition height and ionosonde data, Acta Geodaetica et Geophysica Hung., Vol.37, No.2-3, 171-181, 2002

Syndergaard, S. A new algorithm for retrieving GPS radio occultation total electron content, Geophys. Res. Lett., 29(16), doi:10.1029/2001GL014478, 2002.

Syndergaard, S., D. Flittner, R. Kursinski and B. Herman, Simulating the influence of horizontal gradients on refractivity profiles from radio occultations, to appear in Oersted Proceedings, 4th International Science Team Meeting (OIST-4), Copenhagen, Denmark, 2003a.

Syndergaard, S., D. Flittner, R. Kursinski, D. Feng, B. Herman and D. Ward, Simulating the influence of horizontal gradients on retrieved profiles from ATOMS occultation measurements - a promising approach for data assimilation, Submitted to Proceedings of 1st International Workshop for Occultations Probing the Atmosphere and Climate (OPAC-1), Springer-Verlag, 2003b.

de la Torre Juarez, M. , M. Nilsson, On the detection of water vapor profiles and thin moisture layers from atmospheric radio occultations. J. Geophys. Res.-Atmos. 108, D9, art. no 2002JD002880, 2003.

de la Torre Juarez, M. , G.A. Hajj, E.R. Kursinski, A.J. Mannucci, L.J. Romans. Single frequency retrievals of GPS/MET radio occultations. Int. J. Remote sensing. in press, 2003.

de la Torre Juarez, M., S.S. Leroy, G.A. Hajj, B.A. Iijima, A.J. Mannucci, Air mass estimates of thin temperature structures conducive to polar stratospheric clouds. Submitted to Nature, under review 2003.

Wehrenpfennig, A., N. Jakowski, and J. Wickert, 2001: A Dynamically Configurable System for Operational Processing of Space Weather Data, Phys. Chem. Earth (C), 26, 601-604.

Wickert, J., R. Galas, T. Schmidt, G. Beyerle, Ch. Reigber, Ch. Forste, and M. Ramatschi, 2003: Atmospheric sounding with CHAMP: GPS ground station data for occultation processing, Phys. Chem. Earth., in print.

Wickert, J., 2002: The CHAMP radio occultation experi-ment: Algorithms, Processing system, and First results (in German), Scientific Technical Report 02/07, GFZ Potsdam, Germany.

Wickert, J., G. Beyerle, G. A. Hajj G. A., V. Schwieger, and Ch. Reigber, 2002: GPS radio occultation with CHAMP: Atmospheric profiling utilizing the space-based single difference technique, Geophys. Res. Lett., 29(8), 10.1029/2001GL013982.

Wickert, J., Ch. Reigber, G. Beyerle, R. Konig, C. Mar-quardt, T. Schmidt, L. Grunwaldt, R. Galas, T. Meehan, W. Melbourne, and K. Hocke, 2001a: Atmosphere sounding by GPS radio occultation: First results from CHAMP, Geophys. Res. Lett., 28, 3263-3266.

Wickert, J., R. Galas, G. Beyerle, R. Konig., and Ch. Reigber, 2001b: GPS ground station data for CHAMP radio occultation measurements, Phys. Chem. Earth (A), 26, 503-511.

Wickert, J., T. Schmidt, G. Beyerle, R. Konig, Ch. Reigber, N. Jakowski,The radio occultation experiment aboard CHAMP: Operational data analysis and validation of vertical atmospheric profiles, subm. Journal Met Soc. Jap., 2003.

Wickert, J., G. Beyerle, T. Schmidt, C. Marquardt, R. Konig, L. Grunwaldt, and Ch. Reigber: "GPS radio occultation with CHAMP" First CHAMP Mission Results for Gravity, Magnetic and Atmospheric Studies, Springer Series, ISBN 3-540-00206-5, 371-383, 2003

REPORT OF IAG SPECIAL STUDY GROUP 2.193
GRAVITY FIELD MISSIONS: CALIBRATION AND VALIDATION

http://www.deos.tudelft.nl/~pieter/IAG.SSG/index.shtml

P.N.A.M. Visser (chair) Pieter.Visser@lr.tudelft.nl and C. Jekeli (co-chair) jekeli.1@osu.edu

Summary

This report gives a brief overview of the activities and the achievements of the IAG Special Study Group (SSG) 2.193 "Gravity field missions: calibration and validation" for the period covering January 2000 - April 2003. The SSG was established early 2000 and its objective is to define, evaluate and characterize possibilities and methods for calibration and validation (Cal/Val) of observations taken by gravity field missions and the derived gravity field model products. These activities have been very relevant with the launch of the German CHAMP satellite in July 2000 and the GRACE satellites in March 2002 and the foreseen launch of GOCE in 2006. These missions make use of new generations of GPS receivers and new technologies like ultra-sensitive accelerometers, a gradiometer and a drag-free control system. Many questions in the field of calibrating the several types of observations have been addressed, but are still (partly) open for further research. In addition, new concepts for validating derived gravity field products have been and will be considered, designed and developed, and old concepts reviewed due to the unprecedented demands in accuracy and in both spatial and temporal resolution. In the 2000-2003 time frame, several studies have been carried out to assess and review many Cal/Val possibilities. In addition, several institutes and organizations have been preparing for ground and airborne campaigns to support Cal/Val activities. Finally, a joint effort with the Special Commission "SC7: Gravity Field Determination by Satellites" has resulted in a first set of simulated observations made available to the scientific community. This data set has been used for testing purposes. \\

Introduction and background

The launch of the German CHAMP satellite in July 2000 and of the U.S/German GRACE satellites in March 2002 can be regarded as the early phase of the gravity "pillar" of what can be defined as the "Decade of Geopotential Research", with one more mission to come: the European Space Agency (ESA) GOCE satellite in 2006. These satellites make use of advanced technologies that enable global gravity field mapping with unprecedented accuracy and resolution in space and time.

CHAMP has already provided the scientific community with high-quality observations since May 2001 enabling the production of the first consistent long-wavelength global gravity field models employing a geodetic-quality GPS receiver for high-low Satellite-to-Satellite Tracking (SST) in combination with an ultra-sensitive accelerometer measuring non-conservative accelerations.

GRACE has been monitoring long- to medium-wavelength gravity field variations since March 2002, and will also enable the mapping of the mean global gravity field with a resolution significantly surpassing existing models. To this aim GRACE consists of two low-flyers enabling high-accuracy low-low SST tracking in combination with GPS high-low SST and accelerometers, that are even more sensitive than the one on board of CHAMP. Recently, new gravity field models have been presented with a claimed accuracy of at least one order of magnitude better than any model produced before the launch of GRACE, up to at least degree and order 70. The commissioning phase of GRACE is anticipated to end in 2003, after which its observations might become available to a wide scientific community. It is expected that this will trigger many new Cal/Val activities.

Finally, GOCE will be the first satellite equipped with a space-borne gravity gradiometer (SGG) together with a high-quality GPS/GLONASS receiver and a drag-free control system. GOCE aims at recovering the global mean gravity field with unprecedented resolution.

The observations that are and will be produced by the satellites need to be properly calibrated and reduced to gravity field model products that need to be validated. The calibration entails the conversion of the raw instrument measurements into engineering units within known limits of accuracy and precision, for example cm and mm/s for the SST measurements, m/s2 for the accelerometer and Eotvos units (E or 10-9 m/s2) for the differential accelerometer measurements by the gradiometer. The validation concerns the conversion of these engineering quantities into geophysical units with sufficient accuracy, for example cm for geoid undulations, mgal for gravity anomalies and E for the gravity gradients. Recent experiences with CHAMP and GRACE data have shown that such a calibration is far from trivial and that there are still many open issues.

The satellites are providing and will provide new types of observations never used before in gravity field modeling and the spectral (error) characteristics of these are not well understood. Several calibration methods need to be reviewed, assessed, enhanced and/or designed in order to retrieve these characteristics and guarantee a proper calibration. Due to the required accuracy and resolution, the same can be said about validation methods for the gravity field products.

A number of different categories of possibilities for Cal/Val have been considered and are subject of the activities of this SSG:

- pre-flight calibration of the science instruments;
- on-the-fly calibration and validation;
- use of ground truth data;
- comparison with existing state-of-the-art gravity field models;
- intercomparison between gravity field products from different missions, but also based on different instruments within one mission.

Members

SSG 2.193 has 20 regular members, including the chair and co-chair and 18 corresponding members. The SGG started its activities in January 2000. The names of the members of the SGG and countries are given in the following list:

Chair/co-chair: Pieter Visser (The Netherlands)/Chris Jekeli (USA)

Members: Miguel Aguirre (The Netherlands), Dimitri Arabelos (Greece), Srinivas Bettadpur (USA), Richard Coleman (Australia), Rene Forsberg (Denmark), Cheng Huang (China), Cheinway Hwang (Taiwan), Karl-Heinz Ilk (Germany), Steve Kenyon (USA), Gerard Kruizinga (USA), Jurgen Muller (Germany), Felix Perosanz (France), Tadahiro Sato (Japan), Martijn Smit (The Netherlands), Dru Smith (USA), Hans Suenkel (TU-Graz/Austria), Peter Schwintzer (Germany), John Wahr (USA)

Corresponding members: Alberto Anselmi (Italy), Georges Balmino (France), Stefano Cesare (Italy), Reinhard Dietrich (Germany), Yoichi Fukuda (Japan), Johnny Johannessen (Norway), Helmut Oberndorfer (Germany), Christian LeProvost (France), John Manning (Australia), Reiner Rummel (Germany), Jens Schroeter (Germany), Avri Selig (The Netherlands), C.K. Shum (USA), Christian Tscherning (Denmark), Pierre Touboul (France), Phil Woodworth (Great-Britain), Changyin Zhao (USA), Yaozhong Zhu (China)

Most of the members have been involved very actively in the final preparation and early mission stages of CHAMP and GRACE and preparatory stages of GOCE leading
to activities relevant but not under coordination of this SSG. Many of the members met informally and formally during several international conferences and symposia in the 2000-2003 time frame, e.g. the EGS, AGU, COSPAR and IAG GGG2000 meetings, and a workshop organized by the International Space Science University. The coordinates of a few indicative sessions are included in the bibliography of this report agu2000,ggg2000,agu2002,cospar2002,issi2002,egs2003. Many of them also contributed to national and international studies and research programs that include (preparations for) Cal/Val activities, and also acted as consultants to instrument manufacturers and industry in general.

Specific accomplishments

This report does not provide a complete overview of all Cal/Val activities that took place in the 2000-2003 time frame, but merely provides a snap shot of the many activities that have taken place. Very important developments include the release of high-quality CHAMP observations and the first CHAMP-based gravity field models in the EIGEN series(agu2002,cospar2002), and the presentation of first results of (applications of) GRACE-based gravity field solutions (cospar2002,agu2002,egs2003). Within the GRACE project, many study group members from the Center for Space Research in Austin,Texas, the Jet Propulsion Laboratory in Pasadena, California, and the GeoForschungsZentrum in Potsdam, Germany, work together and compare their results, including gravity field solutions (agu2002,egs2003).

Another important development is the establishment of the European GOCE Gravity Consortium (EGG-C), a collaboration between 10 scientific institutes and univesity groups in preparation of the generation of gravity solutions from future GOCE observations. Within the framework of this consortium, many members of this study group work together on Cal/Val issues (albertella2000, bouman2003, egs2003, johannessen2003, koop2000, koop2001a, koop2002a, oberndorfer2000, rummel2002a, sid2000, sneeuw2002a, visser2000a). Close contacts have been further developed between scientists and colleagues of the Italian aerospace company Alenia responsible for building the GOCE satellite allowing scientists to have access to instrument design parameters and mission scenario information (egs2003).

Many of the study group members are represented in and have strong ties with the CHAMP, GRACE and GOCE missions allowing (preparations for) multi-mission Cal/Val activities and (inter-)comparisons.

It is interesting to note that some group members are involved in satellite missions that do not have the primary objective to measure the earth's gravity field, but might contribute to long-term, long-wavelengths monitoring of this field and its variations (hwang2001). In addition, some group members are involved in feasibility studies for GRACE and GOCE follow-on missions, for example in the framework of the ESA study on "Enabling Observation Techniques for Future Solid Earth Missions".

Several members participated in both national and international cooperations for setting up ground and airborne (gravimetry) campaigns to support Cal/Val of the future gravity missions GRACE and GOCE. Certain members also cooperate with members of
the related SSG 2.162 "Precise Orbits Using Multiple Space Techniques", chaired by Remko Scharroo, and the Working Group "Preparation of Standard Procedures for Global Gravity Field Validation", chaired by Th. Gruber, partly in the framework of Science Working Teams (e.g. JASON-1) and Precise Orbit Determination teams (e.g. ENVISAT). Finally, this SSG contributed to the generation of a data set of simulated CHAMP, GRACE and GOCE observations that was made available to the scientific community. This activity was coordinated by Special Commission SC7, chaired by Karl-Heinz Ilk.

Conclusions and outlook

Many activities have been undertaken by colleagues, members of this SSG in particular, related to Cal/Val methods and procedures of gravity field mission observations and gravity field model products. Most of the efforts were carried out in the framework of ongoing programs related to specific satellite missions, namely CHAMP, GRACE and GOCE, and not specifically in the framework of this SSG. It is foreseen that these activities will be extended and intensified in the years to come. Strong cooperations between many institutes have been established, for example between many European institutes in the framework of EGG-C, and U.S. and European institutes within the GRACE project. Moreover, already preparations for possible gravity field follow-on missions are made.

It is the aim of this SSG to serve in the future as a means for exchanging and distributing information relevant to these efforts, and trigger cooperation between different colleagues at both national and international level. In light of this, it is intended to promote and continue cooperation with SC7, SSG 2.162 and the above mentioned Working Group.

References

The bibliography is indicative for the many activities that took place which are relevant for Cal/Val of several levels of the (expected) products of gravity field missions and is surely not intended to be complete.

Conference sessions

AGU (2000), Fall Meeting, American Geophysical Union, San Fransisco, December 15-19, 2000, Published as a Supplement to EOS Transactions, AGU, Vol. 81. No. 48, pp. F307-F311, November 28.

AGU (2002), New Results From GRACE and Other Gravity Missions, Fall Meeting, American Geophysical Union, San Fransisco, December 8-12 2003, Published as a Supplement to EOS Transactions, AGU, Vol. 83. No. 47, November 28.

COSPAR (2003), Integrated Space Geodetic Systems and Satellite Dynamics -Preface, in 34th COSPAR Scientific Assembly, The Second World Space Congress, Houston, TX, USA, 10-19 October 2002, Adv. Space Res., in press, edited by P.N.A.M. Visser and P. Moore.

EGS (2003), G13 Impact of New And Planned Missions - EGS-AGU-EUG Joint Assembly, Nice, France, 06 - 11 April 2003, Geophysical Research Abstracts, Vol.5, ISSN: 1029-7006.

GGG2000 (2002), Gravity, Geoid and Geodynamics 2000, GGG2000 IAG International Symposium, Banff, Alberta, Canada, July 31-August 4, 2000, vol.\ 123 of International Association of Geodesy Symposia, edited by M.G. Sideris, Springer-Verlag, New York.

ISSI (2003), International Space Science Univeristy, in Workshop on Earth Gravity Field from Space, Bern, Switzerland, 11-16 March, 2002, edited by R.. Rummel G.. Beutler M. Drinkwater and R. von Steiger, Proceedings in press.

Others

Albertella, A., F. Migliaccio, F.~Sanso, and C.C. Tscherning (2000), From Eotvos to mGal, WP4: Scientific data production quality assessment Assessment using Local Space-wise Preprocessing, Contribution to Final Report, ESA/ESTEC Contract No. 13392/98/NL/GD, 157--176, SID/DEOS, April2000.

Bouman, J., R. Koop, C.C. Tscherning, and P. Visser (2003), Calibration of GOCE SGG data using high-low SST, terrestrial gravity data, and global gravity field models, J. Geod., In revision, 12 pp.

Hwang, C. (2001), Gravity recovery using COSMIC GPS data: application of orbital perturbation theory, J. Geod., 75, 117--136.

Ilk, K.H. (2002), Energy Relations for Satellite-to-Satellite Motions, in Geodesy - The Challenge of the 3rd Millenium, edited by E.W. Grafarend et al, Springer-Verlag, Berlin.

Johannessen, J.A., G. Balmino, C. Le Prevost, R. Rummel, R. Sabadini, H. Sunkel, C.C. Tscherning and P. Visser, P. Woordworth, C.W. Hughes, P. LeGrand, and N. Sneeuw (2003), The European Gravity Field and Steady-State Ocean Circulation Explorer Satellite Mission: Impact in Geophysics, Surveys in Geophysics, Accepted.

Koop, R., P. Visser, J. van den IJssel, and R. Klees (2000), From Eotvos to mGal, WP2: Detailed Scientific Data Processing Approach, Contribution to Final Report, ESA/ESTEC Contract No. 13392/98/NL/GD, 29--71, SID/DEOS, April 2000.

Koop, R., P. Visser, and C.C. Tscherning (2001), Aspects of GOCE Calibration, in WPP-188, International GOCE User Workshop, 23-24 April 2001, ESTEC, Noordwijk, The Netherlands, pp. 51--56.

Koop, R., J. Bouman, E.J.O. Schrama, and P. Visser (2002), Calibration and Error Assessment of GOCE Data, in Vistas for Geodesy in the New Millenium, vol.125 of International Association of Geodesy Symposia, edited by J. Adam and K.-P. Schwarz, pp. 167--174, Springer-Verlag, Berlin.

Kusche, J., K.H. Ilk, and S. Rudolph (2000), Impact of terrestrial data on future satellite gravity field solutions, inTowards an Integrated Global Geodetic Observing System (IGGOS), vol.120 of IAG Symposium, edited by R. Rummel et al, pp. 189--192, Springer-Verlag, Berlin.

Oberndorfer, H., J. Muller, R. Dorobantu, C. Gerlach, R. Rummel, N. Sneeuw, R. Koop, P. Visser, P. Hoyng, A. Selig, and M. Smit (2000), Simulation of the GOCE Gravity Field Mission, in Towards an

Integrated Global Geodetic Observing System (IGGOS), IAG symposium 120, Springer, edited by R. Rummel et al, pp. 201--204.

Pail, R. (2003), In-orbit calibration and local gravity field continuation problem, J. Phys. Chem. Earth, In press.

Rummel, R., G. Balmino, J. Johannessen, P. Visser, and P. Woordworth (2002), Dedicated gravity field missions - principles and aims, J. Geodyn, 33, \/(1--2), 3--20.

SID (2000), GOCE End-to-end Closed Loop Simulation, Final Report, ESTEC Contract No. 12735/98/NL/GD, SRON/IAPG/DEOS, January 2000.

Sneeuw, N., J. van den IJssel, R. Koop, P. Visser, and C. Gerlach (2002), Validation of fast pre-mission error analysis of the GOCE gradiometry mission by a full gravity field recovery simulation, J.Geodyn., 33, \/(1--2), 43--52.

Velicogna, I., J. Wahr, and H. Van den Dool (2001), Can surface pressure be used to remove atmospheric contributions from GRACE data with sufficient accuracy to recover hydrological signals?, J.Geophys. Res., 106, \/(B8), 16,415--16,434.

Visser, P.N.A.M. (2001a), GOCE data products for the user community, Contribution to Progress Report 1, GOCE: Preparation of the GOCE Level 1 to Level 2 Data Processing, ESTEC Contract No. 14986/01/NL/DC, 7 pp.,DEOS, June 2001.

Visser, P.N.A.M. (2001b), WP6000: Assessment of GPS-based estimation of non-conservative accelerations - Approach, Report to the Space Research Organization Netherlands (SRON), EOS: GOCE 691-100, 13 pp., DEOS, 9 August 2001.

Visser, P.N.A.M., and J. van den IJssel (2003), Verification of CHAMP accelerometer observations, Adv. Space Res., In press, 6 pp.

Visser, P.N.A.M., R. Koop, and R. Klees (2000), From Eotvos to mGal, WP4: Scientific data production quality assessment, Contribution to Final Report, ESA/ESTEC Contract No. 13392/98/NL/GD, 157--176, SID/DEOS, April2000.

Visser, P.N.A.M., R. Rummel, G. Balmino, H. Sunkel, J. Johannessen, M. Aguirre, P.L. Woodworth, C. Le Provost, C.C. Tscherning, and R. Sabadini (2002), The European Earth Explorer Mission GOCE: Impact for the Geosciences, Ice Sheets, Sea Level and the Dynamic Earth, Geodynamics Series 29, American Geophysical Union, edited by J. Mitrovica and L.L.A. Vermeersen, pp. 95--107.

Woodworth, P.L., and J.M. Gregory (2003), Benefits of GRACE and GOCE to sea level studies, Space Science Reviews, In press.

SPECIAL STUDY GROUP 2.194: “GPS WATER LEVEL MEASUREMENTS”

http://op.gfz-potsdam.de/altimetry/SSG_buoys

T. Schöne

Chairman: Gerry Mader (USA)
Co-chairs: Doug Martin (USA) & Tilo Schöne (Germany)

Introduction

The SSG acts as a forum to exchange information about using GPS-buoys primarily for measuring the instantaneous sea level. Originally the establishment of the SSG was a request of the community to calibrate and monitor the satellite radar altimetry (RA) measurements of recent and forthcoming RA missions. Beside this, members of the group are using the techniques also for river or lake level monitoring as well as for connecting remote tide gauges to a global reference frame.

The GPS buoy technique is still very new. Different groups are using different types of buoys and concepts. One common design is a life-saver type of buoys. The concept is very straightforward and gives good results. Another concept is using ruggedized types of buoys, which are more suitable for harsh conditions and long-term deployment. Unfortunately this concept is very expensive. For example, for the absolute calibration campaign of ENVISAT, the European Space Agency ESA selected a dual concept: ruggedized buoys for the long-term measurements and using life-saver types of buoys in a leapfrog scenario to get more calibration values, if the weather permits operations. In the past two years several campaigns using both type of GPS buoys were carried out. However, an intercomparison of both techniques still needs to be performed.

A web page was established for Special Study Group 2.194 "GPS Water Level Measurements" on the GFZ web server in Potsdam (http://op.gfz-potsdam.de/altimetry/SSG_buoys/). In addition to the Terms of reference for SSG 2.194, the web site provides a list of the members with contact information, Information activities and news of pending conferences and workshops, an electronic library, and an opportunity for members to submit a Technical Note on research and development activities to create a forum for discussing technical issues related to GPS water level measurements. Unfortunately, this feature has not been as active as the Chairs had hoped”. The electronic library is widely used but needs more frequent updating.

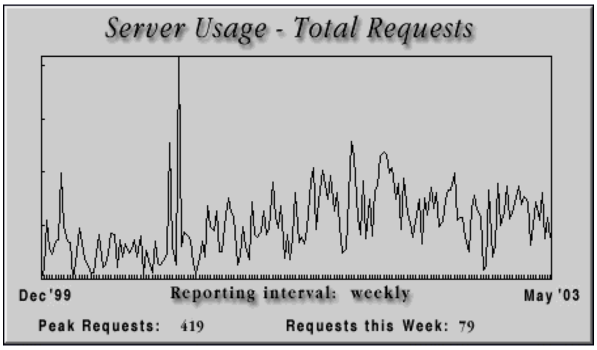


***Figure 1**: Access statistics to the WEB server*

Meetings with SSG 2.194 Participation

A meeting was held in 2000 during the EGS in Nice. Here, mostly colleagues from Europe attended the meeting. In total 5 presentations were given (for the full report see the SSG WEB-page at http://op.gfz-potsdam.de/altimetry/SSG_buoys/ssg_meeting_nice.html).

During the Asia-Pacific Space Geodynamic Project (APSG) Sea Level Workshop held as part of the GLOSS GE7 Meeting in Honolulu, Hawaii (April 23 & 24, 2001) a special session of the SSG was held. In total 7 presentations (oral and poster) were given:

1. T. Schöne, Ch. Reigber, A. Braun, M. Forberg, R. Galas: GPS Buoys for calibrating Radar Altimeters for the SEAL Project
2. M. Bushnell, D. Martin, and J. Sprinke, M. Chin, S. Cofer, D. Crump, and G. Mader, Frank Aikman: Improved Design of the National Ocean Service (NOS) GPS Buoy System
3. P. Bonnefond, P. Exertier, and Y. Menard: Radar altimeter calibration using a GPS-Buoy in Corsica
4. P. Bonnefond, P. Exertier, and Y. Menard: Leveling the sea surface using a GPS Catamaran
5. R. Coleman, C. Watson, N. White, J. Church and R. Govind: Absolute altimeter verification activities in Bass Strait, Australia
6. X. Dong, P. Woodworth, P. Moore, and R. Bingley: Absolute calibration of TOPEX/POSEIDON and JASON-1 using UK tide gauges, GPS and local precise Geoid model
7. M.Martinez-Garcia, J.J. Martinez-Benjamin, and M.A. Ortiz-Castellon: GPS buoys technology applied to the absolute calibration of space radar altimeters and to the regional mapping the sea surface topography

Abstracts of this meeting have been published by IOC (Intergovernmental Oceanographic Commission, Workshop Report No. 180, UNESCO, 2002) and are available via the SSG's WEB page.

REPORTS provided by the MEMBERS

A. Geiger, H.-G. Kahle: Lightweight offshore buoys

New buoys have been designed based on previous experiences. The newly developed buoys have a displacement of 10 kg which is a significant weight reduction compared to the predecessor. With its 40 cm diameter it can easily be handled. The dimension "of the buoy, weight of battery, receiver, and antenna have optimally been chosen and designed in order to reach the exact floating balance. No ballast is needed to stabilize the buoy or to reach the foreseen floating line in the middle of the spherical buoy. The shell is fabricated from polycarbonate, which is transparent for the microwaves also. Therefore, the whole buoy can be waterproofed sealed containing the battery, receiver and antenna. For present buoy experiments two Novatel DL-4 have been installed. The new pinwheel antenna is used. The operation autonomy reaches about 20 hours. The measurement rate can be set to 0.5 sec sampling interval, producing about 5 MB data per hour. First tests where successfully completed. The buoys will be used to calibrated sea surface determination techniques such as airborne or satellite altimetry. The GGL group is also involved in the calibration of the Jason altimetry.

GeoForschungsZentrum Potsdam (GFZ), Germany

In the context of the German Helmholtz Association's strategic project SEAL (Sea Level Change: An Integrated Approach to its Quantification) the GFZ Potsdam has developed a ruggedized offshore GPS-buoy (Fig. 1), which is able to measure the instantaneous sea level with high accuracy. In May 2002 the buoy has been deployed at an intersection point where the actual RA missions TOPEX, JASON-1, ERS-2, ENVISAT, and GFO-1 intersect. The position is the only point in the German Bight that allows data transmission to a land station via an HF radio link.

Fig.1: *The new buoy on test in a friendly sea*

During the first deployment period till August 2002 in total 26 satellite passes has been acquired. Each data set comprises one hour of multi-sensor measurements centered at the satellite pass time. Differential GPS data is collected at 10Hz sampling rate both on the buoy and a reference station. A dynamic motion sensor monitors tilt angles as well as 3-axis accelerations. Thus, together with the dipping depth, which is collected by an underwater pressure sensor, the GPS antenna height can be reduced to the instantaneous sea surface height for every single GPS measurement. Additionally several meteorological sensors provide data every 10 minutes (e.g. air and water temperature, air pressure, wind direction and speed) and three moored tide gauge sensors in the vicinity and a wave tide recorder beneath the GPS-buoy allow to account for the sea surface slope and significant wave height, respectively.

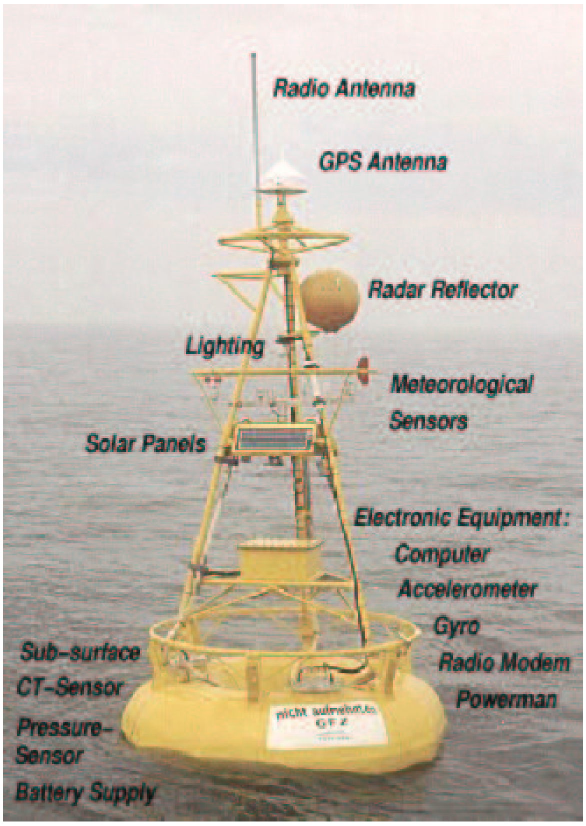


Fig. 1: *GFZ's ruggedized GPS buoy*

The resulting series of coincident measurements is used to derive a range bias for each radar altimeter; the envisaged long-term deployment will allow the monitoring of all missions. Additional information on: http://op.gfz-potsdam.de/seal/.

Institut d'Estudis Espacials de Catalunya (IEEC) & Institut de Ciències del Mar (ICM), Spain
The last activities of the IEEC (Institute for the Space Studies of Catalonia) and the ICM (Institut de Ciències del Mar) were measurements of the sea level with Light GPS buoys, campaigns GRAC-II. Light GPS buoys (2) were used along the Catalan coast (North West Mediterranean) between the months of April and October of 2002, obtaining a set of results that provided measurements of sea level with respect to the Reference Ellipsoid WGS84. The data is being used in order to calibrate ENVISAT RA-2 (altimeter).

45 measurements at 10 different points (approximately at 10 miles from the coast) corresponding to different ENVISAT tracks were performed. The buoys were left to drift freely around the nominal point within a radius of 1 mile. These GPS buoys recorded data during a period of 3 hours centered in the ENVISAT overpass time. Moreover, a reference GPS ground station placed in the coast close to the ENVISAT point was used to derive an estimate of the tropospheric delay. An example of the 45 reports generated is [1].

The principle of this technique is based in the precise geocentric positioning of a GPS antenna placed inside a life-safer. The time series of the antenna phase geocentric location can be translated using GIPSY software to sea level estimates, with single errors of few centimeters (1 Hz estimate) and averaged values of 1 cm uncertainty. During the resent EGS/EUG/AGU a poster was presented [2].

[1] GRAC-II - Preliminary results of 27-MAY-2002 experiment # 12. IEEC-CSIC Research Unit. May 2002. Contact Josep Torrobella, badia@ieec.fcr.es for GRAC-II reports.
[2] Light GPS Buoys used in the Calibration of ENVISAT ALTIMETER. Josep Torrobella & The Grac-II Team, poster presentation, EGS03, Nice, April 2003.

Fig. 1: *The "bi-buoy" system of IEEC and ICM*

The documents are available at ftp://ftp.ieec.fcr.es/ieec/gps/badia/EGS03, files: posterbuoys-egs032.pdf and report147.pdf.

Naval Oceanographic Office, USA
The Naval Oceanographic Office continues to pursue water level measurement using RTK GPS and moored buoy platforms. NAVOCEANO was able to build one buoy and to conduct two preliminary trials; one completed this past April. Data needs still to be analyzed.

Funding at NAVOCEANO for GPS water level determination terminated over a year ago. The existing buoy equipment was provided to hydrographers at NAVOCEANO who now are trying to develop ways to use the buoy in conjunction with small-boat surveys.

Additionally, work was done with the Naval Research Laboratory (NRL) to develop airborne altimetry for ocean circulation over the shelf and slope. We have not yet managed to employ the GPS buoy with the NRL airborne survey. Nevertheless, this remains a goal for both organizations.

Observatoire de la Côte d'Azur - CERGA Bonnefond, P., P. Exertier, O. Laurain, F. Barlier, Y. Ménard, E. Jeansou, A. Orsoni: Radar Altimeter Calibration using a GPS-buoy in Corsica
Observatoire de la Côte d'Azur - CERGA, avenue N. Copernic, F-06130 Grasse
Centre National d'Etudes Spatiales, avenue E. Belin, F-31055 Toulouse

The Absolute calibration site of Corsica is working operationally for calibrating TOPEX/Poseidon and Jason-1 altimeters, using comparisons with tide gauges data. Taking the advantage of this site, a new experiment has been performed to calibrate altimeters: it uses kinematic GPS technique to monitor sea level heights. A reference receiver is placed at a geodetic point (near the lighthouse) while the other is on the sea.
Since February 2000, for each overflight a GPS buoy is placed under the ground track about 10 km off-shore, whenever sea state conditions are not too harsh to ensure safe navigation. GPS and altimetric sea heights are then compared to deduce altimeter biases. Systematic controls are also performed using measurements above the three tide gauges before and after the overflight. Results in the altimeter bias determination is at the same level considering buoy or tide gauges, the GPS data (buoy) also providing an estimation of the wet tropospheric path delay and Significant Wave Height; these parameters are then compared to T/P and Jason-1 measurements. Kinematic GPS (with a Catamaran) has also been used to map the local geoid during two campaigns in 1998 and 1999.

Bonnefond, P., P. Exertier, O. Laurain, F. Barlier Y. Ménard, E. Jeansou, A. Orsoni, B. Haines, D.G. Kubitschek and G. Born, Leveling Sea Surface using a GPS-Catamaran, Marine Geodesy, submitted, 2003.

Fig. 1: *Photo of the GPS-Catamaran at M_2 tide gauge location.*

Fig. 2: *GPS buoy made from a life buoy.*

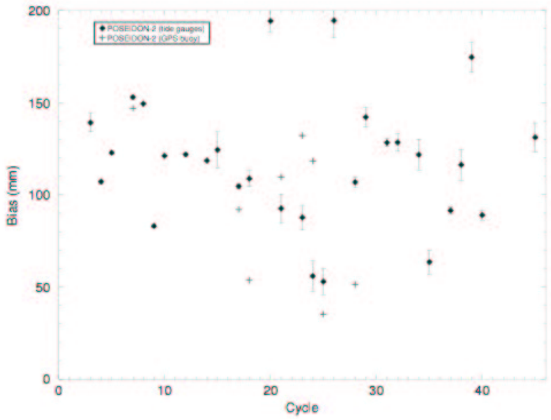


Fig. 3: Jason–1 altimeter bias time series from tide gauges (diamonds) and GPS buoy (crosses). Error bars correspond to the standard errors deduced from the tide gauge determination averaging.

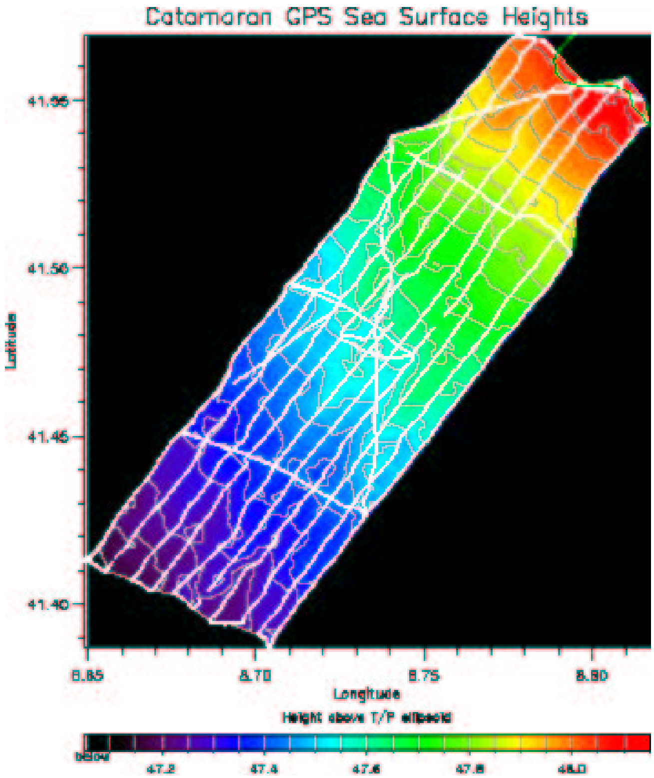


Fig. 4: Contour map of the gridded GPS sea surface heights (in meters). White lines represent data used to compute the surface.

Bonnefond, P., P. Exertier, O. Laurain, Y. Ménard, G. Jan, E. Jeansou, and A. Orsoni, Absolute Calibration of Jason-1 and TOPEX/Poseidon Altimeters in Corsica, Marine Geodesy, submitted, 2003.

Technische Universität Dresden, Institut für Planetare Geodäsie, Germany

A multisensoral measurement system for the determination of sea-level heights at oceanographic platforms was developed at the "Technische Universität Dresden" (Liebsch et. al. 2003). The system consists of a GPS receiver, tide gauges, inclinometers, an air pressure sensor and a data logger. The equipment was installed on two stations of the "Marine Environmental Monitoring Network" (MARNET) in the southern Baltic Sea. MARNET stations are operated by the "Baltic Research Institute Warnemünde" (IOW) on behalf of the "Federal Maritime and Hydrographic Agency" (BSH) of Germany. Since February 2003 both systems are in operation. The Federal Ministry of Education and Research of Germany funded the research project.

G. Liebsch, L. Eberlein and R. Dietrich: Realisation of a multisensoral observation system for the determination of offshore sea-level heights, Poster, EGS-AGU-EUG Joint Assembly, Nice, France, 06-11 April 2003

The Ohio State University (OSU), College of Engineering
GOM – OSU Project Communications

For several years, The Ohio State University (OSU) and Texas A&M University (TAMU) have been working to get access to an oil platform in the Gulf of Mexico (GOM) that is within several kilometers of the triple cover over point for Jason-1, ERS-2, and GPO-1. There were a number of set backs when the lease blocks were sold and new operators had to be contacted. However, that is now history and we can move forward.

Briefly, the project consists of establishing a Continuous Geodetic Reference Station (CGRS) and a tide station on an oil platform in the GOM. The CGRS and tide gauge sensor will be connected by differential levels so the water level time series can be referred to the GPS reference framework to assist with the calibration of the satellite altimeters. In addition to the CGRS and Tide station on an oil platform, we plan to install a GPS unit on a TAMU buoy in the vicinity of the platform. The attached conceptual drawing shows the communications system to be used to access the GPS and tide data and place it on the Internet for direct access by the scientific community.

OSU will do additional GPS buoy (life ring) surveys between the platform and the TAMU/GPS buoy to determine the geoid gradient in the area.

OSU/TAMU plan to conduct site reconnaissance surveys at the platform in the GOM during June 2003. GPS and Tide station installations will begin as soon as station designs are accepted by the platform operator.

The initial action will be to install a Continuous Geodetic Reference Station (CGRS) on the oil platform. The CGRS will require that an antenna be placed on a structurally stable high point with a clear 360º view to the horizon. The antenna will have to be connected to the receiver with low loss coaxial cable. The receiver will require 12 volt DC power supplied via a sealed gel cell battery. The battery will require a float charger operated by 120 volt AC power, or a solar panel, to maintain sufficient battery charge state. The receiver will communicate data to a laptop PC. The laptop PC will require 120 volt AC power. The PC will communicate the data via the digital microwave radio system.

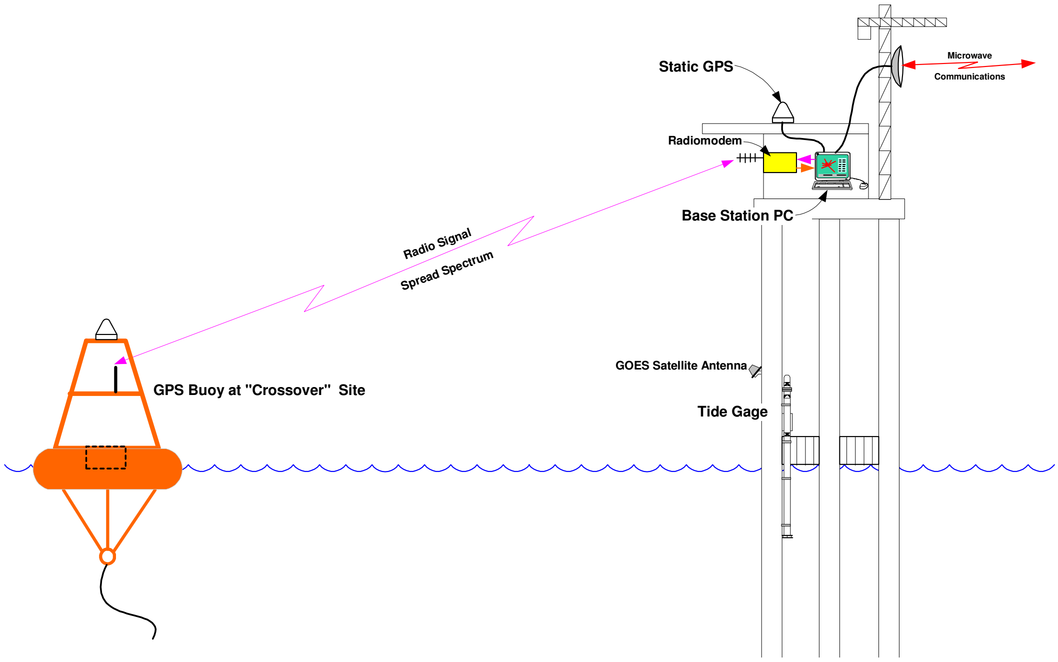


Fig. 1: *communications system for the GOM-OSU project*

Future plans include the installation of a GPS unit on a TAMU TABS buoy located near the triple satellite crossover point, which is within 5 kilometers of the oil platform. This buoy will transmit data via spread spectrum radio modems to the laptop PC on the oil platform. From that point the data will be stored and transmitted in the same manner as the CGRS on the oil platform.

Universität der Bundeswehr München, Institut für Erdmessung und Navigation (IfEN), Germany
For more information about the IfEN activities within the ESA funded project "ENVISAT Radar Altimeter Calibration Using GPS in Buoys", please refer to http://forschung.unibw-muenchen.de/ainfo.php?&id=529.

Universitat Politecnica de Catalunya UPC, Barcelona, Spain
A Spanish/French JASON-1 calibration campaign is being prepared for June 2003 in the area of Ibiza Island in the NW Mediterranean Sea. The main objective, is to map with a new designed, builded and calibrated GPS catamaran, the Mean Sea Surface MSS/local marine geoid gradient in the north area of Ibiza island at one crossing point of an ascending and descending satellite track. One part of a

descending orbit in the SE of the island is also included. Two tide-gauges are installed and operating in the island, one located in San Antonio harbor is a CGPS, the GPS installed on April 7, 2003, the other is located in the Ibiza harbor. This campaign with its associated strategies is expected to have French support (CNES, LEGOS, CERGA and Noveltis) and is based in the experience obtained by three previous campaigns made in March 1999, July 2000 and August 2002 in the Cape of Begur/ Llafranc/ Palamos area. The second and third campaign used data from l'Estartit tide gauge.

Direct absolute altimeter calibration was made from direct overflights using GPS buoys with a toroidal design performed at the ICC based in the original design of the University of Colorado at Boulder. The TOPEX Alt-B bias was estimated processing altimeter and GPS data.

Other main objective of the campaigns was to map with GPS buoys along an ascending T/P ground track about 15-20 km from the NE Spain coast, using coastal tide gauge measurements. In this case indirect absolute altimeter calibration is possible for any other altimetric satellite crossing the MSS, with the only requirement that tide gauges are operational during the overflight. Two tide gauges were placed temporally in Llafranc harbor and was used the data from the permanent L'Estartit tide gauge.

Fig. 1: *GPS buoy of UPC*

University of Tasmania (UTas), Centre for Spatial Information Science, Australia
A short summary of the activities of the UTas group:

1. Our main activity was the work for Jason-1 and T/P RA calibration using GPS bouys. A paper was recently submitted to Marine Geodesy special vol. on Jason-1 cal/val activities.

2. other work involved the use of GPS buoys in the calibration of bottom-mounted and conventional tide gauges, at Davis (Antarctica), Macquarie Island and Burnie, Australia. This work is currently in preparation for journal publication and forms part of a PhD thesis (Chris Watson).

Fig. 1: *The UTas GPS buoy*

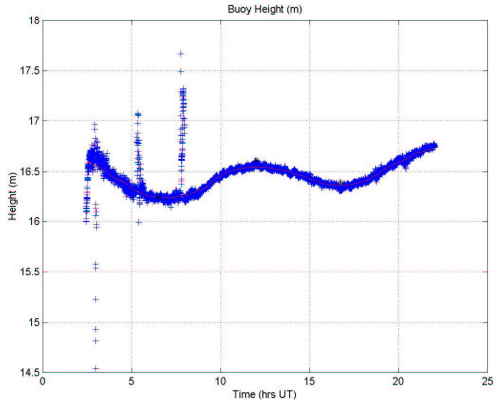


Fig. 2: *The resulting height time series*

Publications by the Members

Blaha, J., G. Born, N. Guinasso, J. Herring, G. Jacobs, F. Kelly, R. Leben, R. Martin, G. Mellor, P. Niiler, M. Parke, R. Patchen, K. Schaudt, W. Scheffner, C. Shum, C. Ohlmann, W. Sturges, G. Weatherly, D. Webb and H. White: Gulf of Mexico ocean monitoring system, Oceanography, 13(2), 2000.

Bonnefond, P., P. Exertier, O. Laurain, F. Barlier Y. Ménard, E. Jeansou, A. Orsoni, B. Haines, D.G. Kubitschek and G. Born, Leveling Sea Surface using a GPS-Catamaran, Marine Geodesy, submitted, 2003.
Bonnefond, P., P. Exertier, O. Laurain, Y. Ménard, G. Jan, E. Jeansou, and A. Orsoni, Absolute Calibration of Jason-1 and TOPEX/Poseidon Altimeters in Corsica, Marine Geodesy, submitted, 2003.

Calmant, S., C. Shum, K. Cheng, W. Scherer and M. Bevis: Earthquake-related offsets in sea levels recorded by Tide Gauges: 2 recent examples in Vanuatu, South West Pacific, Workshop on crustal motion and sea level change, Toulouse, France, September 17-19, 2002.

Calmant, S., K. Cheng, and C. Shum: Sea level series and GPS surveys along the ground tracks of satellite altimeters overflying the tide gauges of the MOTEVAS project, EGS-AGU-EUG Joint Assembly, Nice, France, April 6-11, 2003.

Calmant, S., K. Cheng, C. Shum and D. Martin: Radar altimeter absolute calibration using GPS buoy and tide gauges, Fall AGU Meeting, San Francisco, December 6-10, 2002.

Cardellach, E., D. Behrend, G. Ruffini, A. Rius: The Use of GPS buoys in the determination of oceanic variables, Earth Planets and Space, Vol.52, pp 1113-1116, 2000.

Cardellach, E.: GRAC 2000 GPS Buoy Report, included in the GRAC Report, Cardellach, E., April 2001. Contact Jordi Font, jfont@icm.csic.es for GRAC reports.

Cheng, K., C. Shum and S. Calmant: Radar altimeter absolute calibration using GPS buoy and tide gauges, Weikko A. Heiskanen Symposium In Geodesy: Celebrating 50 years in Geodetic Science at the Ohio State University, Ohio State University, Columbus, Ohio, 1-5 October 2002.

Cheng, K., C. Shum, S. Han, M. Parke, K. Snow, Y. Yi, J. Benjamin, D. Mader, and G. Martin: GPS-Buoy water level instrument: Applications for radar altimeter calibration, IAG International Symposium on Gravity, Geoid, and Geodynamics 2000, July 31-August 4, 2000.

Cheng, K., C. Shum, S. Han, Y. Yi, and D. Martin: Application of GPS-buoy water level instrument for radar altimeter calibration, IAG Symposium Series, 123, M. Sideris (eds), 367-372, Springer-Verlag Berlin Heidelberg, 2001.

Cheng, K., C. Shum, Y. Yi, S. Calmant and D. Martin: Radar altimeter absolute calibration using GPS water level measurements, International Association of Geodesy 2001 Scientific Assembly in Budapest, Hungary, September, 2001.

Cheng, K., C. Shum, Y. Yi, S. Calmant, and D. Martin: Absolute radar altimeter calibration using GPS water level measurements, APSG Sea Level Workshop/GLOSS GE7 Meeting, Univ. of Hawaii, Honolulu, Hawaii, April 23-27, 2001.

Cheng, K., S. Calmant and C. Shum: Absolute calibration of satellite radar altimeters in Lake Erie, and Vanuatu, South Pacific, 27th General Assembly of the EGS in Nice, France, April 21-26, 2002.
Cheng, K.: Absolute calibration of radar altimeters using GPS water level measurements, Master Thesis, Ohio State University, March, 2001.

Huff, Lloyd C., Benjamin W. Remondi: GPS Expedition To Tangier Island, Proceedings of the ION 2000 National Meeting; Navigating into the New Millennium, January 26-28, 2000, Anaheim, CA., pp. 323-332

IOC: Abstracts of Presentations at Workshops during the 7th Session of the IOC Group of Experts on the Global Sea Level Observing System (GLOSS), Honolulu, Hawaii, USA, 23-27 April 2001, 2002

Jekeli, C., and P. Dumrongchai: On monitoring vertical datums with satellite altimetry and tide gauge data on large lakes, International Association of Geodesy 2001 Scientific Assembly in Budapest, Hungary, September, 2001.

Jekeli, C., Heights, the Geopotential, and Vertical Datums, Technical Report, Department of Civil and Environmental Engineering and Geodetic Science, Ohio State University, November, 2000.

Kruizinga, G.L.H., B. Haines, J.J. Martinez-Benjamin, M. Martinez-Garcia, J. Talaya, M.A. Ortiz, B. Perez: "The CATALA experiment, preliminary results of ALT-B calibration using GPS buoys off the Catalonian Coast (Spain)", ALT-B Calibration Workshop, Goddard Space Flight Center, Greenbelt, Maryland, USA, 1999.

Kuo, C., Y. Yi, K. Cheng, and C. Shum: Great Lakes monitoring using space geodetic technologies, Weikko A. Heiskanen Symposium In Geodesy: Celebrating 50 years in Geodetic Science at the Ohio State University, Ohio State University, Columbus, Ohio, 1-5 October 2002.

Kuo, C.: Procedure to compute absolute lake level using Topex/Poseidon altimeter data, Technical Memorandum, Laboratory of Space Geodesy and Remote Sensing Research, The Ohio State University, July 27, 2000.

Liebsch, G., K. Novotny, R. Dietrich, and C. Shum: Comparison of multimission altimetric sea-surface heights with tide gauge observations in the Southern Baltic Sea, Marine Geodesy, 25, 213-234, 2002.

Liebsch, G., L. Eberlein and R. Dietrich: Realisation of a multisensoral observation system for the determination of offshore sea-level heights, Poster, EGS-AGU-EUG Joint Assembly, Nice, France, 06-11 April 2003

Martinez-Benjamin, J., M. Martinez-Garcia, J. Garate, J. Martin-Davila, J. Ferrandiz, M. Vigo-Aguiar, M. Ortiz-Castellon, J. Talaya, B. Perez, G. Kruizinga, B. Haines, O. Colombo, B. Chao, C. Shum, M. Parke, S. Han, and K. Cheng: The T/P CATALA altimeter calibration campaign, Spring AGU Meeting, Washington D.C. May 30-June 3, 2000.

Martinez-Benjamin, J.J., M. Martinez-Garcia, G.L.H. Kruizinga, B. Haines, M. Ortiz, J. Talaya, J. Garate, J. Davila, J. Ferrandiz, M. Vigo-Aguiar, B. Perez, E. Alvarez: "The CATALA Experiment: Absolute Calibration of TOPEX Altimeter-B using GPS buoys in the NW-Mediterranena sea", POSTER, The Ocean Observing System for Climate, OCEANOBS 99, St Raphael, France, 1999.

Martinez-Benjamin, J.J., M. Martinez-Garcia, G.L.H. Kruizinga, B. Haines, M.A. Ortiz, J. Talaya, B. Perez, E. Alvarez, J. Garate, J.M. Davila, J.M. Ferrandiz, M.I. Vigo-Aguiar: "The CATALA campaigns: indirect calibration technique for ENVISAT altimeter calibration", ERS-ENVISAT SYMPOSIUM, Gothenburg, Sweden, 2000.

Martinez-Benjamin, J.J., M. Martinez-Garcia, M. Ortiz, J. Talaya, J.Garate, J. Davila, J. Ferrandiz, M. Vigo-Aguiar, B. Perez, E. Alvarez: "The TOPEX/POSEIDON and JASON-1 Calibration Campaigns in the Cape of Begur and Ibiza Island Regions", POSTER, TOPEX/POSEIDON/Jason-1 Science Working Team Meeting, Miami, USA, 2000.

Martinez-Benjamin, J.J., M. Martinez-Garcia, M.A. Ortiz, J. Talaya, G.L.H. Kruizinga, B. Haines, J. Garate, M. Davila, JM. Ferrandiz, M.I. Vigo-Aguiar, B. Perez, E. Alvarez, O. Colombo, B. Chao, CK. Shum: "The TOPEX/POSEIDON CATALA Altimeter Calibration Campaign", POSTER, American Geophysical Union, AGU-2000 Spring meeting, Washington, USA, 2000.

Martinez-Benjamin,J.J., M. Martinez-Garcia, M.A. Ortiz: "Validation of TOPEX/POSEIDON GDR by independent techniques", POSTER, XXVI General Assembly of the European Geophysical Society (EGS), Nice, France, 2001.

Martinez-Garcia, M., G.L.H. Kruizinga, B. Haines, J.J. Martinez-Benjamin, M.A. Ortiz, J. Talaya, J. Garate, M. Davila: "PRELIMINARY RESULTS OF THE GPS BUOYS DATA PROCESSING IN THE NORTH WESTERN MEDITERRANEAN SEA", POSTER, International Union of Geodesy and Geophysiscs, IUGG, 18-30 July 1999, Birmingham.

Martinez-Garcia, M., J.J. Martinez-Benjamin, M.A. Ortiz: "Analysis and Strategies applied to the GPS buoys data for the TOPEX ALT-B Absolute Calibration in the NW-Mediterranean", POSTER, TOPEX/POSEIDON/Jason-1 Science Working Team Meeting, Miami, USA, 2000.

Martinez-Garcia, M., J.J. Martinez-Benjamin, M.A. Ortiz: "Strategies with GPS for the navigation of buoys", POSTER, GNSS-2001, Sevilla, Spain, 2001.

Moore, T., Close, G., Lee, C., Moore, R.: RiGHt on the Water: River Monitoring Using GPS Heighting, galileo's World, Autumn 2000, pp. 22-27

Moore, T., Close, G., Moore, R.: RiGHt: River Livel Monitoting using GPS Heighting, Proc ION GPS 2000, 13th International Technical Meeting of the Sattelite Division of the Institute of Navigation, 8 pages, Salt Lake City, USA, September 2000.

Moore, T., Zhang, K., Close, G., Moore, R.: Real Time River Level Monitoring using GPS Heighting, GPS Solutions, Vol 4, No 2, ISSN 1080-5370, pp 63 - 67, Fall 2000.

Ortiz, M.A., M. Martinez-Garcia, J.J. Martinez-Benjamin: "GPS buoys for altimeter calibration campaigns", POSTER, GNSS-2001, Sevilla, Spain, 2001.

Schöne, T., A. Braun, C. Reiber, M. Rentsch, and C. Shum: Concept for using GPS-Buoys for RA drift monitoring, ERS-ENVISAT Symposium, Gothenbury, Sweden, 2000.

Schöne, T., A. Braun, C. Reigber: Altimetrie und Meeresspiegel - Möglichkeiten und Grenzen der Beobachtung, Zürich, GAIA 10 (2001) 3, 226-229

Schöne, T., A. Braun, Chr. Reigber: Kontinuierliche Überwachung von Pegelstationen und GPS Hochseebojen, Deutscher Hydrographentag 2001, Potsdam, 2001

Schöne, T., M. Forberg, R. Galas, C. Reigber: GPS-buoys for lifetime RA drift monitoring, AGU Fall Meeting 2002, EOS Trans. AGU, 83(47), Fall Meet. Suppl., Abstract OS52A-0189, 2002

Schueler, T., Zimmermann, B., B. Riedl, G. W. Hein: Radar Altimeter Calibration of the Envisat Satellite: An Autonomous System of High-Precision for Instantaneous Sea Surface Height Determination Proceedings of NTM 2003 – National Technical Meeting, 22-24 January 2003, Anaheim, CA, USA, in press

Shannon, B., D.M. Martin: Kinematic GPS observations to establish a mean lower low water dredging datum directly in a navigation channel, http://op.gfz-potsdam.de/altimetry/SSG_buoys/

Shum, C. K., C. Jekeli, C. Y. Kuo, and Y. Yi: Monitoring lake level changes using satellite altimetry and GPS-buoys, National Sea Grant College Program a Program Assessment Team (PAT) visit, Ohio State

Shum, C., C. Kuo, Y. Yi and C. Zhao: Long-term global sea level change observed by altimetry and tide gauges, International Association of Geodesy 2001 Scientific Assembly in Budapest, Hungary, September, 2001.

Shum, C., D. Brzezinska, B. Hazelton, J. Kwon and C. Zhao: The Ohio State University IGS LEO GPS Pilot Project and Associate Analysis Center, IGS LEO Pilot Project Meeting, GFZ, Potsdam, Germany, February 6-8, 2001.

Shum, C., D. Brzezinska, S. Ge, B. Hazelton, Y. Yi, C. Zhao, M. Bevis, K. Hocke, J. Wickert, G. Jeffress, D. Martin, and M. Szabados: The use of GPS for measuring water vapor and sea level, Fifth Symposium on Integrated Observing Systems, Albuquerque, New Mexico January 15-19, 2001.

Shum, C., K. Cheng, and J. Reutter: Great Lakes monitoring using space geodetic technologies, invited lecture, GLERL Advanced Technology Seminar, Ann Arbor, Michigan, July 9, 2002.

Snay, R., M. Chin, D. Coner, T. Soler, C. Zervas, J. Oyler, M. Craymer, S. Gutman, C. Shum , K. Cheng, and C. Kuo: Great Lakes continuous GPS (CGPS) network for geodynamics, meteorology and safe navigation, Weikko A. Heiskanen Symposium In Geodesy: Celebrating 50 years in Geodetic Science at the Ohio State University, Ohio State University, Columbus, Ohio, 1-5 October 2002.

Torrobella, Josep & The Grac-II Team: Light GPS Buoys used in the Calibration of ENVISAT ALTIMETER., Poster presentation, EGS03, Nice, April 2003.

Torrobella, Josep: GRAC-II - Preliminary results of 27-MAY-2002 experiment # 12. IEEC-CSIC Research Unit. May 2002. Contact Josep Torrobella, badia@ieec.fcr.es for GRAC-II reports.

Tseng, H., C. Shum, C. Zhao, and J. Lin: Absolute sea level measurements from tide gauges and adjacent geodetic station vertical motion solutions, 25th General Assembly of the EGS in Nice, France, April 24-29, 2000.

Watson, C., R. Coleman, N. White, J. Church, R. Govind: Absolute Calibration of TOPEX/Poseidon and JASON-1 using GPS Buoys in Bass Strait, Australia, submitted to Marine Geodesy, Special Volume, 2003

Watson, C.: 'A Contribution to Absolute Sea Level in Tasmania', Thesis for Bachelor of Surveying with Honours, Centre for Spaital Information Science (CenSIS), University of Tasmania, Hobart, p. 197., 1999

Yi, Y., A. Braun, C. Shum, K. Cheng and S. Calment: Envisat RA2 cal/val results, Envisat RA-2/MWR CCVT Sixth Plenary Meeting, ESA/ESRIN, Frascati, Italy, March 25-27, 2003.

Yi, Y., A. Braun, K. Cheng, C. Shum, and S. Calmant: Initial ENVISAT RA-2 Cal/Val results, ENVISAT RA-MWR CCVT Fourth Plenary Meeting, ESA/ESRIN, Frascati, Italy, 3-4 December 2002.

Yi, Y., C. Kuo, C. Shum and C. Jekeli: Long-term Great Lakes water level changes observed by tide gauges and altimetry, International Association of Geodesy 2001 Scientific Assembly in Budapest, Hungary, September, 2001.

Yi, Y., K. Cheng, C. Shum, A. Braun, and S. Calmant: ENVISAT RA-2 calibration/validation, Proc. EGS-AGU-EUG Joint Assembly, Nice, France, April 6-11, 2003.

Zhao. C., C. Shum, Y. Yi, P. Luk, J. Finkelstein, J. Lillibridge, J. McMillan, and M. Rau: GFO radar altimeter data product verifications and ocean circulation studies, IAG Scientific Assembly, Vistas for Geodesy in the New Millennium, Budapest, Hungary, September 2-7, 2001.

Zimmermann, B., T. Schueler, B. Riedl, G. W. Hein, R. J. Biberger: Radar Altimeter Calibration of the ENVISAT Satellite Using an Autonomous GPS-based System of Moored Buoys for Instantaneous Sea

INTERNATIONAL SERVICES:
"THE INTERNATIONAL GPS SERVICE (IGS)"

http://igscb.jpl.nasa.gov

R. Neilan

IGS Mission:
'…to provide the highest quality data and products as the standard for global navigation satellite systems (GNSS) in support of Earth science research, multi-disciplinary applications and education…'

Abstract

The International GPS Service (IGS) is an approved service of the International Association of Geodesy (IAG) since 1994 and of the Federation of Geophysical and Data Analysis Services (FAGS) since 1996. The primary objective of the IGS is to provide a service to support, through GPS data products, geodetic and geophysical research activities. This report will briefly chronicle the past four years of history of the IGS. (See the IAG Travaux series under IAG website Publications listing for previous reports: http://www.gfy.ku.dk/%7Eiag/

Description of the IGS

IGS is based ON over 350 globally distributed permanent GPS tracking sites, three Global Data Centers, many Operational or Regional Data Centers, eight Analysis Centers, an Analysis Center Coordinator, an IGS Reference Frame Coordinator, Network Coordinator, Clock Products Coordinator, and a Central Bureau. The IGS also includes projects dependent on the infrastructure afforded by the IGS. Working groups have been established to focus on the IGS Reference Frame, Troposphere, Ionosphere, and Real-time applications, and data center issues; projects include: Low Earth Orbiters, the International GLONASS Service Pilot Project and TIGA Project for Sea Level studies. An International Governing Board provides policy decisions and directives that guide the development and operations of the IGS (Table 1).

Over 200 institutions and organizations in more than 80 countries contribute to these activities! http://igscb/organization/contorgs.html

The IGS routinely provides various products (Table 2) generated by the IGS Analysis Centers (Table 3):

- High-quality orbits for all GPS satellites (estimated accuracy better than 5 cm), and predicted orbits (~25cm)
- Satellite and station clocks
- Earth Rotation Parameters
- Determination of the tracking site coordinates and velocities in the International Terrestrial Reference Frame (ITRF), in cooperation with the International Earth Rotation Service (IERS)
- Phase and pseudorange observations in daily &/or hourly RINEX files for each IGS tracking site

The tracking data are available at various Data Centers and the combined official IGS orbits and products are available at the Central Bureau and the Global Data Centers. The combined official IGS orbits are produced by the Analysis Center Coordinator located beginning 2003 at the GeoForschungsZentrum Potsdam, Germany.

The Central Bureau is responsible for the day-to-day management of the IGS and is funded by the National Aeronautics and Space Administration (NASA) and located at the Jet Propulsion Laboratory in

Pasadena, California. The Bureau maintains an IGS Information System (CBIS) accessible at: http://igscb.jpl.nasa.gov/

Key developments of the IGS 2000-2003

These reports are generated mid-year for the IUGG meetings, therefore, a few words on the closing of 1999 is in order. The IGS supported the International Symposium GPS '99 held in October in Tsukuba, Japan, which drew nearly 400 participants. IGS conducted a four-hour tutorial planned especially for this symposium that described all aspects of the IGS. At the IGS Board meeting in December of 1999 it was decided to prepare a Call for Participation (CfP) for an IGS Low Earth Orbiter (LEO) Project. This is seen as a new and interesting direction for the IGS, to investigate and evaluate LEO precise orbit determination with on-board GPS receivers and what effect this may have on the IGS products, as well as what service this might be for LEO missions. The Board also approved the creation of a Strategic Planning Group to develop a five-year plan for the IGS. Number of stations in IGS network end of 1999: 229.

2000
Y2K passed quietly for the world and for the IGS network, data and analysis systems. The Strategic Planning Group met a number of times in preparation for a three-day Board retreat that was held in December 2000. A Call for Participation in the LEO project was issued and nearly 30 organizations responded. IGS Reference frame products were generated for the first time. A meeting in Nice during the EGS was held to discuss initiation of an envisioned long-term project to implement a continental reference system for Africa, termed AFREF. Subsequently, the AFREF Mail service was established by IGS Central Bureau. IGS tutorials and outreach were conducted in Cape Town and Harteebeesthoek South Africa. Selective Availability was removed from the GPS system satellites on May 2. A highly successful and enjoyable IGS Network Workshop was held in Oslo Norway in July hosted by the Norwegian Mapping Authority. In September, the US Naval Observatory hosted an IGS Analysis Center Workshop devoted to the time and frequency joint project of the BIPM and IGS. The successful launch of CHAMP, which carries on-board high-quality GPS receivers, was met with enthusiasm by the IGS community and particularly the LEO project participants. SAC-C, an Argentine Space Agency LEO launched in November providing additional GPS flight data. During November, IGS initiated the 'Ultra-rapid Products' making precise orbits and predictions available on a sub-daily schedule. Number of stations in IGS network: 248.

2001
Prof. R. Weber succeeded Prof. T. Springer as IGS Analysis Center Coordinator miraculously fulfilling the University of Bern's commitment to this task through 2002. In February, GeoForschungsZentrum organized a LEO Workshop in Potsdam, Germany, which was co-hosted by the IGS. This was well attended and provided a venue to dsicuss the end-to-end aspects of LEO missions, particularly CHAMP, and their applications which include POD, gravity, atmospheric oocultation, ionospheric tomography. Following the workshop, the first meeting of the IGS Real-time Working Group was held in Potsdam to develop the charter and technical approach to build a real-time IGS sub-network and related processes. Discussions were held in Capetown, South Africa with Surveying and Mapping representatives from most of the southern African nations to discuss and plan a regional realization of AFREF. This was coordinated by South African Surveying and Mapping Director of Survey Services, Richard Wonnacott and took place in conjunction with the CONSAS 2001. The IGS supported a campaign of the Ionospheric Working Group to collect and analyze high-rate data during the period of the total eclipse of the Sun during April. A new project called TIGA led by GFZ was established within the IGS to use GPS observations at tide gauge bench-mark stations in order to assess long-term sea level change. GPS observations will be used to remove the signals from coastal crustal deformation or subsidence from the long-term records. The TIGA has very challenging vertical measurement requirements that will span decades. The project has facilitated analyzing data from stations with high latency data availability – some collected only once per year from remote locations with no access to the internet. This year the IGS published workshop proceedings in conjunction with outside publishing companies: GPS Solutions published the proceedings from the 2000 Analysis Center Workshop; and Physics and Chemistry of the Earth published the IGS Network Workshop proceedings joint with 'Towards Operational Meteorology', the European COST 716 Action "Exploitation of Ground-Based GPS for Climate and Numerical Weather Prediction Applications". (See IGS Website for publication information.) Number of stations in IGS network: 287 stations.

2002
The IGS Strategic Plan 2002-2007 was finalized, published and distributed. The Natural Resources of Canada organized and hosted a full workshop of the IGS titled 'Towards Real-Time'. This was the first workshop in many years that brought all components of the IGS together and it was agreed that this was an excellent workshop. Proceedings of this Ottawa workshop are available at the IGS website. A workshop to discuss the status of the Ionosphere Working Group was held in January at ESA/ESOC in Darmstadt. The LEO twin satellites IGS became a member of a United Nations Action Team on Global Navigation Satellite Systems (GNSS). This Team focuses on the use of GNSS especially in developing countries, and is chartered by the UN Office of Outer Space Affairs to address various GNSS related issues. Recommendations and the Team's report will be submitted to the Committee on the Peaceful Uses of Outer Space (COPUOS) in preparation of the next meeting of UNISPACE in 2004. IGS assisted in the organization of the UN Regional GNSS Workshop in Lusaka, Zambia in July and met there with a number of responsible people from many African nations to further discuss and plan the establishment of a continental reference system for Africa (AFREF). The LEO mission GRACE launched successfully promising additional data for the LEO Working Group. At the December Governing Board meeting, Prof. Christoph Reigber of GFZ Potsdam completed his term as Chair of the Board and was succeeded by Prof. John Dow of ESA/ESOC. Prof. Gerd Gendt, GFZ, succeeded Prof. Robert Weber, AIUB and Technical University of Vienna, as the Analysis Center Coordinator. A GNSS Working Group is set up with plans to position the IGS to take advantage of the future Galileo and modernized GPS. Due to increasing demands on the data and product access, a Data Center Working Group was approved earlier this year. IGS timescale activities moved from USNO to Naval Research Lab. Number of stations in IGS network: 348 Stations.

2003
The key activities of the IGS this year are implementation of the IGS Strategic Plan and preparations to celebrate the 10^{th} Anniversary of the IGS at a Symposium in Bern in March 2004.

Key elements of the IGS strategic plan 2002-2007

Mission
The International GPS Service is committed to providing the highest quality data and products as the standard for global navigation satellite systems (GNSS) in support of Earth science research, multidisciplinary applications, and education. These activities aim to advance scientific understanding of the Earth system components and their interactions, as well as to facilitate other applications benefiting society.

Long-Term Goals and Objectives
- Provide the highest quality, reliable GNSS data and products, openly and readily available to all user communities.
- Promote universal acceptance of IGS products and conventions as the world standard.
- Continuously innovate by attracting leading-edge expertise and pursuing challenging projects and ideas.
- Seek and implement new growth opportunities while responding to changing user needs.
- Sustain and nurture the IGS culture of collegiality, openness, inclusiveness, and cooperation.
- Maintain a voluntary organization with effective leadership, governance, and management.

Strategies of the IGS
To achieve the long-term goals and objectives of the IGS, three key strategies are identified:

- Strategy 1: Ensure delivery of "world-standard" GPS (and other GNSS) data and products, providing the standards and specifications globally.
- Strategy 2: Pursue new opportunities for growth to improve the services and serve a broader range of users.
- Strategy 3: Continuously improve the effectiveness of the IGS organization

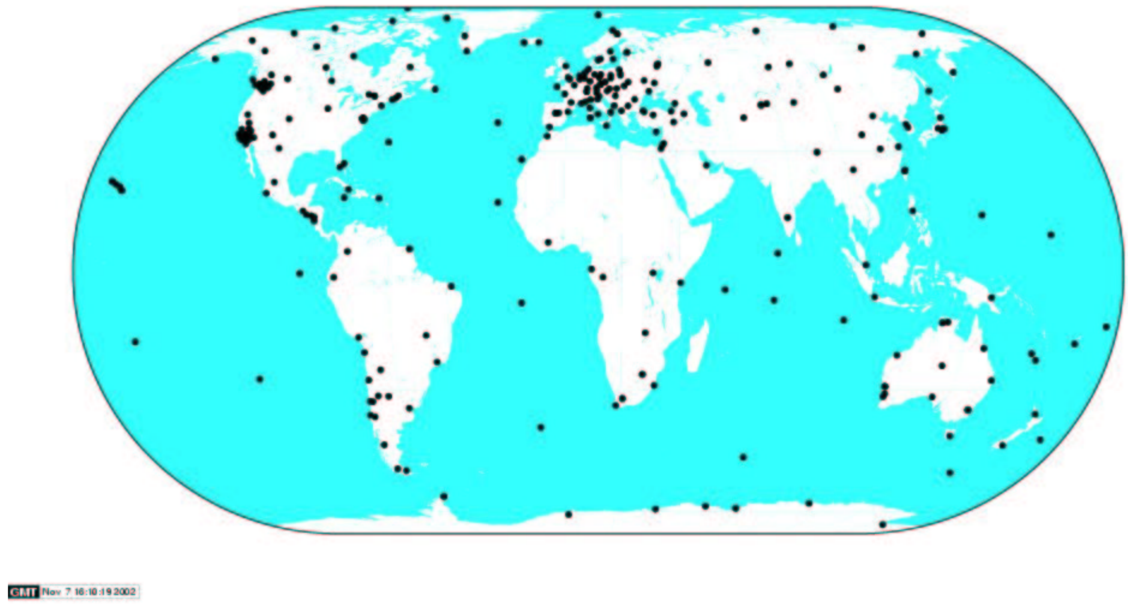


Figure 1. *Station locations of the IGS Tracking Network, late 2002.*

The full text of the IGS Strategic Plan can be found at: http://igscb/overview/pubs.html or ftp://igscb.jpl.nasa.gov/igscb/resource/pubs/IGS_sp.pdf

This document contains more details on the plan, a sgood historical summary of the IGS, a description of each component and a listing of all participating organizations. A copy can be obtained by contacting the Central Bureau.

Links to IGS Organizations:

http://igscb/organization/centers.html

Listing of the 127 IGS Associate members

http://igscb/organization/assocmem.html

IGS Publications:

http://igscb/overview/pubs.html

Acknowledgments

The contributions of the participating agencies worldwide have made the IGS an incredibly successful organization. Coordination of this report was performed by the IGS Central Bureau located at the Jet Propulsion Laboratory, California Institute of Technology and sponsored by the National Aeronautics and Space Administration.

Table 1. The IGS Governing Board Members and Former Members, *terms as noted. Terms begin on January 1 of the stated year and conclude on December 31 of the stated year. Terms of office are generally 4 years for the elected members, and two years for working group or project chairs.*

GB MEMBER 2002	INSITITUTION & COUNTRY	FUNCTIONS	TERM

Christoph Reigber	GeoForschungsZentrum Potsdam, Germany	Chair, Appointed (IGS)	1999-2002
Norman Beck	Natural Resources Canada	Network Representative	2002-2005
Gerhard Beutler	University of Bern, Switzerland	IAG Representative	---
Claude Boucher	Institut Geographique National, ITRF, France	IERS Representative to IGS	---
Carine Bruyninx	Royal Observatory, Belgium	IGS Representative to the IERS	2000-2003
Mark Caissy	Natural Resources Canada	Real-time Working Group, Chair	2001-2002
Loic Daniel	Institut Geographique National, ITRF, France	Data Center Representative	2002-2005
John Dow	ESA/European Space Operations Center, Germany	Network Representative	2000-2003
Joachim Feltens	ESA/European Space Operations Center, Germany	Ionosphere Working Group, Chair	1999-2002
Remi Ferland	Natural Resources Canada	IGS Reference Frame Coordinator	1999-2002
Gerd Gendt	GeoForschungsZentrum Potsdam, Germany	Troposphere Working Group, Chair	1999-2002
Tom Herring	Massachusetts Institute of Technology, USA	IAG Representative	---
John Manning	Australian Survey and Land Information Group	Appointed (IGS)	2000-2003
Ruth Neilan	IGS Central Bureau, Jet Propulsion Laboratory	Director of IGS Central Bureau	---
To be appointed		FAGS Representative	---
Carey Noll	Goddard Space Flight Center, USA	Data Center Working Group, Chair	2002-2004
Jim Ray	U. S. Naval Observatory, USA	Analysis Representative & Precise Time Transfer Project, Co-Chair	2002-2005
Markus Rothacher	Technical University of Munich, Germany	Analysis Representative	2000-2003
Tilo Schoene	GeoForschungsZentrum Potsdam, Germany	TIGA Pilot Project, Chair	2001-2003
Robert Serafin	Natl. Center for Atmospheric Research, USA	Appointed (IGS)	1998-2005
Jim Slater	Natl. Imagery and Mapping Agency, USA	GLONASS Pilot Project, Chair	2000-2002
Robert Weber	University of Bern, Switzerland	Analysis Center Coordinator	2001-2002
To be appointed		LEO Working Group, Chair	1999-2000
Peizhen Zhang	China Seismological Bureau, Insitute of Geology	Appointed (IGS)	2002-2005
Jim Zumberge	Jet Propulsion Laboratory, USA	Analysis Representative	2000-2003
Angelyn Moore	IGS Central Bureau, Jet Propulsion Laboratory	Board Secretariat, Network Coordinator	---

FORMER MEMBER	GB INSTITUTION & COUNTRY	SERVICE
Yehuda Bock	Scripps Institution of Oceanography, USA	1994-1999
Mike Bevis	University of Hawaii, USA	1998-2001

Geoff Blewitt	University of Nevada, Reno, USA	1996-2001
Bjorn Engen	Norwegian Mapping Authority	1994-2001
Martine Feissel	International Earth Rotation Service, France	1994-1995
Teruyuki Kato	Earthquake Research Institute, University of Tokyo, Japan	1994-1995
Jan Kouba	Natural Resources Canada	1994-1999
Gerry Mader	National Geodetic Survey, National Oceanic and Atmospheric Administration, USA	1994-1997
Bill Melbourne	Jet Propulsion Laboratory, USA	1994-1999
Ivan Mueller	Ohio State University, USA	1994-1999
Paul Paquet	Royal Observatory of Belgium	1999-2002
David Pugh	Southhampton Oceanography Center, UK	1996-1998
Bob Schutz	Center for Space Research, University of Texas-Austin, USA	1994-1997
Tim Springer	University of Bern, Switzerland	1999-2000
Mike Watkins	Jet Propulsion Laboratory, USA	1999-2001
Pascal Willis	Institut Geographique National, France	1999

Table 2. IGS Product Tables 2002

GPS Satellite Ephemerides/Satellite & Station Clocks
[GPS Broadcast values included for comparison]

	ACCURACY	LATENCY	UPDATES	SAMPLE INTERVAL
Broadcast	~260 cm/~7 ns	real time	--	daily
Predicted (Ultra-Rapid)	~25 cm/~5 ns	real time	twice daily	15 min/15 min
Rapid	5 cm/0.2 ns	17 hours	daily	15 min/5 min
Final	<5 cm/0.1 ns	~13 days	weekly	15 min/5 min

GLONASS Satellite Ephemerides

Final	30 cm	~4 weeks	weekly	15 min

Geocentric Coordinates of IGS Tracking Stations (>130 sites)

Final horizontal/vertical positions	3 mm/6 mm	12 days	weekly	weekly
Final horizontal/vertical velocities	2 mm per yr/3 mm per yr	12 days	weekly	weekly

Earth Rotation Parameters

Rapid polar motion/PM rates/	0.2 mas/0.4 mas per day/	17 hours	daily	daily
length-of-day	0.030 ms			
Final polar motion/PM rates/	0.1 mas/0.2 mas per day/	~13 days	weekly	daily
length-of-day	0.020 ms			

Atmospheric Parameters

Final tropospheric	4 mm zenith path delay	< 4 weeks	weekly	2 hours

Ionospheric TEC grid (under development)

Table 3. The IGS Analysis Centers

IGS Analysis Centers	
CODE Astronomical Institute-University of Bern	Switzerland
European Space Operations Center / European Space Agency	Germany
FLINN Analysis Center, Jet Propulsion Laboratory/Caltech,NASA	USA
GeoForschungsZentrum Potsdam	Germany
National Geodetic Survey, Geosciences Research Lab, NOAA	USA
Natural Resources Canada	Canada
US Naval Observatory	USA
Scripps Institution of Oceanography	USA

INTERNATIONAL SERVICES:
"INTERNATIONAL LASER RANGING SERVICE (ILRS)"

M. R. Pearlman, C. E. Noll and W. Gurtner

Contributions of the ILRS

The ILRS collects, merges, analyzes, archives and distributes Satellite Laser Ranging (SLR) and Lunar Laser Ranging (LLR) observation data sets of sufficient accuracy to satisfy the objectives of a wide range of scientific, engineering, and operational applications and experimentation. The basic observable is the precise time-of-flight of an ultrashort laser pulse to and from a satellite, corrected for atmospheric delays and spacecraft center-of-mass. These data sets are used by the ILRS to generate fundamental data products, including: accurate satellite ephemerides, Earth orientation parameters, three-dimensional coordinates and velocities of the ILRS tracking stations; time-varying geocenter coordinates, static and time-varying coefficients of the Earth's gravity field, fundamental physical constants, lunar ephemerides and librations, and lunar orientation parameters

Organization and role of the ILRS

The ILRS Tracking Stations range to a constellation of artificial satellites and the Moon with state-of-the-art laser ranging systems and transmit their data on an hourly basis to an Operations or Data Center. Stations are expected to meet ILRS data accuracy, quantity, and timeliness requirements, and their data must be regularly and continuously analyzed by at least one Analysis or mission-specific Associate Analysis Center. Each Tracking Station is typically associated with one of the three regional subnetworks: National Aeronautics and Space Administration (NASA), EUROpean LASer Network (EUROLAS), or the Western Pacific Laser Tracking Network (WPLTN).

Operations Centers collect and merge the data from the tracking sites, provide initial quality checks, reformat and compress the data if necessary, maintain a local archive of the tracking data, and relay the data to a Data Center. Operational Centers may also provide the Tracking Stations with sustaining engineering, communications links, and other technical support. Tracking Stations may perform part or all of the tasks of an Operational Center themselves.

Global Data Centers are the primary interfaces between the Tracking Stations and the Analysis Centers and outside users. They receive and archive ranging data and supporting information from the Operations and Regional Data Centers, and provide these data on-line to the Analysis Centers. They also receive and archive ILRS scientific data products from the Analysis Centers and provide these products on-line to users. Regional Data Centers reduce traffic on electronic networks and provide a local data archive.

Analysis Centers receive and process tracking data to produce ILRS products. They are committed to produce the products on a routine basis for delivery to the Global Data Centers and the IERS using designated standards. Full Analysis Centers routinely process the global LAGEOS-1 and LAGEOS-2 data and provide Earth orientation parameters on a weekly or sub-weekly basis. They also produce other products such as station coordinates and velocities and geocenter coordinates on a schedule consistent with IERS requirements and provide a second level of data quality assurance in the network. Associate Analysis Centers produce specialized products, such as time-varying gravity field measurements, fundamental constants, satellite predictions, precision orbits for special-purpose satellites, regional geodetic measurements, and data products of a mission-specific nature. Associate Analysis Centers are also encouraged to perform quality control functions through the direct comparison of Analysis Center products and the creation of "combined" solutions using data from other space geodetic techniques.

Lunar Analysis Centers produce LLR products such as lunar ephemeris, lunar libration, and Earth rotation (UT0 - UT1). In the field of relativity, LLR is used for the verification of the equivalence principle, estimation of geodetic precession, and examination of the relative change in G.

Central Bureau

The ILRS Central Bureau (CB) is responsible for the daily coordination and management of ILRS activities. It facilitates communications and information transfer and promotes compliance with ILRS network standards. The CB monitors network operations and quality assurance of the data, maintains all ILRS documentation and databases, and organizes meetings and workshops. In order to strengthen the ILRS interface with the scientific community, a Science Coordinator and an Analysis Specialist within the CB take a proactive role to enhance dialogue, to promote SLR goals and capabilities, and to educate and advise the ILRS entities on current and future science requirements related to SLR. The Science Coordinator leads efforts to ensure that ILRS data products meet the needs of the scientific community and there is easy online access to all published material (via Abstracts) relevant to SLR science and technology objectives.

The CB has been actively providing new facilities to expedite communication and performance review, and adding to the technical and scientific database. The information available via the ILRS Web Site has grown enormously since its inception, and many new links to related organizations and sites have been established. The site provides details and photographic material on the ILRS, the satellites and campaigns, individual SLR station characteristics, a scientific and technical bibliography on SLR and its applications, current activities of the Governing Board, Working Groups, and Central Bureau, meeting minutes and reports (including annual reports), tracking plans, and much more. An enhanced search capability has recently been added to the website.

The Central Bureau maintains the web site as the primary vehicle for the distribution of information within the ILRS community. The site, which can be accessed at http://ilrs.gsfc.nasa.gov, includes the following major topic titles: About the ILRS, What's New, Working Groups, Satellite Missions, Global Network, Data and Products, Science and Analysis, Engineering and Technology, Publications, Contact ILRS, Links, Site Map, and Search. Mirrored sites for the ILRS web site are available at the Communications Research Laboratory (CRL) in Tokyo and the European Data Center (EDC) in Munich. The site also includes SLR related bibliographies, Earth science links, historical information, collocation histories, and mail exploders. An on-line brochure provides charts for SLR presentations. A hard copy library of early documentation has been assembled and is listed in the on-line bibliography. An ILRS Reference Card is available to provide easy online access to much of this material and to targeted email exploders.

Governing board and working groups

The Governing Board (GB) is responsible for the general direction of the service. It defines official ILRS policy and products, determines satellite-tracking priorities, develops standards and procedures, and interacts with other services and organizations. There are sixteen members of the Governing Board (GB) - three are ex-officio, seven are appointed, and six are elected by their peer groups (see Table 1). A new Board was installed in November 2002 at the 13th International Workshop in Washington D.C.

Table 1. *ILRS Governing Board (as of May 2003)*

Hermann Drewes	Ex-Officio, CSTG President	Germany
Michael Pearlman	Ex-Officio, Director ILRS Central Bureau	USA
Carey Noll	Ex-Officio, Secretary, ILRS Central Bureau	USA
Werner Gurtner	Appointed, EUROLAS , Governing Board Chair	Switzerland
Giuseppe Bianco	Appointed, EUROLAS	Italy
David Carter	Appointed, NASA, Missions Working Group Coordinator.	USA
Jan McGarry	Appointed, NASA, Data Formats & Procedures WG Deputy Coordinator	USA
Ben Greene	Appointed, WPLTN	Australia
Hiroo Kunimori	Appointed, WPLTN, Missions WG Deputy Coordinator	Japan
Bob Schutz	Appointed, IERS Representative to ILRS	USA
Graham Appleby	Elected, Analysis Rep., Signal Processing WG Coordinator	UK
Ron Noomen	Elected, Analysis Rep. , Analysis WG Coordinator	Netherlands

Wolfgang Seemueller	Elected, Data Centers Rep. , Data Formats & Procedures WG Coordinator	Germany
Peter Shelus	Elected, Lunar Rep., Analysis WG Deputy Coordinator	USA
Georg Kirchner	Elected, At-Large, Networks and Engineering WG Coordinator	Austria
Ulrich Schreiber	Elected, At-Large, Networks and Engineering WG Deputy Coordinator	Germany

Within the GB, permanent (Standing) or temporary (Ad-Hoc) Working Groups (WG's) carry out policy formulation for the ILRS. At its creation, the ILRS established four Standing WG's: (1) Missions, (2) Data Formats and Procedures, (3) Networks and Engineering, and (4) Analysis. In 1999, an Ad-Hoc Signal Processing WG was organized to provide improved satellite range correction models to the analysts. The Working Groups are intended to provide the expertise necessary to make technical decisions, to plan programmatic courses of action, and are responsible for reviewing and approving the content of technical and scientific databases maintained by the Central Bureau. All GB members serve on at least one of the four Standing Working Groups, led by a Coordinator and Deputy Coordinator (see Table 1).

The working groups have attracted talented people from the general ILRS membership who have contributed greatly to the success of these efforts. The Missions WG has formalized and standardized the mission documentation required to obtain ILRS approval for new missions and campaigns. They continue to work with new missions and campaign sponsors to develop and finalize tracking plans and to establish recommended tracking priorities. The Data Formats and Procedures WG has been reviewing existing formats and procedures, rectifying anomalies, providing standardized documentation through the web site, and setting up study subgroups and teams to deal with more complicated or interdisciplinary issues. The Networks and Engineering WG has (1) developed the new ILRS Site and System Information Form, which is being distributed to the stations to keep the engineering database current, (2) provided a new online satellite-link analysis capability for system design and performance evaluation, and (3) initiated the development of the ILRS technology database. The Analysis WG has been working with the ILRS Analysis Centers to develop a unified set of analysis products presented in the internationally accepted SINEX format. Three associated pilot programs are underway to assess differences among analysis products from the different Analysis and Associate Analysis centers. The Signal Processing Ad-Hoc WG is working on improved center-of-mass corrections and signal processing techniques for SLR satellites.

ILRS Network

The ILRS Network as of May 2003 is shown in Figure 1. Traditionally the network has been strong in the US, Europe, and Australia. Through international partnerships, the global distribution of SLR stations is now improving, especially in the Southern Hemisphere. NASA, CNES and the University of French Polynesia have established SLR operations on the island of Tahiti with MOBLAS-8. In cooperation with the South African Foundation for Research Development (FDR), NASA has relocated MOBLAS-6 to Hartebeesthoek (which already has VLBI, GPS, and DORIS facilities) to create the first permanent Fundamental Station on the African continent. MOBLAS-5, long established by NASA and AUSLIG at Yarragadee, Australia, continues to operate with exemplary performance. Operations at the new Australian station on Mt. Stromlo, which replaced the older Orroral site near Canberra, were going extremely well until a catastrophic forest fire destroyed the site and much of the surrounding area. Reconstruction is now being planned.

The NASA TLRS-3 system at Universidad de San Agustin in Arequipa, Peru, has carried the total SLR tracking load for South America in recent years. BKG (Germany) has now established a new site at Concepción, Chile with its newly developed multi-technique Totally Integrated Geodetic Observatory (TIGO). The TIGO, with SLR, VLBI, GPS and absolute gravimetry technique, now provides the first Fundamental Station in South America. A joint Chinese-Argentine SLR station at the San Juan Observatory in western Argentina is being planned with SLR equipment furnished by the Beijing Astronomical Observatory.

The Peoples' Republic of China has made substantial investment in SLR stations and technology over the past two years. The SLR station in Kunming was recently re-established, bringing the total number of Chinese permanent sites to five (Shanghai, Changchun, Wuhan, Beijing, and Kunming). The data quality and quantity from the permanent Chinese stations continue to improve, most notably at Changchun. The Wuhan SLR station has been recently moved to a site outside the city with significantly better atmospheric seeing conditions. The Shanghai SLR station is slated for relocation this year for similar reasons. A Chinese mobile SLR station has occupied sites in Lhasa and Urumuqi, as part of a national geodetic program. A new Russian SLR station started operations near Moscow in 1999, and permission is being requested from the Russian government to integrate it into international SLR operations.

In Japan, an upgraded SLR station at the Communications Research Laboratory (CRL) in Tokyo is now operational. The four Keystone sites at Kashima, Tateyama, Koganei and Miura have been closed, but the new Global and High Accuracy Trajectory determination System (GUTS) SLR system is being developed by NASDA for deployment at Tanegashima.

During the past four years, there has also been considerable activity in Europe. The new state-of-the-art Matera Laser Ranging Observatory (MLRO) with both SLR and lunar ranging capability is now operational with very impressive performance. The Zimmerwald system has been completely rebuilt, with submission of operational data starting again in early 2000 and routine dual-frequency data starting during the past year. The SLR station in Potsdam has been totally upgraded. The French Transportable Laser Ranging System (FTLRS) was operated at the Ajaccio, Corsica in support of Jason and other altimeter satellites, and is now operating at a site near Crete.

Sites in the United States have been relatively stable over the past several years, with efforts continuing to improve overall performance or reducing the cost of SLR operations. The Maui site has been upgraded. A new LLR station is being built in Apache Point, Washington. Work continues on the SLR2000 prototype with field test planned for fall 2003.

ILRS Tracking Priorities and Campaigns

The ILRS is currently tracking 25 artificial satellites including passive geodetic (geodynamics) satellites, Earth remote sensing satellites, navigation satellites, and engineering missions (see Table 2). The stations with lunar capability are also tracking the lunar reflectors. In response to tandem missions (e.g. GRACE-A/-B) and general overlapping schedules, stations have begun tracking satellites with interleaving procedures. The network continues to support three GLONASS satellites selected by the International GLONASS Pilot Project (IGLOS), a project within the International GPS Service (IGS).

The ILRS assigns satellite priorities in an attempt to maximize data yield on the full satellite complex while at the same time placing greatest emphasis on the most immediate data needs. Priorities provide guidelines for the network stations, but stations may occasionally deviate from the priorities to support regional activities or national initiatives and to expand tracking coverage in regions with multiple stations. Tracking priorities are set by the Governing Board, based on application to the Central Bureau and recommendation of the Missions Working Group.

Since several remote sensing missions have suffered failures in their active tracking systems or have required in-flight recalibration, the ILRS has encouraged new missions with high precision orbit requirements to include retroreflectors as a fail-safe backup tracking system, to improve or strengthen overall orbit precision, and to provide important intercomparison and calibration data with onboard microwave navigation systems.

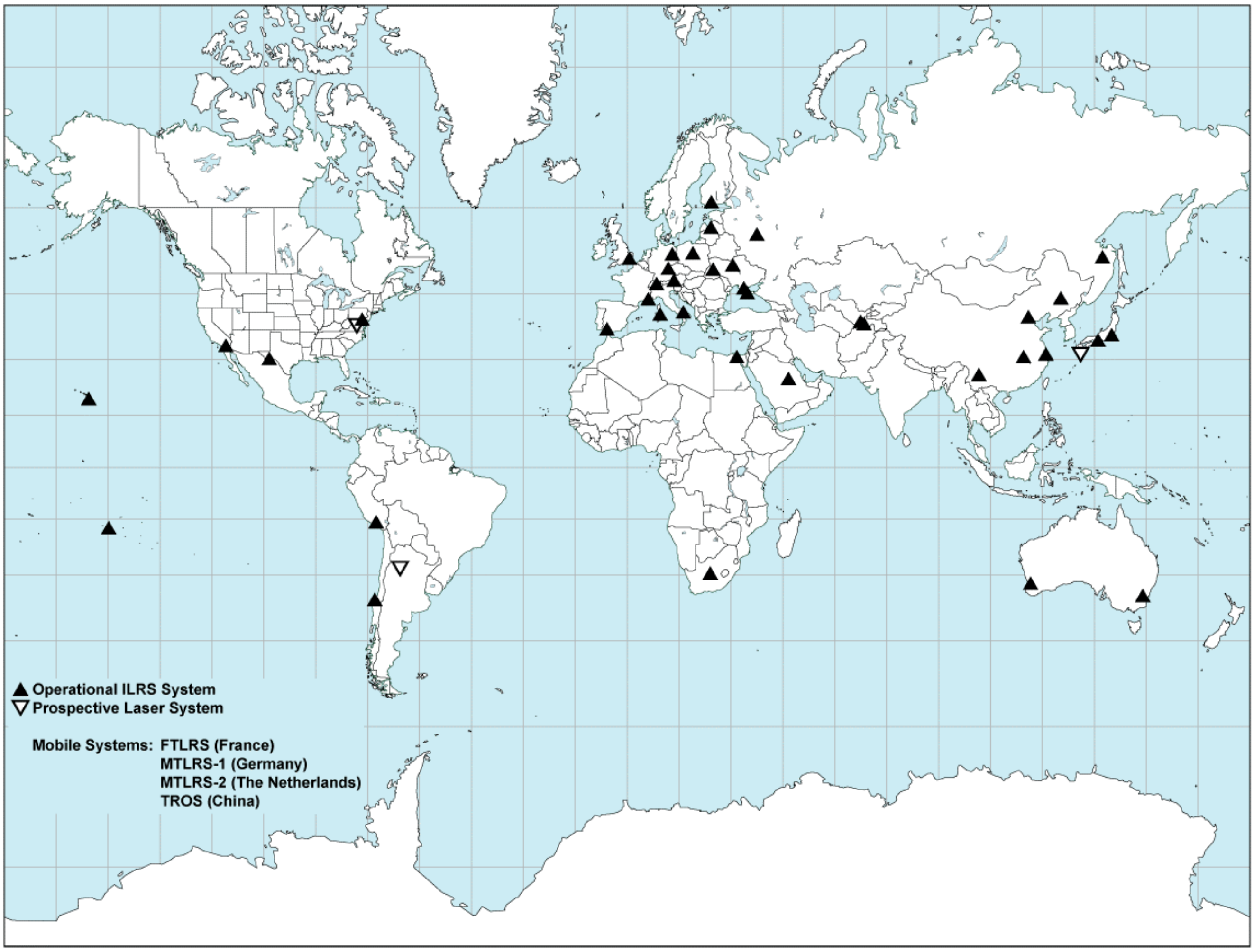


Figure 1. *ILRS Network (as of May 2003)*

Upcomming Missions

At one time, the main task of the international SLR Network was the tracking of dedicated geodetic satellites (LAGEOS, Starlette, etc.). Although we have had requests to revive tracking on older satellites already in orbit (e.g., Beacon-C) to further refine the gravity field with improved accuracy laser data, new requests for tracking are now coming mainly for active satellites. The tracking approval process begins with the submission of a Missions Support Request Form, which is accessible through the ILRS web site. The form provides the ILRS with the following information: a description of the mission objectives; mission requirements; responsible individuals, organizations, and contact information; timeline; satellite subsystems; and details of the retroreflector array and its placement on the satellite. This form also outlines the early stages of intensive support that may be required during the initial orbital acquisition and stabilization and spacecraft checkout phases. A list of upcoming space missions that have requested ILRS tracking support is summarized in Table 3 along with their sponsors, intended application, and projected launch dates.

Table 2. *ILRS Tracking Priorities (as of May 2003)*

Satellite Priorities

Priority	Mission	Sponsor	Altitude (km)	Inclination (degrees)	Comments
1	GRACE-A, -B	GFZ/JPL	485-500	89	tandem mission
2	CHAMP	GFZ	429-474	87.27	
3	GFO-1	US Navy	790	108.0	altimetry/no other tracking technique
4	ENVISAT	ESA	796	98.6	tandem with ERS-2 tracking to commence 40 days after launch
5	ERS-2	ESA	800	98.6	tandem with ENVISAT
6	Jason	NASA/CNES	1,350	66.0	tandem with Topex*
7	TOPEX/Poseidon	NASA/CNES	1,350	66.0	tandem with Jason*
8	Starlette	CNES	815-1,100	49.8	
9	Stella	CNES	815	98.6	
10	METEOR-3M	IPIE	1000	99.64	
11	Beacon-C	NASA	950-1300	41	upgraded from campaign to ongoing mission (Jan-02)
12	Ajisai	NASDA	1,485	50	
13	LAGEOS-2	ASI/NASA	5625	52.6	
14	LAGEOS-1	NASA	5850	109.8	
15	Etalon-1	Russian Federation	19,100	65.3	campaign extended indefinitely
16	Etalon-2	Russian Federation	19,100	65.2	campaign extended indefinitely
17	GLONASS-89	Russian Federation	19,100	65	replaced GLONASS-86 as of 20-Mar-03
18	GLONASS-87	Russian Federation	19,100	65	replaced GLONASS-88 as of 20-Feb-02
19	GLONASS-84	Russian Federation	19,100	65	replaced GLONASS-79 as of 22-Feb-01
20	GPS-35	US DoD	20,100	54.2	
21	GPS-36	US DoD	20,100	55.0	
Lunar Priorities					
Priority	Retroreflector Array	Sponsor	Altitude (km)		
1	Apollo 15	NASA	356,400		
2	Apollo 11	NASA	356,400		
3	Apollo 14	NASA	356,400		
4	Luna 21	Russian Federation	356,400		
5	Luna 17	Russian Federation	356,400		

Once tracking support is approved by the Governing Board, the Central Bureau works with the new missions to develop a Mission Support Plan detailing the level of tracking, the schedule, the points of contact, and the channels of communication. New missions normally receive very high priority during the acquisition and checkout phases and are then placed at a routine priority based on the satellite category and orbital parameters. After launch, New Mission Reports with network tracking statistics and operational comments are issued weekly. The Central Bureau monitors progress to determine if adequate support is being provided. New mission sponsors (users) are requested to report at the ILRS Plenary meetings on the status of ongoing campaigns, including the responsiveness of the ILRS to their needs and on progress towards achieving the desired science or engineering results.

Table 3. *Upcoming Missions (as of May 2003)*

							Mission Request

Mission Name	Support Requester	Mission Type	Planned Launch Date	Mission Duration	Altitude (km)	Inclination (deg)	Form Received
ICESat (GLAS)†	NASA USA	Ice Balance, Oceans	January 2003	3-5 years	600	94	yes
GP-B	NASA-JPL USA	Relativity	October 2003	1-2 years	400	90	yes
NPOESS	NASA, NOAA, DoD USA	Atmosphere	April 2013	7 years	833	98.7	yes

Note: †As of May 2003, ICESat tracking approved for only selected ILRS stations

Meetings and Reports

The ILRS organizes semiannual meetings of the Governing Board and General Assembly, which is open to all ILRS Associates and Correspondents. The spring ILRS General Assemblies are generally held in conjunction with the EGS Symposium in Nice, France, and focus more on mission support. The fall meetings are more oriented toward SLR practitioners. A summary of recent ILRS meetings is shown in Table 4. Detailed reports from past meetings can be found on the ILRS web site.

Table 4. *Recent ILRS Meetings (as of May 2003)*

Timeframe	Location	Meeting
September 1999	The Hague, Netherlands	3rd ILRS General Assembly
January 2000	Frankfurt, Germany	Analysis Working Group
April 2000	Nice, France	4th ILRS General Assembly
May 2000	Delft, Netherlands	Analysis Working Group
November 2000	Matera, Italy	12th International Workshop on Laser Ranging
		5th ILRS General Assembly
March 2001	Nice, France	6th ILRS General Assembly and WG Meetings
		Analysis Working Group
September 2001	Toulouse, France	7th ILRS General Assembly (canceled)
April 2002	Nice, France	7th ILRS General Assembly and WG Meetings
		Analysis Working Group
October 2002	Washington, D.C., USA	13th International Workshop on Laser Ranging
		8th ILRS General Assembly and WG Meetings
		Analysis Working Group
April 2003	Nice, France	9th ILRS General Assembly and WG Meetings
		Analysis Working Group

The ILRS Annual Reports are published yearly and summarize activities within the service each year. They are available as hard copy from the CB or online at the ILRS Web Site.

ILRS Analysis Center reports and inputs are used by the Central Bureau for weekly review of station performance and to provide feedback to the stations when necessary. Special weekly reports on on-going campaigns are issued by email. The CB also generates Quarterly Performance Report Cards and posts them on the ILRS web site. The Report Cards evaluate data quantity, data quality, and operational compliance for each tracking station relative to ILRS minimum performance standards. A catalogue of diagnostic methods, for use along the entire data chain starting with data collection at the stations, has emerged from this process and will be made available on the ILRS web site. The evaluation process has been helpful in comparing results from different Analysis and Associate Analysis Centers, a role soon to be assumed by the Analysis Working Group.

INTERNATIONAL SERVICES:
"THE INTERNATIONAL VLBI SERVICE FOR GEODESY AND ASTROMETRY (IVS)"

W. Schlüter
N.R. Vandenberg

Abstract

This report reviews the results and the progress made over time since the establishment of the IVS. It summarizes and qualifies the products generated continuously by VLBI. Prospective developments and wishes for the products and the related observing programs are given. Finally the ambitious goal set by the IAG with its upcoming IGGOS project (International Geodetic Global Observing System) will be realized, which requests a global reference system on the millimeter level consistent over decades. Within IGGOS the VLBI technique will play a key role.

General remarks and the key role of geodetic VLBI

The Very Long Baseline Interferometry (VLBI) technique has been employed in geodesy for nearly 40 years. Covering intercontinental baselines with highest accuracy, monitoring Earth rotation at the state of the art and providing the quasar positions as the best approach to an inertial reference frame, VLBI significantly contributed to the tremendous progress made in geodesy over the last decades. VLBI was a primary tool for understanding the global phenomena changing the "Solid Earth". Today VLBI continuously monitors Earth rotation and its variations and also crustal movements in order to maintain global reference frames, coordinated within the International VLBI Service for Geodesy and Astrometry (IVS) – a Service of the IAG and IAU. Science and applications set the requirements for the realization and maintenance of global reference frames at VLBI's technical limitations. VLBI, as the unique technique for providing a celestial reference frame and for deriving the full set of Earth rotation parameters, plays the fundamental role of generating the basis for many applications and research in the geosciences.

VLBI today is the key technique for monitoring and realizing global reference frames. The importance of global reference frames has increased as space and satellite technologies, e.g. satellite navigations systems, are employed for many applications in research in particular in geosciences and in all kinds of surveying and navigation. For the description of satellite orbits a "quasi" inertial system is required, which does not rotate with the Earth – a celestial reference frame (CRF). Such a system is realized by positions of radio sources and is internationally available as the International Celestial Reference Frame (ICRF). Point positioning on the surface of the earth needs an Earth fixed system – a terrestrial system (TRF). The terrestrial reference frame is realized through stations for which the positions and velocities are determined and known. The most recent realization (the adopted international realization) is the ITRF2000. Both TRF and CRF systems are needed and the relation between both must be known to an accuracy as best we can, in order to meet the broad spectrum of applications. The relation between the CRF and TRF is described by the Earth Orientation Parameters, which fix the Earth rotation axis with respect to the CRF (d□. d□. and by the polar motion parameters x_p and y_p which fix the Earth's crust. The rotation is described by the parameter DUT1 as the difference between the time scale provided by the Earth rotation itself (Universal Time UT1) and the time scale generated by atomic clocks (Universal Time Coordinated UTC).

As all the parameters are changing with time and no model is precise enough for prediction, the parameters have to be derived continuously from observations. Among the geodetic space techniques (Satellite/Lunar Laser Ranging and GPS etc.), VLBI plays a unique role, as it is the only technique which is capable of realizing and maintaining the CRF, of providing the complete set of Earth orientation parameters and in particular of observing DUT1. Due to superior accuracy in the determination of long baselines VLBI dominates in the determination of the ITRF scale. Because subdaily variations in Earth rotation occur, it is important to observe regularly with adequate resolution in time and accuracy. Regular and more dense observations will become a demand with the request for mm-precise reference frames, consistent for decades, that will be set by the IAG within its upcoming project International Global Geodetic Observing System (IGGOS).

International VLBI Service for Geodesy and Astrometry

The International VLBI Service for Geodesy and Astrometry (IVS) is a Service of the International Association of Geodesy (IAG) and of the International Astronomical Union (IAU) and a member of the Federation of Astronomical and Geophysical Data Analysis Services (FAGS). The charter and the basis for international collaboration is given by the Terms of Reference (ToR) accepted by IAG and IAU and by the proposals provided by individual agencies in response to the call for participation.

IVS is an international collaboration of organizations that operate or support Very Long Baseline Interferometry (VLBI) components. The goals are

- to provide a service to support geodetic, geophysical and astrometric research and operational activities,
- to promote research and development activities in all aspects of the geodetic and astrometric VLBI technique,
- to interact with the community of users of VLBI products and to integrate VLBI into a global Earth observing system.

As IVS has no funds of its own, but is tasked by IAG and IAU for the provision of timely, highly accurate products (Earth Orientation Parameters (EOPs), Terrestrial Reference Frame (TRF), Celestial Reference Frame (CRF), etc.), IVS is dependent on the support of individual agencies. Figure 2 shows the global distribution of the IVS components.

In order to maintain the strong requirement for consistency, which is the basis for realizing and maintaining global reference frames such as the CRF and TRF, IVS initially employed and accepted existing infrastructure, observing programs such as the National Earth Orientation Service (NEOS), coordinated by the US Naval Observatory, or the Continuous Observations of the Rotation of the Earth (CORE), initiated by NASA. During its first two years of existence, the efforts of IVS were concentrated on the installation of new components and adoption of new IVS tasks. Coordination of activities within the service took effort, resources and time to mature.

All the activities of the first years are documented in the Annual Reports of the IVS for the years 1999, 2000, 2001 and 2002 [Vandenberg and Baver, 1999, 2001, 2002, 2003]. The first General Meeting was held in Kötzting/Germany in February 2000, the second General Meeting was held in Tsukuba/Japan in February 2002 and several technical meetings concerning analysis and technology aspects were conducted. Proceedings of the General Meetings are available [Vandenberg and Baver 2000, 2002b]

Emphasis was placed on data analysis, coordinated by the Analysis Coordinator. Today six Analysis Centers provide a timely, reliable, continuous solution for the entire set of five Earth Orientation Parameters (EOPs) - two polar motion coordinates, Universal Time 1 determined by the rotation of the Earth minus Coordinated Universal Time (UT1-UTC), two celestial pole coordinates. The IVS Analysis Coordinator makes a combined solution – the official IVS product – as timely input for the IERS and its combination with the GPS, SLR/LLR and DORIS solutions. It turns out that the IVS combined solution gains 20% in accuracy over the single VLBI solutions.

After the initial phase of IVS as a service the question “Are the products appropriate to meet the service requirements?” came up and a Working Group was established at the 5th Directing Board Meeting in February 2001.

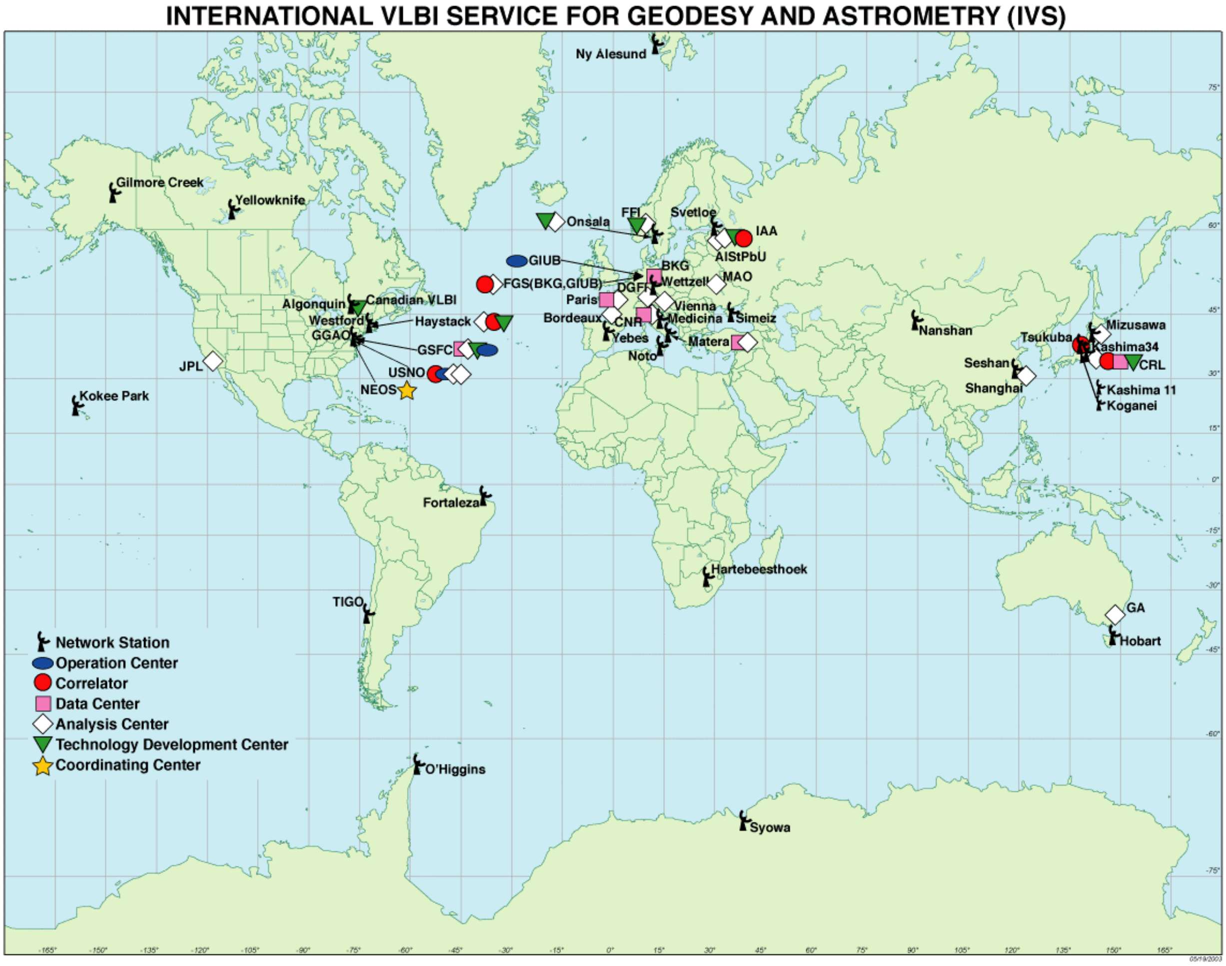


Figure 1: *IVS components and their global distribution*

Review of products and observing programs

At the 4th IVS Directing Board meeting held in September 2000 in Paris, the requirement for reviewing the products and the related observing programs was discussed with the view that IVS must meet its service requirements and improve its products. Because such a review requires overall expertise, a broad discussion and acceptance within the entire community, a Working Group (WG2) for Product Specification and Observing Programs was established at the 5th Directing Board Meeting in February 2001. (The Minutes of all meetings are published and made available on the IVS web site.) The assignment of WG2 was to

- review the usefulness and appropriateness of the current definition of IVS products and suggest modifications,
- recommend guidelines for accuracy, timeliness, and redundancy of products,
- review the quality and appropriateness of existing observing programs with respect to the desired products,
- suggest a realistic set of observing programs which should result in achieving the desired products, taking into account existing agency programs,
- set goals for improvements in IVS products and suggest how these may possibly be achieved in the future,
- present a written report to the IVS Directing Board at its next meeting.

To establish a broad basis for discussion and to secure acceptance in the community, the members were chosen from among experts in the field of geodetic/astrometric VLBI. Led by Professor Harald Schuh from Technical University of Vienna as chair, the following experts are the members of the Working Group:

- *Patrick Charlot, Observatoire Bordeaux/France*
- *Hayo Hase , Bundesamt für Kartographie und Geodäsie, Concepcion/Chile,*
- *Ed Himwich, NVI Inc./Goddard Space Flight Center, Greenbelt/USA,*
- *Kerry Kingham, US Naval Observatory, Washington D.C./USA,*
- *Calvin Klatt, Geodetic Survey Division of Natural Resources Canada, Ottawa/Canda,*
- *Chopo Ma, Goddard Space Flight Center, Greenbelt/USA,*
- *Zinovy Malkin, Institut of Applied Astronomy, St. Petersburg/Russia,*
- *Arthur Niell, MIT Haystack Observatory, Westford-Haystack/USA,*
- *Axel Nothnagel, Geodätisches Institut, Universität Bonn /Germany,*
- *Wolfgang Schlüter, Bundesamt für Kartographie und Geodäsie, Wettzell/Germany,*
- *Kazuhiro Takashima, Geographical Survey Institute, Tsukuba/Japan,*
- *Nancy Vandenberg , NVI Inc./Goddard Space Flight Center, Greenbelt/USA*

A report of the WG2 was presented in November 2001. The IVS Directing Board reviewed the final version and accepted it for publication ,which is available under http://ivscc.gsfc.nasa.gov/WG/wg2 or in the Annual Report 2001 [Vandenberg and Baver, 2002]. The report is the basis for continuous improvements and for related research within IVS over the next few years. The results of the report will help IVS meet the objectives and future requirements set up by the IAG and IAU for research in the geosciences and astronomy.

Products and prospective improvements in the next few years

IVS is required to deliver products according to its ToR. Some products are uniquely provided by VLBI such as UT1, CRF, and celestial pole, other products are available from more than one technique: Polar Motion, EOP, TRF, and certain geodynamical and physical parameters. The IVS products can be defined in terms of their accuracy, reliability, frequency of observing sessions, temporal resolution of the estimated parameters, time delay from observing to final product, and frequency of solutions. The current situation with IVS products is described in detailed tables in the WG2 report. The main IVS products, their current accuracies and the goals are summarized in table 1.

As of late 2001, IVS products were generated from ~3 days/week observing with 6-station networks. The time delay ranged from several days up to 4 months, with an overall average value of 60 days. Over the next four years, the goals of IVS with respect to its products are the following (specific goals for each product are listed in the WG2 report tables):

- improve the accuracies of all EOP and TRF products by a factor of 2 to 4 and improve the sky distribution of the CRF,
- decrease the average time delay from 60 to 30 days, and designate 2 days per week as rapid turnaround sessions with a maximum delay of 3-4 days,
- increase the frequency of observing sessions from 3 to ~7 days per week,
- deliver all products on a regular, timely schedule.

Table 1: *Summary of IVS main products, status and goal specifications*

Products	Specification	Status	Goal (2002-2005)
Polar Motion x_p, y_p	accuracy latency resolution frequency of solution	x_p ~ 100µas, y_p ~ 200µas 1 – 4 weeks ..... 4 months 1 day +3 days/week	x_p , y_p: 50 µas ..... 25 µas 4 – 3 days ..... 1day 1 day ..... 1 h ..... 10 min ..... 7 days/week
UT1-UTC DUT1	accuracy latency resolution	5µs .... 20 µs 1 week 1 day	3µs ..... 2µs 4 – 3 days ..... 1 day 1 day ..... 10 min
Celestial Pole d□□d□	accuracy latency	100 µas .... 400 µas 1 – 4 weeks ..... 4 months	50 µas ..... 25 µas 4 – 3 days ..... 1 day

	resolution frequency of solution	1 day ~ 3 days/week	1 day 7days/week
TRF (x, y, z)	accuracy	5 mm – 20 mm	5mm ..... 2 mm
CRF (□□□	accuracy frequency of solution latency	0.25 mas – 3 mas 1 year 3 – 6 months	0.25mas (improv. distribution) 1 year 3 months .... 1 month

It is certainly feasible to achieve these challenging goals for IVS products, if the proposed observing programs are carried out and if required improvements are realized. The VLBI technique will allow us to provide additional products and IVS intends to set up the extended products summarized in table 2.

Table 2: *Extended products derived by VLBI and intended to be provided by IVS*

Earth Orientation Parameter additions	dUT1/dt (length of day) dx_p /dt; dy_p /dt (pole rates)
Terrestrial Reference frame (TRF)	x- , y- , z – time series Episodic events Annual solutions Non linear changes
Celestial Reference Frame (CRF)	Source structure Flux density
Geodynamical Parameter	Solid Earth tides (Love numbers h, l) Ocean loading (amplitudes and phases A_i, $□_i$) Atmospheric loading (site-dependent coefficients)
Physical Parameter	Tropospheric parameters (e.g.1st IVS Pilot Project) Ionospheric mapping Light deflection parameter γ

Evolving observing programs

To meet its product goals, beginning with the 2002 observing year IVS designed an observing program coordinated with the international community. The 2002 observing program included the following sessions:

- EOP: Two rapid turnaround sessions each week, initially with 6 stations, increasing to 8 as soon as station and recording media resources are available. These networks were designed with the goal of having comparable x_p and y_p results. One-baseline 1-hr INTENSIVE sessions four times per week, with at least one parallel session.
- TRF: Monthly TRF sessions with 8 stations including a core network of 4 to 5 stations and using all other stations three to four times per year. The number of stations may be increased if the correlator can support the increase data load.
- CRF: Bi-monthly RDV sessions using the Very Long Baseline Array (VLBA) and 10 geodetic stations, plus quarterly astrometric sessions to observe mostly southern sky sources.
- Monthly R&D sessions to investigate instrumental effects, research the network offset problem, and study ways for technique and product improvement.
- Annual, or semi-annual if resources are available, 14-day continuous sessions to demonstrate the best results that VLBI can offer, aiming for the highest sustained accuracy.

Although certain sessions have primary goals, such as CRF, all sessions are scheduled so that they contribute to all geodetic and astrometric products. Sessions in the observing program that are recorded and correlated using S2 or K4 technology will have the same accuracy and timeliness goals as those using Mark 4/Mark 5.

To support the IVS Coordinating Center in the coordination of the observing program with the international community and to realize the new program, an Observing Program Committee (OPC) has been established. The new IVS observing program began in January 2002.

The observing program and product delivery can only be accomplished by making some changes and improvements in IVS observing program resources (station days, correlator time, and magnetic media), by improving and strengthening analysis procedures, and by pursuing a vigorous technology development program.

Status and experiences of the new IVS program one year after its implementation

As the official IVS product, a complete set of Earth Orientation Parameter is regularly submitted to the International Earth Rotation Service (IERS). The set is obtained as a combination of the individual solutions of the six IVS Analysis Centers operated at

Geoscience Australia, Canberra, Australia (AUS)
Bundesamt für Kartographie und Geodäsie, Leipzig, Germany (BKG)
NASA's Goddard Space Flight Center, , Greenbelt, USA (GSF)
Institute of Applied Astronomy, St. Petersburg, Russia (IAA)
Astronomical Institute of St. Petersburg University, St. Petersburg, Russia (SPU)
US Naval Observatory, Washington, USA (USN).

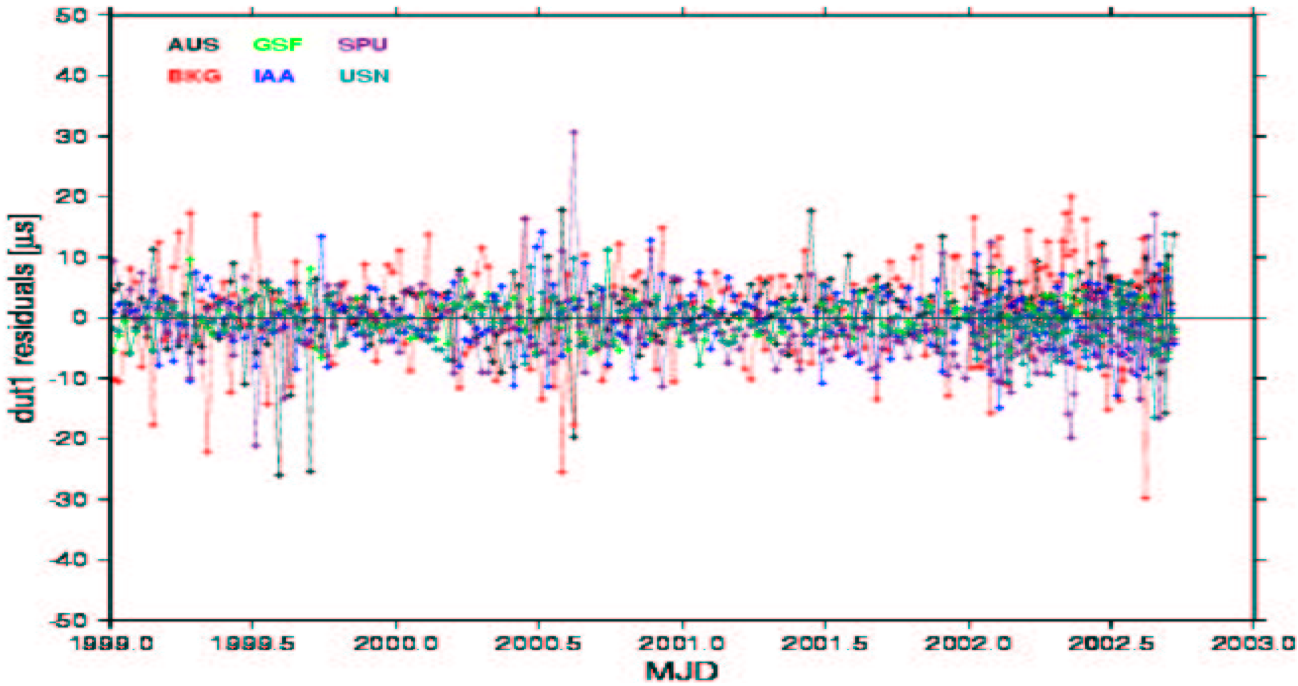


Figure 2: *DUT1 residuals of the individual solutions of the 6 Analysis Centers with respect to the combined solutions derived from the NEOS observations and since 2002 from the IVS R1 and IVS R4 observing programs. Note that the NEOS series was continued as the IVS R4.*

Figure 3 show the residuals of the individual Analysis Centers with respect to the combined solution as an example for the parameter DUT1 (UT1-UTC). Up to the end of the year 2001, the parameters were derived from the NEOS observations, while since January 2002 the IVS R1 and IVS R4 were used. It should be noted that up to the end of 2001 NEOS was the rapid turn around program which since January 2002 is known as the IVS R4.

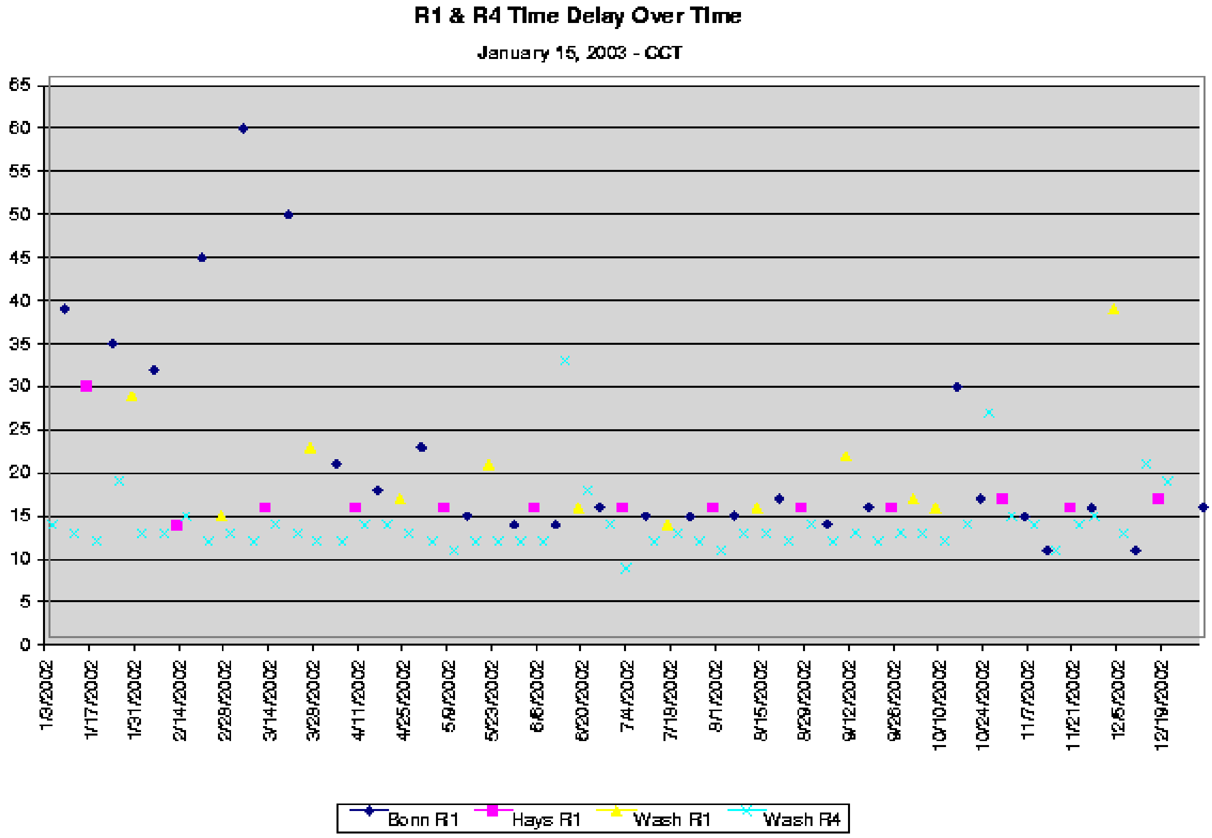


Figure 3: *Delay (in days) between the observation and the availability of the results of the IVS R1 and IVS R4 as performed since January 2002*

The objective of the rapid turn around observation sessions is to minimize the delay between the observations and the availability of the results. For the NEOS the delay was approximately 2 weeks, which has not changed by its transition to the IVS R4 as all the routine procedures were already established. For the IVS R4, as new stations were added the data shipping procedures needed to be set up to be routine. Initially this caused unexpected delays, which were overcome with time. For the IVS R1 processing, experience needed to be gained at the correlators at Bonn, Haystack and Washington during the first months. As shown in figure 4 the delay between the observation to the results is approximately two weeks since April 2002. This should be regarded as significant and real progress, even though the WG2 goal of only 4 days has not been achieved. Improvements still are required for data transmission and a higher throughput at the correlator has to be achieved. Both will be improved after the implementation of the newly developed Mark 5 digital data recording system, which has e-VLBI capabilities, allowing data transmission via high speed Internet links. With Mark 5 no time consuming tape positioning will be necessary at the correlator in case of recorrelations, which will obviously save correlator time and will increase the throughput.

The determination of DUT1 from the near-daily 1-hour observations known as “Intensives” have been carried out since 1983 via the baseline Wettzell-Westford, since 1994 via the baseline Wettzell-Green Bank and since 2000 via the baseline Wettzell-Kokee Park. These baselines employed Mark III, Mark 4, and now Mark 5 systems. In the year 2002 a time series observed on the baseline Wettzell-Tsukba/Japan with the Japanese K4 system was set up. The results agree within the error bars with the results of the original Intensive time series. Figure 4 shows the residuals of both series with respect to the C04 solution from the BIPM.

The VLBI observations from the rapid turnaround observing sessions R1 and R4 allow determination of tropospheric parameters, in particular the wet zenith path delay. An IVS Pilot Project was established by the IVS Directing Board at its 7th Meeting in order to investigate this product and also to set up the capability to provide the zenith wet path delay as an official IVS product. The University of Vienna is combining the solutions of five Analysis Centers. Figure 5 shows the zenith wet delays for an R4 observation in the GPS Week 1180. The results are comparable to those which were provided by the IGS (International GPS Service) or seem to be slightly better. At the 8th Directing Board Meeting it was decided to generate the tropospheric parameter as an official IVS product, which will be available as of the beginning of July 2003.

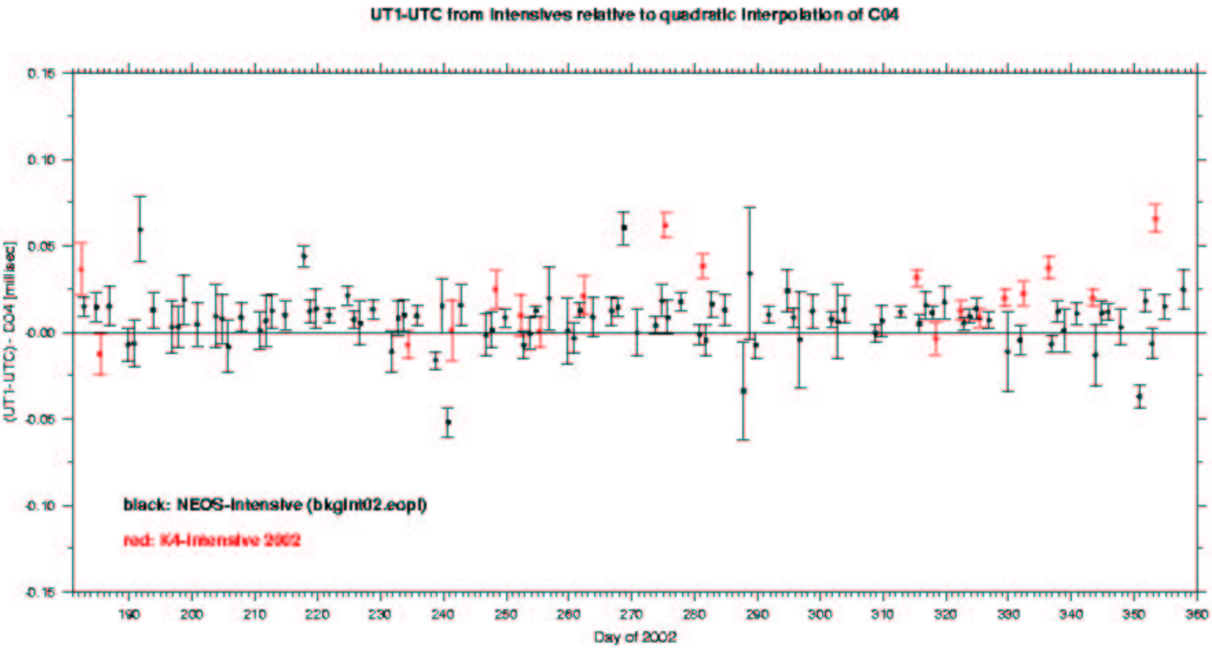


Figure 4: *Comparison of the DUT1 (UT1-UTC) results obtained from the MK 4 and K4 Intensives .*

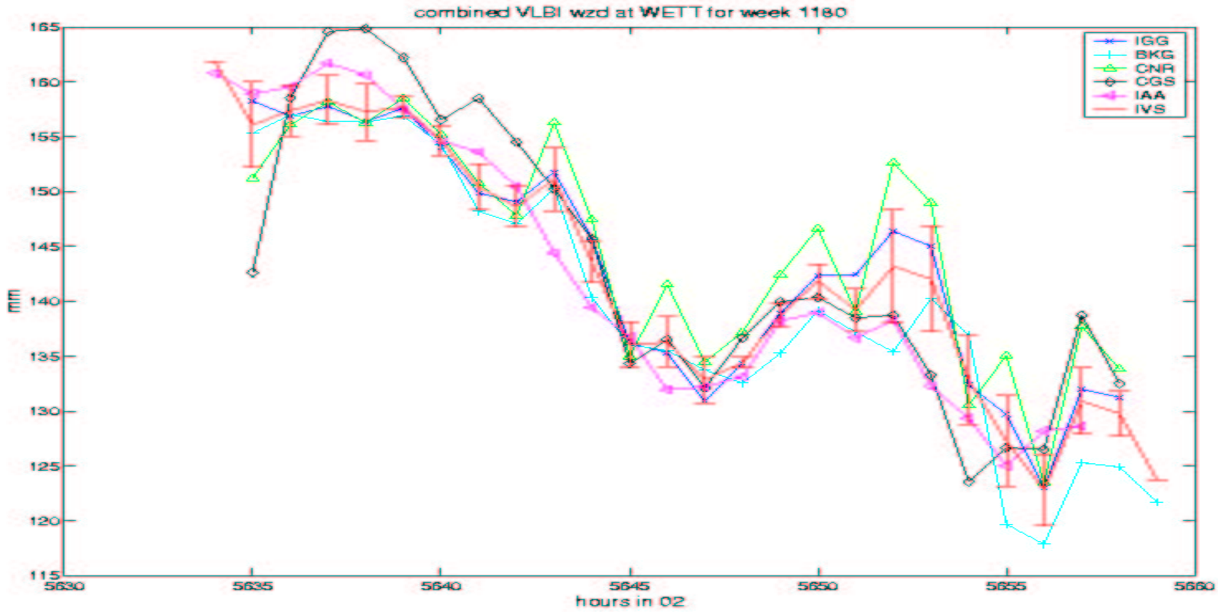


Figure 5: *Wet Zenith Delays, derived from R4 observations, taken in GPS week 1180*

Requirements on IVS components to meet the goals

The WG2 report contains many recommendations for different aspects of IVS, its products, and its programs.

Program resources:
The number of station observing days increased by about 10% in 2002 compared to 2001, with an additional 12% devoted to the CONT02 campaign. Not counting CONT02, the number of observing days will increase in 2003 by another 12%. The required observing days will continuously increase such that by 2005 the top dozen geodetic stations will need to be observing up to 4 days per week – an ambitious goal. Increased station reliability and unattended operations can improve temporal coverage by VLBI and also allow substantial savings in operating costs. Higher data rate sessions can yield more accurate results, and therefore all geodetic stations must be upgraded to Mark 5 technology involving the digital recording system as soon as possible. More stations need to be equipped with S2 and K4 systems so that global geodetic networks can be designed using these systems. The present level of support at the three Mark 4/Mark 5 correlators must be sustained to meet the IVS product goals, and support is needed from the S2 and K4 correlators. The efficiency of the correlators needs to approach a processing factor of unity, i.e. one day processing for one day observing. All correlators must commit to handling the IVS data with priority processing for meeting timely product delivery requirements. High capacity disks will have to be purchased to replace magnetic tapes and additional recording media capacity, equivalent to ~ 300 disks of 200GB capacity, will be needed to support the higher data rate observing that is necessary for increased accuracy. Alternatively, additional media capacity can be realized by using rapid shipping modes to shorten the cycle time. A deployment plan for the Mark 5 system has been proposed. It is expected that by the end of 2003 the correlator and most of the observing stations will be equipped with Mark 5 digital recording systems.

Analysis:
More Analysis Centers and those using different software packages should participate in the analysis that is required for robust IVS products. The increased amount of VLBI data to be produced under the new observing program will require Analysis Centers to handle a larger load. Partially automated analysis procedures will help improve the timeliness of product delivery. New IVS products such as EOP rates, a combined TRF solution, tropospheric parameters and geodynamical parameters should be developed because they can contribute to scientific investigations.

Technology upgrades and improvements: The Mark 5 system should be deployed at as many stations as possible and the correlators should be outfitted with Mark 5 systems, following the deployment proposal. Not only will Mark 5 technology enable higher data rate recording but it will also improve station and correlator reliability and efficiency. In addition, new methods for data transmission, including electronic media, should be strongly pursued because higher data rates, automated observing and processing methods will lead to increased accuracy, reliability, timeliness, and efficient use of resources. Several tests have been conducted on national, continental and global levels. The progress in communication technologies will support the breakthrough for e-VLBI over the next few years.

A Vision Paper 2010 for VLBI is under development by IVS. Considering our increasing requirements (e.g. the IGGOS project, the increase in radio frequency interference, our aging antennas) general refinements and upgrades of VLBI technology are needed in the future. A Working Group, WG3, is in the process of being established with the objective to develop future visions. Goals include unattended observation, improved global coverage of the network, employment of the new data transmission technologies and provision of near real time correlation and products. In collaboration with radio astronomers some guidelines for future developments will be derived.

References

Nothnagel, A.; Ch. Steinforth, IVS Analysis Coordination, IAG CSTG Bulletin no.17, Progress Report 2001, Munich 2002

Schuh, H. et al.; IVS Working Group 2 for Product Specification and Observing programs, Final Report, Annual Report 2001, page 13 – 45, NASA/TP-2002-210001, Greenbelt, MD; February 2002

Schuh H., Boehme, IVS- Zenith Wet path delay , 2002 General Meeting Proceedings, NASA/CP-2002-210002, Greenbelt, MD; June 2002

Vandenberg, N.R. (editor): Annual Report 1999, NASA/TP-1999-209243, Greenbelt, MD, August 1999

Vandenberg, N. R., Baver K.D.(editors): Annual Report 2000, NASA/TP-2001-209979, Greenbelt, MD; February 2001

Vandenberg, N. R., Baver K.D.(editors): Annual Report 2001, NASA/TP-2002-210001, Greenbelt, MD; February 2002

Vandenberg, N. R., Baver K.D.(editors): Annual Report 2002, NASA/TP-2003-211619, Greenbelt, MD; May 2003

Vandenberg, N. R., Baver K.D.(editors): 2000 General Meeting Proceedings, NASA/CP-2000-209893, Greenbelt, MD; June 2000

Vandenberg, N. R., Baver K.D.(editors): 2002 General Meeting Proceedings, NASA/CP-2002-210002, Greenbelt, MD; June 2002

SECTION III:

"DETERMINATION OF THE GRAVITY FIELD"

REPORT OF THE PRESIDENT FOR THE PERIOD 1999-2003

M.G. Sideris

Introduction and Objectives

This report describes very briefly the activities of Section III for the period 1999-2003. Given the numerous activities and large number of significant accomplishment during the last four years, this report should be used only as a "road map" of Section III's activities and, for completeness and detailed information, the interested reader should consult the reports of the special study groups, commissions and services for the same period. In the provided web site addresses, recent results, data sets, publications and other relevant information can be found.

The developments in the gravity field determination expressed in the past IAG by-laws, for which Section III was responsible, are:

1. absolute and relative terrestrial gravity measurements;
2. gravity networks and control stations;
3. non-tidal gravity variations;
4. determination of the external gravity field and geoid from different gravity field data types;
5. reduction and estimation of gravity field quantities.

Structure

In order to achieve its objectives, the Section established the following Structure:

President: Michael G. Sideris (Canada)
Secretary: Gerd Boedecker (Germany)
http://www.ucalgary.ca/~sideris/IAG/sectionIII.html

Commission XIII: International Gravity and Geoid Commission
President: Martin Vermeer (Finland)
Vice-presidents: Rene Forsberg (Denmark) and Michael G. Sideris (Canada)
Secretary: Jacques Liard (Canada)
http://www.iag-iggc.org/

Special Study Groups:

- SSG 3.167: Regional Land and Marine Geoid Modelling
  Chair: I.N. Tziavos (Greece)
  http://olimpia.topo.auth.gr/ssg3167
- SSG 3.177: Synthetic Modelling of the Earth's Gravity Field
  Chair: Will Featherstone (Australia)
  http://www.cage.curtin.edu.au/~will/iagssg3177.html
- SSG 3.184: Use of Remote Sensing Techniques for Validating Heights and Depths
  Chair: Philippa Berry (UK)
- SSG 3.185: Merging Data from Dedicated Satellite Missions with Other Gravimetric Data
  Chair: Nico Sneeuw (Canada)
- SSG 3.186: Altimetry Data Processing for Gravity, Geoid and Sea Surface Topography Determination
  Chair: C. Hwang (Taiwan)
  http://space.cv.nctu.edu.tw/IAG/main.html

International Services:

BGI: International Gravimetric Bureau
Director: J-P. Barriot (France)
http://sirius-ci.cst.cnes.fr:8110/bgi_debut_a.html

IGeS: International Geoid Service
Director: F. Sanso (Italy)
http://www.iges.polimi.it

A substructure was also put in place, whereby the above bodies established sub-commissions and working groups as needed, to tackle specific problems or research areas. These include:

- Working Croup on Intercomparison of Absolute Gravimeters (Chair: Leonid Vitushkin).
- Working Croup on the Arctic Gravity Project (Chair: René Forsberg).
- Working Croup on Antarctica (Chair: Alessandro Capra).
- Sub-commission for Europe (Chair: Ambrus Kenyeres).
- Sub-commission for South-America (Chair: Denizar Blitzkow).
- Sub-commission for South-East Asia (Chair: Bill Kearsley).
- Sub-commission for North America (Chair: Marc Veronneau).

All bodies of Section III operated very successfully and met or exceeded the objectives they had set for themselves. This is evident from the list of publications, scientific exchanges, and meetings and workshops organized. Congratulations are due not only to the chairs and secretaries of the various bodies but also to the individual members who contributed to the work of the Section.

Major Meetings and Schools

Section III was involved directly or indirectly in the organization of many scientific meetings, workshops and international schools. Also, the various bodies within Section III held many business meetings and/or workshops, usually during major international conferences. Of particular important for their service to our colleagues in developing countries are the international schools for the determination and use of the geoid, organized by the International Geoid Service. A non-exhaustive list is given below.

- 4th International School on the Determination and Use of the Geoid, February 21-25, 2000, Johor, Malaysia.
- South America Geoid Workshop, May 17-19, 2000, Sao Paulo, Brazil.
- Arctic Gravity Project meeting June 7 - 8, 2000, St. Petersburg, Russia
- IAG Symposium on Gravity, Geoid, and Geodynamics 2000 (GGG2000), July 31 - August 4, 2000, Banff, Alberta, Canada.
- IAG Symposium on Vertical Reference Systems, February 20 - 23, 2001, Cartagena, Colombia.
- International Comparison of Absolute Gravimeters, June 18 - August 4, 2001, BIPM, Sèvres, France.
- IAG 2001 Scientific Assembly, September 2 - 8, 2001, Budapest, Hungary.
- BGI/ICET Summer Course on Gravity Measuring Techniques, September 4-11 2002, Louvain-La-Neuve, Belgium.
- Instrumentation and Metrology in Gravimetry workshop, October 28 - 30, 2002, European Center for Geodynamics and Seismology (ECGS), Walferdange, Luxembourg
- Third Meeting of the IGGC August 26 - 30, 2002, Thessaloniki, Greece.
- International School on the Determination and Use of the Geoid, Aug. 30 – Sept. 5, 2002, Thessaloniki, Greece.
- Annual Meetings of the European Geophysical Society, and American and Canadian Geophysical Unions, 1999, 2000, 2001, 2002, 2003.
- IAG/IUGG General Assembly, June 30 – July 11, 2003, Sapporo, Japan.

From the old IAG structure to the new one

With IAG being in the process of reorganizing its operations and internal structure, the work of Section III will continue mostly under Commission 2 (Gravity Field) in the new structure. The new Commission 2 will be derived mainly from the existing Section III, with elements of Sections II, IV and V. The five proposed major thematic areas of the new Commission 2 are:

1. Gravimetry and Gravity Networks
2. Precise Geoid Determination
3. Gravity Field Determination from Satellite Altimetry
4. Dedicated Gravity Satellite Missions
5. Temporal variations of the Gravity Field

with sub-commissions on

- Gravimetry and Gravity Networks
- Spatial and Temporal Modelling of the Gravity Field
- Dedicated Gravity Satellite Missions

Several study groups similar to the ones that exist currently would again be established to (i) investigate more specific topics and (ii) coordinate regional efforts of gravity mapping, geoid determination, vertical datums, etc. In addition, the establishment of a new Inter-commission Committee on Planetary Geodesy is currently under study.

Commission 2 will have very strong links to the newly established International Gravity Field Service (IGFS). IGFS consists of:

- Bureau Gravimetrique International (BGI)
- International Centre of Earth Tides (ICET)
- International Geoid Service (IGeS) I, in Milano
- International Geoid Service (IGeS) II, at NIMA
- International Centre of Global Earth Models (ICGEM), at GFZ

IGFS will be a unified structure aiming at collecting, validating and distributing data and software for the purpose of determining the gravity potential and the surface of the Earth a accurately as possibly. The publication of a joint Information Bulletin between the IGeS and BGI is envisaged, as well.

It is evident that under the new structure of IAG, Gravity Field will have again the very prominent place it deserves.

Acknowledgements.

Section III was probably the most active section within IAG in the past four years. This would not have been possible without the tremendous leadership of the section officers, the support of the IAG Executive, and the hard work of all participating colleagues. Many thanks are therefore due to all contributors from the international scientific community for advancing our field of research. I am certain that this tradition will continue in the future with the work of the new Commission 2 under the leadership of its newly elected President, Chris Jekeli.

Commissions of Section III:

Comm XIII: International Gravity and Geoid Commission

M. Vermeer
Chair: J. Liard

Introduction

The International Association of Geodesy's International Gravity and Geoid Commission was established in 1999 at the IAG meeting in Birmingham, UK, merging the activities of the earlier International Gravity Commission and International Geoid Commission. belongs to Section III: Determination of the Gravity Field.

The Commission has a Web page at http://www.iag-iggc.org/ . The Terms of Reference are at http://www.iag-iggc.org/Trms0001.htm.

Services

Services under the auspices of the are the Bureau Gravimétrique International, Toulouse, France, Director: Jean-Pierre Barriot, and the International Geoid Service, Milano, Italy, Director: Fernando Sansó. Web sites of both services are:

- BGI: http://bgi.cnes.fr:8110/
- IGeS: http://www.iges.polimi.it/

Formal meetings

During its first period of operation, a number of fruitful activities took place. Starting at the formal level, the Assembly met, or tried to meet, three times:

- at the GGG2000 in Banff, Canada; minutes are found at [http://www.iag-iggc.org/minutes2000.htm]
  and at http://www.iag-iggc.org/iggc2000.pdf

- at the IAG 2001 Scientific Assembly in Budapest, Hungary 2001: http://www.sztaki.hu/conferences/iag2001/

- at the GG2002 in Thessaloniki, Greece. Minutes at http://www.iag-iggc.org/Minutes2002.htm
  The Chair's address at: http://olimpia.topo.auth.gr/GG2002/KEYNOTE/Vermeer.pdf

At these same meetings, we strived to also organize meetings of the Directing Boards of the Bureau Gravimétrique International and of the International Geoid Service; not successfully on every occasion.The Services have done much valuable work during the reporting period.

Other memorable meetings

- The IAG International Symposium on Vertical Reference Systems in Cartagena, Colombia 2001. chairman's address: http://www.iag-iggc.org/2001AddressToIAGSymposium.htm

- The International Comparison of Absolute Gravimeters 2001 BIPM, Sèvres, France 2001: http://www.iag-iggc.org/ICAG2001.htm

- Instrumentation and Metrology in Gravimetry workshop, European Center for Geodynamics and Seismology (ECGS), Walferdange, Luxemburg 2002:
  http://www.ecgs.lu/html/workshop/workshop_img/img_2002.html

Activities of WGs and Subcommissions

Many of the working groups and subcommissions have been active. Some of our success stories, not exhaustive, are listed here.

The Arctic Gravity Project

The Arctic Gravity Project under the inspiring leadership of René Forsberg and the contructive attitudes of several circumarctic countries, among which Russia, the United States, Canada, Denmark and Norway, held two meetings (St. Petersburg, Russia, 2000, and Ottawa, Canada, 2001) and came to a successful conclusion with the release of an Arctic gravity data set in 2002. Weblink: http://www.nima.mil/GandG/agp/

Thanks to the constructive attitudes of several circumarctic countries, among which Russia, the United States, Canada, Denmark and Norway, a gravity survey map of the Arctic Ocean at 5' resolution was successfully produced and published.

The Antarctic Gravity Project

This Working Group has been headed by Alessandro Capra of the University of Bologna. Dr. Capra also heads the Physical Geodesy project within the Geodesy program (GIANT) of the Geodesy and Geographic Information group of SCAR, the Scientific Committee on Arctic Research.

The purpose of this WG is, similarly to ArcGP, collection and analysis of physical geodesy data, for the development of a new high resolution Geoid for the Antarctic. Weblinks: http://www.scar-ggi.org.au/geodesy/physgeod/index.htm http://www.geoscience.scar.org/

Working Group on Intercomparison of Absolute Gravimeters

In the Working Group on Intercomparison of Absolute Gravimeters, under the leadership of Dr. Leonid Vitushkin of the Bureau International des Poids et Mesures (BIPM, http://www.bipm.org/) in Paris, France, a successful co-operation framework was developed between the absolute gravimetry and metrology scientific ommunities, aimed at making absolute gravity measurements with ballistic gravimeters metrologically traceable. This must be continued in the future.

To this end, Dr. Vitushkin has established in addition to the Working group a similar working group involving the same scientific community, but belonging to the sphere of international metrology under the auspices of the BIPM. In this matter Dr. Vitushkin visited Helsinki, Finland in 2000 on invitation by the Finnish Centre for Metrology and Accreditation, and also found time to discuss with MV.

A letter (appendix) was sent by Fernando Sansó in his capacity as IAG President, and MV as Chair, to the Dr. T.J. Quinn of the Bureau International des Poids et Mesures, stressing the importance of measuring geophysical quantities such as gravity in a metrologically traceable way, mentioning the CIPM Working Group on Gravimetry as an example.

The Subcommission for North America

The Subcommission for North America, chaired by Marc Véronneau, has been active, both in terms of meetings and in terms of geoid determination activities.

A number of Canadian Geoid Workshops have been organized (serial numbers 5-7, in May 2001, 2002, 2003 respectively) typically in conjunction with Canadian Geophysical Union meetings to which some members of
the Sub-Commission for North America attended. Furthermore, the Sub-Commission met at the IAG international symposium of February 2001 in Cartagena (Canada/Mexico), at the US National Geodetic Survey office in November 2001 (Canada/USA) and during the ArcGP meeting in Ottawa (Canada/Greenland/Denmark).

Letters of invitation to join the Sub-Commission for North America were sent to geodetic representatives of all Central America countries and some Caribbean Islands countries. The terms of Reference of the Sub-Commission were published in English and Spanish in the "revista Cartografica" journal.

The primary objective for the Sub-Commission for North America is achieving independently a common geoid model for the overlapping areas between each country. The geoid solutions for Greenland, USA and Canada have significantly converged towards a single solution; however still some areas require some attention (e.g., the Pacific North-West region of USA). Mexico is resuming gravity data collection and followed a series of theoretical and practical geoid courses from Prof. P. Vanicek (UNB) and Dr. J. Janak at INEGI office in Aguascalientes, Mexico.

The activities of the Subcommission have been rather informal.

The Subcommission for South America
This Subcommission was chaired by Denizar Blitzkow.

Considerable efforts were made in the period 2001-2003 in improving the quality, the fundamental station networks and the gravity densification in South America, with special emphasis to Argentina, Brazil, Chile, Ecuador and Paraguay.

The Subcommission for South-East Asia
The Subcommission for South-East Asia, headed by Bill Kearsley, was involved in organizing the IAG Geoid School in Johor, Malaysia, in February 2000.

The Subcommission for Europe
The Subcommission for Europe, chaired by Ambrus Kenyeres, has been active. A number of initiatives were started:

- UEGN2002: Unified European Gravimetric Network. Meeting in Vienna May 2002.

- EUVN_DA: densification of the European Unified Vertical Network, this means a dense GPS/levelling network for geoid control, in cooperation with EUREF.

- ECGN (European Combined Geodetic Network) together with EUREF: combined handling of GPS and absolute gravimetric observations.

- A Subcommission meeting was held in Thessaloniki, Greece, 2002.

- A third Continental Geoid Workshop is planned for 2004 in Riga, Latvia.

The Computing Centre for the European Geoid at the University of Hannover (Heiner Denker) has expressed an interest in continued involvement in the computational effort and determining the next generation European geoid model under the new IAG structure after Sapporo. This could take the form of a Project.

This important work must continue.

A Letter to BIPM

"As representatives of part of the geophysical community, i.e., the community of physical geodesists involved in the study of the Earth's gravity field, we are well aware of the importance of measuring geophysical quantities such as gravity in a metrologically traceable way.

"At a time when the mapping of the Earth's gravity field, with terrestrial methods, airborne techniques and new satellite missions, is making great strides and will potentially benefit mankind immensely, it is important to remain aware of the metrological basis of all the measurements collected in these efforts, so that theory can be validly applied.

"Of course, gravity is only one example of geophysical quantities of great relevance to society; there are a great many others. For all these quantities, measuring them in a metrologically traceable fashion is just as important.

"In this respect we greatly appreciate the long-standing interest of the BIPM in gravimetry and the efforts that the BIPM is making to formalize the link of the measurement of geophysical quantities to the metrology community. The organization by the CIPM of the Working Group on Gravimetry, which was done in close co-ordination with the IGGC, stands as a good example of this."

REPORT OF IAG SPECIAL GROUP 3.167 :

"REGIONAL LAND AND MARINE GEOID MODELLING" (1999-2003)

I. N. Tziavos tziavos@olimpia.topo.auth.gr

Abstract

This report summarizes the activities and achievements of the IAG Special Study Group (SSG) 3.167 "Regional Land and Marine Geoid Modeling" between August 1999 and June 2003. The primary objective of the SSG is the accurate regional-scale land and marine geoid determination by using efficient algorithms and optimally combining heterogeneous data. In terms of applications, and in the frame of the above mentioned leading task, considerable work has been carried out in regional land and marine geoid modeling by applying successfully efficient spectral and stochastic algorithms as well as several new alternatives. Furthermore, the SSG's main task is met by employing large amounts of terrestrial and airborne gravity data, satellite altimetry data from recent and more accurate missions, and new global geopotential models. Recent research work mainly concentrate on the modeling of the long-wavelength part of the earth's gravity field either using the first data of the CHAMP satellite mission, or performing simulation studies related to the expected dedicated gravity field missions (e.g., GOCE, GRACE). The significant improvement obtained during the last years both to the gravity field related data and their accuracy, as well as to the algorithms and numerical techniques, provided the basis to reach the target of the 1cm - geoid on a regional scale, which fulfill the requirements of a wide number of applications in geodesy and in geosciences in general.

Introduction

The SSG "Regional Land and Marine Geoid Modelling" was established for the period 1999-2003 during the 1999 General Assembly of IUGG in Birmingham, the UK. It is a continuation of a previous SSG of IAG (1995-1999) under the same title and the same objectives, since IAG has recognized the importance of the geoid modelling on a regional scale in land and marine areas.

The primary objective of this SSG is the accurate regional-scale land and marine geoid determination mainly emphasizing on the following directions: (a) Investigation of modelling procedures for land and marine geoid, differences between methods and difficulties when working across the land/sea boundary; (b) new efficient ways of working with heterogeneous data for geoid determination; (c) the use of numerical techniques and the possibilities to prescribe or recommend the extent of a standard procedure; (d) revision of procedures for calculating the errors of geoid/quasi-geoids; (e) the impact of GPS - heights not only to validation procedures but also to common adjustments with geoid heights; (f) the contribution of high accuracy and resolution marine geoid to sea surface topography determination and other related oceanographic studies; (g) modelling of long-wavelength errors in regional geoid/quasi-geoid computations by the CHAMP satellite gravity mission and the expected dedicated gravity field missions of GRACE and GOCE; (h) the contribution of airborne gravimetry to geoid modelling in combination procedures.

It is worth mentioning that the work and activities included in this report belong mainly to the members of the SSG who sent me in time their contributions. These contributions are available via the SSG's website at the following URL (http://olimpia.topo.auth.gr/ssg3167). Due to space limitations I describe below that part of the work, which mainly reflects the leading tasks and goals of SSG. Additionally, scientific work by other colleagues is also briefly presented and reference is given to several recent papers published in geodetic journals or in papers presented in geodetic symposia during the last two years. Some results reported in recent dissertations are also discussed. A more complete list of references can be found in the above mentioned web page.

Membership

SSG 3.167 had, primarily, thirty regular members, including the president and ten corresponding members. After the IAG GGG2000 meeting held in Banff (August 2001) eleven colleagues joined SSG as corresponding members. The geographical spread of the SSG members is quite satisfactory. The members expertise range from mathematical and physical geodesy to gravity field applications in different branches of geosciences. The names of the members of the SSG and countries are given below:

Full Members:

I.N. Tziavos	(Greece, chairman)	H. Abd-Elmotaal	(Egypt)	R. Barzaghi	(Italy)
J. Catalao	(Portugal)	J.Y. Chen	(China)	O.C. Dahl	(Norway)
H. Denker	(Germany)	W. Featherstone	(Australia)	R. Hipkin	(United Kingdom)
R. Haagmans	(The Netherlands)	Z. Jiang	(France)	J. Kaminskis	(Latvia)
N. Kuehtreiber	(Austria)	Y. Kuroishi	(Japan)	U. Marti	(Switzerland)
C. Merry	(South Africa)	D. Smith	(USA)	J. Toth	(Hungary)
G.C. Tsuei	(Taiwan)	M. Veronneau	(Canada)		

Corresponding Members:

H. Duquenne	(France)	J. Fernandes	(Portugal)	Y. Fukuda	(Japan)
C. Hwang	(Taiwan)	C. Jekeli	(USA)	W. Kearsley	(Australia)
P. Knudsen	(Denmark)	J. Krynski	(Poland)	M. Kuhn	(Germany)
D. Milbert	(USA)	G. Papp	(Hungary)	K. Prijanta	(Indonesia)
L. Sanchez	(Colombia)	K. Zhang	(Australia)		

Corresponding Members (after the meeting in Banff):

V. Andritsanos	(Greece)	M.E. Ayhan	(Turkey)	A. Bayoud	(Canada)
L. Biagi	(Italy)	J. Brozena	(Canada)	G. Fotopoulos	(Canada)
A. Kenyeres	(Hungary)	C. Kotsakis	(Canada)	M. Pearse	(N. Zealand)
D.R. Roman	(USA)	G.S. Vergos	(Canada)		

Land/Marine Geoid Modelling - Specific Accomplishments

Different geoid or quasi-geoid determinations on a local or regional scale have been carried out by members of the SSG in different sea/land test areas using combinations of heterogeneous data sources referred to high degree and order geopotential solutions. The methods employed range from the classical numerical integration procedures, the spectral FFT techniques and the stochastic least-squares collocation algorithms to the input/output system theory algorithms in the frequency domain (Rodriguez 1999, Abd-Elmotaal 2000, Amod and Merry 2002, Andritsanos and Tziavos 2000, Fotopoulos et al. 2000, Smith 2002, Toth et al. 2000, Tziavos 2000; Kuroishi et al. 2002). The results obtained meet the today accuracy demands of a wide number of applications related to surveying, geodesy, geophysics and other disciplines of geosciences. The quality of the geoid heights produced in land areas was assessed by comparisons with corresponding heights at GPS benchmarks (see, e.g., Featherstone 2001, Marti et al. 2001, Toth et al. 2000). The use of GPS in combined adjustments with gravimetric geoid heights is discussed by Kotsakis and Sideris (2000). The estimated accuracy of the determined geoid/quasi-geoid heights reached in some cases the level of one decimeter and in pure marine geoid solutions found close to one centimeter (Fernandes et al. 2000, Rodriguez 2000, Vergos et al. 2001, Andritsanos 2000, Andritsanos et al. 2000). Gravimetric geoid solutions were also computed on a national scale by different authors and attempts were made to the direction of datum unification (see, e.g., Featherstone 2000, Marti et al. 2001, Fotopoulos et al. 2000, Toth et al. 2000).

Kotsakis (2000) discussed problems occurring in linear signal estimation from discrete gridded data and has drawn interesting conclusions related to modern operational geodesy and practical applications like local/regional geoid determination. Hwang and Lih-Shinn Hwang (2001) computed an improved geoid model for Taiwan with an accuracy ranging from 2 cm to 10 cm in order to assess the accuracy of orthometric heights and detect vertical rates of land motion. Toth et al. (2001) investigated the recovery of gravity and geoid in Hungary from torsion balance data using collocation and spectral techniques. An analysis related to regional high-frequency geoid computations in Canada using a synthetic gravity field is given by Novak et al. (2000). Featherstone (2003) discussed the theory and application of modified kernels in gravimetric quasi-geoid determination in Australia.

Several simulation studies were carried out in the frame of modelling the long wavelength part of the Earth's gravity field taking advantage from the new satellite gravity missions of CHAMP, GRACE and GOCE. Tscherning (2001) has illustrated the advent of pure satellite gravity models by the new missions. These models will considerably improve our possibilities for computing precise quasi-geoidal differences (Featherstone 2003). The expected accuracy could be better enough than that obtained by EGM96. Gravity gradients over Europe using the least squares spectral combination technique for calibration/validation of GOCE data have been computed by Denker (2002).

The effects of density variations on terrain corrections and the handling of topography in practical geoid determination were studied by several authors (see, e.g., Kuhn 2000, Omang and Forsberg 2000, Tziavos and Featherstone 2000, Biagi and Sanso 2000, Tsoulis and Tziavos 2002, Tsoulis et al. 2003). The geophysical dimension of a regional quasi-geoid determination and its correlations with Moho depths and other geophysical parameters have been studied in several papers (see, e.g., Abd-Elmotaal 2000, Kuehtreiber and Abd-Elmotaal 2000, Toth et al. 2000). In the same frame and according to Molodensky theory efficient ways of computing the G1 term and the influence of the grid size of digital elevation models and their errors on quasi-geoid contribution has been also investigated (Amod 2001, Featherstone 2002, Merry 2003).

The essential role of airborne gravimetry in combination solutions with marine gravity observations, satellite altimetry derived and land gravity for high resolution geoid computations is demonstrated in several studies (Bastos et al. 2000, Forsberg 2002). The increasing interest for new airborne gravity surveys during the last two years contributed to the better knowledge of the geoid and sea surface topography in different areas, e.g., Greenland, eastern Mediterranean and Crete island, Azores islands, Corsica (Olesen et al. 2002, Duquenne et al. 2002). The topographic effect to airborne gravity data by testing different resolution digital elevation models and the application of filtering techniques to eliminate the high frequency errors has been investigated by Bayoud and Sideris (2001). Recent advances in the performance of scalar airborne gravimetry on precise geoid computation is given by Novak et al. (2002).

Considerable work has been carried out in the research area of marine gravity field modeling and especially in geoid determination over sea areas by combining terrestrial data with satellite altimetry data. The geoid results reached the level of one decimeter or better in several cases in terms of standard deviation of the differences between the computed geoid heights and the corresponding heights derived from satellite altimetry (Andritsanos et al. 2000, Fernandes et al. 2000, Rodriguez 1999, Rodriguez and Sevilla 2002, Sevilla and Rodriguez 2002). Several authors discussed the role of satellite altimetry in gravity field modelling in self-seas and coastal areas and pointed out inherent problems when working across the land/sea boundary (see, e.g., Andersen and Knudsen 2000, Andritsanos 2000, Hipkin 2000, Vergos et al. 2001, Fernandes et al. 2002). Pure altimetric geoid solutions were carried out taking advantage from the most accurate mission of TOPEX/Poseidon and the high resolution geodetic missions of GEOSAT and ERS-1 (see, e.g., Fernandes et al. 2000, Vergos et al. 2000, Andritsanos et al. 2000). Moreover, marine geoid solutions were computed by combining altimetric data with shipborne gravity data in areas presenting geodynamic and oceanographic interest (see, e.g., Rodriguez 1999, Andritsanos 2000, Fernandez et al. 2000, Vergos et al. 2000, Vergos 2002). Global mean sea surface and marine gravity anomalies from multi-satellite altimetry have been computed by Hwang et al. (2002).

Future Work

Additional work could be done after Sapporo in the frame of a new working group or commission. Some suggestions for future work are summarized as follows:
Investigation of the comparison and combination techniques between geoid/quasi-geoid heights and GPS/levelling heights.
More systematic analysis on the contribution of the new satellite gravity missions to the improvement of the long-wavelength part of a geoid/quasi-geoid determination.
High-resolution marine geoid solutions by combining satellite altimetry, airborne and sea gravimetry data for oceanographic applications.

References

Abd-Elmotaal, H.: A gravimetric geoid for Egypt derived by FFT techniques. Presented at Gravity, Geoid and Geodynamics 2000, Banff, Canada, July 31-August 4, 2000.

Abd-Elmotaal, H.: Vening Meinesz inverse isostatic problem with local and global Bouguer anomalies. Journal of Geodesy, 74/5, 390-398, 2000.

Amod, A.: The use of spectral methods in quasi-geoid determination. Ph.D. Thesis, Dept. of Geomatics, University of Cape Town, 2001.

Amod, A and Merry, C.L.: The use of the two-dimensional spherical FFT for quasi-geoid modelling in South Africa. Survey Review, 36(285): 508-520, 2002.

Andersen, O.B. and P. Knudsen: The role of satellite altimetry in gravity field modelling in coastal areas. Phys. Chem. Earth (A), vol. 25, No. 1, 17-24, 2000.

Andritsanos, V.D., and I.N. Tziavos: Estimation of gravity field parameters by a multiple input/output system. Phys. Chem. Earth (A), vol. 25, No. 1, 39-46, 2000.

Andritsanos, V.D., G.S. Vergos, I.N. Tziavos, E.C. Pavlis and S.P. Mertikas: A high-resolution geoid for the establishment of the GAVDOS multi-satellite calibration site. Proceedings of Gravity, Geoid and Geodynamics 2000, Banff, Canada, July 31-August 4, 2000.

Andritsanos, V.D., M.G. Sideris and I.N. Tziavos: Quasi-stationary sea surface topography estimation using input/output method and error analysis of satellite altimetry. Accepted for publication in Journal of Geodesy.

Andritsanos, V.D.: Optimal combination of terrestrial and satellite data using spectral methods for applications to geodesy and oceanography. Ph.D. Thesis, Dept. of Geodesy and Surveying, Aristotle Univ. of Thessaloniki, 2000.

Bastos, L., C. Cunha, R. Forsberg, A. Olesen, A. Gidskehaug, L. Timmen and U. Meyer: On the use of airborne gravimetry in gravity field modelling: experiences from the AGMASCO project. Phys. Chem. Earth (A), vol. 25, No. 1, 1-8, 2000.

Bayoud F.A. and M.G. Sideris: Geoid determination from airborne gravity data using different filtering frequencies and DTM resolutions, in: Adam and Schwarz (eds.) Vistas for Geodesy in the New Millenium, IAG 2001 Scientific Assembly, vol. 125, pp. 217-222, Budapest, Hungary, Sept. 2-7, 2001.

Biagi, L. and F. Sanso: A new algorithm for fast RTC computation. Presented at Gravity, Geoid and Geodynamics 2000, Banff, Canada, July 31-August 4, 2000.

Denker, H.: Computation of gravity gradients over Europe for calibration/validation of GOCE data, in: Tziavos, I.N. (ed) Gravity and Geoid 2002, Department of Surveying and Geodesy, Aristotle University of Thessaloniki, 341-346.

Duquenne H., A.V. Olesen, R. Forsberg, A. Gidskehaug: Improvement of the gravity field and geoid around Corsica by aerial Gravimetry, in: Tziavos, I.N. (ed) Gravity and Geoid 2002, Department of Surveying and Geodesy, Aristotle University of Thessaloniki, 341-346, 2002.

Featherstone W.E.: Towards unification of the Australian height datum between the mainland and Tasmania using GPS and the AUSgeoid98 geoid model. Geomatics Research Australasia, 73, 30-40, 2000.

Featherstone W.E.: Absolute and relative testing of gravimetric geoid models using GPS and orthometric height data. Accepted for publication in Computers and Geosciences, 2001.

Featherstone, W.E (2002) Band-limited kernel modifications for regional geoid determination based on dedicated satellite gravity field missions, in: Tziavos, I.N. (ed) Gravity and Geoid 2002, Department of Surveying and Geodesy, Aristotle University of Thessaloniki, 341-346.

Featherstone, W.E.: Comparison of different satellite altimeter-derived gravity anomaly grids with ship-borne gravity data around Australia, in: Tziavos, I.N. (ed) Gravity and Geoid 2002, Department of Surveying and Geodesy, Aristotle University of Thessaloniki, 326-331, 2002.

Featherstone, W.E.: Improvement to long-wavelength Australian gravity anomalies expected from the GRACE, CHAMP and GOCE dedicated satellite gravimetry missions, Exploration Geophysics (submitted), 2003.

Fernandes, M.J., L. Bastos, J. Catalao: The role of multi-mission ERS altimetry in the determination of the marine geoid in the Azores, Marine Geodesy, 23, 1-16, 2000.

Fernandes, M.J., L. Bastos, M. Antunes: Coastal Satellite Altimetry – Methods for Data Recovery and Validation, in: Tziavos, I.N. (ed) Gravity and Geoid 2002, Department of Surveying and Geodesy, Aristotle University of Thessaloniki, 326-331, 2002.

Forsberg, R.: Downward continuation of airborne gravity data – an Arctic case story, in: Tziavos, I.N. (ed) Gravity and Geoid 2002, Department of Surveying and Geodesy, Aristotle University of Thessaloniki, 326-331, 2002.

Fotopoulos, G., C. Kotsakis and M.G. Sideris: A new Canadian geoid model in support of levelling by GPS. Geomatica, 54.1, 53-62, 2000.

Hipkin, R.: Modelling the geoid and sea-surface topography in coastal areas. Phys. Chem. Earth (A), vol. 25, No. 1, 9-16, 2000.

Hwang , C. and L.S. Hwang: Use of geoid for assessing trigonometric height accuracy and detecting vertical land motion. Draft, 2001.

Hwang, C., H-Y. Hsu and R-J. Jang: Global mean sea surface and marine gravity anomaly from multi-satellite altimetry: applications of deflection geoid and inverse Vening Meinesz formulae. Journal of Geodesy, 76(8), 407-418, 2002.

Kotsakis, C.: Multiresolution aspects of linear approximation methods in Hilbert spaces using gridded data. Ph.D. Thesis, Dept. of Geomatics Eng., University of Calgary, UCGE Rep. Nr. 20138, 2000.

Kotsakis, C. and M.G. Sideris: On the adjustment of combined GPS/levelling/geoid networks. Journal of Geodesy, 73/8, 412-421, 1999.

Kuehtreiber, N. and H.A. Abd-Elmotaal: Gravimetric geoid computation for Austria using seismic Moho data. Presented at Gravity, Geoid and Geodynamics 2000, Banff, Canada, July 31-August 4, 2000.

Kuhn, M.: Geoidbestimmung unter Verwendung verschiedener Dichtehypothesen. Ph.D. Thesis, DGK, Reihe C, Heft Nr. 520, Munich 2000.

Kuroishi, Y., H. Ando and Y. Fukuda: A new hybrid geoid model for Japan, GSIGEO2002. Journal of Geodesy, 76(8), 428-436, 2002.

Marti, U., A. Schlatter and E. Brockmann: The possibilities of combining levelling with GPS measurements and geoid information. Presented at the EGS XXVI Gen. Assembly, Nice, France, 26-30 March, 2001.

Merry, C.L.: DEM-induced errors in quasi-geoid modelling. Submitted, Journal of Geodesy, 2003.

Novak, P., P. Vanicek, M. Veronneau, S. Holmes, W.E. Featherstone: On the accuracy of modified Stokes's integration in high-frequency gravimetric geoid determination. Journal of Geodesy, 74/9, 644-654, 2000.

Novak, P., M. Kern, K.-P. Schwarz, M.G. Sideris, B. Heck, S. Ferguson, Y. Hammada and M. Wei: On geoid determination from airborne Gravimetry. Journal of Geodesy, 76(9-10), 510-522, 2002.

Olesen, A.V., I.N. Tziavos and R. Forsberg: New Airborne Gravity Data Around Crete - First Results from the CAATER Campaign, in: Tziavos, I.N. (ed) Gravity and Geoid 2002, Department of Surveying and Geodesy, Aristotle University of Thessaloniki, 326-331, 2002.

Omang, O.C.D. and R. Forsberg: How to handle topography in practical geoid determination: three examples. Journal of Geodesy, 74/6, 458-466, 2000.

Rodriguez Velasco, G.: Geoid studies using terrestrial and marine gravity data (in Spanish). Ph.D. Thesis, Universitad Complutense de Madrid, 1999.

Rodriguez Velasco, G. and M. J. Sevilla: Correlation between sea surface topography and bathymetry in shallow shelf seas. Geophysical Journal International. Vol 150 Nº 3, pp 573-587, 2002.

Sevilla, M. J. and G. Rodriguez Velasco: Gravity, Mean Sea Surface and Bathymetry Models Comparison in the Canary Islands. Marine Geodesy. Vol. 25 Nº 4, pp. 313-333, (2002).

Toth, Gy., Sz. Rosza, V.D. Andritsanos, J. Adam and I.N. Tziavos: Towards a cm-geoid for Hungary: recent efforts and results. Phys. Chem. Earth (A), vol. 25, No. 1, 47-52, 2000.

Smith, D.A.: Computing components of the gravity field induced by distant topographic masses and condensed masses over the entire Earth using 1-D FFT approach. Journal of Geodesy, 76(3), 150-168, 2002.

Toth, Gy., Sz. Rosza, J. Adam and I.N. Tziavos: Gravity field modeling by torsion balance data-a case study in Hungary, in: Adam and Schwarz (eds.) Vistas for Geodesy in the New Millenium, IAG 2001 Scientific Assembly, vol. 125, pp. 193-198, Budapest, Hungary, Sept. 2-7, 2001.

Tscherning, C.C.: Geoid determination after the first satellite gravity missions (draft version). In the Festschrift volume for Prof. Torge, 2001.

Tsoulis, D. and I.N. Tziavos: A comparison of some existing methods for the computation of terrain corrections in local gravity field modelling, in: Tziavos, I.N. (ed) Gravity and Geoid 2002, Department of Surveying and Geodesy, Aristotle University of Thessaloniki, 326-331, 2002.

Tsoulis, D., H. Wziontek and S. Petrovic: A bilinear approximation of the surface relief in terrain corection computations. Accepted for publication to Journal of Geodesy, 2003.

Tziavos, I.N. and W. Featherstone: First results of using digital density data in gravimetric geoid computation in Australia. Proceedings of Geodynamic, Gravity and Geoid 2000, Banff, Canada, July 31-August 4, 2000.

Tziavos, I.N.: The geoid in the Mediterranean-Recent results and future plans. Invited paper, presented at the FIG Symposium “Mediterranean Surveyors in the new millennium”, Malta, Sept. 18-21, 2000.

Vergos, G.S., F.A. Bayoud, M.G. Sideris and I.N. Tziavos: High-resolution geoid computation by combining shipborne and multi-satellite altimetry data in the eastern Mediterranean sea. Presented at the EGS XXVI Gen. Assembly, Nice, France, 26-30 March, 2001.

Vergos G.S. (2002) Sea Surface Topography, Bathymetry and Marine Gravity Field Modeling. MSc Thesis, Submitted to the Faculty of Graduate Studies in Partial Fulfillment for the Degree of Master of Science, Department of Geomatics Engineering, University of Calgary, UCGE Report 20157, February 2002.

FINAL REPORT OF IAG SPECIAL STUDY GROUP 3.177:

"SYNTHETIC MODELLING OF THE EARTH'S GRAVITY FIELD"

http://www.cage.curtin.edu.au/~will/iagssg3177.html

W.E. Featherstone

Disclaimer

This final report only gives the Chair's perspective of the work undertaken by IAG SSG 3.177 between August 1999 and May 2003. It is therefore important to acknowledge that it is inevitably incomplete and does not include all the active SSG members' activities; for this I apologise. These other activities will be reported in a paper presented to the IUGG General Assembly in Sapporo, which will probably be included in the conference proceedings published by Springer.

Introduction

In April 1996, the Executive Committee of IAG Section III (Determination of the Gravity Field) endorsed the out-of-cycle creation of SSG 3.177 "Synthetic Modelling of the Earth's Gravity Field". The primary objective of this SSG was to develop the theoretical basis and computational methods necessary to construct simulated [synthetic] models of the Earth's gravity field for use in geodesy. A progress report for the SSG's activities until 1999 was published in the 1995-1999 Traveaux, which is available from the IAG's website (http://www.gfy.ku.dk/~iag/Travaux/ssg3177.htm).

Gravity field researchers have often relied on empirical error estimates to validate their results, generally based on observed data. A classic example is gravimetric geoid determination, where the computed models are often compared with GPS and geodetic levelling data that have their own error budgets. The availability of synthetic gravity field models now avoids this somewhat undesirable scenario and gives a more independent validation of the procedures used (e.g., Novàk et al. 2001, Featherstone 1999, 2002). Arguably, this now aligns gravity field research with other areas of the Earth sciences, notably seismology, where synthetic datasets are used on a routine basis.

The final outcome of this SSG is a variety of software packages and synthetic gravity field models, which are freely available on the SSG's website, and will be made more widely available via the IAG's International Gravity and Geoid Commission (IGGC). It is anticipated that these will allow for future objective testing of the theories and methodologies used in gravity field determination and modelling. They may even contribute to the resolution of some of the differences encountered between gravity field researchers around the world. It is hoped that these synthetic models will now be used on a routine basis.

Concept of a Synthetic Earth Gravity Model

A synthetic Earth gravity model (SEGM) generates self-consistent gravity field parameters based on a realistic-as-possible representation of the Earth. Using Newton's law of gravitation, for instance, the gravitational potential and its derivatives in arbitrary directions can be uniquely determined from any given mass distribution. These self-consistent, synthetic [simulated] gravity field quantities can be used to study the different theories and methods used in practise to analyse the Earth's gravity field without relying on actual observations, which are subject to measurement and reduction errors.
Take the example of geoid determination: the gravity field researcher takes the synthetic gravity anomalies (either supplied or computed using the available software), inserts them into his/her own algorithms and computer software, then compares the output to the entirely self-consistent geoid heights from the same synthetic field. Any differences should then be investigated to determine whether they are algorithmic or software errors; see Novàk et al. (2001) and Featherstone (1999, 2002).

There are three possible approaches to constructing an SEGM. Of course, hybrid combinations of these options are also possible.

1. Source models use reasonably realistic mass-density information to produce the gravity field by [usually numerical] integration of Newton's law of gravitation.

2. Effect models represent the gravity field based in some way on observations, so as to make them realistic, but the input data used are assumed completely error-free or well-known error models are artificially introduced.

3. Analytical models use exact mathematical relationships among the gravity field parameters for an arbitrary mass distribution, but may be limited by the level of reality that can be expressed by analytical functions.

Membership of SSG 3.177

Full Members

Will Featherstone (Australia, Chair)
Erik Grafarend (Germany)
Roger Hipkin (United Kingdom)
Christopher Jekeli (USA)
Zdenek Martinec (Czech Republic)
Roland Pail (Austria)
Doug Robertson (USA)
Gabriel Strykowski (Denmark)
Ilias Tziavos (Greece)
Peter Vajda (Slovak Republic)
Yoichi Fukuda (Japan)
Roger Haagmans (The Netherlands)
Simon Holmes (USA)
Rüdiger Lehman (Germany)
Yuri Neyman (Russia)
Gabor Papp (Hungary)
Walter Schuh (Austria)
Gyula Toth (Hungary)
Petr Vanicek (Canada)
Martin Vermeer (Finland)

Corresponding Members

Giampietro Allasia (Italy)
Hans Engels (Germany)
Rene Forsberg (Denmark)
Michael Kuhn (Australia)
Adam Dziewonski (USA)
Edward Osada (Poland)
Spiros Pagiatakis (Canada)
Michael Sideris (Canada)
Hans Sünkel (Austria)
Sten Claessens (Australia)
Jonathan Evans (United Kingdom)
Jonathan Kirby (Australia)
Gabi Laske (USA)
Marcel Mojzes (Slovak Republic)
Judit Benedek (Hungary)
Dean Provins (Canada)
Dru Smith (USA)
Christian Tscherning (Denmark)

Effects SEGMs

Synthetic Fields Based on Spherical Harmonics (Excluding Error)

Some SSG members have used ultra-high-degree simulated spherical harmonic coefficients to construct SEGMs. One such model, computed at Curtin University of Technology, Australia, extends to degree 5400 (to 45 degrees latitude) and to degree 2700 (over the whole Earth). These limits are set by computer underflow and overflow errors in IEEE double precision (Holmes and Featherstone 2002a, b). The SEGM is based on EGM96 and GPM98, which are assumed totally error-free. The ultra-high-degree coefficients were created artificially by scaling and 'recycling' EGM96 and GPM98 coefficients according to the Tscherning-Rapp variance model.

Featherstone (1999, 2002) used an earlier version of the above SEGM over Western Australia to test the theories and software used to produce AUSGeoid98. A similar study was conducted by Novàk et al. (2001) to validate the Stokes-Helmert and modified kernel theories used at the University of New Brunswick, Canada. Other (unpublished) experiments have used a refinement of the above SEGM to test the gravimetric computation of vertical deflections using modifications of Vening-Meinesz's formulas.

Synthetic Fields Based on Spherical Harmonics (Including Error)

As part of a collaborative project "Refinement of Observation requirements for GOCE" for the European Space Agency (ESA), a consortium of investigators has generated an SEGM based on spherical harmonics to degree 1800. A FORTRAN program (harmexg.f) is available at http://www.gfy.ku.dk/~cct/goce-study.htm, or via the SSG's website, and can be used to generate point and grid values of the gravity field.

This SEGM is consistent with a priori statistical information using a simple random-number generator. The simulated errors in the spherical harmonic coefficients are calculated corresponding to a normal distribution with a given variance and zero mean. These can be used to generate global or local gravity field models. This field will probably be used to validate the GOCE mission when it is launched in 2006. To the best of the author's knowledge, it has not yet been used for other gravity field validations.

Source SEGMs

Synthetic Fields Based on Point Masses

Claessens et al. (2001) use 500 free-positioned point masses beneath Perth, Western Australia to construct a geoid model consistent with gravity observations. This led to the identification of errors in the marine gravity data, as well as confirming the misfit between satellite-altimeter-derived gravity anomalies in near-coastal regions. As such, this SEGM has indirectly found an additional application in detecting errors in regional gravity data.

Synthetic Fields Based on Mass-density Distributions (Forward Models)

Numerous members of the SSG have been working on forward models for various applications. For instance, Papp and Benedek (2000) use Newtonian integration of a 3D topographic mass-density model to determine curvature of the plumblines inside the topography. Nagy et al. (2000) have published a review-type paper on determining gravity field quantities from right rectangular prisms. Kuhn (2003) has presented the use of mass-density data in geoid computation. Papp and his group in Hungary also continue to develop the 3D model of the lithosphere in Central Europe for improved forward modelling.

The geophysical community is also conducting work related to the construction of a SEGM, though these activities are not a formal part of this SSG. These studies are based on forward modelling to generate gravity fields due to reasonably sophisticated geological structures. Geological forward modelling software, some of which is in the public domain, is given at http://www.earth.monash.edu.au/~mark/strmodlinks.html. However, this software is not necessarily optimised for geodetic studies, so should be treated with extreme caution if used in geodesy.

Lehmann (1999, 2001) has produced an SEGM using MATLAB (version 4.2 or later) script files, principally to test altimetry-gravimetry problems. However, this synthetic field can also be adapted, or used directly, to generate other gravity field quantities, such as spherical harmonics between degrees 11 and 2160. It is based on an axisymmetric model of the Earth that is made as-realistic-as-possible. Pseudo-random, un-correlated noise can be introduced into this SEGM. A copy of the 'user manual' and the MATLAB script files are available via the SSG's website.

Kuhn and Featherstone (2003a) use a spherical harmonic expression of Newton's integral to derive an optimal spatial data resolution of different mass distributions to be used in forward gravity field modelling. For example, the topographic masses and their density distribution are required at a spatial resolution of ~20 km in order to generate the global effect on the geoid with an accuracy of 1 mm. In order to model gravity, a much finer resolution is needed. For example, an accuracy of 0.01 mGal requires a ~10 m resolution of the topographic masses.

Kuhn and Featherstone (2003b) construct a preliminary SEGM based on gravity forward modelling using geophysical data only. This uses the JGPE95 5x5-arc-min digital elevation model for topography and bathymetry, and CRUST 2.0 2x2-arc-degree model (Mooney et al. 1998) for the geometry and density distribution of five different layers down to the Moho. The results show that a lot of patterns in the geoid (as given by EGM96) are well represented by this SEGM. However, there are also several less well-represented regions. Overall this particular SEGM has a spectral power greater than that of the EGM96 resulting in a peak-to-peak magnitude of about 250 m.

Recent studies have concentrated on using additional information on the Earth's mantle and its dynamic behaviour. The information used comprises seismic velocity anomalies, converted into density anomalies using a constant factor, and Love numbers in order to express the dynamic behaviour of the mantle. First results show that the peak-to-peak magnitude of the SEGM is reduced to a more realistic

120 m. The remaining discrepancies with respect to EGM96 are suspected to be un-modelled anomalies situated in the mantle, which are the subject of ongoing studies.

Dennis and Featherstone (2003) construct a simple SEGM based on an 8 km-high prismoidal mountain of constant mass density using the exact analytical expressions for the gravity field generated by right rectangular prisms (Nagy et al., 2000). Importantly, this gives a SEGM inside the (albeit simplified) topography for which the equipotential surfaces and plumblines were unambiguously defined. It was used to test the approximations used to compute orthometric heights.

Analytical SEGMs

Allasia (2001) has developed analytic solutions of Newton's integral for a continuous mass-density distribution. The multivariate interpolation operator can be used to interpolate the mass density or directly the potential function, as well as to remap them onto a regular grid or discrete points. This paper has set a theoretical framework, but no practical application of this method has yet been achieved (to this author's knowledge). This method appears to have the potential to generate a completely error-free (i.e., with no approximations) SEGM. It may also be possible to generate gravity field quantities inside the topographic masses, but further work is probably required to verify this.

Hybrid SEGMs

Haagmans (2000) has constructed a global SEGM that can generate gravity field quantities exterior to the Earth's surface at various spatial resolutions, and at aircraft and satellite altitudes. The model is based on a spherical harmonic expansion of an isostatically compensated topography and EGM96. The maximum degree is 2160, which corresponds to a spatial resolution of 5x5-arc-min. This SEGM is formed by two sets of spherical coefficients: one describing the synthetic Earth's topography (SET) and one describing the synthetic Earth's gravity field potential (SEP).

Claessens (2002) extends Haagmans's work to give a more realistic SEGM power spectrum. EGM96 is used to describe the low degrees, whereas the medium and high degrees are obtained from a global topographic-isostatically induced potential. Haagmans's (2000) matching procedure yielded potential coefficients with an unrealistically low power in the high degrees. Therefore, a so-called refined Kaula method was used, which leads to a more realistic power spectrum. In this method, generalised Kaula functions are estimated through the power spectra of the EGM96 and topographic-isostatic potential coefficients.

Downloadable Synthetic Gravity Fields and Software

As stated, a variety of SEGMs and computer software packages are available at the SSG's website (http://www.cage.curtin.edu.au/~will/iagssg3177.html). These are as follows.

Precomputed effects SEGM grids

Self-consistent synthetic gravity anomalies (at the geoid), geoid heights and vertical deflections (at the geoid) over Australia are available on a 2x2-arc-min grid (corresponding to spherical harmonic degree 5400) between the geographic bounds (108°E-160°E, 8°S-45°S). These were computed using the error-free effects SEGM, described earlier and used by Novàk et al. (2001) and Featherstone (1999, 2002). The format of each of these data files is an array, which can be converted to the format of geocentric geodetic longitude, geocentric latitude and quantity using the FORTRAN77 program sid2gmt.f.

- ausga.zip gravity anomalies at the geoid.
- ausn.zip geoid heights.
- ausew.zip east-west vertical deflections at the geoid.
- ausns.zip north-south vertical deflections at the geoid.

Self-consistent synthetic gravity anomalies (at the geoid), geoid heights and vertical deflections (at the geoid) over Greece are available on a 5x5-arc-min grid between the geographic bounds (18°E-30°E, 34°N-42°N). These data files were constructed in exactly the same way as the Australian data, but using the degree 2160 error-free effects SEGM.

- grga.zip gravity anomalies at the geoid.

- grn.zip geoid heights.
- grew.zip east-west vertical deflections at the geoid.
- grns.zip north-south vertical deflections at the geoid.

Software to Compute SEGMs
harmexg.f is a FORTRAN77 program to generate point and grid values of the gravity field, with the inclusion of random noise. A full description of the construction of this SEGM is given at http://www.gfy.ku.dk/~cct/goce-study.htm. It is also briefly described above in the section on effects SEGMs.
Ruediger Lehmann's MATLAB (v 4.2 or later) script files, including a description of the axisymmetric SEGM (summarised earlier under the section on source SEGMs), are in the file axi.zip which can be downloaded from the SSG's website.

Additional SEGMs and software will be added to the SSG website as they become available. They will also be distributed more widely via the IAG's International Gravity and Geoid Commission (IGGC) website after the term of SSG 3.177 expires.

Suggested Future Work: Tow New SSGs

While SSG 3.177 has not achieved all of its originally stated aims, significant progress has been achieved in many areas. There are several possible reasons for the aims not being met; the most likely being the initial scope of the SSG was too broad in relation to the number of active members. The aforementioned studies using source and/or effect SEGMs are defined for, or focus only upon, the external gravity field. Therefore, probably the main deficiency of the SEGMs is that they cannot be used to test important issues such as downward continuation and the treatment of topographic effects in gravity field modelling.

Accordingly, future studies (probably coordinated by a new SSG) must concentrate on SEGMs that rigorously describe the gravity field inside the topographic masses. An external gravity field that generates gravity gradients should also be considered for calibrating and validating the dedicated satellite gravimetry missions (CHAMP, GRACE and GOCE). Several investigators have already generated synthetic datasets (e.g., Balmino et al. 1999, Müller. and Oberndorfer 1999, Sneeuw et al. 2001, 2002, Oberndorfer and Müller 2002, Visser et al. 2002), but these activities should probably be coordinated and formalised through a new SSG.

Therefore, it is recommended that SSG 3.177 should evolve into two new SSGs; one to concentrate on synthetic gravity field modelling of the gravity field inside the topography, and another to concentrate on producing synthetic gravity gradient models for the current and planned dedicated satellite gravity missions.

References and Bibliography

Allasia G (2001) Approximating potential integrals by cardinal basis interpolants on multivariate scattered data, Computers and Mathematics with Applications 43(3-5): 275-287

Balmino G, Perosanz F, Rummel R, Sneeuw N, Sünkel H (1999) CHAMP, GRACE and GOCE: mission concepts and simulations, Bolletino di Geofisica Teoria ed Applicata, 40(3-4): 555-563

Claessens SJ (2002) A synthetic Earth model analysis, implementation, validation and application, MSc thesis, Delft University of Technology, Delft, 75 pp.

Claessens SJ, Featherstone WE, Barthelmes F (2001) Experiences with point-mass gravity field modelling in the Perth region, Western Australia, Geomatics Research Australasia 75: 53-86.

Dennis ML, Featherstone WE (2003) Evaluation of orthometric and related height systems using a simulated mountain gravity field, in: Tziavos IN (ed) Gravity and Geoid 2002, Department of Surveying and Geodesy, Aristotle University of Thessaloniki, 389-394.

Kuhn M, Featherstone WE (2003a) On the optimal spatial resolution of crustal mass distributions for forward gravity field modelling, in: Tziavos IN (ed) Gravity and Geoid 2002, Department of Surveying and Geodesy, Aristotle University of Thessaloniki, 195 -200.

Kuhn M, Featherstone WE (2003b) On the construction of a synthetic Earth gravity model (SEGM), in: Tziavos IN (ed) Gravity and Geoid 2002, Department of Surveying and Geodesy, Aristotle University of Thessaloniki, 189-194.

Kuhn M (2003) Geoid determination with density hypotheses from isostatic models and geological information, Journal of Geodesy 77(1-2): 50-65.

Featherstone WE (1999) Tests of two forms of Stokes's integral using a synthetic gravity field based on spherical harmonics, in: Krumm FW, Schwarze VS (eds.), Quo Vadis Geodesia, Institute of Geodesy, University of Stuttgart, Stuttgart, Germany, 101-112.

Featherstone WE (2002) Tests of two forms of Stokes's integral using a synthetic gravity field based on spherical harmonics. in: Grafarend EW, Krumm FW, Schwarze VS (eds), Geodesy - The Challenge for the Third Millennium, Springer, Berlin, 163-171.

Haagmans R (2000) A synthetic Earth model for use in geodesy, Journal of Geodesy 74: 503-511.

Hipkin RG (2001) The statistics of pink noise on the sphere: applications to mantle density anomalies, Geophysical Journal International 144: 259-270.

Holmes SA, Featherstone WE (2002a) A unified approach to the Clenshaw summation and the recursive computation of very high degree and order normalised associated Legendre functions, Journal of Geodesy 76(4): 279-299.

Holmes SA, Featherstone WE (2002b) Extending simplified high-degree synthesis methods to second latitudinal derivatives of geopotential, Journal of Geodesy 76(8): 447-450.

Lehmann R (1999) Studies on the altimetry-gravimetry problems for geoid determination, Physics and Chemistry of the Earth 24(1): 47-52.

Lehmann R (2001) Numerical aspects of altimetry-gravimetry problems, in: Bencolini B (ed.), Proceedings of the IV Hotine-Marussi Symposium on Mathematical Geodesy, Springer, Berlin, 21-32

Mooney WD, Laske G, Masters TG (1998) CRUST 5.1: a global crustal model at 5x5 degrees, Journal of Geophysical Research 103: 727-747.

Müller J, Oberndorfer H (1999) Simulation of the gradiometer mission GOCE, Artificial Satellites, 34: 41-55

Nagy D, Papp G, Benedek J (2000) The gravitational potential and its derivatives for the prism, Journal of Geodesy, 74 (7/8): 552-560.

Novàk P, Vaníček P, Veronneau M, Holmes S, Featherstone WE (2001) On the accuracy of modified Stokes's integration in high-frequency gravimetric geoid determination, Journal of Geodesy, 74(11): 644-654.

Oberndorfer H, Müller J (2002) GOCE closed-loop simulation, Journal of Geodynamics, 33: 53-63.

Papp G, Benedek J (2000) Numerical modelling of gravitational field lines – the effect of mass attraction on horizontal coordinates, Journal of Geodesy, 73(12): 648-659.

Ramillen G (2002) Gravity/magnetic potential of uneven shell topography, Journal of Geodesy 76: 139-149.

Sneeuw N, Dorobantu R, Gerlach C, Müller J, Oberndorfer H, Rummel R, Koop R, Visser PNAM, Hoyng P, Selig A, Smit M (2001) Simulation of the GOCE gravity field mission, in: Bencolini B (ed.), Proceedings of the IV Hotine-Marussi Symposium on Mathematical Geodesy, Springer, Berlin, 21-32

Sneeuw N, van den Ijssel J, Koop R, Visser P, Gerlach C (2002) Validation of fast pre-mission error analysis of the GOCE gradiometry mission by a full gravity field recovery simulation, Journal of Geodynamics, 33: 43-52.

Visser PNAM, Rummel R, Balmino G, Sünkel H, Johannessen J, Aguirre M, Woodworth PL, Le Provost C, Tscherning CC, Sabadini R (2002) The European Earth explorer mission GOCE: impact for the geosciences, in: Mitrovica JX, Vermeersen BLA (eds), Ice Sheets, Sea Level and the Dynamic Earth, Geophysical Monograph, 29, American Geophysical Union, Washington.

SPECIAL STUDY GROUP 3.184:

"USE OF REMOTE SENSING TECHNIQUES FOR VALIDATING HEIGHTS AND DEPTHS"

P.A.M. Berry

Objectives

With the growing need for precise elevations and depths on both regional and global scales, it is an appropriate task for geodesists to provide high quality models to the growing market of users.
A key objective of this study group is therefore the production of improved topographic and bathymetric data for geodetic requirements. The definition of a strategy for inclusion of new data from current and forthcoming space missions for the requirements of geodesy will also form a key part of the work of this study group.

Summary

The remit of this study group is to investigate the role of remote sensing techniques in determining heights and depths. Considerable progress has been made, especially in terrain and bathymetric mapping, in evaluation and incorporation of new space-based datasets. During the last four years, several new key missions, IceSAT, Envisat and Jason-1 (e.g. Zwally et al, 2002; Dorandeu, et al 2003; Milagro-Perez et al, 2003), have been launched and successfully commissioned, the SRTM dataset has been processed and is now being incrementally released.

One initial focus of the study group has been the investigation of the potential of land altimeter data to contribute to global mapping. Several regional studies have been carried out (e.g. Hilton et al, 2003) which have both validated the altimeter datasets and confirmed the accuracy of the regional comparison DEMs. The effects of DEM errors on the regional gravity models have also been investigated.

The first global–scale comparison with this independently derived altimeter dataset has allowed the large-scale errors in existing public domain Global Digital Elevation Models to be quantified. These were found to be far more extensive than previously reported. By combining retracked ERS-1 Geodetic Mission data with the best available ground truth, a new 30" GDEM – ACE – has been created in collaboration with ESA (Berry et al, 2000e). Over 40% of the earth's land heights have been changed in this new model, which has been used in the subsequent derivation of the combined terrain and bathymetric model DTM 2002 (Saleh & Pavlis, 2002). The scope of land altimetry has been restricted over rough terrain by altimeter design limitations: however, the new Envisat RA-2 altimeter (Benveniste, 2003) has already demonstrated recovery of data from the Himalayas and Andes mountain ranges. The role of altimetry in assessment of DEMs is therefore set to continue over all terrain, with an increasing number of research groups now contributing to this research area.

The SRTM dataset (Senus, W.J., 2000). is now becoming available. Data are already published over the USA, and release of data over South America is imminent. These data should provide very significant further enhancement of global land topography (Smith & Sandwell, 2003). The pixel resolution which will be on public release is currently the subject of discussion with the user community. Detailed global assessment of these data is not yet available: however, initial assessments of data quality over the USA are high, with the effects of shadowing and layover generally reported as having some impact in mountainous terrain.

Initial results from IceSAT are promising, with good performance over both the cryosphere and in regional land applications (e.g. Zwally & Brenner, 2001: Zwally et al, 2002). The forthcoming Cryosat mission should further enhance cryospheric mapping applications, particularly on the Antarctic coastal margins and over sea ice.

The bathymetric models continue to improve, and show very significant enhancements over GEBCO (e.g. Sandwell & Smith 2001; 2002). A major working group initiative on bathymetry has also reported within this period (.SCOR 2002). A dedicated bathymetric mission is currently being proposed as the optimum strategy further to enhance model accuracy.

One developing focus of this study group and other colleagues during this period has been the ability to make global scale measurements of inland water heights using the series of past and current altimeter missions and IceSAT (e.g. Compos et al, 2001). It has recently been determined that useable data have been gathered over the majority of the earth's large lake systems (Berry & Pinnock, 2003), demonstrating the potential to extract a decadal historical global lake climatology. The latest altimeter missions, Envisat and Jason-1, also have the capability to provide near-real-time data delivery, potentially permitting global independent monitoring of river and lake systems. ESA are now developing a new high level hydrology product for distribution to the user community. These results are also expected to form a valuable input to the analysis and interpretation of GRACE data.

Conclusions and Recommendations

With the incremental release of the high resolution SRTM dataset, cryospheric mapping addressed by IceSAT and the future Cryosat mission, Jason-1 and Envisat RA-2 and the continued acquisition of SAR data, the next few years should see a further quantum leap in quantity and quality of topographic data available over the whole earth. Global and regional validation of the SRTM dataset is one clear priority for future work. Bathymetric models continue to improve; a case is currently being made for a dedicated bathymetric mission.

The potential for inland water monitoring on a global scale has been established. This research area is growing rapidly both in terms of scientific advancement and number of participating research groups, and has global scientific and political implications. The integration of these results with GRACE data is the subject of current research.

Members

- Philippa Berry (UK, chair)
- Jerome Benveniste (Italy)
- Denizar Blitzkow (Brazil)
- Anita Brenner (USA)
- Peter Challoner (UK)
- Simon Ekholm (Denmark)
- Joanna Fernandes (Portugal)
- Yoichi Fukuda (Japan)
- Bill Kearsley (Australia)
- Steve Kenyon (USA)
- Roland Klees (Netherlands)
- Luciana Marc (Germany)
- Nikos Pavlis (USA)
- Dru Smith (USA)
- Gabriel Strykowski (Denmark)
- G.-C. Tsuei (Republic of China)
- Hilary Wilson (Germany)

Corresponding members

- W. Featherstone (Australia)
- Alan Hittelman (USA)
- Dave Sandwell (USA)
- M. Sideris (Canada)
- C.C. Tscherning (Denmark)

Publications list

Bamber, J.L, S. Ekholm, W.B. Krabill, A new, high-resolution digital elevation model of Greenland fully validated with airborne laser data, J. Geophys. Res., 106(B4),
6733-6746.

Benveniste, J. ; ENVISAT RA-2/MWR, 2003. Cross-Calibration and Validation Results. European Geophysical Assembly, Nice France, April 2003.

Berry, P.A.M., 1999; Global Digital Elevation Models – fact or fiction. Astronomy & Geophysics, July 1999. Vol. 40-3. PP3.10-3.13.

Berry, P.A.M., Dowson, M & Pinnock, R.A., 2000; An independent evaluation of accuracy of regional DEMs using satellite altimeter data. European Geophysical Assembly, Nice, France, April 2000.

Berry, P.A.M., Pinnock,R.A., Hilton, R.D. & Johnson, C.P.D.,2000a; A new Global Digital Elevation Model at 30" resolution: first generation. European Geophysical Assembly, Nice, France, April 2000.

Berry, P.A.M., Johnson, C.P.D. & Hilton, R.D., 2000b; Correction of Digital elevation data using altimeter derived heights. European Geophysical Assembly, Nice, France, April 2000.

Berry, P.A.M., Pinnock, R.A., Johnson, C.P.D., Hilton, R.D. & Dowson, M., 2000c; ACE: a new Global Digital Elevation Model. IAG General Assembly, Banff, Canada July, 2000.

Berry, P.A.M., Pinnock R.A. ,Hilton, R.D. ,Johnson, C.P.D & Dowson, M., 2000d; Characteristic Error Signatures of Current Global Digital Elevation Models. IAG General Assembly, Banff, Canada July, 2000.

Berry, P.A.M., Pinnock,R.A., Hilton, R.D. & Johnson, C.P.D.,2000e; ACE: a new GDEM incorporating satellite altimeter derived heights. ERS-ENVISAT symposium "Looking Down to Earth in the New Millennium" , Gothenburg, Sweden, October 2000.

Berry, P.A.M, Hilton, R.D., Johnson, C.P.D. & Pinnock, R.A., 2001a; The New ACE GDEM - Implications For Gravity Field Models. European Geophysical Assembly, Nice, France, April 2001.

Berry, P.A.M, Hilton, R.D & Johnson, C.P.D., 2001b; Global Digital elevation models –current and future. IAG scientific assembly September 2001.

Berry, P.A.M., Hilton, R.D. & Johnson, C.P.D. 2002; ACE: first full release of the new 30" GDEM incorporating satellite altimeter derived heights. European Geophysical Assembly, Nice France, April 2002.

Berry, P.A.M. & Pinnock, R.A. 2003; The potential contribution of satellite altimetry to retrieval of the global runoff budget. European Geophysical Assembly, Nice France, April 2003.

Berry, P.A.M., & Pinnock, R.A. 2003; Height retrieval over inland water targets by retracking satellite altimeter data. European Geophysical Assembly, Nice France, April 2003.

Berry, P.A.M., Dowson, M. & Garlick, J.D. 2003; Global assessment of ENVISAT RA-2 performance over non-ocean surfaces. European Geophysical Assembly, Nice France, April 2003.

Blitzkow D., 1999. Toward a 10 ' Resolution Geoid for South America: a Comparison Study. Physics And Chemistry Of The Earth Part A-Solid Earth And Geodesy 24 (1): 33-39 1999

Campos ID, Mercier F, Maheu C, ochonneau G, Kosuth P, Blitzkow D, Cazenave A., 2001. Temporal variations of river basin waters from Topex/Poseidon satellite altimetry. Application to the Amazon basin.. Comptes Rendus De L Academie Des Sciences Serie Ii Fascicule A-Sciences De La Terre Et Des Planetes 333 (10): 633-643 Nov 30 2001

Dorandeu, J.; Ablain, M.; Benveniste, J.; Dibarboure, G.; Faugere, Y.; Mertz, F.; Soussi, B.; Vincent, P., 2003. Progress in validation of Jason-1 and Envisat through cross-calibration European Geophysical Assembly, Nice France, April 2003.

Dowson, M. & Berry, P.A.M., 2000; ENVISAT RA-2: Potential for land topographic mapping. ERS-ENVISAT symposium “Looking Down to Earth in the New Millennium” , Gothenburg, Sweden, October 2000.

Gille, S.T., Yale, M.M., & Sandwell, D.T., Global correlation of mesoscale ocean variability with seafloor roughness from satellite altimetry., Geophys. Res. Lett., 27 , No9, 1251,1254, 2000.

Hilton, R.D., Featherstone, W.E., Berry, P.A.M., Johnson, C.P.D & Kirby, J.F., 2003; Comparison of digital elevation models over Australia and external validation using ERS-1 satellite radar altimetry. Australian Journal of Earth Sciences, Vol. 50 pp157-168

Johnson, C.P.D. & Berry, P.A.M., 2001; Validation and correction of space derived Digital Elevation Models using ERS satellite altimeter data. IAG scientific assembly September 2001.

Milagro-Perez, M.P.; Soussi, B.; Baker, S.; Zanife, O.-Z.; Dumont, J.-P.; Muir, A.; Legresy, B.; van den Bossche, M.; Benveniste, J., 2003. Verification of The RA2/MWR Level 2 Geophysical Reference Processors. European Geophysical Assembly, Nice France, April 2003.

Pinnock, R.A. & Berry, P.A.M.,2001; Potential for global scale hydrological monitoring using ERS altimetry. IAG scientific assembly September 2001.

Pinnock, .R.A. & Berry, P.A.M., 2002; Global scale hydrology from satellite altimeter missions: current status and future prospects. European Geophysical Assembly, Nice France, April 2002

Saleh, J. & Pavlis, N.K., 2002. The development and evaluation of the global digital terrain model DTM2002. IAG workshop, Thessaloniki, Greece, Summer 2002.

Sandwell, D.T. & Smith, W.H.F., 2002; Bathymetric estimation from altimetry, International Workshop on Satellite Altimetry for Geodesy, Geophysics and Oceanography, Wuhan China, 8-13 September 2002.

Sandwell , D.T. & Smith , W.H.F., Bathymetric estimation, Chapter 12 in Satellite altimetry and Earth sciences. ed. L.L. Fu & A. Cazenave, Academic Press, 441-457, 2001

Sandwell, D.T. Smith, W.H.F, Gille, S. & Soofi, K., Bathymetry from space: white paper in support of a high resolution ocean altimeter mission,
http://topex.ucsd.edu/marine_grav/white_paper.pdf.

SCOR 107 FP, 2002. Improved Global Bathymetry - final report of SCOR Working group 107. IOC Technical Series No 63, UNESCO 2002

Senus, W.J., 2000. Global Mapping Shuttle Radar Topography Mission (SRTM) 4th Global Spatial Data Infrastructure Conference, Cape Town, South Africa, March 2000.

Smith, B & Sandwell, D.T., Accuracy and resolution of shuttle radar topography mission data. Geophys. Res. Lett., in press 2003.

Smith DA and DR Roman, 2000b, A new high resolution DEM for the Northwest United States, Surv Land Inf Syst, (in press).

Smith, D.A., and D.R. Roman, 2000: Recent Advances in the Acquisition and Use of Terrain Data for Geoid Modelling over the United States, presented at IAG Session G3/W of the IUGG meeting in Birmingham, England from July 18 - 30, 1999.

Smith, W.; Sandwell, D.; Raney, K.. The future of short-wavelength geophysical altimetry EGS Nice, 2003.

Zwally, H. J. & Brenner, A. C.,2001. Ice Sheet Dynamics and Mass Balance, Chapter 9 in Satellite Altimetry and Earth Sciences, ed by Lee-Lueng Fu and A. Cazenave Academic Press, International Geophysics Series. Vol 69. 2001.

Zwally, H. J., Schutz, b., Abdalati, W., Abshire, J., Bentley, C., Brenner, A., Bufton, J., Dezio, j., Hancock, D., Herring, T., Minster, B., Quinn, K., Palm, S., Spinhirne, J. & Thomas, R.,2002. ICESat's laser measurements of polar ice, atmosphere, ocean, and land, Journal of Geodynamics 34 (2002) 405-445

SPECIAL STUDY GROUP 3.186:

"ALTIMETRY DATA PROCSESSING FOR GRAVITY, GEOID AND SEA SURFACE TOPOGRAPHY DETERMINATION"

C. Hwang

Introduction

Since the Seasat mission of 1978, satellite altimetry has found its wide applications in geodesy, geophysics and oceanography. As new satellite missions such as GFO-1, ENVISAT JASON-1, and CRYOSAT continue to contribute to the existing data sets of Seasat, Geosat, ERS-1/2, and TOPEX/POSEDION, more applications will be exploited. We are in need of more sophisticated data processing techniques to explore these applications. For example, coastal geoids, gravity anomalies tide models and bathymetry models derived from satellite altimetry have important engineering applications, which did not receive much attention in the past. But exploiting satellite altimetry in coastal areas requires much more sophisticated correction models and data processing techniques than in the open oceans. For example, the data and coordinate systems of different satellite missions should be properly weighted/corrected and unified in order to obtain an optimal multi-satellite data set for subsequent analyses. Shipborne gravity data are abundant in many areas of the oceans, and have high quality and good spatial resolution. They should be combined with altimetry data for global gravity and geoid computation and estimation of high-degree geopotential model. Bathymetry model is an important element in, e.g., the general circulation model of the world oceans and the hydrodynamic tide model, and should be optimally derived with altimetry and other data. Eddies in coastal areas are associated with coastal upwelling, which are extremely important for marine production.

Because of the need to tackle these problems, SSG3.186 was formed. The members of SSG3.186 are listed in the following table.

Name (country)
V. D. Andritsanos (Greece)
O. Andersen (Denmark)
D. Chao (China)
S. A. Chen (Taiwan)
X. Deng (Australia)
C. Hwang (Taiwan)
Y. Fukuda (Japan)
J. W. Kim (Korea)
J. Klokocnik (Czech Republic)
P. Knudsen (Denmark)
J. Li (China)
P. Hsu (Taiwan)
P. Medevedev (Russia)
P. Moore (UK)
M. Rentsch (Germany)
T. Schoene (Germany)
C. K. Shum (USA)
G. S. Vergos (Canada)
G. Venuti (Italy)
Y. Wang (USA)
Y. Yi (USA)

Subjects of study

The selected aims and problems associated with IAG SSG 3.186 are:

1. improving the quality of coastal altimeter data by improving geophysical corrections, retracking waveforms and "tuning" altimeter measurements
2. promoting engineering applications of coastal altimetry with high quality coastal geoid, gravity anomaly, bathymetry, ocean tide and sea surface topography models from altimetry
3. investigating the best method and the best altimeter data type for computing gravity anomalies, mean sea surface heights from multi-satellite altimeter data
4. developing a best technique to compute bathymetry from altimeter-derived geoids or gravity anomalies, with emphasis on the downward continuation and filtering problems
5. finding a best strategy and data sources to combine shipborne gravity/airborne gravity and altimeter data for generating global and regional gravity anomalies and geoids
6. improving orbit accuracies of altimetric satellites and accuracies of the long wavelength gravity field by crossover and other methods
7. unifying the coordinate systems between two or more satellite missions for determining long-term time series of oceanographic parameters

International altimetry workshop

As part of the activities of SSG 3.186, the *"International Workshop on Satellite Altimetry for Geodesy, Geophysics and Oceanography: Summer Lecture Series and Scientific Applications"* was held in Wuhan, China from September 8 to 13, 2002 (see http://space.cv.nctu.edu.tw/altimetryworkshop/altimetry.htm). This is a joint workshop of IAG SSG3.186 (chaired by C Hwang) and IAG Section II (chaired by CK Shum of the Ohio State University), and was hosted by Wuhan University with Dr JC Li as the chair of the local organizing committee. The scientific program was organized by the Scientific Committee chaired by C Hwang. The workshop's aim is to offer free lectures on various subjects of satellite altimetry for beginners and for advanced researchers, and to provide a forum for presentations and discussions of latest results in altimetric research. A total of 60 abstracts were received and 65 people participated in this workshop. These participants are from Austria (2), Australia (1), Canada (1), China (26), Czech Republic (1), Denmark (2), France (1), Germany (2), Italy (2), Japan (1), Korean (2), Netherlands (2), Taiwan (13), UK (1), and USA (7). On September 9 and 10, 2003, the following five three-hours lectures were delivered:

Lecture 1: Principles of satellite altimetry and application to sea level change studies, by CK Shum, Ohio State University, USA

Lecture 2: Ocean tide modeling with altimetry and geodetic applications, by Kato Matsumoto, National Astronomical Observatory, Japan

Lecture 3: Marine gravity and geoid from multi-satellite altimetry and applications, O.B. Andersen, National Survey and Cadastre, Denmark

Lecture 4: Altimeter waveform retracking for land/ocean use, by P. Berry, De Montfort University, UK

Lecture 5: Bathymetric estimation from altimetry, by D. T. Sandwell, Scripps Inst. of Oceanography, USA

On September 11-13, the following three keynote speeches were delivered:

Speech 1: Geodetic application of satellite altimetry, W. Bosch, DGFI, Germany

Speech 2: Present-day sea level change: observations from satellite altimetry and tide gauges and causes, by A. Cazenave, CNES, France

Speech 3: Advances in Ocean Dynamics from Satellite Altimetry, L.L. Fu, NASA/JPL, USA

On September 11-13, 8 scientific Sessions were held, including G1 (chaired by C Zhao), G2 (W Bosch), G3 (EL Mathers), GO1 (H Schuh), GO2 (J Klokocnik), GO3 (C Hwang), O1 (C Zuffada) and O2 (HZ Xu). A total of 37 papers were presented.

A proceedings volume, which will be included in the IAG symposium series and published by Springer-Verlag, will be due out in the summer of 2003. This volume contains 30 peer-reviewed papers conforming to the standard of Journal of Geodesy.

Summary, recommendation and future work

The international altimetry workshop held in China, 2002, highlighted the activities of SSG3.186. The five lectures delivered in this workshop cover a wide range of applications and disciplines and also provide basic tools for the attendees. The papers presented in the scientific sessions cover a large portion of the proposed subjects of study in SSG 3.186. Overall speaking, despite reported progress in data processing and theory, improvement in the proposed subject areas is still needed. Detailed of the works carried by out the members can be found in the publications listed in Section 5 below.

One focus of SSG3.186 is on shallow-water altimetry for gravity and geoid computations, for which new algorithm for data filtering and outlier detections have been presented. In particular, a new altimetry data type, called differenced was used. If it is not sea surface height, geoid gradient or differenced height, what will be a better altimeter data type for marine gravity and geoid determinations? It was shown that use of retracked altimetry can improve the accuracy of predicted marine gravity and geoid. Currently, only retracked ERS is used for marine geoid and gravity determinations. It will still yet to use more retracked altimetry such as those from Geosat/GM will contribute to the prediction accuracy. The application of retracked altimetry data can be also extended to tidal prediction and SST determination for oceanography.

Many members and his colleagues have devoted time to tackling the problem of bathymetric prediction from altimetry data. Two methodologies, one stochastically based and the other FFT-based, have been used. However, from their improved results, it seems there is room for gaining more prediction accuracy in terms of theory and data processing technique. What is the best conversion theory and procedure for deriving bathymetry from gravity or geoidal height? Members in this SSG need to have a deeper understanding of geophysics in this problem before a better method is devised.

Members in this SSG study SST recovery from satellite altimetry and application to oceanography mainly over deep oceans. Compared to shipborne methods, significant results have been achieved, e.g., Hwang and Chen (2000a), Hwang and Chen (2000b), and Hwang and Kao (2002). However, SST studies over shallow waters were not carried out among the SSG members. It is not clear whether SST can be used for deriving geostrophic currents over shallow waters because of the complex ocean dynamics here. It is indeed very desired to see if coastal oceanography can benefit from satellite altimetry.

Another challenge is the combination of data from multi-sensors, such as satellite/air-borne altimeters, ship/air-borne gravimeters, for marine geoid/gravity determination. Different sensors have different noise levels and spatial resolutions, which make the combination a difficult task.

Many groups have computed global sets of marine gravity and mean SSH, so it will be necessary to perform an inter-comparison of these results and compute an optimal set from these various sets using a weighted average method, something like the method for combing the IGS orbit of GPS. SSG3.186 may then presents this optimal set of marine gravity and mean SSH to the world scientific community for various applications.

Publications of members related to SSG3.186 over 1999-2003

Andersen, O. and Knudsen, P., The role of satellite altimetry in gravity field modelling in coastal areas, Phys. Chem. Earth, 25, 17-24, Pergammon, Berlin, 2000.

Andersen, O.B., and P. Knudsen, The role of satellite altimetry in gravity field modeling in coastal areas, Phys. Chem. Earth, 25 (10), 17-24, 2000.

Andersen, O.B., P. Knudsen and R. Trimmer, The KMS99 global gravity field from ERS and Geosat altimetry, Proc. ERS-Envisat Symp. 2000, Göteborg, Sweden. 2000.

Andritsanos VD, Vergos GS, Tziavos IN, Pavlis EC and Mertikas SP. A High Reososution Geoid for the Establishment of the Gavdos Mulit-Satellite Calibration Site. International Association of Geodesy Symposia, Vol. 123 Sideris (ed.), Gravity Geoid and Geodynamics 2000, Springer - Verlag Berlin Heidelberg, pp. 347-354, 2001.

Andritsanos, V.D., and I.N. Tziavos, Estimation of gravity field parameters by a multiple input/output system. Phys. Chem. Earth (A), 25 (1), 39-46, 2000.

Andritsanos VD, Vergos GS, Tziavos IN and Pavlis EC, Alternative Geoid Solutions in the Southern Aegean Sea: Comparisons and Results. Presented in the EGS Millennium General Assembly, April 25-29,Nice, France, 2000.

Anzenhofer, M., A. Braun, M. Rentsch, C. Reigber, and C. Shum, Coastal Altimetry and Application, EGS, The Hague, Netherlands, April 1999.

Anzenhofer, M., C. Shum, and M. Renstch, Coastal altimetry and applications, Ohio State University Geodetic Science and Surveying Report #464, 2000.

Braun, A., S. Eickschen, A. Helm, M. Rentsch, T. Schöne: The ENVISAT RA-2 Value-Added Ocean/Ice Processor at GFZ Potsdam, ESA - ERS/ENVISAT Symposium, Gothenburg, Sweden, Oct 2000, Abstract volume.

Deng, X. and W. Featherstone, Analysis of ERS-2 satellite altimeter waveform data around Australian coasts, paper presented to the Annual Research Seminar, The University of New South Wales, Sydney, Australia, 20-21 November, 2000.

Deng, X., Featherstone, W.E., Hwang, C. and Shum, C.K, Improved Coastal Marine Gravity Anomalies at the Taiwan Strait from Altimeter Waveform Retracking, Proceedings of International Workshop on Satellite Altimetry for Geodesy, Geophysics and Oceanography: Summer Lecture Series and Scientific Applications, Wuhan, China, September, 2002.

Deng, X., Featherstone, W.E., Hwang, C. and Berry, P.A.M. Retracking ERS-2 Radar Altimeter Waveform Data in Australia's Coastal Zone, Proceedings of IAG 2001 Scientific Assembly, Budapest, Hungary, September, 2001.

Deng, X. and Featherstone, W.E., Analysis of ERS-2 Satellite Radar Altimeter Waveform Data around Australian Coasts, oral paper presented to the University of New South Wales Annual Research Seminar, Sydney, Australia, November [abstract in: Geomatics Research Australia, No.73], 2001.

Deng, X. and Featherstone, W.E, Improved Determination of Sea Surface Heights Close to the Australian Coast from ERS-2 Satellite Radar Altimetry, oral paper presented to the XXIII General Assembly of the International Union of Geodesy and Geophysics (IUGG2003), Sapporo, Japan, July, 2003.

Deng, X., Featherstone, W.E., Hwang, C. and Berry, P.A.M., Estimation of Contamination of ERS-2 and POSEIDON Satellite Radar Altimetry Close to the Coasts of Australia, Marine Geodesy, Vol. 25, No. 4, pp. 249-271, 2002.

Deng, X., Featherstone, W.E., Hwang, C. and Berry, P.A.M, Analysis of Poseidon and ERS-2 Satellite Radar Altimeter Waveform Data around Australian Coasts, in: Schwarz, K.P. and Adam, J. (eds), Vistas for Geodesy in the New Millennium, Springer, Berlin, pp. 543-550,2002.

Deng, X., W. Featherstone, C. Hwang, and C. Shum, Improved coastal marine gravity anomalies at the Taiwan Strait from altimeter waveform retracking, Wuhan Altimeter Workshop, Springer-Verlage Berlin Heidelberg, submitted 2003.

Esselborn, S., und C. Eden: Sea Surface Height changes in the North Atlantic Ocean Related to the North Atlantic Oscillation, Geophys. Res. Letters, 28, 3473-3476, 2001.

Grebenitcharsky RS, Vergos GS and Sideris MG, Combination of gravity, altimetry and GPS/Leveling data for the numerical solution of altimetry-gravimetry boundary value problems. International Association of Geodesy Symposia, Vol. 125 J. Ádám and K.-P. Schwarz (eds.), Vistas for Geodesy in the New Millennium, Springer – Verlag Berlin Heidelberg, pp. 150-155, 2002.

Helm, A., A. Braun, S. Eickschen and T. Schoene. "Calibration of the Shuttle Radar Topography Mission X-SAR Instrument Using a Synthetic Altimetry Data Model", Canadian Journal of Remote Sensing, Volume 28, Number 4, August 2002, 573-580, 2002.

Hwang, C, and S.-A. Chen, Circulations and eddies over the South China Sea derived from TOPEX/Poseidon altimetry, J. Geophys. Res.,105, 23,943-23,965, 2000a.

Hwang, C., and S.-A Chen, Fourier and wavelet analyses of TOPEX/Poseidon-derived sea level anomaly over the South China Sea: A contribution to the South China Sea Monsoon Experiment, J. Geophys. Res., 105, 28,785-28,804. 2000b.

Hwang, C, and H.-Y. Hsu, 2001. A global mean sea surface grid from Seasat, Geosat, ERS-1, and TOPEX/POSEIDON altimetry: application of deflection-geoid formula, IAG Scientific Assembly, Budapest, 2-9 September, 2001.

Hwang, C., HY Hsu and RJ Jang, Global mean sea surface and marine gravity anomaly from multi-satellite altimetry: applications of deflection-geoid and inverse Vening Meinesz formula J. Geod., Vol. 76, pp. 407-418, 2002.

Hwang, C. and R. Kao. TOPEX/POSEIDON-derived space-time variations of Kuroshio Current: applications of a gravimetric geoid and wavelet analysis, Geophys. J. Int., 151, 835-847, 2002.

Hwang, C., R. Kao, and C-R. Wu, TOPEX/POSEIDON observations of eddies in the Subtropical Counter Current area: kinematic characteristics of anticyclonic and cyclonic eddies, paper submitted to J. of Geophys. Res., 2002.

Hwang, C., Hsu, H.Y. and Deng, X., Marine Gravity Anomaly from Satellite Altimetry: A Comparison of Methods over Shallow Waters, Proceedings of International Workshop on Satellite Altimetry for Geodesy, Geophysics and Oceanography: Summer Lecture Series and Scientific Applications, Wuhan, China, September, 2002.

Klokocnik J, Wagner CA, Combinations of Satellite Crossovers to Study Orbit and Residual Errors in Altimetry, Celest. Mech. 74: 231-242. 1999.

Klokonick, J., C.A. Wagner and J. Kostelecky, Residual errors in altimetry data detected by combinations of single- and dual-satellite crossovers, J. Geod., 73, 671-683, 2000.

Klokocnik J, Wagner CA, Kostelecky J 2000: Residual Errors in Altimetry Data Detected by Combinations of Single- and Dual-Satellite Crossovers, J. Geod. 73: 671-683, 2000.

Klokocnik J, Reigber Ch, Schwintzer P, Wagner CA, Kostelecky J, Evaluation of pre-CHAMP Gravity Models GRIM5-S1 and GRIM5-C1 with Satellite Crossover Altimetry, GFZ Sci. Techn. Rep. STR 00/22, Potsdam, J. Geod. 2002, 76: 189-198, 2000.

Medvedev, P., The use of the satellite altimetry data for Sea of Okhotsk and Caspian Sea studies and the plans of GPS and GLONASS applications, IAG Scientific Assembly, Budapest, Sep 2-9, 2001.

Rentsch, M., A. Braun, T. Schöne, T. Gruber, and P. Schwintzer, Recent results and applications from GFZ marine gravity grids, EGS XXV General Assembly, Nice, France, 26 April, 2000.

Rentsch, M., A. Braun, A. Helm, T. Schöne: Operational Altimetry at GFZ- From ERS-2 to Envisat. ESA - ERS/ENVISAT Symposium, Gothenburg, Sweden, October 2000., Abstract volume.

Schöne, T., S. Eickschen: Wind Speed and SWH Calibration for Radar Altimetry in the North Sea, ESA - ERS/ENVISAT Symposium, Gothenburg, Sweden, October, 2000, Abstract volume.

Schöne, T., M. Forberg, R. Galas, C. Reigber: GPS-buoys for lifetime RA drift monitoring, AGU Fall Meeting 2002, EOS Trans. AGU, 83(47), Fall Meet. Suppl., Abstract OS52A-0189, 2002.

Shum, C., Y. Yi, C. Zhao, T. Urban, B. Berwin, R. Benada, and V. Zlotnicki, Improved ERS-1 mission radar altimeter geophysical data record data product (DVD-ROM), JPL/PODAAC, March 2000.

Shum, C. Global gravity field modeling: geophysical applications, Invited lecture at the Crustal Deformation Laboratory, Geography and Crustal Dynamics Research Center, Geographical Survey Institute, Tsukuba, Japan, February 28, 2001.

Shum, C., Altimeter methods for satellite geodesy, Keynote speaker, International Workshop on Satellite altimetry for Geodesy, Lecture 1: Principles of satellite altimetry and application to sea level change studies, Wuhan, China, September 8-13, 2002.

Tocho C, Vergos GS, Sideris MG, Optimal Marine Geoid Determination In The Atlantic Coastal Region Of Argentina. Presented at the 2003 General Assembly of the International Union of Geodesy and Geophysics (IUGG2003), June 30 – July 11, Sapporo, Japan, 2003.

Tziavos IN, Vergos GS and the GAVDOS Team, A Survey of Marine Geoid Estimation Using Satellite and Shipborne Data in Gavdos. Presented at the XXVII EGS General Assembly, April 21-26, Nice, France, 2002a.

Tziavos IN, Vergos GS and the GAVDOS Team, A Survey of Marine Geoid Estimation Using Satelite and Shipborne Data in Gavdos II. Presented at the 3rd Meeting of the International Gravity and Geoid Commission (IGGC), Gravity and Geoid 2002 - GG2002, August 26-30, Thessaloniki, Greece, 2002b.

Urban, T., J. Ries, B. Tapley, and C. Shum, The integration of twenty-five years of sea-level measurements from satellite altimetry, IUGG Symposia, JSG11, Birmingham, UK, July, 1999.

Vergos, G.S., and M.G. Sideris, Improving the estimation of bottom ocean topography with satellite altimetry derived gravity data using the integrated inverse method, IAG Scientific Assembly, Budapest, 2-9 September, 2001.

Vergos GS, Bayoud FA, Sideris MG and Tziavos IN, High-Resolution Geoid Computation by Combining shipborne and Multi-Satellite altimetry Data in the Eastern Mediterranean Sea. IGeS Buletin Special Issue, Vol. 13, Proceedings of the EGS 2001 - G7 Session "Regional and Local Gravity Field Approximation", I.N. Tziavos and R. Barzaghi (eds.), pp. 85-99, March 25-30, Nice, France, 2002.

Vergos GS, Grebenicharsky RS and Sideris MG, Combination of Multi-Satellite Altimetry and Shipborne Gravity Data for Geoid Determination in a Coastal Region of Eastern Canada. IGeS Buletin Special Issue, Vol. 13, Proceedings of the EGS 2001 - G7 Session "Regional and Local Gravity Field Approximation", I.N. Tziavos and R. Barzaghi (eds.), pp. 100-115, March 25-30, Nice, France, 2002.

Vergos GS, Sideris MG, Improving the Estimation of Bottom Ocean Topography with Altimetry-Derived Gravity Data Using the Integrated Inverse Method. International Association of Geodesy Symposia, Vol. 125,J.

Ádám and K.-P. Schwarz (eds.), Vistas for Geodesy in the New Millennium, Springer – Verlag Berlin Heidelberg, pp. 529-534, 2001.

Vergos GS and Sideris MG, Estimation of High-Precision Marine Geoid Models Offshore Newfoundland, Eastern Canada. 3rd Meeting of the International Gravity and Geoid Commission (IGGC), Tziavos (ed.), Gravity and Geoid 2002 - GG2002, pp. 126-131, 2003a.

Vergos GS and Sideris MG, Altimetry-Derived Marine Gravity Field Estimation Using Single- and Multi-Satellite Data. 3rd Meeting of the International Gravity and Geoid Commission (IGGC), Tziavos (ed.), Gravity and Geoid 2002 - GG2002, pp. 308-313, 2003b.

Vergos GS, Grebenicharsky RS and Sideris MG, Sea Surface Topography and Geostrophic Flow Estiamtion from Multi-Satellite Altimetry and Shipborne Gravity Data Using Wavelet Decomposition. 3rd Meeting of the International Gravity and Geoid Commission (IGGC), Tziavos (ed.), Gravity and Geoid 2002 - GG2002, 314-319, 2003.

Vergos GS, Andritsanos VD, Tziavos IN, On the Determination of Marine Geoid Models by Least-Squares Collocation and Spectral Methods Using Heterogeneous Data. Presented at the 2003 General Assembly of the International Union of Geodesy and Geophysics (IUGG2003), June 30 – July 11, Sapporo, Japan, 2003.

Vergos GS, Grebenicharsky RS and Sideris MG, Improving the Marine Geoid by Combining Satellite and Shipborne Data. Presented at the 3rd Annual Conference of the GEOIDe Network of Centers of Excellence (NCE), June 21 – 22, 2001, Fredericton, New Brunswick, Canada, 2001.

Vergos GS, Sideris MG, On Improving the Determination of the Gravity Field by Estimating the Bottom Ocean Topography with Satellite Altimetry and Shipborne Gravity Data. Presented at the Joint IAPSO/IABO Oceanographic Meeting, Mar del Plata, Argentina, October 21-28, 2001.

Vergos GS and Sideris MG, Bottom Ocean Topography Estimation Improvement Using Altimetry and Depth Soundings. Presented at the XXVII EGS General Assembly, April 21-26, Nice, France, 2002a.

Vergos GS and Sideris MG, Marine Geoid Estimation Using Satellite and Shipborne Data. Presented at the Annual Scientific Meeting of the Canadian Geophysical Union, May 18-21, Banff, Canada, 2002b.

Vergos GS and Sideris MG, Gravity Field and Quasi-stationary Sea Surface Topography Estimation Using Heterogeneous Data. Presented at the Annual Scientific Meeting of the Canadian Geophysical Union, May 18-21, Banff, Canada. 2002c.

Vergos GS, Sideris MG, Tziavos IN, High-Resolution and High-Accuracy Marine Geoid Estimation in the Aegean Sea Using Satellite and Shipborne Data. Presented at the 3rd Meeting of the International Gravity and Geoid Commission (IGGC), Gravity and Geoid 2002 - GG2002, August 26-30, Thessaloniki, Greece, 2002.

Wagner CA, Klokocnik J, Kostelecky , Improvement of Geopotential and Detection of Interannual Oceanographic Signals from Inversion ofSingle and Dual Satellite Altimetry, VUGTK Prague-Zdiby, ser. Vol. 46, # 26, 39 pages, 2000.

Wang, Y., The satellite altimeter data derived mean sea surface GSFC98, Geophys. Res. Lett., 27 (5), 701-704, 2000.

Yi, Y., C. Shum, H. Tseng, M. Anzenhofer, M. Rentsch, and C. Hwang. On the advances of marine gravity anomaly models determined from GEOSAT, ERS-1 and TOPEX/POSEIDON satellite radar altimetry, IUGG Symposia, G3, Birmingham, UK, July, 1999.

Yi, Y., A. Braun, K. Cheng, C. Shum, and S. Calmant, Initial ENVISAT RA-2 Cal/Val results, ENVISAT RA-MWR CCVT Fourth Plenary Meeting, ESA/ESRIN, Frascati, Italy, 3-4 December 2002.

Yi, Y., A. Braun, C. Shum, K. Cheng and S. Calment, Envisat RA2 cal/val results, Envisat RA-2/MWR CCVT Sixth Plenary Meeting, ESA/ESRIN, Frascati, Italy, March 25-27, 2003.

Yi, Y., K. Cheng, C. Shum, A. Braun, and S. Calmant, ENVISAT RA-2 calibration/validation, Proc. EGS-AGU-EUG Joint Assembly, Nice, France, April 6-11, 2003.

Zhao. C., C. Shum, Y. Yi, P. Luk, J. Finkelstein, J. Lillibridge, J. McMillan, and M. Rau, GFO radar altimeter data product verifications and ocean circulation studies, IAG Scientific Assembly, Vistas for Geodesy in the New Millennium, Budapest, Hungary, September 2-7, 2001.

Zhao, C., C. Shum and Y. Yi, Ionosphere corrections of radar altimeters and calibration results of GFO, Invited, International Workshop on Satellite altimetry for Geodesy, Geophysics and Oceanography: Summer Lecture Series and Scientific Applications, Wuhan, China, September 8-13, 2002.

List of papers published in the proceedings of international altimetry workshop on altimetry (available by order to Springer-Verlag in summer 2003)

Denis L. Volkov and Hendrik M. van Aken, Low frequency change of sea level in the north atlantic ocean as observed with satellite altimetry

Cinzia Zuffada, Stephen Lowe, Yi Chao and Robert Treuhaft, Oceanography with GPS.

Zhang Ruihua, Shi Pan, Peng Fuqing, Xia Zheren and Liu Guangming, Determination of $30' \times 30'$ marine gravity anomalies from multisatellite altimetry.

X. Dong, C. Huang, P. Woodworth, P. Moore, R. Bingley, Absolute calibration of the ers-2 altimeter using UK tide gauges.

S. kahlouche, A. Rami, S.A Benahmed Daho, Topex altimetric mean sea level and gravimetric geoid in the north of Algeria.

Cho-Teng Liu, Ching-Hsi Nan, Chung-Ru Ho, Nan-Jung Kuo, Ming-Kuang Hsu, and Ruo-Shan Tseng, Application of satellite remote sensing on the tuna fishery of eastern tropical Pacific.

Carla Braitenberg, Elena Pagot, Yong Wang, and Jian Fang, Bathymetry and crustal thickness variations from gravity inversion and flexural isostasy.

Lifeng Bao and Yang Lu, Recovering deflections of vertical from a tangent plane of gridded geoidal heights from altimetry.

Guoqi Han, Current Variability over the Scotian Slope in the 1990s.

Jingyng Bao, Dingbo Chao, Jinping Zhao, Qi Wang and Yanchun Liu, harmonic tidal analysis along T/P tracks in China Seas and vicinity.

Y. Yang, C. T. Liu, T. N. Lee, and W. E. Johns, Geostrophic uncertainty and anomalous current structure in association with mesoscale eddies delineated by altimeter observations east of Taiwan.

Ole B. Andersen, The M_4 Shallow water tidal constituent from altimetry and tide gauges.

Gao Jinyao, and Jin Xianglong, Joint application of altimeter data and egm96 to submarine tectonic and geodynamic study in west pacific.

Jianguo Hu, Zhengtao Wang, Jiancheng Li, and Dingbo Chao, Sea level changes detected by using satellite altimeter data and comparing with tide gauge records in China Sea.

Yang Lu, and Hou-Tse Hsu, Pseudo-harmonic representation of gravity field over South China Sea.
Jiang Weiping Li Jiancheng, Wang Zhengtao, Determination of global mean sea surface using multi-satellite altimetric data.

Huang Motao, Zhai Guojun, Bian Shaofeng, Ouyang Yongzhong,Liu Yanchun, and Liu Chuanyong, Comparisons of three inversion approaches for recovering gravity anomalies from altimeter data.

C Hwang, R Kao and CR Wu, The kinematics of mesoscale eddies from TOPEX/POSEIDON altimetry over the Subtropical Counter Current.

Gustavo Acuna and Wolfgang Bosch, Absolute comparison of satellite altimeter observations and tide gauge registrations in Venezuela.

J. Benveniste, M.P. Milagro-Perez, M. Roca and G. Levrini, The Envisat Ra-2 radar altimeter system.

C Hwang, HY Hsu, Marine gravity anomaly from satellite altimetry: a comparison of methods over shallow waters.

Jeong Woo Kim, Daniel Roman and Ralph R.B. von Frese, Enhanced Free-air Gravity Anomalies by Satellite Radar Altimetry.

Lucy Mathers, An intercomparison of parametric models of sea state bias for the TOPEX, Poseidon and Jason altimeters.

Sergey A. Lebedev, Oleg I. Zilberstein, Sergey K. Popov and Olga V. Tikhonova, Analysis of temporal sea level variation of the Barents and the White seas by satellite altimetry data, results of hydrodynamic simulation and tide gauge data.

J. Klokočník, C.A. Wagner and J. Kostelecký, Accuracy assessment of the earth gravity field models by means of independent satellite crossover altimetry,

Chen Lu-Ying and Xu Hou-ze, Determination of sea level height variation by dynamics crossovers adjustment.
Schuh, H. , G. Estermann, J.-F. Crétaux_, and T. van Dam, Investigation of hydrological and atmospheric loading by space geodetic techniques.

Changyin Zhao, C. K. Shum and Yuchan Yi, Calibration results of GFO.

C.K. Shum, Yuchan Yi, Ole Andersen and Per Knudsen, Extreme southern ocean tide modeling using radar altimeters

Section IV

General Theory and Methodology

Report of the President for the Period 1999 – 2003

B. Heck

Introduction and Objectives

According to the IAG by-laws and the terms of reference, section IV in the hitherto existing structure of the IAG covers general aspects of geodetic theory and methodology. In contrast to other IAG sections, the scope of Section IV is not confined to a specific topic in Geodesy such as positioning, or gravity field determination, or geodynamics; the accent here is rather on the systematic (mathematical) treatment of groups of problems. Therefore it is quite natural that most topics treated by the bodies in Section IV are shared in one way or another with other IAG sections, adding a different, more general point of view, but without just duplicating the work. Ideally, the mathematical problems occurring in the topic-oriented sections should be reflected upon in Section IV and solved on a general basis. Another principal scope of Section IV is to develop mathematical tools and to take up available approaches already developed in other fields of Science and to adapt them to Geodesy; a prominent historical example is Least Squares Collocation which was developed in the seventies mainly in Section IV and nowadays is a basic tool in many branches of Geodesy. In recent years, e.g. spatial statistics, robust statistical methods, fuzzy theory and the use of wavelets have been thoroughly investigated in Section IV tor applications in Geodesy; some of these approaches seem to be very promising and to become highly efficient tools in geodetic data analysis.

Structure

The principal structure as well as its title was given to Section IV at the 18th IUGG General Assembly in Hamburg 1983. In 1991 the Special Commission 1 on „Mathematical and Physical Foundations of Geodesy“ has been added as a new structure element besides the conventional Special Study Groups. This basic structure, consisting of Special Commission 1 and Special Study Groups, has been retained in the past period 1999 – 2003. While the Special Study Groups have clearly defined topics reflecting the most important aspects of contemporary geodetic theory, the Special Commission covers broader and long-term items of geodetic theory in its sub-commissions and working groups.

In order to achieve its objectives, Section IV has established the following structure in detail:

President:
Bernhard Heck (Germany)
Secretaries:
Christopher Jekeli (USA)
Yuanxi Yang (China)
Special Commission SC1:
Mathematical and Physical Foundations of Geodesy
Chair: Petr Holota (Czech Republic)

Subcommission 1:
Statistics and Optimization
Chair: Peiliang Xu (Japan)
Working Group:
Spatial Statistics for Geodetic Science
Chair: Burkhard Schaffrin (USA)

Subcommission 2:
Numerical and Approximation Methods
Chair: Willi Freeden (Germany)
Subcommission 3:
Boundary Value Problems
Chair: Rüdiger Lehmann (Germany)
Subcommission 4:
Geometry, Relativity, Cartography, GIS
Chair: Volker Schwarze (Germany)
Subcommission 5:
Hydrostatic/isostatic Earth reference Models
Chair: Alexander Marchenko (Ukraine)

Special Study Groups
In 1999 the following five Special Study Groups have been established:

SSG 4.187: Wavelets in Geodesy and Geodynamics
Chair: Wolfgang Keller (Germany)
SSG 4.188: Mass Density from Joint Inverse Gravity Modelling
Chair. Gabriel Strykowski (Denmark)
SSG 4.189: Dynamic Theories of Deformation and Gravity Fields
Chair: Detlef Wolf (Germany)
SSG 4.190: Non-Probabilistic Assessment in Geodetic Data Analysis
Chair: Hansjörg Kutterer (Germany)
SSG 4.191: Theory of Fundamental Height Systems
Chair: Christopher Jekeli (USA)

In 2001 another Special Study Group has been added:

SSG 4.195: Fractal Geometry in Geodesy
Chair: Erik W. Grafarend (Germany)

A detailied description of the above structure of Section IV is provided in the Geodesist's Handbook 2000 (Special Issue of the Journal of Geodesy, Vol 74, No. 1, pp. 106-115)

Major Scientific Achievements

The past (and simultaneously the last) four year period marked a very productive and successful period in the 20 years lifetime of Section IV, having been involved in many activities of the IAG. The great progress in geodetic theory and methodology has been made visible in presentations by Section IV members on the occasion of scientific symposia and workshops; the scientific work has also been documented by publications in peer-reviewed international journals such as Journal of Geodesy, Geophysical Journal International, Journal of Geophysical Research, and others, as well as in national journals and publication series and in Symposia Proceedings (in particular in the Springer IAG Symposia series).

Section IV has been represented at many IAG sponsored symposia and seminars. Only some of the most eminent events are highlighted below:

- International Symposium on Gravity, Geoid and Geodynamics in Banff/Canada, July 31 – August 4, 2000,
- Seventh International Winter Seminar in Sopron/Hungary, February 19-23, 2001,
- IAG Symposium on Vertical Reference Systems, Cartagena/Columbia, February 20-23, 2001,
- First International Symposium on Robust Statistics and Fuzzy Techniques in Geodesy and GIS, Zurich/Switzerland, March 12-16,2001 (Organized by SSG 4.190),
- IAG Scientific Assembly in Budapest/Hungary, September 3-7, 2001,
- 5th Hotine-Marussi Symposium on Mathematical Geodesy in Matera/Italy, July 10-14, 2002 (which was an extremely successful meeting in the series of the traditional Section IV Symposia),
- W.A. Heiskanen Symposium in Geodesy in Columbus/Ohio, USA, October 1-5, 2002.

Furthermore, Section IV contributed significantly to the EGS General Assemblies held in Nice/France on an annual basis since 2000. Finally, Section IV will be represented at a number of Symposia and sessions organized on the occasion of the IUGG General Assembly in Sapporo/Japan, June 30 - July 11. In particular, a profile of the research activities and a survey of the most important results will be presented in Symposium G04 „General Theory and Methodology“ organized by Section IV, where the work of the sub-entities (Special Commission, Special Study Groups) will be reported, too.

Major scientific achievements have been made in particular in the various modelling aspects covering physical and mathematical modelling of geodetic observations as well as stochastic and non-stochastic methods of data evaluation. Below an attempt is made to provide a short (probably subjective and biased) summary of the most important steps of progress:

Physical aspects of modelling in Geodesy are related to the basic theories of Physics (Newtonian mechanics, theory of relativity, quantum theory) forming in some way the background of any modelling of geodetic observations. Significant advances in the past four-year period are visible in the theory of fundamental reference frames and height systems, in methods for the description of the Earth's space- and time-variable gravity field and deformation, and in modelling the propagation of electromagnetic signals in refractive media; advanced models in these fields have become necessary due to the rapid development in the quality and availability of space geodetic observations.

The mathematical aspects of geodetic modelling refer to new developments in numerical mathematics and digital signal processing, including advanced tools such as wavelet analysis in one and two dimensions; applications in Geodesy range from time series analysis (e.g. polar motion) to feature extraction and data compression. Special emphasis has also been put into the formulation and solution of boundary value problems as well as inverse and improperly posed problems, related e.g. to downward continuation.

Since the foundations of least squares adjustment by C.F. Gauß stochastic methods of data evaluation have played a dominant role in Geodesy, in particular in the framework of quality analysis. Strong progress has been made in the adaption of statistical inference – including Bayesian statistics – to the fields of Geodesy and Surveying, digital Photogrammetry and image processing, and digital topography and cartography. Other topics belonging to this subject are stochastic signal analysis and geostatistics.

Traditionally and methodologically, a distinction is made between deterministic and stochastic signals in geodetic observations. More and more, deterministic signal analysis makes use of wavelet transforms instead of the classical Fourier techniques. Recently, the spectrum of uncertainty in geodetic data and models has been extended from the purely random status; non-random uncertainty of the data can be taken into account using interval mathematics, fuzzy data analysis and artificial neural networks.

Details about the progress achieved in the past four-year period can be studied in the reports by the Special Commission 1 and the Special Study Groups of Section IV that follow in the sequel.

The Future of Geodetic Theory in IAG

After having worked well for decades, the Section structure of IAG will be dissolved with the IUGG General Assembly in Sapporo and fitted to recent requirements and developments. The new IAG structure, decided at the IAG Scientific Assembly 2001 in Budapest, will bring great changes concerning the organisation of theoretical and methodological work in the IAG. The former Section structure, sometimes criticized as inconsistent, will be replaced by a Commission structure, involving four topic-oriented commissions. The task of these new commissions is to promote the advancement of science, technology and international cooperation in their field. Besides the services, the commissions will form the main scientific components of the new IAG structure.

In the new structure an entity like the present section IV is no more foreseen and visible at the highest level of organization below the EC, the level of the commissions and services. But this by no means should indicate that geodetic theory and methodology will not play a fundamental role anymore. Since one of the major tasks of the new commissions is the promotion of science, these bodies will be responsible for the development of theory in their respective fields, too. Of course, this procedure cannot include the development of general, topic-independent approaches of data analysis and mathematical-physical foundations, methodology and "general" theory of Geodesy. After many discussions a solution of this problem could be found consisting of the creation of the creation of an Inter-Commission Committee on Theory, reporting directly to the EC. It is expected that the existence of such a committee will make sure that e.g. mathematically interested geodesists and application-oriented mathematicians and physicists furthermore will find a home and meeting-place within IAG.

Furthermore, the Inter-Commission Committee on Theory should provide a channel of cooperation amongst the different commissions, on the ground of methodology, and support a closer collaboration between „theoreticians“ and „practicioners“ in the topic-oriented work of the Commissions. Finally, this Committee is intended to serve as an interface to other fields of Science, in particular Mathematics, Physics and Earth Sciences.

Acknowledgements

Concluding this general report, I wish to express my sincere thanks to all officers and colleagues having contributed to the extremely successful work of Section IV in the past four-year period. It is the work of many scientists in Geodesy, Mathematics and other branches of Science, often associated with months and years of great effort, which produced the outstanding results achieved in Section IV and helped the Section to accomplish its mission for the benefit of the IAG as a whole. My personal thanks go also to the officers of Section IV for the excellent cooperation. Finally, it is my sincere wish and hope that geodetic theory and methodology will find its due position in the new structure of IAG.

SPECIAL COMMISSION 1

MATHEMATICAL AND PHYSICAL FOUNDATIONS OF GEODESY

P. Holota holota@pecny.asu.cas.cz

Introduction

The Special Commission on Mathematical and Physical Foundations of Geodesy (CMPFG) was established by the International Association of Geodesy on the occasion of the 20th General Assembly of the International Union of Geodesy and Geophysics in Vienna in 1991, as a consequence of the need for a permanent structure working on the foundations of geodesy. The establishment of the special commission is essentially associated with the preparatory work done by K.-P. Schwarz (the Section IV president of that time) and the Section IV Steering Committee of that time. It met with a considerable support. The main objectives of the special commission were the following:

- to encourage and promote research on the foundations of geodesy in any way possible;
- to publish, at least once every four years, comprehensive reviews of specific areas of active research in a form suitable for use in teaching as well as research reference;
- to actively promote interaction with other sciences;
- to closely cooperate with the special study groups in Section IV - General Theory and Methodology. (As an IAG structure the CMPFG belongs particularly to this section).

These formulations are short but in reality they represent a challenging program. It was published in the 2000 issue of The Geodesist's Handbook [Journal of Geodesy (2000), Vol. 74, No. 1]. In addition one can read about details concerning the CMPFG on the website of the commission at http://pecny.asu.cas.cz/IAG_SC1/ which contains also the bibliography of the CMPFG . (Note that there is an intention to keep this website working also after the 23rd General Assembly of the IUGG in Sapporo, 2003.)

In a sense, in the period 1999-2003 the research program of the CMPFG represented a continuation of the activities developed during two four-year terms (stating with 1991) when the commission was successfully chaired by E.W. Grafarend. In the research program of the CMPFG the main focus was on: *statistical problems in geodesy, numerical and approximation methods, geodetic boundary value problems, on problems in geometry and differential geodesy, relativity, cartography, on equilibrium reference models and also on the theory of orbits and dynamics of systems.*

In this field the CMPFG derived important driving impulses especially from the work of the IAG. As a minimum let us mention, e.g., two problems that were discussed at a special plenary session held in Birmingham on the occasion of the 22nd General Assembly of the International Union of Geodesy and Geophysics in 1999: *1) "Are our contemporary theoretical and computer models sufficient to handle the 1:10^9 accuracy in frame realization, Earth rotation, positioning etc. consistently?"; - 2) "Can we be sure that sensor and/or model deficiencies do not enter into geophysical interpretation?".* Of course, there are also other facts that stimulated the work of the CMPFG. The close tie between geodesy and mathematics is one of them. This tie is confirmed in the whole history of the development of these two disciplines, which is well-known, but it is worthwhile to mention that more than three decades already there exists an independent research program for a theory and methodology oriented body in the structure of the IAG.

Structure and Members

The broad spectrum of research objectives of the CMPFG led to a subdivision of its research program into specific tasks. In 1999, immediately upon its approval by the IAG, the following subcommissions were established:

Subcommission 1 "Statistic and Optimization"
Chair: P. Xu (Japan)

Working Group "Spatial statistics for geodetic science"
Chair: B. Schaffrin (USA)

Subcommission 2 "Numerical and Approximation Methods"
Chair: W. Freeden (Germany), http://www.mathematik.uni-kl.de/~wwwgeo

Subcommission 3 "Boundary Value Problems"
Chair: R. Lehmann (Germany)

Subcommission 4 "Geometry, Relativity, Cartography and GIS"
Chair: V. Schwarze (Germany, in the period 1999-2001)

Subcommission 5 "Hydrostatic/isostatic Earth's Reference Models"
Chair: A.N. Marchenko (Ukraine), http://people.polynet.lviv.ua/sc5/

The theory of orbits and dynamics of systems were an exception. In general problems that have a tie to this topic are given a considerable attention in many branches of science. Here the topic was left within the framework of the special commission itself. The focus was on the interplay between mathematics (especially analysis) and applications that together with problems related to methods of integration, modelling, analysis of perturbations and qualitative aspects in the evolution of trajectories have an essential relation to space geodetic methods and inertial systems. Now, after four years, the original intention broad visible achievements. The work of the CMPFG members resulted in a number of very valuable contributions. They concern, e.g., dynamic satellite geodesy on the torus; the relation between analytical and numerical integration in satellite geodesy; energy relations for the motion of satellites within the gravity field; the use of asymptotic series, celestial mechanics and physical geodesy; satellite geodesy on curved space-time manifolds; differential equations in inertial navigation systems etc. Considerable research activities of CMPFG members develop also in the field of dedicated satellite mission, independently as well as in a contact with IAG Special Commission 7 (Satellite Gravity Field Missions, http://www.geod.uni-bonn.de/SC7/index.html.)

The following distinguished scientists have been invited to work in the CMPFG:

Ex officio Members
B. Heck (Germany), President of Section IV;

C. Jekeli (USA), Secretary of Section IV, Chairman SSG 4.191: Theory of fundamental height systems http://www-ceg.eng.ohio-state.edu/~cjekeli/ssg4-191.htm ;

Yuanxi Yang (China), Secretary of Section IV;

W. Keller (Germany), Chairman SSG 4.187: Wavelets in geodesy and geodynamics http://www.uni-stuttgart.de/iag ;

G. Strykowski (Denmark), Chairman SSG 4.188: Mass density from integrated inverse gravity modelling http://research.kms.dk/~ssg4188/study_group/index.html ;

D. Wolf (Germany), Chairman SSG 4.189: Dynamic theories of deformation and gravity field;

H. Kutterer (Germany), Chairman SSG 4.190: Non-probabilistic assessment in geodetic data analysis http://www.dgfi.badw.de/ssg4.190/welcome.html ;

E.W. Grafarend (Germany), Chairman SSG 4.195: Fractal geometry in geodesy (The proposal for this SSG was adopted at the Executive Committee meeting in Budapest, September 4, 2001) http://www.uni-stuttgart.de/gi/

Individuals
M. Bougeard (France), C. Cui (Germany), A. Dermanis (Greece), E.W. Grafarend (Germany), http://www.uni-stuttgart.de/gi/, E. Groten (Germany), K.H. Ilk (Germany), http://www.geod.uni-bonn.de/SC7/index.html , J. Janak (Slovak Republic), R. Klees (The Netherlands), L. Kubacek (Czech Republic), Z. Martinec (Czech Republic), G. Moreaux (Denmark), J. Otero (Spain), M. Petrovskaya (Russia), R. Rummel (Germany), F. Sacerdote (Italy), K.-P. Schwarz (Canada), M. Sideris (Canada), N. Sneeuw (Canada), H. Sünkel (Austria), L. Svensson (Sweden), P. Teunissen (The Netherlands), C.C. Tscherning (Denmark), P. Vanicek (Canada), G. Venuti (Italy), M. Vermeer (Finland), R.J. You (Taiwan)

Maintenance of liaisons with related activities:
IUGG Committee on Mathematical Geophysics: M. Vermeer (Finland)

Additional Members invited to work in:
Subcommission 1: J.A.R. Blais (Canada), Y. Kagan (USA), M. Sambridge (Australia), Y.X. Yang (China), S.D. Pagiatakis (Canada)

Working Group: Shaofeng Bian (China), W. Caspary (Germany), K. Kraus (Austria), S. Meier (Germany)

Subcommission 2: C. Jekeli (USA), W. Keller (Germany), J. Mason (England), V. Michel (Germany), F.J. Narcowich (USA), Z. Nashed (USA), E. Schock (Germany), L. Schumaker (USA), J. Sloan (Austria), G. Steidl (Germany), L. Sjöberg (Sweden), L. Svensson (Sweden), C.C. Tscherning (Denmark), J. Ward (USA)

Subcommission 3: M. Günter (Germany), M. Kern (Canada), Yu.M. Neyman (Russia), Yu.A. Rozanov (Russia), N. Weck (Germany), W. Wendland (Germany), K.J. Witsch (Germany), A.I. Yanushauskas (Lithuania)

Subcommission 4: S.A. Klioner (Germany), D. Milbert (USA), M. Schmidt (Germany)

Subcommission 5: O.A. Abrikosov (Ukraine), V.K. Kholshevnikov (Russia), S. Kostyanev (Bulgaria), D. Lelgemann (Germany), H. Moritz (Austria), G. Papp (Hungary)

Corresponding Members invited to work in Subcommission 1: O. Abrikosov (Ukraine), M.Y. Markuze (Russia), C. Shi (China) and in the Working Group: N. Cressie (USA), J. Menz (Germany), J. Pilz (Austria), A. Stain (Netherlands)

Subcommissions

The subcommissions were very productive. It can be seen from the bibliography of the CMPFG which is accessible on the website of the special commission (at the address given above and also in the end of this report). It contains a rich list of entries that document the research done by the members of the special commission in the reported period. (Note that the bibliography on the website is an open material that is under a process of a permanent completion.) Some of the achievements reached by CMPFG members get a special IAG recognition, see Sect. 8. In the sequel, for page limit, we have to confine ourselves to some highlights only.

Subcommission 1.
This subcommission placed emphasis on areas such as statistics and optimization for inverse problem theory, space techniques and informatics science. Since almost all realistic models are nonlinear, and especially because global optimization has been developing rapidly theoretically and practically, the title of the subcommission was changed from "Statistics" to "Statistics and Optimization" for 1999-2003. Also the goals for this Subcommission were clearly defined. The major new development was achieved in the following areas:

(1) Inverse Problem Theory.

The major progress in this area has been related to the determination of geopotential fields from space geodetic observations. Xu investigated the L-curve method from the point of view of quality control. The Delft group (Kusche, Klees, and Ditmar) has been focused on comparing different regularization methods, development of techniques to deal with color noises, and stochastic models.

(2) Space Techniques.
The achievements in this area are very significant, geodetically and mathematically, in particular, in multiplicative noise models and mixed integer linear models. In the case of multiplicative noise models, Xu (1999) developed bias-corrected least squares methods and a Bayesian method to deal with (In-) SAR-like multiplicative models. Geodetic applications of multiplicative noise models can be found in the dissertation of Hanssen and other reports from the Delft group. In the case of mixed integer linear models, The contributions are mainly in three aspects: GPS ambiguity decorrelation; statistics and Lower and upper probability bounds; and integer Bayesian estimation. The Delft group led by Teunissen has made a great contribution to this area, by developing and testing the so-called LAMBDA method and a number of lower and upper probability bounds for the integer estimators, in particular, the simple rounding method. Xu (1998) further investigated the integer programming and its applications to GPS. Hassibi and Byod (1998) and Grafarend (2000) developed the LLL algorithm for GPS decorrelation. Xu (2001) developed The inverse Cholesky integer decorrelation and showed that it outperformed the integer Gaussian decorrelation and the LLL algorithm, and thus indicates that the integer Gaussian decorrelation is not the best decorrelation technique and further improvement is possible; and (ii) no decorrelation techniques available up to the present can guarantee producing a smaller condition number in the case of high dimension. Recently, Xu (2003) first developed a method to construct Voronoi cells and systematically study the fitting of the Voronoi cell V_0 from inside and outside. He then derived a number of new lower and upper bounds for the probability with which the estimated integers $\hat{z}$ are correct. And finally he gave the tests of two hypotheses on the integer mean. Bayesian integer estimation has been developed by Gundlich and Koch (2002), de Lacy et al (2002) and others.

(3) Informatics Science.
In this regard, Xu (1999, 2002) developed some isotropic probabilistic models for use in geodesy. They have been used in quality control of strain/stress tensors. These models have also played a key role in numerically comparing the performances of different GPS decorrelation methods. The most significant advantage of the approach is that it does not depend on nor favour any particular satellite-receiver geometry and weighting system;
(4) Global optimization.
In this regard, Xu (2002, 2003a,b) developed a new global optimization method for nonlinear nonconvex inversion by combining local optimization methods with feasible point finders. Local optimization algorithms have been proved to be robust, reliable and quickly convergent to a local optimal solution in the neighbourhood of a starting point. Feasible point finders serve as an engine, either for repelling or lifting the whole algorithm from trapping into a local optimal solution or for providing the warranty that the global optimal (earth model) solution has been found correctly. A number of examples of one- and multiple-dimensions will be used to demonstrate how the method works. The method has also recently been applied to determine stress state from fault-slip data (Xu 2003).

(5) in addition to the above mentioned areas,
we have also seen some development on those traditional topics, such as linear and/or nonlinear model; robust estimation and its geodetic applications (Yang and others). In particular, Xu (2003) found that the nonlinear filtering theory of nonlinear continuous systems may have a fundamental defect in the foundation.

Working Group.
The Working Group on "Spatial Statistics for Geodetic Science" was founded within Subcommission 1 in order to highlight this increasingly important area in view of novel applications that reach far beyond the classical case of gravity field interpolation. A variety of issues was investigated from a more fundamental point of view, including: - the interplay and equivalences among least-squares collocation, Kriging, spline interpolation, multiquadrics and (biharmonic) wavelets; - collocation/Kriging for data with skew probability density function; - non-probabilistic (e.g. fuzzy) methods in a spatial environment such as GIS; - spatial filtering of Kalman type with and without further constraints; - hierarchical Bayesian analysis, soft unbiasedness, reliability measures, missing values in spatial models, etc.

Members of the subcommission and the working group brought significant contributions to a number of meetings listed in Sect. 7, but in particular to the Workshop of IAG-SSG 4.190 "Non-probabilistic Assessment in Geodetic Data Analysis", Karlsruhe, 2000 and to the IAG 1st International Symposium on Robust Statistics and Fuzzy Techniques in Geodesy and GIS, Zurich, 2001.

Subcommission 2 (http://www.mathematik.uni-kl.de/~wwwgeo).
An intensive mathematical research oriented to problems in the representation and approximation of the Earth's gravitational potential, to problems in physical geodesy and in the treatment of modern space geodetic data was in the focus of interest of this subcommission. The season is that one has to think of the geopotential as a "signal" in which the spectrum evolves over space in significant way. This space-evolution of the frequencies is not reflected in the Fourier transform in terms of non-space localizing spherical harmonics. Wavelet transforms are a counterpart. Therefore, aspects of constructive approximation, decorrelation, data compression etc. were treated within the wavelet theory. Moreover, an uncertainty principle was formulated and used as it gives appropriate bounds for the quantification of space and frequency properties of trial functions in geodesy. In the focus there were also combined models, where expansions in terms of spherical harmonics are combined with local methods, e.g. radial base function techniques as splines, wavelets, mass-points, finite elements etc. In the limited time span of the four years the subcommission also significantly progressed in the methodology of the treatment of spaceborn observations. In addition to a number of interesting papers presented at the meetings listed in Sect. 7 and entries in the CMPFG bibliography also an important contribution on "Multiscale modelling of GOCE data products" to the ESA International GOCE User Workshop held in Noordwijk, The Netherlands, 2001, resulted from the work of Subcommission 2.

Subcommission 3.
This subcommission focused on boundary value problems (BVPs) in physical geodesy. These problems are essentially connected with the use of potential theory and the theory of partial differential equations in the determination of the gravity field and figure of the Earth. In the reported period the research carried out by the subcommission concentrated on the refinement of the solution of the standard problems and new mathematical models, on free-datum and multi-datum BVPs, as they arise from unknown height datums; on mixed BVPs and especially various types of altimetry-gravimetry problems with their capability to give a mathematical model for a combined use of different data on the boundary; on stochastic BVPs; overdetermined and constraint BVPs; BVPs on special surfaces and also on pseudo BVPs. The research covered also non-classical methods in the solution of BVPs, as variational methods with their close tie to the concept of the so-called weak solution. The application of boundary element techniques was investigated too, similarly as the use of various function bases. A considerable attention was given to the apparatus of ellipsoidal harmonics. A remarkable progress was achieved in its application for the solution of practical problems of geodetic relevance. Within traditional concepts the role of the BVPs is rather well-known in physical geodesy, but nowadays the work of the subcommission is strongly influenced by new striking impulses. Among others they reflect the progress in the data collection, data accuracy, higher requirements on the accuracy of the solution and also a need for mathematical modelling associated with the use of modern technologies, as e.g. airborn gravimetry and dedicated satellite missions (a spacewise approach, Slepian's problem etc.). The results of this subcommission were clearly visible and heard with interest at nearly all the meetings listed in Sect. 7.

Subcommission 4.
Geometry oriented problems, relativity aspects, cartography and GIS defined the field of interest of this subcommission. Within the research carried out in this subcommission geometry means the Marussi-Hotine approach to differential geodesy, foundations of Gaussian differential geodesy, geometry of plumblines as geodesics in conformal 3-manifould, Fermi's coordinates etc. The main progress was achieved in the use of the theory of relativity, in particular in the reformulation of geodetic measurement processes within the framework of general relativity. Here the metric tensor plays an important role and it was represented with respect to a set of appropriate charts. Using the words of the subcommission chairman, we knew that almost every quantity of interest in geodetic and geophysical applications refers to a geocentric, Earth-fixed coordinate system (chart). Therefore, the space-time metric with respect to an Earth-fixed chart was derived at first post Newtonian order. The field equations determining the terrestrial gravitational field were derived and its explicit representation was outlined. On this basis the impact of the results on the modelling of geodetic measurement process including space-time positioning scenarios as well as the high-precision gravitational filed estimation was discussed. The subcommission took an active part in a number of international meetings. Its results achieved in cartography and GIS

were presented at the IAG 1st International Symposium on Robust Statistics and Fuzzy Techniques in Geodesy and GIS, Zurich, 2001.

Subcommission 5 (http://people.polynet.lviv.ua/sc5/).
This subcommission was a new substructure of the CMPFG. Nevertheless it proved to be very active. The research carried out within the subcommission covered the construction of piecewise radial density models, stable determination of parameters of radial density models and variational problems. It also focused on the low-frequency Earth's gravity field and the evolution of the Earth's principal axes and moments of inertia completed with a canonical form of the solution. Corresponding changes of the 3D mass density model were also considered. Some research was oriented to incompressible fluid Earth, to the compressibility and vicoelestic perturbations. For the density recovery from seismic velocities the solution was based on three differential equations and the density function was separated into a hydrostatic (main) part and an additional small part due to chemical/phase inhomogenieties or superadiabatic temperatures. Some famous laws (Legendre-Laplace, Roche, Darwin, Gauss) were considered for radial density distribution in connection with the solution of the famous Clairaut, Poisson and Williamson-Adams differential equations. In the interpretation of reproducing kernels it was shown that the set of all suitable kernel functions may be interpreted as a finite sum of two point singularities (pole and dipole) and also straight line singularities. Moreover, an optimum point mass model of the global gravitational filed was compiled. In addition to some of the meetings listed in Sect. 7, e.g. the IAG 2001 Scientific Assembly in Budapest, the results achieved in the subcommission were also presented at the International Symposium on Modern Achievements of Geodetic Science and Industry, Lviv, Ukraine, 2002.

Business Meeting in Banff

The CMPFG proved to be an important discussion forum. This was evident from the business meeting of the commission organized in Banff on the occasion of the IAG International symposium "Gravity, Geoid and Geodynamics 2000". A circular letter distributed well before the meeting met with a good response. "What you think is the most urgent problem to be solved related to the foundations of geodesy" this was a key question formulated by C.C. Tscherning and circulated with the letter. The response was obvious and mirrored the impact of the future or up-coming satellite missions. In particular the following urgent problems were mentioned (in the formulations by R. Rummel):

- How to deal in a proper way with the actual Earth boundary when bringing down the high resolution gravity information from GOCE from satellite altitude to the Earth's surface? Should one simply apply some kind of topographic correction or are there better and/or more correct ways?
- A mission like GRACE drifts (in the course of the entire mission length) down from, say 500 km to 300 km. While going down the gravity field is sampled in a changing manner and at the same time it drifts through several regimes of resonance. At the same time one tries to recover the temporal variations of the gravity field. Thus one is faced with a very complicated sampling/aliasing problem, which to my best knowledge is not sorted out so far.
- A similar problem in altimetry which certainly affects, for example, estimates of sea level change. Again the satellite samples time variable effects such as tides in a very complicated time and space pattern. What is the aliasing situation there, what could be done to improve it?
- In real world satellite sensors such as accelerometers or gradiometers do not show a normally distributed noise behavior but drifts and a similar effects cause systematic distortions which result in e.g. 1/f (f = frequency) behavior. We have taken into account these things but in an ad hoc manner. Could one work on stochastic models on the sphere for processes with less favorable error behavior?
- Currently several groups try to determine center-of-mass changes of the Earth from the analysis of global tracking data. What is the proper formulation of datum definition and S-transformation for a real deformable Earth with moving plates, how should a center-of-mass change determination be correctly formulated from the theoretical point of view?

K.-H. Ilk mentioned another view. He pointed out *"three problem areas related to the satellite missions CHAMP, GRACE and COCE":* - analysis of the observation system; - modelling and data analysis aspects; - applications in geosciences, oceanography, climate change studies and other interdisciplinary research topics. Finally, M. Vermeer suggested for discussion the term *"best practices"* and the use of *"common sense"* in connection with modern techniques in geodesy. He recalled that in traditional geodesy there were these common sense rules such as *"working from the large to the small"* and many many more. With new techniques, and the availability of fast computers and complex theories, sometimes it seems that common sense has been a bit forgotten.

The subsequent discussion at this business meeting concerned some reflections on the running process towards the new structure of the IAG. B. Heck, the president of IAG Section IV outlined the key aspects that motivate this initiative. His information were then amplified by F. Sanso, the IAG president who paid a considerable attention to the work of the CMPFG itself and than focused on a detailed explanation of principles and actions that are most frequently discussed within the IAG executive in preparing the concepts for the new IAG structure. The business meeting of the CMPFG was well attended, not only by the members, but also by a number of participants of the Banff symposium "Gravity, Geoid and Geodynamics 2000".

Business Meeting in Budapest

The meeting took place in the building of the Hungarian Academy of Sciences in 2001, concurrently with the IAG Scientific Assembly in Budapest. It was well attended and organized as a Joint business meeting of IAG Section IV and the CMPFG (IAG Special Commission 1). The meeting and its program were announced on the website of the CMPFG with a considerable advance. The main items of the agenda were: results achieved, new topics and trends, liaisons with related activities, the publication of the results and finally the position of Section IV and the commission within the process towards the new IAG structure. The meeting was attended by the IAG secretary general and also by the president of the IAG, who himself reviewed the work of Section IV and CMPFG and expressed a supporting standpoint of the IAG executive to future activities in this field of geodesy.

Hotine-Marussi Symposium and the Business Meeting in Matera

This business meeting was held in Centro di Geodesia Spaziale "C. Colombo" in Matera (Italy) on the occasion of the V Hotine-Marussi symposium on Mathematical Geodesy, which by tradition is an important forum to the discussion on theoretical problems in geodesy. For the business meeting the whole morning segment was reserved in the program of the symposium on 19 July 2002. This gave to the participants of the symposium an excellent opportunity to take part in the meeting. The meeting was open by the chairman of the CMPFG. He updated information concerning the structure of the commission and its work in the period passed. Thanks to local organizers it was possible to arrange a direct connection with the server of the CMPFG and in this way to support the introductory talk by an on-line presentation of the content of the CMPFG www-page. This gave all the information a great degree of authenticity and met with an explicit recognition of the participants and also the IAG secretary general and the president of the IAG who took part in the meeting. It was explicitly stated that the CMPFG website represents a very good source of information which, through the Internet, may be used especially by students of geodesy to get (without limits) useful knowledge on the program and work of the commission.

The discussion at the meting then focused on problems related to the reorganization process in the IAG and to the possibilities of mapping IAG research activities of theoretical and methodological nature into the new structure of the IAG. Information on this process were given by the president of Section IV with explanations concerning the aims and concepts followed by the IAG in the reorganization process. Details were also mentioned concerning the Planning Committee for the new Inter-Commission Committee on Theory (ICCT), the preparatory work done by the committee and the position and role of the ICCT within the IAG in the period after the Sapporo IUGG General Assembly in 2003.

Participation in International Scientific Meetings and Boards

In the reported period the CMPFG was well represented at a number of IAG sponsored meetings and also at important scientific occurrences organized by other IUGG bodies or by EGS (European Geophysical Society), EUG (European Union of Geosciences), ECGS (European Center for Geodymanics and Seismology), ESA, AGU and other international and local scientific organizations. In all these cases a stress on the mathematical and physical nature of geodetic problems, typical for the research done in the CMPFG, was clearly visible in the presented or invited contributions prepared by CMPFG members. For space limit let us highlight only the following events:

- 25th General Assembly of the European Geophysical Society, Nice, France, 2000;
- Geostatistics Congress, Cape Town, South Africa, 2000;
- Workshop of IAG-SSG 4.190 "Non-probabilistic Assessment in Geodetic Data Analysis", Karlsruhe, Germany, 2000;
- 4th International Symposium on Spatial Accuracy, Amsterdam, Netherlands, 2000;
- XIX ISPRS Congress, Amsterdam, Netherlands, 2000;
- IAG International Symposium "Gravity, Geoid, and Geodynamics 2000", Banff, Canada, 2000;
- 9th International Symposium on Spatial Data Handling, Beijing, China, 2000
- 9th International Symposium on Matrices and Statistics in Honor of C.R. Rao's 80th Birthday, Hyderabad, India, 2000;
- IAG 1st International Symposium on Robust Statistics and Fuzzy Techniques in Geodesy and GIS, Zurich, 2001;
- ESA International GOCE User Workshop held in Noordwijk, The Netherland, 2001.
- 26th General Assembly of the European Geophysical Society, Nice, France, 2001;
- IAG 2001 Scientific Assembly, Budapest, 2001;
- AROPA Workshop (Analytical Representation of Potential Field Anomalies for Europe), "Institute d'Europe", Castle of Münsbach, Luxembourg, 2001;
- 27th General Assembly of the European Geophysical Society, Nice, France, 2002;
- V Hotine-Marussi Symposium on Mathematical Geodesy, Matera, Italy, 2002;
- 3rd Meeting of the IAG International Gravity and Geoid Commission, Thessaloniki, Greece, 2002;
- Weikko A. Heiskanen Symposium in Geodesy, Celebrating 50 Years of Geodetic Science at The Ohio State University, A Look to the Future, Columbus, Ohio, 2002;
- EGS-AGU-EUG Joint Assembly, Nice, France, 2003;

Frequently, the members and officers of the CMPFG took part in the work of scientific (program) and organizing committees or were entrusted to act as conveners of individual scientific sessions. The CMPFG was also involved in the work of the committee for selecting the Best Student Paper at the IAG Scientific Assembly in Budapest. In the period 1999-2003 members of the CMPFG worked also in the editorial board of the Journal of Geodesy.

Publications recognized by the IAG

In this report it is proper to make also an explicit mention that achievements reached by some of CMPFG members get a special IAG recognition in the period 1999-2003. At its meeting in Nice, 2000, the IAG Executive Committee decided to give Dr. Peiliang Xu (the chair of the Subcommission 1) the IAG young authors award for his paper "Biases and the accuracy of, and an alternative to, discrete nonlinear filters", published in the Journal of Geodesy, Vol. 73(2000), pp. 35-46. Also in 2001 the awarded publication originated from the work of one of CMPFG members. In Budapest the IAG Executive Committee decided to give the IAG young authors award to Dr. Rüdiger Lehmann (the chair of the Subcommission 3) for his paper "Altimetry-gravimetry problems with free vertical datum", published in Journal of Geodesy, Vol. 74(2000), pp. 327-334. [Note for the sake of completeness that on this occasion the award was given to two authors sharing the same (i.e. the first) place. The second was Christopher Kotsakis with his paper "The multiresolution character of collocation", published in the Journal of Geodesy, Vol. 74(2000), pp. 275-290.]

Acknowledgements.

Concluding this brief report, I wish to thank all my colleagues from IAG Special Commission SC1 for excellent cooperation and the results achieved, which often meant months and years of a great endeavor and devoted work. Your help was very important for the commission in order that it accomplished its mission. Many thanks and much success in your further work!

References

- The bibliography of the CMPFG may be found at http://pecny.asu.cas.cz/IAG_SC1/ , as already mentioned above. Also www-links inserted in the text of the report may be used for a similar purpose. Note again that there is an intention to keep the server with the CMPFG home page working also after the 23rd General Assembly of the IUGG in Sapporo, 2003.
- In 2001 a Mid-term report of the CMPFG for the period 1999-2001 was prepared and submitted to the IAG Central Bureau before the IAG 2001 Scientific Assembly in Budapest. The report was then posted on the website of the CMPFG and also published in the IAG Travaux, Vol. 32 – General and technical reports 1999-2001, together with similar reports of other IAG structures. Subsequently, the volume (on CD-ROM) was distributed by the IAG Central Bureau at the IAG Scientific Assembly in Budapest, especially among national committees of IAG member countries. This editorial initiative helped to inform the international scientific community about the profile and activities of the IAG in connection with the organizational changes prepared within the IAG.

SPECIAL STUDY GROUP 4.187:

"WAVELETS IN GEODESY AND GEODYNAMICS "

W. Keller

The main fields of the SSG activities have been

1. publications
2. software development
3. education
4. comparison of different wavelet based algorithms

Publications

The members of the SSG have published more than 60 papers in scientific journals and on conferences. These contributions can be divided into four groups

1. pattern recognition,
2. spherical wavelets,
3. filtering and prediction,
4. enhancement of numerical processes

and without claiming to be complete the main content of these papers will be briefly reviewed here.

Pattern recognition

Many wavelet applications are based on the properties of wavelets to reflect local changes in the regularities of signals. Frequently, these local irregularities are related to features which have to be extracted from the signal. Most of the publications about wavelet applications belong to this field. The goal is to find certain signatures which, on different scales, are hidden in the signal.

One group of pattern recognition techniques deals with the interpretation of signal registration from different geodetic measuring systems : Superconducting gravimeters, airborne gravimeters and so on. The publications [8],[22],[38] and [53] can be counted to this group. A more exotic application of pattern recognition using wavelets is the study of atmospheric turbulence and seafloor topography as reported in [5], [8] and [11].

In the opposite way, in order to represent the main features of a signal it is sufficient to store those wavelet-coefficients, which are related to the main features and neglect all the others - leading to considerable data compression rates. In [42] wavelet compression for digital terrain models is studied. The degree of regularity of a signal can be read from its wavelet spectrum.

Another typical application of wavelets for pattern recognition is the analysis of polar motion. The time series of the coordinates of the instantaneous position of the Earth's rotation axis is frequently analyzed by different kinds of wavelets. Such studies aim at the detection of time varying features of the polar motion.

Contributions, which belong to this group of investigations are [46]-[48]. A special emphasis on the analysis of short-periodic variations in the Earth's polar motion is put on in the papers [52] and [55].

Polar motion analysis techniques which are close to but not exactly identical to wavelet analysis are described in [1] and [2].

Last but not least, wavelets are frequently used for gravity field modeling. A topic which is discussed in the contributions [29], [55]. A particular emphasis on the combination of land and marine gravity data along the coastlines can be found in the publications [23]-[26] and [56]. Aspects of data gridding and smoothing are considered in the publications [45] and [59]. Compact data representation is a major goal in the publication [45].

Spherical wavelets

A vast amount of contributions about the wavelet analysis comes from the Geomathematical Group of the Kaiserslautern University. For years this group, led and inspired by W. Freeden, develops the theory and application of harmonic wavelets on the sphere. In the period from 1999 to 2003 the application of the now mature theory to the analysis of the Earth's gravitational and magnetical field was in the focus of the activities of this group.

Papers dealing with the spherical wavelet analysis of the Earth's magnetic field are [3], [4],[5]. General questions related to the representation of scalar and vectorial functions on a sphere by spherical wavelets are discussed in [7], [12].

Since practically, no data is noise free also the question of the de-noising of the given signal using spherical wavelets has been discussed in the papers [12],[14] -[18].

A great impact on geodetic research was made by the launches of the dedicated gravity field satellite missions CHAMP and GRACE. Naturally, these new data sources also have been reflected in techniques for the analysis of these data.

Paper which are related to data collected from CHAMP or GRACE are [15], [14], [19] , [36], [37] and [38].

Filtering and prediction

The ability of wavelets to decompose a given signal into a sequence of non-overlapping (or slightly overlapping) frequency bands can be used for an optimization of prediction and filtering algorithms. The publications [31] – [33] and [36] deal with this problem.

The time-frequency resolution property of wavelets is the key for the extension of the known filtering algorithms from the stationary to the non-stationary case. These questions are discussed in the publications [27] and [28].

In a more general setting the time series of the polar motion can be considered as realizations of stochastical processes. A systematic extension of the theory of stochastical processes to wavelet bases can be found in [49],[50] and [51].

A final contribution (which still lies within the general framework of multiresolution signal analysis and estimation) was also made regarding the frequency-domain filtering of non-stationary noise from deterministic spatial fields [37], [36] and [38]. An appealing aspect of this work was that the derived noise filters contained explicitly the data resolution parameter of the discrete input data, which led to very interesting conclusions regarding the interplay between data noise and sampling resolution level in linear signal estimation.

Enhancement of numerical processes

Operators occurring in the formulation of geodetic problems are usually discretized with respect to some system of base functions. The discretized operator leads to a linear system of equations, which is usually large and fully occupied. If wavelets are used as base function the resulting system will have a large number of very small entries and only few large entries. Neglecting the small entries leads to a sparse system, which can be used for pre-conditioning. This line has been followed in [30] Due to the multi-resolution properties of wavelets, different components of the solution are associated to different scales of the base function. In this way a natural connection between wavelet discretization and multi-grid iteration is established as it is reported in [31]. If even more for the representation of the given data and the unknowns solution different wavelet base systems are used, these systems can be chosen in such a way that the resulting matrix becomes diagonal. This is demonstrated in [20].

Similar ideas are followed in [46].

Software development

In order to provide the geodetic community with ready-to-use tools for wavelet analysis the most important wavelet-related algorithms as

- windowed Fourier transformation
- continuous wavelet transformation
- discrete wavelet transformation
- 2D-discrete wavelet transformation

were coded in ANSI-C and tested with the GNU compiler collection gcc. These programs are command-line driven. In order to facilitate the use of these algorithms Tck/Tk graphical user interfaces and utilities for the visualization of the results using the GMT tools were supplied. Since gcc, Tcl/Tk and GMT are not available on every platform a transformation to the platform independent JAVA system has been carried out. Both the C and the JAVA versions of the algorithms can be downloaded from the SSG 4.187 home-page.

Education

In order to provide young scientists a basic knowledge in wavelet theory SSG members were involved as lecturers in two courses on wavelets:

- Course “Wavelets for Geodetic Science” at the Ohio State University, Columbus OH
- graduate course Wavelets in Geodesy and Geodynamics , University of Calgary, August 4-21, 2000

Comparison of algorithms

In order to provide a scale for comparison of different wavelet algorithms a synthetic polar motion test data-set was created by Dr. Schmidt and was made available to the SSG via the SSG home-page. The members of the SSG were requested to analyze the data with their own algorithms and to submit the results. From the results conclusions about the strength and the weakness of different algorithms should be drawn. Unfortunately, the resonance to this project was disappointingly low.

References

Arfa-Kaboodvand K, Groten E, Zavoti J, Varga P: Stochastische und deterministisch Analyse sowie Modellierung der Erdrotation mit Schwerpunkt: Polschwankung und UT1(=LOD), basierend auf GPS-Daten. Mitteilungen des Bundesamtes fürKartographie und Geodäsie, 1999; 5: 126-133.

Arfa-Kaboodvand, K, Groten E, Varga P, Zavoti J: Interpretation of high frequency polar motion and length of day variations. IERS Technical Note 2000; 28: 15-25.

Bayer M., Freeden W. Maier T.; A Vector Wavelet Approach in Iono- and Magnetospheric Geomagnetic Satellite Data. Journal of Atmospheric and Solar-Terrestrial Physics, (63), 581-597, 2001.

Bayer M., Freeden W., Maier T; Wavelet analysis of the geomagnetic field within source regions of ionospheric and magnetospheric currents. Berichte d. Arbeitsgruppe Technomathematik, Fachbereich Mathematik, Univ. Kaiserslautern, Bericht No. 217,(1999)

Bayer M.; Geomagnetic Field Modelling From Satellite Data by First and Second Generation Wavelets. PhD thesis, University of Kaiserlautern, Geomathematics Group, 2000. Shaker Verlag, Aachen.

Beth S., Casott N., Deussen D., Freeden W. and Witte B.; Digital Meterological Sensors for the Detection of Atmospheric Turbulence and Their Geodetic Application. In: Altan-Gründig, editor, 3rd German-Turkish Joint Geodetic Days, 1:91-99, 1999.

Beth S.; Multiscale Approximation by Vector Radial Basis Functions on the Sphere. PhD thesis, University of Kaiserslautern, Geomathematics Group, 2000. Shaker Verlag, Aachen.

Beth, S. ;Boos, T.; Freeden, W.; Casott, N.; Deussen, D.; Witte, B: On the wavelet determination of scale exponents in energy spectra and structure functions and their application to CCD camera data In: K.-P. Schwarz (Ed.) Geodesy Beyond 2000: The Challenges of the First Decade Birmingham, 1999 IAG General Assembly Birmingham , July 19 - 30, 1999 pp. 221 - 226 Springer-Verlag Berlin Heidelberg 2000

Bruton, A.M.; Schwarz, K.-P.,Skaloud,J.: The use of wavelets for the analysis and de-noising of kinematic geodetic measurements In: K.-P. Schwarz (Ed.) Geodesy Beyond 2000: The Challenges of the First Decade Birmingham, 1999 IAG General Assembly Birmingham , July 19 - 30, 1999 pp. 227 - 232 Springer-Verlag Berlin Heidelberg 2000

Dreher, S.; Lalancette, M.F.: Estimating Lithosphere Characteristics With Wavelet Admittance and Coherence of Gravity and Seafloor Topography. paper given at the IAG International Symposium on Gravity, Geodesy and Geodynamics held in Banff, July 31 - August 4, 2000

Doufexopopolou, M.G. ; Bartha, G.C.: A Strategy to Approach a Multi-scale Space/Time Problem by Only data Information. Paper given at the IAG International Symposium on Gravity, Geodesy and Geodynamics held in Banff, July 31 - August 4, 2000

Freeden W., Groten E., Michel V., and Kaboodvand A.; Geoidal Reconstruction, Decomposition, Fast Computation, and Noise Cancellation by Harmonic Wavelets. Studia Geophysica et Geodeatica (accepted), 2001

Freeden W., Hesse K.; On the Multiscale Solution of Satellite Problems by Use of Locally Supported Kernel Functions Corresponding to Equidistributed Data on Spherical Orbits. Studia Scientiarum Mathematicarum Hungarica (39), 37-74, 2002.

Freeden W., Michel V., Stenger M.; Multiscale Signal-to-Noise Thresholding. Acta Geodaetica et Geophysica Hungarica (36): 55-86, 2001.

Freeden W., Maier T.; SST-Regularisierung durch Multiresolutionstechniken auf der Basis von CHAMP-Daten. Berichte der AGTM 252 (Weiterbildung), 2002

Freeden W., Maier T., Zimmermann S.; A Survey on Wavelet Methods for(Geo)Applications. Revista Mathematica Complutense. (accepted), 2001. Kaiserslautern, Bericht No. 208; also in Journal of Geodesy, Vol. 73 (1999), No. 9, pp. 452-465.

Freeden W., Michel V.; Least squares geopotential approximation by windowed Fourier transform and wavelet transform. Berichte d. Arbeitsgruppe Technomathematik, Fachbereich Mathematik, Univ. Kaiserslautern, Bericht No. 216, (1999)

Freeden W., Michel V.; Least-squares Geopotential Approximation by Windowed Fourier Transform and Wavelet Transform. In: Springer Lecture Notes in Earth Sciences, R. Klees and R. Haagmans, editors, (90): 189-241, 2000.

Freeden W., Michel V., Nutz H.; Satellite-to-Satellite Tracking and Satellite Gravity Gradiometry (Advanced Techniques for High-Resolution Geopotential Field Determination). Journal of Engineering Mathematics (43),19-56, 2002

Gilbert A., Keller W.: Deconvolution with Wavelets Journal of Geodesy. Journal of Geodesy 2000(74) pp. 306-320

Haagmans,R.H.N.; Dorst, L.L.; Francis, O.: Wavelets and Statistical Testing for Improved Analysis of Super Conducting Gravimeter Data at the main Tidal Frequencies.paper given at the IAG International Symposium on Gravity, Geodesy and Geodynamics held in Banff, July 31 - August 4, 2000

Horowitz, F.G., Strykowski, P.; Hornby, P.; Boschetti, F.; Cox, S.J.D.: A Multiskale Skeletonization of The EGM96 Gravity Disturbances, Locally Compared with Australian Geophysical data.paper given at the IAG International Symposium on Gravity, Geodesy and Geodynamics held in Banff, July 31 - August 4, 2000

Grebenitcharsky R., M.G. Sideris (2002) Altimetry-gravimetry boundary value problems with smoothness conditions in coastal regions, in I.N. Tziavos and R. Barzaghi (editors), XXVI General Assembly of EUROPEAN GEOPHYSICAL SOCIETY - G7 Session, Nice, France, 25-30 March, 2001, IgeS Bulletin N13, 2002, pp. 121-133

Grebenitcharsky R., G. S. Vergos, M. G. Sideris (2001) Combination of gravity, altimetry and GPS/Leveling data for the numerical solution of the altimetry-gravimetry boundary value problems, in J. Adam and K.P.Schwarz (editors) "Vistas for geodesy in the new millennium", IAG 2001 Scientific Assembly, Budapest, Hungary, Sep. 2-7, 2001, Springer, IAG Symposia, Vol. 125, pp. 150-156

Grebenitcharsky R., M. G. Sideris (2002) Application of spherical pseudo-differential operators and spherical wavelets for numerical solutions of the fixed altimetry-gravimetry boundary value problem, presented at "V Hotine-Marussi symposium on Mathematical geodesy", Matera, Italy, June 17-21, 2002 (submitted and reviewed for the proceeding of the symposium)

Grebenitcharsky R., M. G. Sideris (2002) Data smoothing along a mountainous coastline for use in altimetry-gravimetry boundary value problem solutions, in "3rd Meeting of International Gravity and Geoid Commission, Tziavos (ed.), Gravity and Geoid 2002 - GG2002, 2003", 223-228

]Keller W.: A Wavelet Approach to Non-Stationary Collocation In: K.-P. Schwarz (Ed.) Geodesy Beyond 2000: The Challenges of the First Decade Birmingham, 1999 IAG General Assembly Birmingham , July 19 - 30, 1999 pp. 208 - 213 Springer-Verlag Berlin Heidelberg 2000

Keller W. ; A Wavelet Solution to 1D Non-stationary Collocation With an Extension to the 2D case . In: Sideris M.. (ed.), Gravity, Geoid and Geodynamics 2000. International Association of Geodesy Symposia, Vol. 123,Springer-Verlag, Berlin Heidelberg (2001), pp. 79 -85.

Keller, W.: Wavelets in Geodesy and Geodynamics Lecture Notes, Universtity of Calgary 2000

Keller W.;A Wavelet Approach for the Constructiom of Multi-Grid Solvers for Large Linear Systems. In: J. Adam, K.-P. Schwarz (Eds.): Vistas for Geodesy in the New Millennium. IAG Symposia Vol. 125. pp 265-270. Springer Verlag Berlin Heidelberg 2002.

Keller W.; The Use of Wavelets for the Acceleration of Iteration Schemes. Hotine-Marussi-Symposium, Matera 2002,(accepted)

Kotsakis C. The Multiresolution Character of Collocation. Journal of Geodesy, 74(3-4): 275-290. 2000

Kotsakis C.: The role of Statistical Collocation as a tool for constructing Generalized Multiresolution Analyses in the $L^2(\Re)$ Hilbert Space. Bollettino di Geodesia e Scienze Affini, 59(2): 125-160.

Kotsakis C.: Wavelets and Collocation: An Interesting Similarity In: K.-P. Schwarz (Ed.) Geodesy Beyond 2000: The Challenges of the First Decade Birmingham, 1999 IAG General Assembly Birmingham , July 19 - 30, 1999 pp. 227 - 232 Springer-Verlag Berlin Heidelberg 2000

Kotsakis, C.: Multiresolution Aspects of Linear Approximation Methods in Hilbert Spaces Using Gridded Data Department of Geomatics Engineering UCGE Reports Number 20138

Kotsakis C. : Can we filter non-stationary noise from geodetic data with fast spectral (FFT) techniques? Bulletin of the International Geoid Service, 11: 93-114.2001

Kotsakis, C.; Sideris M.G.: Aliasing Error Modelling in Single-input Single-output Linear Estimation Systems. In IAG Symposia (M.G. Sideris, ed.): "Gravity, Geoid and Geodynamics", vol. 123, pp. 43-48, Springer-Verlag, New York.

Kotsakis C., Sideris M.G. A modified Wiener-type filter for geodetic estimation problems with non-stationary noise. Journal of Geodesy, 75(12): 647-660.2001

Liu, L.T.; Hsu, H.T. ; Sun H.P.: Wavelet-characterized Approach to Harmonic Analysis of Tide Gravity Observations.paper given at the IAG International Symposium on Gravity, Geodesy and Geodynamics held in Banff, July 31 - August 4, 2000

Maier T.; Multiscale Geomagnetic Field Modelling From Satellite Data: Theoretical Aspects and Numerical Applications (Universität Kaiserslautern (dem FB Mathematik eingereichte Dissertation)), 2002

Maier T., Mayer C.; Multiscale Downward Continuation of CHAMP FGM-Data for Crustal Field Modelling. Proceedings of the 1st CHAMP Science Meeting (accepted), 2002,Mathematische Geologie Band 5, C-Press Verlag Dresden

Mayer C. Maier T. ; Multiscale Determination of Radial Current Distribution from CHAMP FGM-Data. Proceedings of the 1st CHAMP Science Meeting (accepted), 2002

Meier, S.; Zur K-Frage: Kompressionsraten der schnellen Wavelettransformation aus statistischer Sicht. ZfV,128(2003), No.2, 31-39

Nagy D, Franke R, Battha L, Kalmár J, Papp G, Závoti J: Evaulation of various gridding methods. Acta Geod. Geoph. Hung., 1999; 34: 177-184, L

Salamonowitcz, P.H.: A Wavelet Based Gravity Model with Application to the Evaluation of Stoke's Integral.paper given at the IAG International Symposium on Gravity, Geodesy and Geodynamics held in Banff, July 31 - August 4, 2000

Schaffrin, B., Mautz, R., Schmidt, M., Shum , C.K.; Representation of spatial functions using B-spline wavelets with compact support. Proceedings of the Heiskanen Symp., Columbus OH, Oct 2002

Schmidt M.,Schuh H.; Wavelet-Analyse der mit VLBI beobachteten Nutationsreihen, ZfV 124(1999),1, 24 – 30

Schmidt M.,Schuh H.;ABILITIES OF WAVELET ANALYSIS FOR INVESTIGATING SHORT-PERIOD VARIATIONS OF EARTH ROTATION, IERS (2000) Technical Note No 28, 73-80

Schmidt M.,Schuh H.; Wavelet-Analyse von Erdrotationsschwankungen, ZfV 126(2001),1, 94 – 100

Schmidt M.; Ein Beitrag zur zweidimensionalen Wavelet-Analyse von Zufallsprozessen, ZfV 126(2001), 270 – 275

Schmidt M.; Grundprinzipien der Wavelet-Analyse und Anwendungen in der Geodäsie, Shaker-Verlag, Reihe Geodaesie Band 9, 2001

Schmidt M.; Wavelet-Analyse von Zeitreihen, In: Schuh, H., Soffel, M. and Hornik, H. (eds.); Vorträge im 4. DFG-Rundgespräch im Rahmen des Forschungsvorhabens 'Rotation der Erde' zum Thema 'Wechselwirkungen im System Erde'. German Geodetic Commission (DGK), Series A, No 118, 46-56, 2002

Schmitz-Hübsch, H.; Wavelet-Analysen der Erdrotationsparameter im hochfrequenten Bereich. Schriftenreihe der Deutschen Geodätischen Kommission, Reihe, Heft A 118, München 2002.

Schmitz-Hübsch, H., Schuh H.; Seasonal and short-period fluctuations of Earth Rotation investigated by Wavelet Analysis., In: Grafarend E.W., Krumm F.W.,Schwarze V.S.(Eds.);Geodesy- The Challenge of the 3rd Millenium,Springer Verlag Berlin 2002

Liu,L.T.;Hsu,H.T.: Wavelet Application in Airborne Gravimetry..paper given at the IAG International Symposium on Gravity, Geodesy and Geodynamics held in Banff, July 31 - August 4, 2000

Klees, R.; Haagmanns,R.: Wavelets in the Geosciences. Lecture Notes in Earth Sciences, Springer-Verlag, Berlin, Heidelberg, New York, 2000

Kuroishi Y. ;Keller, W.: The Improvement of Marine Gravity Field Models for Japan with Ship- and Altimetric Gravity Data Based on a 2-dimensional Wavelet Analysis. Paper given on the EGS/AGS General Assembly, Nice 2003

Vergos G.S., Grebenitcharsky R., M. G. Sideris (2002) Sea Surface Topography and Geostrophic Flow Estimation from Multi-Satellite Altimetry and Shipborne Gravity Data Using Low-pass Filtering and Wavelet Decomposition, "3rd Meeting of International Gravity and Geoid Commission, Tziavos (ed.), Gravity and Geoid 2002 - GG2002, 2003", 314 -319.

Závoti J: Modified versions of the estimates based on the least squares and minimum norm. Acta Geod. Geoph. Hung., 1999; 34: 79 –86, L

SPECIAL STUDY GROUP 4.188:

"MASS DENSITY FROM JOINT INVERSE GRAVITY MODELING"

G.Strykowski

Special Study Group 4.188 was established by IAG in 1999 at the IUGG General Assembly in Birmingham, UK for a period of 4 years. The topic was mass density modeling in general with possible implications for the development of new methods of physical geodesy. In particular, the link to the solid earth geophysics via source modeling was emphasized. The members of the study group included geophysicists from outside the geodetic community. SSG 4.188 has an official web page: http://research.kms.dk/~ssg4188/study_group/index.html containing a list of members and associated members, a list of relevant references, and the reports on the activities of the study group.

Concerning the work of the study group in practice, the relevant research was conducted among individual scientists and groups of scientists, both members and non-members, and not as a part of the formalized study group activity under the IAG umbrella. In fact, the effort to formalize the activities of the study group was minimal. In practice, we met at conferences for informal discussions, exchange of ideas and contacts; also jointly with other study groups (SSG 3.177). New members joined during the lifetime of the study group. Interested non-members participated in our informal meetings. The official recognition by IAG is, nevertheless, important. It is obvious that the establishment of the study group as a part of the IAG structure emphasizes the importance of the topic as such.

Chairman's report: Inclusion of the mass density information in the new methods of physical geodesy

The following report can be viewed as a manifesto – a call on revising the methods of physical geodesy in the direction of physics/geophysics. The main objective is to include mass density information explicitly. The particular wording is the personal opinion of the chairman, but the main ideas evolved (among others) during the informal meetings of the study group.

In geodesy, the gravity plays a crucial role in the definition of heights through the concept of geopotential numbers - a definition, which is consistent with the measuring technique in practice. The leveling instrument uses a level (i.e. the local direction of the plumb line) to define the horizontal. The absolute zero-level surface for heights – the geoid – is also directly related to the Earth's gravity field. It is defined as the equipotential surface of the Earth's gravity potential approximating (in a complicated way) the mean sea surface of the Earth. Thus, the definition of the absolute level for heights is not purely geometrical, e.g. some reference ellipsoid approximating the shape of the Earth, but rather incorporates the importance for the human activity of the interface between the land and the sea.

In the geodetic community there are those who voice an opinion of abolishing the concept of the geoid altogether. Almost all problems of physical geodesy can be solved using the external gravity potential. The height differences are more important than the absolute heights. These ideas can probably be traced back to the way the physical geodesy evolved in the past - a consequence of a long tradition based on mathematics in an attempt to circumvent the difficult task of obtaining information about the mass density distribution, i.e. the information about the source of the gravitational potential. Nothing illustrates this point more explicitly than the theory of Molodensky who in his definition of heights (through the concepts of the telluroid and the quasigeoid) deliberately avoided inclusion of any mass density assumption.

The alternative to the above is to include the mass density information and the Newton's law of gravitational attraction explicitly in the methods of physical geodesy. If the mass density distribution between the geoid and the Earth's surface were known, the modeling of the geoid would be simple. In principle, it corresponds to computing orthometric heights for known mass density (i.e. not necessarily Helmert's orthometric heights). In order to be consistent, the leveling data should also be corrected using the same mass density model.

Returning to the geodetic tradition of the past, and looking at the problem of geoid modeling in the original framework of the gravity potential and the Newton's law of gravitational attraction, one can wonder that it was possible to model successfully the geoid without explicitly addressing the mass density. The key to understand this success lies in the independent knowledge of the source geometry – the geometry of the terrain. This geometrical information is an important part of the mass density information. Once the shape of the source body (the terrain) and its location with respect to the gravity station is known, the average mass density value of the terrain enters as a multiplicative factor relating the measured gravitational attraction with the forward modeled gravitational attraction of the known geometry of the terrain. In geophysics, the method of Nettleton makes use of this dependence to estimate the average mass density value of the terrain. Nettleton's method (in a slightly modified version) can also be used to estimate the average mass density value of the geological layers with known geometry. Algebraically, one can express the unknown average mass density of the terrain using the known gravity information and the known terrain geometry information and, subsequently, to substitute it in order to remove the explicit addressing of mass density. This is why the geodesists of the past did not worry much about mass density. Notice, however, that even Molodensky uses terrain information in his method.

Another reason for the success of the past is the fact that the physical absolute mass density distribution of the upper crust is reasonably homogenous. Gravitational potential depends on the absolute mass density of the source body. Even a relatively large mass density deviation of some 0.3 g/cm^3 with respect to the standard value of 2.67 g/cm^3 yields only a moderate relative error of approximately 10%. Thus, even a rough assumption on the mean mass density value, e.g. a standard value, is adequate. This is one more reason why mass density modeling has not been a serious issue in the mainstream physical geodesy. Of shore it is not an issue at all. We are virtually on top of the geoid and the mass density of the seawater is even more homogenous than that of the landmasses.

It should also be mentioned, that the modeled standard geoid over the land areas often uses an implicit assumption of 2.67 g/cm^3 on the absolute mass density value. Such geoid model deviates from the existing true equipotential surface of the Earth's gravity field, which depends on the existing true mass density distribution. In the standard model, the gravimetric signal generated by intra topographic mass density anomalies is implicitly interpreted as stemming from below the geoid. The problem is, in fact, that of the ambiguity of a solution to the inverse gravimetric problem. Many different geoid models and the associated mass density models will be consistent with surface measurements (the leveling and the external gravity field). This is probably why some geodesists want to abolish the concept of the geoid altogether; because it is mathematically non-unique. The problem of geoid modeling without mass density information is mathematically ill-posed.

In the following, I will argue against the idea of abolishing the geoid. In fact, I think that it is the standard methods of physical geodesy that should be revised and changed to incorporate mass density information explicitly. My main arguments are:

1. Mass density is the source of the gravitational attraction. By including mass density directly in our methods we will move physical geodesy from the mathematical world of ill-posed problems towards the physics of the problem. We will also serve better the geophysical community.

2. Modeling by including mass density is robust and can yield better accuracy of the modeled geoid. This possibility should be investigated. Especially in light of increasing demands on the accuracy of the modeled geoid.

Elaborating on 1: Newton's law of gravitational attraction implies that a physical gravitational signal is generated by a physical source. Newton's law is virtually exact at all length scales relevant for the geodetic problems. All methods of geoid modeling associate parts of the measured gravitational signal with the gravitational response of the terrain, the gravitational response of the sources below the geoid, and with the noise. In the present days methods this is often left to the intrinsic mathematical structure of the method. The details are hidden to the modeler and its physical plausibility is not verified. Nevertheless, the physics of the problem yield additional constrains which can be utilized. For example, if the attraction of the terrain is modeled and subtracted from the measured gravity anomalies, and there is still a high frequency difference in the gravity residuals for neighboring stations (i.e. for short distances in space), these differences can only be noise stemming from either the error in the station heights, the measurement error of gravity (of any kind) and/or the attraction of the high frequency part of the terrain above the Nyquist frequency of the available DEM. It cannot come from a physical source within the terrain because it would require too high mass density value. This example illustrates conceptually how the physics of the problem can be used to remove noise from surface gravity measurements. In fact, using Newton's law of gravitational attraction it is possible to obtain perfect consistency between the measured gravity data, the station heights and the terrain model (DEM). Also, we do not need to know what the sub-geoid sources are. We only need to know their gravitational response. Conceptually, our task is to model the gravity vector inside masses down to the geoid. To those who are in doubt: why do we accept in our methods the use of dubious mathematical filters (which are completely arbitrary with respect to the physics of the problem), stochastic processes, integration with or without modified kernels, but are suspicious when using a valid physical law, which would make our input data perfectly consistent?

Referring to the importance of the interaction with geophysics, the geophysical community is the main scientific customer of the geodetic community. Geodetic results are used as important input in geophysical modeling. How to explain to a geophysicist that it is not the equipotential surface of Newton-Gauss-Listing that we are modeling, but, in fact, a graviequivalent model which, under simplified assumptions on mass density distribution, is consistent outside the sources with leveling? Geodetic models are (hopefully) adequate to serve geodetic purposes, but are they adequate to serve the purpose of geophysicists?

Elaborating on 2: It requires a lot of mass to produce an effect on the geoid. It implies that we ask ourselves the following question: how good do we really need to know the mass density to pin the geoid down to the accuracy of say 1 cm? The obvious answer is that we probably do not need detailed mass density information at all. The knowledge of the main mass density anomalies (main geological units) is probably sufficient. One last argument, in the present day methods the verification of the geoid goes via leveling. We find "the depth to the geoid" relative to the surface stations (through the orthometric heights). This is why precise heights of the leveling points are so important. In the Newtonian approach the topography produces some gravitational potential on the ellipsoid (or anywhere inside the masses). It is robust. If we move the Alps up or down few meters they will still produce the same gravitational potential. Small errors in the DEM will not change the gravitational potential. With the modern GPS surveys the Alps are pined to the ellipsoid quite well. The rest is easy. We need to make the surface gravity data and the DEM consistent. We can do it using Newton's law (see above). What is left in these model surface gravity anomalies after the subtraction of the gravitational effect of the terrain stems from the sources below the geoid. We can harmonically downward continue this signal and compute the attraction of the terrain at any point in space. In fact, we can map the gravity vector through the masses and (if we dare to believe it) the model surface gravity values yield the geopotential numbers or at least geopotential number differences.

What about the Stoke's integration? It is not necessary. Why use gravity anomalies in Australia to model the geoid undulations in Europe? Condensation methods? Not needed. They are the pre-computer age techniques.

Finally, we will shortly outline how to reconcile the results of the past with the results that could be obtained by the proposed techniques. We could start by modeling the standard geoid by assuming a standard mass density value of 2.67 g/cm^3 for the landmasses. The subsequent correction between the standard geoid and the geoid of Newton-Gauss-Listing is computed using the anomalous mass density distribution. It is, thus, not necessary to compute the geoid from scratch for the new mass density distribution. The advantage of this procedure is that we will be able to compare with the results of the past. Also, standard geoid is a good model when crossing the national borders. We can imagine that the level of knowledge on details of the mass density distribution will vary from one country to another. We also need to find proper terms for these different geoids – especially in relation to the associated mass density model.

Geodetic research on mass density in the years 1999-2003 – a brief outline

This short outline presents the hot topics of the geodetic research involving mass density as presented at the international conferences and published in Journal of Geodesy. In the years 1999-2003 the geodetic research involving mass density span over the whole spectrum of topics ranging from studying the mathematical properties of the mass density distribution, the condensation techniques – the higher order effects of truncated series, graviequivalent source modeling (e.g. point masses) and the direct inclusion of mass density information of the topography in geoid and gravity field modeling. Some effort was also put into development of fast, space domain based techniques of forward modeling of the gravitational response of known structures. Geophysical models of the mass density of the crust and their response (and comparison with the measured) were also studied. One could also mention the renewed interest in using the gravity gradient measurements and the astro-geodetic measurements in modeling. These data are sensitive to the high frequency part of the local terrain.

Geophysical research on mass density in the years 1999-2003 – a brief outline

In the geophysical literature the relevant hot topics are the construction of a worldwide average crustal mass density model of the Earth and on studying the mantle mass density anomalies on the continental scale using the gravity, seismics and heat flow information. A number of papers deal with modeling the geometry of the geological structures from gravity and other geophysical data (mainly seismics) in different parts of the world. Some work on the ambiguity domain (i.e. the ambiguity of the solution to the inverse gravimetric problem) was also conducted. One review article in Geophysics attempted to explain to the geophysicists the mystery of geodetic concepts.

Special Study Groups 4.189:

"Dynamic theories of deformation and gravity fields"

D. Wolf

Scientific program

SSG 4.189 `Dynamic theories of deformation and gravity fields' was established in response to the continuing need to develop improved dynamical models for the interpretation of time-dependent deformation and gravity fields as better data became available from GPS, VLBI and absolute gravity measurements or were expected from the satellite gravity missions CHAMP and GRACE. Whereas the development of improved theoretical models for the different types of forcing responsible for the deformation and gravity fields was defined as the principal activity of SSG 4.189, a substantial portion of its research during the period 1999-2001 also involved the application of existing theory.

Regular members

H. Abd-Elmotaal (University of Minia, Egypt)
J.-P. Boy (Goddard Space Flight Center, USA)
V. Dehant (Royal Observatory of Belgium, Belgium)
R. Eanes (University of Texas, USA)
J. Engels (University of Stuttgart, Germany)
J. Fern\'andez (Ciudad University, Spain)
G. Kaufmann (University of G\"ottingen, Germany)
Z. Martinec (Charles University, Czech Rebublic)
G. Milne (University of Durham, UK)
H.-P. Plag (Norwegian Mapping Authority, Norway)
G. Spada (University of Urbino, Italy)
W. Sun (University of Tokyo, Japan)
P. Varga (Geodetic and Geophysical Research Institute, Hungary)
K. Wieczerkowski (GeoForschungsZentrum, Potsdam, Germany)
D. Wolf (GeoForschungsZentrum Potsdam, Germany)
P. Wu (University of Calgary, Canada)

Associate members

P. Gegout (Louis Pasteur University, France)
E. Grafarend (University of Stuttgart, Germany)
J. Hinderer (Louis Pasteur University, France)
L. Sj\"oberg (Royal Institute of Technology, Sweden)

Scientific results

Theory

Starting with elastic earth models, Sun and Sj\"oberg (1999a) revisited the classical problem of surface loading of a radially symmetric elastic body and studied the radial dependence of the load Love numbers and the Green functions for displacement, potential and gravity perturbations. Grafarend (2000) computed the gravity field of an arbitrary deformable body under the assumption that the topographic surface, the interfaces and the internal mass distribution vary over time. Grafarend et al. (2000) and Varga (2002) studied the relationship between the incremental Cartesian moments of the mass density, the incremental moments of inertia and the incremental gravitational potential coefficients for an arbitrary deformable body. As excitation, they considered tidal forcing, normal and tangential surface forcings and rotational variations. Dehant et al. (1999) calculated tidal Love numbers for rotating aspherical earth models. In addition to elastic earth models, they also investigated effects caused by assuming an inelastic convecting mantle.

In several papers, the problem of load-induced, viscoelastic perturbations of a compressible earth initially in hydrostatic equilibrium was considered. Wolf (2002) reviewed the general theory of gravitational viscoelastodynamics for arbitrary earth models. Whereas Wolf and Kaufmann (2000) and Klemann et al. (2003) were concerned with the 1D plane-earth approximation of the theory, Martinec et al. (2001a) and Wolf and Li (2002) considered the problem for a 1D spherical earth consisting of compositionally homogeneous shells. In the latter case, the density stratification was given by Darwin's law, which can be shown to satisfy the field equations governing the initial state.

Mitrovica et al. (2001) revisited the problem of coupling the sea-level equation with a 1D viscoelastic earth model and investigated effects on observables of glacial-isostatic adjustment induced by true polar wander. They concluded that the rotational feedback may in particular modify predictions of relative sea-level change.

Attempts were also made to obtain solutions of the field equations for 2-D and 3-D incompressible viscoelastic earth models. Whereas Kaufmann and Wolf (1999) obtained an approximate analytical solution for a 2-D plane earth, Martinec and Wolf (1999) and Martinec (2002) derived analytical solutions for axisymmetric spherical problems. Analytical solutions are required to test more general numerical solutions for arbitrary 2-D or 3-D viscoelastic earth models (Martinec, 1999, 2000, O'Keefe and Wu, 2002, Wu, 2002a, 2002b).

Glacial loading

Wieczerkowski et al. (1999) employed formal inverse theory to infer the viscosity stratification below Fennoscandia from the relaxation-time spectrum of the glacial-isostatic adjustment. More recently, Milne et al. (2001) and Park et al. (2002) considered GPS data from Fennoscandia and from North America, respectively. They showed that lithosphere thicknesses and asthenospere viscosities inferred from this type of data are consistent with the values obtained using other types of data. Kaufmann and Amelung (2000) used subsidence data from the artifical Lake Mead, Nevada, to infer the viscosity stratification in this region and found very low viscosity values. Thoma and Wolf (2001) interpreted land uplift induced by the recent melting of the Vatnaj\"okull ice cap, Iceland, and also found anomalously low values for the lithosphere thickness and asthenosphere viscosity.

Wu (1999, 2002c, 2002d) raised the question of whether relative sea-level changes in Hudson Bay and along the Atlantic coast of North America can also be explained in terms of glacial-isostatic adjustment with non-Newtonian rheology. His results show that reconciling all sea-level data may be difficult for such rheologies. However, with tectonic stress considered, the assumption of non-Newtonian rheology becomes more reasonable (Wu, 2001). Giunchi and Spada (2000) developed a spherical earth model with non-Newtonian rheology and concluded that, for this model, the long-wavelength signatures of glacial-isostatic adjustment become largely insensitive to the viscosity of the lower mantle. Spada (2001) used Monto-Carlo inversion to infer the mantle viscosity below North America from VLBI data. In particular, he found that two values of the lower-mantle viscosity are consistent with the observational data. Kaufmann and Lambeck (2000) interpreted convectively supported geoid perturbations as well as glacially induced changes of sea level, rotation and the gravity field and inferred global average values of the upper- and lower-mantle viscosities. In a follow-up paper, Kaufmann and Lambeck (2002) considered various types of data in their global inversion of glacial-isostatic adjustment and suggested a two-order of magnitude jump of viscosity between upper and lower mantle.

Wu et al. (1999) discussed the question of whether deglaciation-induced stresses are sufficiently strong to have triggered paleo-earthquakes in Fennoscandia. They found that glacial-isostatic adjustment is probably the cause of the large postglacial faults observed but is unlikely to be responsible for the current seismicity in this region. Wu and Johnston (2000) studied a similar problem for North America and concluded that stresses are sufficiently strong for triggering earthquakes at locations not too far from the former ice-sheet margin. Klemann and Wolf (1999) investigated the consequences of a ductile layer inside an otherwise elastic lithosphere for glacial-isostatic adjustment. Their results show that the stress pattern is significantly affected by the presence of such a layer.

Kaufmann (2000, 2002) predicted glacially induced variations of the gravity field due to Pleistocene and present-day changes in glaciation and discussed the question of their detectability by the satellite missions CHAMP and GRACE. In a regional study, Hagedoorn and Wolf (2003) investigated the influence of Pleistocene and modern glacial changes on various geodetic observations in Svalbard. Kaufmann et al. (2000), Martinec et al. (2001b) and Kaufmann and Wu (2002a, 2002b) revisited the issue of glacial-isostatic adjustment in Fennoscandia. In particular, they investigated whether lateral variations in lithosphere thickness and viscosity may be resolved from the observational record.

In a study of long-term changes of the Martian north polar ice cap, Greve et al. (2003) attempted to constrain lithosphere thickness and heat flux below the ice cap, but found rather large trade-offs.

Topographic, tidal and environmental loading

Abd-Elmotaal (1999a) calculated Moho depths for a test area in Austria using the Vening Meinesz and the Airy-Heiskanen isostatic models and compared the results with seismic Moho depths. Abd-Elmotaal (1999b, 2000) reviewed the inverse Vening Meinesz isostatic problem defined as finding the Moho depth for which the isostatic gravity anomalies become zero. Later, Abd-Elmotaal (2001) studied the problem of computing the geoid using seismic Moho depths. Sun and Sj\"oberg (1999b) calculated global geoid perturbations on the assumption that the topographic loads are compensated by elastic deformation only. They found positive correlations between the calculated and observed perturbations, although large differences remained for long wavelengths due to the neglect of dynamic processes.

Dehant et al. (2000) computed the response of Mars to nutational, tidal and loading excitation and studied the influence of the planet's material properties on its response. Ray et al. (2001) estimated the tidal dissipation by estimating the body-tide phase lag using satellite-tracking and satellite-altimetry data. Greff-Lefftz et al. (2002) investigated the influence of the inner-core viscosity on tidal gravity perturbations and concluded that very precise VLBI observations may be used to constrain this parameter. In a regional study, Arnoso et al. (2001) analyzed tidal gravity observations from Lanzarote, Canary Islands, and discussed whether they can be used to resolve structural details of the upper crust below the island.

Hagedoorn et al. (2001) and Boy et al. (2002a, 2002b) investigated the total atmospheric contribution to gravity perturbations using an elastic earth model. They found that their results are superior to those obtained by simply using empirical relationships between pressure and gravity changes. In a related study, Van Hoolst et al. (2002) considered the degree-one displacement inside Mars due to seasonal redistributions in the Martian atmosphere.

Seismo-volcanic forcing

Nostro et al. (1999) compared spherical and flat viscoelastic earth models for computing co- and postseismic deformations in order to assess in which cases the neglect of sphericity and self-gravitation is justified. In a related study, Boschi et al. (2000) calculated the global deformation caused by a shear dislocation located in the mantle. Important points of their study were the consideration of sources below the lithosphere and effects due the presence of a low-viscosity asthenosphere. Assuming a point dislocation, Sun and Okubo (2002) revisited the problem of sphericity for elastic earth models and also considered the influence of stratification. They concluded that the neglect of these features is in general not justified. Folch et al. (2000) considered the viscoelastic deformation caused by an inflated magma chamber and investigated the errors introduced by neglecting the finite dimension of the chamber or the topography of the region. Topographic effects on intrusion-induced deformations were also investigated by Charco et al. (2002). In a further study, Fern\'andez et al. (2001) interpreted deformation and gravity change data from Long Valley Caldera, California. They showed that incorrect interpretations may result if only one type of data is used.

Other activities

The research carried out in SSG 4.189 was reported by several of its members and invited guests at the (1) 7th International Winter Seminar on Geodynamics on `Viscoelastic Theories in Geodynamics' (Sopron, Hungary, February 19-23, 2001), (2) Minisymposium on `Mantle Viscosity: Inferences from Glacial Isostasy and Non-hydrostatic Geoid' (Prague, Czech Republic, October 24-26, 2001), and (3) Workshop on `Time-variable Deformation and Gravity Fields: Theory, Observations and Modelling' (Lanzarote, Spain, February 18-21, 2003).

Selected publications of members: 1999-2003

Abd-Elmotaal, H., 1999a. Inverse Vening Meinesz isostatic problem: theory and practice. Boll. Geod. Sci. Aff., 58, 53-70.

Abd-Elmotaal, H., 1999b. Moho depths versus gravity anomalies. Surv. Rev., 35, 175-186.

Abd-Elmotaal, H., 2000. Vening Meinesz inverse isostatic problem with local and global Bouguer anomalies. J. Geod., 74, 390-398.

Abd-Elmotaal, H., 2001. Precise geoid computation using seismic Moho information. Boll. Geod. Sci. Aff., 60, 227-238.

Arnoso, J., Fern\'andez, J., Vieira, R., 2001. Interpretation of tidal gravity anomalies in Lanzarote, Canary Islands. J. Geodyn., 31, 341-354.

Boschi, L., Piersanti, A., Spada, G., 2000. Global postseismic deformation: deep earthquakes, J. Geophys. Res., 105, 631-652.

Boy, J. P., Gegout, P., Hinderer, J., 2002a. Gravity variations and global pressure loading. J. Geod. Soc. Japan, 47, 267-272.

Boy, J.-P., Gegout, P., Hinderer, J., 2002b. Reduction of surface gravity data from global atmospheric pressure loading. Geophys. J. Int., 149, 534 -545.

Charco, M., Brimich, L., Fernandez, J., 2002. Topography effects on the displacements and gravity changes due to magma intrusion. Geol. Carpathica, 53, 215-221.

Dehant, V., Defraigne, P., Wahr, J.M., 1999. Tides for a convective earth. J. Geophys. Res., 104, 1035-1058.

Dehant V., Defraigne P., Van Hoolst T., 2000. Computation of Mars' transfer function for nutation tides and surface loading. Phys. Earth Planet. Inter., 117, 385-395.

Fern\'andez, J., Charco, M., Tiampo, K. F., Jentzsch, G., Rundle, J. B., 2001. Joint interpretation of displacements and gravity changes in volcanic areas. A test example: Long Valley Caldera, California. Geophys. Res. Lett., 28, 1063-1066.

Folch, A., Fern\'andez, J., Rundle, J.B., Mart\'{\i}, J., 2000. Ground deformation in a viscoelastic medium composed of a layer overlying a half space. A comparison between point and extended sources. Geophys. J. Int., 140, 37-50.

Giunchi, C., Spada, G., 2000. Postglacial rebound in a non-Newtonian spherical earth. Geophys. Res. Lett., 27, 2065-2068.

Grafarend, E.W., 2000. The time-varying gravitational potential field of a massive, deformable body. Stud. Geophys. Geod., 44, 364-373

Grafarend, E.W., Engels, J., Varga, P., 2000. The temporal variation of the spherical and Cartesian multipoles of the gravity field: the generalized MacCullagh representation. J. Geod., 74, 519-530.

Greff-Lefftz, M., Dehant, V., Legros, H., 2002. Effects of inner core viscosity on gravity changes and spatial nutations induced by luni-solar tides. Phys. Earth Planet. Inter., 129, 31-41.

Greve, R., Klemann, V., Wolf, D., 2003. Ice flow and isostasy of the north polar cap of Mars. Planet. Space Sci., 51, 193-204.

Hagedoorn, J.M., Wolf, D., 2003. Pleistocene and recent deglaciation in Svalbard: implications for tide-gauge, GPS and VLBI measurements. J. Geodyn., 35, 415-423.

Hagedoorn, J.M., Wolf, D., Neumeyer, J., 2001. Determination of atmospheric influence on high-accuracy gravity measurements with elastic earth models. In: Sideris, M.G., ed.: Gravity, geoid, and geodynamics 2000, pp. 185-192. Springer, Berlin.

Kaufmann, G., 2000. Ice-ocean mass balance during the Late Pleistocene glacial cycles in view of CHAMP and GRACE satellite missions. Geophys. J. Int., 143, 142-156.

Kaufmann, G., 2002. Predictions of secular geoid changes from Late Pleistocene and Holocene Antarctic ice-ocean mass imbalance. Geophys. J. Int., 148, 340 -347.

Kaufmann, G., Amelung, F., 2000. Reservoir-induced deformation and continental rheology in vicinity of Lake Mead, Nevada. J. Geophys. Res., 105, 16341-16358.

Kaufmann, G., Lambeck, K., 2000. Mantle dynamics, postglacial rebound and the radial viscosity profile. Phys. Earth Planet. Inter., 121, 301-327.

Kaufmann, G., Lambeck, K., 2002. Glacial isostatic adjustment and the radial viscosity profile from inverse modeling. J. Geophys. Res., 107, 2280, doi: 10.1029/2001JB000941

Kaufmann, G., Wolf, D., 1999. Effects of lateral viscosity variations on postglacial rebound: an analytical approach. Geophys. J. Int., 137, 489-500.

Kaufmann, G., Wu, P., 2002a. Glacial isostatic adjustment on a three-dimensional laterally heterogeneous earth: examples from Fennoscandia and the Barents Sea. In: Mitrovica, J.X., Vermeersen, B.L.A., eds.: Ice sheets, sea level and the dynamic earth, pp. 293 -309. American Geophysical Union, Washington.

Kaufmann, G., Wu, P., 2002b. Glacial isostatic adjustment in Fennoscandia with a three-dimensional viscosity
structure as an inverse problem. Earth Planet. Sci. Lett., 197, 1 -10.

Kaufmann, G., Wu, P., Li, G., 2000. Glacial isostatic adjustment in Fennoscandia for a laterally heterogeneous earth. Geophys. J. Int., 143, 262-273.

Klemann, V., Wolf, D., 1999. Implications of a ductile crustal layer for the deformation caused by the Fennoscandian ice sheet. Geophys. J. Int., 139, 216-226.

Klemann, V., Wu, P., Wolf, D., 2003. Compressible viscoelasticity: stability of solutions for homogeneous plane-earth models. Geophys. J. Int., 153, 569-585.

Martinec, Z., 1999. Spectral, initial value approach for viscoelastic relaxation of a spherical earth with a three-dimensional viscosity - I. Theory. Geophys. J. Int., 137, 469-488.

Martinec, Z., 2000. Spectral-finite element approach to three-dimensional viscoelastic relaxation in a spherical earth. Geophys. J. Int., 142, 117-141.

Martinec, Z., 2002. Semi-analytical solution for the viscoelastic relaxation in spherical earth with an axisymmetric craton. Acta Geod. Geophys. Hung., 37, 61-78.

Martinec, Z., Wolf, D., 1999. Gravitational viscoelastic relaxation of eccentrically nested spheres. Geophys. J. Int., 138, 45-66.

Martinec, Z., Thoma, M., Wolf, D., 2001a. Material versus local incompressibility and its influence on glacial-isostatic adjustment.Geophys. J. Int., 144, 136-156.

Martinec, Z., Cadek, O., Fleitout, L., 2001b. Can the 1D viscosity profiles inferred from postglacial rebound data
be affected by lateral viscosity variations in the tectonosphere? Geophys. Res. Lett., 28, 4403-4406.

Milne, G.A., Davis, J.L., Mitrovica, J.X., Scherneck, H.-G., Johansson, J.M., Vermeer, M., Koivula, H., 2001. Space-geodetic constraints on glacial isostatic adjustment in Fennoscandia. Science, 291, 2381-2385.

Mitrovica, J.X., Milne, G.A., Davis, J.L., 2001. Glacial isostatic adjustment on a rotating earth. Geophys. J. Int., 147, 562-578.

Nostro, C., Piersanti, A., Antonioli, A., Spada, G., 1999. Spherical versus flat models of coseismic and postseismic deformations. J. Geophys. Res., 104, 13115-13134.

O'Keefe K., Wu, P., 2002. Effect of mantle structure on postglacial induced horizontal displacement. In: Mitrovica, J.X., Vermeersen, B.L.A., eds.: Ice sheets, sea level and the dynamic earth, pp. 109 -118. American Geophysical Union, Washington.

Park, K.-D., Nerem, R.S., Davis, J.L., Schenewerk, M.S., Milne, G.A., Mitrovica, J.X., 2002. Investigation of glacial isostatic adjustment in the northeast U.S. using GPS measurements. Geophys. Res. Lett., 29, 10.1029/2001GL013782.

Ray, R.D., Eanes, R.J., Lemoine, F.G., 2001. Constraints on energy dissipation in the Earth's body tide from satellite tracking and altimetry. Geophys. J. Int., 144, 471-480.

Spada, G., 2001. Mantle viscosity from Monte Carlo inversion of very long baseline interferometry data. J. Geophys. Res., 106, 16375 -16385.

Sun, W., Okubo, S., 2002. Effects of earth's spherical curvature and radial heterogeneity in dislocation studies-for a point dislocation. Geophys. Res. Lett., 29, 46-1-46-4.

Sun, W., Sj\"oberg, L.E., 1999a. Gravitational potential changes of a spherically symmetric earth model caused by a surface load. Geophys. J. Int., 137, 449-468.

Sun, W., Sj\"oberg, L.E., 1999b. A new global topographic-isostatic model. Phys. Chem. Earth, 24, 27-32.

Thoma, M., Wolf, D., 2001. Inverting land uplift near Vatnajökull, Iceland, in terms of lithosphere thickness and viscosity stratification. In: Sideris, M.G., ed.: Gravity, geoid, and geodynamics 2000, pp. 97-102. Springer, Berlin.

Van Hoolst, T., Dehant, V., de Viron, O., Defraigne, P., Barriot, J.P., 2002. Degree-one displacements on Mars.
Geophys. Res. Lett., 29, 6-1-6-4.

Varga, P., 2002. Short and long term variations of the polar moment of inertia and of the model of the earth. Acta Geod. Geophys. Hung, 37, 79 -92.

Wieczerkowski, K., Mitrovica, J., Wolf, D., 1999. A revised relaxation-time spectrum for Fennoscandia, Geophys. J. Int., 139, 69-86.

Wolf, D., 2002. Gravitational viscoelastodynamics. Acta Geod. Geophys. Hung., 37, 1, 29-60.

Wolf, D., Kaufmann, G., 2000. Effects due to compressional and compositional density stratification on load-induced Maxwell-viscoelastic perturbation. Geophys. J. Int., 140, 51-62.

Wolf, D., Li, G., 2002. Compressible viscoelastic earth models based on Darwin's law. In: Mitrovica, J.X., Vermeersen, L.L.A., eds.: Ice sheets, sea level and the dynamic earth, pp. 275-292. American Geophysical Union, Washington.

Wu, P., 1999. Modeling postglacial sea-levels with power law rheology and realistic ice model in the absence of ambient tectonic stress. Geophys. J. Int., 139, 691-702.

Wu, P., 2001. Postglacial induced surface motion and gravity in Laurentia for uniform mantle with power-law rheology and ambient tectonic stress. Earth Planet. Sci. Lett., 186, 427-435.

Wu, P., 2002a. Mode coupling in a viscoelastic self-gravitating spherical earth induced by axisymmetric loads and lateral viscosity variations. Earth Planet. Sci. Lett., 202, 49 -60.

Wu. P., 2002b. Effects of nonlinear rheology on degree 2 harmonic deformation in a spherical self-gravitating earth. Geophys. Res. Lett., 29, 10.1029/2001GL014109.

Wu, P., 2002c. Postglacial induced surface motion, gravity and fault instability in Laurentia: evidence for power law rheology in the mantle? In: Mitrovica, J.X., Vermeersen, B.L.A., eds: Ice sheets, sea level and the dynamic earth, pp. 219 -231. American Geophysical Union, Washington.

Wu, P., 2002d. Effects of mantle flow law stress exponent on postglacial induced surface motion and gravity in Laurentia. Geophys. J. Int., 148, 676 -686.

Wu, P., Johnston, P., 2000. Can deglaciation trigger earthquakes in N. America? Geophys. Res. Lett., 27, 1323-1326.

Wu, P., Johnston, P., Lambeck, K., 1999. Postglacial rebound and fault instability in Fennoscandia. Geophys. J. Int., 139, 657-670.

Special Study Groups 4.190:

"Non-probabilistic assessment in geodetic data analysis"

H. Kutterer, kutterer@dgfi.badw.de

Motivation

Geometrical and physical models can only be approximations of the reality. Hence, the difference between the selected model and the data is uncertain. In Geodesy, these differences either remain unclassified or are considered as exclusively random. The first case leads to estimation theory including robust techniques. In the second case stochastics based on probability theory supplies a variety of methods for modelling as well as for data analysis and assessment. Contrary to this, stochastics is not always the adequate theoretical basis to handle problem-immanent uncertainties. Two examples may give an idea. In applications like, e.g., Real-Time Kinematic Differential GPS, imprecision due to unknown systematic effects is the most relevant type of uncertainty. Besides, in GIS modelling there are often fuzzy or vague transitions between spatial objects regarding the respective semantics.

The probabilistic point of view is normative. It does not allow to handle different types of uncertainty in a distinct way. In order to establish a general methodology for the comprehensive assessment of uncertainty in data analysis it is necessary to identify and to classify the occuring uncertainties in typical geodetic applications. Within the work of the IAG SSG 4.190 (SSG) several mathematical theories were considered which are not based on probability theory such as interval mathematics and fuzzy theory. One prominent topic was the joint treatment of random-type uncertainty (stochasticity) and imprecision of the data. Three fields of application were studied: GPS data processing, deformation analysis, GIS.

Membership structure

Chairman: H. Kutterer (Germany)

Members:
O. Akyilmaz (Turkey)
M. Brovelli (Italy)
A. Brunn (Germany)
A. Carosio (Switzerland)
B. Crippa (Italy)
G. Joos (Germany)
K. Heine (Germany)
S. Leinen (Germany)
B. Merminod (Switzerland)
F. Neitzel (Germany)
W. Niemeier (Germany)
J. Ou (China)
D. Rossikopoulos (Greece)
B. Schaffrin (U.S.A.)
E. A. Shyllon (Nigeria)
A. Stein (The Netherlands)
J. Wang (Australia)
Y. Yang (China)
J. Zavoti (Hungary)

Corresponding Members:
R. Fletling (Germany)
J. B. Miima (Germany)
M. Molenaar (The Netherlands)
S. Schön (Germany)
W.-D. Schuh (Germany)
R. Viertl (Austria)
A. Wieser (Austria)

Organizational notes

During the period from 1999 to 2003 one scientific symposium and three working meetings were held within the frame of the SSG. The `First Symposium on Robust Statistics and Fuzzy Techniques in Geodesy and GISA took place in Zurich, Switzerland, from March 12 to March 16, 2001. It was organized by A. Carosio and H. Kutterer who also edited the proceedings volume (Carosio and Kutterer, 2001). A first working meeting took place on April 7, 2000 in Karlsruhe, Germany. The participation of E. A. Shyllon was funded by the IAG what is gratefully acknowledged. A second SSG working meeting was held during the Zurich symposium. The third and last meeting was organized on the occasion of the IAG Scientific Assembly 2001 in Budapest, Hungary.

SSG website and mailing list

The SSG maintains the website www.dgfi.badw.de/ssg4.190. The site contains formal details (terms of reference, objectives, list of members), information on the work of the SSG (notes, minutes of the working meetings, Zurich symposium report, bibliography) and a mailing list. It is planned to keep the site beyond the IUGG General Assembly 2003 in Sapporo, Japan, and to update it when required.

Results

Qualification and quantification of uncertainty
Uncertainties of the data are due to the random selection of the data, the random variability of the data (central limit theorems), imprecision of the observation procedure and instruments (round-off errors, recording of correction data), lacking reliability of the data, reduced credibility of the data (data are recorded reliably, but their adequacy for the modelled situation is questionable), data gaps, or lacking consistency of data coming from different sources. Uncertainties of the estimation or inference procedures result from simplifications for (convenient) mathematical treatment (e.g., linearized models), (ambiguous) choice of the optimum principle of parameter estimation, or decisions based on discrete alternatives and on threshold values.

The uncertainty of models or concepts is not considered in classical Geodesy. Nevertheless, there are uncertainties of the model because of the incomplete (human) knowledge (modelling of the 'state of the art'), necessary simplifications due to the complexity of the real world (naming of and restriction to the relevant characteristics), modelling of a substitute ('proxy') situation (discretization of continuous objects and processes), fuzziness or imprecision of linguistic expressions or descriptions ('gross error', 'high temperature'), imprecision or inaccuracy of some 'known' model parameters, ambiguity (non-uniqueness in a crisp sense), or vagueness (non-uniqueness in a fuzzy sense, non-specificity).

Aiming at the assessment and management of uncertainty in typical geodetic data analysis it is indispensable to register, to characterize, and to categorize the essential contributors and effects. The set-up of a corresponding questionnaire is the key to the assessment of uncertainty. It can serve as a basis for the improvement of particular procedures in use and for the comparison of procedures. A proposed questionnaire can be found on the SSG webpages. Such a questionnaire is particularly recommended as a basis for the assessment of routine data analysis like in the IAG data services. This could help to get a deeper understanding of the data products to be used or interpreted.

Mathematical theories for the assessment of uncertainty
Mathematical theories which are adequate for (at least) some parts of uncertainty modelling and handling can be divided into theories which are more or less based on the theory of probability and into theories which are not. The approximation theory is the most fundamental approach since uncertainty is considered in terms of approximation errors which are minimized by minimizing a suitable measure for the distance between model and data. Probabilistic theories are the theory of stochastics with uncertainty modelled by means of random variables, the Bayes theory allowing the use of stochastic (sometimes subjective) prior knowledge (Koch, 1990) and the evidence theory (Shafer, 1976). The last theory can be understood as a generalization of the Bayes theory; uncertain prior knowledge is modelled and assessed using credibility and plausibility measures. Finally, robust statistics has to be settled between pure approximation theory and stochastics.

Non-probabilistic theories are interval mathematics (Alefeld and Herzberger, 1983), fuzzy theory (Dubois and Prade, 1980), possibility theory (Dubois and Prade, 1988), the theory of rough sets and the artificial neural networks (ANN). Interval mathematics allows to consider imprecise data whereas fuzzy theory comprises both fuzziness (or imprecision) of the model and of the data. The main branches of fuzzy theory are fuzzy logic and fuzzy data analysis. The latter can be understood as a generalization of interval mathematics. There are approaches to combine probabilistic and non-probabilistic theories like, e.g., by Viertl (1996) who develops a statistics for imprecise data with extensions to Bayesian statistics.

There is a need in geodetic data analysis for the selection of the adequate kind of mathematics, for the definition of particular measures of uncertainty, and for the combination of the most suitable mathematical theories if several types of uncertainty occur in the applications. For further information and for a extended list of references see the SSG website. Within the SSG the main focus was on robust statistics and on geodetic applications of both fuzzy logic and fuzzy data analysis to handle classical model-data deviations in general and to consider (non-random) data and model imprecision.

Interval mathematics and fuzzy data analysis

Imprecision of the data can be taken into account either by intervals or fuzzy numbers. An interval is defined by its lower and its upper bound or, equivalently, by its meanpoint and its radius. The radius of the interval is a proper measure of imprecision. A fuzzy number is typically defined by its membership function which is controlled by a meanpoint parameter and a spread parameter. Fuzzy numbers can be understood as generalized intervals. Imprecision measures based on fuzzy numbers are proportional to the spreads (Kutterer, 2002a). The definition of vectors is unique in case of intervals. In fuzzy theory there are several ways like, e.g., the use of the minimum rule or of quadratic forms (Kutterer, 2001c, 2002a).

Least-squares (LS) adjustment is a typical technique in geodetic data analysis. The case of observation intervals and their impact on the LS estimator (LSE) was discussed by Schön and Kutterer (2001a, b, 2002) in order to solve two problems. First, in geodetic practice imprecision needs to be quantified. Second, the impact of observation imprecision on the estimated parameters can be reduced using mathematical optimization techniques. Both aspects are studied in detail by Schön (2003). Kutterer (2001c) discusses two fuzzy-theoretical ways to introduce imprecision to the LSE in a Gauss-Markov model. The first one is the fuzzy-extended LSE where the imprecise observations vector is inserted into a consistent extension of the LSE. The meanpoint of the fuzzy-extended LSE is equivalent to the classical LSE. Its spreads quantify the imprecision in addition to the variance-covariance matrix which represents stochastic dispersion. The second one is based on the maximum similarity principle and leads to the fuzzy LSE in the strict sense and to the hybrid fuzzy LS approximation.

As in geodetic practice neither the stochastic nor the interval or fuzzy approach are adequate to jointly handle stochasticity and imprecision, fuzzy extensions of confidence regions and hypothesis tests for stochastic and imprecise data have been developed. The main idea is to apply the extension principle of fuzzy theory to the respective mathematical relations. The derivation of fuzzy-extended confidence regions to the resolution of GPS phase ambiguity parameters was studied in Kutterer (2001b, 2002b). Statistical hypothesis tests for imprecise data are derived in Kutterer (2003).

Fuzzy systems and artificial neural networks

In many applications of control theory and of decision theory it is either expensive or just impossible to acquire complete and precise information on all relevant parameters and relations. Hence, the need for moderate complex but adequate models leads to the development of fuzzy systems which are based on fuzzy logic. Fuzzy systems consist of four components: an input component, an inference component, an output component and a feedback connection from the output to the input. The input component comprises an interface which allows to fuzzify real input data by means of linguistic variables such as @length@ with the fuzzy states @short@, @medium@, @long@. The inference component consists of a fuzzy rule base and a method for the aggregation of the resulting fuzzy set. The output component yields real parameters which are derived from the fuzzy result by a defuzzification method.

Fuzzy models were used successfully by Heine (1999, 2001) for the modelling of deformation processes. Leinen (2001) studied the On-The-Fly resolution of GPS phase ambiguities as a multi-attribute decision making process in order to assess the importance of some evidence pro or contra a particular candidate solution. Aliosmanoglu and Akyilmaz (2002) considered outlier detection in geodetic networks based on fuzzy logic. Joos (2001) presented the @egg-yolk@ approach which allows to model fuzzy transition zones between spatial objects in GIS such as meadows and forests. Graeff (2002) compared probabilistic and fuzzy approaches in case of template matching for GIS data acquisition. An adaptive network fuzzy inference system (ANFIS) was studied by Akyilmaz and Kutterer (2003) for the short-term prediction of Earth orientation parameters. Wieser (2001a, b) and Wieser and Brunner (2002a, b) show the benefit of fuzzy logic for the determination of a realistic variance model for GPS data and correspondingly for improved robust estimates for kinematic processing of short baselines.

The artificial neural networks (ANN) represent an independent methodology to handle various types of uncertainty. They have been developed in order to imitate human thinking. They are composed of a large number of simple processors (neurons) that are massively connected and operate simultaneously. ANN are trained based on examples what is called machine learning. During the training process individual weights are assigned to the neurons. Some work has been done on the application of ANN to geodetic problems. Heine (1999) and Niemeier and Miima (2001) considered the modelling of deformation processes. Note that both fuzzy systems and ANN are solely mathematical representations of the underlying physical processes. They offer easy-to-handle best-fit solutions but they are - at least at first glance - inadequate for physical interpretation.

Estimation theory including robust techniques

The use of robust techniques for the reliable estimation of parameters and derived quantities is important in case of insufficient knowledge of the statistical properties of the data. Within the frame of the SSG several progress has been achieved. Wicki (2001) describes the BIBER estimator which is used by the Swiss Federal Office of Topography for geodetic networks. Kanani and Carosio (2001) use the BIBER estimator for the automatic vectorization of areal objects from digital topographic maps. Yang studies - together with varying co-authors - robust estimators in applications such as satellite laser ranging in order to handle systematic errors (Yang et al., 1999a), kinematic GPS positioning (Yang et al., 2001b), and dynamical sea surface models (Yang et al, 1999a).

Maximum correlation adjustment (MCA) is based on the quantitative comparison of data and model by means of their correlation coefficient (Neitzel, 2001). A set of solutions is obtained by maximizing the correlation coefficient. In geometric deformation analysis the Helmert transformation is one of the MCA solutions. Finally, some extensions of classical estimation theory are mentioned which are relevant in the scope of the SSG. Schaffrin and Iz (2001) study an extended estimator which is adequate to handle partial inconsistencies when integrating heterogeneous data sets. The Best Linear Minimum Partial Unbiased Estimator (BLIMBPE) is described in Schaffrin and Iz (2002).

Perspectives

Two main outcomes of the SSG>s work should be emphasized. First, there is a clear need for a distinct modelling and handling of the different types of problem-immanent uncertainties. Second, there are different mathematical theories which allow a dedicated treatment. There is certainly a competition of methodologies in some fields but in most parts they are complementing each other. One example is represented by the soft computing techniques which comprise fuzzy techniques, ANN and genetic algorithms. A second example in data analysis is a joint modelling and inference strategy in a combined stochastic, fuzzy and Bayesian framework. Once established, this allows to integrate stochasticity and imprecision of the data as well as model and prior information uncertainty. Both given examples reflect essential and de manding challenges in geodetic data analysis for the near future.

General references

Alefeld, G.; Herzberger, J. (1983): Introduction to Interval Computations. Academic Press, New York.

Dubois, D.; Prade, H. (1980): Fuzzy Sets and Systems. Academic Press, New York.

Dubois, D.; Prade, H. (1988): Possibility Theory, Plenum Press, New York.

Koch, K. R. (1990): Bayesian Inference with Geodetic Applications. Springer, Berlin Heidelberg.

Shafer, G. (1976): A Mathematical Theory of Evidence. Princeton University Press, Princeton.

Viertl, R. (1996): Statistical Methods for Non-Precise Data. CRC Press, Boca Raton New York London.

Publications by SSG members in the frame of the SSG

Akylimaz, O; Ayan, T.: Optimization of deformation networks by using fuzzy approach. In: CD-ROM Proceeding of the IAG 2001 Scientific Assembly, Budapest, 02.09.-07.09.01, 2001.

Akyilmaz, O.; Kutterer, H.: Prediction of Earth orientation parameters by fuzzy inference systems. Report No. 75, DGFI, München, 2003.

Aliosmanoglu, S.; Akyilmaz, O.: A comparison between statistical&fuzzy techniques in outlier detection. In: Ádám, J.; Schwarz, K.-P. (Eds.): Vistas for Geodesy in the New Millenium. IAG Symposia, Vol. 125, Springer, 382-387, 2001.

Brovelli, M.A.; Sansò, F.; Venuti, G.: A discussion on the Wiener-Kolmogorov prediction principle with easy to compute and robust variants. In: Carosio, A.; Kutterer, H. (Eds.), 25-38, 2001.

Carosio, A.; Kutterer, H. (Eds.): Proceedings of the First International Symposium on Robust Statistics and Fuzzy Techniques in Geodesy and GIS. Swiss Federal Institute of Technology Zurich, Institute of Geodesy and Photogrammetry - Report No. 295, 2001.

Graeff, B.: Querying raster data structures - probabilistic and non-probabilistic approaches on knowledge based template matching methods. In: Ádám, J.; Schwarz, K.-P. (Eds.): Vistas for Geodesy in the New Millenium. IAG Symposia, Vol. 125, Springer, 371-376, 2002.

Heine, K.: Beschreibung von Deformationsprozessen durch Volterra- und Fuzzy-Modelle sowie Neuronale Netze. Deutsche Geodätische Kommission, Series C, Nr. 516, München, 1999.

Heine, K.: Potential applications of fuzzy methods in geodetic fields. In: Carosio, A.; Kutterer, H. (Eds.), 87-94, 2001.

Joos, G.: Modeling Uncertainty in GIS. In: Carosio, A.; Kutterer, H. (Eds.), 133-138, 2001.

Kanani, E.; Carosio, A.: Automatic vectorisation of areal objects by robust estimation techniques. In: Carosio, A.; Kutterer, H. (Eds.), 159-168, 2001.

Kutterer, H.: Uncertainty assessment in geodetic data analysis. In: Carosio, A.; Kutterer, H. (Eds.), 7-12, 2001a.

Kutterer, H.: An imprecise search space for GPS phase ambiguity parameters. In: Carosio, A.; Kutterer, H. (Eds.), 215-220, 2001b.

Kutterer, H.: Some considerations on Fuzzy Least-Squares. In: Sideris, M. (Eds.): Gravity, Geoid and Geodynamics 2000. Springer, Berlin Heidelberg, 73-78, 2001c.

Kutterer, H.: Zum Umgang mit Ungewissheit in der Geodäsie - Bausteine für eine neue Fehlertheorie. DGK, Reihe C, Nr. 553, München, 2002a.

Kutterer, H.: Joint treatment of random variability and imprecision in GPS data analysis. Journal of Global Positioning Systems, Vol. 1, No. 2:96-105, 2002b.

Kutterer, H.: Statistical hypothesis tests in case of imprecise data. Proceedings of the 5th Hotine-Marussi Symposium, Springer, Berlin, 2003 (accepted for publication).

Leinen, S.: Fuzzy-Logic Based GPS On-The-Fly Ambiguity Search. In: Carosio, A.; Kutterer, H. (Eds.), 209-214, 2001.

Neitzel, F.: Maximum Correlation Adjustment in Geometrical Deformation Analysis.In: Carosio, A.; Kutterer, H. (Eds.), 123-132, 2001.

Niemeier, W., Miima, J.B.: A Neural Network Approach for Modelling Geodetic Deformations. In: Carosio, A.; Kutterer, H. (Eds.), 111-116, 2001.

Ou, J.: Selection of Quasi-Accurate Observations and "Hive-Off" Phenomena about the Estimators of Real Errors. In: Carosio, A.; Kutterer, H. (Eds.), 73-78, 2001.

Rossikopoulos, D.: Modeling Alternatives in Deformation Measurements. In: Carosio, A.; Kutterer, H. (Eds.), 117-122, 2001.

Schaffrin, B.; Iz, H.B.: Integrating heterogeneous data sets with partial inconsistencies. In: Sideris, M. (Eds.): Gravity, Geoid and Geodynamics 2000. Springer, Berlin Heidelberg, 49-54, 2001.

Schaffrin, B.; Iz, H.B.: BLIMPBE and its geodetic applications. In: Ádám, J.; Schwarz, K.-P. (Eds.): Vistas for Geodesy in the New Millenium. IAG Symposia, Vol. 125, Springer, 377-381, 2002.

Schön, S.: Analyse und Optimierung geodätischer Messanordnungen unter besonderer Berücksichtigung des Intervallansatzes. Ph.D. Thesis, University of Karlsruhe, Germany, Summer 2003.

Schön, S.; Kutterer, H.: Interval-based description of measurement uncertainties and network optimization. In: Carosio, A.; Kutterer, H. (Eds.), 41-46, 2001a.

Schön, S.; Kutterer, H.: Optimal design of geodetic monitoring networks by means of interval mathematics. In: Whitacker C. (Eds.): Proceedings of the 10th FIG International Symposium on Deformation Measurements, 19.03.-22.03.2001, Orange, California, U.S.A., 362-371, 2001b.

Schön, S.; Kutterer, H.: Network optimization with respect to systematic errors. In: Ádám, J.; Schwarz, K.-P. (Eds.): Vistas for Geodesy in the New Millenium. IAG Symposia, Vol. 125, Springer, 329-334, 2002.

Shyllon, E.A.: Techniques for modeling uncertainties inherent in Geomatics Data: Fuzzy System Approach. In: Carosio, A.; Kutterer, H. (Eds.), 139-144, 2001.

Viertl, R.: Description and Analysis of Fuzzy Data. In: Carosio, A.; Kutterer, H. (Eds.), 19-24, 2001.

Wicki, F.: Robust estimator for the adjustment of geodetic networks. In: Carosio, A.; Kutterer, H. (Eds.), 53-60, 2001.

Wieser, A: A Fuzzy System for Robust Estimation and Quality Assessment of GPS Data for Real-Time Applications. In: Proc ION GPS 2001, Salt Lake City, pp 2998-3008, 2001a.

Wieser, A: Robust and fuzzy techniques for parameter estimation and quality assessment in GPS, Ph.D. Thesis, TU Graz, Ingenieurgeodäsie - TU Graz, Shaker Verlag Aachen, 253 p, 2001b.

Wieser, A: Fuzzy Logic and GPS: Benefitting from uncertainty. GPS World, March: 38-47 (in print), 2003.

SECTION V:

"GEODYNAMICS"

REPORT BY THE PRESIDENT FOR THE PERIOD 1999-2003

C. R. Wilson

Overview

With the reorganization of the IAG to take effect at the meeting in Sapporo, this report is a final one for the Geodynamics Section V of the IAG. In the future, Geodynamics will retain its identity as the new Commission 3, but sub-entities will change. Geodynamics Section activities within the Commissions, Special Commissions, the Joint Working Group, and the International Services are described in individual reports below. In addition to the work described below, Section V President Wilson headed the Scientific Organizing Committee of the Seventh International Congress of Earth Sciences, in Santiago Chile, October 2002, sponsored by IAG. Additional information is contained in the report of Commission XIV below. Section V Vice President Veronique Dehant chaired the joint IAU-IUGG working group on Precession and Nutation, overseeing development of new precession-nutation models, and accounting for the non-rigid nature of the Earth and influences of geophysical fluids. These studies have been important in implementing fundamental changes in astrometry and modern space geodesy. As discussed in the International Earth Rotation Service (IERS) report below, the IERS began implementing new IAU resolutions that fundamentally redefine the Celestial Reference System (CRS) to take full advantage of precision available with modern VLBI. The new precession-nutation models are an important element of high precision geodesy that enables the study of geodynamics. As the IAG representative to the IERS Directing Board, Section V President Wilson participated in a number of IERS activities, including two workshops related to the implementation of the new CRS. Wilson has also participated in the IERS Global Geophysical Fluids Center work of the IERS, which, as noted below, will become a major element of IAG and Geodynamics Commission work in the future.

The executive officers of Section V (Wilson and Dehant) participated in the effort to map the old IAG onto the new structure adopted in Budapest IAG assembly, in 2001. This new structure places the IERS and other services on the same level as Commissions. This is important because in many ways the services like IERS have become leaders in setting geodetic practice. For example, the IERS conventions document forms, in effect, the geodetic standard in use today. Under the new IAG structure, it should be easier to coordinate activities of the services with those of the IAG, by establishing joint review of such standards and conventions. For example, the IAG plans an inter-commission committee on geodetic standards for this purpose, to carry on the work of Special Commission 3 (reported below). An example of inconsistency between IAG resolutions and the IERS conventions is the treatment of the zero-frequency terms in the Earth tides. This sort of conflict can be reconciled over the next few years in this new inter-commission committee on geodetic standards.

Under the new IAG structure, the initial proposal is for Geodynamics (new Commission 3) to include three main subcommissions. One is concerned with crustal deformation, the second with the impact of geophysical fluids on geodetic observations, and the third with earth tides. A subcommission on crustal deformation would be expected to transfer many of the activities under the current Commission XIV, as reported below, though some changes are possible. The subcommission on Earth tides would also be expected to continue the work of the current Earth Tide Commission, as reported below. The new activity, geophysical fluids, is an outgrowth of Special Commission 8 (Sea Level and Ice Sheets, reported below), the IAPSO/IAG special study group on non-tidal ocean effects (reported below), and several special study groups on atmospheric and related influences on earth rotation that were active over the past period of over a decade. Redistribution of air and water dominate the changes in Earth rotation and gravity field at many time scales (days to decades). This subcommission will link the new Geodynamics Commission 3 to other commissions, and services. Notably, the International Earth Rotation Service (IERS) has a geophysical fluids center, and that activity should form the core of the new geophysical fluids sub-commission. The bigger role of services in IAG, especially of IGS as the biggest player in crustal deformation, should strengthen the activities related to crustal deformation. There are many other opportunities for the future under the new IAG. These are likely to grow out of IAG projects, in combination with a multitude of new measurements available, including satellite-based gravity, ice sheet heights from laser altimetery, as well as the expanding geodetic networks of permanent GPS stations.

COMMISSION V:

"EARTH TIDES (1999-2003)"

S. Takemoto, President

During past four years the IAG Commission V organized the 14th International Symposium on Earth Tides in 2000 and the combined workshop of the ETC Working Group 7 and GGP in 2002.

The 14th International Symposium on Earth Tides (ETS2000)

The ETS2000 was held in Mizusawa, Iwate, Japan from August 28 to September 1, 2000. The Symposium sessions were: Tidal instrumentation; Results of ground based observations; Tidal observations using space techniques; Modeling of solid earth tides and related problems; Atmospheric and oceanic loading effects; Data processing; Superconducting gravimeters; Tidal studies in tectonic active regions; Tides on planet. 138 participants (including 10 accompanying persons) from 21 countries reported fully on their results of continuing researches on Earth tides and thus contributed to the progress of further research of Earth and Planetary Tides. Proceedings of scientific papers were published in the Journal of the Geodetic Society of Japan Vol. 47, No. 1, 2001. Other Reports on the ETS2000 including the list of participants were published in BIM (BULLETIN D'INFORMATIONS MAREES TERRESTRES). Following 11 resolutions were adopted at the closing session of the ETS2000.

ETS2000 Resolutions

1. Recognising the importance of the observation of tidal effects and of the determination of tidal parameters by space geodetic techniques, the ETC recommends to continue this observational effort; to compare the results obtained by different space geodetic techniques between each other and with the results of ground based tidal measurements.

2. Recognising the importance of the new international services on space geodetic techniques, the ETC recommends that WG6 establishes or intensifies the cooperation with the analysis coordinators of these international services concerning the tidal modelling.

3. Considering the new fields of tidal research in lunar and planetary geodesy, the ETC recommends that the tidal community should take an active part in space missions related to lunar and planetary geodesy; requests a proper archiving of the data and metadata acquired during those missions and normal access to the world-wide geodetic community.

4. Considering the increasing interest of the tidal community to lunar and planetary researches, the ETC recommends that a session on tides on the planets should be included in the future earth tides symposia.

5. Recognising the importance of a global Earth coverage with superconducting gravimeters for the study of weak geophysical signals, for the determination of the liquid core resonance parameters, for the study of the polar motion effects on gravity, for the intercomparison of the load vectors derived from recent ocean tides models, for the study of global and regional gravity changes to validate the results of the dedicated satellite missions, the ETC recommends to extend the GGP observation period for an additional 6 year period starting July 2003, to maintain the existing sites and to encourage the installation of new GGP stations especially in the Southern hemisphere and in polar regions.

6. Recognising the fact that presently the calibration of the superconducting gravimeters participating to the world-wide GGP project is not homogeneous, the ETC recommends that systematic calibration campaigns with absolute gravimeters should be planned and realised before the end of the current GGP observation period, through an international cooperative effort.

7. Recognising the importance to keep in operation several calibration techniques for gravimeters to allow a mutual accuracy control, the ETC recommends that inertial calibration platforms and moving

mass calibration devices should continue to be developed or maintained besides more usual calibration methods such as intercomparison with absolute or well-calibrated relative instruments.

8. Recognising the importance of environmental data for the interpretation of tidal measurements, the ETC recommends:
   a) to record the following parameters:
      - The barometric pressure, temperature, precipitation, and ground water level. The sampling rate for the recording of environmental parameters should correspond to the sampling rate of the geodynamic data observed. A sufficient resolution and accuracy of the measurements of the environmental parameters should be granted.
      - Although the difficulties of monitoring soil moisture are recognised, its is recommended to undertake efforts to realize a continuous monitoring of this parameter.
      - The monitoring of wind is also recommended because wind might produce short-period noise as well as long-period modulations.
   b) to correct gravity data in long term studies for local (diameter 100km), regional (diameter 2000 km), and global atmospheric pressure signals as all three produce significant effects.
   c) to develop correction models for gravity, tilt, and strain related to:
      - ground water table variations
      - snow, rain and soil moisture
      - stress resulting from temperature variations

9. Noting the importance for tidal measurements of accurate error estimates and appreciating that such estimates can be made only if the power spectral density of the noise is known, the ETC recommends to show noise spectra as Power Spectral Density expressed in unit 2/ frequency.

10. On behalf of all participants of the 14th International Symposium on Earth Tides, the ETC thanks the Japanese National Committee for Geodesy, the Science Council of Japan, the Geodetic Society of Japan, the National Astronomical Observatory of Japan, the City of Mizusawa and the Iwate Prefecture for their generous support to the Symposium.

11. ETC thanks the Local Organising Committee : Masatsugu Ooe (Chairman), Tadehiro Sato (Secretary) , Jiro Segawa (President of Geodetic Society of Japan) and the staff, for their wonderful welcome and their many efforts in making the 14th International Symposium on Earth Tides a great scientific success.

Combined Workshop of ETC-WG6 and GGP

A combined meeting of the ETC Working Group 7: Analysis of Environmental ata for the Interpretation of Gravity Measurements (Chairperson: Corinna Kroner) and the Global Geodynamics Project (Chairperson: David Crossley) was held in Jena, Germany during the period of March 11-15, 2002. The GGP Workshop concentrated on all issues surrounding superconducting gravimetry - instrumentation, site development, data processing, while at the meeting of the WG addressed topics on environmental effects on gravimeter, tilt, strain, and seismometer data. In all, 39 scientists from 16 countries participated. Proceedings of the Combined Workshop of ETC-WG6 and GGP were published in the Bulletin d'Informations des Marees Terrestres (BIM). Vols. 135 and 136, 2002.

Renewal of the ETC Homepage

The new ETC Homepage was opened at the following address:
http://www-geod.kugi.kyoto-u.ac.jp/iag-etc/ The standard software for the prediction of earth tide phenomena and for the processing of earth tide observations can be downloaded from the Electronic Information Service in ETC HP.

2nd ETC Medal

The ETC steering committee decided to award the 2nd ETC Medal (ETC Medal 2000) to the late Professor Hans-Georg Wenzel for his outstanding contribution to international cooperation in earth tide research. The ETC awarded the Medal to Ms Marion Wenzel at the Opening Session of ETS2000 on August 28 2000 at Mizusawa, Japan.

Next International Symposium on Earth Tides

The next (15th) International Symposium on Earth Tides will be held in Ottawa, Canada from 2-6 August 2004.

COMMISSION XIV:

"CRUSTAL DEFORMATION"

S. Zerbini

The Terms of Reference of the Commission on Crustal Deformation (Commission XIV) are described in the following.

Space geodetic measurements provide nowadays the mean to observe deformation and movements of the Earth's crust at global, regional and local scale. This is a considerable contribution to global geodynamics by supplying primary constraints for modeling the planet as a whole on the one hand, but also for understanding geophysical phenomena occurring at smaller scales. There are many geodetic signals, which can be observed and are representative of the deformation mechanisms of the Earth's crust at different spatial and temporal scales. The time scales range from seconds to million of years in the case of plate tectonics and from millimeters to continental dimension for the spatial scales.

Gravimetry, both absolute and relative, is a powerful tool providing information to the global terrestrial gravity field and its temporal variations. Superconducting gravimeters allow a continuous acquisition of the gravity signal at a given site with precision of $10^{-10.}$ This is important in order to be able to detect and model environmental perturbing effects as well as the weak gravity signals associated with vertical crustal movements of the order of mm/yr.

These geodetic observations together with other geophysical and geological sources of information provide the mean to understanding the structure, dynamics and evolution of the Earth system.
Commission XIV comprises the following sub-Commissions:

1. Working group of European Geoscientists for the Establishment of Networks for Earth science Research (WEGENER, Chair: Luisa Bastos, Portugal);
2. Geodetic and Geodynamics programs of the Central European initiative (CEI, Chair Janusz Sledzinski, Poland);
3. Asia-Pacific Space Geodynamics program (APSG, Chair: Ye Shuhua, China);
4. Central and South America (Co-Chairs: Alejandro Gutiérrez, Costa Rica and Rodrigo Barriga, Chile);
5. Africa (Chair: Ludwig Combrink, South Africa);
6. Antarctica (Chair: Alessandro Capra, Italy);

encompassing most of the tectonically active areas of the Planet. The sub-Commissions deal with main scientific objectives having common general aspects and, in parallel to these objectives, follow the development of technology and measurement techniques capable to best fulfil the scientific objectives. This allows a close interaction between the various sub-Commissions, which shall organize, on a regular basis, conferences or assemblies of the sub-Commissions themselves or, for selected scientific and technological subjects of common interest to most of them.

Primary, general objectives of Commission XIV are:

- to study 3-D tectonic motions, in active tectonic regions, postglacial rebound and sea-level fluctuations and changes in relation to vertical tectonics along many parts of the coastlines and in relation to environmental fluctuations/changes affecting the geodetic observations;
- to promote, develop and coordinate international programs related to observations, analysis and data interpretation for the three fields of investigation mentioned above;
- to promote the development of appropriate models.

Commission XIV has the following structure:
Bureau

President:
Susanna Zerbini (Italy, zerbini@df.unibo.it)
Vice-Presidents:
Hans-Gert Kahle (Switzerland, hans-gert.kahle@geod.baug.ethz.ch)

Bernd Richter (Germany, bernd.richter@bkg.bund.de)

Secretary:

Tonie VanDam (Luxembourg, tvd@ecgs.lu)

Members:

Rodrigo Barriga (Chile) rbarriga@igm.cl
Luisa Bastos (Portugal) lcbastos@oa.fc.up.pt
Geoffrey Blewitt (USA) gblewitt@unr.edu
Yehuda Bock (USA) ybock@ucsd.edu
Claude Boucher (France) boucher@ensg.ign.fr
Carine Bruyninx (Belgium) C.Bruyninx@oma.be
Eric Calais (France) calais@faille.unice.fr
Alessandro Capra (Italy) alessandro.capra@mail.ing.unibo.it
Ludwig Combrink (South Africa) ludwig@hartrao.ac.za
James Davis (USA) jdavis@cfa.harvard.edu
Martine Feissel (France) feissel@ensg.ign.fr
Alejandro Gutiérrez (Costa Rica) gechever@una.ac.cr
Michael Pearlman (USA) mpearlman@cfa.harvard.edu
Christoph Reigber (Germany) reigber@gfz-potsdam.de
Robert Reilenger (USA) reilinger@erl.mit.edu
Hans-Geog Scherneck (Sweden) hgs@oso.chalmers.se
C. K. Shum (USA) ckshum@osu.edu
Janusz Sledzinsky (Poland) sledzinski@gik.pw.edu.pl
Shuhua Ye(China) ysh@center.shao.ac.cn

Activities 1999-2003

The Commission XIV Bureau met on four occasions:

- September 21, 2000, San Fernando, Spain;
- December 17, 2000, San Francisco, USA;
- March 29, 2001, Nice, France;
- September 4, 2001, Budapest, Hungary.

The last Bureau meeting will take place in July 2003, in Sapporo, during next IUGG.

During the first meeting, the Board membership, Subcommissions organization and Commission activities were discussed and revised. During the subsequent meetings particular attention was given to support and coordinate the work carried out by the Subcommissions. In particular, the Bureau agreed that a major activity of Commission XIV be the support to the formation of a global "velocity field" from the combination of regional contributions along the lines of the GPSVEL Project (see WEGENER section of this report).

A meeting with the representatives of the Central (including the Caribbean area) and South America Subcommission took place in Miami prior to the December 2000 Bureau meeting in San Francisco. They agreed to survey the relevant activities underway and the resources available. The South America co-chair announced the international Symposium on "Recent Crustal Deformation in South America and Surrounding Areas". This event, supported by the Commission took place in Santiago, Chile, in October 2002 (see South America section of this report).

Commission XIV co-sponsored the "Tenth International Symposium on Recent Crustal Movements held in Helsinki, Finland, August 27-31, 2001. There were more than 70 participants in the symposium and 60 presentations covering a wide variety of topics. As a result, a special issue of the Journal of Geodynamics (2003) has been produced containing 13 manuscripts.

Commission XIV has a web site at the following address: http://www.df.unibo.it/commXIV/.

In the following the activities of the Subcommissions are described.

<u>Publications</u>

Journal of Geodynamics, Special Issue, Crustal Deformation, 2003, vol. 35 N. 4-5.

WEGENER

During the period 1999-2003 the main objectives of the WEGENER sub- commission were maintained. Therefore, the activities were centered on:

- study of the three-dimensional deformations and gravity along the African-Eurasian plate boundaries and in the adjacent deformation zones in order to contribute to a better understanding of the associated geodynamical processes;
- monitoring of three-dimensional deformations in a large region centered around Fennoscandia in order to determine the magnitude and extent of the present-day postglacial rebound in that area, thereby extending our knowledge about the viscoelastic properties of the Earth;
- investigation of height and sea-level variations in order to identify and separate the processes contributing to these variations.

Within this period the WEGENER board had the following meetings:

- Nice, France, April, 27, 2000;
- San Fernando, Spain, September, 21, 2000;
- Nice, France, March 26, 2001;
- Budapest, Hungary, September, 5, 2001;
- Athens, Greece, June 14, 2002.

The main decisions and outcomes of these meetings were:

- to promote the cooperation of researchers from different geosciences and to strengthen the cooperation with African research groups with enlargement of activities in Africa;
- to support the GPSVEL project, managed by Geoffrey Blewitt, by promoting the interest and willingness to provide GPS data/solutions within the WEGENER area of interest. As a result, several contributions were sent including solutions from more than 100 stations distributed all over Europe;
- to support the interest for the realisation of a coordinating Center that could produce "WEGENER solutions" mainly (but not exclusive) from permanent GPS stations and episodic campaigns. There was agreement on the realisation of such a center that should also address issues such as data quality and control and comparison of processes and products. As a first step, the WEGENER Directing Board decided to start the setup of a Data Base Center supporting the generation of a detailed velocity field in the WEGENER study area. This may be seen as a part of the global GPSVEL-Project (Blewitt et al., 2000).

This project should start with the collection and combination of GPS and other solutions for coordinates and/or velocity estimates. The center should act in order to guarantee the quality for non-IGS or non-EUREF sites, and should not superimpose, but be complimentary to these Services, by dedicating also special attention to the use of GPS data from episodic campaigns.

A second step should be the application of an integrated approach to a selected region where data from different geosciences would be jointly analyzed and interpreted.

A first a document entitled “Processing and Submission Guidelines for GPS Solutions to be integrated to a WEGENER Data Base” was prepared by Matthias Becker, Carine Bruyninx and Rui Fernandes to be disseminated among potential contributors. This document contains guidelines and requirements to be followed for submission of solutions to such a Center and concentrates on how GPS campaigns of finite duration can be processed and correctly tied to the ITRF. It was first delivered to the participants of the 11th General Assembly of the WEGENER project that took place in Athens in June 2002.

During the period 1999-2002, two General Assemblies were organized. One took place at San Fernando, in Spain, in September 2000, hosted by the Real Instituto Y Observatorio de la Armada, and the other one at Vouliagmeni (Athens), in Greece, in June 2002, hosted by the Department of Rural and Surveying Engineering of the National Technical University of Athens. The main themes for these Assemblies were:

- Geodynamics;
- Plate tectonics;
- Integrated observation techniques.

Two special issues of international journals were produced. In 2000, the Journal of Geodynamics published a special issue, which compiles six manuscripts resulting from presentations made during the eighth WEGENER general assembly. In 2002, a special issue of Global and Planetary Change was published dealing with height and sea-level variations resulting from the SELF II project .

One concern in the organization of these Assemblies was to bring together researchers from different disciplines (geodesy, geophysics, geology, seismology, etc.) in order to contribute to merge expertise and solutions towards a more comprehensive and correct interpretation of the analysis results.

Special support was given to the participation of Colleagues from North African Countries. Pursuing the goal of taking the general Assemblies to different countries of the WEGENER area, and with the purpose to strengthen the cooperation with North Africa, there was a proposal for organizing the next WEGENER Assembly in a North African Country. The Colleagues from Morocco kindly agreed to host the next (12^{th}) general assembly in 2004.

Publications

Blewitt G., Lavallée D., Clarke P.J., Nurutdinov, Holt W.E. Kreemer C., Meertens C.M. Shiver W.S., Stein S., 2000, GPSVEL Project: Towards a Dense Global GPS Velocity Field. In Book of Extended abstracts of the 10^{th} General assembly of the WEGENER Project, San Fernando, Spain, 18-20 September 2000, Boletin ROA, N.3/200,

Journal of Geodynamics, 2002, Special Issue WEGENER: Observations and Models, vol. 30, N. 3, pp.287-388.

Global and Planetary Change, 2002, Special Issue Sea Level Fluctuations in the Mediterranean: Interactions with Climate Processes, vol. 34, N. 1-2, pp 1-140.

Geodetic and Geodynamic Programs of the Central European Initiative (CEI)

Plan of action of the CEI Section C "Geodesy" includes:

- realisation of the Project CERGOP (Central Europe Regional Geodynamics Project) and post-UNIGRACE (UNIfication of GRAvity system in Central and Eastern european countries) actions;
- activities of 13 CERGOP Study Groups;
- activities of the CEGRN (Central European GPS Reference Network) Consortium and
- actions of two Section's Working Groups on University Education Standards and on Satellite Navigation Systems;
- cooperation with the European Geophysical Society (EGS).
-

The first phase of the Project CERGOP was concluded in 1998. Since 1998 the second phase of the Project is being realized. The proposal of the second phase of the Project CERGOP-2 "A Multipurpose and Interdisciplinary Sensor Array for Environmental Research in Central Europe (CERGOP-2/Environment)" was selected by the European Commission and will be financially supported during the next three years. Fourteen European countries participate in the second phase of the project and the total number of CERGOP-2 stations is 63. About 30 CERGOP-2 points are permanent stations that are also contributing to other international projects. Many CEGRN sites are part of the IGS permanent network. Some CERGOP Processing Centers are also EUREF Local Analysis Centers (EUREF LOC) and process routinely data for the EPN (European Permanent Network). Monitoring GPS CEGRN campaigns were performed in 1999 and 2001 (CERGOP-2). Next campaign is scheduled for 2003. Five CERGOP Processing Centers compute velocity vectors of the stations in the Central European area. One of the main parts of the international activities within the CERGOP project is the work of CERGOP Study Groups (CSG). At present, there are 13 study groups covering particular fields of activity supporting the realisation of the Project and, in general, they form the relevant "workpackages" of the EU Project CERGOP-2/Environment. In particular, the activities of seven study groups concern the geodynamics of particular European regions such as the Eastern Alps and the North and Eastern Adriatic Sea, Romania Plate, Pannonian Basin, Plitvice Lakes/Croatia, Tatra Mountains, Northern Carpathians and Balkan Peninsula. A set of eight volumes of geotectonic monographs was published; the publications include the main scientific results obtained for the regions studied by CERGOP study groups and summarize the main achievements of all studies. Suggestions are also presented for the further continuation by means of advanced technologies.

The CERGOP was an impulse for establishment of the CEGRN Consortium of institutes involved in the realisation of the Project. The Consortium was created with the aim to maintain, currently upgrade and develop the CEGRN established in the frame of CERGOP, as well as to perform coordinated monitoring of satellite CEGRN campaigns and to organize and maintain the CEGRN (CERGOP) Data and Processing Centers. The Consortium will also be a seedbed of new European projects and initiatives. At the moment 14 European institutions are members of the Consortium.

The UNIGRACE project was launched in 1997 as multipurpose interdisciplinary project and it ended in 2002. It consisted in the establishment of absolute gravity stations covering the area from the Baltic Sea to the Adriatic and the Black Seas. It constitutes an excellent frame for the connection of the national gravimetric networks and it provides a unified precise gravity frame in Central and Eastern Europe linked to the Western European network. Ten absolute gravity intraplate and seven tide-gauge stations were measured in 12 countries. The gravity observations were carried out by means of five absolute gravimeters from Austria, Finland, France, Germany and Poland. The observation campaigns of the UNIGRACE project were successfully performed in 1998/1999 and 2000/2001. The analyses of the gravity data of the UNIGRACE campaigns indicate that there are unclear considerable changes of the gravity values at some absolute stations. These changes cannot be explained by accounting for the effects of station point displacements, water table level variations, atmospheric effects or other known factors. For this reason, all countries participating in UNIGRACE agreed to continue, as a UNIGRACE follow-up action, the further investigation of the gravity time variations/change at main European stations. In 2003, a detailed programme of the project will be adopted and the funding aspects will be discussed as well.

Section C Working Group on University Education Standards organizes yearly an international educational seminar/workshop or symposium. The subjects of these events include satellite DGPS techniques and field training for application to different geodetic purposes. Lately the WG has initiated close cooperation with the professional organization FIG (Federation International de Geometres). Working Group on Satellite Navigation Systems has organized several planned actions in 2000, 2001 and in 2002. The actions considerably contribute to exchange of information and to initiate the broad application of satellite positioning systems to land, marine and air navigation in CEI countries.

Cooperation with EGS results in the yearly organization of a symposium on the geodetic and geodynamic programs carried out in the frame of the international cooperation of CEI countries.

CEI Section C "Geodesy" and the Subcommission "Geodetic and Geodynamic Programs of the Central European Initiative (CEI)" declares to supply and release to the aims of the Commission XIV the following results:

- results of the GPS campaigns of CEGRN carried out in the frame of CERGOP;
- velocity vectors of about 60 sites in Central Europe computed by the CERGOP Processing Centers from the CERGOP, EXTENDED SAGET, EUREF campaigns;
- information on progress in determination of quasi-geoid in the Tatra Mountains;
- information on local geodynamic projects realized in Central Europe within the CEI bilateral and multilateral cooperation;
- information on work progress concerning the 7 CERGOP Study Subgroups CSG.5/i of the CSG.5 "Geotectonic analysis of the region of Central Europe";
- information on geotectonic monographs prepared by the CERGOP Study Subgroups CSG.5/i "Geotectonic analysis of the region of Central Europe";
- information on progress in the realisation of the post-UNIGRACE actions.

CEI has developed a web page at the following address: http://www.gik.pw.edu.pl/igwiag/cei.html

Asia-Pacific Space Geodynamics program (APSG)

The APSG was endorsed by the IAG on its Boulder Meeting in 1995. The early shape of APSG was formed in the First APSG Workshop, May 13-17, 1996 in Shanghai, China. In Tahiti, French Polynesia, May 12-16, the Second APSG Workshop was held. The Third APSG Workshop was held in Tsukuba, Japan, on Oct. 20, 1999, along with the International GPS Symposium. The Fourth APSG Workshop came back to Shanghai on May 14-19, 2001.

On the 2001 Shanghai Workshop, the Scientific Working Group N. 4, Gravimetry in the Asia-Pacific Region, was established. Numbers 1-to-3 are Geodynamics and Natural Hazards of the Indo-Eurasian Collision, Geodynamics and Natural Hazards of the Western Pacific Region and Impact of Sea Level variations on the Asia-Pacific Region.

The Management Board consists of representatives from 9 Countries, namely: Australia, China, France, Germany, Indonesia, Japan, South Korea, Russia and USA.

Beginning from 1997, APSG VLBI Experiments including 6 VLBI stations in the Asia-Pacific region were organized, to support the yearly campaign of APRGP (Asia-Pacific Regional Geodetic Project). Scientific results of the Scientific Working groups mentioned above have been reported and exchanged on the APSG Workshops and relevant meetings.

The Gravimetry Group has a plan to perform Precise Gravity Observation in East Asia with Super Conducting and Absolute Gravimeters (FG-5) in China, Japan and Indonesia, in the 2003-2005 time frame.

The Institute of Astronomy, RAS, and the Irkutsk State Technical University organized an APSG International Seminar on Aug. 5-10, 2002, at Irkutsk, Russia. At this seminar, by recognizing the very broad area of GPS applications with mm level of accuracy, a resolution on establishing a Working Group on the Methods of GPS Measurements and Data Processing was accepted. An International Seminar on this topic will be held in early June 2003, in Bishkek, Kyrgyzstan, to exchange and discuss the optimal allocation of observing networks, construction of geodetic monuments, analyses of GPS data, comparison of different software, parameters and processing methods. The seminar is timely and important for precise GPS measurements.

During the IAG/IUGG Meeting in Sapporo, a short APSG meeting will be held to discuss the results in recent years and plans for the future. The 5th APSG Workshop will be held in Hong Kong in 2004.

The Asia-Pacific region is been suffering for many serious natural hazards, APSG needs to be strengthened, and all colleagues interested in the program are warmly welcome to join.

The APSG Subcommission has a Web site at the following address: http://center.shao.ac.cn/APSG and can be contacted at the following e-mail: apsg@center.shao.ac.cn.

Central and South America

Central America

The activities in South America were mainly concerned with the establishment of RONMAC (Red de Observacion de Nivel del Mar para America Central) in Central America. The RONMAC project has been devised by the U.S. Government in direct response to the impact of Hurricane Mitch on four Central American countries: El Salvador, Guatemala, Honduras, and Nicaragua. Participating Agencies are:

- United States Agency for International Development (USAID), Funding Agency ;
- Center for Operational Oceanographic Products and Services, National Oceanic and Atmospheric Administration (CO-OPS/NOAA), of the US Department of Commerce, as Administrating Agency ;
- Unit for Sustainable Development and Environment of the Organization of American States (OAS/USDE), as Executing Agency;
- Regional Committee for Water Resources (CRRH), as Regional Coordinating Agency;
- National agencies in El Salvador, Guatemala, Honduras, and Nicaragua, as direct counterparts and beneficiaries of the RONMAC project.

The main objectives of this project are: a) support development and improvement of the geodetic framework of Central America; b) provide basic meteorological data to national and regional agencies; c) sea-level monitoring and establishment of long-term means sea level data series. At present, there are 11 operational RONMAC stations in Central America: Panama (2), Nicaragua (2), Honduras (1), El Salvador (3), Guatemala (2), Belize (1). There are also five satellite transmitting meteo-marine stations in Costa Rica to be upgraded as RONMAC type. LABCODAT has been established as a data quality control and spare parts center in Costa Rica.

Two training courses have been offered to Central American Meteorology and Geophysics technicians with the aim of providing them with the tools for appropriately operate and maintain the stations. Periodic refreshing courses will be conducted in the future.

RONMAC Web site (http://www.oas.org/ronmac/) where the user may download the data every three hours is available. Annual tide tables have been included in this site. It is expected this year the inclusion of a larger number of local predictions as well as periodic sea level and SST monthly control maps.

South America

In October 2002, an IAG international Symposium entitled "Recent Crustal Deformation in South America and Surrounding Areas", took place in Santiago de Chile. It was organized in 7 sessions, in which 41 oral and 25 poster presentations were given. Scientists from several countries attended. This event gave also the opportunity to south American geodesy practitioners and students to acquire new knowledge and experience from major experts in the field.

In parallel with the above-mentioned Symposium, a meeting dedicated to SIRGAS was held. The Geocentric Reference System for South America is intended to establish and maintain a reference network, together with defining a geocentric Datum. At this meeting, the current situation in each of the countries involved regarding the Reference Framework was presented. The main topic was the mission set for each country for the vertical control of data covering the continent.

The presence in Chile at Conception of the Transportable Integrated Geodetic Observatory (TIGO) is of major importance because of the increased interest that this generates for geodetic research on the continent. This is, in fact, the first and only fiducial geodetic station operating in South America.

Africa

The Hartebeesthoek Radio Astronomy Observatory (HartRAO) has in the past four years developed its Space Geodesy Programme to the extent that it has become one of five fiducial geodetic installations in the world. The three major space geodetic techniques; VLBI, SLR and GPS are supported. A DORIS system is also collocated with these three systems.

VLBI: 17 % of the 26 m radio telescope time has been allocated to geodetic VLBI, this leads to an average of 56, 24-hour experiments per year. Upgrade to MKV disk cartridge to replace the thin tape system has been budgeted for to keep abreast of latest developments.

SLR: MOBLAS6 achieved operational status in mid 2001, achieved superior performance level in mid 2002, and is constantly in the top ten SLR tracking sites as far as performance is concerned.

GPS: HartRAO joined the TIGA pilot project of the IGS as regional data enter and associate analysis center, in addition to being an IGS regional data center. Two GPS systems have been collocated with tide gauges, a further similar system is in progress. To support densification of the ITRF and the GPSVEL project, a total of seven permanent GPS systems have been installed, two of which are in other countries (Botswana and Zambia). A project has been established to equip each of the 14 Southern Africa Development Community (SADC) countries with at least one permanent GPS system. This will contribute greatly towards studies of the East African Rift system, evaluation of the African plate motion as consisting of the Nubian and Somalian plates, and will facilitate the conversion of the SADC region from obsolete datums (e.g. Clark 1880) to ITRF.

Several projects have been initiated to further the study of crustal dynamics. Analysis of data and development of reduction techniques is showing great promise to determine vertical crustal motion due to earth tide effects as determined by GPS. This will allow calibration of gravity changes due to earth tide effects at installations such as superconducting gravimeters, and the longer term component could be used to calibrate satellite (e.g. CHAMP) orbits.

HartRAO has collaborated with several institutions to develop space geodetic applications in the region, especially for geodynamics. Future plans include the conversion of MOBLAS6 to a Lunar Laser Ranging capability and the replacement of MOBLAS6 with an SLR2000 system.

Antarctica

The sub-commission promoted activities contributing to the study of crustal deformation processes in Antarctica and enhanced the co-operation with the GIANT (Geodetic Infrastructure of Antarctica) program of SCAR (Scientific Committee on Antarctic Research) WGGGI (Working Group on Geodesy and Geographic Information). The geodynamics studies were performed in close collaboration with the members of the SCAR

Antarctic Neotectonics Group of Specialists (ANTEC), an interdisciplinary group empanelled to improve the understanding of the unique character of the neotectonics regime of the Antarctic plate.

The main activities focused on:

- periodic measurement campaigns for crustal deformation monitoring continued in 2001, 2002 and 2003 as well as field campaigns by GPS networks and GPS permanent trackers. At continental level, observations were performed within the SCAR GPS Epoch (Dietrich et al., 2001) and, at regional level, within VLNDEF (Victoria Land Network for DEFormation control) and TAMDEF (Trans Antarctic Mountain DEFormation control). These latter ones were carried out by the Italian Geodesy Project (Capra et al., 2001) and by the NSF scientific Project (Hothem et al. 02).
- Development of permanent geodetic observatories (GPS, DORIS, VLBI, tide gauges, absolute and cryogenic gravimetry) and the applications of collocation techniques. Integration of local and regional networks was encouraged, particularly by the data processing for international reference frame definition. AUSLIG (Australia) started the TIGA Project, a GPS Tide Gauge benchmark monitoring Pilot Project, regarding the whole Antarctica continent.

Publications

Capra A., Gandolfi S., Mancini F.,Sarti P., Vittuari L.(2001) VLNDEF project: geodetic contribution to geodynamics study of Victoria land, Antarctica. Proceedings of Gravity, Geoid and Geodynamics GG2000 IAG symposium, Banff, Alberta, Canada, July 2000 ,pp. 379-385.

Capra A., Gandolfi S., Mancini F.,Sarti P., Vittuari L . (2001) “VLNDEF project for crustal deformation control of northern Victoria land”. AGS ’01 (Antarctic Geodesy Symposium), St.Petersburg, Luglio 2001, SCAR Report N.21, pp.8-10, January 2002.

Dietrich R., Dach R., Engelhardt G., Ihde J., Korth W., Kutterer H.J., Lindner K., Mayer M., Menge F., Miller H., Muller C., Niemeier W., Perlt J., Pohl M., Salbach H., Schenke H.W., Scohne T., Seeber G., Veit A., Volksen C. (2001) “ITRF coordinates and plate velocities from repeated GPS campaigns in Anatrctica – an analysis based on ndifferent individual solutions”. Journal of Geodesy,74:756-766.

Hothem L., Wilson T., Willis M. (2002) “TAMDEF. GPS measurements of bedrock crustal deformations. Reports of AGS 02 Symposium, Wellington, N.Z. http://www.scar-ggi.org.au/geodesy/ags02/

Special Commission 3:

"Fundamental Parameters"

E. Groten

Introduction

When present accuracies of the order of $\pm$ 10^{-9} or $\pm$ 10^{-10} (as applied in VLBI = Very Long Baseline Interferometry) are considered, fully relativistic reference frames have to be applied as recently adopted for ICRS (= International Celestial Reference Systems) by IAU (= Intern. Astron. Union) at its General Assembly in Manchester (Groten, 2000a, b). Clear distinction between defining, primary and derived constants is necessary (Kinoshita, 1994). Corresponding updated terrestrial reference systems have been considered by modifying ITRS (= Intern. Terrestrial Reference System) but such modifications have not yet been adopted by IAG or IUGG (= Intern. Union of Geodesy and Geophysics). Ellipsoidal Somigliana-type reference systems of various kind were proposed by Ardalan, Grafarend and others (Grafarend and Ardalan, 2001) in terms of GDR 2000 etc but did not yet replace officially the IAG system GRS 80 (= Geodetic Reference System). See also the Piezetti-type solution by Bursa et al. (2002b) leading to a semi-major axis of a = 6 378 136,6 $\pm$ 0.06) m. WGS 84 in its updated form of 1997 (= World Geodetic System of NIMA), where NIMA is the National Imagery and Mapping Agency of the USA, suffers from the fact that the basic four parameters are derived from almost one and the same satellite system so that they are no longer mutually independent. This can lead to inconsistencies. With the new developments in high-precision clocks (in terms of atomic interferometry with cooled atoms) reaching accuracies better than $\pm$ 10^{-14} a new era may start where geodesy contributes stronger to fundamental physics and global high-precision navigation (Heitz, 2001). Kopeikin and Fomalont (www.nature.com/nsu/030106/030106-8.html) recently came to the somewhat controversial and premature conclusion that gravity propagates at about the speed of light leading to a kind of stepwise reconciliation between relativistic and quantum concepts. The main advantage for time measurements in the new system is the linear relation of UT 1 to the new "earth rotation angle", which replaces Greenwich Apparent Sidereal Time in the future.

Time variations

Corresponding to the desired "sub-microarc-second" accuracy of ICRS the need for updated geodetic reference systems is obvious. Also in view of temporal variations of the surface the structure and the dimensions of solid and fluid parts of the earth a dynamic global vertical Datum all over the earth, is needed. With modern altimetry and ongoing tide gauge networks, such as GLOSS, WOCE, TIGA etc., the altimetric-gravimetric boundary value problem has to be solved even if it is considered as an "improperly posed problem" in Hadamard's sense. Pioneer work by Bursa, Grafarend, Kakkuri and others (Bursa et al., 2002a) demonstrate the possibility; even though the accuracy is not yet as good as demanded; for details see (Ardalan and Grafarend, 2001). However, with new altimetric satellites, such as JASON-1, accuracies can be improved. As two thirds of the earth's surface are ocean, the monitoring of temporal variations is mandatory. As far as tectonic activity on land is concerned, Japan with its permanent GPS-network has demonstrated its abilities to establish very effective monitoring systems. Besides ITRF or, in scaled form, ITRS there is a large number of densifications and other monitoring permanent space geodesy networks so that sufficient information on dislocations and exact coordinates in well defined geocentric reference frames will be available. With the new system, ICRS, IAU also adopted a new time system which is related to a conventional potential value at the geoid (= $W°$) so that astronomical time systems demonstrate a tendency to go away from the earth, as was already demonstrated by the fact that ICRF is no longer referred to precession and nutation parameters of the earth. In determinations of $W°$ the error inherent in the terrestrial gravitational constant GM is almost negligible since new values of GM (Pavlis, 2002) reconfirm previous determinations. Moreover, it is interesting to realize that the numerical value of $W°$ is less affected by errors in the volume of the geoid than the shape of the level surface of $W°$, i.e. the absolute geoid (Groten, 2001). Moreover, W^o does not depend on specific permanent tidal regimes. IAG needs the new parameter set in applications of the new formula of precession and nutation as recently adopted by IAU. A typical case is the new value of dynamic flattening $H = (C-(A+B)/2)/C$ where A, B and C are the principal moments of inertia of the earth. It also takes profit from the newly adopted definition and implementation of the "intermediate pole" as a substitute of CEP (= Celestial Ephemeris Pole) and the new NRO (= non-rotating origin) according to Prof. Guinot, replacing the traditional equinox; it is denoted by CEO (= Celestial Ephemeris Origin). Thus we come close to a non-rotating quasi-inertial system in space in the Newtonian sense. With time systems (such as GPS-time, GALILEOSAT-time) we need time and coordinates clearly related to different reference frames, where in view of potential differences general relativistic, and in view of relative motions special relativistic reductions need to be applied. In (Brumberg and Groten, 2001, 2002) several specific aspects have been considered and inconsistencies in the new system were pointed out. Still free wobbles are not yet fully implemented in the definition of the new reference frame. The temporal variations of fundamental contants, such as W^0, in terms of $dW^0/dt \equiv \dot{W}^0$ etc., are today as important as the constants themselves or even more important in view of practical problems inherent in the determination of W^0 etc. This is relevant in view of consistent reference systems.

Special Geodetic Aspects

With VLBI-measurements, Quasars and other distant sources are observed. With new navigation systems, as in case of EGNOS, geostationary satellites are being used. Thus we have a variety of high-precision observations of macrocosmic type to be carefully processed. Targets are located in celestial and observers are in terrestrial frames. Contrary, in superconducting gravimetry, in tidal or tectonic extensometry and in case of tilt observations typical microcosmic observations are being carried out which are basically related with the aforementioned accuracies to microcosmic dimensions where quantum mechanics, Brownian motion and Heisenberg's uncertainly relation become relevant. Both types of observations have to be combined and to be integrated into similar systems, where the aforementioned work such as the one by Kopeikin et al. becomes relevant.

Nevertheless, the mathematical background within potential theory of physical geodesy and conservative forces, where loss of energy vanishes, is relatively simple. But with temporal changes of longer period, as in case of El Nino etc., the role of the atmosphere, on the one hand becomes more import, when mass and energy exchange between oceans and atmosphere needs to be taken into account. On the other hand, the attractive effect of the atmosphere (approximated by a radially stratified homeoid) in space (at satellite altitude) and at various elevations of the surface of the earth varies with time and locations. With CHAMP tomography, atmospheric sounding and limb studies giving temporal variations of the structure of the atmosphere associated results become more important, also for practical applications such as climatic research and weather forecast.. Non-gravitative effects in the atmosphere as well as friction and dissipation in the deeper earth interior put higher demands on mathematical treatment. Thus, viscosity and anelasticity considerations down to the non-hydrostatic CMB (= Core-Mantle-Boundary) and even deeper down to the inner core where Slichter-modes become now relevant, lead to "improperly posed" problems as discussed above which are, however, more complicated than in case of the geodetic BVPs (= Boundary Value Problems).

Practical Aspects

The Subcommission of SC-3 of Prof. J. Rueger (UNSW) which models the atmosphere, has great impact on telemetric and telematic needs in improving refractive models. On the other hand, the use of various tidal results in order to solve the BVP and determine parameters, such as the quality factor, Q, characterizing the distribution of anelasticity in the frequency and space domains, has substantial importance for SEDI (Study of Earth's Deep Interior). It seems that VLBI-observations yielding Q = 30 000 (for free core nutation frequency) are more accurate and less perturbed by loading and other atmosphere perturbations than superconducting gravimetry. But both techniques now yield Q = 30 000. The difference with respect to other observational results, such as wobble-effective Q etc., do no longer pose problems, as the latter are not as accurate as VLBI and super-conducting gravimetry. Long-period variations related to free-core-nutation represent, at this time, the most reliable results anyway. But shorter period variations still need better observations, as in case of ocean tides or Slichter-modes in the inner core.

Also the long-term averages of dislocation vectors deduced from permanent GPS-stations still pose problems. Iceland is one of the few locations on earth where the oceanic tectonic activities in ridges are observable at the surface and where, consequently, the convective mass transfer from the deeper earth's interior to the lithosphere can be observed directly at the earth's surface. Various extensometric, gravimetric, repeat leveling, GPS and tilt observations were carried out there under quite unique climatic limitations. The aforementioned long-term averages of dislocations usually do not reveal the continuous or discontinuous lithospheric motion along and across such faults which can be observed in Iceland and which reveal more detailed information on types of flow of the recently generated lithospheric material.

As far as the global parameters themselves are concerned, it seems that long-time uncertainties of the numerical value of Newton's Gravitational Constant, G, have been solved by Gundlach's recent (Gundlach and Merkowitz, 2000) excellent measurements at Seattle. Another recent determination which yields a slightly higher value is by Quinn et al. (2001). Thus G is now much better determined (Mohr and Taylor, 2002). Whereas the original attempts to interpret discrepancies between various determinations of G in terms of "fifth force" effects (and associated considerations of E. Majorana's gravitational absorption and shielding) have lost a lot of their previous interest (Zürn, 2003), recent speculations around the geomagnetic field influences on measurements of G are now under consideration (Mbelek and Lachièze-Rey, 2002). Latitude-dependent discrepancies, real or apparent, are characteristic for modeling processes of terrestrial parameters; Kaula discussed such phenomena in case of Lamé's constants, Wahr found them in case of tidal parameters; other examples are well known. In so far such a discussion around G is not surprising. New research in view of ongoing G-determinations appears necessary. With the new definition of the earth's rotation vector, a clear separation is needed in polar motion and UTC (= Universal Time Coordinated) as well as LOD (= Length of Day) measurements between new and earlier observations in view of high-frequency differences between "intermediate" and "celestial" Ephemeris Pole. The temporal changes of obliquity (of the ecliptic) deviating from standard modeling, which were postulated by B. Chao and others, possibly affect climatic variations in addition to the Milankovich's-concept and other green-house perturbations may also become relevant in the new reference frames.

The role of gravimetry

The recent determination of the terrestrial gravitational constant
GM = 398 600 441.7) $\times 10^6 m^3 s^{-2}$by E. Pavlis (2002) and the update of the Newtonian gravitational constant by Gundlach et al. from the University Washington in Seattle leading to a new optimal estimate (Varga, private comm., 2002) of G = (6672.1 $\pm$ 30) $\times 10^{-14} m^3 s^{-2}$ kg^{-1} imply a substantially improved scaling of terrestrial and satellite gravity spaces. Intuitively, I still trust more in a slightly higher G-value such as 6672.6 $\times 10^{-14}$ $m^3 s^{-2}$ kg^{-1} held in the past by SC-3. The formal accuracies of recent G-determinations are of the order of $\pm 10^{-5}$ thus indicating the increased quality of observations. Summarizing the present "state of the art" we may conclude that there are basically two slightly different opinions: that the bias is much larger in the older observations so that a weighted average between the recent measurements by Quinn et al. and those by Gundlach and Merkowitz should yield the best estimate of G, leading to a numerical value around G = (6674.1 $\pm$ 0.09) $\times 10^{-14} m^3 s^{-2}$ kg^{-1}, would be appropriate; or that the biases are not yet well understood in all observations so that, with appropriate caution, a "current best estimate" should be derived from all available observations until new results are obtained from ongoing experiments.

A third (substantial) revision of previous reports of SC-3 (Groten, 2000a) is related to "secular" and aperiodic global changes of the earth's shape and its gravity field. We meanwhile well understand that those changes are basically superpositions of solid earth, atmospheric and oceanic effects. This is similar to the interaction of atmospheric, loading, solid earth and oceanic tidal effects in the periodic part of the spectrum. Moreover, in view of relatively short and narrow observation windows, long-periodic tides, such as the 18.6 year period, etc. may interact with "secular" perturbations. GRACE will contribute to a significant step forward. The second zonal harmonic C_2 is a good example which is representative for other parameters, too. Cox and Chao (2002) have pointed out that the decrease in C_2 is more than compensated since 1998 by a positive $\dot{C}_2$. Whereas the decrease was supposed to be a consequence of postglacial rebound the surprising change since 1998 could be due to oceanic effects which did not exist in this form and in such a size before 1998. We may hope to detect similar variations and "turn-around" effects in the future for other global parameters of the earth. Therefore, care is necessary in deriving "secular" variation rates from short observation intervals; as far as this example is representative also for other global parameter variations originating from similar complex geophysical origins (superposition), "secular" changes derived in the past may not always be considered as really secular.

It was generally considered a great honor when I was elected at the IUGG General Assembly at Moscow in 1971 to chair the Special Study Group (SSG) of IAG on Special Techniques in Gravimetry in succession of the great Tauno Honkasalo whose outstanding reputation was lateron mistakenly jeopardized by erroneous interpretations (for details see Hipkin, 2002) of the so-called "Honkasalo-term" in permanent tides. Heikkinen did a lot to repair those misinterpretations. Unfortunately, many details of the achievements of gravimetry were never published but rather privately circulated. One reason for that were the well known deficiencies of gravimetry where (1) the well known non-uniqueness of gravimetric interpretations, (2) unmodeled perturbations in instrumental drift and (3) unmodeled effects in differential equations in formulating uplift in post-glacial investigations and isostatic modeling led to a series of controversies. So I refrain here from referring in detail to numerous publications or unpublished results. Moreover, still unexplained features do exist. Deficient static models of isostatic equilibrium, starting from Airy-Heiskanen over Pratt-Hayford and Vening-Meinesz' lateral isostaty could never fully explain dynamic isostatic behavior, as, e.g. formulated by D. Peltier. Insofar also A. Bjerhammar's dynamic uplift models never fully explained the actual situation in Fennoscandia and the long series of repeat gravimetry only led to useful results of post-glacial uplift when GPS and similar additional technology became available. Nevertheless, the viscosity deduced from such uplift rates is very valuable in deducing viscosity for the earth mantle. Superconducting gravimetry led to a substantial step forward and gave way to numerous new results in studying the earth's inner core. Absolute gravimetry, as one of the very few absolute measurement techniques in geodesy, contributed a lot and will still contribute in the future when altimetry together with tide gauge data over oceanic areas and second derivatives of the potential obtained from GRACE, GOCE etc. projects will globally lead to potential differences which need stabilization within the associated integration processes. It is a pity that not all absolute gravity measurements are being published, as those by NIMA (National Imagery and Mapping Agency) and other organizations. This concerns also J. Faller's results where he used P. Varga's heavy ring calibration technique to contribute to a new determination of the Newtonian gravitational constant in connection with recent discussions on Fifth Force Experiments. The role of mechanical stationary relative gravimeters was evaluated when W. Zuern emphasized, at that time, the superiority of some of such meters over superconducting gravimeters in the high-frequency domain >1mHz. In so far, still the full spectrum of terrestrial gravimetry is appreciated in spite of its inferiority to satellite, mainly LEO-type satellites, in global studies. Thus B. Chao's investigations on the contribution of numerous big reservoirs on earth to changes of moments of inertia of the earth and his evaluations of periodic atmospheric (and oceanic) effects in time variability of low degree harmonics in the earth's gravitational field could never sufficiently be verified by terrestrial gravimetric experiments. The study of atmospheric gravitational fields variations was limited to very local and also loading effects. Particularly, GRACE-data will substantially improve our knowledge previously deduced from more precise information on low degree (and low order) gravity field harmonics variability. However, there is a variety of perturbing effects which needs more detailed consideration. One of them is ocean floor pressure variation. This effect acts over large parts of the time spectrum. It also affects other geodetic observations, such as polar motion. Ocean bottom effects were over long time, almost ignored. Regional Earth's surface (crustal) and upper mantle variations will still take profit from more detailed gravitational information using stationary terrestrial gravimetry. Aperiodic earthquake precursors as detected by us in the seismic belt of China at Lanzhou still need further detailed investigations, as too many unmodeled effects still exist and too many possible candidates can be associated with the observed anomalies in the gravimetric records (Groten, 1996). Anyway, gravimetry (in moving vehicles) in combination with precise positioning and determinations of temporal changes of position now enables improved interpretations which sufferred in the past from local equivalence of inertial and gravitational accelerations. But still numerous unmodeled instrumental effects need explanations in terrestrial gravimetry. A. Kiviniemi was one of the pioneers in that respect but even he could not explain, e.g., surprising tares and jumps in mechanical gravimetric records observed in the Rhinegraben after heavy rainfall etc. which might be indications of rapid gravity changes of the order of some tens of microgals.

Concerning mantle anelasticity and tidal friction:

Already more than a decade ago, at the Intern. Earth Tide Symposium of IAG at Helsinki in 1989, I had formulated the assumption that anelasticity as deduced from tidal gravimetry is often overestimated. Zschau found in 1986 from Chandler wobble data $Q \cong 270$ at principal tidal frequencies such as M_2. Ray (2002) attributes only about 5 percent of total tidal friction to solid earth dissipation; he found for M_2 a value of about $Q = 280$ (Ray et al. 2001). In a detailed investigation he attributes for the principal tidal part 2.4 terawatts to the ocean, 0.1 terawatts to the solid earth and the rest of the total planetary dissipation of 2.536 terawatts to the atmosphere. Whereas 1.7 terawatts is attributed to shallow seas, about 0.7 terawatts is attributed to the deep ocean. As original Chandler wobble data had indicated $Q \cong 100$ and less, the extremely low anelasticity for the FCN-period could appear as a clear indication of the significant difference between strong ocean and low solid friction.

Concerning specific modes:

Concerning the free core nutation (FCN) period specifically, it had been presumed that air pressure perturbations may strongly perturb results of superconducting gravimetry, leading to a quality factor of the order of $Q = 3000$ and more. With the classical definition of Q as the ratio of dissipation ΔE and total energy E over one cycle we get

$$\frac{2\pi}{Q} = \frac{\Delta E}{E} = \frac{1}{E} \oint \frac{dE}{dt}\, dt$$

which is free of any mechanism. Meanwhile Q = 30 000, as derived from VLBI-data has been corroborated almost exactly by Prof. Sun Heping and Prof. Sato using all available superconducting gravimetric results after careful reductions (priv. communication, 2002). For the foregoing value there is a significant numerical deviation from the wobble-effective values of Q around 200. Summarizing the present “state of the art” we may conclude that the quality factor Q does slightly depend on frequency and even more on the underlying mechanism of friction and dissipation. The overwhelming part may occur in the ocean, two thirds of it in the shelf areas and some part at the core-mantle boundary (CMB).

Conclusions

In view of a variety of practical needs the improved determination of global “parameters” (not really “constants”) appears important (Adam and Schwarz, 2001). More real-time high precision solutions for navigation etc. are demanded and related precise global needs have to be fulfilled. Temporal changes of harmonic coefficients of the geopotential, besides the low-order zonal harmonics, are quite intricate in their determination but need to be considered up to higher degrees of tesserals and sectorials. Also the different types of earth rotations variability (from sub-diurnal to tidal friction) need additional investigation. This holds also for long-term polar migration and its interpretation in terms of polar cap melting processes. The results found for profiles of mantle viscosity strongly depend on assumptions on CMB-flattening. The results by Molodensky and Groten (2001; 2002) agree, to some extent, quite well with those found earlier by Herring et al. (1986) and others. Nevertheless, the non-hydrostatic CMB-flattening still poses problems and leads to discrepancies in the results. The long-term variations (periods of diurnal period upwards) still perturb a variety of other measurements, as in case of the quality factor Q, and loading and similar effects still need more intensive studies. In contrast, also the sub-diurnal variations of the earth’s spin rate involves still open questions. The aforementioned results obtained from GPS give more qualitative than exact quantitative information, even though valuable information on ocean-atmosphere interaction has been found. Also the origin of El-Nino Southern Oscillation is still an open question. The role of ocean bottom pressure variations and its impact is surprisingly pronounced in various effects.

Acknowledgement: Very valuable discussions with W. Zürn on various topics are appreciated.

References

Adam, J. and K.-P. Schwarz (Eds.): Vistas for Geodesy in the New Millennium. IAG Symposia, Vol. 125, Scientific Assembly, Budapest, Hungary, Sept. 2-7, 2001, Springer Verlag, Heidelberg.

Ardalan, A. and E. Grafarend (2001): A new estimate of the time derivative of the Geoid Gauge $\dot{W}_O$, presented at the IAG scientific assembly, Budapest, 2-8 September, 2001.

Brumberg, V.A. and E. Groten (2001): A note on Earth’s rotation angular velocity in the general-relativity framework. Journal of Geodesy 75: 673-676.

Brumberg V.A. and E. Groten (2002): IAU resolutions on reference systems and time scales in practice. Astron. Astrophys. 347: 1070-1077.

Bursa, M., E. Groten, St. Kenyon, J. Kouba, K. Radej, V. Vatrt, M. Vojtiskova (2002a): Earth dimension specified by geoidal geopotential. Stud. geophys. geod. 46 (2002), 1-8.

Bursa, M., St. Kenyon, J. Kouba, K. Radej, Z. Sima, V. Vatrt, M. Vojtiskova (2002b): Dimension of the earth’s general ellipsoid. Earth, Moon and Planets 91: 31-41.

Cox, C.M. and B.F. Chao (2002): Detection of a largescale mass redistribution in the terrestrial system since 1998. Science 297, 831-833.

Grafarend, E. and A. Ardalan (2001): Time evolution of a world geodetic datum: IAG Symposia, Vol. 125, Scientific Assembly, Budapest, Hungary, Sept. 2-7, 2001, Springer Verlag, Heidelberg.

Groten, E. (1996): Stationary Gravity Measurement at Lanzhou, Shanghai and Wuhan. Geo- wissenschaften 14, Heft 7-8:313-314.

Groten, E. (2000a): Report of Special Commission 3 of IAG, in: Proc. IAU Coll. 180 “Towards Models and Constants for Sub-Microarcsecond Astrometry (K. J. Johnsten et al., eds.), 337-352, U.S. Naval Obs. Washington.

Groten, E. (2000b): Report on “Fundamental Geodetic Parameters” of IAG-Special Commission 3, IAU-Gen. Ass., Manchester August 2000.

Groten, E. (2001): Do we need a new reference system? IAG Symposia, Vol. 125, Scientific Assembly, Budapest, Hungary, Sept. 2-7, 2001, Springer Verlag, Heidelberg.

Gundlach, J.H. and St. M. Merkowitz (2000): Measurement of Newton’s Constant Using a Torsion Balance with Angular Acceleration Feedback. Physical Review Letter, Vol 85, No. 14, 2869-2872.

Heitz, S. (2001): Gravimeter und Gradiometer. Mitt. Geod. Inst., Rhein. Friedr.-Wilhelms-Univ. Bonn, Nr. 88, 2. verb. Aufl., Bonn.

Herring, T.A., C.R. Gwinn, I.I. Shapiro (1986): Geodesy by radio interferometry: studies of the forced nutation of the Earth. J. Geophys. Res., Vol 91, No B5, 4745-4765.

Hipkin, R.G.: Is there a need for a geodetic datum 2000? Discussion of a “Heiskanen & Moritz’ proposition”. IAG Symposia, Vol. 125, Scientific Assembly, Budapest, Hungary, Sept. 2-7, 2001, Springer Verlag, Heidelberg.

Kinoshita, H. (1994): Is the equatorial radius of the earth a primary constant, a derived constant or a defining constant? Studia Geophys. et Geodaetica, 38/2, 109-116.

Mbelek, J.P. and M. Lachièze-Ray (2002): Possible Evidence from Laboratory Measurements for a Latitude and Longitude Denpendence of G (Manuscript)

Mohr, P.J. and B.N. Taylor (2002): The Fundamental Physical Constants, in: Physics Today, Aug. 2002, 423-430

Molodensky, M.S. and E. Groten (2001): On the upper bound of the liquid core viscosity. Studia geophys. et geodaetica, 45, 1, 12-36.

Molodensky, M.S. and E. Groten (2002): On the models of the lower mantle viscosity consistent with the modern data of core-mantle boundary flattening. Studia geophysica et Geodaetica, vol 46/3, 411-433.

Pavlis, E (2002): Dynamical Determination of Origin and Scale in the Earth System from Satellite Laser Ranging. IAG Symposia, Vol. 125, Scientific Assembly, Budapest, Hungary, Sept. 2-7, 2001, Springer Verlag, Heidelberg, 36-41.

Quinn, T.J.et al (2001): A New Determination of G Using Two Methods, in: The American Physical Society, Vol 87, No.11, Sept. 2001.

Ray, R.D., R.J. Eanes and F.G. Lemoine (2001): Constraints on energy dissipation in the Earth’s body tide from satellite tracking and altimetry. Geophys. J. Int. 144:471-480.

Ray, R. (2002): Tidal friction in the Earth and Ocean, Proc. 89th Journées Luxembourgeoises de Géodynamique, Nov. 12-14, 2001.

Zürn, W. (2003): Fifth form experiments and Newtons's Big G, DGG-Mitt. (in press).

Special Commission 8:

"Sea Level and Ice Sheets"

M. Bevis

During the reporting period SC 8 organized the development of a broader working group, called CGPS@TG, to address the technical issues associated with retrofitting of tide gauges with continuous GPS stations. This is a joint working group of IAG (SC 8), IAPSO (CMSLT), the IGS, PSMSL and GLOSS, and has a website at www.soest.hawaii.edu/cgps_tg. We organized an international meeting in Honolulu, which eventually led to the production of a position paper 'Technical Issues and Recommendations Related to the Installation of Continuous GPS stations at Tide Gauges' which was published by Bevis et al. (2002) as well as being reproduced on the CGPS@TG website. This website also contains a number of useful case studies. SC 8/CGPS@TG organized a second and larger international meeting in Toulouse, France in Sept. 2002, which was funded by the IUGG, with additional support from IOC. Most of the funding was used to provide travel support, with priority given to scientists coming from developing countries. This meeting had an associated one-day workshop for people just entering the field (usually ocenaographers with little geodesy background, or geodesists with little background in oceanography and tide gauges). While SC 8 and CGPS@TG have focused mainly in the science driving the positioning of tide gauges, the technical requirements of field work, and the accumulation of metadata, we are not funded to perform operational activities. The most pressing problem in this area was the lack of a suitable GPS data processing stream. Both SC 8 and CGPS@TG worked with IGS to lobby for, and later to support the development of an IGS pilot project (TIGA) that will provide operational support via global geodetic analysis of the data produced by the CGPS@TG community. Finally, the two international meetings were used to introduce oceanographers to relevant developments in geodesy and geophyics, most notably the measurement and modeling of glacial isostatic adjustment (postglacial rebound), and the difficulties and opportunities presented by seasonal signals in the position times series of CGPS stations, both at tide gauges and more generally. The aim of SC8 is an important topic in the Antarctic research community. In cooperation with the SCAR working group on Geodesy and Geographic Information (since 2002 "Standing Scientific Group on Geosciences") the compilation of Antarctic tide gauge data and their reference to the ITRF by GPS fixing made good progress. Furthermore, ground truth activities for the new satellite gravity missions (CHAMP,GRACE) and altimetry missions (ENVISAT,ICESat) have been supported.

Reference

Bevis, M., W. Scherer, and M. Merrifield (2002) Technical Issues and Recommendations Related to the Installation of Continuous GPS stations at Tide Gauges, Marine geodesy, 25, 87 - 99.

Joint Working Group on Geodetic effects of non-tidal oceanic processes

R. Gross

The IAG/IAPSO Joint Working Group (JWG) on Geodetic Effects of Nontidal Oceanic Processes was formed at the XXII General Assembly of the IUGG that was held in Birmingham during July, 1999 for the purpose of: (1) promoting investigations of the effects of nontidal oceanic processes on the Earth's rotation, deformation, gravitational field, and geocenter; and (2) fostering interactions between the geodetic and oceanographic communities in order to gain greater understanding of these effects. Since it was formed, five meetings-of-opportunity of the JWG have been held: (1) on December 15, 1999 in conjunction with the 1999 Fall Meeting of the AGU that was held in San Francisco, California; (2) on April 27, 2000 in conjunction with the XXV General Assembly of the EGS that was held in Nice, France; (3) on March 29, 2001 in conjunction with the XXVI General Assembly of the EGS that was held in Nice, France; (4) on April 25, 2002 in conjunction with the XXVII General Assembly of the EGS that was held in Nice, France; and (5) on April 7, 2003 in conjunction with the 2003 Joint Assembly of the EGS-AGU-EUG that was held in Nice, France. Summaries of the latter four meetings have been or will soon be published in the IAG Newsletter that appears in the Journal of Geodesy.

In the last few years a number of exciting developments have occurred in the area of ocean/solid Earth interactions. The importance of oceanic processes to exciting polar motion in general (Furuya & Hamano 1998; Ponte *et al.* 1998; Johnson *et al.* 1999; Nastula & Ponte 1999; Chen *et al.* 2000; Nastula *et al.* 2000, 2002; Wünsch 2000, 2002a, 2002b; Ponte *et al.* 2001, 2002; Thomas *et al.* 2001; Leuliette *et al.* 2002a; Ponte and Ali 2002) and the Chandler wobble in particular (Celaya *et al*. 1999; Ponte & Stammer 1999; Gross 2000; Brzezinski & Nastula 2002; Brzezinski *et al.*, 2002b; Gross *et al.* 2003; Liao *et al.* 2003) has been demonstrated by applying ocean models to Earth rotation studies. In addition, ocean models have enabled the relatively smaller, but still detectable, influence of oceanic processes on the length-of-day (lod) to be studied (Marcus *et al.* 1998; Johnson *et al.* 1999; Chen *et al.* 2000; Kakuta *et al.* 2000; Ponte & Stammer 2000; Höpfner 2001; Ponte and Ali 2002; Ponte *et al.* 2001, 2002). The oceanic torques acting on the solid Earth are also being studied (de Viron *et al.* 2002; Fujita *et al.* 2002; Hughes 2002). As global ocean general circulation models continue to improve, and ocean data assimilation systems develop (Ponte *et al.* 2001), more progress can be expected.

Since the formation of the Joint Working Group, the effect of oceanic mass redistribution on the orbits of satellites (Chen *et al.* 1999a; Johnson *et al.* 2001a), the Earth's gravitational field (Cazenave *et al.* 1999; Cheng & Tapley 1999; Gruber *et al.* 2000; Foldvary and Fukuda 2001a, 2001b, 2002; Johnson *et al.* 2001b; Leuliette *et al.* 2002b; Wünsch *et al.* 2002; Reigber *et al.* 2003), geocenter (Cazenave *et al.* 1999; Chen *et al.* 1999b; Bouillé *et al.* 2000; Johnson *et al.* 2001b; Crétaux *et al.* 2002), surface gravity measurements (Sato *et al.* 2001), and station positions (Mangiarotti *et al.* 2001) have also been studied. The launch of CHAMP and GRACE will enable even more detailed studies of the influence of the oceans on the Earth's gravitational field (Wahr *et al.* 1998). Furthermore, CHAMP and GRACE will directly measure the mass term of the Earth rotation excitation functions (Gross 2001, 2003) as well as fluctuations in ocean-bottom pressure (Ponte 1999). Thus, the next few years should prove as exciting as have the last few years in studying the geodetic effects of nontidal oceanic processes.

As can be seen in the studies of, for example, the EOPs (Earth Orientation Parameters) and the change in the J2 term of the global gravity field, the oceans play an important role in Earth system dynamics (ESD). Measurements of sea surface height (SSH) variability obtained from satellite altimetry have revolutionized our knowledge of the role of the oceans. For the ESD, the important physical quantity directly affecting its change is the mass redistribution in the oceans, not the change in the SSH itself, because, as is well known, the observed SSH variations from satellite altimeters include as a major part steric changes due to thermal and salinity changes in the oceans which do not produce any gravity effects. By combining the altimeter data with the data obtained from satellite gravity missions such as CHAMP, GRACE and GOCE, we can expect to separate the steric changes and to reveal the true mass transport in the oceans. On the one hand, the validation and calibration of satellite data based on observations on the ground, in the ocean and on the sea floor are important for interpreting the satellite data because the observation data by satellites are a result of integrating over many related phenomena. More over, for the data obtained from the gravity satellites, the effect of air pressure changes on the ocean surface is contaminated by an effect of aliasing. In order to study the mass transport in the oceans and the aliasing effect in the satellite gravity data due to air mass changes on the sea surface, it is recommended to develop network campaign observations with ocean bottom pressure gauges at selected locations in the world oceans. An ocean region where the El Niño effect appears is a candidate for this observation purpose and the network should be designed so that we can detect the mass transport in not only the east-west direction but also the north-south direction. Reports from individual JWG members on their activities are given below:

Brzezinski.
We studied the nontidal oceanic influences on Earth rotation by using the methods which had been earlier developed and applied for estimating atmospheric effects (Brzezinski *et al.* 2002a). We focused our attention on the excitation of the 14-month free Chandler wobble. By using an 11-year time series of the ocean angular momentum (OAM) we concluded (Brzezinski and Nastula 2002) that within the limits of accuracy the coupled system atmosphere/ocean fully explains the observed Chandler wobble during the period 1985-1996. Similar study using a 50-year OAM series (Brzezinski *et al.* 2002b) yielded less promising results, which could be attributed to the differences in the underlying ocean circulation models. Our first attempt to estimate the nontidal oceanic contribution to nutation (Petrov *et al.* 1999) showed that the OAM series produced so far were still not adequate for studying the diurnal and subdiurnal effects. The most important tasks for the future within the subject of the oceanic excitation of Earth rotation were pointed out in a review paper (Brzezinski 2003).

B. Chao.
The Space Geodesy research group at the NASA Goddard Space Flight Center made numerous studies on oceans' roles in changing the Earth's rotation and low-degree gravity field. In addition to the global effects, three specific ocean basins have been targeted: North Atlantic (in association with the North Atlantic Oscillation), Mediterranean Sea (a joint project with scientists from the University of Alicante, Spain), and the extratropical Pacific (in searching for the causes of the 1998 anomaly in the Earth's J2 series found in satellite-laser-ranging data). Three main types of data are examined: (1) TOPEX/Poseidon altimetry data, (2) sea-surface temperature data, (3) ocean general circulation model output. Extensive use of the Empirical Orthogonal Function / Principal Component numerical technique has been made. Progress has been reported at various international meetings, including the AGU, EGS, and T/P SWT. Publications include Chao and Zhou (1999), Johnson *et al.* (1999, 2001b), Chen *et al.* (2000), O'Connor *et al.* (2000), Chao *et al.* (2001), and Fujita *et al.* (2002).

T. Johnson.
The U.S. Naval Observatory in an effort to improve its predictions of UT1-UTC examined the usefulness of introducing atmospheric angular momentum data into the EOP combination and prediction process. The study showed that the atmosphere could not account for all of the variability on time scales ranging from six days to 15 days. Using the Parallel Ocean Climate Model (POCM), we determined that this variability was the result of non-tidal ocean variability (Johnson *et al.* 2003). These results along with the results of earlier studies (Ponte *et al.* 1998; Johnson 1998; Johnson *et al.* 1999; Ponte *et al.* 2002) indicate that the ocean appears to excite variations in Earth's rotation on time scales ranging from a few days to a few years. In another study, Johnson *et al.* (2001b) indicated that non-tidal oceanic variability could account for some of the perturbations in the orbits of the Lageos I and Lageos II satellites on timescales of several days to a few years that result from temporal variations in the Earth's gravitational field but that are unexplained by the atmosphere. Furthermore, it was shown by Johnson *et al.* (2001a) that the effects of oceanic variability could be observed in the orbit perturbations of GPS satellites. We have also shown that the intermediate and lower layers of global ocean circulation models appear to require much more than 30 years to spin up (Johnson 1999). However, the application of sea level adjustments, also known as the Greatbatch correction, effectively removes most of this effect as well as the effects of the Boussinesq approximation. These results indicate that the examination of trends in momentum would be a better test of model spin-up than the use of kinetic energy.

J. Nastula.
It was shown that oceanic excitation, when added to atmospheric excitation, leads to substantial improvements in the agreement with observed polar motion excitation at seasonal and intraseasonal periods (Nastula and Ponte 1999). It was also shown by Brzezinski and Nastula (2002) that variations of the angular momentum of the coupled atmosphere/ocean system (with a little bit higher contribution from the ocean source) can explain within the error limits the observed Chandler motion during the 1985-1996 interval. In more recent studies, Brzezinski *et al.* (2002b) extended the analysis of Brzezinski and Nastula (2002) by using a 50-year time series of OAM estimated by Ponte (2000, personal communication). The obtained estimate of the oceanic excitation power, 18.1 mas^2/ cpy, is in good agreement with the residual excitation

derived from a simultaneous use of polar motion and atmospheric angular momentum data, 20.3 mas^2/ cpy. Regional patterns of atmospheric and oceanic excitation were analysed separately and compared with each other (Nastula *et al.* 2000, 2002). The results confirm recent findings that oceans supplement the atmosphere as an important source of polar motion excitation. Analysis of regional AAM and OAM signals were performed for monthly and longer periods (Nastula *et al.* 2000) and for periods shorter than 10 days (Nastula *et al.* 2002). The influence of specific geographic areas on polar motion excitation was discovered. Regional characteristics of short period excitation of polar motion are generally in agreement with those obtained from analyses performed for signals at monthly and longer periods. The AAM and OAM signals associated with pressure terms were found to be of the same order of magnitude, while signals associated with winds were substantially larger then those associated with ocean currents. The strongest polar motion excitation due to variability of atmospheric pressure, oceanic pressure and wind terms is connected with some specific areas over northern and southern mid-latitudes. The spatial pattern of pressure plus inverted barometer (IB) term is dominated, however, by maxima over land areas with Eurasia being especially important. Oceanic excitation due to currents is strong in the North Pacific and the Southern Oceans. Variability in oceanic bottom pressure tends to be large in mid and high latitude regions.

R. Ponte.

Ponte *et al.* (2002) addressed the influence of climate variability on ocean angular momentum (OAM). Possible anthropogenically induced signals included trends and changes in the seasonal cycle of OAM, but their effects on Earth rotation were relatively weak. In contrast, OAM signals related to natural climate variability were found to be important sources of excitation, particularly for the annual, Chandler, and Markowitz wobbles. Ponte and Ali (2002) demonstrated the role of OAM signals for excitation of sub-weekly polar motion and length-of-day variations and the importance of deviations from an inverted barometer response to atmospheric pressure at these rapid time scales. Uncertainties in the atmospheric pressure fields remain a problem in determining those signals (Ponte and Ray 2002; Ponte and Dorandeu 2003). Similar uncertainties in seasonal wind stress torques over the ocean, which affect OAM and the planetary angular momentum budget, were discussed in Ponte *et al.* (2003).

T. Sato.

Differential GPS observations were conducted on the fast ice in Lutzow-Holm Bay, Antarctica (Aoki *et al.* 2000). The vertical displacement, was clearly detected. Tidal variation derived from GPS showed good agreement with those from pressure gauges. GPS measurements of the vertical displacement of fast ice near Syowa Station, Antarctica, were conducted between April and December 1998 (Aoki *et al.* 2002). The GPS derived sea level, combined with observed sea ice thickness, supported a conventional bottom pressure gauge result with an RMS error of 0.007 m. Coherent sea level variations were clearly detected for five coastal tide gauge data around Antarctica on intraseasonal time scales (Aoki 2002). The coherent variations had significant negative correlations with an index of the atmospheric annular mode variation (Antarctic Oscillation). Important new findings from 14 months of observations of ocean bottom pressure variations in the southeastern Pacific are reported by Fujimoto *et al.* (2003). One is a pressure increase starting in December 1997 at almost the same time as the termination of the 1997-98 El Niño. It is also coincident with a remarkable change in the J2 term of the Earth's gravity field. These results suggest that the El Niño might have brought about mass redistribution in the eastern Pacific Ocean. The other feature in the observations is a local pressure variation across the spreading axis of the ultra-fast spreading southern East Pacific Rise. It is estimated that the seafloor near the spreading axis was depressed at a rate of about 20 mm/month. The gravity effects of sea surface height (SSH) variations were studied by Fukuda *et al.* (1999). They applied the EOF (Empirical Orthogonal Function) analysis to both SSH data and induced gravity changes and showed that one of the EOF components was strongly correlated with ENSO (El Niño/Southern Oscillation) like SSH variations. Based on the POCM (Parallel Ocean Climate Model, Stammer *et al.* 1996) and the TOPEX/POSEIDON (T/P) altimeter, the effects of SSH variations on gravity observations were estimated (Sato *et al.* 2001). The thermal steric component of SSH variations was estimated by assuming a simple linear relationship between the time variations in the SSH and SST fields. The predicted gravity changes at the three observation sites (i.e. Esashi in Japan, Canberra in Australia and Syowa Station in Antarctica) were compared with the actual data obtained from the superconducting gravimeters installed at these three sites. We have also tried to investigate the effects of SSH on the gravity observations in other frequency bands. Our computations suggest that ENSO-like ocean oscillations contribute 2 to 3 microgals peak-to-peak amplitude to gravity variations in the equatorial Pacific at the maximum.

References

Aoki, S., Coherent sealevel response to the Antarctic Oscillation, *Geophys. Res. Lett.*, 29(12), doi:10.1029/2002GL015733, 2002.

Aoki, S., T. Ozawa, K. Doi, and K. Shibuya, GPS observation of the sea level variation in Lutzow-Holm Bay, Antarctica, *Geophys. Res. Lett.*, 27, 2285-2288, 2000.

Aoki, S., K. Shibuya, A. Masuyama, T. Ozawa, and K. Doi, Evaluation of seasonal sea level variation at Syowa Station, Antarctica, using GPS observations, *J. Oceanogr.*, 58, 519-523, 2002.

Bouillé, F, A. Cazenave, J. M. Lemoine, and J. F. Crétaux, Geocentre motion from the DORIS space system and laser data to the Lageos satellites: Comparison with surface loading data, *Geophys. J. Int.*, 143, 71-82, 2000.

Brzezinski, A., Oceanic excitation of polar motion and nutation: An overview, in *IERS Technical Note 30: Proc. IERS Workshop on Combination Research and Global Geophysical Fluids*, edited by B. Richter, in press, Bundesamts für Kartographie und Geodäsie, Frankfurt am Main, Germany, 2003.

Brzezinski, A., and J. Nastula, Oceanic excitation of the Chandle wobble, *Adv. Space Res.*, 30, 195-200, 2002.

Brzezinski, A., Ch. Bizouard, and S. Petrov, Influence of the atmosphere on Earth rotation: What new can be learned from the recent atmospheric angular momentum estimates?, *Surv. Geophysics*, 23, 33-69, 2002a.

Brzezinski, A., J. Nastula, and R. M. Ponte, Oceanic excitation of the Chandler wobble using a 50-year time series of ocean angular momentum, in *Vistas for Geodesy in the New Millennium*, edited by J. Adám and K.-P. Schwarz, pp. 434-439, IAG Symposia vol. 125, Springer-Verlag, New York, 2002b.

Cazenave, A., F. Mercier, F. Bouille, and J. M. Lemoine, Global-scale interactions between the solid Earth and its fluid envelopes at the seasonal time scale, *Earth Planet. Science Lett.*, *171*, 549-559, 1999.

Celaya, M. A., J. M. Wahr, and F. O. Bryan, Climate-driven polar motion, *J. Geophys. Res.*, 104, 12813-12829, 1999.

Chao, B. F., and Y.-H. Zhou, Meteorological excitation of interannual polar motion by the North Atlantic Oscillation, *J. Geodyn.*, 27, 61-73, 1999.

Chao, B. F., W. O'Connor, D. Zheng, and A. Y. Au, Reply to Wunsch, *J. Geophys. Int.*, 146, 266, 2001.

Chen, J. L., C. R. Wilson, R. J. Eanes, and B. D. Tapley, Geophysical contributions to satellite nodal residual variation, *J. Geophys. Res.*, 104, 23237-23244, 1999a.

Chen, J. L., C. R. Wilson, R. J. Eanes, and R. S. Nerem, Geophysical interpretation of observed geocenter variations, *J. Geophys. Res.*, 104, 2683-2690, 1999b.

Chen, J. L., C. R. Wilson, B. F. Chao, C. K. Shum, and B. D. Tapley, Hydrological and oceanic excitations to polar motion and length-of-day variation, *Geophys. J. Int.*, 141, 149-156, 2000.

Cheng, M., and B. D. Tapley, Seasonal variations in low degree zonal harmonics of the Earth's gravity field from satellite laser ranging observations, *J. Geophys. Res.*, 104, 2667-2681, 1999.

Crétaux, J.-F., L. Soudarin, F. J. M. Davidson, M.-C. Gennero, M. Bergé-Nguyen, and A. Cazenave, Seasonal and interannual geocenter motion from SLR and DORIS measurements: Comparison with surface loading data, *J. Geophys. Res.*, 107(B12), 2374, doi:10.1029/2002JB001820, 2002.

de Viron, O., V. Dehant, and H. Goosse, The "hidden torque": The art, for a torque, to dominate everywhere and appear in no equation, in *Vistas for Geodesy in the New Millennium*, edited by J. Adám and K.-P. Schwarz, pp. 423-427, IAG Symposia vol. 125, Springer-Verlag, New York, 2002.

Foldvary, L., and Y. Fukuda, Evaluation of temporal variations on the gravity field caused by geophysical fluids and their possible detection by GRACE, in *Gravity, Geoid, and Geodynamics 2000*, edited by M. G. Sideris, pp. 143-148, IAG Symposia vol. 123, Springer-Verlag, New York, 2001a.

Foldvary, L., and Y. Fukuda, IB and NIB hypotheses and their possible discrimination by GRACE, *Geophys. Res. Lett.*, 28, 663-666, 2001b.

Foldvary, L., and Y. Fukuda, Effects of atmospheric variations on the marine geoid determined by forthcoming gravity satellite, in *Vistas for Geodesy in the New Millennium*, edited by J. Adám and K.-P. Schwarz, pp. 187-192, IAG Symposia vol. 125, Springer-Verlag, New York, 2002.

Fujimoto, H., M. Mochizuki, K. Mitsuzawa, T. Tamaki, and T. Sato, Ocean bottom pressure variations in the southeastern Pacific following the 1997-98 El Niño event, *Geophys. Res. Lett.*, 30(9), doi:10.1029/2002GL016677, 2003.

Fujita, M., B. F. Chao, B. V. Sanchez, and T. J. Johnson, Oceanic torques on solid Earth and their effects on Earth rotation, *J. Geophys. Res.*, 107, 10.1029/2001JB000339, 2002.

Fukuda, Y., T. Sato, Y. Tamura and Y. Aoyama, The effect of sea-surface height variations on the long-period gravity changes, *Bollettino di Geofisica Terica ed Applicata*, 40(3-4), 511-517, 1999.

Furuya, M., and Y. Hamano, Effect of the Pacific Ocean on the Earth's seasonal wobble inferred from National Center for Environmental Prediction ocean analysis data, *J. Geophys. Res.*, 103, 10131-10140, 1998.

Gross, R. S., The excitation of the Chandler wobble, *Geophys. Res. Lett.*, 27, 2329-2332, 2000.

Gross, R. S., Gravity, oceanic angular momentum, and the Earth's rotation (invited), in *Gravity, Geoid, and Geodynamics 2000*, edited by M. G. Sideris, pp. 153-158, IAG Symposia vol. 123, Springer-Verlag, New York, 2001.

Gross, R. S., CHAMP, mass displacements, and the Earth's rotation, in *First CHAMP Mission Results for Gravity, Magnetic and Atmospheric Studies,* edited by Ch. Reigber, H. Lühr, and P. Schwintzer, pp. 174-179, Springer-Verlag, New York, 2003.

Gross, R. S., I. Fukumori, and D. Menemenlis, Atmospheric and oceanic excitation of the Earth's wobbles during 1980–2000, *J. Geophys. Res.*, in press, 2003.

Gruber, Th., Ch. Reigber, and J. Wünsch, Estimation of ocean mass redistribution by means of altimetry and circulation models and its impact on the gravity field, in *Towards an Integrated Global Geodetic Observing System (IGGOS)*, edited by R. Rummel, H. Drewes, W. Bosch, and H. Hornik, pp. 218-221, IAG Symposia vol. 120, Springer-Verlag, New York, 2000.

Höpfner, J., Atmospheric, oceanic, and hydrological contributions to seasonal variations in length of day, *J. Geodesy*, 75, 137-150, 2001.

Hughes, C. W., Torques exerted by a shallow fluid on a non-spherical, rotating planet, *Tellus*, 54A, 56-62, 2002.

Johnson, T. J., The role of the ocean in the planetary angular momentum budget, Ph.D. thesis, 134 pp., Univ. of Texas, Austin, 1998.

Johnson, T. J., The effects of the correction for mass non-conservation in global ocean circulation models on predicted oceanic angular momentum variability, *EOS, Trans. Amer. Geophys. Union*, 46, 80, 1999.

Johnson, T. J., C. R. Wilson, and B. F. Chao, Oceanic angular momentum variability estimated from the Parallel Ocean Climate Model, 1988-1998, *J. Geophys. Res.*, 104, 25183-25195, 1999.

Johnson, T. J., P. Kammeyer, and J. Ray, The effects of geophysical fluids on motions of the Global Positioning System satellites, *Geophys. Res. Lett.*, 28, 3329-3332, 2001a.

Johnson, T. J., C. R. Wilson, and B. F. Chao, Nontidal oceanic contributions to gravitational field changes: Predictions of the Parallel Ocean Climate Model, *J. Geophys. Res.*, 106, 11315-11334, 2001b.

Johnson, T. J., B. J. Luzum, and J. Ray, Improved near-term UT1R predictions using forecasts of atmospheric angular momentum, *J. Geodyn.*, in press, 2003.

Kakuta, C., T. Tsubokawa, and K. Iwadate, Coupling of long oceanic waves in the Pacific Ocean and the rotating elastic Earth during the 1986-1987 El Niño, *J. Geophys. Res.*, 105, 3089-3094, 2000.

Leuliette, E. W., and J. M. Wahr, Climate excitation of polar motion, in *Vistas for Geodesy in the New Millennium*, edited by J. Adám and K.-P. Schwarz, pp. 428-433, IAG Symposia vol. 125, Springer-Verlag, New York, 2002a.

Leuliette, E. W., R. S. Nerem, and G. L. Russell, Detecting time variations in gravity associated with climate change, *J. Geophys. Res.*, 107(B6), doi:10.1029/2001JB000404, 2002b.

Liao, D., X. Liao, and Y. Zhou, Oceanic and atmospheric excitation of the Chandler wobble, *Geophys. J. Int.*, 152, 215-227, 2003.

Mangiarotti, S., A. Cazenave, L. Soudarin, and J. F. Crétaux, Annual vertical crustal motions predicted from surface mass redistribution and observed by space geodesy, *J. Geophys. Res.*, 106, 4277-4291, 2001.

Marcus, S. L., Y. Chao, J. O. Dickey, and P. Gegout, Detection and modeling of nontidal oceanic effects on Earth's rotation rate, *Science*, 281, 1656-1659, 1998.

Nastula J., and R. M. Ponte, Further evidence for oceanic excitation of polar motion, *Geophys. J. Int.,* 139, 123-130, 1999.

Nastula J., R. M. Ponte, and D. A. Salstein, Regional signals in atmospheric and oceanic excitation of polar motion, in *Proceedings of IAU Colloquium 178, Polar Motion: Historical and Scientific Problems,* Cagliari, Sardinia, Italy, ASP Conference Series, 463-472, 2000.

Nastula, J., R. M. Ponte, and D. A. Salstein, Regional high-frequency signals in atmospheric and oceanic excitation of polar motion, *Adv. Space Res.*, 30, 369-374, 2002.

O'Connor, W., B. F. Chao, D. Zheng, and A. Y. Au, Wind stress forcing of the North Sea pole tide, *J. Geophys. Int.*, 142, 620-630, 2000.

Petrov, S., A. Brzezinski, and J. Nastula, First estimation of the non-tidal oceanic effect on nutation, in *Proc. Journées Systemes de Reference Spatio-Temporels 1998*, edited by N. Capitaine, pp. 136-141, Obs. de Paris, Paris, 1999.

Ponte, R. M., A preliminary model study of the large-scale seasonal cycle in bottom pressure over the global ocean, *J. Geophys. Res.*, 104, 1289-1300, 1999.

Ponte, R. M., and A. H. Ali, Rapid ocean signals in polar motion and length of day, *Geophys. Res. Lett.*, 29(15), doi:10.1029/2002GL015312, 2002.

Ponte, R. M., and J. Dorandeu, Uncertainties in ECMWF surface pressure fields over the ocean in relation to sea level analysis and modeling, *J. Atmos. Oceanic Technol.*, 20, 301-307, 2003.

Ponte, R. M., and R. D. Ray, Atmospheric pressure corrections in geodesy and oceanography: A strategy for handling air tides, *Geophys. Res. Lett.*, 29, doi:10.1029/2002GL016340, 2002.

Ponte, R. M., and D. Stammer, Role of ocean currents and bottom pressure variability on seasonal polar motion, *J. Geophys. Res.*, 104, 23393-23409, 1999.

Ponte, R. M., and D. Stammer, Global and regional axial ocean angular momentum signals and length-of-day variations (1985–1996), *J. Geophys. Res.*, 105, 17161-17171, 2000.

Ponte, R. M., D. Stammer, and J. Marshall, Oceanic signals in observed motions of the Earth's pole of rotation, *Nature*, 391, 476-479, 1998.

Ponte, R. M., D. Stammer, and C. Wunsch, Improving ocean angular momentum estimates using a model constrained by data, *Geophys. Res. Lett.*, 28, 1775-1778, 2001.

Ponte, R. M., J. Rajamony, and J. M. Gregory, Ocean angular momentum signals in a climate model and implications for Earth rotation, *Clim. Dyn.*, 19, 181-190, 2002.

Ponte, R. M., A. Mahadevan, J. Rajamony, and R. D. Rosen, Uncertainties in seasonal wind torques over the ocean, *J. Climate*, 16, 715-722, 2003.

Reigber, Ch., H. Jochmann, J. Wünsch, K. H. Neumayer, and P. Schwintzer, First insight into temporal gravity variability from CHAMP, in *First CHAMP Mission Results for Gravity, Magnetic and Atmospheric Studies,* edited by Ch. Reigber, H. Lühr, and P. Schwintzer, pp. 128-133, Springer-Verlag, New York, 2003.

Sato, T., Y. Fukuda, Y. Aoyama, H. McQueen, K. Shibuya, K. Asari, and M. Ooe, On the observed annual gravity variation and the effect of sea surface height variations, *Phys. Earth Planet. Inter.*, 123, 45-63, 2001.

Stammer, D., R. Tokmakian, A. Semtner, and C. Wunsch, How well does a 1/4° global circulation model simulate large-scale oceanic observations?, *J. Geophys. Res.*, 101, 25779–25811, 1996.

Thomas, M., J. Sündermann, and E. Maier-Reimer, Consideration of ocean tides in an OGCM and impacts on subseasonal to decadal polar motion excitation, *Geophys. Res. Lett.*, 28, 2457-2460, 2001.

Wahr, J., M. Molenaar, and F. Bryan, Time variability of the Earth's gravity field: Hydrological and oceanic effects and their possible detection using GRACE, *J. Geophys. Res.*, 103, 30205-30229, 1998.

Wünsch, J., Oceanic influence on the annual polar motion, *J. Geodyn.*, 30, 389-399, 2000.

Wünsch, J., Oceanic and soil moisture contributions to seasonal polar motion, *J. Geodyn.*, 33, 269-280, 2002a.

Wünsch, J., Erratum to "Oceanic and soil moisture contributions to seasonal polar motion", *J. Geodyn.*, 34, 709-710, 2002b.

Wünsch, J., M. Thomas, and T. Gruber, Simulation of oceanic bottom pressure for gravity space missions, *Geophys. J. Int.*, 147, 428-434, 2002.

INTERNATIONAL SERVICES OF SECTION V:

"INTERNATIONAL EARTH ROTATION SERVICE"

Jan Vondrak, Chairman of the Directing Board
Bernd Richter, Director of the Central Bureau

The new organization of the IERS

After ten years of activity it became necessary to reorganize the IERS for various reasons: the re-organization of the space techniques SLR, Lunar Laser Ranging, VLBI, and GPS into International Services (DORIS being now organized as a pilot program) and the development of a new component: the Global Geophysical Fluids Center (GGFC) dealing with motion of the various fluid layers and their relationship with reference frames and Earth dynamics. The re-organization of the Service began in November 1999, when the Call for Participation was issued. The Letters of Intent were reviewed by the IERS Directing Board (DB) at its meeting in December 1999 (San Francisco). It was decided to set up a Proposal Review Committee (PRC) with the task to evaluate all proposals and prepare the corresponding recommendations for the next IERS DB meetings. The PRC was composed of knowledgeable scientists, under the chair of I.I. Mueller, at the beginning of 2000. Its first recommendations were discussed at the IERS DB meeting in Washington (June 2000), and some of them accepted. Nevertheless, there were still several multiple proposals for the same components. The primary scientists of these were further contacted by the PRC and, in some cases, new joint proposals were asked for. The IERS DB was able to take final decisions at its meeting in Frankfurt a.M. (September 2000). Several minor changes of the Terms of Reference were adopted by the 'old' Directing Board at its last meeting in San Francisco (December 2000), mainly reflecting a slightly changed structure of the ITRS Product Centers. The new structure of the IERS began operation on January 1, 2001.

The main changes in IERS structure are: The previous Sections and Sub-Bureaus of the Central Bureau are now autonomous components within the IERS and are called Product Centers; The Central Bureau moved from Paris to Frankfurt am Main in Germany and has now primarily administrative functions; New elements of the structure are Combination Research Centers, ITRS Combination Centers and the Analysis Coordinator; External International Services (like IGS, ILRS and IVS) serve as Technique Centers of the IERS.

According to the IERS Terms of Reference, the primary objectives of the IERS are to serve astronomical, geodetic and geophysical communities by providing: International Celestial Reference System and Frame (ICRS, ICRF); International Terrestrial Reference System and Frame (ITRS, ITRF); Earth Orientation Parameters (EOP) that define the transformation between the ICRS and ITRS; Relevant geophysical data (i.e., information on the distribution and motion of the atmosphere, terrestrial and oceanic water, mantle, core...); Conventions (i.e., standards, constants, models, algorithms, software...).

To cover this broad field of interest and to realize the products, the new IERS Terms of Reference define the following components of the new IERS:

Technique Centers (TC) that are generally autonomous independent services, cooperating with the IERS. There is typically only one TC per technique, and it provides its operational products to the IERS. At the moment, these are the following: International VLBI Service (IVS); International GPS Service (IGS); International Laser Ranging Service (ILRS); International DORIS Service (IDS) that has however not yet been formed; the technique serves as a Pilot Experiment of the CSTG.

Product Centers (PC) that are responsible for the products of the IERS. They are: Earth Orientation PC, responsible for monitoring long-term orientation parameters, publications for time dissemination and announcements of leap seconds. It is located at Observatoire de Paris. Rapid Service/Prediction PC, responsible for providing Earth orientation parameters on a rapid basis, primarily for real-time users. It is placed at U.S. Naval Observatory, Washington D.C. Conventions PC is responsible for the maintenance of the IERS conventional models, constants and standards. Joint proposal of U.S. Naval Observatory (Washington D.C.) and Bureau International des Poids et Mesures (Sèvres) was accepted. International Celestial Reference System PC, responsible for the maintenance of ICRS and its realization, ICRF. Joint proposal of Observatoire de Paris and U.S. Naval Observatory was accepted. International Terrestrial Reference System PC, responsible for the maintenance of ITRS and its realization, ITRF. It is located at IGN, Marne-la-Vallée. Global Geophysical Fluids PC, responsible for providing relevant geophysical data sets and related results. This center now consists of eight Special Bureaus (for Atmosphere, Core, Gravity/Geocenter, Hydrology, Loading, Mantle, Oceans, and Tides), and is hosted at NASA's Goddard Space Flight Center.

Combination Centers: ITRS Combination Centers, responsible for providing ITRF products by combining ITRF inputs from the Technique Centers and other sources. Three institutions established ITRS Combination Centers: DGFI, Munich, Germany; Geomatics Canada, Ottawa, Canada; IGN, Marne-la-Vallée, France. Combination Research Centers, responsible for the development of combinations from data (or products) coming from different techniques. They are expected to provide their solutions to Analysis Coordinator. There are now eleven of them AICAS & CTU, Prague, Czech R.; FGS & DGFI, Munich, Germany; FGS & FESG, Munich, Germany; FGS & GIUB, Bonn, Germany; GFZ, Potsdam, Germany; FFI, Kjeller, Norway; GRGS, Toulouse, France; IGN, Marne-la-Vallée, France; JPL, Pasadena, USA; IAA, St. Petersburg, Russia; ASI, Matera, Italy.

Analysis Coordinator (Markus Rothacher, TU Munich, Germany) is responsible for long-term and internal consistency of the IERS reference frames and other products, for ensuring the appropriate combination of the TC products into a single set of official IERS products and for archiving them.

Central Bureau (placed at BKG, Frankfurt a. M., Germany, under the direction of Bernd Richter) is the administrative center of the IERS. It is responsible for the general management (according to the directives given by the Directing Board), for coordinating the activities, IERS publications, archiving the products and it also serves as the communication center with the users. The CB presently designs a data center to store and archive all products which are necessary for the IERS products and also those which are necessary to re-compute the products.

Directing Board that exercises general control over the activities of the IERS. The chairperson, elected by the Board from its members (Jan Vondrák, Astronomical Institute, Academy of Sciences of the Czech Republic, Prague), is the official representative of the IERS to external organizations. The DB consists of two representatives of each of the Technique Centers, one for each of the Product Centers, one for all Combination Research Centers together, a representative of the Central Bureau, Analysis Coordinator, and the representatives nominated by the IAU, IAG/IUGG and FAGS.

IERS Activities in 2000-2003

The IERS DB in its new composition met at least twice a year: Meeting No. 30 in Washington, June 3-4, 2000; No. 31 in Frankfurt a.M., September 14-15, 2000; No. 32 in San Francisco, December 18, 2000; No. 33 in Nice, March 26, 2001; No. 34 in Brussels, September 26, 2001; No. 35 in Paris, April 20, 2002; No. 36 in Munich, November 22, 2002; and No. 37 in Paris, April 2, 2003 to decide on important matters of the Service like structural changes, overall strategy, creating working groups, launching projects, changing Terms of Reference, etc.

The IERS organized two Workshops and a Retreat: The first was the IERS Workshop on the Implementation of the IAU 2000 Resolutions (Paris, April 18-19, 2002). It included detailed presentations and explanations of the contents of the Resolutions, the background reasons for their adoption, associated concepts and implementations as well as answers to specific questions. About 80 participants from 20 countries took part in the meeting. The Proceedings were printed as IERS Technical Note No. 29 and are available also online through IERS's website. The results of this workshop are, to some extent, reflected in IERS Conventions 2000, and also in new IERS products (celestial pole offsets referred to new precession-nutation model IAU2000A), published since the beginning 2003. The second workshop was the IERS Workshop on Combination Research and Global Geophysical Fluids (Munich, November 18-21, 2002). Its main goal was to improve all IERS products in accuracy, consistency, stability, timeliness, user-friendly access, and documentation, and to make first steps towards a rigorous combination of the various products, contributing thus significantly to the realization of an "International Global Geodetic Observation System" (IGGOS). The workshop was divided into two strongly related parts: different aspects of the comparison and combination of the results of all major space geodetic techniques; IERS Global Geophysical Fluid Center (GGFC), the present status of its products and its role in future. The Proceedings of this Workshop will be published as IERS Technical Note No. 30.

The IERS Retreat (Paris, March 31 - April 1, 2003) was summoned to review the present and propose future IERS products, ensure their better mutual consistency, to specify the IERS requirements and to develop a vision for the future. Discussion on possible organizational consequences led to the concrete proposals for the DB meeting that immediately followed the Retreat.

Among the most important decisions made by the DB in 2000-2003 belong: Creation of the new ITRS Combination Center in Canada; Creation of the new GGFC Special Bureau for Loading; Creation of the new Combination Research Center in Italy; Decision to contribute to the prepared IAG Pilot Project IGGOS; Launching the IERS Combination Pilot Project; Establishment of Working Groups: on Combination, the ITRF datum, and Site co-location; Changing the name to International Earth rotation and Reference systems Service, without changing the acronym (IERS).

INTERNATIONAL SERVICES:

"Permanent Service for Mean Sea Level (PSMSL)"

P. Woodworth

Introduction

The PSMSL is operated at the Proudman Oceanographic Laboratory (POL), Bidston Observatory under the auspices of the International Council for Science (ICSU), and is a member of the Federation of Astronomical and Geophysical Data Analysis Services (FAGS). The PSMSL reports to the International Association for the Physical Sciences of the Ocean Commission on Mean Sea Level and Tides (IAPSO/CMSLT) and has an Advisory Board consisting of scientists expert in each area of sea level research. Annual reports on the work of the PSMSL are circulated each year to the International Association of Geodesy (IAG), the Intergovernmental Oceanographic Commission (IOC), IAPSO, FAGS, and other relevant bodies and are available publicly via the web at: http://www.pol.ac.uk/psmsl/ This same web page also serves as a source of PSMSL data and ancillary information.

PSMSL Staff

Mr. Graham Alcock took early retirement in 2000. Graham was closely involved in PSMSL and GLOSS matters for over 20 years, being the main organiser of over 10 GLOSS training courses, having represented PSMSL and GLOSS at many international meetings, and having authored several important GLOSS reports. Dr. Philip Axe also left PSMSL and POL in 2000 to take up an appointment in Sweden and is now based at SMHI.. Of particular note during 2001 was the MBE (Member of the British Empire) awarded by the Queen to Mrs. Elaine Spencer in the 2001 New Year's Honours List. Elaine was PSMSL Technical Secretary between 1974 and 1999. The development of the PSMSL data set formed part of the citation for the award. Two new scientists joined the PSMSL in 2002 following increased funding received from the UK Natural Environment Research Council. The first was Dr. Svetlana Jevrejeva from Tallinn in Estonia, who has published a number of papers on climate variability including studies of sea ice changes in the Baltic related to the North Atlantic Oscillation. The second was Dr. Simon Holgate from Liverpool University who has a background in sea-level related geology, geography and palaeo-carbon flux studies. Svetlana and Simon will lead the PSMSL data collection in future, with some continued assistance from Mrs. Rose Player.

PSMSL Data Receipts for 1999-2003

On average, approximately 1500 station-years of data were entered into the PSMSL database during each year of the period. This compares well to rates obtained in previous years. Most data originated from Europe, North America and Japan, but all regions are represented in the receipts at some level. Important data gaps in South America, Africa and parts of Asia are receiving special attention as part of the JCOMM GLOSS programme (see below). Figure 1 indicates the locations from which data were received during 1999-2003. Comparison to the corresponding figure produced in the PSMSL report for the IUGG in 1999 shows slightly fewer stations this time in Africa and South America and considerably more in the Arctic. The main method for distribution of PSMSL data is now unquestionably the internet, almost all other methods now having been abandoned. However, regular CDs and now DVDs are produced as backups and for people in some countries without good web access. A DVD was produced in 2002 with the PSMSL data set as part of the final conference of the World Ocean Circulation Experiment (WOCE), containing all tide gauge data collected during the programme.

GLOSS Activities

The Global Sea Level Observing System (GLOSS) is a project of the Joint Commission for Oceanography and Marine Meteorology (JCOMM) of the Intergovernmental Oceanographic Commission (IOC) and World Meteorological Organisation (WMO). One of the main aims of GLOSS is to improve the quality and quantity of data supplied to the PSMSL. GLOSS has been one of the first components of the Global Ocean Observing System (GOOS). GLOSS network status as perceived by the PSMSL is reviewed each year and can be found at http://www.pol.ac.uk/psmsl/programmes/gloss.info.html while a review of progress within the programme has been prepared by the PSMSL as a 'GLOSS Adequacy Report' submission to the 2003 IOC Assembly. Meetings of the GLOSS Group of Experts, which is the management committee for the programme, have been held every two years alongside scientific and technical workshops. GLOSS training courses have been held in many countries since the mid-1980s. Since 1999, courses have been held in Brazil (1999), Saudi Arabia (2000), Guatemala (2001), India (2003), Chile (2003) and Malaysia (2003). (The Guatemala and India courses were not official IOC-funded GLOSS courses but had significant GLOSS participation). The GLOSS training programme also includes web based materials, training manuals, newsletters and tidal software. As an example of training materials, the PSMSL with some support from GLOSS funded Dr. Glenn Milne of the University of Durham to produce maps of sea level change through the Holocene period, showing the changes in coastlines which resulted. A joint project between the IOC International Oceanographic Data and Information Exchange (IODE) Committee, GLOSS and PSMSL to conduct a 'data archaeology' survey of historical sea level records, was begun by Dr. Lesley Rickards. This project has the aim of extending existing time series and gaining access to observations which are not in digital form.

European Projects

A European Union (EU) funded sea level study called SELF-2 for the Mediterranean was completed during the period with PSMSL and POL participation, with concentration at POL on mean sea level changes, storm surge modelling, absolute gravity and tidal loading. The EU EOSS project aimed to enhance sea level (tide gauges) and land level (GPS) monitoring, and associated data exchange in Europe, primarily by sets of bilateral (i.e. no new cost) agreements. That project ended in September 2001 with an international conference in Dubrovnik, Croatia, and was followed by Calls for Participation in a new European Sea Level Service (ESEAS) which it is hoped will continue and extend the work of EOSS, and put the provision of sea and land level information from Europe on a sounder basis. In 2000, Dr. Woodworth attended the first Coordination Meeting of the MedGLOSS programme at Haifa, Israel organised by Dr. Dov Rosen. MedGLOSS is a joint programme of the International Commission for the Scientific Exploration of the Mediterranean Sea (CIESM) and IOC and aims to install and coordinate a network of gauges for the Mediterranean and Black Seas.

Altimetry and Gravity Field Activities

Participation has continued in European and US altimeter working groups during the period. Dr. Woodworth is a Principal Investigator for the TOPEX/POSEIDON and JASON-1 missions and of particular interest to the PSMSL is the symbiosis between altimetry and tide gauge measurements with gauges being used extensively by the project to calibrate the altimeter data set. During 2001, Dr. Xiaojun Dong from the Shanghai Astronomical Observatory joined the sea level group at POL through a Fellowship from the Royal Society, with the object of researching the best methods for ongoing altimeter calibration using tide gauge data. This resulted in one paper being accepted for publication in Marine Geodesy with other work in progress. Drs. Woodworth and Hughes of POL have during the period been members of the Mission Advisory Group (MAG) of the European Space Agency (ESA) Gravity Field and Steady State Ocean Circulation Experiment (GOCE) mission which is planned for launch in 2006. This is a major development for ocean circulation and sea level studies in the next decade. Drs. Hughes and Woodworth are also involved in the use of data from the US-German Gravity Recovery And Climate Experiment (GRACE).

Geodetic Fixing of Tide Gauge Benchmarks

In 1997, an important meeting on tide gauge benchmark fixing was held at the Jet Propulsion Laboratory, prior to the fifth meeting of the GLOSS Experts (GE5). This meeting was organised jointly by the IGS Central Bureau, the PSMSL and IOC/GLOSS and resulted in an excellent workshop report on the use of GPS at gauge sites for measuring long term changes in vertical land movements and for altimeter calibration. In 1999 and 2001, follow-up meetings were held in Toulouse, France and Honululu, USA alongside GE6 and GE7 respectively. In September 2002, a study week was organised on vertical crustal motion and sea level change and on the use of GPS at tide gauges in Toulouse. The week included the development of the TIGA project at GFZ, Germany which aims to better understand the uncertainties in the use of GPS in this role further, and was held under the auspices of the IGS/PSMSL/IAPSO/IAG/GLOSS CGPS@TG working group which had been formed at the 1997 JPL meeting. As part of CGPS@TG work, regular surveys have been conducted on behalf of the PSMSL, EUREF and other organisations on the availability of permanent GPS stations near to tide gauges by Dr. Guy Woppelmann of the University of La Rochelle.

Publications

The PSMSL has a responsibility to not only collect and redistribute sea level information, but also to analyse data and publish scientific results. The main papers published each year are listed in PSMSL Annual reports. However, three important ones may be mentioned here. The Third Assessment Report (TAR) of the Intergovernmental Panel on Climate Change (IPCC) was published during 2001 with Chapter 11 on sea level changes led by Dr. J. Church (Australia) and Dr. J. Gregory (UK) and with Dr. Woodworth as a Lead Author. In 2002 a major paper was published by Dr. Woodworth and others on the use of tide gauges during WOCE. Finally, a review paper of the work of the PSMSL was published in the Journal of Coastal Research in 2003.
GLOUP . The PSMSL is responsible to the IAPSO Commission on Mean Sea Level and Tides for the maintenance of the data base of pelagic (bottom pressure recorder) information. This data base, called GLOUP (Global Undersea Pressures), was maintained during the period by Dr. Chris Hughes and can be inspected at: http://www.pol.ac.uk/psmslh/gloup/gloup.html

Other PSMSL Activities

Mr. Philip Knight of POL has written a newsgroup type software called the ‘PSMSL Forum’ which allows discussion via emails of matters of importance to the PSMSL, such as developments in tide gauge technology or sea level research. The software is presently being tested by volunteers and the utility of such a forum will be assessed during 2003. The opportunity has been taken whenever possible to publicise the work of the PSMSL in newspapers and on radio and TV. Presentations were given in the period in all three media in several countries and details can be found in the PSMSL Annual Reports. Plans have advanced for POL’s relocation from Bidston Observatory to a new building on the campus of Liverpool University in September 2003. This will include the relocation of the PSMSL. Our new postal address and phone and fax numbers will be advertised on the PSMSL web pages as soon as possible but our email and web addresses will be unchanged. We expect that any disruption to the work of the PSMSL will be temporary. It can be seen that 1999-2003 has been a further active period with regard to important workshops and conferences, and a busy one with regard to data acquisition and analysis. Particular thanks as usual go to PSMSL staff, and also to the staff of the Proudman Oceanographic Laboratory who provide the extended Service.

INTERNATIONAL SERVICES:

"BUREAU INTERNATIONAL DES POIDS ET MESURES – TIME SECTION

F. Arias

International time scales

Reference time scales International Atomic Time (TAI) and Universal Coordinated Time (UTC) have been computed regularly and have been published in the monthly BIPM Circular T. Definitive results for 1999, 2000, 2001 and 2002 have been available, in the form of computer-readable files from the BIPM website (http://www.bipm.org), and on printed volumes of the respective Annual Reports of the BIPM Time Section. Work has been done to automate the calculation of the time scales TAI and UTC published monthly in the BIPM Circular T. Several modifications have been introduced in Circular T, starting in May 2003: results are given to 0.1 ns; the list of time links used in the calculation of the current circular is provided; and a new format has been adopted for the layout of the circular.

Algorithms for time scales

Research concerning time scale algorithms includes studies to improve the long-term stability of the free atomic time scale EAL and the accuracy of TAI. The weighting procedure of clocks participating in TAI has been revised and modified. Until 31 December 2000, the maximum relative weight of clocks participating into TAI was fixed to 0.700%. With the improvement of the commercial atomic clocks, this method became inefficient to discriminate between the best clocks. Since January 2001 the maximum relative clock weight has been established each month, depending on the number of participating clocks. This modification improves the stability of the international time scales.The medium-term stability of EAL, expressed in terms of the Allan deviation, is estimated to be 0.6×10^{-15} for averaging times of 20 to 40 days over the period.

Primary frequency standards developed and operated by the National Institute of Standards and Technology (NIST, USA), the Communications Research Laboratory (CRL, Japan), the Paris Observatory (OP, France) and the Physikalish-Technische Bundesanstalt (PTB, Germany) reported their measures to the BIPM. The global treatment of these individual measurements led to a relative departure of the duration of the TAI scale unit from the SI second on the geoid ranging, in 2002, from $+6 \times 10^{-15}$ to $+11\times 10^{-15}$, with an uncertainty smaller than 3×10^{-15}. The frequency offset between TAI and EAL is changed when necessary; this operation is referred to as the "steering of TAI". Following the recommendations of the Consultative Committee on Time and Frequency, changes were implemented to render the data used in TAI, as well as the results, more accessible to the users and to make the procedures of calculation even more transparent and traceable. Since April 2000 two modifications had been implemented: a new model to characterise the instability of the free atomic scale EAL, and a more complete representation of the uncertainty of the deviation of the TAI scale interval relative to that of the Terrestrial Time TT.

Time links

Two techniques of time transfer are used at present to compare clocks in TAI: GPS common-views based on C/A measurements and two-way satellite time and frequency transfer (TWSTFT). In the last decade the time links computed at the BIPM used the classical GPS common-view technique based on C/A-code measurements obtained from single-channel receivers. The commercial availability of newly developed receivers has stimulated interest in extending the classical common-view technique for use of multi-channel dual-code dual-system (GPS and GLONASS) observations, with the aim of improving the accuracy of time transfer. Since July 1999 GPS multi-channel links and TWSFTF links have been progressively introduced in TAI. Ionospheric maps and precise operational satellite ephemerides provided by the International GPS Service (IGS) are routinely used to correct all links in regular TAI calculations since May 2000. In addition, the BIPM Time section carries on research on new techniques of time transfer, such as the utilisation of geodetic type receivers. These activities had been developed in the period 1999-2002 in the frame of the IGS/BIPM pilot project to study accurate time and frequency comparison using GPS phase and code measurements, and have been incorporated to the IGS as a current activity since 2003. A pilot experiment (TAIP3) was proposed in April 2002 to laboratories participating to TAI. The goal was to study time links computed with GPS P3 data obtained from geodetic-type dual-frequency receivers. Comparisons of such P3 time links with other techniques presently used for TAI have been conducted in the aim of evaluating the long term stability of P3 time links and, as a matter of fact, to assess the long-term stability of the other techniques. It has been concluded that the reliability and long-term stability of P3 links are adequate for their use in TAI computation.

Space-time references

The BIPM/IAU Joint Committee on general relativity for space-time reference systems and metrology (JCR), concluded his work in January 2001. Its activities have been undertaken by the IAU working group on Relativity, Celestial Mechanics, Astrometry and Metrology (RCMAM). Studies have been conducted at the BIPM in collaboration with other members of the JCR/RCMAM, they concern the extension of the relativistic framework to allow a correct treatment for time transformations and the realisation of barycentric coordinate time at the full post Newtonian level and the realisation of geocentric coordinate times. Since January 2001 the BIPM, jointly with the USNO, is the Conventions Product Centre of the International Earth Rotation Service (IERS).

INTERNATIONAL SERVICES:

"INTERNATIONAL CENTER FOR EARTH TIDES"

B. Ducarme

The staff of ICET, which is completely supported by the Royal Observatory of Belgium, our host Institution, is composed as follows:Prof. B.Ducarme, Director(part time);Mrs. L.Vandercoilden, technician(full time);Mr. M.Hendrickx, technician(part time). The Royal Observatory of Belgium has hosted ICET since 1958 and continues to provides numerous administrative and scientific facilities especially for the publication of the " Bulletin d'Information des Marées Terrestres" (BIM), for the tidal data processing and since 1997 for the maintenance of the ICET/GGP data base.

Terms of reference

The terms of reference of the International Centre for Earth Tides(ICET) can be summarised as follows: as World Data Centre C, to collect all available measurements on Earth tides; to evaluate these data by convenient methods of analysis in order to reduce the very large amount of measurements to a limited number of parameters which should contain all the desired and needed geophysical information; to compare the data from different instruments and different stations distributed all over the world, evaluate their precision and accuracy from the point of view of internal errors as well as external errors; to help solving the basic problem of calibration by organising reference stations or realising calibration devices; to fill gaps in information and data; to build a data bank allowing immediate and easy comparison of earth tides parameters with different Earth models and other geodetic and geophysical parameters ; to ensure a broad diffusion of the results and information to all interested laboratories and individual scientists. These goals are achieved essentially by the diffusion of information and software, the data processing, the training of young scientists and the welcome of visiting scientists.

Main Commitments

It appears first that most geodetic measurements are affected by earth tides, as at the centimetric level the tidal displacement of the station is no more negligible. It will thus remain an important task for ICET to provide algorithms for tidal computation or analysis. For example the geophysicists, such as seismologists or volcanologists, who are measuring crustal deformations for natural hazards monitoring, are now conscious of the necessity of dealing properly with the tidal signals. In a similar way absolute gravity measurements require accurate tidal corrections that should take into account the local tidal parameters. These parameters have to be computed including oceanic tidal loading effects or even require in situ tidal gravity observations.
On the other hand the earth tidal scientific community is limited. The last International Symposium on Earth Tides, held in Mizusawa, Japan from August 28 to September 1st, 2002 , brought together only a bit more than one hundred and twenty participants. The groups are always very small and often marginally involved in tidal research. The papers dealing specifically with tidal studies are not fitting so well to international journals. It is thus very important to keep a specialised diffusion and information medium. It is the vocation of the "Bulletin d'Information des Marées Terrestres"(BIM). ICET is generally publishing two eighty pages issues per year.

Besides this basic activity, which is the scientific challenge for the beginning of this century?

The mathematical modelisation of the astronomical tidal forces as well as the elastic response of the Earth made decisive progress. It is now possible to model the astronomical tidal forces to within 5 nanogal in the time domain. The different mathematical techniques for the evaluation of the tidal response of the Earth do agree now to better than 0.1%. The most recent models include inelasticity in the mantle.

The last problems to be solved are linked to the fluid elements of our planet: liquid core resonance, oceanic loading, meteorological effects, underground water.

Among the ground based observations only gravity tides are able to give informations valid at the regional level. The other components(tilt, strain, volume change) are heavily depending of the local parameters of the crust, including cavity or topography effects. These observations should be mostly used to monitor tectonic deformations after removing the tidal phenomena.

Tidal gravity observations are able to provide constrains on the liquid core resonance by means of very precise observations in selected sites. The same is valid also for the selection of the most realistic model for the elastic or inelastic response of the Earth. For that purpose it is essential to improve the calibration methods in order to achieve a 0.1% accuracy in amplitude and a 0.01° accuracy in the phase determination. It is also necessary to use up to date oceanic tides models for tidal loading corrections. The determination of the amplitude factor of the polar motion effect on gravity will constrain the Earth viscosity at low frequency.

To achieve these goals it will be necessary to tackle three main questions: oceanic tidal loading, atmospheric pressure effects, underground water. It is only possible through a coordinated effort and a multidisciplinary approach including Astronomy, Geodynamics, physical Oceanography, Hydrology and Climatology..

Ongoing projects

These objectives are now directly addressed by the "Global Geodynamic Project"(GGP). A network of 20 stations equipped with cryogenic gravimeters is in operation since July 1997, using a similar hardware and the same procedures for data acquisition. A first 6 years term finishes in July 2003 and a second term 2003-2009 will start immediately after.

Besides tidal research, an important objective of GGP is to study the residues after elimination of the tidal contribution in order to detect inertial accelerations such as free oscillations of the Earth core and mantle with periods larger than 50 minutes, which are difficult to observe by means of conventional seismometers. In fact the cryogenic gravimeters are extra-large band instruments covering phenomena with period ranging from one second to more than one year. GGP is a unique opportunity to obtain high quality well calibrated tidal observations, and ICET has been interested to support this project since its beginning. ICET is responsible for the "Global Geodynamics Project-Information System and Data Centre" (GGP-ISDC, http://etggp.oma.be/). The data owners can upload themselves the original minute sampled data. The data are carefully preprocessed at ICET using a standard procedure, to correct for tares and spikes. The data are then decimated to one hour and analysed. The analysis results are directly communicated to the data owners. This follow up is required to detect quickly the anomalies that could affect the data. Each year CD-ROM's are edited with the raw and corrected minute data as well as the log files and the auxiliary data, when available. The members of the GGP consortium can download data older than one year. After two years the data are fully opened to the public.

The archiving of the data is rather complex as the data are only released according to a strict time table. The data are sent to ICET only one year after their production. During one additional year the data are only available to the GGP members and can be freely accessed only after two years. The software provided for the management of GGP-ISDC by the GeoForschungZentrum Potsdam is continuously updated. With the collaboration of guest scientists ICET pushed forward researches using the GGP data sets and concerning the liquid core resonance, the determination of the pole tide and the detection of the inner core oscillations known as Slichter's mode. We have now more than 20 high quality data sets with a minimum length of three year and we can provide on request not only tidal parameters, oceanic loading corrections according to different models but also tidal residues to study non tidal effects such as core modes. These series, if they are well constrained by absolute measurements, will be also useful in the interpretation of satellite gravity data. To improve the tidal loading corrections ICET gathered the most recent oceanic tides models.

Ongoing Activities

The "Bulletin d'Information des Marées Terrestres"(BIM) is printed in 300 copies.Some 275 copies are sent to libraries and individual scientists all over the world. It is devoted to scientific papers concerning tidal research. From May 2000 until October 2002, six issues n° 132 to 137 have been published with a total number of 720 pages. In 2002 we had the opportunity to publish the proceedings of the "Third Workshop of the Global Geodynamics Project (GGP) on superconducting Gravimetry" and of the "Meeting of the ETC-

Working Group 7 on Analysis of Environmental Data", held in Jena, Germany, from March 11 to 15,2002. For the first time all the published papers were immediately available on the ICET WEB site.

ICET made an agreement with Marion Wenzel, wife of late Prof.H.G.Wenzel, who inherited the property rights on the ETERNA tidal analysis and prediction software. ICET is now authorised to distribute freely this software among the scientific community for non commercial purposes. This initiative met a great success as some forty CD-ROMS with ETERNA software are requested from ICET each year since May 2000.

The ICET WEB site (http://www.astro.oma.be/ICET/) has been updated and developed. Besides general information including historical aspect and last ICET reports, it proposes to the visitors an access to: the general bibliography on Earth Tides from 1870-1997 either by alphabetical order of the first author or following the decimal classification introduced by Prof. P.Melchior; the table of content of all the previous BIM, n° 1-137, and starting from BIM 133 an electronic version of the papers; tidal analysis and preprocessing software available from different WEB sites or on request from ICET. Most of the information requests (one per week minimum) concerned software. Most of them followed the consultation of the WEB site. This site is one of the most frequently consulted among the pages of the Royal Observatory of Belgium (ROB), which is the host agency.

According to the internal GGP rules ICET is preparing annually CD-ROM's, with the raw and processed minute data. We already edited CD-ROM's for the 4 first years, 1997/07 to 2001/06, of the project.

Visitors

ICET welcomed more than 20 visitors. Besides visitors coming only for a short stay we must consider also guest scientists and trainees. The guest scientists bring their own know how or data to work at ICET during several weeks or even months. Some of them worked on the ICET and GGP data banks, as Dr. A.Kopaev(Sternberg Astronomical Institute, Moscow), Prof. H.P. Sun and his assistants (Institute of Geodesy and Geophysics, CAS, Wuhan, China), Prof. A.P. Venedikov (Institute of Geophysics Sofia). Others brought their own data sets to perform tidal analyses using the ICET software and computing facilities, as Dr. E.Boyarski and Prof. L.Latynina (Institute of Physics of the Earth, RAS, Moscow), Prof. L.Brimich (Geophysical Institute, SAS, Bratislava Slovakia), Prof Silvia S.Schwab ("Universidade Federal de Parana", Curitiba, Brazil), Dr. V.Timofeev(Institute of Geophysics, UIGGM, Novosibirk, Russia). Mrs P.Beddows (School of Geographical Sciences, Bristol University, UK) came to receive intensive training on earth tide data processing and analysis.

Summer School

In the framework of the International Gravity Field Service (IGFS) recently created inside IAG, a summer course on "Terrestrial Gravity Data Acquisition Techniques" has been organised jointly by ICET and the "Bureau Gravimétrique International" (BGI), with the support of IAG and FAGS. Some 45 students from 27 countries took part to this school that took place on the campus of the Catholic University of Louvain in Louvain-la-Neuve, Belgium from September 4 to 11. A CD-ROM with all the teaching material is under preparation. The aim of this summer school was the training in gravimetric techniques of people involved in geodesy, geodynamics, geophysics or geology. At the end of the school, they were able to operate relative gravimeters and handle gravity data in order to realise gravity networks, densification surveys or microgravimetric studies. Special attention was paid to the tidal gravity corrections. There were three different types of activities: lectures, field practice and case studies. The case studies were talks given by specialists who are using the gravimetric techniques in Geodesy and Geophysics or for civil engineering applications.

Planned developments

Following the creation inside IAG of the International Gravity Field Service (IGFS), ICET will deepens its cooperation with the other confederated bodies. We believe that the members of IGFS should develop a common WEB site to stress their complementarity. Given the connections already developed with the International Gravimetric Bureau (BGI) we shall try a common experience at a smaller scale. For that purpose, according to the new FAGS funding policy, in line with the new ICSU strategy, we presented a bid for funding together with the BGI for the development of a common WEB site. With an improved WEB site it will be possible also to convert partly the "Bulletin d'Information des Marées Terrestres" into an electronic journal. It will speed up the publication of the papers, which are generally dedicated to ongoing researches, and reduce drastically the costs. Another possibility offered inside IGFS is to appoint "Fellows", which are individual scientists wishing to contribute to the Service activities. It will be possible to develop a network of contributors who can provide their expertise to ICET in answering to very specialised questions, developing new software and so on.

OUT OF SECTION

GEODETIC ASPECT OF THE LAW OF THE SEA

(GALOS)

Chairman : B. G. Harsson

Mandate

The mandate of GALOS is to formulate recommendations concerning geodetic aspects of international maritime boundary delimitation within the framework of the Law of the Sea Convention 1982 for the IAG member countries. The geodetic tasks involved in the delimitation are:

1) Accurate area determination.

2) Definition of offshore limits, both geometrical and as continental shelf limits.

3) Definition of equidistant boundaries.

4) Definition of partial effect boundaries.

5) Determination of base points.

Program of work since 1999

At the international ABLOS conference in Monaco 1999, under the title "Technical aspects of Maritime Boundary delineation and delimitation" GALOS was offered to convene the session for geodetic aspects. Seven presentations were given in this session. All together the conference had four sessions during two days in September. The proceedings were published by the International Hydrographic Bureau in Monaco.

After the ABLOS conference a GALOS business meeting was held in Monaco.
A new GALOS web-site is finished at the address: www.gdiv.statkart.no/galos

Also for the next international ABLOS conference "Accuracies and Uncertainties in Maritime Boundaries and Outer Limits", which will be held in Monaco 18 – 19 October 2001, GALOS is offered to convene one session.

Members

Members are:

G. Carrera	(Canada/Mexico)	
E. W. Grafarend	(Germany)	
D. Grant	(New Zealand)	
E. Groten	(Germany)	
B. G. Harsson	(Norway) -	Chairman
H. G. Henneberg	(Venezuela)	
K. de Jong	(The Netherlands)	
F. Madsen	(Denmark)	
S. Mira	(Indonesia)	
B. Murphy	(Australia)	
S. Nichols	(Canada)	
S. Oszczak	(Poland)	
C. Rizos	(Australia)	
G. Seeber	(Germany)	
M. Sasaki	(Japan)	
A. B. H. Salem	(Tunisia)	
L. E. Sjöberg	(Sweden)	

W. A. van Gein	(The Netherlands)
P. Vanicek	(Canada)
J. D. Zund	(USA)

Observer:

T. Katsura	(Japan)
N. R. Guy	(South Africa)

The relation GALOS – ABLOS

The chairman of GALOS is appointed as one of the three IAG-members in ABLOS, which has all together 10 members. ABLOS is the Advisory Board on Hydrographic, Geodetic and Marine Geo-Scientific Aspects of the Law of the Sea. The other seven members of ABLOS are: 3 appointed from the International Hydrographic Organization (IHO), 3 from the Intergovernmental Oceanographic Commission (IOC) and the Division for Ocean Affairs and the Law of the Sea of the UN Office of Legal Affairs (DOALOS) has one representative in an ex-officio capacity.
The web-address to ABLOS is: http://www.gmat.unsw.edu.au/ablos/

GALOS-member Jack Weightman dead.
It is with the deepest regret that we had to announce the passing away of our colleague Jack Weightman the 15th January 2001 after a short illness. He had been an active member of GALOS since GALOS started up in 1988.

IAG WG:

"THE WORKING GROUP ON EDUCATION"

B.Heck, M.Sideris and C.C.Tscherning

At the meeting of the Executive Commmittee in November 1999 a proposal by C.C.Tscherning for creating an Education Commission was presented http://www.gfy.ku.dk/~iag/educcom.htm

The proposal was discussed briefly at the meeting and it was decided to form a Working Group with the authors of this report as members to consider the proposal, and report at the EC meeting in April 2000.

The committee agrees that it is important that IAG plays an even stronger role in geodetic education. This could primarily be done by facilitating the exchange of information about teaching material and courses and by helping in organizing international courses at different levels.

In order to study the problem of exchanging educational information, an experimental home-page was established associated with the IAG home-page: http://www.gfy.ku.dk/~iag/eduwg.htm

This home-page shows which kinds of material could be made available in different categories.

The committee has discussed whether a "Commission" should be established, but consider it sufficient to establish a smaller Special Commission (SC) of active teachers from the different continents directly reporting to the EC. In a new structure it might be merged with another commission.

The SC should have the following tasks:

1. Collect and distribute information about existing courses, educational material (lecture noters, powerpoint presentations, www-material) and curricula. This should be done using a home-page much like the experimental one mentioned above. The maintenance of this home-page should be done by an institution after an announcement of opportunity. (The IAG Education Service (?)). This institution should also be responsible for checking the quality of the material posted on the home-page.

2. Review proposals for courses and contingently propose courses in areas (both geographical and topical) where there are no identified activities (and a need, obviously).

3. Foster cooperation between institutions offering PhD-training, cf. the DOGE proposal. The EU framework programs gives possibilities at least within Europe.

4. Investigate the use of new educational tools. Especially tools for distance learning.
5. Also this should be done after an announcement of opportunity.

6. The SC should not try to establish a standard curriculum, but inform of the various ways geodesy is taught at different places. The SC may however on request evaluate curricula.

IAG - CDC

International Association of Geodesy - Committee for Developing Countries

(1999 – 2003)

D. Blitzkow and E. S. Fonseca Jr.

IAG - CDC (International Association of Geodesy/Committee for Developing Countries)
XXIII General Assembly of the International Union of Geodesy and Geophysics
Sapporo – Japan / June 30 – July 11, 2003

History

During the General Assembly in Vienna, August 1991, the IUGG (International Union of Geodesy and Geophysics) requested to each of its constituent associations to reinforce actions towards Developing Countries. For this reason the IAG Executive Committee, at its meeting in Columbus, March 1992, set up an IAG Committee for Developing Countries (IAG - CDC). The committee had several activities on the coordination of Michael Louis. With his retirement the activities have been discontinued. At the EC meeting in Como, November 1999, a proposal by the president has been approved to restart the activities of IAG - CDC under the coordination of Denizar Blitzkow.

Objectives

1. To encourage and to facilitate present participation of developing countries in geodetic activities with a significant contribution to their own development as well as to the development of geodesy in general.

2. To request all IAG bodies and organizations to take into account, in their activities, the needs and capabilities of developing countries in order to ensure a profitable participation of them.

IAG - CDC Membership

Denizar Blitzkow (Brazil) - Chairman
Edvaldo Simões da Fonseca Junior (Brazil)
J.Y. Chen (China)
Charles Merry (South Africa)
Salah Mahmoud (Egypt)
Salem Kahlouche (Algeria)
José Napoleon Hernandez (Venezuela)
John Manning (Australia).

General Information - Activities (1999 – 2003)

Many activities and happenings have occurred in different countries in the last four years with important contributions to developing countries.

South America
Gravity Surveys
Gravity activities related to the establishment of fundamental gravity network as well as densification surveys have been carried out in several countries during the last few years. The following countries have improved the gravity coverage due to these actions: Argentina, Brazil, Chile, Equator, and Paraguay.

This initiative has been coordinated by D. Blitzkow and supported by NIMA (USA), GETECH (University of Leeds – UK), and many national organizations in the different countries. As a consequence, several improved versions of the geoid have been derived for the continent as an effort of EPUSP/IBGE and with some particular cooperation like IGeS (International Geoid Service) and recently GFZ (GeoForschungsZentrum). Some countries are carrying out particular efforts to compute their own geoid model, like Argentina, Brazil, Colombia, Uruguay and Venezuela.

TIGO Project
The TIGO (Transportable Integrated Geodetic Observatory) is a project of cooperation that involves the following organization in Germany and Chile: Bundesamt für Katographie und Geodäsie, Universidad de Conception, Universidad del Bio Bio, Universidad Catolica de la Santissima Conception and Instituto Geografico Militar (IGM). The following technologies or facilities are available at the site, in Conception, since 2000:

- VLBI
- SLR
- GPS
- Time-keeping
- Super conducting gravity meter
- Seismometer
- Meteorological station
- Water vapour radiometer.

More information can be obtained at the following site: www.wettzell.ifag.de/tigo/

Workshop: South America Geoid 2000
The South America Geoid 2000 workshop held at Escola Politécnica, Universidade de São Paulo, May 17 - 19, 2000, was organized by IGeS (International Geoid Service), SCGGSA (Sub-Commission for Gravity and Geoid in South America), CDC (Committee for Developing Countries) and was also supported by IAPSO (International Association of the Physical Science of the Ocean).

IAG-CDC Participation: D. Blitzkow, R. Barzaghi, O. Andersen and R. Forsberg.

IAG Symposium – Vertical Reference System (VeReS)
The VeReS Symposium was organized by the Instituto Geográfico Agustín Codazzi (IGAC), Bogotá and held in the city of Cartagena – Colombia, from February 20 to 23, 2001. Besides IAG and Pan-American Institute of Geography and History (PAIGH), the UNESCO Division of Earth Sciences and the German Carl Duisberg Gesellschaft sponsored the symposium.

SIRGAS Projet
In April, 2003 the Central Bureau of SIRGAS (Geocentric Reference System for the Americas) under the coordination of Luiz Paulo Souto Fortes as the president, presented the SIRGAS 2000 campaign final coordinates as well as their accuracy estimates. These results were generated by DGFI (Deutsche Geodätische Forschungsinstitut), from the individual results of the two processing centres: DGFI, in Munich, Germany, and IBGE, in Rio de Janeiro, Brazil. The results can be fund at: www.ibge.gov.br/sirgas

Africa
African Reference System (AFREF): Southern Africa
Representatives of 8 countries in Southern Africa met in Cape Town on the 13th and 14th of March 2001 to discuss a regional project within the broader 'AFREF' project to create a uniform geodetic reference system for Africa. The 8 countries present were: Botswana, Malawi, Mozambique, Namibia, South Africa, Swaziland, Zambia and Zimbabwe.

IAG Participation: Sansò, F., Neilan, R..

Organization of Africa gravity data for geoid computation
The purpose of this project is to carry out a determination of the geoid in Africa. A major part of the project will be to collate and merge gravity anomaly data sets for Africa. Because of the paucity of these data and their poor distribution, the geoid that will result won't be very precise, but it should still be a substantial improvement over the global EGM96 model. An equally important part of the project will be to develop geoid computation expertise within Africa.

To do the African Geoid a working group was created with the following objectives:

- Identifying and acquiring data sets - gravity anomalies, DEM's, GPS/leveling;
- Training African geodesists in geoid computation;

- Merging and validation of gravity data sets, producing 5' gridded and mean Δg;
- Computation of African geoid, and evaluation using GPS/leveling data.
- A preliminary geoid model for Africa is prepared to be presented at XXIII General Assembly of IUGG, Sapporo – Japan.

IAG - CDC Coordination: C. Merry, D. Blitzkow.

2nd Workshop on the definition of the North African Reference Frame (2° Atelier Nord Africain de Géodésie)
Representatives of the following countries participated to the workshop: Algeria, Libya, Morocco, Mauritania and Tunisia.

During the workshop a project was created to unify the Geodetic Reference Frame in North Africa (NAFREF).
To do the unification 3 working groups were set up:

1. WG I: Definition and establishment of a Terrestrial Reference System for North Africa.
2. WG II: Unified Geoid Determination.
3. WG III: Establishment of a General Committee for the realization of NAFREF. It was divided into two committees: Coordination Committee and Scientific Committee.

IAG - CDC Participation: F. Sansò, Z. Altamimi, M. Sarrailh, S. M. Alves Costa.

GEOCENTRIC REFERENCE SYSTEM FOR THE AMERICAS

(SIRGAS)

H. Drewes, drewes@dgfi.badw.de

The project on the geocentric reference system for the Americas (SIRGAS) was continued by observation campaigns, symposia and meetings during the elective period 1999-2003. Two symposia were organised by IAG entities in co-operation with SIRGAS: “Symposium on Vertical Reference Systems”, Cartagena, Colombia, February 2001, and “Symposium on Crustal Deformations in South America and Surrounding Areas”, Santiago, Chile, October 2002. The SIRGAS Project Committee had official meetings in Cartagena, Colombia, February 21 and 22, 2001, in Budapest, Hungary, September 6, 2001, and in Santiago, Chile, October 21 and 22, 2002. Two SIRGAS Bulletins were issued, No. 6, February 2002 and No. 7, December 2002.

Approximately 130 participants participated in the IAG Symposium on Vertical Reference Systems, Cartagena, February 20-23, 2001. More than 70 papers were presented (oral and posters) under five topics: (1) Vertical control systems, (2) Height determination techniques, (3) Height reference surfaces, (4) Sea level and height systems, (5) Unification of vertical reference systems. After a strict review process, 64 papers were published in the IAG Symposia series (Vol. 124). A report is published in J. of Geodesy (75) 679-680, 2001. The IAG Symposium on Crustal Deformation in South America and Surrounding Areas, Santiago, Chile, 21.-25.10.2002 was organised in conjunction with the 4th Chilean Symposium on Earth Sciences. It included the sessions (1) Earthquake studies, (2) South American reference frame, 3) Andean evolution, (4) Vertical motion (5) South American plate kinematics, and (6) Sea level change with a total of some 60 oral and poster presentations.

The SIRGAS Project, installed in 1993 by IAG, PAIGH, and the US National Imagery and Mapping Agency (NIMA) for the definition and realisation of the South American Geocentric Reference System, was extended to Central and North America and the Caribbean. During the seventh United Nations Regional Cartographic Conference for the Americas, New York, January 2001, a resolution was released recommending to all the American countries the integration of their national reference systems into SIRGAS. Consequently, the SIRGAS Project Committee decided during its meeting in Cartagena, Colombia, February 2001, to change the synonym of the abbreviation SIRGAS to "Sistema de Referencia Geocéntrico para las Américas" (Geocentric Reference System for the Americas) and to invite the Central and North American as well as Caribbean countries to participate in the project and nominate their delegates to the Project Committee.

New Statutes have been released in 2002 by the SIRGAS Committee. A complete organisation structure of the project is defined, the major components being the Executive Committee, the Directive Council, the Scientific Council, and the Working Groups. The sponsoring agencies, among those the IAG, is represented by a voting member in the Executive Committee.

An extended GPS observation campaign over ten days of each 24 hours was performed in May 2000 including 184 stations in North, Central and South America, the Caribbean as well as Galapagos, Easter Islands and O’Higgins, Antarctica. For South America this was the first repetition of the May 1995 observation campaign. SIRGAS Working Group I "Reference System" will include a comparison of the 1995 and 2000 results to derive station velocities for the realisation of a kinematic reference system. For the use of SIRGAS Working Group II "Geocentric Datum" a number of additional stations of national networks were included in order to improve the transformation parameters from the classical networks to the SIRGAS (and ITRF) reference frame.

The establishment of a "vertical datum" (SIRGAS Working Group III) was a major objective of the 2000 GPS campaign. All the reference tide gauges that define national height systems (levelling networks) and additional levelling points, in particular at the borders between neighbouring countries, were included for this purpose. The goal is to derive the relation between classical (normal or orthometric) and modern (ellipsoidal) height reference systems. A close co-operation with the IAG Gravity and Geoid Commission (XIII), in particular its sub-commission for South America, was established.

The SIRGAS project made an essential progress in the realisation of the geocentric reference system and the unification of the vertical systems. The latter activities are also performed in a global scale, in particular in co-operation with the European Vertical Reference System (EVRS) towards a unified world height system.

MEETINGS

MINUTES OF THE IAG - EXECUTIVE COMMITTEE MEETING AT THE XXII IAG/IUGG GENERAL ASSEMBLY, BIRMINGHAM, JULY, 1999.

Three meeting were held during the IUGG GA in Birmingham. For each meeting the agenda items treated as well as participants is listed below.

1. Meeting. Monday, July 19, 1999, 11.00-12.45.
Agenda Items treated: 2,3,4,5,6,8
Present were: K.P. Schwarz, (President), F.Sanso (1. Vice President), J.O.Dickey (2. Vice President), C.C.Tscherning (Secretary General), F.Brunner (President Section 1), R.Forsberg (President Section 3), P. Holota (President Section 4), M.Feissel (President Section 5), C.Boucher (President Commission X), P.Willis (Secretary Section 2), G.Beutler (President Commission XII), M.Sideris (secretary Section 3), B.Heck (Secretary section 4), C.Wilson (Secretary section 5), T.Tanaka (President Commission VII), W.Torge (Past president), I.I.Mueller (Honorary President), H.Moritz (Honorary President).
Note: Titles refer to old EC.

2. Meeting. Saturday, July 24, 9.00 - 16.00.
Agenda Items treated: 1,7,8,9,10,11,12,13,14,15,16,17,18,19
Present were: G. Beutler, C. Boucher, F.-K. Brunner, M. Feissel, R. Forsberg, B. Heck, C. Jekeli, R. Rummel, F. Sansò, K.-P. Schwarz, M. Sideris, H. Sünkel, T. Tanaka, W. Torge, C.C. Tscherning, P. Willis.

3. Meeting. Monday, July 26, 1999, 19.00 - 20.30
Agenda Items treated: 20,21,22,23

Present were: Y.Yuanxi (Secretary sec 4), C. Boucher, M. Feissel, W. Torge, T. Tanaka, B. Heck, P. Holota, P. Willis, R. Rummel, M. Sideris (President Sec 3), G. Beutler (First vice president), M. Vermeer (President of Commision), F. Brunner, C. C. Tscherning, K.-P. Schwarz, J. O. Dickey, F. Sanso (President), O. Andersen.

The new Executive Committee members (elected at the previous Council meeting) were invited to participate in this meeting. Note: Titles of new members of the EC.

Minutes.

1. Adoption of the minutes of the EC meeting in Paris.
The minutes were adopted without change.

2. Birmingham Organisation.
The organisation and program of the General Assembly were presented by the Secretary General.

3. Proposals for new nominations.
The list of nominations, prepared by the Nomination Committee, was presented by the president of the Nomination Committee, W.Torge. The CVs of the nominated persons were made available for inspection at the IAG office. Further nominations may be submitted according to the by-laws.

4. Proposal for members of the audit committee.
The Bureau proposed the following persons: G.Harsson (Norway), J.Adam, (Hungary) and R.Wonnacott (South Africa).

5. Nomination of the members of the resolution committee.
The following persons were nominated for the Resolution Committee: F.Sanso', J.Dickey, A.Dodson and C.Merry.

6. New fellows.
The procedure for appointing fellows was discussed. Officers who end their term during the General Assembly are eligible. It was discussed whether presidents of sub-commissions should be elected fellows. G.Beutler also pointed out that members of Scientific Bodies of some services also were eligible. It was decided to ask the section presidents to give recommendations that would be discussed at the next session. Here the following Fellows were elected:

O. Balt. Andersen, (Denmark), D.Arabelos (Greece), L.Ballani (Germany), B.Benciolini (Italy), M.Bevis (USA), G.Blewitt (UK), J.Bosworth (USA), A.Cazenave (France), T.Clark (USA), J.Degnan (USA), V.Dehant (Belgium), H.Drewes (Germany), B.Ducarme (Belgium), W.Featherstone (Australia), W.Freeden (Germany), T.Herring (USA),K.-H. Ilk (Germany), P. de Jonge (The Netherlands), J.Johanssen (Sweden), P.Knudsen (Denmark), Z-X Li (PRC), J.Manning (Australia), N.Pavlis (USA), C.Rizos (Australia), C.Rocken (USA), I.Tziavos (Greece), M.Vermeer (Finland), M.Wei (Canada), D.Wolf (Germany), S.Zerbini (Italy).

7. Venue of IAG Scientific Assembly 2001.
Applications had been received from Budapest (Hungary), Copenhagen (Denmark), Sopron (Hungary), Warsaw (Poland). After presentation of each venue by the country representatives and a comparison of the different venues, Budapest was selected.
The contact between the Executive Committee and the Local Organizing Committee to be finally decided Monday 26th.

8. IAG representatives to external bodies
BGI Directing Board: Dr. M.Vermeer (Finland), President of the Gravity /Geoid Commission.
IAPSO Commission on Mean Sea Level and Tides: M.Bevis to be contacted.
IAU Working Group on Astronomical Standards (WGAS): E. Groten (Germany), continuing.
IAU ICRS Working Group: T. Herring (USA), continuing.
ICET Directing Board: Dr. S.Takemoto, (Japan), President Earth Tide Commission.
ICL: S.Zerbini, (Italy)..
IERS Directing Board: C. Reigber (Germany), continuing, or his nominee.
IGS Governing Board: G. Beutler (CH), (ex-officio), T. Herring (USA), IAG Representative. ISO TC 211: J.Ihde (Germany), continuing.
IUGG Inter-Association Committee for Mathematical Geophysics: M. Vermeer (Finland), continuing.
IUSM Executive Board: I.I. Mueller (USA) K.-P. Schwarz (Canada), continuing to next meeting. New representatives will be nominated if there is a need after the next meeting.
PAIGH (PanAmerican Institute for Geography and History): W. Torge (Germany), continuing.
SIRGAS: H. Drewes (Germany), continuing.
WMO/IUGG Working Group on data exchange for forecast of natural disasters. S.Zerbini.
SCAR WG-GGI.: R.Dietrich (Germany).
The procedure for further elections were discussed, and it was proposed that in several cases the sections could make the appointment. It was decided to ask the representatives for bi-annual reports. The Bureau will review the reports. The Bureau may prepare a few questions to be answered in the report.

9. Adoption of new SSG.
It was decided that all special study group and special commissions should deliver complete description and member-list to the section presidents by the end of September. Section presidents should then compile and forward the complete list to the Central Bureau for inclusion on the IAG web page.
EC members will be asked to comment on the descriptions before the end of October. Adoption of the descriptions of the SSG's (and SC) would then be carried out via e-mail vote. Subsequently discussion can be held at the EC meeting in November. The President stressed that the special study groups should be international in membership and focussed in their research. If possible the research objectives should be agreed upon by the SSG membership.

The following SSG were then established and the president appointed:
Section I: Positioning
- SSG 1.179: Wide area modelling for precise satellite positioning - S. Han (Australia)
- SSG 1.180: GPS as an atmospheric remotesensing tool - H. Van der Marel (The Netherlands),
- SSG 1.181: Regional permanent arrays - R.Weber (Austria),
- SSG 1.182: Multipath mitigation - M.Steward (Australia)

Section II: Advanced Space Technology

SSG2.162: Precise orbits using multiple space techniques - R. Scharroo (USA) to continue until decision is made at first EC meeting.

SSG 2.183: Spaceborne INSAR technology - R.Hanson (The Netherlands).

Section III: Determination of the gravity field

SSG 3.167: Regional land and marine gravity field modelling. - I.Tziavos (Greece) Continuing.

SSG 3.177: Synthetic Modelling of the Earths gravity field - W. Featherstone (Australia), continuing.

SSG 3.178: Arctic Gravity Project R. Forsberg, was to become a working group within the new IGGC.

SSG 3.184: Use of remote sensing techniques for validating heights and depths - P. Berry (UK)

SSG 3.185: Merging data from dedicated satellite missions with other gravimetric data- N. Sneeuw (Germany).

SSG 3.186: Altimetry data processing for gravity, geoid and sea surface topography determination - C. Hwang (Taiwan).

Section IV: General theory and methodology

SSG 4.187: Wavelets in Geodesy and geodynamics- W. Keller (Germany)

SSG 4.188: Mass density from integrated inverse gravity modelling - G. Strykowski (Denmark)

SSG 4.189: Dynamic theories of deformation and gravity field - D. Wolf (Germany)

SSG 4.190: Non-probabilistic assessment in geodetic data analysis - H. Kutterer (Germany)

SSG 4.191: Theory of Fundamental Height Systems - C.Jekeli (USA).

Section V: Geodynamics

IAG/IAPSO working group: Geodetic effects of non-tidal oceanic processes - R. Gross (USA)

SC8 should establish contacts with an IAPSO commission on Geodetic fixing of tide gauges. Mike Bevis will be contacted on this.

K.P.Schwarz and J.Dickey expressed concerns about the overwhelming number of SSG Chairpersons from Europe.

10. New IAG Structure - program / procedure of work.

The resolution on the restructuring process was adopted with one modification.

The following members were proposed for the steering committee:

G. Balmino (France), G. Beutler (Switzerland), F.K. Brunner (Austria), J.O. Dickey (USA), M. Feissel (France), R. Forsberg (Denmark), R. Rummel (Germany), K.-P. Schwarz (Canada), and ex-officio, F.Sanso'.

G.Beutler was proposed as chairperson of the Steering Committee.

The steering committee is responsible for contacting a large group of experts and users and to develop a proposal by the end of 2000.

The proposal must be adopted at an extraordinary council meeting at the Scientific Assembly in 2001 and implemented at the General Assembly in 2003.

11. Sponsorship of Symposia.

Sponsorship of the following meetings were given:

XIII International Course on Engineering Surveying - Munich (Germany) - March 13-17, 2000.

International Workshop on "Perspectives of Geodesy in South-East Europe" - Dubrovnik (Croatia) - May 2-6, 2000.

International Congress on Geodesy and Cartography - Caracas (Venezuela) - December 2000.

12. JofG Editorial Board proposal.

The proposal from the Editor-in-Chief was adopted:

Editor-in-Chief: P.J. G. Teunissen (The Netherlands), Assistant Editor-in-Chief: F.H.Schroeder (The Netherlands), IAG Information Editor: O.B.Andersen (Denmark), Book-review editor: C.C.J.M.Tiberius (The Netherlands).

Editors: R.Barzaghi (Italy), C.Brunini (Argentine), F.K.Brunner (Austria), A.Dodson (UK), W.E.Featherstone (Australia), W.Fredeen (Germany), T.A.Herring (USA), P.Holota (Czech rep.), H.T.Hsu (PRC), K.H.Ilk (Germany), A.Kleusberg (Germany), R.B.Langley (Canada), S.Okubo (Japan), B.Schaffrin (USA), I.N.Tziavos (Greece), M.Vermeer (Finland), P.Willis (France), P.Xu (Japan).

13. IAG Budget.

K.-P.Schwarz proposed that not more than the equivalent of half of the quadrennial IUGG contribution is kept as a bank reserve. As a consequence of this the following budget was approved: (Amounts in USD).

<T BO DY	Receipts			Expenditures	

>					
15	IUGG Allocation	100000	11	Administration	50000
2	UNESCO grants	0	12	Publications	12000
3	OTHER grants	0	13	Assemblies	60000
4	Contracts	0	14	Symposia & meetings	30000
5	Sales of publications	12000	16	Grants	25000
6	Miscellaneous	35000	18	Miscellaneous	6000
7	Total receipts	147000	19	Total Expenditures	183000
8	Banks (Jan. 1, 1999)	94000	20	Banks (Dec. 31, 2003)	58000</TBODY>

14. IAG Fund.
The fund will be included in the IAG accounts following the advice of the Audit Committee.
The new Assistant Secretary General (K.Keller (Denmark)), will make a special effort to raise more money, contacting fellows, associates, institutions and private companies.

15. Proposal for Joint IUGG/BIPM Commmittee on a CTRS.
C. Boucher presented the proposal received via IUGG from BIPM.
C. Boucher, G. Beutler (rep IAG), and a IUGG representative to IERS (C. Reigber or his successor) were appointed as members of a committee to propose procedures for the adoption of an ITRF within IAG/IUGG and its dissemination to other agencies. The name of the committee should be decided by the committee themselves.

16. Journal Artificial Satellites.
CSTG recommended that the Polish Journal Artificial Satellites is not made the official journal of an IAG body. The EC agreed with the arguments given in their letter.
K.-P. Schwarz and C.C. Tscherning will send a letter to the Polish Space Research Centre explaining the IAG position.

17. Rules for IAG Young Author Award.
The rules proposed by the President were adopted. The revised rules are available from the IAG home page

18. Proposals for new IAG Services: ILRS, IVS, DORIS, EOSS.
The proposal for ILRS and IVS were adopted. CSTG was thanked for their work with these proposals.
A more developed proposal will be expected from DORIS. The EOSS proposal was not acceptable since it was a regional and not an international service proposed. The group is invited to work inside IAG (Comm. X and SC 8).

19. Rules for Bomford Prize.
The proposal by K.P.Schwarz was accepted. The revised rules are available from the IAG home page

20. Status of Handbook and Travaux.
O.Andersen reported on the preparations of the Travaux and the Handbook. 80% of the material has been received or promised before mid August for the Travaux. The remaining 20% will not come. 50% of the representatives of IAG to other bodies have responded.
Publication is foreseen on a CD in late September. The Travaux will also be available on the web. With the CD an order list for the Travaux as a book will be distributed.
The Handbook has a final deadline after the next EC meeting (finalising SSG descriptions). This will result in a publication in February of 2000. Parts of the Handbook will be available on the web as soon as the material is ready.

21. Audit Committee report.
CCT presented the report that had been distributed. The outgoing president will write to the three members to thank them for their work.
The Central Bureau got a mandate to merge the IAG general account with the account for the IAG fund to limit costs and facilitate administration.

22. Resolution Committee Report.

FS presented the resolutions. The resolutions were adopted after revision for presentation at the Council.

23. Miscellaneous.
A. Birmingham proceedings.
At present there are nearly 90 pre-orders in hand. Springer has required a minimum of 150 pre-orders in order to publish the proceedings. It was decided to publish proceeding with the number of pre-orders we are getting even though this might result in a 3000$ expense for IAG. It was mentioned that we might be saving a corresponding amount on the Travaux. The President proposed that e-mails are written to all IAG participants at the IUGG shortly after the meeting to ask once more for pre-orders.
B. Earth Science Focus on Urban Issues.
During the last four years the IUGG has drawn attention to what earth sciences can do to urban regions in the future. Its was discussed in which manner IAG can contribute to solving urban problems. The issued was postponed to the next EC meeting.
C. Advertising IAG
W. Torge strongly recommended that the next EC take up the issue of advertising the IAG in the next 4-year period.

Minutes of the EC meeting in Nice, 28-29th April, 2000, held in connection with the EGS XXV general assembly.

The following were present.

F. Sanso	President
G. Beutler	First Vice President.
D. Blitzkow	Second Vice President
C. C. Tscherning	Secretary General
O. Andersen	Ass. Sec. General
K. Keller Ass.	Sec. General
C. Rizos	Secretary Sec 1.
C. K. Shum	President Sec 2.
M. Sideris	President Sec 3.
G. Boedecker	Secretary Sec 3.
B. Heck	President Sec 4.
C. Wilson	President Sec 5.
V. Dehant.	Secretary Sec 5.
H. Drewes	President Comm VIII.
C. Boucher	President Comm X
M. Vermeer.	President Comm XIII
S. Zerbini	President Comm XIV.
I. Mueller	Past President
K. P. Schwarz	Past President

1. Approval of agenda
F. Sanso presented the agenda containing several additions, and this was approved.

2. Adoption of minutes of Como EC meeting
The Minutes of the EC meeting on 28-29th November, 1999, in Como, Italy, had been distributed by e-mail and were published as part of the IAG newsletter in JoG 74/02. They were adopted by the EC without corrections.

3. Proposal for an IAG retiree association.
I. Mueller had distributed a proposal for establishing an association of IAG retiree/seniors/past officers as a forum to contribute expertise of value to IAG. The association would be open to all IAG fellows and associates, and have meetings at Scientific Assemblies and an electronic newsletter. The EC agreed on the general idea of having such an association, and awaits the formal proposal from I. Mueller at the SA in Budapest.

4. IAG Scientific Assembly in Budapest 2001.
I. Mueller presented the status of the preparation of the Local Organizing Committee (LOC) for the SA in Budapest (3-7 Sept 2001). The preparations are under control and the LOC has established a web page for communication. The Academy of Sciences, where the SA will be held, has 11 meeting rooms of various sizes (max 320 persons). The LOC requests that IAG specify requirements with respect to rooms and sizes at least 3-5 weeks before the SA. Details on the scientific program are given under item 8.

5. Feedback on Travaux/Handbook and IAG newsletter.
O. Andersen informed that the Travaux was distributed on CD and is also available from the Central Bureau (CB) as a book. The Geodesist's Handbook is published, but only a few members of the EC had received it so far. O. Andersen reported that Springer takes up to 2-3 month in printing issues, and also sometimes merges issues which delays publication of the IAG newsletter. This is problematic, and EC stressed that it should be avoided in the future. The IAG Secretary will contact the Editor-in-chief on this issue. Possible distribution of an electronic quarter-annual newsletter via e-mail was considered.

6. Collaboration with ION. (Institute of Navigation).
The president of ION has approached IAG for coorporation on a GPS book jointly written by authors from IAG and ION. The EC decided to ask F. Sanso to contact R. Neilan, P.Willis, G. Hein or W. Gurtner to establish liaison and to define a fruitful coorporation with ION, based on areas where IAG has strength

7. Report from the review committee (herinafter RC)
G. Beutler presented the report of the IAG review committee (RC) and went through the Executive summary available at ftp://ubecx.unibe.ch/aiub/iag Only part 5(IAG mission and objectives) and part 6 (IAG structure) were subsequently discussed in detail. Once the comments made below have been given to the RC they have the mandate to create the proposal that should be presented to the EC in March 2001 and subsequent to council at the SA in 2001.

IAG mission and objectives.
A revision of the suggested IAG mission and objectives was carried out, and it was recommended that two more points should be added: a preamble on the usefulness of geodesy for society and another bullet on emerging technologies.
IAG structure.

It was decided by vote that the IAG structure should have commissions, services, and a communication/outreach branch and a few projects represented on the same level. Projects on this top level will be established by the EC. GIGGOS may be one of them, but has not been selected at this point in time.

There was agreement on establishing a communication and outreach branch, and that a call for participation should be drafted. It was recommended by the EC that the review committee consider the flexibility within the IAG structure and allows for establishment of inter-commission/service bodies (i.e., for geodetic theory or techniques, which presently resides within commissions)

Structure of the IAG Central bureau, IAG bureau, EC and Council. G. Beutler pointed out that the commission names were not fixed by the proposal, and that he would appreciate input from EC members on this.

It was strongly stressed that there should be no appointed members in the EC. Services, commissions and members can nominate members, which will subsequently be elected by the Council.

The importance of the Council was stressed. A suggestion for improved communication between the EC and the Council would be to initiate informative meetings at the SA.
Individual Membership and Nominations/Voting.

K. P. Schwarz introduced possible scenarios for IAG personal membership based on the IAVCEI model. It was clarified that the issue of personal membership is not necessarily linked to the review process, but that it would be advantageous to introduce it at the same time if the EC agrees to go this route. In the IAVCEI model, personal members have benefits (i.e. discounts on participation in General Assemblies and journal subscription, voting rights). The EC gave its approval in principle to develop a proposal for personal membership that has different levels of membership fees (developing countries) and benefits. It also decided that voting rights should not be given to individual members. The proposal will have to be approved by the EC.

Finally the EC agreed to invite I. Mueller and J. Kauba to join the review committee for finalising the proposal for IAG restructuring.

8. Scientific program for the IAG Scientific Assembly (SA) in Budapest.
K. P. Schwarz had prepared and distributed a proposal for the scientific program for the SA in Budapest in 2001. Four symposia are proposed, two of them will run in parallel every day. Friday will be devoted to the IAG restructuring. The possibility of awarding a prize for the best student presentation using the IAG fund was discussed.

It was decided to publish all presented and poster papers whose mauscripts are available at the meeting on a CD without review. A selected number of representative papers will be reviewed for publication in the IAG/Springer symposia series. The registration fees will be increased to include the cost of producing the proceedings. The review process should be strict to be representative of the quality of science that IAG stands for. J. Adam will be asked to serve as editor of the proceedings. It was left to the convenors to accept/reject abstracts and carry out the review process. Besides the CD containing all abstracts and remaining un-reviewed papers, there will be an official IAG CD containing mid term reports of the bodies (especially the SSG) of the IAG.

9. Collaboration with sister societies (FIG, ISPRS, etc) after IUSM
It was stressed that the collaboration should be on the working level and as concrete as possible. Obvious collaboration should be co-sponsoring of each other?s symposia.

10. ISPRS has requested support for becoming a member of ICSU
The Bureau has issued a positive response to the ISPRS request for ICSU membership.

11. Report from the WG on Education
The report of the WG was presented by C. Tscherning. It was questioned whether there should be any "checking" of teaching material, and it was agreed that only the functionality of the links from the homepage to the proposed material will be checked. C. Tscherning was elected as president of the Committee on Education.

12. Report from the Committee for Developing Countries (CDC).
D. Blitzkow had found it difficult to make progress in the work. The goals of the former CDC had been reviewed, and a number of concrete activities were taking place in South America. Despite IAG had allocated USD 4000 to the CDC it was not at all sufficient to start any meaningful activity due to the large cost of air-travel within Africa.

A workshop will be organized in May 2000 in Sao Paulo on the South-American geoid cosponsored by the Int. Geoid Service (IgeS). G. Beutler referred to the position paper of J. Manning, which contained useful considerations concerning the developing countries. J.Manning had also pointed to the activities of the UN regional Cartographic Conferences. It was concluded that we have to start with local geodesists, and in this sense the schools were a good entry point.

13. Discussion of IAU recommendation.
E. Groten had informed the Bureau about the IAU request of having a reference value of the gravity potential for time-corrections. It was recommended to use the best current value.

14. Request from GALOS to Recognize Galo Carrera as an IAG Fellow
GALOS had requested that the work of Galo Carrera was recoginzed by IAG. The EC decided to award him the fellowship of IAG.

15. IAU request of IAG representative to IAU Commission 19.
Clark Wilson was proposed, and accepted.

16 IAG Sponsored meetings.
To be summarized from the IAG homepage. J. Manning has requested the IAG endorsement of a regional workshop in Mongolia. An IAG representative was requested. The meeting is recognized as a fine initiative, and J.Manning will be asked to represent IAG. A meeting on Recent Crustal Movements in Helsingfors in August has been organized, and could be in conflict with the Scientific Assembly. It was felt that the way in which the first announcement of this meeting used the IAG name was inappropriate. This was conveyed to the organizers by M.Vermeer. S.Zerbini is advising the LOC with respect to the program. Com. XIV will sponsor the meeting.

17. IAG collaboration with EGS and AGU.
IAG SSG co-sponsorship is possible together with AGU/EGS at international meetings. This would be a way to achieved IAG goals. IAG SSG could be used as a bridge between AGU and EGS. IAG ought to be visible, by co-sponsering sessions etc. F. Sanso will contact AGU and EGS concerning collaboration.

18.Young author's award
F. Sanso refered to the letter of P. Teunissen, editor-in-chief of the JofG, which had been distributed in advance. Of the four candidates proposed. Dr. Xu. was unanimously chosen for his paper "Biases and the accuracy of, and an alternative to, discrete nonlinear filters", Published in JoG, Vol. 73, pp. 35-46, 1999.

19. Gravity field service.
A meeting will be held in Milan concerning unification of the three gravity services. BGI, IGS, IETC. NIMA might provide a new GDEM (SRTM (100-200m)) to improve global gravity. The EC encouraged this initiative.

20. Next meetings.
Next EC meeting: (EGS 2001 26-30 of March) 30-31/3 2001. Major items will be IAG restructuring, and SA planning.

Ole B. Andersen

Minutes of the EC meeting in Nice, 30-31th March, 2001.

The following were present.

F. Sanso	President
G. Beutler	First Vice President.
D. Blitzkow	Second Vice President
C. C. Tscherning	Secretary General
O. Andersen	Ass. Sec. General
A. Dodson	President Sec 1
C. K. Shum	President Sec 2
M. Sideris	President Sec 3
B. Heck	President Sec 4
C. Jekeli	Secretary Sec 4
Y. Yang	Secretary Sec 4
C. Wilson	President Sec 5
H. Drewes	President Comm. VIII
C. Boucher	President Comm X
S. Zerbini	President Comm XIV
K. P. Schwarz	Past President
J. Adam	LOC of IAG SA meeting in Budapest.

1. Approval of agenda
FS presented the agenda containing several additions, and this was approved.

2. Confirmation of adoption of minutes of the 2000 IAG meeting in Nice, France
The Minutes of the EC meeting in Nice, 28-29th April, 2000 were published as part of the IAG newsletter in JoG 74/06 and on the IAG web page. The Minutes were adopted by the EC with the following correction

under item 7 (Report from the review committee, IAG structure): Inter-commission/service bodies reside within sections and not within commissions.

3. Report from the Review Committee.
G. Beutler presented the IAG review 2000-2001 Executive Summary and went through the IAG Missions and Objectives. These were adopted with minor revisions.
The key elements of the IAG structure were presented. EC adopted the following titles for commissions with the provisional content specified in the proposal for new Statutes and By-laws.

Comm 1. Geometric reference frames
Comm 2. Gravity field
Comm 3. Earth Rotation and Geodynamics
Comm 4. Positioning and Applications.

The Bureau will distribute the adopted executive summary to the National Representatives within two weeks of the EC.

The review committee was thanked and the committee was dissolved. G. Beutler was asked to present the executive summary in Budapest.
It was decided that if the Council in Budapest passes the change of structure, a committee for the realization of the new IAG structure should be established. G. Beutler assisted by the section presidents should lead this committee. The committee should have the freedom to invite additional committee members.

A procedure for handling amendments to the Statutes and By-laws was established by the EC:
It was underlined that amendments should be send through the National representatives and should be send to the Secretary General before the end of June.
All amendments will be presented to the Council in Budapest. Amendments will be mailed to the EC prior to the Council meeting for possible support. The Amendments will be posted on the IAG internet site and distributed to the National Representatives before the Council meeting.

4. Proposal for new statutes and by-laws.
The Secretary General received the proposal for new statues and by-laws 6 months ahead of the Council meeting Budapest, which is why they can be considered at this meeting.
According to the new Statutes a review committee shall review the Statutes and Bylaws every eight years to ensure an up-to-date structure IAG. The first review shall take place in 2007.

The proposals for new Statutes and By-laws with the amendments made at the EC meeting were unanimously adopted by the EC for presentation to the Council in Budapest. The Bureau will distribute the proposal to the National Representatives within two weeks of the EC.

IAG Guidelines for the Establishment of Sub-commissions, Study Groups, Commission Projects, Inter-commission Committees and IAG Projects were distributed for information at the EC meeting. It was decided that they should not be included to the By-laws.

C. Jekeli put forward a motion for a mechanism to change the status of the inter-commission committees. B. Heck supported the motion. The motion reads: “The EC may recommend to the council and seek its approval to grant full commission status to an inter-commission committee”. The motion was not adopted by the EC.

5. 20001 IAG Scientific Assembly in Budapest.
K.-P. Schwarz and J. Adam presented the status of the preparation for the IAG meeting. Presently 274 have pre-registrated representing 58 countries.
Advertising was discussed. IAG agreed to advertise GPS World and Galileo World at the meeting in Budapest by distributing free sample copies. O. Andersen was asked to contact Springer with respect to similar arrangement with the Journal of Geodesy. C.C. Tscherning should explore the possibilities of advertisement in EOS, and C. K. Shum agreed to announce the meeting at the upcoming spring AGU.

The meeting arrangement proceeds as planned and the second circular had been distributed. The list of symposium convenors and session chairs was distributed for information.
K.-P. Scwartz will establish a small committee to elect best poster and oral presentation among young scientist.

Financial support has been obtained from ESA and NASA, and IAG will be able to support a substantial number of scientists.

6. Bi-annual report.
Bi-annual reports from all the entities within IAG will form an official IAG publication. This publication will be distributed on CD in Budapest and will published on the IAG Internet site. The section presidents are responsible for compiling the material within their sections. Status were:
Sec 1. All entities have been contacted and have responded positively
Sec 2. All entities have been contacted. Reports are already available on the Section web site.
Sec 3. All entities have been contacted. Most have responded positively
Sec 4. All entities have promised to send material at end of April.
Sec 5. All entities have been contacted and have responded. The section will report via the section website.

7. Collaboration with sister societies.
F. Sanso reported on a meeting with ISPRS, IUG, FIG, IHO, ICA and IAG at the ISPRS meeting in Amsterdam, July 2000.
A proposal for establishing a joint board of spatial information societies will be addressed at the next meeting with the societies, which will take place 2. Sept. 2001 in Budapest.
It was decided to discuss how the collaboration could be enlarged with other organizations/societies at the EC meeting in Budapest.

FIG has drafted a memorandum of understanding, which had been distributed prior to the meeting. The EC adopted the memorandum of understanding.
It was decided that F. Sanso should ask R. Neilan to become IAG representative to the Institute of Navigation (ION).
C. Boucher was asked to prepare a proposal for establishing a group to look into implementation of ITRF including communication between the involved organizations.

8. Report from the Committee for Developing Countries
D. Blitzkow presented the work of the CDC. A South American geoid workshop was successfully held in Sao Paolo in 2000 with participation from most South America countries. The committee's work in South America is very successful.
Meeting was held with C. Merry (S. Africa) on establishing a working group on creating an African geoid.
Commission X and the IGS central Bureau suggested the establishment of an African continental reference system (AFREF). The "Interest and motivation for establishing AFREF" document was distributed prior to the meeting and presented by C. Boucher.

9. Report on the Journal of Geodesy.
P. Teunissen reported on the Journal of Geodesy. Printed and online versions are available. Volume 74 contains ten issues (two double issues) and the Geodesists Handbook and will be finished shortly. Volume 75 will be finished in 2001 and will contain three double issues).
Review process has been lowered from 10 to 9 month on average, but the production time has been increased from 4 to 5 month.
Special issues on "GLONASS" (guest editor P. Willis) and on "New parameters for Earth orientation" (guest editor T. Herring) are foreseen, and review papers are also planned. It was stressed that interaction with the section presidents is important in defining special issues.
The IAG newsletter suffers from Springers production time. Springer has agreed that IAG can issue electronic news on a regular basis.

10. Gravity Field and Figure of the Earth Service. (GFFS)
M. Sideris presented a suggestion for establishment of a new IAG service "Gravity Field and Figure of the Earth Service (GFFS)" formed by joining the following services (BGI, ICET, IGeS) supplemented with the following centers/services (PSMSL, ICGEM (international center for global earth gravity models)). The EC agreed to set up a coordination group headed by M. Sideris to create/prepare the terms of reference for the service. The coordination group should prepare the material for establishment of the service at the Budapest meeting.

11. IAPSO Scientific Assembly (Mar de la Plata, Argentina, October 2001*)*
The EC approved to co-sponsor the IAPSO meeting in October and to have a joint IAG/IAPSO symposium called "Gravity, geodesy and the ocean circulation as inferred from altimetry".

12. IUGG General Assembly in Sapporo 2003.
C. C. Tsherning asked for input on themes for the IUGG GA as well as names of union symposia for the IUGG GA by the end of July.

13. Next meeting.
The next EC meeting will be held in Budapest, Tuesday 4. September 2001. The subsequent meeting will be held 26-27th April, 2002 in association with the next EGS meeting.

Ole B. Andersen

Minutes of the IAG-EC meeting in Nice 26. and 27. April 2002.

The following were present.

F. Sanso	President
G. Beutler	First Vice President.
D. Blitzkow	Second Vice President
C. C. Tscherning	Secretary General
O. Andersen	Ass. Sec. General
A. Dodson	President Sec 1
C. K. Shum	President Sec 2
G. Boedecker	Secretary Sec 3
C. Wilson	President Sec 5
V. Dehant	Secretary Sec 5
H. Drewes	President Comm. VIII
C. Boucher	President Comm. X
S. Zerbini	President Comm. XIV
K. P. Schwarz	Past President
P. Xu	Rep. IAG intercommission committee on theory.
S. Takemoto	President Comm. V.

0. Memorandum
The IAG honoured the past president of IAG P. A. Leppan and past secretary general of IAG.
J. J. Levallois. Both passed away in 2001.

1. Approval of agenda
F. Sanso presented the agenda containing several additions, and this was approved.

2. *Brief reports from each section (Section Presidents)*
The section presidents of section 1,2,3 and 5 reported that the sections are working well.
The EC appointed C. Wilson to liaison with IERS in preparing a resolution on the celestial reference frame, which IAG can carry forward at the IUGG meeting in Sapporo. IERS should also be asked for a brief article for Journal of Geodesy on the celestial reference frame.

3. Report from the IAG planning committee.
G. Beutler presented the minutes from the planning committee meeting which had taken place the same morning. The minutes are available from http://www.gfy.ku.dk/~iag/newstructure/newstructure.htm

G. Beutler had received a proposal to set up an entity dealing with fundamental constants. The EC decided to establish a planning group, which should report at the IUGG2003 meeting in Sapporo. C. Wilson agreed to chair this planning group. G. Beutler and C. Wilson will make a letter to the head of the services with a request for nomination of a person to join the planning group.

C. Tscherning reported on the establishment of an IAG outreach branch. The announcement had been widely distributed and published in the IAG newsletter. Until now only a few institutions had shown interest.

K.-P. Schwarz stressed that the institutions should contribute with one full-time secretary. The EC decided that IAG must be active in finding a suitable place for the IAG outreach branch (C. Tscherning).

4. Report from the Planning Committee for the Intercommission Committee on Theory
Peiliang Xu presented the report of the Intercommission Committee on Theory. P. Xu stressed the importance of establishing joint working groups with the different IAG commissions in the future structure.

5. Report from the planning committee on the IAG project
G. Beutler distributed and presented the status report from the planning committee on the IAG project IGGOS, which was prepared at the third meeting of the group on Thursday 26 April. The EC approved to appoint G. Beutler to chair the IGGOS planning group until the IUGG meeting in Sapporo with H. Drewes serving as secretary.

6. Comments received on the new Statutes and by-laws.
C. Tscherning reported on the comments received on the new statutes and by-laws from the National Committee of Poland. These are available on http://www.gfy.ku.dk/~iag/Compol.htm
The EC decided to adopt the editorial changes suggested by the national representative of Poland. The suggestion of omitting the word astrometric in the description of commission 1 in the by-laws that reads: "Theory and coordination of astrometric observation for reference frame purposes", was not adopted. V. Dehant will contact the national representative of Poland.
Updated Statutes and By-laws are available at the IAG website. K.-P. Schwarz agreed to look into re-formulating the Statutes and By-laws on the subject of personal membership as this still causes some confusion.

7. Experience from the Budapest Scientific Assembly
K.-P. Schwarz presented the report from the Budapest Scientific Assembly which has been published as part of the IAG newsletter in the Journal of Geodesy. All comments have been very positive, and the EC thanked K.-P. Schwarz and the LOC for the great work done in association with the Budapest meeting. The reviewed proceeding is in press with Springer.

The EC discussed the publication of reviewed publications in association with the IUGG2003 meeting. It was decided to have reviewed proceedings and that the cost of the proceedings should be added to the registration fee. The EC decided to form an editorial board for this meeting. This will consist of 8 members: the convenors from each geodesy session, and F. Sanso. It was decided that this board should set up set up a clear set of rules for reviews and deadlines before the IUGG2003 meeting. The Joint Symposia chaired by the IAG will not be published as part of the IAG reviewed proceedings.
The EC appointed C. Tscherning to liaison with the LOC and to prepare the final program. Abstracts will be handled by IUGG, but C. Tscherning was appointed to assist in the assignment of abstract to the different IAG sessions in corporation with the session convenors.
O. Andersen was appointed editor by the EC for the 2003 version of the IAG Travaux and Geodesists Handbook.

8. IUGG2003 - General Assembly in Sapporo 2003.
C. C. Tscherning reported on the preparation for the next IUGG meeting. IAG related meetings will be confined to 7 days (Wednesday, first week (July 2, 2003) to Thursday, second week (July 10, 2003). The EC will meet on Tuesday the first week (July 1, 2003). Each session has 1.5 days except for IGGOS which has two days. A preliminary time schedule was presented, see http://www.gfy.ku.dk/~iag/iugg03time.htm .

9. Nominations of IAG and IUGG officers.
The nomination procedures for the IUGG and the IAG elections were presented by K-.P.Schwarz. A draft call for IAG nominations was discussed. The final call is available at http://www.gfy.ku.dk/~iag/callnom.htm.
It was considered important that a geodesist became a member of the new IUGG Bureau. The President and the Secretary General were asked to contact possible candidates. Proposals from the EC should be send to the Secretary General before June 1, 2003.

10. Resolution on permanent earth tides effects.
The issue was postponed to the next IAG meeting.

11. Best paper award

Two of the three suggestions from the Editor in Chief of Journal of Geodesy P. Teunissen were send out for e-mail vote after the EC meeting to enable the members to read the papers. The winner of the award has subsequently been found, and is: S. Skone, Calgary.

12 Any other business.
K.-P. Schwarz mentioned that Springer will take over "GPS Solutions". IAG appointed C. Tscherning to keep in close contact with Springer to clarify how the best synergy with Journal of Geodesy could be obtained.

United Nations and GNSS will have a meeting in Zambia in July. IAG should be represented at the meeting especially with respect to the AFREF

The EC appointed C.K. Shum, G. Beutler and A. Dodson to lead a planning group for an IAG project on GNSS.

K.-P. Schwarz pointed out that there is a potential problems with the new IAG By-laws, as they opens for re-election of Commission presidents. This was not possible for Section Presidents in the old IAG by-laws. The EC decided to clarify the text as to ensure that Commission presidents can not be re-elected.

13. Next meeting.
The next EC meeting will be held 10-11th April, 2003 in association with the joint EGS-AGU meeting in Nice, France.

Ole B. Andersen, IAG information editor

Minutes of the EC meeting in Nice, 11. April, 2003.

The following were present.

F. Sanso	President
G. Beutler	First Vice President.
D. Blitzkow	Second Vice President
K.-P. Schwarz	Past President.
C. C. Tscherning	Secretary General
O. Andersen	Ass. Sec. General
A. Dodson	President Sec 1
P. Willis	Secretary Sec 2
M. Sideris	President Sec 3
B. Heck	President Sec 4
C. Wilson	President Sec 5
V. Dehant	Secretary Sec 5
S. Takemoto	President Comm. V.
H. Drewes	President Comm. VIII
C. Boucher	President Comm. X
M. Vermeer.	President Comm. XIII
S. Zerbini	President Comm. XIV
J. Adam	Hungarian rep. for COB
M. Poutanen	Finnish rep. for COB

1. Approval of agenda
F. Sanso presented the agenda containing several additions, and this was approved.

2. Result of election
C. C. Tscherning presented the result of the election of new officers for the IAG Executive committee for 2003-2007.
The following members have been elected.

President: G. Beutler
Secretary General: C. C. Tscherning

Vice president: M. Sideris
President of commission 1. H. Drewes
President of commission 2. C. Jekeli
President of commission 3. V. Dehant
President of commission 4. C. Rizos
Members at large: L. P. Fortes and C. Merry
Service representatives: R. Neilan, M. Rothacher, H. Schuh
President of the Outreach branch to be elected (se below).

3. Report from the IAG Planning Committee

G. Beutler presented the work of the IAG planning committee (available from www.gfy.ku.dk/~iag/new_iag_feb_28_2003.pdf). The EC adopted the report and decided to place “Earth tides” within commission 3 as sub-commission 3.3.

A commission for satellite dynamics was suggested. The four commission presidents were asked to place this within the new structure before the IUGG meeting in Sapporo

The EC adopted the proposal to affiliate Commission 1 with COSPAR as a subcommission. The president of Commission 1 should contact COSPAR.

The EC agreed that the president of Section 3 and the president of the new Commission 2 should make recommendations to the EC concerning representation from the International Gravity Field Service (IGFS) in the new structure.

4. Report from meeting with new officers

F.Sanso reported from the meeting with the new IAG officers. He pointed out that the current section presidents and the newly elected officers would have to finalize the "fine-structure" of the new IAG between now and Sapporo. A letter, to be drafted by
Gerhard Beutler, would be sent out to these colleagues in May to explain the work to be done.

5. Communication and Outreach branch

J. Adam presented the offer from the Hungarian Academy of science.

M. Poutanen presented the offer from the Finnish Geodetic Institute.

The EC acknowledged both proposal with thanks, and elected the Hungarian Academy of science to host the IAG Communication and Outreach branch.

EC established a planning committee for establishing the outreach branch headed by M. Sideris.

6. Membership fee.

The EC adopted a personal membership fee of USD 50 per year or USD 150 if paid for 4 years in advance. Students and retired scientist can obtain free membership if accepting e-mail communication only.

7. Report from planning Committee for the Intercommission Committee on Theory (ICCT) and appointment of president

B. Heck presented the report of the planning committee. The EC unanimously appointed Peiliang Xu as president of the ICCT and asked B. Heck to revitalize the planning committee for establishing the ICCT and appointment of vice-president before Sapporo.

The ICCT should nominate an IAG representative to the CGM committee on mathematical geophysics.

8. Report from the planning committee on the IAG project IGGOS

G. Beutler presented the work by the IGGOS planning committee on the IAG project (available from www.gfy.ku.dk/~iag/iggos_prop_feb_28_2003.pdf). The EC expressed its thanks to the IAG planning committee. The IGGOS definition phase will last from 2003-2005 with approval of the official IGGOS at the IAG scientific assembly in 2005. The EC should elect a president for IGGOS before Sapporo. The planning committee should act as nomination committee and distribute the documents to the Council for adoption in Sapporo.

9. Report from the planning committee on the Inter Commission Committee on Geodetic Standards and appointment of president

The EC voted in favor of continuing the planning committee on the Inter Commission Committee on Geodetic Standards. The EC stressed the interconnection with the members of the IGGOS definition phase group.

10. Experiences with the New Statutes and By-laws.
K.-P. Schwarz presented the first experience with the New Statutes and by-laws, which in general seem to work in practice. Suggestions to changes/specifications/clarifications of the Statutes and By-laws were subsequently brought forward. The EC decided to apply Roberts Rules if there is an election tie, and bring the decision to council. The EC expressed the thanks for the work carried out.
A new Cassinis committee will be established in Sapporo for possible changes to be implemented by 2008.
M. Sideris raised the problems of placing umbrella organizations like IGFS.

11. Suggestion for task force for IAG on "Geodesy on the planets"
The EC appointed V. Dehant to establish an ad hoc group to investigate the possibility of preparing a proposal for IAG involvement on geodesy on the planets. The group should report back to the Bureau.

12. Brief reports from each section (Section Presidents).
Section 1: A. Dodson reported that two of the SSG's are very successful. Two SSG are not responding.
Section 2: H. Drewes reported on CSTG.
Section 3: M. Sideris reported that four of the five are extremely active and successful. BGI is not responding.
Section 4: B. Heck reported that Special commission 1 is working very well. All SSG are working well, two extremely well.
Section 5: C. Wilson reported that all entities are working well.

13. Report from the editor of Travaux
The IAG Travaux will be distributed on CD to all participants in Sapporo. The report from the IAG planning committee and available national reports will be distributed on the same CD. It is the responsibility of the section officers to compile the material of their respective sections by mid May 2003.

14. Preparation of appointment of IAG Fellows
C.C. Tscherning seeks nominations by the section presidents from the sections entities. Final list will be presented at the next EC meeting in Sapporo

15. IUGG2003 Sapporo
C. C. Tscherning presented the IAG part of the IUGG program for Sapporo. S. Takemoto presented the official and social arrangements. A total of 60.000 USD have been given out in travel grant supporting nearly 80 young scientists and scientist from developing countries.
Selected presentations will be screened and may be published as a special IAG symposium proceeding. Selected presentation from G07 (IGGOS) may be published as a special issue of the Journal of Geodesy. This will be discussed with Peter Teunissen.

16. Bomford Prize.
The evaluation committee elected Ramon Hanssen as winner of the IAG 2003 Bomford Prize

17. Young authors award for 2002.
The issue has been postponed to the next EC meeting in Sapporo.

18. Levallois medal.
The EC elected George Veis of the National Technical University of Athens, Greece for the 2003 Levallois medal.

19. IAG prepresentatives to various bodies.
The EC elected H. Schuh to succeed J. Cambell as IAG representative in the IVS directing board.
The EC decided to recommend IUGG to appoint H. Drewes as official IUGG representative in the UN Cartographic Office

20 DORIS Service.
H. Drewes informed the EC that there would be an application of DORIS to become an official IAG service. CSTG supports the proposal. The EC agreed that the application can be treated by the Bureau once that terms of reference have
been forward, and that the International DORIS Service (IDS) could start in Sapporo, under the condition that Terms of Reference are presented before Sapporo..

21. IAU resolution on celestial reference frames.
The EC decided to bring forward and endorse the IAU resolutions on celestial reference frames to IUGG in Sapporo.

19. Next meeting.
The next EC meeting will be held in Sapporo on Tuesday 1 July from 8.30 –12.30
Ole B. Andersen, IAG assist. gen. secretary

Meeting report

IAG SPONSORES MEETINGS

REPORT ON THE SOUTH AMERICA GEOID 2000

The South America Geoid 2000 workshop held at Escola Politécnica, Universidade de São Paulo, from May 17 to19, 2000, was organized by IGeS (International Geoid Service), SCGGSA (Sub-Commission for Gravity and Geoid in South America), CDC (Committee for Developing Countries) and it was also supported by IAPSO (International Association of the Physical Science of the Ocean). The workshop had the following objectives:

- To assemble as many countries as possible from South America to compute a geoid model.
- To encourage cooperation between oceanographers and geodesists for the computation od geoid in coastal areas.
- To encourage every country to cooperate with SCGGSA for data delivery.
- To encourage every country to compute a local geoid model with the data available.
- To discuss different efforts for data acquisition in the continent.

The countries that participated to the activities were the following:
Argentina, Brazil, Chile, Ecuador, Paraguay and Uruguay.

The program of the workshop (attached) addressed special attention to the geoid, but, airborne gravity and the next special satellites: Champs, GRACE and GOCE received attention too in a lecture.

A decisive contribution to the success of the workshop came from the participation of Riccardo Barzaghi (Italy), René Forsberg (Denmark) and Ole Andersen (Denmark).

One day and half was dedicated to geoid computations. Every country had a computer available with softwares to accomplish the different tasks: Stokes numerical integration, fast Fourier techniques and fast collocation.

A few meetings were also organized to discuss the following topics: SIRGAS, CDC, the new structure of IAG and airborne gravity.

D. Blitzkow.

REPORT OF THE 14TH INT. SYMPOSIUM ON EARTH TIDES (ETS2000)

The 14th International Symposium on Earth Tides (ETS2000) was successfully held in Mizusawa, Japan, during the period from August 28 to September 1, 2000. 137 participants from 21 countries reported fully on their results of continuing researches on Earth tides and thus contributed to the progress of further research of Earth and Planetary Tides.

1. Officers of the Commission
The President of the IAG Commission V (Earth Tides) was elected by the Council of IAG at the IUGG/IAG General Assembly held in Birmingham, UK, in July 1999.Before the opening session of the ETS2000, the President consulted opinion of the National Representatives of the Commission on proposal to ask Jacques Hinderer and Olivier Francis to continue their office until the next IUGG/IAG General Assembly to be held in Sapporo, Japan, in July 2003, and obtained their approval.

At the opening session of ETS2000, the Commission elected J. Hinderer as Vice-President and Francis as Secretary without a dissenting voice. Congratulation to Jacques Hinderer and Olivier Francis, and the best wishes for their future work.

3. ETC Homepage
Now, the ETC Homepage can be seen through the following address,
http://www-geod.kugi.kyoto-u.ac.jp/iag-etc/

4. 2nd ETC Medal

The ETC steering committee decided to award the 2nd ETC Medal (ETC Medal 2000) to the late Prof. Hans-Georg Wenzel for his outstanding contribution to international cooperation in earth tide research. His contribution to gravity and Earth tides researches is so well known through the papers more than 150. He is famous by development of a new tidal potential catalogue, a worldwide synthetic gravity tides model, and the Earth tides data processing package so called ETERNA. With grateful appreciation for the numerous services rendered by Prof. Hans-Georg Wenzel during his lifetime, all participants of ETS2000 paid one-minute's tribute to him with deepest sympathy. The ETC awarded the 2nd ETC Medal to Ms Marion Wenzel at the Opening Session of ETS2000 on August 28 2000 at Mizusawa, Japan.

5. ETC Working Groups
At the opening session of ETS2000, chairpersons of following Working Groups reported their activities,
Working Group 4 "Calibration of Gravimeters", (M.van Ruymbeke),
Working Group 5 "Global Gravity Monitoring", (B. Richter),
Working Group 6 "Earth Tides in Geodetic Space Techniques, (H. Schuh),
Working Group 7 "Analysis of Environmental data for the interpretation of gravity measurements", (G. Jentzsch).

The Earth Tide Commission thanks all members and chairpersons of WGs which have been active during the last period, for their fruitful work.

ETC accepted the conclusions of the reports of the Working Groups and decided according to their wishes:

- To close Working Group 4 (Calibration of Gravimeters, Chairperson: M.van Ruymbeke).
- To close Working Group 5 (Global Gravity Monitoring, Chairperson: B. Richter).
- To extend for another 4 year term the activities of the Working Group 6 (Earth Tides in Geodetic Space Techniques) under the new chairperson-ship.
- To extend for another 4 year term the activities of the Working Group 7 (Analysis of Environmental data for the interpretation of gravity measurements) under the new chairperson-ship.
- To create Working Group 8 on "Gravitational Physics" under the chairperson-ship of Prof. Lalu Manshinha to tackle among others the following scientific problems: The Problem of Aberration: Modern tidal position catalogs assume that the true position of the tide causing body is responsible for the tidal forces, rather than the apparent position, as in optical astronomy. The problem may have consequences, as it may imply relative velocities between the gravity and optical signals. This is a case for experts in Celestial Mechanics and in Earth Tides. The Gravitational Shielding:There is currently no accepted theory of gravity that incorporates or predicts gravitational shielding. The problem is possibly different from the absorption of gravitational radiation by matter. The Earth Tide community should think about, and search for, the consequences of shielding.

6. Directing Board of the International Center for Earth Tides (ICET)
The ICET Directing Board (S.Takemoto (Chair), B.Ducarme, T.F.Baker, D.Crossley, H.T.Hsu and O. Francis (Non-voting member)) met together on August 29, 2000 at the Z-hall in Mizusawa. The main subject for discussion was "Future activity of ICET and re-organization of the IAG services". ICET-DB discussed on the GFFS (Gravity Field and Figure of the Earth Service) proposed by Prof. F. Sanso, which is a new Service including activities of BGI, IGeS and ICET.

Because of a restriction of time, ICET-DB could not draw a conclusion at Mizusawa and decided to continue our discussion by E-mail. ICET-DB will draw a conclusion not later than the end of October 2000.

7. RESOLUTIONS adopted by the Earth Tide Commission
The Earth Tide Commission has adopted the following resolutions at the closing session of the 14th International Symposium on Earth Tides, August 28 - September 1, 2000, Mizusawa, Japan.

1/ Recognizing the importance of the observation of tidal effects and of the determination of tidal parameters by space geodetic techniques,
the ETC recommends
to continue this observational effort;
to compare the results obtained by different space geodetic techniques between each other and with the results of ground based tidal measurements.

2/ Recognizing the importance of the new international services on space geodetic techniques

the ETC recommends
that WG6 establishes or intensifies the cooperation with the analysis coordinators of these international services concerning the tidal modelling.

3/ Considering the new fields of tidal research in lunar and planetary geodesy
the ETC recommends
that the tidal community should take an active part in space missions related to lunar and planetary geodesy ;
requests a proper archiving of the data and metadata acquired during those missions and normal access to the world-wide geodetic community.

4/ Considering the increasing interest of the tidal community to lunar and planetary researches
the ETC recommends
that a session on tides on the planets should be included in the future earth tides symposia.

5/ Recognizing the importance of a global Earth coverage with superconducting gravimeters
for the study of weak geophysical signals,
for the determination of the liquid core resonance parameters,
for the study of the polar motion effects on gravity,
for the intercomparison of the load vectors derived from recent ocean tides models,
for the study of global and regional gravity changes to validate the results of the dedicated satellite missions,
the ETC recommends
to extend the GGP observation period for an additional 6 year period starting July 2003, to maintain the existing sites and to encourage the installation of new GGP stations especially in the Southern hemisphere and in polar regions.

6/ Recognizing the fact that presently the calibration of the superconducting gravimeters participating to the world-wide GGP project is not homogeneous
the ETC recommends
that systematic calibration campaigns with absolute gravimeters should be planned and realized before the end of the current GGP observation period, through an international cooperative effort.

7/ Recognizing the importance to keep in operation several calibration techniques for gravimeters to allow a mutual accuracy control,
the ETC recommends
that inertial calibration platforms and moving mass calibration devices should continue to be developed or maintained besides more usual calibration methods such as intercomparison with absolute or well-calibrated relative instruments.

8/ Recognizing the importance of environmental data for the interpretation of tidal measurements the ETC recommends:

a/ to record the following parameters:
- The barometric pressure, temperature, precipitation, and ground water level. The sampling rate for the recording of environmental parameters should correspond to the sampling rate of the geodynamic data observed. A sufficient resolution and accuracy of the measurements of the environmental parameters should be granted.
- Although the difficulties of monitoring soil moisture are recognized, its is recommended to undertake efforts to realize a continuous monitoring of this parameter.
- The monitoring of wind is also recommended because wind might produce short-period noise as well as long-period modulations.

b/ to correct gravity data in long term studies for local (diameter 100 km), regional (diameter 2000 km), and global atmospheric pressure signals as all three produce significant effects.

c/ to develop correction models for gravity, tilt, and strain related to:
- ground water table variations

- snow, rain and soil moisture
- stress resulting from temperature variations

9/ Noting the importance for tidal measurements of accurate error estimates
and appreciating that such estimates can be made only if the power spectral density of the noise is known
the ETC recommends
to show noise spectra as Power Spectral Density expressed in unit 2/ frequency.

10/ On behalf of all participants of the 14th International Symposium on Earth Tides, the ETC thanks the Japanese National Committee for Geodesy, the Science Council of Japan, the Geodetic Society of Japan, the National Astronomical Observatory of Japan, the City of Mizusawa and the Iwate Prefecture for their generous support to the Symposium.

11/ ETC thanks the Local Organising Committee : Masatsugu Ooe (Chairman), Tadehiro Sato (Secretary) , Jiro Segawa (President of Geodetic Society of Japan) and the staff, for their wonderful welcome and their many efforts in making the 14th International Symposium on Earth Tides a great scientific success.

8. IAG Travel Awards
The following 5 persons are winners of IAG Travel Award.
Alexander Kopaev, (Moscow, Russia), Janusz Bogusz, (Warsaw, Poland), Carla Braitenberg, (Trieste, Italy), Sun He-Ping (Wuhan, P.R. China), Zhigen Yang (Shanghai, P.R. Chin)

9. Publication of the ETS2000
Proceedings of scientific papers will be published as a special issue of the Jour. Geod. Soc. Japan. Other Report on the ETS2000 including the list of participants will be appeared in the next issue of BIM

10. Next Symposium
During the ETS2000, Canadian Colleagues (Profs. D. Smylie, L. Mansinha and S. Pagiatakis) kindly offered to have the next (15th) International Symposium on Earth Tides in Canada in 2004. The Earth Tide Commission acknowledges the receipt of this invitation.
Shuzo Takemoto

IAG/IAPSO JOINT WORKING GROUP ON GEODETIC EFFECTS OF NONTIDAL OCEANIC PROCESSES

Meeting held on March 29, 2001 in Nice, France in conjunction with the XXVI General Assembly of the European Geophysical Society (EGS) during which presentations were given by R. Gross, T. Sato, B. Chao, and A. Brzezinski.

The oceans have a major impact on global geophysical processes of the Earth. Nontidal changes in oceanic currents and ocean-bottom pressure have been shown to be a major source of polar motion excitation and also measurably change the length of the day. The changing mass distribution of the oceans causes the Earth's gravitational field to change and causes the center-of-mass of the oceans to change which in turn causes the center-of-mass of the solid Earth to change. The changing mass distribution of the oceans also changes the load on the oceanic crust, thereby affecting both the vertical and horizontal position of observing stations located near the oceans.

Recognizing the important role that nontidal oceanic processes play in Earth rotation dynamics, an IAG/IAPSO Joint Working Group on Geodetic Effects of Nontidal Oceanic Processes was formed at the XXII General Assembly of the IUGG in Birmingham. The objective of this IAG/IAPSO Joint Working Group is to investigate the effects of nontidal oceanic processes on the Earths rotation, deformation, gravitational field, and geocenter, and to foster interactions between the geodetic and oceanographic communities in order to promote greater understanding of these effects. R. Gross described the International Earth Rotation Service (IERS) Special Bureau for the Oceans (SBO). The IERS Special Bureau for the Oceans is one of seven Special Bureaus of the IERS Global Geophysical Fluids Center

(GGFC) which was established on January 1, 1998 in order to help relate dynamical properties of the atmosphere, oceans, mantle, and core to motions of the Earth, including its rotation. In particular, the IERS

Special Bureau for the Oceans is responsible for collecting, calculating, analyzing, archiving, and distributing data relating to nontidal changes in oceanic processes affecting the Earth's rotation, deformation, gravitational field, and geocenter. The oceanic products available through the IERS SBO are produced primarily by general circulation models of the oceans that are operated by participating modeling groups and include oceanic angular momentum, center-of-mass, bottom pressure, and torques. Through the IERS SBO web site at http://euler.jpl.nasa.gov/sbo, oceanic data can be downloaded and a bibliography of publications pertaining to the effect of the oceans on the solid Earth can be obtained. Currently, two different oceanic angular momentum data sets are available. The IERS SBO is one possible source of data that can be used by the IAG/IAPSO Joint Working Group in their investigations on the geodetic effects of nontidal oceanic processes.

T. Sato discussed the effect of sea surface height variations on superconducting gravimeter measurements. Good agreement with gravity measurements at 3 different sites were obtained using results from both an ocean model and from TOPEX/POSEIDON measurements which had been corrected for the steric changes in sea surface height that have no gravitational signature. This study of the results of gravity observations clearly shows that gravity measurements from satellites and on the ground have an important role to play when studying the effects of oceanic variability on the local and global geophysical processes of the Earth. He then presented plans for deploying ocean- bottom pressure recorders off the coast of Japan at TOPEX and Jason-1 crossover points.

As the mission scientist for the GRACE Mission Office, B. Chao discussed the use of oceanic general circulation models to dealias GRACE gravitational field measurements. The GRACE project is currently planning on producing gravitational field solutions at monthly intervals. Since the distribution of mass within the oceans changes more rapidly than this, the gravitational effect of this rapid oceanic mass movement will be aliased in the monthly solutions unless it is modeled and removed from the GRACE measurements. A barotropic, or perhaps a baroclinic, ocean model driven by either NCEP or ECMWF surface winds and fluxes will likely be operated by the GRACE project in order to model and remove the high frequency variations in oceanic mass distribution that will not be sampled by the GRACE monthly gravitational field solutions. Since this scheme will most likely not be able to perfectly remove the aliased signals, the user community should be cognizant of the uncertainties that will be introduced by this procedure. Similar aliasing effects are also expected to occur due to rapid atmospheric, hydrologic, and ocean-tidal mass movement, and the GRACE project is also planning to use atmospheric and ocean tide models to similarly remove these effects.

A. Brzezinski summarized the results on the oceanic excitation of the Chandler wobble that he and J. Nastula presented at the 33rd COSPAR Scientific Assembly held in Warsaw, Poland during July 16-23, 2000 (to appear in Advances in Space Research). Using the POLE98 polar motion series, the NCEP/NCAR reanalysis atmospheric angular momentum series obtained from the IERS Special Bureau for the Atmosphere, and the 11-year-long oceanic angular momentum (OAM) series of Ponte et al. (J.Geophys. Res., vol. 104, pp. 23393-23409, 1999) obtained from the IERS SBO, they demonstrated that the OAM series is highly coherent with the lacking non-atmospheric excitation of the observed Chandler wobble signal. In terms of the excitation power, the combined effect of the atmosphere and ocean explains about 80% of the free wobble, which agrees to within 1-sigma uncertainty with the result recently published by R. Gross (Geophys. Res.Lett., vol. 27, pp. 2329-2332, 2000).

B.

The next meeting is scheduled to be held in conjunction with the XXVII General Assembly of the EGS that will be held in Nice, France during April 22-26, 2002. The exact date and time of this meeting will be announced later. In order to receive announcements of this and all future meetings, please contact Richard Gross at richard.Gross@jpl.nasa.gov.
R. Gross

FIRST INTERNATIONAL SYMPOSIUM ON ROBUST STATISTICS AND FUZZY TECHNIQUES IN GEODESY AND GIS, ZURICH, SWITZERLAND, MARCH 12-16, 2001

The 'First International Symposium on Robust Statistics and Fuzzy Techniques in Geodesy and GIS' took place at the Swiss Federal Institute of Technology (ETH) in Zurich, Switzerland, from March 12-16, 2001. It was initiated by the members of the Special Study Group (SSG) 4.190 of the International Association of Geodesy (IAG) on 'Non-probabilistic assessment in geodetic data analysis'. It was organized by Prof. A. Carosio, ETH Zurich,, and Dr. H. Kutterer, DGFI Munich, chairman of the SSG. Nearly 60 participants from 15 countries attended the symposium.

The program of the meeting consisted of applications of robust statistics and fuzzy theory, mainly in the fields of geodetic engineering, deformation analysis, geographic information systems, satellite-based positioning (GPS), and photogrammetry. Therefore five technical sessions and a panel discussion were organized. In advance, two tutorials were given on robust statistics (A. Carosio) and on fuzzy logic (H. Kutterer, S. Schön) on monday, March 12.

The symposium was opened on tuesday, March 13, with a welcome address by Prof. B. Heck, University of Karlsruhe, president of the IAG section IV. Two invited lectures followed. The first one was presented by Prof. F. Hampel, ETH Zurich, who considered both the historical development of robust statistics and recent mathematical problems. The second one was given by Prof. R. Viertl, Technical University of Vienna, who motivated the non-precision approach and showed the application of statistical methods to non-precise data based on the extension principle of fuzzy theory. H. Kutterer gave the last lecture in this session on a general viewpoint of uncertainty assessment.

In the technical session on geodetic engineering four talks were focussed on robust statistics: kinematic positioning (Y. Yang), the BIBER estimator (F. Wicki), and the reliability of robust estimators (M. Berber, S. Hekimoglu). One talk considered the use of interval mathematics for the measurement uncertainties (S. Schön). L. Soukup discussed 'least squares without minimization'.

The second technical session on deformation analysis showed a variety of different assessment methods: a conic fitting algorithm (O. Akyilmaz), inference on deformation measures like strain tensors (J. Cai), fuzzy deformation analysis (K. Heine), Plucker coordinates (R. Jurisch), artificial neural networks (J. B. Miima), modelling alternatives in deformation measurements (D. Rossikopoulos), and maximum correlation adjustment (F. Neitzel).

The third session which was on Geographic Information Systems (GIS) consisted of four talks, three using fuzzy logic (G. Joos, S. Keller, E. Stefanakis) and one on robust estimation techniques (E. Kanani). The following session was dedicated to GPS data processing and analysis: real-time prediction of failures (C. Dacheng), robust techniques (A. Wieser, Y. Yang), and fuzzy methods (S. Leinen, H. Kutterer).

The last technical session of the symposium was on photogrammetry, remote sensing, and image processing. F. Sanso discussed the Wiener-Kolmogorov prediction problem with the application to digital terrain models. L. Mussio considered semantic ambiguity questions for pattern recognition. M. Scaioni showed the use of the LMS estimator for outlier rejection in automatic aerial triangulation.

The last day of the symposium started with an introductory talk by F. Sanso on the challenges for the IAG in data analysis in the fields of geodesy and GIS, especially regarding the modelling of uncertainty by probabilistic and non-probabilistic techniques. A panel discussion on data analysis within IAG closed the symposium.

The proceedings of the symposium are published as Report No. 295 of the Institute of Geodesy and Photogrammetry of the Swiss Federal Institute of Technology Zurich (ETH). Further information can be found on the website of the IAG SSG 4.190. The address is www.dgfi.badw.de/ssg4.190. Last but not least a warm thanks goes to the local committee around A. Carosio at the ETH Zurich for the excellent organization of the symposium.

H. Kutterer

IAG Subcommission for Europe (EUREF)

The 11th symposium of the EUREF Subcommission was held in Dubrovnik from 16. - 19.5.2001. Proceedings will be published in AMitteilungen des Bundesamtes für Kartographie und Geodäsie@.

On this symposium the following resolutions were adopted:

Resolution No. 1
The IAG Subcommission for Europe (EUREF)
recognising that
-in May/June 1994 the EUREF-SLOCRO-94 campaign in Slovenia and Croatia was observed,
-in September/October 1995 the Slovenia-95 and CROREF-95 campaigns in Slovenia and Croatia were observed,
-in August/September 1996 the CROREF-96 campaign in Croatia was observed,
and all the results were submitted to the EUREF Technical Working Group as a combined EUREF-CRO-94/95/96 solution, where it was accepted as class B standard (about 1 cm at the epoch of observations)

endorses the subsets of points for Croatia submitted to the EUREF Technical Working Group as improvements and extensions of EUREF89,

but considering that two points in Croatia observed during the EUREF-CROSLO-94 campaign were destroyed,

recommends that all old Croatian points should be deleted from the EUREF database and replaced by the subset of points selected from the EUREF-CRO-94/95/96 solution.

Resolution No. 2
The IAG Subcommission for Europe (EUREF)

considering
- the availability of the ITRF2000 as an improved and accurate realisation of the ITRS,
-the improved determination of the rotation of the Eurasian plate using ITRF2000 site velocities,
recommends to replace the NNR-NUVEL-1A rotation rate values by the ones derived from ITRF2000 in the transformation formula linking ETRS89 to ITRS.

Resolution No. 3
The IAG Subcommission for Europe (EUREF)

recognising the significant practical and scientific value of the EVRS

noting the usefulness of improving its realisation EVRF2000

asks national levelling data providers to UELN/EUVN to inform the Technical Working Group on the tidal system and other corrections used,

recommends that in the future levelling data be submitted in the zero tidal system according to the EVRS definition and corresponding IAG resolution 16, 1983.

Resolution No. 4
The IAG Subcommission for Europe (EUREF)

recognising
-the European Vertical GPS Reference Network (EUVN) with its GPS-derived ellipsoidal heights and levelled connections to UELN,
-the definition of the European Vertical Reference System EVRS with its first realisation UELN 95/98, called EVRF2000,
considering
-this implicit pointwise realisation of a European geoid consistent with both ETRS89 and EVRS,
-the existence of a large number of regional and local geoids in Europe,

-the urgent need by the navigation community for a height reference surface,

asks its Technical Working Group and the European Subcommission of the IAG IGGC (International Gravity and Geoid Commission) to take all necessary steps to generate a European geoid model of decimetre accuracy consistent with ETRS89 and EVRS.

Resolution No. 5
The IAG Subcommission for Europe (EUREF), which held its eleventh EUREF symposium in Dubrovnik from May 16-18, 2001, expresses its heartfelt thanks to the Local Organising Committee, its chairman ZELJKO BACIC and the State Geodetic Administration, as well as the Cadastre Office in Dubrovnik and the International Centre of Croatian Universities, for organising the symposium and for the excellent arrangements resulting in a very successful meeting.

Joao Agria Torres, Lisbon: jatorres@ipcc.pt
Helmut Hornik, Munich: hornik@dgfi.badw.de

MEETING REPORTS

FIRST INTERNATIONAL SYMPOSIUM ON ROBUST STATISTICS AND FUZZY TECHNIQUES IN GEODESY AND GIS
ZURICH, SWITZERLAND, MARCH 12-16, 2001

The 'First International Symposium on Robust Statistics and Fuzzy Techniques in Geodesy and GIS' took place at the Swiss Federal Institute of Technology (ETH) in Zurich, Switzerland, from March 12-16, 2001. It was initiated by the members of the Special Study Group (SSG) 4.190 of the International Association of Geodesy (IAG) on 'Non-probabilistic assessment in geodetic data analysis'. It was organized by Prof. A. Carosio, ETH Zurich, and Dr. H. Kutterer, DGFI Munich, chairman of the SSG. Nearly 60 participants from 15 countries attended the symposium.

The program of the meeting consisted of applications of robust statistics and fuzzy theory, mainly in the fields of geodetic engineering, deformation analysis, geographic information systems, satellite-based positioning (GPS), and photogrammetry. Therefore five technical sessions and a panel discussion were organized. In advance, two tutorials were given on robust statistics (A. Carosio) and on fuzzy logic (H. Kutterer, S. Schön) on monday, March 12.

The symposium was opened on tuesday, March 13, with a welcome address by Prof. B. Heck, University of Karlsruhe, president of the IAG section IV. Two invited lectures followed. The first one was presented by Prof. F. Hampel, ETH Zurich, who considered both the historical development of robust statistics and recent mathematical problems. The second one was given by Prof. R. Viertl, Technical University of Vienna, who motivated the non-precision approach and showed the application of statistical methods to non-precise data based on the extension principle of fuzzy theory. H. Kutterer gave the last lecture in this session on a general viewpoint of uncertainty assessment.

In the technical session on geodetic engineering four talks were focussed on robust statistics: kinematic positioning (Y. Yang), the BIBER estimator (F. Wicki), and the reliability of robust estimators (M. Berber, S. Hekimoglu). One talk considered the use of interval mathematics for the measurement uncertainties (S. Schön). L. Soukup discussed 'least squares without minimization'.

The second technical session on deformation analysis showed a variety of different assessment methods: a conic fitting algorithm (O. Akyilmaz), inference on deformation measures like strain tensors (J. Cai), fuzzy deformation analysis (K. Heine), Plucker coordinates (R. Jurisch), artificial neural networks (J. B. Miima), modelling alternatives in deformation measurements (D. Rossikopoulos), and maximum correlation adjustment (F. Neitzel).

The third session which was on Geographic Information Systems (GIS) consisted of four talks, three using fuzzy logic (G. Joos, S. Keller, E. Stefanakis) and one on robust estimation techniques (E. Kanani). The following session was dedicated to GPS data processing and analysis: real-time prediction of failures (C. Dacheng), robust techniques (A. Wieser, Y. Yang), and fuzzy methods (S. Leinen, H. Kutterer).

The last technical session of the symposium was on photogrammetry, remote sensing, and image processing. F. Sanso discussed the Wiener-Kolmogorov prediction problem with the application to digital terrain models. L. Mussio considered semantic ambiguity questions for pattern recognition. M. Scaioni showed the use of the LMS estimator for outlier rejection in automatic aerial triangulation.

The last day of the symposium started with an introductory talk by F. Sanso on the challenges for the IAG in data analysis in the fields of geodesy and GIS, especially regarding the modelling of uncertainty by probabilistic and non-probabilistic techniques. A panel discussion on data analysis within IAG closed the symposium.

The proceedings of the symposium are published as Report No. 295 of the Institute of Geodesy and Photogrammetry of the Swiss Federal Institute of Technology Zurich (ETH). Further information can be found on the website of the IAG SSG 4.190. The address is www.dgfi.badw.de/ssg4.190. Last but not least a warm thanks goes to the local committee around A. Carosio at the ETH Zurich for the excellent organization of the symposium.

H. Kutterer

SECOND INTERNATIONAL SYMPOSIUM: GEODYNAMICS OF THE ALPS-ADRIA AREA BY MEANS OF TERRESTRIAL AND SATELLITE METHODS

Last autumn the beautiful city of Dubrovnik became a meeting point of the international geodetic community again. It was after a long interruption lasting almost exactly 9 years. In 1989 the participants of the First International Symposium on Gravity Field Determination and GPS-Positioning in the Alps-Adria Area left the Dubrovnik Inter-University Centre, the venue of the symposium, with a believe that they will reconvene at the same place in four years. However, the reality and the difficult time in this area prepared another development.

Only last year the reconstructed Inter-University Centre of Dubrovnik became the venue of the Second International Symposium: Geodynamics of the Alps-Adria Area by means of Terrestrial and Satellite Methods which was held here between September 28 and October 2, 1998. The symposium was sponsored by the International Association of Geodesy and it also had a generous local support. In total 43 interesting papers were presented by scientists coming from 9 different countries to the audience of over 70 participants. The meeting was organized by Prof. K. Èoliæ (as the local organizer, University of Zagreb) and Prof. H. Moritz (as the international co-organizer).

At the opening session a number of addresses was presented by local and international representatives. Then the participants of the symposium heard a very interesting lecture by K. Èoliæ and H. Moritz on Rudjer Boškoviæ (1711-1787), a native of Dubrovnik and a remarkable figure in the history of modern European science who also made considerable contributions to geodesy and geophysics.

The symposium itself was subdivided into 10 session: 3 sessions were devoted to Geodynamics and chaired subsequently by H. Seeger, G. Rossi and C. Marchesini. Then G. Schmitt chaired a session on Geoid, F. Vodopivec a session on GPS, P. Holota a session on Positioning and Gravity, P. Pesec chaired a session on CERGOP, E. Groten a session on the Theory and finally two session devoted to practical works were chaired by A. Zeman and K. Kaniuth.

The first session on Geodynamics started with a paper by Hussein A. Abd-Elmotaal who discussed inverse Vening Meinesz Moho depths for the Eastern Alps. Then Z. Altiner et al. presented a talk on crustal deformations in the Adriatic sea area as inferred on the basis of GPS observations. Subsequently, E. Groten and St. Leinen treated deformation monitoring around a large viaduct close to Istambul using GPS and levelling. Finally, F. Vodopivec and D. Kogoj discussed the geodynamics in Slovenia and A. Zeman approached a problem of estimating vertical dynamics on the territory of former Austro-Hungarian empire on the bases of results of historical levellings.

The second session on Geodynamics was opened by A. Caporali who in his talk attacked a problem of constraining the rheology of continental lithosphere near Orogens with the use of Bouguer gravity anomalies.

The programme of the session continued with a paper by D. Miškoviæ on problems of national reference frame and geodynamic investigations in Slovenia. Then B. Richter et al. discussed absolute gravity measurements in Croatia approached as a standardized base net for geodynamic, height and gravity studies. Finally, G. Schmitt and C. Marchesini informed about geodetic activities with respect to geokinematics in Friuli and the Eastern Alps.

At the last session on Geodynamics E. Prelogiæ et al. treated recent tectonic movements and earthquakes in Croatia and then G. Rossi and M. Zadro discussed geodynamic processes at the northern boundary of Adria plate, especially strain-tilt measurements and modelling. The session was closed with a paper by P. Vyskoèil (presented in absentia by H. Moritz) on the map of vertical movements of Dinaridies Eastern Alps, Pannonian Basin and the Bohemian Massif.

As already mentioned, together with geodynamics oriented sessions there were also sessions on closely related topics in Dubrovnik.

The paper by H. Abd-Elmotaal et al. *stared the Geoid session*. The talk was devoted to the influence of implementing the seismic Moho depths in geoid computation. K. Arsov and H. Sünkel approached the problem of influence of the resolution of DEM in gravity reduction. They used fractal models of the topography for their analyses. E. Groten and K. Seitz discussed a detailed geoid of Germany based on EGM96. N. Kühtreiber presented a recent geoid computation for Audtria and N. Kühtreiber et al. then concluded the session with results of a geoid computation for the central part of the Alps-Adria area.

At the GPS session A. Caporali devoted his talk to an analysis of a GPS network along the Alpine Arc. K. Kaniuth and Stuber attacked the problem of accuracy and reliability of height estimates in regional GPS networks. H. Seeger et al. contributed with results of a re-computation of the EUREF GPS campaigns in Croatia and Slovenia. Finally, M. Marjanoviæ and Lj. Rašiæ discussed the results of the EUREF 1997 GPS campaign in Croatia.

Also the Gravity was discussed at a separate session. Here J. Flury brought an information on a local gravity filed determination in the Estergebirge. E. Gueguen and C. Doglioni discussed the geodynamic evolution of the Appeninic subduction. R. Marjanoviæ-Kavanagh contributed with experiences with a new digital tiltmeter and G. and G.K. Walach presented a Bouguer gravity map of Styria.

The session on CERGOP was opened by D. Miškoviæ et al. They presented results of the GPS-measurements in the Bovec-Tolmin earthquake region. H. Düller and P. Pesec contributed with information on the Austrian permanent GPS-network. P. Pesec then summarized the current status of the Austrian IDNDR project (Crustal dynamics of the Adriatic microplate and the adjacent East-Alpine area). Finally, J. Šimek discussed possible topics for the international cooperation within CEI/CERGOP on the background of current European project.

Within theory oriented session the audience heard a contribution by P. Holota on Galerkin's method in the determination of the disturbing potential. Then an analysis of a straight line equation by M. Lapaine and new concepts of boundary value problems of physical geodesy after GPS presented by H. Moritz.

Finally, *two working sessions were devoted to practical works*. Here K. Èoliæ et al. contributed with two talks: on the survey of the Plitvice-lakes (the phenomenon in the Karst of the Dinaric Alps with satellite and terrestrial measurements) and on the 3-D geodynamic network of broader area of the city of Zagreb. Then Z. Kapoviæ et al. presented results of the geodynamic research of the historical center in the city of Dubrovnik with precise geometric levelling. Subsequently M. Plazibat approached linear transformation between old and new national networks by means of finite elements and M. Solariæ discussed a visibility analysis of GPS satellites in Central Europe.

At the closing session (chaired by B. Gajèeta) the participants adopted a number of important resolutions. They are as follows:
Resolution 1 - The Symposium,

> *recognizing* the need of a regular exchange of ideas and research results in the field of the 'tectonic scenario' in the wider Alps-Adriatic region and
> *having in mind* the hospitality of the Croatian colleagues,
> *recommends* regular meetings in a four years cycle in the city of Dubrovnik, with one intermediate meeting at a different place between two of these symposia.

Resolution 2 - The Symposium,

recognizing the need of further research concerning the 'tectonic scenario' in the wider Alps-Adriatic region and of studies concerning earthquake disaster prevention in this region,

recommends the establishment of a corresponding Special Study Group in Section V 'Geodynamics' of IAG, with due relation to CERGOP.

Resolution 3 - The Symposium,

considering that the area of the Plitvice Lakes is not only a National Heritage under the patronage of UNESCO (No. 148), but also very important for different reasons such as Dinaric Karst geology, effect of tourism etc. and

considering that important geodetic and geodynamical studies have already been performed by the Geodetic Faculty of Zagreb University,

recommends that this area be declared an *International Geodynamic Test Area* in which all relevant geodetic methods are to be applied.

Resolution 4 - The Symposium,

recognizing the need of permanent GPS stations and

considering the existence of such stations e.g. in Croatia and Slovenia.

recommends the establishment of at least one permanent GPS station on the territory of Bosnia and Herzegovina.

Resolution 5 - The Symposium,

recognizing the great and successful efforts of Prof. Èoliæ and Prof. Moritz and their staff in preparing and organizing this symposium and

appreciating the importance of the topics under consideration for applied and theoretical surveying, geodesy, geodynamics and related practical activities by universities and state organizations in and around the Alpine-Adriatic Area up to the Panonnian Basin,

expresses its sincere thanks for the wonderful days in the beautiful city of Dubrovnik, which is under the patronage of UNESCO (No. 149), and in the stimulating environment of IUC in free Croatia.

The scientific programme of the symposium was enriched by the presentation of the book by H. Horitz: Science, Mind and the Universe (U. Wichmann Vlg., Heidelberg, 1995) and its translation into Croatian. On this occasion an introductory lecture was held by Acad. N. Trinajstiæ who gave an interesting outline of philosophy and discussed its contemporary trends.

The participants of the symposium spent nice and well organized time together and during an interesting excursion had a possibility to learn more about the marvelous city of Dubrobnik and its beautiful surrounding. The symposium was a clear success. The Proceedings will be published by the Geodetic Survey of Croatia.

P. Holota

REPORT ON THE INTERNATIONAL CONFERENCE ON TECHNICAL ASPECTS OF MARITIME BOUNDARY DELINEATION AND DELIMITATION, INCLUDING UNCLOS ARTICLE 76 ISSUES (ABLOS), MONACE, 9-10 SEPTEMBER, 1999.

Seventy-six attendees from twenty-nine countries were present at the Conference. In addition the International Hydrographic Bureau (IHB) personnel, members of the UN Commission on the Outer Limits of the Continental Shelf and the UN Division of Ocean Affairs and Law of the Sea participated. The sessions and papers were organised by the Conference Committee chaired by P. Vaniçek, chairman of ABLOS, and the Conference Proceedings, containing the 26 paper presented, will be produced by the IHB.

The Conference was divided into four sessions over a span of two days. In the first session, "Issues concerning the UN Commission on the Limits of the Continental Shelf", convened by G. Carrera, topics related to the approach of the UN CLCS to submissions made by coastal states were considered in contributions presented by members of the Commission. The following papers were delivered: CROKER, Peter, CLCS Member (Ireland), "The mandate and work of the Commission on the Limits of the Continental Shelf".HINZ, Karl, CLCS Member (Germany), "A review of continental margins of the world". LAMONT Iain, CLCS Member (New Zealand), "Formulating the New Zealand Continental Shelf Claim: A First Step". BREKKE, Harald, CLCS Member (Norway), "Uncertainties and errors in sediment thickness". CARRERA, Galo, CLCS Member (Mexico) "Wide continental margins of the world: a survey of marine scientific requirements and international regional cooperation needs posed by the implementation of Article 76 of UNCLOS". ALBUQUERQUE, Alexandre and CARRERA, Galo, CLCS Members (Brazil and Mexico) "Information on the outer limits of the extended continental shelf".

The second session, "Geodetic issues, with emphasis on errors in maritime boundaries and how to reduce them", convened by B.G. Harsson, dealt with specifically geodetic problems of delineation and delimitation of maritime boundaries. The following papers were delivered: CARRERA, Galo, (Canada) "The impact of the seabed roughness on the location of the outer limits of the extended continental shelf". GROTEN, Erwin, (Germany) "Coastal Boundaries and Vertical Datums. VANIÇEK, Petr, (Canada) "Propagation of errors from shore baselines seaward".SJOBERG, Lars, M Fan and Milan Horemuz, (Sweden) "Accuracy of computed points on a median line, factors to be considered", MURPHY, Brian, Philip Collier, David Mitchel andl Bill Hirst., (Australia) "Maritime zone boundary generation from straight baselines defined as geodesics". OSZCZAK, Stanislaw, A.Wasilewski, Z.Rzepecka (Poland) " RTK/ DGPS service in maritime boundary delimitations". ELEMA, I. and Kees de JONG, (The Netherlands) "The determination of boundaries at sea between Belgium and The Netherlands".

The third session, "Tools needed for boundary delimitations", convened by R. Macnab, dealt specifically with hardware and software that would be necessary to obtain the data to substantiate a continental shelf claim. The following papers were delivered: PALMER, Hal, Lorin Pruett, and Kurt Christensen, (USA), "GIS applications to maritime limit and boundary delimitation". MONAHAN, David, Michael S. Loughridge, Meirion T Jones, Larry Mayer, (Canada, USA, UK) "A model for using publicly available data and methodologies to begin preparing a claim to an extended continental shelf under article 76 of the United Nations Convention on Law of the Sea (UNCLOS)". MONAHAN, David and Larry Mayer, (Canada) "An examination of publicly available bathymetry data sets using digital mapping tools to determine their applicability to Article 76 of UNCLOS". HIRST, Bill, Brian Murphy and Phil Collier, (Australia) "An Overview of Australian Maritime Zone Boundary Definition". BORISSOVA, Irina Philip A. Symonds, Robin Gallagher, Bruce C. Cotton and Gail Hill, (Australia) "A set of integrated tools based on ArcView for defining the outer limit of Australia's continental shelf". BENNETT, John, (USA) "Contrast of the 'Surface of Directed Gradients' with the 'Surface of Maximum Curvature' to compute the foot of the continental slope". HARDING, Jennifer, Herman Varma, John Hart and Ron Macnab, (Canada) "The HH code: facilitating the management, manipulation, and visualization of bathymetric data".

In the last session, "Other issues and case studies (not necessarily related to Article 76)", convened by C. Rizos, specific issues and case studies were the subjects of discussion. The following papers were delivered: MONAHAN, David and David Wells, (Canada) "Achievable uncertainties in the depiction of the 2500m contour and their possible impact on continental shelf delimitation". MACNAB, Ron, (Canada) "Article 76 in the Arctic - a catalyst for international collaboration". CHERKASHOV, Georgi, A., Gramberg I.S. Makorta A.P., Kaminsky V.D., Naryshkin G.D., Poselov V.A., Sorokin M.Yu. (Russia) "Bathymetry and Deep Structure of the Arctic Continental Margin of Russia in the context of article 76 UN Convention on the Law of the Sea". COAKLEY, Bernard, (USA) "Contribution of the SCICEX Project Towards the Implementation of Article 76 of the UN Convention on the Law of the Sea in the Arctic Ocean". SYMONDS, Phil, (Australia) "Austalia's approach to defining its extended continental shelf: progress and issues arising".

The Conference, staged in the beautiful new offices of IHB, was considered a great success and a possibility that a bi-annual ABLOS-sponsored conference could become a regular international venture in Monaco was discussed. It was the first time that the IHB offices have been utilised for a conference of this format and it was evident that the facilities would not be adequate to support a conference wit a larger number of participants. It is anticipated that the assistance of the Principality of Monaco will have to be sought if this was to become a regular venture.
P. Vaniçek

MEETING REPORT OF THE IAG/IAPSO JOINT WORKING GROUP ON GEODETIC EFFECTS OF NONTIDAL OCEANIC PROCESSES HELD IN CONJUGATION WITH THE EGS XXV GENERAL ASSEMBLY, NICE, FRANCE, APRIL, 2000.

The oceans have a major impact on global geophysical processes of the Earth. Nontidal changes in oceanic currents and ocean-bottom pressure have been shown to be a major source of polar motion excitation and also measurably change the length of the day. The changing mass distribution of the oceans causes the Earth's gravitational field to change and causes the center-of-mass of the oceans to change which in turn causes the center-of-mass of the solid Earth to change. The changing mass distribution of the oceans also changes the load on the oceanic crust, thereby affecting both the vertical and horizontal position of observing stations located near the oceans. Products of oceanic general circulation models (OGCMs) have been used to study these and other geodetic effects of nontidal oceanic processes. Data assimilation systems similar to those employed in numerical weather prediction are beginning to be used with OGCMs to improve their fidelity. In the near future, time-varying gravitational field measurements, which over the oceans can be interpreted as time-varying ocean-bottom pressure measurements, will be available from the CHAMP and GRACE satellites. The assimilation of these new data types into OGCMs can be expected to further improve the accuracy of global ocean models, and hence the accuracy of the predicted effects of oceanic processes on the Earth's rotation, deformation, gravitational field, and geocenter.

Recognizing the important role that nontidal oceanic processes play in Earth rotation dynamics, an IAG/IAPSO Joint Working Group on Geodetic Effects of Nontidal Oceanic Processes was formed at the XXII General Assembly of the IUGG in Birmingham. The objective of this IAG/IAPSO Joint Working Group is to investigate the effects of nontidal oceanic processes on the Earth_s rotation, deformation, gravitational field, and geocenter, and to foster interactions between the geodetic and oceanographic communities in order to promote greater understanding of these effects. A meeting of this IAG/IAPSO Joint Working Group was held on April 27, 2000 in Nice, France in conjunction with the 25th General Assembly of the European Geophysical Society during which presentations were given by Rui Ponte, Chris Hughes, and Richard Gross.

Rui Ponte discussed an oceanographic data assimilation system being created by collaborators from the Massachusetts Institute of Technology (MIT), the Scripps Institution of Oceanography, and the Jet Propulsion Laboratory. The ocean model component of the data assimilation system, originally developed at MIT, is currently run on a 2x2 degree horizontal grid with constant mixing coefficients and a simple convective adjustment scheme. Future improvements will include finer resolution, more realistic mixed layer physics and eddy parameterizations, and relaxation of the volume conserving formulation. The oceanographic data currently being assimilated include altimetric measurements of sea surface height, hydrographic sections, and sea surface temperature measurements. Other types of data (e.g., floats, XBT profiles) will also be included in the future. Routine calculation of oceanic angular momentum and torque quantities from the output of the assimilation system is envisioned.

Chris Hughes described the GLObal Undersea Pressure (GLOUP) data bank. For more information about GLOUP and/or to obtain the series of historical ocean-bottom pressure measurements see the GLOUP home page at http://www.pol.ac.uk/psmslh/gloup/gloup.html.

Richard Gross described the International Earth Rotation Service (IERS) Special Bureau for the Oceans (SBO). The IERS Special Bureau for the Oceans is one of seven Special Bureaus of the IERS Global Geophysical Fluids Center (GGFC) which was established on January 1, 1998 in order to help relate dynamical properties of the atmosphere, oceans, mantle, and core to motions of the Earth, including its rotation. In particular, the IERS Special Bureau for the Oceans is responsible for collecting, calculating, analyzing, archiving, and distributing data relating to nontidal changes in oceanic processes affecting the Earth's rotation, deformation, gravitational field, and geocenter. The oceanic products available through the IERS SBO are produced primarily by general circulation models of the oceans that are operated by participating modeling groups and include oceanic angular momentum, center-of-mass, bottom pressure, and torques. Through the IERS SBO web site at http://euler.jpl.nasa.gov/sbo, oceanic data can be downloaded and a bibliography of publications pertaining to the effect of the oceans on the solid Earth can be obtained. Currently, two different oceanic angular momentum data sets are available. The IERS SBO is therefore one possible source of data that can be used by the IAG/IAPSO Joint Working Group in their investigations on the geodetic effects of nontidal oceanic processes.

Meetings of the IAG/IAPSO Joint Working Group on Geodetic Effects of Nontidal Oceanic Processes are planned to be held twice-per-year in conjunction with major conferences in order to foster interactions on this topic between the geodetic and oceanographic communities. These meetings, which are open to all interested individuals, will generally be held in the Spring in conjunction with the EGS conference in Europe and in the Fall in conjunction with the Fall AGU conference in the United States. The next meeting will be held in conjunction with the Fall 2000 AGU conference in San Francisco, California during December 15-19, 2000 with the exact date and time to be announced later. In order to receive announcements about this and all future meetings, please contact Richard Gross by sending an email message to him at

Richard.Gross@jpl.nasa.gov R. Gross

WORKING MEETING OF THE IAG SSG 4.190 ON NON-PROBABILISTIC ASSESSMENT IN GEODETIC DATA ANALYSIS

The first working meeting of the IAG SSG 4.190 took place at the Geodetic Institute, University of Karlsruhe (GIK), on April 7, 2000. 11 members and corresponding members were participating. The meeting was opened with a welcome note by B. Heck, president of the IAG Section IV on General Theory and Methodology. H. Kutterer, chairman of the SSG, continued with a short review of the terms of reference and objectives. The main part of the meeting consisted of oral presentations by members of the SSG on the topics fuzzy-theory (E. A. Shyllon, K. Heine), robust estimation (A. Carosio), artificial neural networks (J. B. Miima), interval mathematics (S. Schön), GIS for local geoid computation (M. Brovelli), and on general uncertainty theory (H. Kutterer).
It was decided to have annual closed working meetings of the SSG. Besides, it is planned to organize an open international workshop on robust and fuzzy techniques in March 2001 in Zürich.
The financial support of the stay of E. A. Shyllon by the IAG is gratefully acknowledged as well as the sponsoring of the organization of the meeting by the GIK.

H. Kutterer

Meeting Reports

Minutes of the Organizational Meeting for African Reference System "AFREF"
Held April 27, 2000, Centre Universitaire Mediterranean (CUM), Nice, France

Meeting Objective:
Discuss possible organization of a project to establish a common geodetic reference system throughout Africa compatible with the International Terrestrial Reference System (ITRF). Discuss ways to involve the international geodesy community to work with African nations to develop a single, uniform, continental geodetic reference
system meeting international standards to replace the myriad national reference systems, many of which have not been maintained, and are out of date and inaccurate.

Meeting Organization:
Called by Claude Boucher, head of Commission X of the International Association of Geodesy (IAG) "Global and Regional Networks", also head of the ITRF and the representative of the International Earth Rotation Service (IERS) to the International GPS Service (IGS). The IGS is active globally in supporting the mission of the IAG & IERS/ITRF through the techniques and applications of the Global Positioning System (GPS). GPS is the most economical and widely accessible modern geodetic technology for realizing a continental reference network throughout Africa.

Executive Summary
The decision was taken at this preliminary meeting to pursue the coordination of a project designated "AFREF", the objective of which is to establish a continental, robust and homogenous geodetic reference system throughout Africa. Africa remains the only continent with paucity of satellite geodetic measurements, especially GPS observations, either episodic, or continuous. There are a few notable exceptions: locations in South Africa, single stations in Malindi, Kenya; Mas Palomas, Canary Islands, Spain; Libreville, Gabon and at previous times a station each in Ghana and Cote 'd Ivorie.

Difficulties of in-country support, communications, reliable infrastructure and lack of resources hinder permanent, high quality GPS station implementations a Helwan, Egypt; Adis Ababa, Ethiopia; Rabat, Morocco; and Kampala, Uganda, for example, where equipment have been installed.
This meeting and earlier ad-hoc discussions have highlighted the importance of a renewed effort to realize a reference system for this continent through international collaboration directly with the African nations. It was emphasized that the must truly be a joint effort with Africans to be successful and that it must focus on the transfer of appropriate technology to sustain the references with modern instrumentation, e.g. GPS and other satellite techniques. It is also noted that resources will be required to enable organizational participation and project activities (e.g. travel, equipment, technical support, etc.)
The meeting attendees agreed to further explore and pursue a joint project 'AFREF' with the Africans and other international partners, and that such a project should:

1. Support and ensure the fundamental basis for the national 3-d reference networks for today and in the future through a continental African geodetic network fully consistent and homogeneous with the global reference frame of the ITRF.
2. Establish continuous, permanent GPS stations such that each nation or each user has free access (and at least within 1000km) of such stations.
3. Provide a sustainable development environment for technology transfer, so that these activities will enhance the national networks and numerous applications with readily available technology
4. Understand the necessary geodetic requirements of participating national and international agencies.
5. Assist in establishing in-country expertise for implementation, operations, processing and analyses of modern geodetic techniques, primarily GPS.

Ruth Neilan, acknowledging contributions from Jim Slater

*Minutes of the SIRGAS (*Sistema de Referencia Geocentrico para Las Americas) *committee meeting, held on october 21 and 22, 2002 Santiago, Chile*

The president of the Committee highlighted the financial support given by the International Association of Geodesy (IAG), decisive for holding the meeting. The Pan-American Institute of Geography and History (PAIGH), which had approved funds for the project in 2002, could not honor this commitment due to financial difficulties that it is currently facing. Therefore IAG responded to our last minute request, enabling the attendance of eight participants of seven countries of South America, which was decisive for the success of the meeting.
All annexes can be found under http://www1.ibge.gov.br/home/geografia/geodesico/sirgas/principal.htm or http://www.ibge.gov.br/sirgas

1. Status on the integration of the South American countries to SIRGAS (R. Barriga, President of the WG II) (Annex I)

2. Presentation of the SIRGAS 2000 GPS campaign results by the processing centers
   2.1 IBGE (S. Costa) (Annex II)
   2.2 DGFI (K. Kanniuth)
   The coordinates obtained in the individual solutions of each processing center (DGFI with Bernese, DGFI with GIPSY and IBGE with Bernese) shown a consistency between each other of about 5 mm in the horizontal components and 7.5 mm in the vertical component.
   Resolution: The SIRGAS Committee decided that the final solution of the SIRGAS 2000 GPS campaign will be generated by the combination of three solutions: DGFI´s, using the Bernese software; DGFI´s, using the GIPSY software; and IBGE´s, using the Bernese software.

3. Combination of the processing centers´ results (H. Drewes/K. Kanniuth/S. Costa)
   3.1 Combination strategy and connection to ITRF2000
   M. Kumar, from NIMA, presented the following issue: the ITRF solutions are generated using the tide-free system, which is not realistic and contradicts the IAG Resolution 16 of 1983 (Annex III)
   Resolution: To keep using the tide-free system in the SIRGAS 2000 results and to formally suggest to IAG to manage with the International Earth Rotation Service (IERS) the solution of this issue.

3.2 Determination of velocities

According to H. Drewes, it is not enough to consider the results of the SIRGAS 1995 and 2000 campaigns for the determination of the SIRGAS stations velocities.

Resolution: The SIRGAS Committee approves H. Drewes´ proposal of considering the observations of permanent GPS stations and of geodynamic campaigns, in addition to the results of the SIRGAS 1995 and 2000 campaigns, for the determination of the velocity field of the South American continent.

3.3 Final results (coordinates and velocities)

Resolution: The SIRGAS Committee accepts in advance as official the final combined results of the SIRGAS 2000 GPS campaign, to be generated by the processing centers in near future.

Resolution: The SIRGAS Committee defines the date of December 20, 2002, as the deadline for the processing centers to release the final combined results of the SIRGAS 2000 GPS campaign.

Resolution: The SIRGAS Committee defines the date of March 28, 2003, as the deadline for DGFI to release the results of the velocity field for the South American continent.

Resolution: The procedures to generate the official results of the SIRGAS 2000 GPS campaign will be described in a final report, similarly to that released during the IAG Scientific Assembly, held in Rio de Janeiro, in 1997.

Resolution: The SIRGAS Committee proposes to include in the SIRGAS 2000 GPS campaign final report a special acknowledgment to the processing centers – DGFI and IBGE – by the enormous efforts carried out and by the excellence of the results obtained.

4. Use of the SIRGAS 2000 final results (H. Drewes, Representative of IAG)

   Resolution: The SIRGAS Committee proposes to include in the SIRGAS 2000 GPS campaign final report detailed instructions about how to use the campaign final results.

   It was recommended that, for countries that have not adopted yet SIRGAS 1995 as reference system, they should adopt the system based on the SIRGAS 2000 results, reference epoch 2000.4.

5. Presentations of the Working Group III "Vertical Datum" (L. Sanchez, President of WG III, and H. Drewes, Representative of IAG)

   5.1 Introduction (Annex IV)

   5.2 Urgent need of a modern vertical reference system (Annex V)

   5.3 Computation of geopotential numbers and physical heights (Annex VI)

   5.4 Reference surface: considerations regarding W0 (Annex VII)

   5.5 Future activities (Annex VIII), recommending to countries:

- Geodetic leveling of the SIRGAS2000 stations
- Connection of leveling networks between neighboring countries
- Identification and typing of all leveling lines that connect SIRGAS2000 stations
- Typing of the national leveling networks
- Identification of the network nodes
- UNIFIED determination of the quasi-geoid
- Determination of the sea surface topography (SSTop) (GPS positioning of tide gauges)

The WG III president offered support to the member countries of the SIRGAS Committee regarding the computation of geopotential numbers and help with parallel tasks. It is emphasized that the height differences to be used in computations are the observed ones, WITHOUT any error distribution or adjustment.

6. Continuation of the discussion on the new statute proposal (L. Fortes and C. Brunini)

   Resolution: The SIRGAS Committee approves the new project Statute, corresponding to the version originally proposed by the representation of Argentina, with the modifications discussed during the meeting in Santiago del Chile.

   With the approval of the Statute (Annex IX), the substitute representative of Argentina in the Committee, Claudio Brunini, proposed the names of Luiz Paulo Souto Fortes, from IBGE/Brazil, and Eduardo Andrés Lauría, from IGM/Argentina, respectively for president and vice-president of the project for the next term (2003-2007). The current president of the SIRGAS Committee will contact all countries embraced by the project in order to confirm the names of the representatives in the Committee and, consequently, to define the necessary quorum for electing the new project authorities. This election will be carried out by electronic mail and the elected authorities will be installed in office in July 2003, at the General Assembly of the International Association of Geodesy.

7. Closing (L. Fortes)
   Resolution: The SIRGAS Committee acknowledges the Instituto Geográfico Militar of Chile for the excellent organization of the meeting and for the support to the Committee members.
   L. Fortes, IBGE Brazil

Ninth Business Meeting of Ablos, held at the Hydrographic and Oceanographic Department Japan Coast Guard, Tokyo, October 23-25, 2002
Meeting report is available at: http://www.gmat.unsw.edu.au/ablos/minutes02.pdf

X IAG International Symposium on Recent Crustal Movements, Helsinki, Finland, August 27-31, 2001

The tenth IAG (International Association of Geodesy) International Symposium on Recent Crustal Movements (SRCM) was held in Helsinki, Finland, August 27.-31., 2001. The main organizer of the Symposium was the Finnish Geodetic Institute. Co-organizers were the Department of Geology, University of Helsinki, Department of Geophysics, University of Helsinki, and Department of Surveying, Helsinki University of Technology. Scientific programme was planned together with Prof. Susanna Zerbini, University of Bologna, Italy, the president of the IAG Section V, Commission XIV, Crustal Deformation.

More than 70 participants, and 60 presentations during the symposium show the importance and wide variety of the topic. Natural and athropozenic hazards was one of the topics, as a part of the crustal movements can be violent and rapid, causing both human and materaial losses. Some movements, although slow but still of a great importance, such as the postglacial rebound or the eustatic rise of the sea level, can help us to study and understand global changes, such as warming and its causes, and deglaciation. The proceedings of the Symposium will be published in the Journal of Geodynamics (JoG), an official journal of the European Geophysical Society.
Markku Poutanen, Finnish Geodetic Institute, Secretary of the SRCM symposium

---

Report of the International Congress on Geodesy and Cartography, Caracas, Venezuela 18-22 March, 2002 (IAG sponsored)

Co-Sponson: Instituto Geográfico de Venezuela Simón Bolívar (DIGECAFA), Dirección de Hidrografía y Navegación (DHN), Fundación Venezolana de Investigaciones Sismológicas (FUNVISIS), Petróleo de Venezuela (PDVSA), Sociedad Venezolana de Ingenieros Geofísicos (SOVG), Instituto Nacional de Canalizaciones (INC), Colegio de Ingenieros de Venezuela (CIV), Asociación Venezolana de Ingenieros Geodestas (ASOVIG),
Organized by: Venezuelan Association Of Geodetic Engineers (ASOVIG)

General Program
Opening Ceremony, Session I and II –Reference Systems, Geoid, Session III and IV–Satellite Techniques, Session V and VI –Geographical Information Systems, Session VII–Cadastre, Session VIII – Interdisciplinary Applications, Session IX–Photogrammetry and Cartography, Session X–Cartography and Remote Sensing, Session XI–Remote Sensing, Session XII–Geodetic Measurements in Engineering

Statistics
There were 72 oral paper presentations from 123 Authors, 62 University students, and 152 registrated participants.

Oral presentations:
In the following, there were presented 72 individual and multinomial papers. The paper titles and their authors are (not in chronological and schematic order):

Acuña (Venezuela), Bosch (Germany): Improving comparisons of satellite altimeter observations and tide gage registrations for unifying height systems in the Caribbean area. *Alves, Blitzkow, (Brazil):* Modern concepts and techniques of control and forms to monitor tide gage stations with GPS. *Alves, Blitzkow, et al. (Brazil): Sea* level determination 1831 and 2000 with GPS, leveling and tide gage observations. *Arrieche, (Venez):* Experiences of hiperspectral remote sensing in the Venezuelan Oil Industry. *Azcarate, Martinez, et al., (Venez):* Design and application of an interactive system of digital images. *Blanco, Gajardo, et al.,* *(Venez):* Geotechnical, geophysical and hydraulic studies to define the stability of Mamo Mesa Venezuela. *Blanco, Gajardo, et al., (Venez):* Observation system of Viaduct No.1 of highway Caracas-La Guaira. *Orlando, Barromé, (Venez):* Geodetic and instrumental control of the Hydroelectrical Complex of the Lower Caroni River. *Buyana, Guevara, et al., (Venez*): Methology of Geoid ondulation determination with heterorgenic geodetic data. *Clayton, Jacques, et al., (Brazil):* Methodology to locate the most favorable areas for installation of small hydropower systems in a GIS environment. *Cardozo, Núñez, et al., (Brazil):* Orthomosaic generation from a digital, nonmetric camera. *Carvalho., et al., (Brazil):* Methology for hydraulic works registration of Bahia State, Brazil. *Carvalho, et al., (Brazil):* Fluvial dynamics of Sao Francisco River using Landsat 7/ETM + images. *PimenteL et al., (Brazil)*: Digital cartography for management of water distribution networks. *Pimentel, Ferreira, (Brazil): Teodoro* Sampaio and the beginning of systematic cartography in Brazil. *Pimentel, Nero, (Brazil):* Cartographic documents: Determination of geometric quality in Brazil. *Correa E Castro, Blitzkow, (Brazil):* Recovery of South American gravity nets by Chile and Paraguay. *Daal, Balcázar, et al. (Venez), TREMEL (Germ):* GPS Campaign REGVEN 2000. *Carvalho et al. (Brazil):* Geobotanical analysis of geological structures using hyper spectral images. *Cogliano, Galban, et al., (Argentina*): First comparison of height networks between Chile and Argentina. *Laura Delgado et al. (Venez):* Remote Sensing – Digital terrain models and GIS: Tools for Malaria control. *Do Nacimiento et al. (Brazil):* Morphologic analysis of the Grande River basins as subsidy for ecological zoning using GIS. *Dolande, Montezuma, et al. (Venez):* Cartographic cover of Esequibo territory by Landsat TM and ETM. *Dominguez et al., (Venez):* Calibration of position equipments for offshore seismic surveys. *Fontes, et al., (Brazil):* Use of GIS in management of National Park in Brasilia. *Francoso, et al., (Brazil):* GIS for historical rescue. *Francoso, et.al., (Brazil):* GIS en Sao Paulo State. *Freitas, et al., (Brazil):* Cartographic actualization with IKONOS, using IKONOS 2 satellite for cartographic actualization in maps up to 1:2500. *Fuenmayor, et al., (Venez):* SIRGAS – REGVEN point densification for PDVSA. *Gechele, Nixon, et al., (Venez):* GIS implantation by GPS in coastal areas of Maracaibo lake. There were considered Hydro Pro, Pathfinder Office, Auto Cad and Arcview. *Gonzalez, Digecafa, (Venez):* Evaluation of quick static positioning for medium distances. *Guerra, et al., (Venez):* The homogeneous treatment unit (UHT), an SIG tool for perforation dispositions.*Guevara, et al., (Venez):* Evaluation of precision of image orthorectification of IKONOS Satellite in urban areas of Caracas. *Guillen, et al., (Venez):* System implantation and proof for vehicle control by GPS. *Henneberg (Venez):* Geodetic measurements of neotectonics and recent crustal movements. *Hernandez, (Venez):* Evolution and actual situation of Venezuelan geocentric reference system. *Hoyer, Hernandez*, *et al., (Venez):* Geoid determination in Venezuela by minimum square collocation. *Hoyer, et al., (Venez):* GPS measurements processing of REGVEN project*. Hoyer, et al., (Venez):* RENDON: GPS measurements in the area of the Yacambú-Quibor hydraulic system. *Jauregui, et al., (Venez*): Elaboration of digital stereo-orthophotos. *Liberal, (Venez):* Three dimensional geodetic model and GPS application. *Lopez, et al., (Venez):* Optimization of GPS applications in the Venezuelan Oil Industry. *Marquez, Mecinca, (Venez):* DIN 18723 and application for certification of theodolites and level instruments *Martin, et al., (Venez*): Impact of the new official DATUM of Venezuela (SIRGAS – REGVEN) in geodetic activities of PDVSA. *Alves, Pimentel, (Brazil):* Digital terrain model. *Nero, Pimentel, (Brazil*): Map digitalizations: Comparitive studies of methodologies. *Ordóñez, et al., (Colombia):* Deformation measurements of GALERAS Volcano, Colombia. *Ordóñez, et al., (Colombia):* GPS measurements for micro gravity studies of Galeras volcano, Colombia. *Mora, et al., (Colombia): Satellite* geodesy for tectonic deformation measurements in NE of South America. *Oropeza, (Venez*): Digital rural cadastre of watering systems in Falcón State, Venezuela. *Rincon, Et Al., Hoyer, et al., (Venez):* Satellite altimeter studies of the Atlantic Front of Venezuela *Rios, (Venez):* GIS tendency in geography*. Rivas, et al., (Venez):* GIS for sub terrain installations in urban areas. *Rivas, et al., (Venez*): Use and methology of multimedia to execute technical evaluation of road communication systems. *Rivas, et al., (Venez):* Measurements, analysis and composition of the atlas of road systems. *Rivas, et al., (Venez):* Application of ISO VALUE Lines for residential buildings using a GIS system. *Stamato, (Brazil):* Is an electronic atlas a geographic information system? *Swanston, (Venez): An* approximation to a new cadastral registration system. *Swanston, (Venez):* Quality control of radar orthoimagery. *Taylhardat, Hernandez, (Venez):* GIS-Exploration processes. *Vallee, Parra, (Venez):* Cartography of hydrocarbon emanations. PRAOG, *TIESZEN, (USA*): Development of exploration, access and dissemination of geospace data (clearinghouse) in different Central American countries caused by hurricane Mitch.*Vera, et al. (Venez):* Geomorphological vision of North and South America. *Wildermann, et al., (Venez):* Comparison of different height systems in Venezuela. *Gavel (USA):* Data evaluation for space positioning for oil wells.

Special presentations:
Henneberg, (Venez): Marine Geodesy. *Drewes, (Germ):* Why do we need a new height system? *Guevara, (USA):* The Geospace paradigm and its impact on a bearable progress*. Rendon, (Venez):* The project for modernization of the national seismology network. *Drewes, (Germ):* The international reference system ITRF

and its continental amplification (SIRGAS). *Vera, (Venez):* Technological promotion – Air transportable remote system for "Alto Resources Venezuela, C.A." *Prelat, (USA):* Hyper spectral technology for evaluation of national resources and environment.

Heinz Henneberg, National IAG Representative

Report on IAG 2001 Scientific Assembly of the International Association of Geodesy, Budapest, Hungary, 2--7 September 2001

by J. Adam and K.-P. Schwarz

It was in September 1906 that the predecessor of the IAG, the 'Internationale Erdmessung', organized its 15th General Assembly at the Hungarian Academy of Sciences in Budapest. It was 95 years later, in September 2001 that the IAG returned to this beautiful city to hold its Scientific Assembly, IAG 2001, in the historical premises of the Academy. The meeting took place from September 2-7, 2001 and continued the tradition of Scientific Assemblies, started in Tokyo (1982) and continued in Edinburgh (1989), Beijing (1993) and Rio de Janeiro (1997). Held every four years at the midpoint between General Assemblies of the IAG, they focus on giving an integrated view of geodesy to a broad spectrum of researchers and practitioners in geodesy and geophysics. The convenient location of the main building of the Hungarian Academy in downtown Budapest and the superb efforts of the Local Organizing Committee contributed in a major way to the excellent atmosphere of the meeting.

In the opening session of the IAG 2001 Scientific Assembly, participants were welcomed by Attila Mesko, Deputy Secretary-General of the Hungarian Academy of Sciences, Fernando Sanso, president of the International Association of Geodesy (IAG); Klaus-Peter Schwarz, Chairman of the Program Committee and Jozsef Adam, Chairman of the Local Organizing Committee (LOC). The welcome address of the IAG president Fernando Sanso is attached to this report.

As at previous meetings, the scientific part of the program was organized as a series of symposia, which, as a whole, provided a broad overview of actual geodetic research activities. To emphasize an integrated view of geodesy, the symposia did not follow the pattern of the IAG Sections, but focussed on current research topics to which several IAG Sections could contribute. Each symposium had 5 sessions with presented papers and poster sessions on two consecutive days. Since the majority of papers were presented as posters, an effort was made to give ample exposure to this form of presentation. Besides having each poster up for two consecutive days in the main hall of the building, it was also decided that no parallel sessions would be scheduled during the poster sessions. This gave considerable exposure to the poster presentations and led to good interactions between authors and participants.

The scientific program dealt with the following topics:

Symposium A: Fine-tuning Reference Frame Implementation, Convenors: C.K. Shum (USA) and A.H. Dodson (UK)

- A1 Space Techniques: Coordination and Combination Methods, Chair: H. Drewes (Germany), Co-chair: J. Hefty (Slovak Rep.)
- A2 Non-tidal Earth Gravitation and Geocenter Motion, Chair: B.F. Chao (USA), Co-chair: P. Biro (Hungary)
- A3 Regional Reference Networks, Chair: R. Weber (Austria), Co-chair: L.W. Baran (Poland)
- A4 Vertical Datums: Determination Techniques and Unification, Chair: C. Jekeli (USA), Co-chair: J. Ihde (Germany)
- A5 Is there a Need for a Geodetic Datum 2000?, Chair: C. Boucher (France), Co-chair: E. Groten (Germany)
- AP Poster Session, (Responsible: A.H. Dodson)

Symposium B: From Eotvos to Satellite Gradiometry - New Vistas in Measuring and Modeling the Earth's Gravity Field, Convenors: M.G. Sideris (Canada) and B. Heck (Germany)

- B1 Advances in the Theory of Gravity Field and Geoid Determination, Chair: P. Holota (Czech Rep.), Co-chair: A. Marchenko (Ukraine)
- B2 Use of Gravity Data from Earth and Planetary Satellite Missions, Chair: H. Ilk (Germany), Co-chair: M.Petrovskaya (Russia)

- B3 Airborne Gravimetry, Chair: L. Bastos (Portugal), Co-chair: A. Kopaev (Russia)
- B4 Advanced Technologies for High-resolution Global and Regional , Digital Elevation Models (DEM), Chair: P.A.M. Berry (UK), Co-chair: I.N. Tziavos (Greece)
- B5 Advances in Numerical Techniques and Approximation Methods, Chair: R. Klees (The Netherlands) Co-chair: J. Zavoti (Hungary)
- BP Poster Session (Responsible: B. Heck)

Symposium C: Geometry and Beyond - Using Global Navigation Satellite System (GNSS) in New Ways, Convenors: C. Rizos (Australia) and J. Adam (Hungary)

- C1 Probing the Atmosphere with GNSS, Chair: H. vander Marel (The Netherlands), Co-chair: A. Kenyeres (Hungary)
- C2 Low Earth Orbiter Satellite Missions, Chair: P. Schwintzer (Germany), Co-chair: J.B.Zielinski (Poland)
- C3 New Concepts in Engineering Geodesy, Chair: H. Kahmen (Austria), Co-chair: Á. Detrekoi (Hungary)
- C4 Probabilistic and Non-probabilistic Assessment in Data Analysis, Chair: H. Kutterer (Germany), Co-chair: A. Dermanis (Greece)
- C5 Biases in GNSS Positioning, Chair: M. Stewart (Australia), Co-chair: S. Tatevian (Russia)
- CP Poster Session (Responsible: J. Adam)

Symposium D: Modeling Earth Processes and Global Change
Convenors: C. Wilson (USA) and V. Dehant (Belgium)

- D1 Ocean-Solid Earth Interactions, Chair: R. Gross (USA), Co-chair: P.Varga (Hungary)
- D2 Variations in Earth Orientations, Chair: J. Vondrak (Czech Rep.), Co-chair: A. Brzezinski (Poland)
- D3 Global and Regional Sea-level Changes, Chairs: A. Cazenave (France) and D.P. Chambers (USA), Co-chair: M.Poutanen (Finland)
- D4 Global and Regional Plate Motions and Deformations, Chairs: S. Zerbini (Italy) and C. Wilson (USA), Co-chair: I. Joo (Hungary)
- D5 Satellite Altimetry for Oceanography and Geodesy, Chair: C.Hwang (Taiwan), Co-chair: M.Vermeer (Finland)
- DP Poster Session (Responsible: V. Dehant)

Special Sessions

- E1 Scientific Cooperation in Geodesy and Geophysics in Central and Eastern European Countries (CEEC), Chair: J. Sledzinski (Poland), Co-chair: F. Vodopivec (Slovenia)
- E2 Research Challenges for Young Scientiests, Chair: K.P. Schwarz (Canada)
- E3 Information Session on the New Structure of the IAG, Chair: G. Beutler (Switzerland)

The scientific program of the meeting was organized by the symposium conveners and the chairpersons of the session. The symposium conveners decided on the acceptance of the submitted abstracts and, in cooperation with the session chairs, on the final program. The session chairs took an active role in soliciting papers for their sessions and were responsible for the selection of papers for oral presentation and the review process. In addition, they organized the review process for the topic of their respective session. This was a major job, considering that a total of 126 oral and 254 poster presentations were made. Special thanks are therefore expressed to all symposium conveners and session chairpersons for organizing the symposia and sessions.

For the first time in the history of the General and Scientific Assemblies, two best student paper awards were announced by the IAG, one to the author of a paper presented orally, and the other to the author of a poster paper. The award for the orally presented paper went to Michael Kern of the University of Calgary, Canada, and the award for the poster paper to Suzanne N. Lyons of the Scripps Institution of Oceonography, USA. Congratulations to both of them.

The IAG Executive Committee decided to select about 100 representative papers, for publication in the reviewed IAG/Springer proceedings series. The selected papers were reviewed by the same review process used for the Journal of Geodesy. Special thanks are expressed to all session chairpersons for getting the reviews in under a very tight time schedule. The co-operation of both authors and reviewers in trying to meet the deadlines was highly appreciated. It made the timely publication of these proceedings possible. The volume contains a representative sample of 93 reviewed papers from all sessions, as well as nine papers presented in the special sessions. This volume (number 125) will be available by the end of March. Note that a CD containing all papers that were submitted for publication in time (deadline: November 30, 2001) was issued and mailed already to all conference participants early in February, 2002.

During the IAG 2001 Scientific Assembly, in addition to IAG Bureau and Executive Committee meetings, 21 Special Study Groups, Special Commission, Commission and Ad hoc group specially organized meetings for discussions and exchanges. Furthermore, meetings of the Joint Board of Sister Societes and the Editorial Board of the Journal of Geodesy took place in Budapest.

Full- and half-day excursions were offered for the participants and accompanying persons to explore Budapest and the countryside (Danube Bend and Godollo Palace). A Welcoming Reception at the Picture Gallery Hall of the Academy and an IAG Banquet at the Citadella Restaurant on the top of Gellert Hill were organized for participants and accompanying persons.

In the closing session of the IAG 2001 Scientific Assembly, the IUGG President Masaru Kono addressed the participants. Following that, brief summaries of the symposia were given by conveners (C.K. Shum, B. Heck, C. Rizos and C.R. Wilson). Finally, closing remarks were presented by J. Adam, Chairman of the LOC and Prof. F. Sanso, President of the IAG.

The meeting attracted a larger number of participants (449 registered participants from 54 countries) and papers (380) than previous Scientific Assemblies. This is in part due to the generous financial and promotional support given by a number of agencies. It made the support of students and colleagues from developing countries possible and gave the social events an additional touch of hospitality. Special thanks go to the International Association of Geodesy (IAG), the Hungarian Academy of Sciences (HAS), the European Space Agency (ESA), the US National Aeronautics and Space Administration (NASA), the Jet Propulsion Laboratory (JPL), the Budapest University of Technology and Economics (BUTE), the Eotvos Lorant and Geophysical Institute (ELGI), the Hungarian Scientific Research Fund (OTKA), and the Ministry of Education. IAG, HAS, ESA and NASA are thanked for their financial contributions.

As decided at the last General Assembly of the IAG in Birmingham in1999, a special IAG Council Meeting took place after the conference in order to make a decision on the proposed restructuring of the IAG. The proposal, presented by the chairman of the Restructuring Committee, Gerhard Beutler, and supported by the IAG Executive, was accepted with small modifications.

The responsibility for organizing this conference was shared by the Program Committee (chairman: Klaus-Peter Schwarz, members: Alan H. Dodson, Che-Kwan Shum, Michael G. Sideris, Bernhard Heck, Clark R. Wilson as IAG Section Presidents) and the Local Organizing Committee (chairman: Jozsef Adam, members: Ivan I. Mueller as IAG Representative, Laszlo Banyai, Gusztav Hencsey, Ambrus Kenyeres, Gabor Papp, Viktor Richter, Gyula Toth). The credit for the professional running of the conference goes to the staff of the conference bureau of the Computer and Automation Research Institute of the Academy. Special thanks are expressed to the Head of this Department, Gusztav Hencsey, and to staff member Viktor Richter for their efficient and friendly organization.

Those interested in more details of the program may consult the web site http://www.sztaki.hu/conferences/iag2001 . The reviewed proceedings will be published by Springer Verlag and will be available at the end of March 2002.

Geodesy on the Move
Presidential address to the IAG Scientific Assembly in Budapest

F. Sanso
DIIAR, Sez. Rilevamento, Politecnico di Milano, Piazza Leonardo da Vinci 32, I-20133 Milano, Italy.

Ladies and Gentlemen, dear Friends and Colleagues,

it seems yesterday that we were leaving the IUGG General Assembly in Birmingham outlining the work program for the next four years and announcing that we would meet here in Budapest to verify whether we were marching in the right direction.

Six lines have been put down as the main streets along which to develop the IAG action:

- the first, institutional and most obvious is to develop Geodesy as science in itself,

the others are

- to improve the relations with other sciences and their organization,
- to improve the IAG impact in terms of Services towards other sciences and the society in general,
- to improve IAG penetration into the developing countries,
- to improve the internal IAG organization,
- to widen the scientific manpower on which IAG is based.

I will try to review these in short with one warning: this talk has been prepared a few days ago in the Alps while I was in the so-called ``vacations'' and I had with me only little material, so it is based mainly on my memory which is scarce and even fading.

I hope I still have clear the overall design, but I am pretty sure that I am forgetting important names and facts, so please accept my apologies for that and take this presentation more as a collection of examples rather than being exhaustive.

Point 1:to develop geodesy as a science in itself.

I will dwell little on that because this item is maybe more appropriate for the last session of this Assembly, when we will have a more precise overview on what is going on in geodesy and surroundings, yet I cannot refrain from saying at least two small things.

Trivializing, we could say that our job is:

- to survey the earth (and the planets) with new advanced techniques in a consistent worldwide way,
- to develop new methods to describe our measurement models and to analyze the available data both theoretically and numerically, which means qualitatively and quantitatively.

For the first point I would say that what we already have and we already planned to have in a few years, is what we were dreaming of only few years ago.

Just think of the continuous monitoring of GPS permanent stations by IGS, the global survey by SAR of all the continental topography (I am talking of the SRTM mission) as well as the moinitoring of the oceanic surface by the many altimetric missions and, not to be forgotten, the complete imaging of the earth's global gravity field with CHAMP and subsequently GOCE, including its time variations by the GRACE mission. This is really an age of globalization of Geodesy against which none can protest!

As for the second point the production of new ideas in Geodesy is at the same time too narrow (I will talk about that in the meeting with the young geodesists) and too large to be mentioned in detail. I just want to quote the names of Chris Kotsakis and Rudiger Lehman because they share this year the prize for the bast paper award. I believe it is consulating to see that computers have not killed our thinking in Geodesy letting our beautiful tradition of the Hotine, Marussi, Baarda, Moritz and Krarup continue.

Point 2: to improve the relation with other sciences and their organization.

Are we moving in this direction?

- Planetology I would say we are in strict and even improving relation.Last spring I was sitting in a room in Matera, listening to Dave Smith that took the audience on a fly across mountains and channels of Mars, I mean the true topography computed by NASA, not science fiction! We know that a new ``train'' is leaving for Mars under an ESA project, where our last Bomford prize awarde, Veronique Dehant, is playing a very important role. If I can mention it, there is another mission, Mercury orbiter, approved by ESA, where Italian geodesists have the same role too. But let us come to the other geophysical sciences.

- Solid Earth Physics we share the whole subject of geodynamics to which we contribute all the information coming from the ballet of the earth barycenter, the polar motion and the spinning rate as well as the time variations of the first harmonics of the gravity field. This is our contribution to global dynamics, which we primarily provide through the International Earth Rotation Service. To this we have to add the information on plate tectonics, which is basically coming from the IGS international network of GPS permanent stations, jointly with the other space techniques. Not to be forgotten all the other information on crustal deformation and gravity field variations which complete the picture at a local level. On the earthquakes we have important things to say with the new ideas of combining GPS, and SAR information; think of the Colfiorito earthquake in Italy and that of Izmit inTurkey,

- Oceanography we share again a large number of subjects of common interest; our definition of height datum, the geoid, was historically based on the abstract concept of mean sea level and, unfortunately, we are still discussing about this definition. I do not think I need to underline the importance of altimetric satellite missions for both sciences; I just want to mention that still after many years IAG and IAPSO seem to me like two dogs one running after the tail of the other. We believe that from altimetry we can subtract the dynamic height of oceans to get the geoid there to construct global models, the oceanographers believe that we can provide them a high resolution geoid by our global models so that they can constrain the geostrophic part of the motion. It is a little more complicated than that, but only the forthcoming gravity missions will be able to cut this Gordian knot. Certainly the relations between the two associations are excellent: we have joint symposia and a proposal to run a joint Scientific Assembly could come for the next time, even geophysical associates that were thought to be traditionally far from IAG, like the hydrologists or the atmospheric physicists have discovered that Geodesy is useful to them.

Just six weeks ago at the IUGG Executive Meeting H.C. Davies, the president of IAMAS, has claimed that, contrary to all his expectations, he had to admit that important information could come from GPS or SAR sounding of the atmosphere, and he prized us for that.

So this is the traditional line of ``good relations'' with geophysical associations, with which we share the union organization as well as with the other geophysical societies and we have the impression that we are serving well this traditional field of action.

But there is the other side of our life which is the relation of Geodesy to Surveying, Photogrammetry, Remote Sensing, Cartography and so forth, all the more applied and engineering disciplines that were borne as particular techniques, with associations taking care of the relations with the world of professions. They drifted away, maybe too much, particularly across the Eighties and early Nineties, and this has been a mistake which our executive has tried to counteract by increasing the contacts and the joint activities with FIG, ISPRS and so on. We had joint symposia, schools, and study groups and not only because we think that we have something to teach, but also because we have something to learn. I am thinking for instance of a nice Symposium on Non-standard Non-probabilistic Methods organized in Zurich by Kutterer (SSG 4.190) together with Alessandrio Carosio who's specialty is GIS theory.

We should never forget that it is in IAG genome to be an interface between geosciences and engineering applications, and whenever we forget it we loose as a science and as an organization.

Point 3: to improve the IAG impact in terms of Services towards other sciences and the general society.

I already mentioned the fantastic work performed by the International Earth Rotation Service and the International GPS Service; they are based on a very large international cooperation and give to IAG quite a substantial contribution in the effort of maintaining its outstanding position among geosciences.

It is incredible that, in spite of the continuous threat of the supporting organizations to cut their budget, they have always been able to evolve facing new challenges and providing new products of larger and larger utility.

We would like to be more powerful and authoritative to say to the supporters that they have to continue their effort because it is a honour to be able to serve such a large community in such a good manner! Nor one should forget the relatively new Services like the Laser Ranging Service and the VLBI Service, who play specific essential roles within the same general subjects. Nor I want to forget the Services related to the gravity field like the glorious Bureau Gravimetrique which, together with the International Geoid Service and the International Center for Earth Tides, will join into a new International Gravity Field Service, already here in Budapest; this also with the support of new centers provided by NIMA and GFZ.

To close this point let me at least mention two Services with a clear strong interdisciplinary character: the Permanent Service for the Mean Sea Level and the Bureau International des Poids et Mesures (Time section).

I will explain in a few minutes the enhanced role that Services will play in IAG structure.

Point 4: to improve the diffusion of IAG organization into Developing Countries.

This is not a ritual statement that we repeat every time to keep our soul free of any sense of guilt.
This is a real line for our organization and we proved it by stimulating important projects of international cooperation.

Let us think for instance of SIRGAS and then to the many scientific activities in South America, including the choice of bringing our Scientific Assembly in Rio. We have now a very active South American community which is showing everywhere at the international level. Similar success we had in the South-East Asia Pacific area, where not only our Services and, for instance, International Schools have done very well but also the development of IAG has been boosted by leading nations of the area like Japan, China, Australia.
Nevertheless we always had problems with the African continent.

Despite the historical enterprise of ADOS, despite the many bilateral contacts, we never had a real IAG organization there. At least till recently. However, thanks to the efforts of our Commission X (on Global and Regional Geodetic Networks) and XIV (on Crustal Deformation), as well as of the action of IGS for the full internationalisation of the Earth Reference Frame and our Committee on Developing Countries, we finally see a centripetal motion in Africa around geodetic themes.

In particular, from seven to eight nations in South Africa and six nations in North Africa are setting up joint international geodetic structures under the auspices of IAG and of the Organization Africain de Cartographie et Teledetection.

It was the end of May when I was sitting in Algiers in a room with 150 African colleagues for the Duexieme atelier nord africain de geodesie. We only need to improve our efforts there because we are getting a very positive response; only we still have to think a little bit of the linguistic barrier, but I believe this will be quickly overcome with younger generations.

To achieve that, these nations need support and for sure IAG has not the possibility of financing projects. However, I am proud to say that most of our budget goes to support travels to allow people from developing countries to participate in international meetings. This is a policy with general consensus but we have to acknowledge the particularly firm action of our Secretary General in this direction.

Point 5: to improve the internal IAG organization.

It is not a mania of esthetic order, but the response of a living organism to its needs of growth.
To accomplish what we have illustrated we need:

- a swifter structure in IAG where people from our or other disciplines, particularly young people, could easily find their place if they are interested.

This implies reducing the number of layers and bureaucracy in IAG;

- a structure where Services would be more free to act, to set up projects, schools, to penetrate into new nations on behalf of IAG by contacting the national agencies and, more generally, the users of geodetic products, by affiliating them directly and giving them an international stage where to report their new findings;
- a structure where developing countries could better find scientific support to finally stand on their own legs and contributing back to the IAG evolution.

Along these lines new statutes and bylaws have been elaborated by a commission under the leadership of our Vice President, Gerhard Beutler. They have been discussed by the Executive and then publicized through the IAG home page. I am glad to say that we received reactions, comments and suggestions very sensible and appropriate.

So a final version will be submitted to the IAG Council, which is holding an extraordinary meeting here in Budapest and, in case of approval, they will be already applied in Sapporo at the next IUGG General Assembly.

Also, in this way we feel we have accomplished a mandate by our Assembly in Birmingham, to widen the scientific manpower on which IAG is based. While closing the XXII General Assembly I said to the audience "Come all several and plenty, come to IAG in Budapest and bring your best piece of geodetic work".

Dear friends, this is the Fifth scientific Assembly, after Tokyo, Edinburgh, Beijing and Rio.
In Tokyo we had 360 people and 177 papers, in Edinburgh 360 and 250 papers, in Beijing 350 people and 295 papers, in Rio 350 people and 279 papers; in Budapest we have up to 3 days ago 472 registrations and 427 papers, and I believe that counting the last minute registration we will end up well over 500!
I do not want to be triumphal but I think I am allowed to congratulate with you, because you are moving exactly in the direction you have chosen in Birmingham and though the way is still long I want to say welcome Geodesy to open your march.

IAG/IAPSO Joint Working Group on
Geodetic Effects of Nontidal Oceanic Processes

The oceans have a major impact on global geophysical processes of the Earth. Nontidal changes in oceanic currents and ocean-bottom pressure have been shown to be a major source of polar motion excitation and also measurably change the length of the day. The changing mass distribution of the oceans causes the Earth's gravitational field to cange and causes the center-of-mass of the oceans to change which in turn causes the center-of-mass of the solid Earth to change. The changing mass distribution of the oceans also changes the load on the oceanic crust, thereby affecting both the vertical and horizontal position of observing stations located near the oceans.

Recognizing the important role that nontidal oceanic processes play in Earth rotation dynamics, an IAG/IAPSO Joint Working Group on Geodetic Effects of Nontidal Oceanic Processes was formed at the XXII General Assembly of the IUGG in Birmingham. The objective of this IAG/IAPSO Joint Working Group is to investigate the effects of nontidal oceanic processes on the Earth's rotation, deformation, gravitational field, and geocenter, and to foster interactions between the geodetic and oceanographic communities in order to promote greater understanding of these effects. A meeting of this IAG/IAPSO Joint Working Group, its fifth, was held on April 7, 2003 in Nice, France in conjunction with the 2003 Joint Assembly of the European Geophysical Society (EGS), the American Geophysical Union (AGU), and the European Union of Geosciences (EUG) during which presentations were given by R. Gross, and O. de Viron.

R. Gross described the International Earth Rotation Service (IERS) Special Bureau for the Oceans (SBO). The IERS Special Bureau for the Oceans is one of eight Special Bureaus of the IERS Global Geophysical Fluids Center (GGFC) which was established on January 1, 1998 in order to help relate dynamical properties of the atmosphere, oceans, mantle, and core to motions of the Earth, including its rotation. In particular, the IERS Special Bureau for the Oceans is responsible for collecting, calculating, analyzing, archiving, and distributing data relating to nontidal changes in oceanic processes affecting the Earth's rotation, deformation, gravitational field, and geocenter. The oceanic products available through the IERS SBO are produced primarily by general circulation models of the oceans that are operated by participating modeling groups and include oceanic angular momentum, center-of-mass, bottom pressure, and torques. Through the IERS SBO web site at < http://euler.jpl.nasa.gov/sbo >, oceanic data can be downloaded, software to compute the oceanic angular momentum, center-of-mass, and bottom-pressure from the modeled temperature, salinity, and horizontal velocity fields can be obtained, and a bibliography of publications pertaining to the effect of the oceans on the solid Earth can be retrieved. Currently, three different oceanic angular momentum data sets and two different oceanic center-of-mass data sets are available. Links are also provided to related web sites from which observed and modeled ocean-bottom pressure data sets are available. The IERS SBO is one possible source of data that can be used by the IAG/IAPSO Joint Working Group in their investigations of the geodetic effects of nontidal oceanic processes. O. de Viron described the nontidal effect of the oceans on geodetic parameters using the CLIO model. The Coupled Large-scale Ice Ocean (CLIO) model is a baroclinic Boussinesq model developed at the Universite Catholique de Louvain in Belgium to study ocean dynamics and, in particular, the interaction between sea-ice and the oceans. It has been adapted in order to account for the oceans' response to atmospheric pressure forcing. The results presented at the meeting come from an 11-year simulation spanning 1992 to 2002. The model is forced using NCEP reanalysis data: 6 hourly pressure and friction drag, daily surface air temperatures and wind speeds, and monthly climatologies of relative humidity, cloud fraction, precipitation rate, and river runoff. It was shown that the model is adequate to study the oceans' effect on geodetic quantities: the derived oceanic angular momentum (OAM) is similar at low frequency to other OAM series and the omparison between the model-derived ocean-bottom pressure is similar to the few measurements that are available. On the other hand, the model seems to be overreacting by a factor of two at periods less than 5 days. This is still under investigation.

R. Gross discussed the oceanic contribution to Earth rotation changes using the ECCO model. As part of JPL's participation in the Estimating the Circulation and Climate of the Ocean (ECCO) consortium, ocean models are being used to simulate the general circulation of the oceans. Oceanic angular momentum computed from these models have been compared to observed changes in the Earth's rotation during 1980-2000. Although nontidal changes in the Earth's length-of-day on time scales of a few days to a few years are primarily caused by changes in the angular momentum of the zonal winds, other processes such as oceanic current and bottom pressure changes can be expected to cause the length-of-day to change as well. On intraseasonal time scales, atmospheric surface pressure, oceanic currents, and ocean-bottom pressure are found to be about equally effective in causing the length-of-day to change, while upper atmospheric winds are found to be less effective than these mechanisms. On seasonal time scales, the upper atmospheric winds are more important than the sum of currents and bottom pressure in causing the length-of-day to change, and, except at the annual frequency, are even more effective than surface pressure changes. On interannual time scales, oceanic currents and bottom pressure are found to be only marginally effective in causing the length-of-day to change. For polar motion, a remarkable 70% of the observed polar motion excitation variance during 1993-1999 is explained by the sum of atmospheric and oceanic angular momentum, with the coherence between the observed and modeled excitation being dramatically improved across a broad frequency band when the angular momentum of the oceans is added to that of the atmosphere.

Meetings of the IAG/IAPSO Joint Working Group on Geodetic Effects of Nontidal Oceanic Processes have been held during the past four years in conjunction with major conferences in order to foster interactions on this topic between the geodetic and oceanographic communities. A report of the activities of the Joint Working Group will be presented at the XXIII General Assembly of the IUGG to be held in Sapporo, Japan during June 30 to July 11, 2003. In order to receive a copy of this report, please contact Richard Gross at < Richard.Gross@jpl.nasa.gov >.
R. Gross

Report of the International Workshop on Satellite Altimetry for Geodesy, Geophysics and Oceanography: Summer Lecture Series and Scientific Applications, Wuhan, China September 8 to 13, 2002.

The www address is http://space.cv.nctu.edu.tw/altimetryworkshop/altimetry.htm.

The workshop was hosted by the Wuhan University with Dr JC Li as the chair of the LOC. The scientific program was organized by the Scientific committee chaired by C Hwang. The workshop's aim is to offer free lectures on various aspects of altimetric research for beginners and for advanced researchers, and to provide a forum for presentations and discussions of latest results in satellite altimetry.

A total of 60 abstracts were received and 65 people participated in this workshop. These participants are from Austria (2), Australia (1), Canada (1), China (26), Czech Republic (1), Denmark (2), France (1), Germany (2), Italy (2), Japan (1), Korean (2), Netherlands (2), Taiwan (13), UK (1), and USA (7).

On Sep 9 and 10, 2003, five three-hours lectures were delivered by CK Shum (principles of altimetry), K. Matsumoto (ocean tides), O.B. Andersen (marine gravity and geoid), P. Berry (waveform retracking) and DT Sandwell (bathymetry estimation). Three keynote speeches were delivered by W Bosch (geodetic applications), A Cazenave (sea level change) and LL Fu (ocean dynamics from altimetry).

The scientific sessions began on Sep 11 and contains Sessions G1 (chaired by C Zhao), G2 (W Bosch), G3 (EL Mathers) , GO1 (H Schuh), GO2 (J Klokocnik), GO3 (C Hwang), O1 (C Zuffada) and O2 (HZ Xu) with 37 papers presented.

Chair of Org committee: C. Hwang, Taiwan.

NEW IAG STRUCTURE

New IAG Structure: Status March 2003

G. Beutler

on behalf of the
IAG Committee for the Realization of the New IAG Structure

Members of the

IAG Committee for the Realization of the New IAG Structure:

"Alan Dodson" <Alan.Dodson@nottingham.ac.uk>
"Bernhard Heck" <heck@geomatics.ucalgary.ca>
"Klaus Peter Schwarz" <schwarz@geomatics.ucalgary.ca>
"C.K. Shum" <ckshum@osu.edu>
"Michael G. Sideris" <sideris@ucalgary.ca>
"Clark Wilson" <clarkw@maestro.geo.utexas.edu>
"C.C.Tscherning" <cct@gfy.ku.dk>
"Ruth E. Neilan" <ruth.neilan@jpl.nasa.gov>
"Manning John" <johnmanning@auslig.gov.au>
"Fernando Sanso" <fsanso@ipmtf4.topo.polimi.it>

1. Introduction and Overview ....
2. The New Structure in Overview ....
3. Commission 1 *(Task Leader: C.K. Shum)* ....
4. Commission 2: Gravity Field *(Task leader: Michael G. Sideris)* ....
5. Commission 3 Earth Rotation and Geodynamics *(Task Leader: Clark Wilson)* ....
6. Commission 4 Positioning and Applications *(Task leader Alan Dodson)* ....
7. Inter-Commission Committee on Theory *(Task leaders: Bernhard Heck and Peiliang Xu)* ....
8. Inter-Commission Committee on Geodetic Standards (Task leader Clark Wilson) ....
9. Outreach Branch (Task leader: Christian Tscherning) ....
10. IAG Project IGGOS (Task leader: Gerhard Beutler) ....
11. Summary and Action Items ....
12. References ....

Introduction and Overview

The new IAG structure was developed after the IUGG General Assembly in Birmingham in summer 1999. Between summer 1999 and summer 2001 a thorough review of the IAG work and structure was performed by the so-called IAG Review Committee, the work of which is documented in (Beutler et al., 2001), a report which was presented at the IAG Scientific Assembly in Budapest in September 2001 in Budapest. At the same meeting, the proposed new structure was accepted by the IAG Executive Committee and later on by the IAG Council, which held an extraordinary meeting on September 8, 2001 in Budapest.

At the same meeting (Rummel et al., 2001) proposed to create the IGGOS, the Integrated Global Geodetic Observing System as IAG's first project.

It is worthwhile to cite a few lines from the new IAG Statutes and IAG By-Laws, which were accepted by the IAG Council at the September 8, 2001 meeting. According to these Statutes the Mission of the Association is defined as:

The MISSION of the Association is the advancement of geodesy, an earth science that includes the study of the planets and their satellites. The IAG implements its mission by advancing geodetic theory through research and teaching, by collecting, analyzing, and modeling observational data, by stimulating technological development and by providing a consistent representation of the figure, rotation, and gravity field of the earth and planets and their temporal variations.

The Association's objectives are subsequently stated in the IAG Statutes. The future scientific work of the Association is further specified in the new IAG By-Laws:

The scientific work of the Association is performed within a component-structure consisting of Commissions, Services, the Communication and Outreach Branch, and IAG Projects, hereafter called the Association-components or components.

The new ByLaws allow it furthermore to establish Inter-Commission Committees, where the following rules shall be observed according to the IAG ByLaws:

Inter-commission Committees shall handle important and permanent tasks involving all commissions. Each Inter-commission Committee shall have a steering committee consisting of the following membership:

a. *President appointed by the IAG Executive Committee.*
b. *Vice-president appointed by the IAG Executive Committee.*
c. *One representative from each Commission*

The terms of reference for each Inter-commission Committee shall be developed by a planning group appointed by the IAG Executive Committee. The Inter-commission Committees report to the IAG Executive Committee. The Inter-Commission Committee will be reviewed every eight years.

The following specific tasks were identified in Budapest to be achieved between the IAG Scientific Assembly 1999 and the IUGG General Assembly 2003 in Sapporo:

- The existing IAG Structure should be mapped into the new one.
- An Inter-Commission Committee on Theory should be created by a dedicated planning group
- IGGOS should be set up as the first IAG project by a dedicated planning group.

A call for proposals should be issued for the the new Communication and Outreach Branch
The work of mapping the old structure into the new one, of creating the planning group for the ICC on Theory, and of issuing the call for the outreach branch was given to the IAG Committee for the realization of the new IAG structure. It was decided furthermore that the creation of a planning group for the IAG Project called IGGOS (Integrated Global Geodetic Observing System) should be left to the initiative of Reiner Rummel and Gerhard Beutler (see section 10 of this report).

The planning group for the Inter-commission Committee on Theory was set up early in 2002. The group members are:

- Bernhard Heck (Chair)
- Veronique Dehant
- Christopher Jekeli
- Chris Rizos
- Nico Sneeuw
- Peiliang Xu

The discussions within this group and of the group with a broader community were rather intense, but very interesting. A convergence was reached and summarized in an e-mail sent out by the Chairman on July 2, 2002. The outcome of the work is presented in section 7 of this report. It is in essence based on a summary by Bernhard Heck and the first report of the Planning Group compiled by Peiliang Xu.

The IAG Committee for the realization of the new IAG structure held three meeting (on September 6, 2001 in Budapest, on December 11, 2001 in San Francisco, and on April 26, 2002 in Nice).
The five Section presidents agreed to serve as task leaders for the creation of the four new commissions and the Inter-Commission Committee on Theory. The outcome of their work will be summarized in sections 3-7. Christian Tscherning, IAG Secretary General, is the task leader for the establishment of the Communication and Outreach Branch.

At its meeting in Nice the Committee decided to support a proposal made by Proff. Erwin Groten (who was invited to attend the Nice meeting) and Erik Grafarend to create an Inter-commission Committee on Geodetic Standards. It was furthermore decided that Section V should take the leadership in the planning group for this committee, and that the IAG services, in particular the IERS, IGS, IVS, ILRS, and the gravity-related services should be represented in the planning group. (The IAG EC actually asked Clark Wilson, president of Section V to chair this planning group and to create it with prominent representation from the services, in particular from the IERS, the IGS, IVS, ILRS, and the gravity-related services.)

The New Structure in Overview

The services associated so far with the IAG were invited to become official IAG Services under the new structure. The following services made the decision to follow this invitation in the sense defined by the new IAG Statutes and By-Laws:

- The IERS (International Earth Rotation Service)
- The IGS (International GPS Service)
- The ILRS (International Laser Ranging Service)
- The IVS (International VLBI Service for Geodesy and Geodynamics)
- The BGI (International Gravimetric Bureau)
- The IGES (International Geoid Service)
- The ICET (International Centre for Earth Tides)
- The PSMSL (Permanent Service for Mean Sea Level)

The IAG services work and act in a relatively independent way. Their decision to join the IAG as services in the sense of the new statutes and by-laws could not be „enforced“ by the IAG. The Committee on the Realization of the New Structure is very much pleased by this positive response.
According to the IAG By-Laws the following four commissions shall be set up:

Commission 1 *Reference Frames*
Objectives:
a. Establishment, maintenance, improvement of the geodetic reference frames.
b. Advanced terrestrial and space observation technique development for the above purposes.
c. International collaboration for the definition and deployment of networks of terrestrially-based space geodetic observatories.
d. Theory and coordination of astrometric observation for reference frame purposes.
e. Collaboration with space geodesy/reference frame related international services, agencies and organizations.

Commission 2 *Gravity Field*
Objectives:
a. Terrestrial, marine, and airborne gravimetry.
b. Satellite gravity field observations.
c. Gravity field modeling.
d. Time-variable gravity field.
e. Geoid determination.
f. Satellite orbit modeling and determination.

Commission 3 *Earth Rotation and Geodynamics*
Objectives:
a. Earth Orientation (Earth rotation, polar motion, nutation and precession).
b. Earth tides.
c. Tectonics and Crustal Deformation.
d. Sea surface topography and sea level changes.
e. Planetary and lunar dynamics.
f. Effects of the Earth's fluid layers (e.g., post glacial rebound, loading).

Commission 4 *Positioning and Applications*
Objectives:
a. Terrestrial and satellite-based positioning systems development, including sensor and information fusion.
b. Navigation and guidance of platforms.

c. Interferometric laser and radar applications (e.g., Synthetic Aperture Radar).
d. Applications of geodetic positioning using three dimensional geodetic networks (passive and active networks), including monitoring of deformations.
e. Applications of geodesy to engineering.
f. Atmospheric investigations using space geodetic techniques.

Each Commission shall have a Steering Committee, with a maximum of twelve voting members, which shall define the appropriate sub-structure of the Commission, which may consist of the following components:

a. Sub-commissions,
b. Study Groups.
c. Commission Projects

A planning group for the IGGOS was set up, a first meeting was held in May 2002 in Washington, a second in October 2003 in Munich. The proposal of this group is contained in the separate document (Beutler, Drewes, Rummel, 2003). The status of the realization of the prominent elements of the new IAG structure is summarized in the following sections.

Commission 1 (Task Leader: C.K. Shum)

This proposal emerged from discussions in Nice before, at the, and after the third meeting of the IAG Committee for the Realization of the New IAG Structure on April 26, 2002. It is proposed to set up the following Sub-commissions (SC):

- *SC1.1: Coordination of Space Techniques*
  Take over the coordinating role of its predecessor CSTG in a changed environment. The SC shall establish and further the contact of the space geodetic services based on space techniques, in particular IERS, IGS, ILRS, IVS and commission projects like DORIS.

- *SC1.2: Global Reference Frame*
  Address research-related and practical aspects of establishing the global reference frame. Address fundamental issues of the multi-technique global geodetic observatories. This SC must play a strong role in the new IAG project IGGOS. Its activities shall be coordinated with the IERS. SC1.3 shall in particular establish and maintain the contact with COSPAR.

- *SC1.3: Regional Reference Frames*
  SC1.3 shall offer a home for service-like regional reference frame activities AND address common aspects of these units. In order to avoid the creation of sub-sub-commissions , it is proposed to formally establish
  - SC1.3a: EUREF,
  - SC1.3b: SIRGAS,
  - SC1.3c: NAREF,
  - SC1.3c: AFREF,
  - SC1.3e: APSG, and
  - SC1.3f: SCAR (Antarctic)

  with the understanding that these subcommissions also form the steering committee of SC1.3. Aspects of common interest shall be addressed, combined workshops, sessions at workshops, etc. shall be organized.

- *SC1.4: Satellite Dynamics*
  This SC shall address problems of satellite dynamics, which are outside the scope of the services. One might, e.g., think of the materialization of the celestial reference frame in satellite geodesy as a central theme, where aspects like the transfer of the Quasar-derived frame into the optical domain, but also the the value of modern high-accuracy astrometric places (based on modern telescopes, CCD-equipment) could be addressed.

The following three Commission Projects are proposed:

- *CP1.1: Altimetry:*
  The project shall promote the free access to all satellite altimetry data and its use for geodetic reference frames, in particular height systems. It shall set up the basis for a unified multi-mission long-term record of altimeter data and investigate new techniques and application areas of satellite

altimetry (e.g., off-nadir altimetry, altimetry over land, laser altimetry etc.). The necessary steps towards the establishment of an altimetry service shall be studied.

- *CP1.2: GNSS:*
  The main objective of this project is the coordination of geodetic activities with respect to the new global navigation satellite systems. The links to the international bodies involved in the establishment of new missions and systems shall be maintained and intensified. The adequate use of GNSS for geodetic applications shall be studied in cooperation with the subcommissions of Commission 1.

- *CP1.3: DORIS:*
  The project shall coordinate the establishment of a DORIS service. In this task, it is cooperating closely with the other components of Commission 1 and the existing IAG services in this field (IERS, IGS, ILRS, IVS). The project will be discontinued as soon as a DORIS Service is installed.

Commission 2: Gravity Field (Task leader: Michael G. Sideris)

The new Commission is derived mainly from the existing Section III (Determination of the Gravity Field), with elements of Sections II, IV and V. When mapping the old into the new structure, one may argue that the new Commission 2 should consist of the existing Section III, of Special Commission 7 (Satellite Gravity Field Missions) from Section II, of Special Commission 1 (Physical Foundations of Geodesy) with Sub-commission 3 (Boundary Value Problems) from Section IV, and even of part of Comission 5 (Earth Tides) from Section V. Of course the latter can fit as well under the new Commission 3 (Earth Rotation and Geodynamics).

Although the theoretical aspects of SC1 and its sub-commission 3 could be covered under the proposed Inter-Commission Committee on Theory, it is felt that their natural place is under the new Commission 2, with full cooperation and coordination with the activities of the Inter-Commission Committee.

The five major thematic areas of the new Commission 2 will be:
- Gravimetry and Gravity Networks
- Precise Geoid Determination
- Gravity Field Determination from Satellite Altimetry
- Dedicated Gravity Satellite Missions
- Temporal variations of the Gravity Field

Based on the above themes. there are currently only three major elements planned, that will define the structure of Commission 2. In terms of Sub-commissions, these are:

- *SC2.1: Gravimetry and Gravity Networks*

- *SC2.2: Spatial and Temporal Modelling of the Gravity Field*

- *SC2.3: Dedicated Gravity Satellite Missions*

The proposed SC2.3 might be part of SC2.1 or SC2.2, but, given the very high importance of the new satellite missions, it is felt that, at least initially, there should be a separate sub-commission to deal with the special issues and the variety of applications of these missions. Several study groups similar to the ones that exist currently would again be established to (i) investigate more specific topics and (ii) coordinate regional efforts of gravity mapping, geoid determination, vertical datums, etc.

Commission 2 has very strong links to the newly established International Gravity Field Service (IGFS). consisting of:
- Bureau Gravimetrique International (BGI)
- International Centre of Earth Tides (ICET)
- International Geoid Service (IGeS) I, in Milano
- International Geoid Service (IGeS) II, at NIMA
- International Centre of Global Earth Models (ICGEM), at GFZ

IGFS's terms of reference are available under a separate document. It is clear that the givenning bodies of Commission 2 and IGFS should have a few common members on their Boards to ensure constant communication and proper coordination of their activities.

Commission 3 Earth Rotation and Geodynamics (Task Leader: Clark Wilson)

As discussed at the IAG reorganization planning meeting on April 26, the new Commission 3 Earth Rotation and Geodynamics, replaces Section V Geodynamics in the current structure. Activities not proposed to be included in the two subcommissions below are proposed to be assigned as follows:

- The present International Earth Tide Commission is proposed to be assigned to new Commission 2;
- Activities of the present Fundamental Parameters special commission will be assigned to a new Inter-Commission Committee which will report its results via the IERS Conventions;
- The services (IERS, PMSL, ICET, BIPM time division) will acquire representation on a level with Commissions in the IAG executive committee.

Commission 3 is proposed to consist initially of two subcommissions:

- *SC3.1: Crustal Deformation*
  This proposed subcommission includes activities now under Commission XIV in the current IAG structure. The present Subcommission XIV contains sub-units related to particular geographical regions, including long-standing projects such as WEGENER, APSG, and the Central European Initiative, as well as Africa and Antarctica. The objectives of the current Commission XIV (described on its website http://www.df.unibo.it/commXIV/) are proposed to continue: First, to study 3-D motions, in active tectonic regions, post-glacial rebound and sea-level fluctuations and changes in relation to vertical tectonics along many parts of the coastlines and in relation to environmental fluctuations/changes affecting the geodetic observations; Second, to promote, develop and coordinate international programs related to observations, analysis and data interpretation for the three fields of investigation mentioned above; Third to promote the development of appropriate models.

- *SC3.2: Earth Orientation and Global Geophysical Fluids*
  This proposed subcommission includes activities within the IERS Global Geophysical Fluids Centers (GGFC). There are 7 special bureaus organized to examine the influence of the earth's mobile constituents (fluids) on the earth's orientation, defined broadly in terms of length of day, polar motion, nutations, geocenter and gravity. The 7 special bureaus are concerned with estimating influences of the core, mantle, oceans, terrestrial hydrology, atmosphere, and ocean tides. Activities under the present Special Commission 8 (Sea Level and Ice Sheets) are expected to be incorporated within the appropriate special bureaus. This proposed subcommission will follow the current goals of the GGFC (taken from the GGFC website http://bowie.gsfc.nasa.gov/ggfc/): to compute time variations of angular momenta and related torques, gravitational coefficients, and geocenter shift for all geophysical fluids based on global observational data, and/or products from state-of-the-art models, and to conduct scientific sessions at international meetings and conferences.

Commission 4 Positioning and Applications (Task leader Alan Dodson)

The new Commission 4 will focus on multi-sensor applications, kinematic positioning, atmosphere propagation, monitoring of local geodynamic applications, etc.
The Commission shall have strong links to IAG-external organisations like FIG, ION, and (perhaps) to ISPRS. IAG-internally, the Commission must be linked to the IGS (implying an IGS representation on the Commission's steering committee).

Proposed Sub-commissions:

- *SC 4.1 :Multi-sensor systems*
- *SC 4.2: Dynamic monitoring&analysis of structural and local geodynamic deformation*
- *SC 4.3: GNSS measurement of the atmosphere*
- *SC 4.4: Application of satellite & airborne imaging systems (e.g., INSAR, LIDAR)*

Two commission projects are proposed:

- *CP 4.1: GPS Meteorology, Climate, and Space Weather*

- *CP 4.2: Real-time monitoring systems*

Open issues still are: the terrestrial systems, the height system.

Inter-Commission Committee on Theory (Task leaders: Bernhard Heck and Peiliang Xu)

The proposed Terms of Reference for the Inter-Commission Committee on Theory are:

- Theory is contained within all IAG Commissions/Sections, the Inter-Commission Committee on Theory should primarily be a channel of cooperation amongst the different commissions, on the ground of methodology. The liaison with the Commissions is established through the ICCT's steering committee, the liaison to the broader field of mathematics and physics through the ICCT Advisory Committee. The Committee should be represented in the Steering Committees of IAG Project(s) either by a member of type c) or d) (IAG By-Laws, 1.4) in order to play its role.
- In recognization of the fact that geodesy has exposed new mathematical problems that have not been encountered or not been properly or thoroughly solved in mathematics, the Inter-Commission Committee on Theory encourages frontier research in the fields of mathematics as encountered in geodesy.
- The Inter-Commission Committee on Theory helps IAG in articulating the challenges of geodesy, in terms of mathematics and physics, with the aim to attract young talent to geodesy. It also interacts with scientists in other areas of science and engineering.
- In recognization of the fact that geodesy has an important role to play in understanding the physics of the Earth, the Inter-Commission Committee on Theory thus particularly encourages closer research ties with the relevant areas of the Earth Sciences.

Structure of the ICCT:

- The ICCT's Steering Committee is composed of its president and vice-president (both appointed by the IAG Executive Committee) and one representative from each of the four IAG Commissions.
- The ICCT Advisory Committee consists of the ICCT Steering Committee plus a number of colleagues from mathematics, physics, theoretical geophysics, etc. This advisory committee should provide an interface to external sister communities and should be understood as an extended ICCT Steering Committee, where the additional members have voice but no vote. The panel does establish the contact between theoretical geodesists and practically oriented mathematicians who should have their home in the new IAG structure.
- *Working Groups of Type 1:* These are joint working groups set up by the Committee and the Commissions. They should establish a close cooperation between theory and application within IAG. SC1.4 (although at present not set up in this way) might be an example. A concrete list of working groups should be established till spring 2003.
- *Working Groups of Type 2:* These internal Working Groups concentrate on basic theoretical problems (e.g., general statistical and numerical methods for geodetic data evaluation) or summarize geodetic theory and methodology in a concise way. A concrete list will be prepared by the ICCT Planning Committee for the 2003 Spring Meeting of the IAG Executive Committee.

The working groups also might be called study groups.

Inter-Commission Committee on Geodetic Standards

The planning group should be established as soon as possible.

Outreach Branch

The process of setting up the Outreach Branch is in the hands of the secretary general.

IAG Project IGGOS (Integrated Global Geodetic Observing System)

The IGGOS planning group is chaired by Gerhard Beutler till summer 2003, Hermann Drewes is the planning group's secretary. The group met twice, once in Washington and once in Munich.

The planning group held a first meeting in Washington on May 27, 2002 in Washington. The meeting was intense and at times controversial. The establishment of IGGOS seemed to be far from trivial. A vision and a mission statement as well as objectives for IGGOS were subsequently proposed by Gerhard Beutler, Jim Ray, John Manning, Hermann Drewes, and Reiner Rummel.

The second meeting of the planning group took place on November 22, 23 in Munich at DGFI, the German Geodetic Research Institute. This meeting was extremely constructive and successful. In a first phase the vision, mission and objectives for IGGOS were briefly reviewed and finalized (to the extent that such statements may ever reach a final form).The agreed upon version of the IGGOS vision, mission, and objectives are reproduced in this document. The primary (and ambitious) goals of the November 2002 IGGOS planning group meeting were to reach a consensus on the following four aspects:

- Strategy to develop an IGGOS Science Rationale,
- strategy to develop an IGGOS Science Plan,
- strategy to develop an IGGOS Structure, and
- outline of a realistic IGGOS Schedule.

The meeting resulted in the proposal to actually establish the IGGOS as IAG's first project. The full text is contained in the reference (Beutler, Drewes, Rummel, 2003).

Summary and Action Items

Summary: The present document gives an overview of the status of the IAG Restructuring process. The process is complex and needs to be finalized between the two IAG Executive Committee Meetings in Nice (April 2003) and in Sapporo (July, 2003). The work must be performed mainly by the IAG Bureau, the five section presidents, and the newly elected IAG officers.

Specific concerns were brought forward by Bernhard Heck. They are not yet resolved, which is why this task has to be addressed by the same group in the time frame mentioned above. The concerns are:

- The proposed structure of Commission 1 seems to be not fully consistent with the original objectives of the new Commissions, which should act as scientific entities instead of reflecting regional initiatives. The substructure of Commission 1 is felt to be too close to the structure of the present Section I. Scientific aspects should be more pronounced. Regional initiatives should get another status and might be organized by advisory panels for the respective regions rather than in Sub-Commissions.
- The natural place for the present Earth Tide Commission is Commission 3; this topic is explicitly stated in Section 1.2.1 of the new IAG Bylaws.
- There is a strong interrelation visible between SC3.1 on Crustal deformation in Commission 3 and SC 4.2 (local geodynamic deformation). It might be preferable to create a joint sub-entity. The open issues addressed to in item 3.4 might be solved in the following way: - terrestrial systems belong to Commission 1,-height systems might be integrated in Commission 2.

Thanks to the work of Bernhard Heck, Peiliang Xu, Véronique Dehant, and the entire ICCT planning committee we now have a concrete proposal concerning the objectives and the structure of the new Inter-Commission Committee on Theory.

No progress was made up till now with the ICC on Geodetic Standards. We should have concrete proposals at the Nice Executive Committee meeting. Otherwise the ICC on Standards cannot be set up in Sapporo.
It should be possible to formally establish the definition phase for IGGOS in summer 2003. The proposal will be made at the Nice Executive Committee meeting.

Concrete Action Items:

- Review of the above document by the IAG Committee for the Realization of the New IAG Structure by the IAG Executive prior to April 1.
- Define and approve workplan between Nice and Sapporo IAG EC Meetings.

References

G. Beutler, F. Brunner, J. Dickey, M. Feissel, R. Forsberg, I.I. Mueller, R. Rummel, F. Sanso, and K.P. Schwarz: The IAG Review 2000-2001: Executive Summary. International Association of Geodesy Symposia, Volume 125, pp. 603-608, Springer-Verlag 2002.

R. Rummel, H. Drewes, G. BeutlerL Integrated Global Geodetic Observing System (IGGOS): A Candidate IAG Project. International Association of Geodesy Symposia, Volume 125, pp. 609-614, Springer-Verlag 2002.

G. Beutler, H. Drewes, Ch. Reigber, R. Rummel: Proposal to Establish the Integrated Global Geodetic Observing System (IGGOS) as IAG’s First Project. IAG Executive Committee, Spring 2003.

Proposal to Establish the

"Integrated Global Geodetic Observing System (IGGOS)"

as IAG's First Project

On behalf of the IGGOS Planning Group:

G. Beutler, H. Drewes, C. Reigber and R. Rummel

Preamble

The new IAG structure was developed after the IUGG General Assembly in Birmingham in summer 1999. Between summer 1999 and summer 2001 a thorough review of the IAG work and structure was performed by the so-called IAG Review Committee, the work of which is documented in (Beutler et al., 2002, IAG Symposium 125, pp. 603-608), a report presented at the IAG Scientific Assembly in Budapest in September 2001. The proposed new structure was accepted by the IAG Executive Committee and later on by the IAG Council, which held an extraordinary meeting on September 8, 2001 in Budapest.

At the same meeting (Rummel et al., 2002, IAG Symposium 125, pp. 609-614) proposed to create the IGGOS, the Integrated Global Geodetic Observing System as IAG's first project. In view of the fact that the new structure was not yet in place in 2001, the rules to set up the IGGOS as the first IAG project (defined in the new IAG Bylaws) could not be followed literally. The IAG Executive Committee therefore asked Reiner Rummel and Gerhard Beutler to establish the IAG Planning Group with the goal to set up IGGOS as IAG's first and only project in summer 2003. The group was created in spring 2002 after an organizational meeting of a smaller group convened by Reiner Rummel in Munich in December 2001.

The IGGOS Planning Group and its Meetings

The planning group for IGGOS is composed as follows:

- Members related to the realization of the reference frame: *Claude Boucher, Hermann Drewes, Markus Rothacher*
- Members related to the gravity field and sea level: *Rene Forsberg, Reiner Rummel, C.K. Shum*
- Members related to Earth rotation and geodynamics: *Veronique Dehant, Suzanna Zerbini, Kosuke Heki*
- Members related to services related to geometry: *Mike Pearlman, Chris Reigber, Norman Beck*
- Members related to services related to gravity and sea level: *Fernando Sanso, Phil Woodworth, Mike Watkins*
- Members related to networks: *Wolfgang Schlüter, John Manning*
- Relation to NASA projects: *Tom Yunck, Ruth Neilan*

The planning group is chaired by Gerhard Beutler till summer 2003, Hermann Drewes is the planning group's secretary. The group met twice, once in Washington and once in Munich. Jan Kouba served as deputy for Norman Beck at the Munich meeting.

The planning group held a first meeting in Washington on May 27, 2002 in Washington. The meeting was intense and at times controversial. The establishment of IGGOS seemed to be far from trivial. A vision and a mission statement as well as objectives for IGGOS were subsequently proposed by Gerhard Beutler, Jim Ray, John Manning, Hermann Drewes, and Reiner Rummel.

The second meeting of the planning group took place on November 22, 23 in Munich at DGFI, the German Geodetic Research Institute. This meeting was extremely constructive and successful. In a first phase the vision, mission and objectives for IGGOS were briefly reviewed and finalized (to the extent that such statements may ever reach a final form).The agreed upon version of the IGGOS vision, mission, and objectives are reproduced in this document. The primary (and ambitious) goals of the November 2002 IGGOS planning group meeting were to reach a consensus on the following four aspects:

- Strategy to develop an IGGOS Science Rationale,
- strategy to develop an IGGOS Science Plan,
- strategy to develop an IGGOS Structure, and
- outline of a realistic IGGOS Schedule.

IGGOS Vision, Mission and Objectives

Vision:

- IGGOS provides the scientific and infrastructure basis for all geodetic global change research in Earth sciences.
- IGGOS views the Earth system as a whole by including the solid Earth as well as the geophysical fluid components, the mean and (climate-sensitive) time-varying gravity field in its products.
- IGGOS integrates different techniques, different models, and different approaches in order to achieve a better consistency, long-term reliability and understanding of geodetic, geophysical, geodynamical and global change processes.
- IGGOS provides geodesy's contribution (products and discoveries, and their uncertainties) to Earth sciences.
- IGGOS integrates the work of IAG and is the bridge to the other geosciences.

Mission:

- IGGOS integrates the three pillars of geodesy, namely
  1. geometry and kinematics,
  2. Earth orientation and rotation, and
  3. gravity field and its variability

  to achieve maximum benefit for the scientific community and society in general.
- IGGOS promotes the scientific research in geodesy.
- IGGOS recognizes the achievements of Space Geodesy and other fields of geodesy.
- IGGOS identifies a consistent set of geodetic products, establishes the requirements concerning the products' accuracy, time resolution, and consistency.
- IGGOS identifies IAG service gaps and develops strategies to close them.
- IGGOS stimulates close cooperation between existing and new IAG services.
- IGGOS is geodesy's central interface to the scientific community and to society in general.

Objectives:

- IGGOS aims at maintaining the stability of and providing the ready access to the existing time series of geometric and gravimetric reference frames by ensuring the generation of uninterrupted time series of state-of-the-art global observations related to the three pillars of geodesy.
- IGGOS focuses in the first phase on all aspects relevant to ensure the consistency of geometric and gravimetric products. This includes space-borne and terrestrial aspects.
- The targeted overall accuracy and consistency of IGGOS products is of the order of 10^{-9} or better.
- IGGOS shall be established as an official partner in the IGOS, United Nation's Integrated Global Observing Strategy.

Science Rationale and Development of an IGGOS Science Plan

Science Rationale: IGGOS shall have a central theme and a master product. This general theme must be scientifically sound, broad and include all the activities IGGOS might envisage in future. *Global Deformation Processes and Mass Exchange Processes* is proposed to be the central theme.

Under the umbrella of geometry plus Earth rotation plus gravity field this theme encompasses virtually all facets of geodesy. In addition, it may easily be translated and broken down into tangible individual sub-themes and -products. From the general theme one general product may be derived, encompassing the following scientific questions/areas:

- The global patterns of tectonic motion (global with, in addition, "enlargements" of regional scenes) including inter-plate and intra-plate deformation,

- The global patterns of height changes (in one datum, and on all time scales, of geodynamic as well as of anthropogenic origin) on land, of ice covers (including glaciers), and of sea level,
- Deformation (loading as well as expansion) due to the mass exchange between atmosphere, oceans, hydrology, ice and solid Earth,
- Separation of effects of ocean mass changes from motion and from thermal expansion and salinity contraction,
- Separation of ocean effects from solid earth effects (“absolute” sea level),
- Quantification of atmosphere water vapor, which is the largest greenhouse gas,
- Quantification of angular momentum exchange, torque, and
- quantification of mass exchange between the components of system Earth.

The above list is not meant to be final and will be further developed.

The master theme and the products derived from it will address the relevant science issues related to geodesy and geodynamics in the 21st century, but also issues relevant to society (global risk management, natural resources, climate change, earthquake, volcanic eruptions, shoreline erosions, subsidence, extreme weather forecasting, ocean forecasting and others). It is a master theme of a dimension that can neither be produced in splendid geodetic isolation (one would in any event need GLOSS and others) nor by one geodetic entity alone (it requires the cooperation of the services, the “big players”, of regional projects and input from national organizations).

In order to shape the master theme and the master-product a sound and comprehensive IGGOS Science Plan is required. The IGGOS science plan shall provide a logical framework for the work of IGGOS. The master theme and the corresponding product(s) must be put into a broader science and application context. It should also include an analysis of our state-of-art in the science field under discussion, strength and deficiencies, recommendations of what should be done. If possible, priorities should be set.

The IGGOS Science Plan should serve as the basis for the implementation of IGGOS in 2005. A working plan should be derivable from it. Furthermore it should be an attractive document for presentation to potential future partners and clients.

Initial IGGOS Structure

The following general principles will be observed:

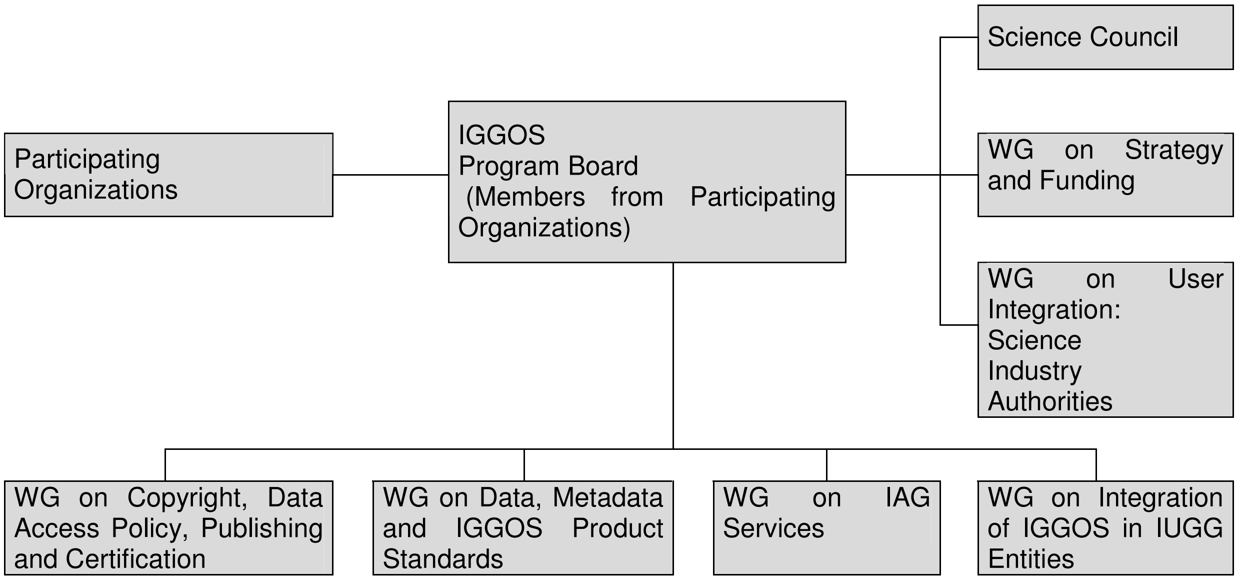
- IGGOS will be based on the existing IAG Services. IGGOS is in particular not taking over tasks of existing, and well working IAG services.
- New entities will be established only if there is a stringent requirement.
- IGGOS must be the recognized by partners outside IAG, e.g., by UNESCO, ICSU, IGOS, GOOS, GTOS, governments, inter-government organizations, WCRP, IGBP, etc., as geodesy’s contribution to Earth sciences. For this purpose contacts have to be established to these organizations.
- IGGOS must promote its master product and the related sub-products.
- IGGOS will enforce quality management (validation, calibration, ensure the 1 ppb level) either by a new IGGOS entity or by delegating this task to one or several of the existing services.

The initial structure to be established in summer 2003 for the definition phase of the IGGOS Project must be simple and should not be in conflict but cooperate with the existing IAG services.

The key elements of the initial IGGOS structure are:

1. The IGGOS Program Board as the central oversight entity.
2. Few well-defined working groups. The tasks of the working groups are to a high degree independent of the tasks of the IAG services.
3. The establishment of a Science Council may be considered.

Figure 1: Initial IGGOS Organization



The initial IGGOS (for the definition phase 2003-2005) is explained by Figure 1. The working groups specified should serve as typical examples. The precise structure still may be altered between the Nice and Sapporo Executive Committee meetings by the IGGOS Planning Group.

Comments concerning Figure 1:

- Science Council: It would be a primary task of the science council to develop the IGGOS science rationale and then the science plan. Should the decision be taken not to establish the science council, the IGGOS Program Board should take over these responsibilities. The Inter-Commission Committee on theory must be represented in the Science council or in the group setting up the science plan.
- WG on Strategy and Funding: Funding has to be addressed on a long-term basis by all permanent IAG entities requiring a heavy infrastructure. As IGGOS per se will be (at least initially) based – exactly like all IAG services – on a voluntary cooperation of the relevant research organizations in the field, the IGGOS funding strategy must be developed in close cooperation with these organizations. It seems therefore appropriate to establish a working group related to this topic. The aspect is clearly not dealt with consistently within the existing IAG services structure.
- WG on User Integration: This task is in part dealt with by the IAG services. A common policy on the IAG level is, however, missing. This WG must be set up in close cooperation with the services.
- WG on Data, Metadata, and Data Standards: A central issue for IGGOS, indeed. Here, the key products and their consistency levels have to be defined. This WG must be set up in close cooperation with the services.
- WG on Copyright, Data Access Policy, Publishing and Certification: Many of these issues have to be addressed today on a case by case basis. There should, however, be general rules for the entire field of IGGOS.
- WG on IAG Services: The key issue within this WG is a thorough analysis of the existing IAG structure. Does it make sense to combine certain services into one? (The question might be asked in the case of IGS, ILRS, and possibly IVS). What new services should be set up? Is it correct to distinguish within IAG between level 1 services (e.e., IGS, ILRS, IVS, etc.), dealing with raw observations and generating products which are more or less based on these observations only, and level 2 services (e.g., IERS) using the products of several level 1 services and generating new products or meta products, which are consistent with all the information from level 1? Shall there be one, two, or more level 2 services within IGGOS?
- WG on Integration of IGGOS in IUGG entities: This WG has the task to set (so-to-speak) the foreign ministry of IGGOS. It must be the goal to have IGGOS acknowledged as a member in the important international programs dealing with global change, etc. The IGOS is but one important example.

Schedule for the Realization of IGGOS

The schedule is based on the assumption that the IAG Executive Committee, at its meeting of April 11, 2003 in Nice will approve the plan presented in Section 8 to establish the IGGOS.

1. The IGGOS planning group will meet once between the Nice and Sapporo IAG Executive committee meetings with the goals (a) to propose a chairperson for the IGGOS definition phase, (b) to finalize the IGGOS structure for the IGGOS definition phase, (c) to formally establish the IGGOS Program Board, (d) to decide whether or not to establish an IGGOS Science Council, (e) agree on a final version for the science rationale.
2. The concrete proposals concerning the issues mentioned above will be presented for approval to the IAG EC at its Sapporo meeting.
3. The IGGOS, as IAG's first project, will be realized in two steps, namely (a) in the IGGOS definition phase (2003-2005), (b) in the official IGGOS project thereafter.
4. IGGOS, in particular the science plan developed between 2003 and 2005, should be a central issue of the IAG Scientific Assembly 2005.

Proposal for the Establishment of IGGOS to the IAG Executive Committee

The IAG Planning Group proposes to establish the IGGOS as IAG's fist project in the following way:
1. Vision, Mission and Objectives are those outlined in Section 3.
2. The definition phase for IGGOS will start on August 1, 2003 and it will end at the IAG Scientific Assembly in 2005.
3. The definition phase of IGGOS will be led by the IGGOS Program Board. Membership in and Chairperson of the IGGOS Board will be proposed by the IAG Planning Group of IGGOS at a meeting between the Nice and Sapporo meetings. Both issues need confirmation by the IAG Executive Committee and the IAG Council.
4. The initial IGGOS structure for the time interval 2003-2005 of the IGGOS definition phase is in essence as illustrated by Figure 1. Modifications by the IAG Planning Group still are possible and may be proposed at the meeting of the IAG planning group in spring 2003. The finalized structure needs approval by the IAG Executive at the Sapporo meeting.
5. Structure, vision, mission, and objectives of the official IAG Project will be developed during the IGGOS definition phase between 2003 and 2005 and presented to the IAG Executive for approval at its meeting in 2005 associated with the IAG Scientific Assembly.