The Inter-Commission Committee on Theory (ICCT)

President: **Peiliang Xu** (Japan)
Vice-President: **Athanasios Dermanis** (Greece)

Terms of Reference

Geodesy as a subject of science has witnessed and has been based on some of the most important mathematical and physical inventions and technological achievements in the history of civilization. For mathematical and physical foundations, we mention Kepler's laws on a planet orbit, Newton's laws (the law of universal gravitation and the second law of motion), Gauss' least squares method and geometry, Stokes' and Bruns' formulae to compute the geoid and Vening Meinesz's formula to compute the deflection of vertical, Einstein's theory of relativity and Kaula's theory of satellite geodesy. For most important technological achievements, we may mention computing technology, information technology and space technology, among others, which not only have fostered more theoretical geodetic research in return but have also completely changed the image of and working environment for geodesists. It is recognized that theoretical breakthroughs in geodesy came only when geodesy demonstrated itself as a great challenge and thus attracted the great intellects of the time. We may also notice that these theoretical breakthroughs had a deep root in solving a practical geodetic or astronomic problem of the time.

As part of the restructuring of the IAG, and in particular, the former IAG Section IV on Geodetic Theory and Methodology, the Intercommission Committee on Theory (ICCT) was formally approved and established after the IUGG XXIII Assembly in Sapporo. According to the IAG By Laws, Inter-Commission Committees are asked to handle "well-defined, important and permanent tasks involving all Commissions". However, from the ICCT point of view, and keeping in mind generality of theory, the ICCT must think and act beyond geodesy. As a result, the ICCT is to continue theoretical research of the former IAG Section IV on General Theory and Methodology, but with emphasis on solving „practical" challenging geodetic problems in mind. With the history of theoretical geodetic research in mind as a mirror, the ICCT will, in particular, encourage and promote active and direct interactions with other IAG Entities that directly deal with measurements, in order to further flourish theoretical research on a solid „practical" foundation.

Objectives

As a result of the IAG restructuring, and recognizing that geodetic observing systems have advanced to such an extent that geodetic measurements: (i) are now of unprecedented high accuracy and quality, can readily cover a region of any scale up to tens of thousands of kilometres, consist of non-conventional data types, and can be provided continuously; and (ii) consequently, demand new mathematical modelling in order to obtain best possible benefit of such technological advance, the ICCT

1. strongly encourages frontier mathematical and physical research, directly motivated by geodetic need/practice, as a contribution to science/engineering in general and the foundations for Geodesy in particular;
2. provides the channel of communication amongst the different IAG entities of commissions /services/ projects, on the ground of theory and methodology, and directly cooperate with and support these entities in the topics-oriented work;
3. helps the IAG in articulating mathematical and physical challenges of geodesy as a subject of science and in attracting young talents to geodesy. The ICCT should certainly try to attract and serve as home to mathematically motivated/oriented geodesists and to applications-oriented applied mathematicians; and
4. encourages closer research ties with and directly gets involved with relevant areas of the Earth Sciences, bearing in mind that geodesy has been playing an important role in understanding the physics of the Earth.

Steering Committee

Peiliang Xu (President of the ICCT, Japan)
Athanasios Dermanis (Vice-President of the ICCT, Greece)
Zhengyuan Zhu (Rep of Commission I, Germany)
Nico Sneeuw (Rep of Commission II, Canada)
Tim van Hoolst (Rep of Commission III, Belgium)
Jinling Wang (Rep of Commission IV, Australia)

Structure

Working Groups:

WG ICCT1: Inverse Problems and Global Optimization
Chair: **Juergen Kusche** (Germany)

WG-ICCT2 Dynamic Theories of Deformation and Gravity Fields
Chair: **D. Wolf** (Germany)

WG-ICCT3: Functional Analysis, Field Theory and differential Equations
Chair: **Jinhai Yu** (China)

Inter-Commission Study Groups

IC-SG2.5: Aliasing in gravity field modeling
(Joint with Commission 2)
(Description: See Commission 2)
Chair: **C.C. Tscherning** (Denmark)

IC SG2.6: Multiscale Modeling of the Gravity Field
(Joint with Commission 2)
(Description: See Commission 2)
Chair: **W. Freeden** (Germany)

IC-SG4.2 Statistics and Geometry in Mixed Integer Linear Models, with Applications to GPS and InSAR
(Joint with Commission 4)
(Description: See Commission 4)
Chair: **A. Dermanis** (Greece)

Inter-Commission Working Groups

IC-WG 1: Quality Measures, Quality Control and Quality Improvement
(Joint with Commission 1 and 2)
Chair: **H. Kutterer** (Germany)

IC-WG2: Integrated theory for Crustal Deformation
(Joint with Commission 1 and 3)
Chair: **K. Heki** (Japan)

IC-WG3: Satellite Gravity Theory
(Joint with Commission 1 and 2)
Chair: **N. Sneeuw** (Canada)

IC-WG 1.2.1: Datum Definition of Global Terrestrial Reference Frames
(Joint with IERS and Commission 1)
(Description: See Commission 1)
Chair: **Geoffrey Blewitt** (USA)

Advisory Committee

Prof E.W. Grafarend (Germany)
Prof B. Heck (Germany)
Dr P. Holota (Czech Republic)
Prof C. Jekeli (USA)
Prof S. Kotz (USA)
Prof R. Rummel (Germany)
F. Sanso (Italy)
C.K. Shum (USA)
S. Takemoto (Japan)
A. Tarantola (France)
P. Teunissen (The Netherlands)
C.C. Tscherning (Denmark)

Working relations.

In order to realize the vision and goals of the ICCT within the new IAG structures, the ICCT has proposed to build up a working relationship with the Commissions by setting up joint study groups. The ICCT is pleased that the IAG Executive Committee approved this unconventional approach. Despite the fact that these joint entities were initiated by the ICCT, some of their descriptions are included under the Description of the Commissions. This "measure" should underline the autonomy of the Commissions within their field and it undoubtedly also underlines the good will of the ICC on Theory to build up a sound working relationship with the Commissions. More specifically, the ICCT is organized as follows: Steering Committee, Advisory Committee, ICCT joint working groups with the Commissions and ICCT internal working groups.

Working Group

WG ICCT1 - Inverse Problems and Global Optimization

Chair: **Juergen Kusche** (Germany)

Terms of Reference

At the Sapporo General Assembly of the IUGG, June 30 to July 11, 2003, the International Association of Geodesy (IAG) has approved the Intercommission Commitee on Theory (ICCT) as a part of its new structure. ICCT is the successor of the former IAG Section IV on General Methodology and Theory. In order to support its work the ICCT establishes internal and joint working groups (study groups). One of these internal working groups will be directed towards the study of inverse problems in geodesy, in theory and applications. The purpose of this document is to describe its background, potential research area and objectives, and terms of reference for the period of 2003--2007.

Background

It is well recognized that many, if not most, geodetic problems are in fact inverse problems: we know to a certain level of approximation the mathematical and physical model that projects the parameter space onto the data space; given a possibly blurred element of the data space, the observations, we want to recover the governing discrete parameters or continuous fields. The situation is further complicated by the fact that these problems are often ill--posed in the sense that only generalized solutions can be retrieved, that non--trivial nullspaces exist or that the solutions do not depend continuously on the data.

In particular gravitational modelling from space gravity missions has been (and will be undoubtly in the future) intensively investigated using Inverse Problem Theory; including the study of regularization methods and smoothing techniques and the quality of gravity models. With the cutting--edge aims of the new gravity missions (recovery of monthly surface mass variations from GRACE, constraining viscosity/lithospheric/postglacial rebound models from GRACE time variable gravity and from GOCE static geoid pattern analysis) it can be expected that Inverse Problem Theory will be even more important for the space gravity community.

But there are other, more classical geodetic problems that have been identified as inverse and ill--posed and attracted researchers: The inverse gravitational problem where we are interested in modelling the earth's interior density from gravity observations, different kinds of downward continuation problems in airborne gravimetry and geoid determination, certain problems in the context of satellite altimetry and gravity modelling, the problem of separating geoid and dynamic ocean topography, the problem of inferring excitations/earth structure parameters from observed polar motion, deriving stress or strain tensors from observational surface monitoring data, or certain datum problems in the definition of reference frames. A very recent problem of ill--posed type is the orbit differentiation problem: non--conventional gravity recovery methods like the energy conservation approach and the acceleration approach require GPS--derived kinematic satellite orbits to be differentiated in time, while counteracting noise amplification at the same time.

Inverse Problem Theory itself as a joint branch of applied mathematics and statistics is concerned with extracting (maximum) information about systems from observed data. It is rapidly evolving, theoretically and computationally. We should keep track with new developments e.g. in multi-parameter regularization schemes, global optimization theory, stochastic inversion, Bayesian methods, data assimilation in general, etc. In geodesy, we also have to develop inverse methods that can be used for large--scale problems, involving high degree and order gravity field models from space gravity missions and high--resolution discretizations of the density field or the dynamic ocean topography, for example.

Finally, it should be noted that the working group will not have to start from the scratch: Several IAG special study groups in the past have been dealing with inverse problems, either directly or in a related sense. In the new IAG structure, close cooperation will take place eg with the inter-commission working group on Satellite Gravity Theory.

Scope

The working group brings together people working on inverse problem theory in general and its applications in geodesy. The central research issue is, besides a thorough theoretical understanding of inverse problems in geodesy, to extract maximum information from data by properly developing mathematical/statistical methods in a uniquely defined sense of optimality, and to apply these methods to geodesy. In particular, the following objectives can be identified:

- Identification and theoretical understanding of the nature of inverse and/or ill--posed problems

- Development and comparison of mathematical and statistical methods for the proper treatment of inverse problems.
- Recommendations and communication of new inversion strategies within the IAG and to the broader community.

The working group will focus activities in the following research areas:

- Studies on the mathematical structure of the nullspace in problems where ambiguous solutions occur.
- Studies on the application and quality of regularization methods in practical geodetic problems: that is, where we are confronted with coloured noise, heterogeneous data, partially over- and under-determination, different sources of ill-posedness like data gaps plus downward continuation, etc.
- Studies on global optimization methods and theory.
- Investigation of formal measures for the quality of regularized or constrained solutions.
- Study on the use of techniques for treating inverse problems locally, e.g. through locally adapted regularization wavelets.
- Studies on the representation of prior information
- Study of Bayesian and Monte Carlo inversion schemes in geodetic and joint geodetic/geophysical problems
- Study on nonlinear inversion in geodetic problems, i.e. avoiding linearization schemes.
- Studies on efficient numerical implementation of inverse methods.
- Studies on theory and application of joint geodetic/geophysical inversion schemes.

Program of Activities

- Email discussion
- Launching a web--page for dissemination of information, expressing aims, objectives, plus providing a bibliography. This would also give members (and other interested individuals) a platform to communicate individual views and results, and stimulate discussions.
- Identification of, and communication with related bodies within the new IAG structure.
- Monitoring and presentation of activities, either of working group members or external, that is relevant for the research area.
- Organizing of WG meeting or session, in coincidence with a larger event, if the presence of working group members appears sufficiently large.

Working Group

WG ICCT2 - Dynamic theories of deformation and gravity fields

Chair: **D. Wolf** (Germany)

Terms of References

Recent advances in ground-, satellite and space-geodetic techniques have detected temporal changes of deformation and gravity covering a wide period range. These changes are related to different types of processes acting near the earth's surface or in its interior.

Forward and inverse modelling of the deformation and gravity changes require the development of dynamic theories for 1-D, 2-D and 3-D earth models.

Program of Activities

- Development of generalized Love-number formalisms for static forcing functions (normal and tangential surface forces, volume forces, dislocations).
- Development of generalized Love-number formalism for periodic forcing functions Fourier-transformed Love numbers) and aperiodic frocing functions (Laplace-transformed Love numbers)
- Development of 3-D viscoelastic earth models for modelling processes responsible for deformation and gravity changes.
- Investigation of effects due to density stratification, compressibility, rheology and lateral heterogeneity.
- Forward modelling of deformation and gravity changes caused by atmospheric, cryospheric, hydrospheric and internal forcing functions.
- Inverse modelling of measured deformation and gravity changes in terms of mantle viscosity and forcing functions.

Membership

Chairman: D. Wolf (Germany)
H. Abd-Elmotaal (Egypt), J.-P. Boy (USA), L. Brimich (Slovakia), B. Chao (USA), J. Fernandez (Spain), L. Fleitout (France), E. Ivins (USA), G. Kaufmann (Germany) V. Klemann (Germany), Z. Martinec (Czech Republic), J.X. Mitrovica (Canada), G.A. Milne (UK), G. Spada (Italy) W. Sun (Japan), L.L.A. Vermeersen (Netherlands), P. Wu (Canada),
Associate Members
E.W. Grafarend (Germany), J. Hinderer (France), L.E. Sjöberg (Sweden), P. Varga (Hungary)

Working Group

WG ICCT3 - Functional Analysis, Field Theory and Differential Equations

Chair: **Jinhai Yu** (China)

Terms of Reference

With the rapid development of measurement techniques, in particular, thanks to space GPS geodesy and gravity satellite missions, a huge number of geometrical and physical data, with the unprecedented high accuracy, would become routinely available to study the shape of our planet, its gravity field and time variations. These high quality data would certainly provide new challenges to geodesist, practically and theoretically. In order to meet such challenges and to derive most benefit for geodesy, the ICCT decided to form a working group and investigate existing and new mathematical theory/methods. Also keeping in mind the importance of geodetic boundary value problems, we would like to make this new working group by extending the conventional geodetic boundary value problems to functional analysis, field theory and differential equations.

Objectives

- Investigate frontier research in functional analysis, field theory and partial differential equations, and potential applications in geodesy, in particular, geopotentials and geodetic boundary value problems (GBVP).
- Encourage interdisciplinary research in mathematically modeling different types of geo-data in terms of functional analysis, field theory and differential equations, directly motivated by the IAG concept of Earth Observing Systems, and bearing in mind the importance of interaction between geodesy and other Earth Sciences areas.
- Further theoretical research in stochastic differential equations, nonlinear filtering and possible geodetic applications.

Program of Activities

- Establish a website to serve as an open forum for its members and those who are interested in this subject.
- If possible, there will be working meetings at international symposia.
- Plan to publish a compilation of the most important papers.

Membership

Chair: Jinhai Yu (China)

Sten Claessens (Australia)
Bernhard Heck (Germany)
Peter Holota (Czech Republic)
Wolfgang Keller (Germany)
Juergen Kusche (The Netherland)
Fei Li (China)
Lintao Liu (China)
Hossein Nahavandchi (Iran)
Jesus Otero (Spain)
Margarita Petrovskaya (Russia)
ChungDing Zhang (China)

Inter-Commission Working Group

IC-WG1 Quality measures, quality control, and quality improvement

(joint with Commission 1 and 2)

Chair: **Hansjörg Kutterer** (Germany)

Terms of Reference

Geodesy generates und supplies various products for use in its own community as well as a service for related disciplines. Typically, the respective skills of the creator and of the user of the products are not congruent. Hence, originary products are needed whose essential properties are documented and quantified comprehensively. Up to now, a rigorous quality control is not common in Geodesy. International standards for quality management which are used outside Geodesy for manufacturing and services need to be specified regarding the particular field of interest. Present shortcomings in Geodesy are, e.g., the lack of specific measures of quality and the unsatisfactory assessment of the processes upon which geodetic products are based. In addition, the accuracies of the results from space-geodetic techniques are still too optimistic.

Objectives

There is a need for a thorough scientific foundation of quality in Geodesy. The theoretical delevopments have to be adapted to key applications in Geodesy. Hence, there are two main tasks: the set-up of a general concept and its exemplary application. A literature research which concerns scientific publications as well as documents on standardized quality management is essential to show the range of definitions of quality and the main fields of application.
In order to make quality measurable, the contributors to the quality of the final product have to be identified and defined mathematically. Therefore the process chains to derive geodetic products have to be studied. Their intrinsic properties such as the sometimes unclear rank deficiencies of the respective normal equations have to be compiled and optimised. Side information in data processing and analysis (e.g., for stabilization and regularization in view of consistency) needs to be assessed. Finally, suitable optimisation approaches have to be elaborated under consideration of the related uncertainty.
Once a general concept for quality control in Geodesy is established and recommended, quality improvement can be tackled based on the mathematical quality measures, the analysis of process chains and optimisation techniques.

Membership

Chair: Hansjörg Kutterer (Germany)

Orhan Akyilmaz (Turkey)
Manuela Krügel (Germany)
Rodrigo Leandro (Canada)
Rüdiger Lehmann (Germany)
Stefan Leinen (Germany)
Frank Neitzel (Germany)
Burkhard Schaffrin (U.S.A.)
Steffen Schön (Germany)
Emmanuel Shyllon (Nigeria)
Volker Stahl (Germany)
Mike Stewart (Australia)
Jinling Wang (Australia)
Andreas Wieser (Canada)
Yuanxi Yang (China)

Corresponding members
Jürgen Kusche (The Netherlands)
Reinhard Viertl (Austria)
Rainer Fletling (Germany)

Program of Activities

- Installation of a website for communication, presentation and outreach purposes
- Regular distribution of circular mails on the progress of the work
- Survey on the present handling of quality issues in Geodesy, identification of shortcomings, mainly regarding:
- Quality measures in use
- Uncertainty modelling for space-geodetic techniques (cooperation with IAG Commission 1)
- ISO 9000 ff recommendations
- Side information (rank deficiencies or weaknesses, regularization or stabilization)
- Development of a general quality concept for geodetic purposes
- Compilation and mathematical formulation of quality measures
- Recommendation of proper uncertainty measures (in particular for space-geodetic techniques)
- If possible, there will be a specific workshop
- Publication of a compilation of the most important results such as of the survey on quality modelling

Inter-Commission Working Group

IC-WG2 Integrated theory for crustal deformation

(joint with Commission 1 and 3)

Chair: **Kosuke Heki** (Japan)

Terms of Reference

In the new structure of International Association of Geodesy, establishment of this joint working group was proposed by the Intercommission Committee on Theory (ICCT President: P.Xu), the Commission on Earth Rotation and Geodynamics (President: V. Dehant), and the Commission for Positioning (President: H. Drewes). Owing to recent densification of Global Positioning System arrays in boundary zones of tectonic plates, e.g. in Japan and western North America, there are increasing demands for realistic theoretical models and computational programs incorporating recent theoretical progresses. The joint WG, chaird by Kosuke Heki and composed of about 10 members with expertise in various fields of crustal deformation studies, is expected to strengthen ties between modellers and those working on various observational data of crustal deformation.

Objectives

The WG is supposed to bridge the three commissions by identifying important theoretical problems in crustal deformation studies, looking for solutions, feeding back solutions to research communities. These problems will include, surface deformation of the realistic Earth due to dislocation at depth, crustal movement due to various loads, analysis of time series including jumps and periodic components, combination of data from different techniques, finite element methods to simulate crustal activities in subduction zones, incorporation of viscoelasticity, etc.. The goal is for worldwide researchers to share the most advanced information on models and software packages for particular issues in crustal deformation studies.

Program of Activities

As a task of the WG, it is planned to make a website for standard software packages for crustal deformation studies. In such studies we follow several steps, e.g. time series analysis of GPS, tide gauge, etc., linear regression, identification of jumps, search for set of faults or inflation sources, inversion of complicated slip distribution, temporal evolution of slips, modeling postseismic transients, drawing diagrams, and so on.

For the individual steps, there are public domain software packages used by majority of researchers. Also there may be new programs which will become standards in the future. For example, new programs to calculate surface displacement due to fault dislocation at depth have been developed for spherical and layered Earth cases in addition to the classical half-space.

The website will hopefully provide information on the availability of source codes, their whereabouts, references, example of applications, contact addresses of the authors, etc. That will help the research community, especially those starting crustal deformation studies. During the term of four years, the WG will define items of tasks for which standard software packages are sought (1st year), then make the proto-type webpage (2nd year), reinforce examples and references of each item (3rd year), and let the finished page be directly linked from the IAG website (4th year).

Membership

Chair: Kosuke Heki (Japan)

Danan Dong (USA)
Kazuro Hirahara (Japan)
Teruyuki Kato (Japan)
Shin'ichi Miyazaki (USA)
Barbara Meisel (Germany)
Frank Roth (Germany)
Wenke Sun (Japan)
Kelin Wang (Canada)
Simon D. Williams (UK)
Tetsuichiro Yabuki (Japan)

Inter-Ccommission Working Group

IC-WG3 Satellite Gravity Theory

(joint with Commission 1 and 2

Chair: **Nico Sneeuw** (Canada)

Objectives

Against the backdrop of the gravity satellite missions champ, grace and goce, the overall objective of the working group is to be a focus of activities in the following research areas, related to the geodetic boundary value problem (gbvp) of satellite gravimetry:

- Installation of a website for communication, presentation and outreach purposes
- Regular distribution of circular mails on the progress of the work
- Survey on the present handling of quality issues in Geodesy, identification of shortcomings, mainly regarding:

Gravity Field Estimation from Satellite Data
- Novel approaches, e.g. energy integral approach or the use of numerically derived accelerations from leo orbit data (champ), and potential di_erences from grace. Also novel algorithmic approaches to dealing with huge quantities of satellite data.
- Inverse Theory related to satellite gravimetry. In conjunction with the IAG working group on inverse theory.
- Band limitation and filtering: Dealing with bandlimited satellite data, i.e. filtering either explicit or through the stochastic model.

Merging
- Mixed observable normal equations: Weights for normal equation systems from mixed sources—different satellites, terrestrial sets, different observables. Generalized cross validation (gcv), variance component estimation (vce), in combination with Monte Carlo techniques. To be tested and validated with real satellite and terrestrial data sets.
- Regional combination: Optimal combination of global (satellite-only) models and terrestrial data for regional geoid modelling in the overlapping spectral band. Seamless spectral merging by proper weighting and corresponding kernel modification has to be investigated.

Time-Variable Gravity
- Earth sciences: Interface of geodesy with oceanography, hydrology, solid earth science and glaciology.
- Sampling issues: High-frequency aliasing into monthly champ and grace gravity field solutions, orbit decay and ground-track variation. Theory development how the time variable sampling geometry influences the time-variable gravity recovery (also for future gravity missions).
- Unified approach: Time-variable gravity recovery combined with geocenter variations, station loading and/or earth rotation.

Gravity Field Representation
- Multi-resolution: Application of multiresolution representations to satellite geodesy.
- Ultra-high degree spherical harmonics: Algorithmic gains in stability and speed.
- Time-variable modelling: Convenient modelling in its relation to gravity estimation.

Satellite Orbit Dynamics
- Formation flying: Investigation into stability of leo formations and their application to follow-on gravity field missions.

Program of Activities

- Internal email discussions.
- Organization of working group meeting and organization of sessions at larger meetings. Potential candidate venues are the Joint AGU/CGU meeting, Montreal, Canada, 2004 and the Gravity, Geoid and Space Missions meeting, Porto, Portugal, August 2004.
- Launch of a website for communications, information dissemination and links to data sources (satellite data, terrestrial gravity, synthetic earth models,…).
- Monitoring and presentation of activities - either by WG members or external
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Membership

Chair: Nico Sneeuw (Canada)
Pavel Ditmar (Netherlands)
Christian Gerlach (Germany)
Rossen Grebenitcharsky (Canada)
Shin-Chan Han (USA)
Michael Kern (Austria)
Christopher Kotsakis (Canada)
J¨urgen Kusche (Netherlands)
Jiancheng Li (China)
Philip Moore (UK)
Roland Pail (Austria)
Nikos Pavlis (USA)
Thomas Peters (Germany)
Hanspeter Schaub (USA)
Yunzhong Shen (China)
Isabella Velicogna (USA)
Pieter Visser (Netherlands)
Franziska Wild (Germany)
Dah-Ning Yuan (USA)