International Laser Ranging Service
Analysis Working Group

Minutes of AWG Meeting

Perugia, Italy
July 10, 2007

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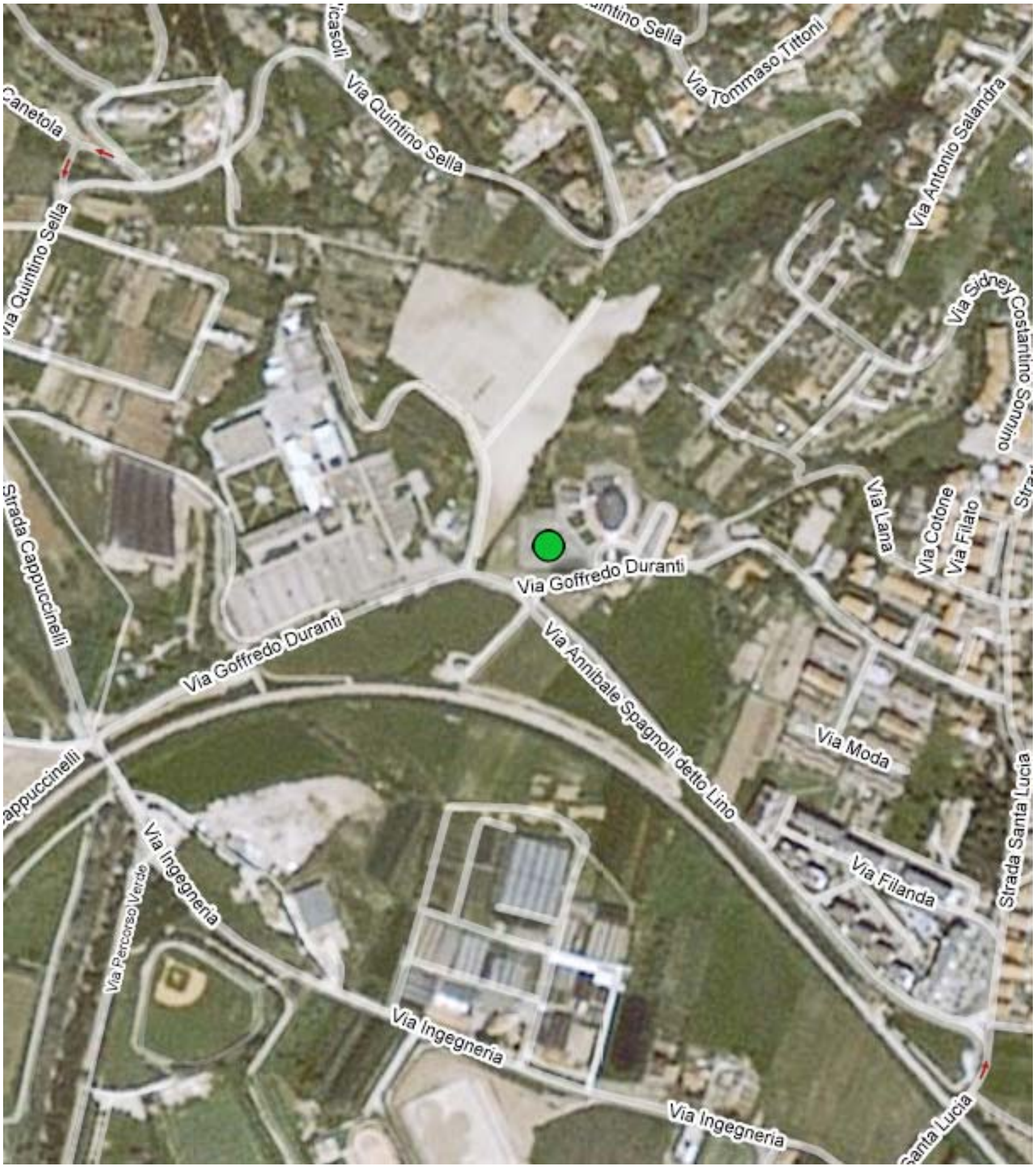
AWG Coordinators

JCET-ISG-2007-04

Joint Center for Earth Systems Technology
University of Maryland Baltimore County
Baltimore, Maryland, 21250

August 13, 2007

AWG Summer meeting – Uni. Of Perugia, DICA
July 10, 2007
Starting at: 9:00 am in Aula 13



DICA - Università degli Studi di Perugia

Dipartimento di Ingegneria Civile e Ambientale

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Opening – Agenda review and adjustment & announcements

A special meeting of the AWG took place at the School of Environmental Engineering of the University of Perugia, during the second week of the 2007 General Assembly of the IUGG. This meeting was intended to give the ACs and CCs a second opportunity to discuss in detail some of the action items that they were tasked with during the previous AWG meeting in Vienna, Austria. To accomplish this within a day, no other reports were allowed for and participants were kept to a minimum, with only the key-persons from each AC/CC. The list of the attendees is appended after the brief description of the topics that were discussed.

1) Introduction

The meeting begun with a more detailed announcement about the Unified Analysis Workshop (UAW) that Markus Rotacher is organizing for the end of the year. The dates and a general list of topics have been proposed. When more concrete information is available, we will distribute them to all. What was known at this time were the following:

- Dates: December 5-7, just prior to the fall AGU meeting, in the San Francisco area
- It is expected that the workshop will comprise of 5-6 representatives from each technique, principally from the group of analysts and product combination groups.

2) LLR report (given here since it was left off the Vienna program)

Jürgen Mueller (IFE/Uni-Hannover), the LLR representative, gave a brief presentation of the state of things in this area, with emphasis in the network (past, current, and future), the analysis procedures, the science done and some of the concerns they have. At present they work with data from McDonald and a very limited amount from Apache Point/APOLLO; Wettzell will start in the next 2-3 years, and Grasse is expected to come back next year. A lot of the data in the 90s, fit at 2 cm residual wrms in that period, but the fits worsen to 4 cm in the recent years. The increase seems to be due to the stop of Grasse and the use of worse observations from McDonald, from 2002 on. As far as the new APOLLO data, 70 NPs from April to December 2006, they do not fit nearly as well as expected and have been downweighted to avoid outright rejection in the analysis. The reason behind this is not clear, calibration problem? Some of the scientific topics of analysis include the determination of G, $\dot{G}$, and $\ddot{G}$:

$\dot{G} / G \approx (2\pm7)\ 10^{-13}\ y^{-1}$ and $\ddot{G} / G \approx (4\pm5)\ 10^{-15}\ y^{-2}$

One of the areas LLR is useful for is the recovery of UT0 in 70s, when no other precise data are available.

3) Historical LAGEOS data analysis (1983-1992)

- status: DGFI and GFZ still missing, CC only started , no results. Single solutions should be delivered to CCs by the end of August, combination by the end of September, Grasse
- list of sites for EOP referencing (from SLR2005) and core sites from the bias analysis (action item Luceri)

4) Recent data analysis and reports on action items from Vienna:

- Appleby / NSGF AC

Stanford corrections for **Herstmonceux**: One-way correction at -5.5 ± 2 mm
Herstmonceux : from Oct. 1, 1994 to Jan. 31, 2002, because of the other range bias (ranges were too short by 8 ± 2 mm), the combination implies that we should **add** 2.5 mm to one-way ranges. From Feb. 1, 2002 to Feb. 10, 2007 we must subtract only the 5.5 mm due to the Stanford ET nonlinearities. A preliminary table for other stations was compiled and Potsdam is under test. Corrections for Potsdam will be sent to Luceri and tests will be done for a short period before sending a message to the AWG. It was

suggested that NSGF contact Francis Pierron and ask that FTLRS participate in the Stanford ET comparisons.

▪ Luceri / ASI AC

A bias analysis was performed for the all the sites of the network. The problematic sites were presented together with suggestions for the bias to be applied in the next re-analysis. After a careful examination of the findings and the options presented by Luceri, it was agreed that she will contact the stations and everything should be clarified and accepted by the end of July. Horst Müller of DGFI is also compiling biases for the network, so an exchange of results will be done for comparison. After the completion of this study, a new list of sites for EOP referencing will be prepared (new "core" sites for the NEOS product referencing). Some of the key-observations for a handful of sites:

- Zimmerwald: there is a conflict between the station-reported biases and those supported by the data analysis
- Riyadh: check the early years signature and delete data prior to 2001
- Grasse: eliminate from NEOS list
- Katziveli: delete data prior to 1998
- Quincy: ~10 mm (L1) and 7 mm (L2) due to barometer bias
- Beijing: Delete data prior to installation of the SPAD
- Urumqi: Only 2003 data to be used
- Kunming: Delete data during frequency eror
- Potsdam: Stanford correction to be used for the early data (Appleby will supply)
- Borowiec: Delete 1993 data, 2003:88 (???)
- Bar Giyyora: Keep only last occupation

A resolution of the various station-dependent issues, after discussions with the responsible engineers, will be communicated to the AWG as soon as it is ready (soon!).

▪ Kelm / DGFI CC

Rainer Kelm presented a comparison between ILRSA and ILRSB combination results. He finds that GA and NSGF are more "noisy" than the rest of the ACs. A comment from Sciarretta on the GA submissions, suggests that GA still has a problem with their LOD estimates, since they are **marginally** acceptable. Results of test combinations for the 1983-1993 series were also shown: 2 weeks, one in 1983 and another in 1989. Kelm proposes the use of the two-digit numbering convention for the new time series 1983 -> starting from 10, the second digit to be changed for re-submissions due to errors and such. Pavlis will check with Carey that the archives keep ONLY the latest version of the submission files from each AC.

5) Interim *a priori* SLR-ITRF

▪ Luceri / ASI AC

As agreed at the last AWG, a new TRF has been generated from the combination of ITRF2000, ITRF2005 and the new stations added after the development of ITRF2005. Tentatively its name is SLR2005, although it is not based ONLY on SLR data, simply to denote that it contains only SLR sites. This TRF will be temporary and used by the AWG until a new ILRS reference frame is constructed from the official ILRS combined weekly solutions. Comparisons with ITRF2000 and ITRF2005 were presented in terms of coordinate residuals and velocities. The new reference frame seems to combine the best from the two input ITRFs. It was agreed to use only one velocity for Arequipa estimated with the data before the earthquake (SOLN 1). It will be sent to Horst Mueller for tests. It will be completed with the EPOCH BLOCK (from Pavlis) and the ECCENTRICITY BLOCK.

NOTE ADDED DURING COMPILATION: Solution is ready and will be distributed as soon as the checks have been completed (H. Müller and Pavlis action).

- Sciarretta / ASI CC

Ideas and timeline for the stacked ILRS reference frame (ILRS05) were presented. The static solution (over 1983-2007) will be ready within the end of December. This reference frame will be updated weekly; algorithms for routine update will be studied starting from January. Kelm agrees with the proposed timeline.

6) New products

- Orbits

ASI is ready to distribute the orbits in SP3c format. Luceri will send SP3 files, one for each satellite, to Pavlis in the ftp area set by Carey. Tests to be done by Pavlis and Mueller with their versions for those weeks. It was agreed that orbit files be referenced in "final" AC-TRF for the specific week and in separate files for each satellite.
CCs are already working on the algorithm for the combination to an official file

- Daily production of ILRS NEOS submissions

The proposal for the daily submission is to deliver loose solutions each day, similar to the actual standard ones and covering the data until midnight of the day before (which is dictated by the data latency for the core sites). H. Müller commented here that there is still a harmonization problem between the two DACs, often finding different data between the two (especially for McDonald, Yarragadee, and Hartesbesthoek). The single solutions will be combined daily and the "core site"-constrained EOP will be delivered daily from CC to the community through NEOS. The combined loose solution will still be delivered once a week. A non-public archive will be set at CDDIS and EDC for daily ACs solution. Pavlis will talk with Carey Noll and Seemüller to setup the directories. AC submissions ASAP and CC report at Grasse.

Important note from the CCs: The ACs should check their production lines of their SINEXs to ensure that they comply with the format, contents are correct and even naming conventions are followed (e.g. JCET AC is missing "pos+eop" from the file names). Sciarretta agreed to send out a list of "recurring" mistakes and the culprits, so that we can ensure we correct these prior to sending out daily products. This is VERY IMPORTANT, since there is no time to manually correct such mistakes on a daily basis! PLEASE, give this top priority.

7) Grasse Technical ILRS workshop (September 24-28)

Pavlis showed the program of the workshop focusing on the sessions having a close link with the AWG activities. Many of the workshop sessions will be used to "extend" the AWG workshop activities in order to cover more topics than a single day meeting would allow.

8) Improvement of current products

- Test dataset for ECMWF still to be prepared
- Target signature, product to be improved (we will discuss this at Grasse)

Action items

Open action items from past AWG meetings

ACs	prepare for new format SLR data
ACs	include conversion of orbit solutions into SP3c format (step-size 2 minutes for LAGEOS; 15 minutes for Etalon)
AWG	re-assess AWG core stations status + general ILRS classification
AWG	make overview of station activities 1993-present, based on eccentricity file and "pos+eop" info
CCs	prepare for combination of SP3c files
Mareyen	develop 2-day analysts get-together in Frankfurt(???)

Mareyen	investigate reasons for degradation of BKG(???) contribution to operational product
Müller (H)	develop slr_discontinuities file further (1992-2006)
Müller (Jürgen)	develop validation plan for (new) LLR stations
Noomen, Pearlman, Gurtner	homogenization of QC reports
Noomen	get letter expressing general support for ILRS activities from IERS chairman
Noomen, Luceri, Gurtner	develop report with pos+eop use for stations and managers
Noomen	organize guest editorial board for JoG special issue
Noomen	check IERS procedure for station documentation after earthquakes and such
Noomen	get Delft QC procedure running again
Pavlis	check of the GRGS orbits and transformation matrices
Pearlman	remind Simosato to become IGS station

▪ New action items

Pavlis	dataset for the test on the models of atmospheric loading and gravity
Pavlis, Luceri	new ITRF for SLR analysis
Luceri	new list of core sites from SLR2005 for daily EOP referencing
Luceri	contact stations to rationalize biases seen in the data analysis
Müller (H)	exchange and compare bias estimates with Luceri
Appleby	send Luceri the Potsdam Stanford ET corrections to test
Appleby	contact Francis Pierron to test their Stanford ET
Müller (H), Pavlis, Luceri	exchange and compare orbits in SP3c format
Pavlis	check with GA/Mt. Stromlo the reason for delayed submissions of data
Pavlis	check with Noll that ONLY latest SINEX versions are online
Pavlis	check with Noll and Seemüller to generate archive for daily submissions
Pavlis, Luceri	pilot project for the generation of a bias list, etc.
Müller (H), Pavlis, Luceri	validate the SLR2005 (final version)
ACs	verify that your SINEXs are formatted correctly for daily submissions !!!
CCs	start combination from pre-1993 time series, after DGFI & GFZ submission
ACs and CCs	work on generating daily submission of weekly solutions

Closing comments

See you all in Grasse!

Participants

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ANNEX

Presentations at AWG meeting of 07/07/10

- AWG_Perugia2007_presentations.pdf

ILRS/AWG Meeting, Perugia, Italy, July 2007

Lunar Laser Ranging 2007

Jürgen Müller[1], L. Biskupek[1], U. Schreiber[2]

1) Institut für Erdmessung, Leibniz University of Hannover, Germany
2) Technical University Munich and Wettzell Observatory, Munich, Germany

Contents

Introduction

- Motivation

Lunar Laser Ranging

- Data distribution and accuracy
- Scientific potential
  (example gravitational constant)
- Future requirements

Conclusions

Motivation

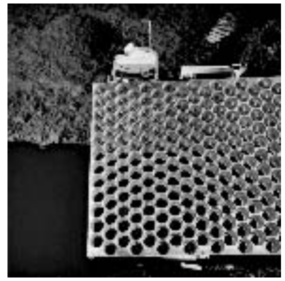
- Observations (37 years) and modelling at cm-level
- Long-term stability (orbit, reference frames, EOPs)
- Determination of
    + Earth-Moon dynamics
    + relativity parameters

Observatories on the Earth

Deployment of the Retro-Reflectors

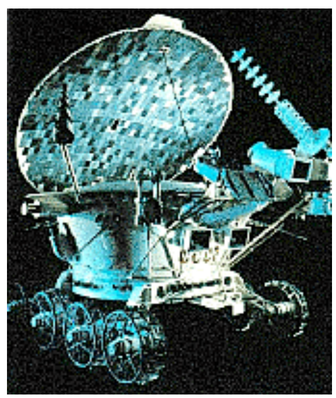
Apollo 11
July 1969

Apollo 14
Jan./Feb.`71

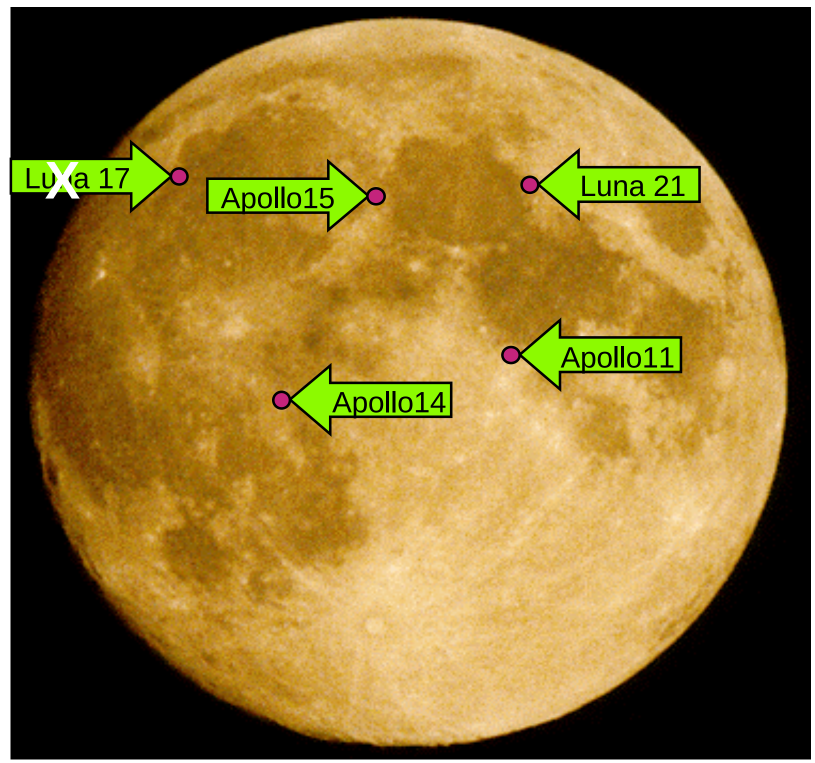


Apollo 15
Jul./Aug.`71

Luna 17
Nov.`70...

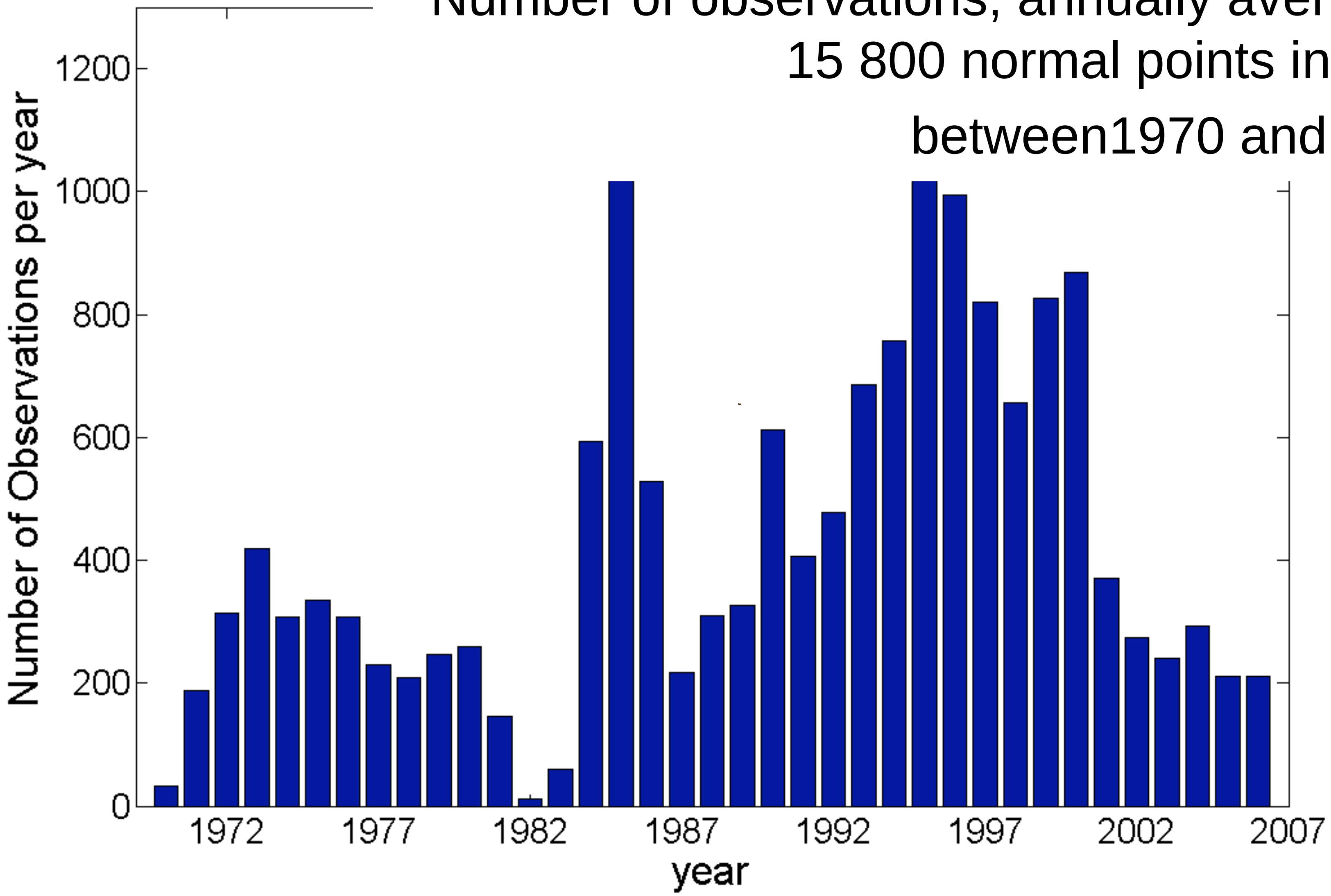


Luna 21
Jan.`73...



LLR Observations per Year

Number of observations; annually averaged;
15 800 normal points in total,
between1970 and 2006



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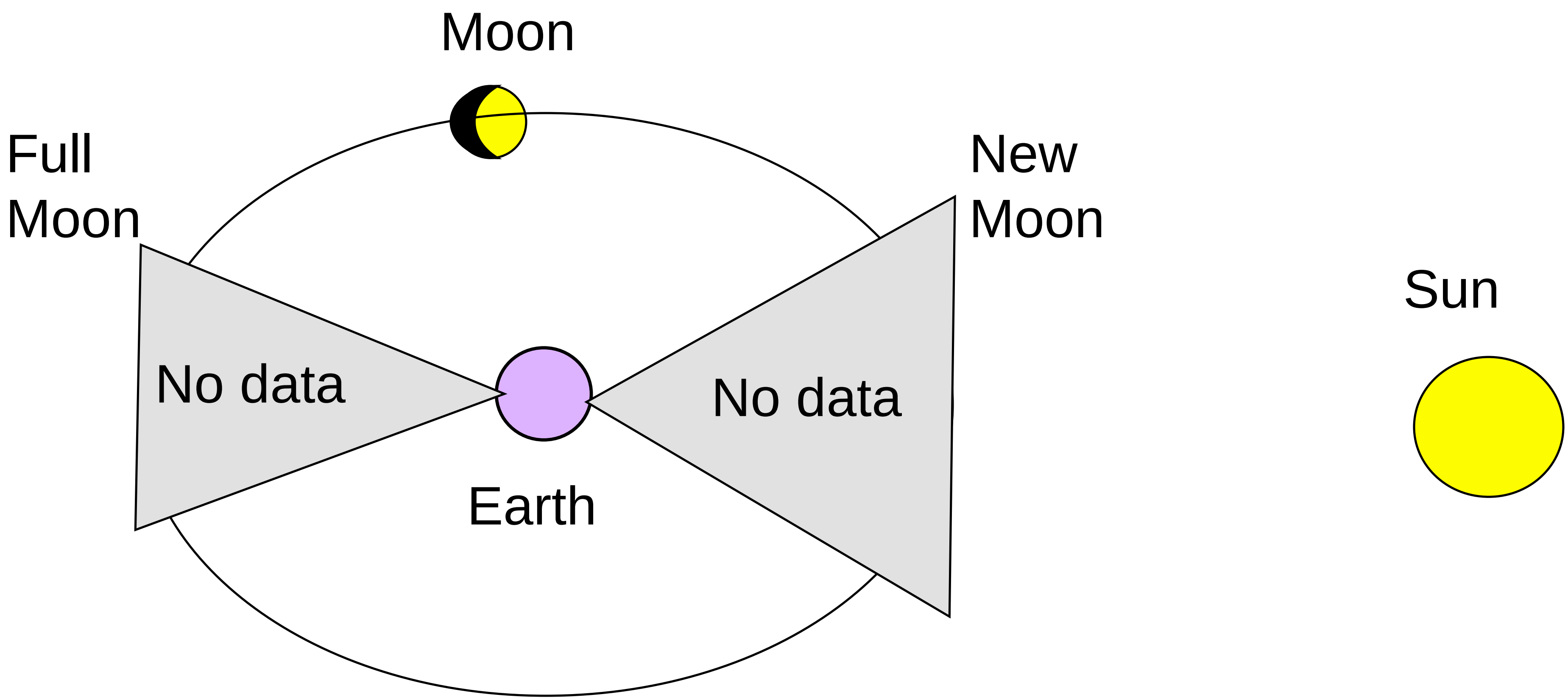
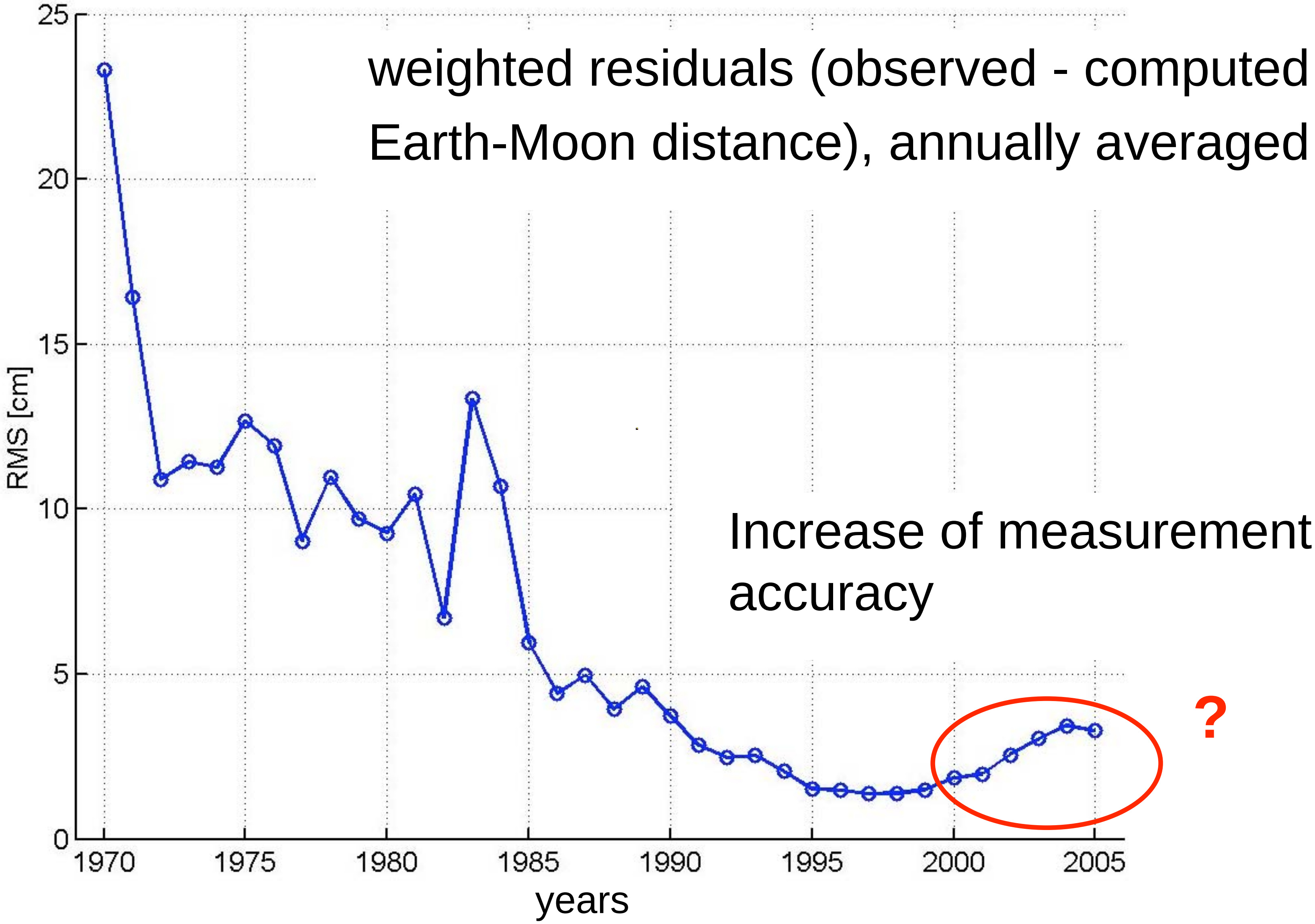
Distribution of Observations per Synodic Month



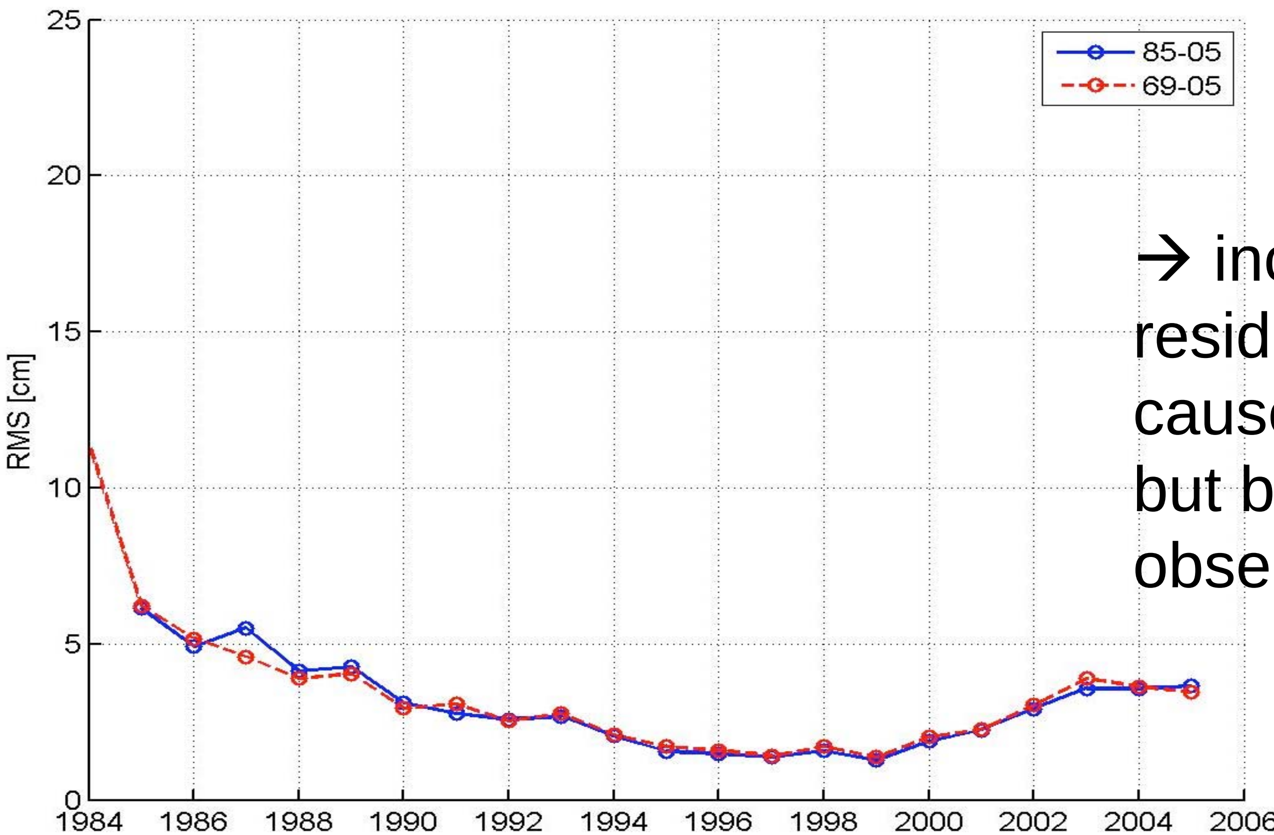
→ large data gaps near Full and New Moon

Annual Residuals



Error Study: Integration

- Data: 12.1969 – 11.2005
- Remove data of the first 5, 10, 15 years
- Calculation of new initial parameters



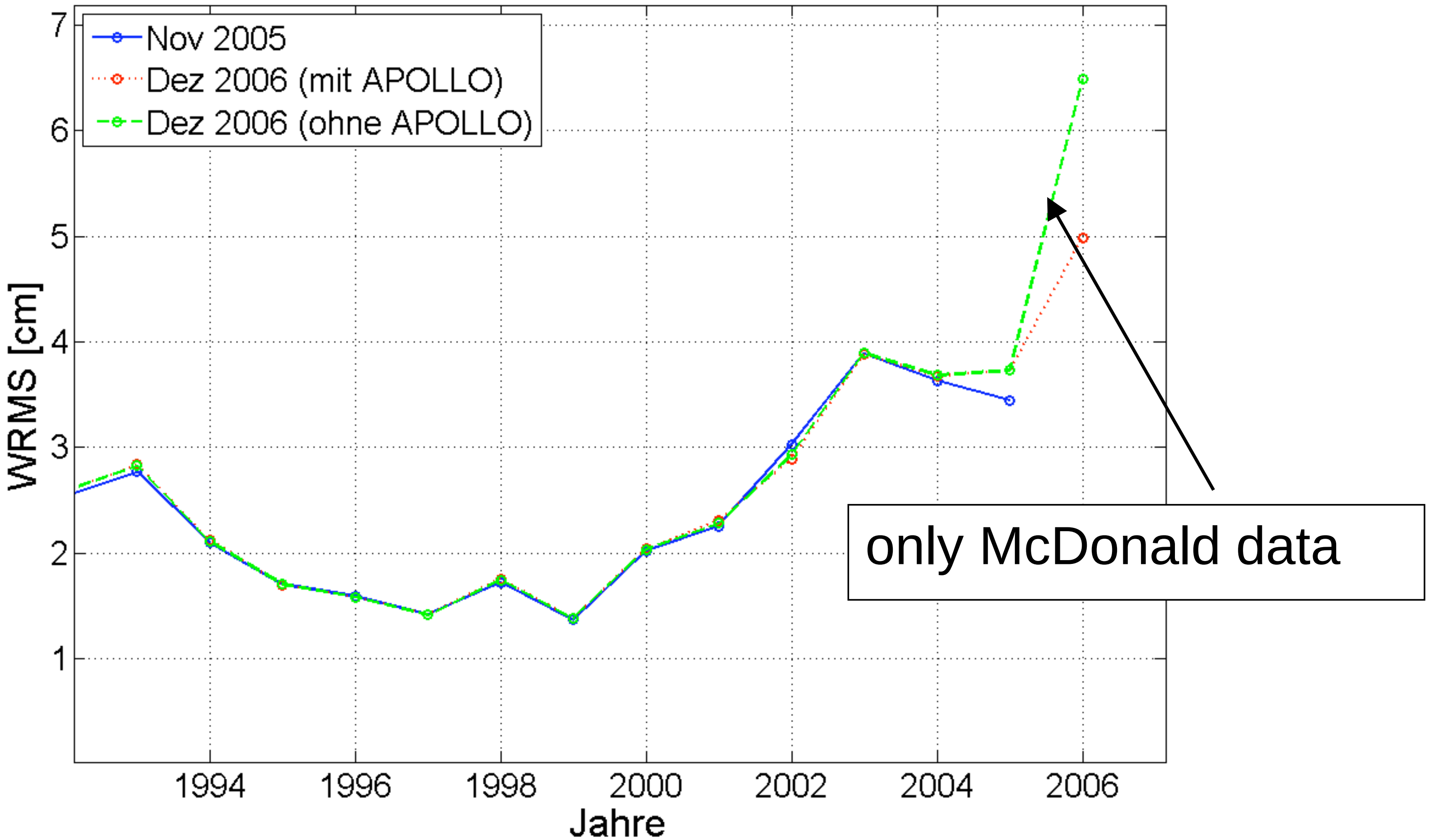
→ increase of residuals not only caused by modeling, but by worse observations

Use of New APOLLO Data

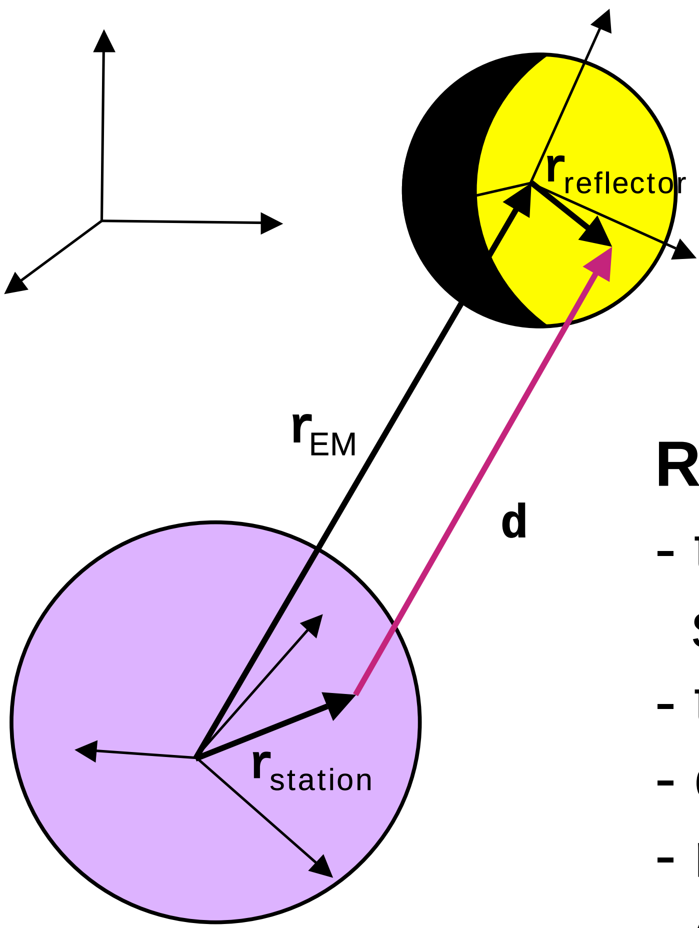
- New site APOLLO in New Mexico (USA),
  - „mm accuracy“
  - 3,5 m telescope
  - Improved receiver optics
  - Local control measurements

- Software changes → 7 stations
- 70 normal points (04.06 – 12.06)
- Accuracy of observatiosn down-scaled by 10

Solution until December 2006



LLR Observation Equation



$$d = c\frac{\tau}{2} = \left|\mathbf{r}_{EM} - \mathbf{r}_{station} + \mathbf{r}_{reflector}\right| + c\Delta\tau$$

$$\frac{d^2\mathbf{r}_{EM}}{dt^2} = -\frac{GM_{E+M}}{r_{EM}^3}\mathbf{r}_{EM} + \mathbf{b}_{Newtonian} + \mathbf{b}_{Relativity}$$

Relativity in LLR

- transformation between reference systems (Moon, Earth, inertial)
- transformation between time systems
- orbital motion of the solar system bodies
- rotation of Earth and Moon
- gravitational time delay (Shapiro)

- effect: several meters

Example: Gravitational Constant G

Investigation of secular and quadratic variations

$$G = G_0\left(1 + \frac{\dot{G}}{G}\Delta t + \frac{1}{2}\frac{\ddot{G}}{G}\Delta t^2\right)$$

Results

$$\frac{\dot{G}}{G} = (2 \pm 7)\cdot 10^{-13}\,\mathrm{yr}^{-1}$$

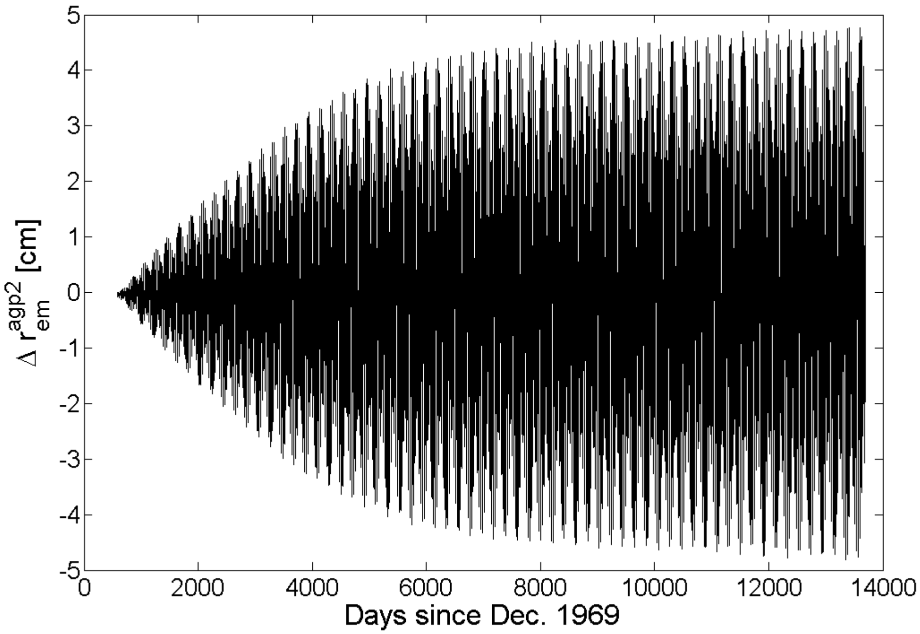
$$\frac{\ddot{G}}{G} = (4 \pm 5)\cdot 10^{-15}\,\mathrm{yr}^{-2}$$

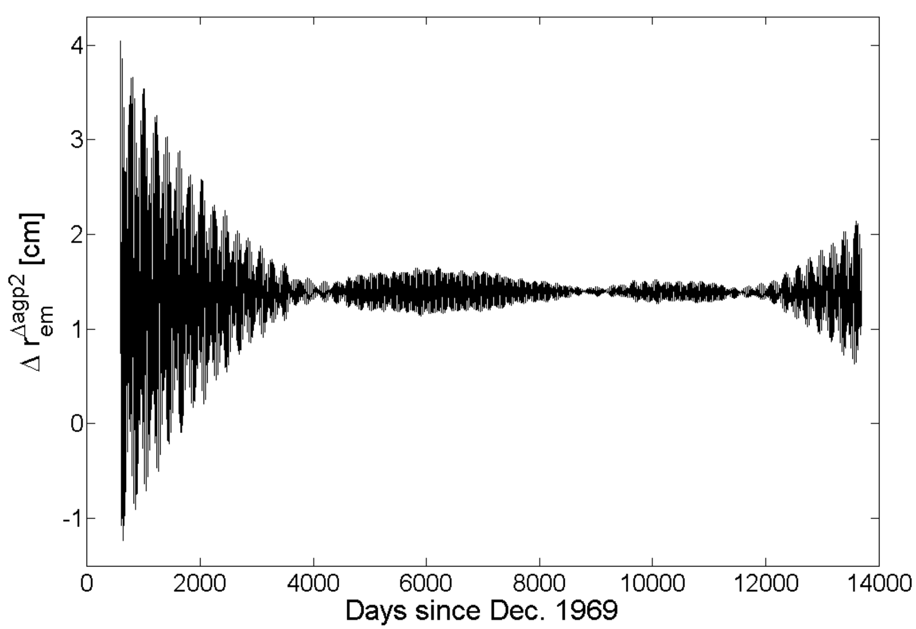
Sensitivity Study for $\ddot{G}$

Sensitivity analysis via

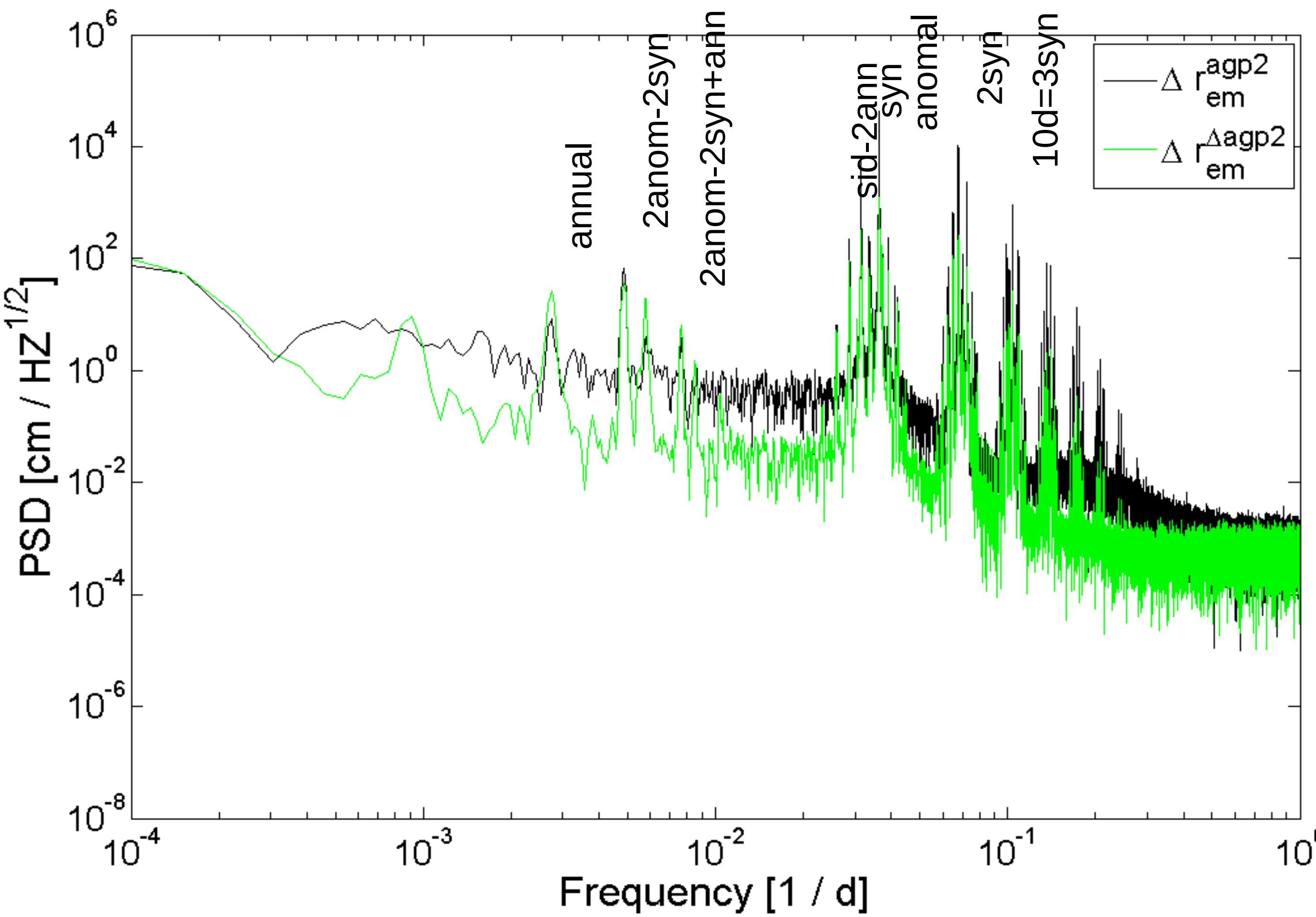
$$\Delta r_{em}(\ddot{G}) = \delta r_{em} / \delta\ddot{G} * \Delta\ddot{G}$$

Separation of free and forced terms → two orbit solutions: 1) perturbed, 2) un-perturbed → difference





Corresponding Spectrum



New Ranging Measurements – Why?

New data needed to constrain lunar interior structure

- improve measurements of forced librations
- measure tidal distortion (amplitude and phase)
- lunar oscillations as response to large quakes or impacts?

Improve on limits of relativistic effects

- time variability of the gravitational constant
- test of strong equivalence principle (Nordtvedt effect)

Improve the tie between the lunar network and the radio reference frame (VLBI)

Above goals require more data, more accurate data, and unbiased measurements!

Validation Plan for (new) LLR Sites ?

„We are happy with each single LLR measurement at all.“

Possible rules

- Quality, short/long-term biases?
- normal points per year/month, number of passes

Science requirements (input also from Pete Shelus)

- Lunar interior (sub-cm NPs, 1 hour, 5 times per month)
- Spacecraft navigation, ephemeris (sub-cm NPs, homogeneous distribution througout the month)
- General relativity (sub-cm NPs, as often as possible, i.e. covering all lunar phases, every lunation)
- ...

Conclusions

Use of LLR

- Reference frames (ITRF, dynamic ICRF)
- Earth orientation (IERS)
- Dedicated investigations
    - Dynamics of the Earth-Moon system
    - Relativistic effects
    - Lunar rotation and interior
    - Lunar geodetic network

Connection of gravitational physics and geodetic areas

Preparation of a new lunar ranging experiment

(combination with other techniques, support GGOS)

Results - Relativity

Parameter	Results
Nordtvedt parameter η (violation of the strong equivalence principle)	$(6 \pm 7) \cdot 10^{-4}$
time variable gravitational constant $\dot{G}/G\,[yr^{-1}]$ $\ddot{G}/G\,[yr^{-2}]$ (→ unification of the fundamental interactions)	$(2 \pm 7) \cdot 10^{-13}$ $(4 \pm 5) \cdot 10^{-15}$
difference of geodetic precession Ω_{GP} - Ω_{deSit} [″/cy] (1.92 ″/cy predicted by Einstein's theory of gravitation)	$(6 \pm 10) \cdot 10^{-3}$
metric parameter γ - 1 (space curvature; γ = 1 in Einstein)	$(4 \pm 5) \cdot 10^{-3}$
metric parameter β - 1 (non-linearity; β = 1) or using $\eta = 4\beta - \gamma_{Cassini} - 3$ with $\gamma_{Cassini}-1$ ($\sim 10^{-5}$)	$(-2 \pm 4) \cdot 10^{-3}$ $(1.5 \pm 1.8) \cdot 10^{-4}$

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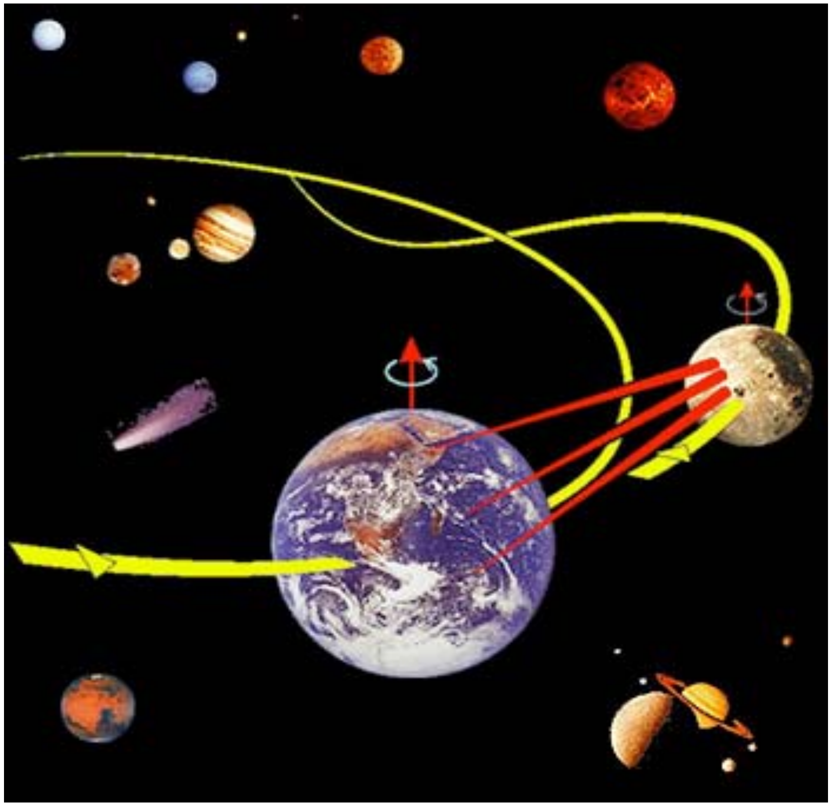
Results – Relativity (2)

Parameter	Results
Yukawa coupling constant $\alpha_{\lambda=400\,000\text{ km}}$ (test of Newton's inverse square law for the Earth-Moon distance)	$(3 \pm 2) \cdot 10^{-11}$
special relativity $\zeta_1 - \zeta_0 - 1$ (search for a preferred frame within special relativity)	$(-5 \pm 12) \cdot 10^{-5}$
influence of dark matter δ_{gc} [cm/s^2] (in the center of the galaxy; test of strong equivalence principle)	$(4 \pm 4) \cdot 10^{-14}$
preferred frame effect α_1 (search for a preferred frame within general relativity)	$(-4 \pm 9) \cdot 10^{-5}$
preferred frame effect α_2 (search for a preferred frame within general relativity)	$(2 \pm 2) \cdot 10^{-5}$

Reference Systems

- Selenocentric (reflector coordinates, lunar rotation)
- Geocentric (station coordinates and velocities, Earth rotation)
- Inertial (Earth/Moon orbits, signal propagation)



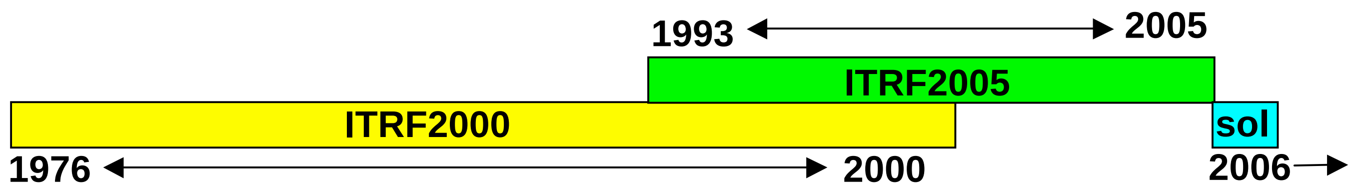
Waiting for a new ILRS05: SLR2005

V. Luceri – e-GEOS S.p.A.

G. Bianco - Agenzia Spaziale Italiana

Waiting for a new ILRS05: SLR2005

The best from the latest SLR reference frames



Benefits from :

ITRF2000

- Pre-1993 sites

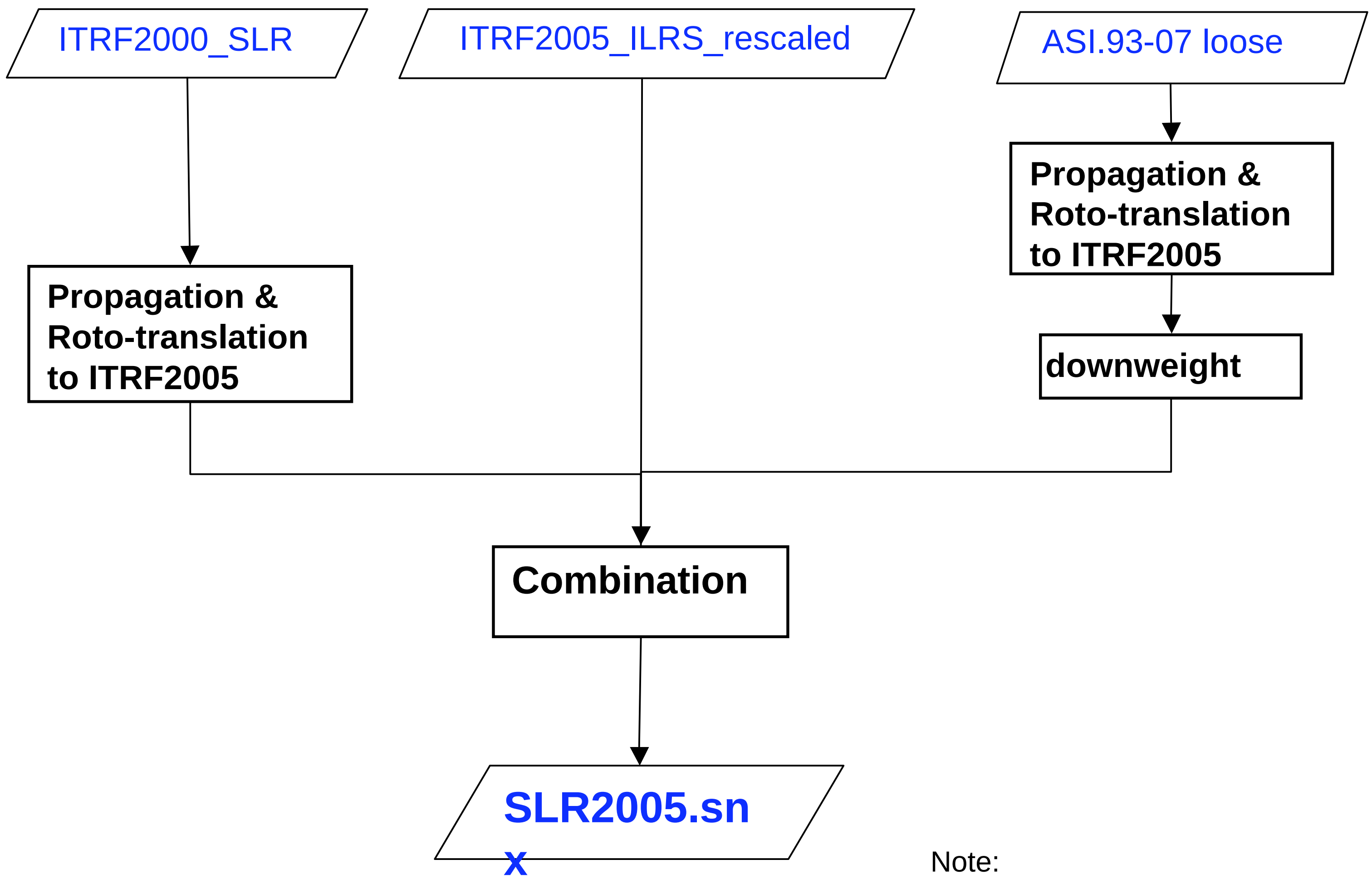
ITRF2005 rescaled

- New models, better estimates
- New sites up to 2005

Updated solution

- New sites since 2006

SLR2005 generation flowchart



Note:

ASI.93-07 was downweighted and a subnetwork of “core sites”+”new sites” was extracted from the solution to be combined with the other 2 TRF with the aim to minimize its influence over the network.

Bad stations in ITRF2005 – edited before combination

```
+SOLUTION/EPOCHS
*Code PT SOLN T Data_start__ Data_end____ Mean_epoch__
 7122  A    1 C 92:364:20108 93:010:41381 93:004:30953    ok in ITRF2000
 7123  A    1 C 93:112:25806 93:310:42948 93:211:34377    ok in ITRF2000
 7883  A    1 C 93:335:28394 94:042:64147 94:006:46271    ok in ITRF2000
 7882  A    1 C 94:075:53242 94:130:15383 94:102:77512    ok in ITRF2000
 7411  A    1 C 94:193:04556 94:258:43738 94:225:67347    ok in ITRF2000
 7525  A    1 C 94:199:13073 94:279:84021 94:239:48547    ok in ITRF2000
 7520  A    1 C 95:238:65872 95:260:74471 95:249:70172    ok in ITRF2000
 7847  A    1 C 96:098:46968 96:105:50693 96:102:05631    bad also in ITRF2000
 7307  B  1 C 97:253:56118 97:298:62932 97:276:16325  not in ITRF2000, discarded
 7307  D  1 C 99:260:46043 99:288:43839 99:274:44941  not in ITRF2000, discarded
 7355  A  1 C 01:119:62133 01:145:75983 01:132:69058  not in ITRF2000, discarded
 7830  A  1 C 03:097:70658 03:290:51783 03:194:18021  not in ITRF2000, discarded
 7357  A  1 C 03:217:45220 03:290:67834 03:254:13327  not in ITRF2000, discarded
 7823  A  1 C 04:172:04739 04:178:01370 04:175:03054  not in ITRF2000, discarded
 7130  A  1 C 05:213:45454 05:307:03282 05:260:24368  not in ITRF2000, discarded
 7358  A  1 C 05:214:30940 05:333:72723 05:274:08632  not in ITRF2000
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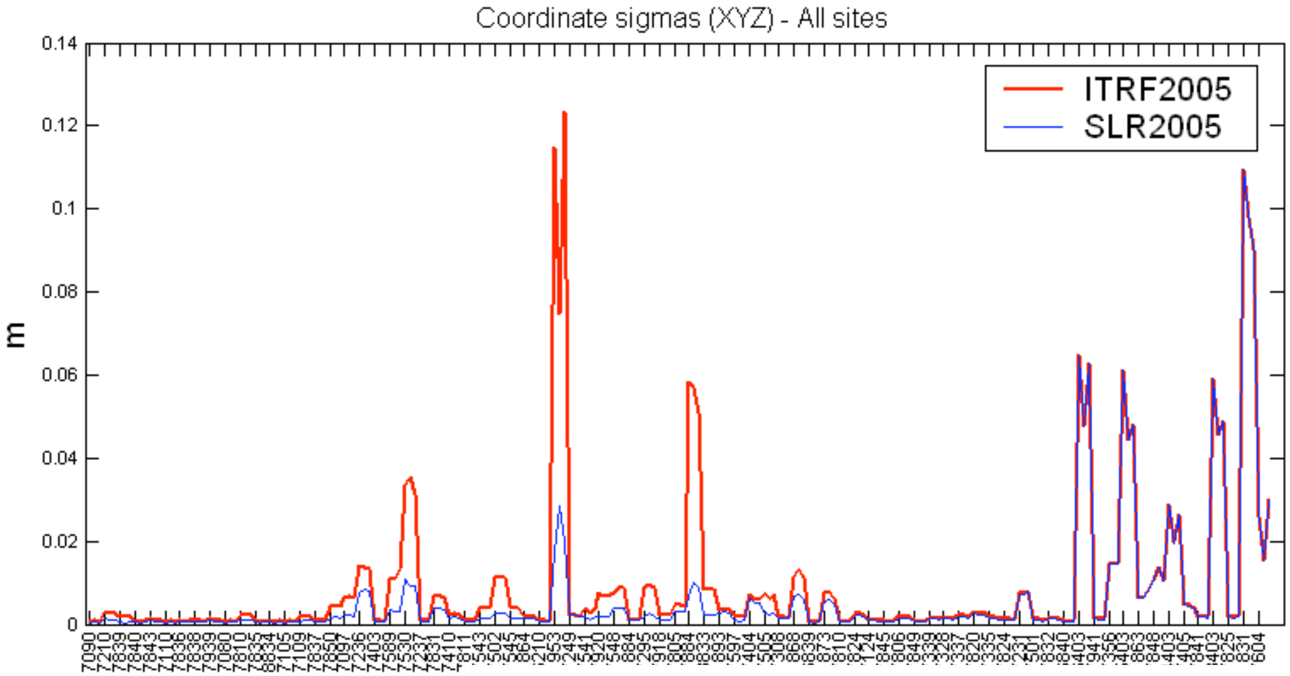
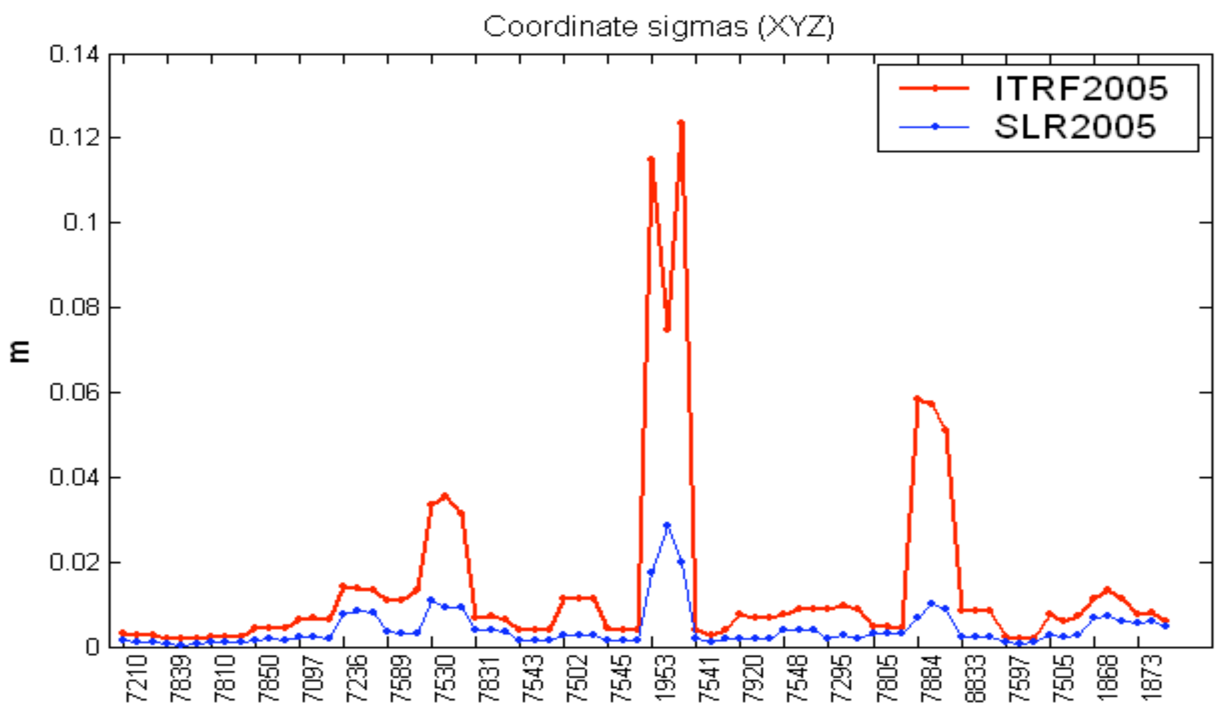
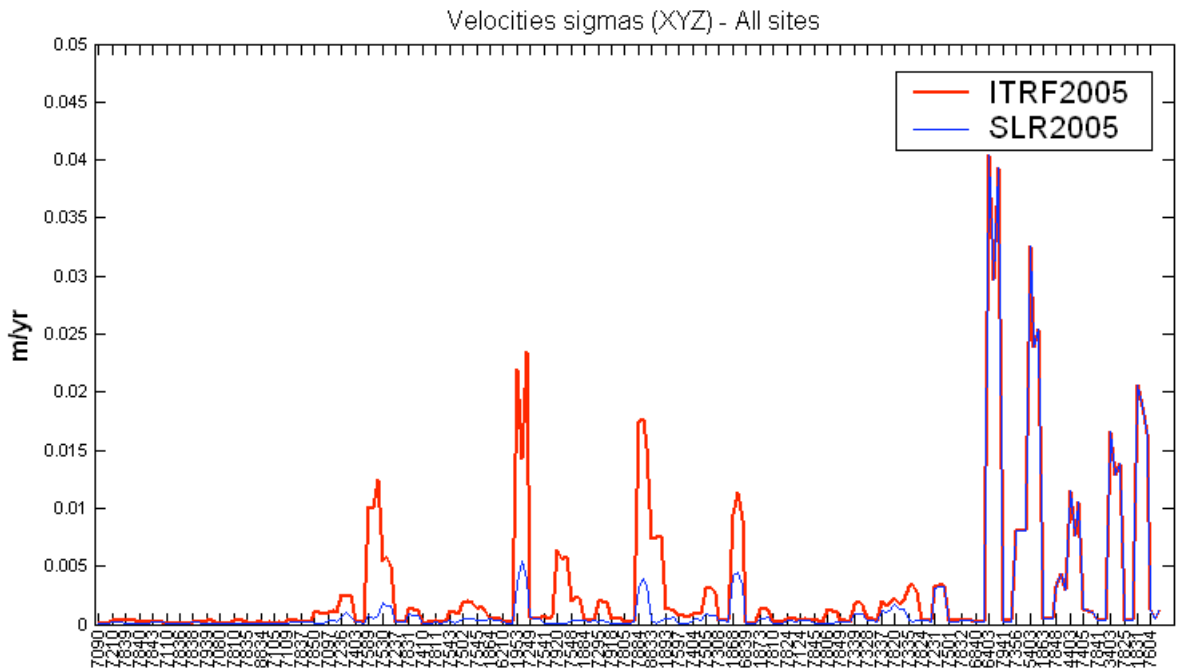
sigma comparison



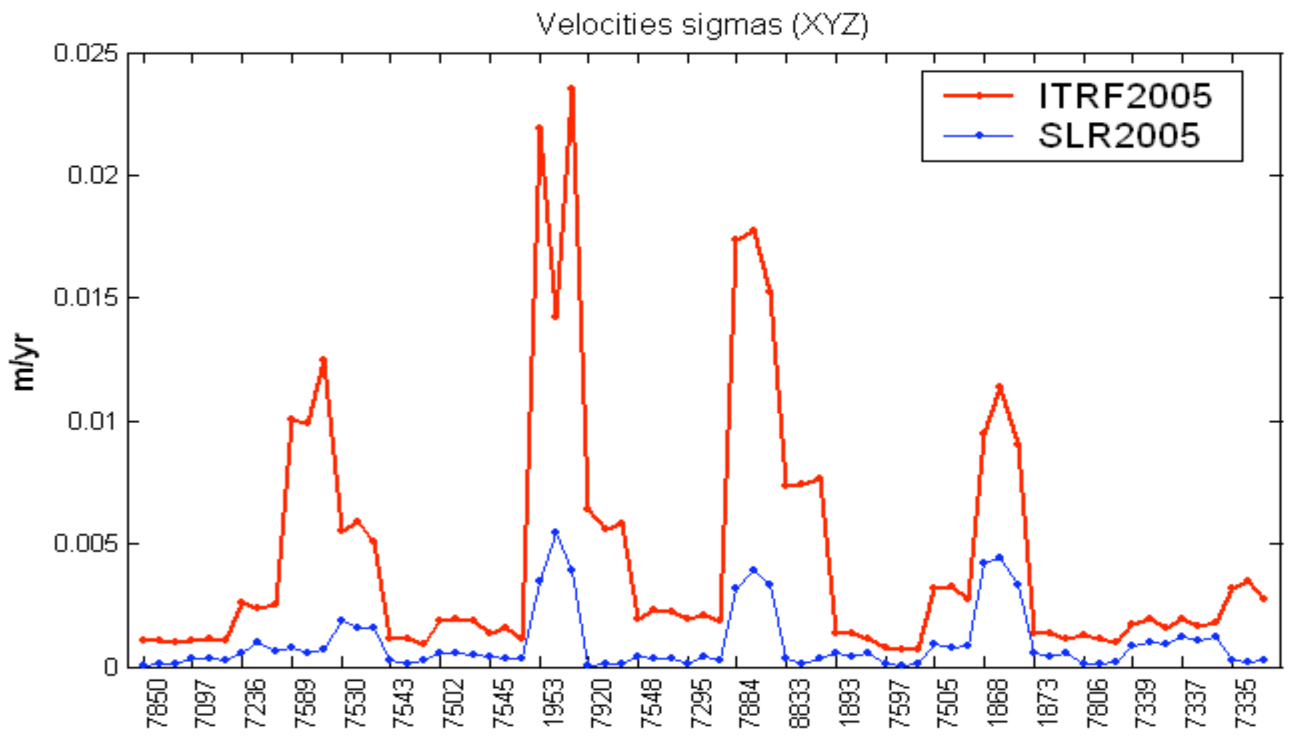


Sites with 3D sigma difference greater than 0.002 m

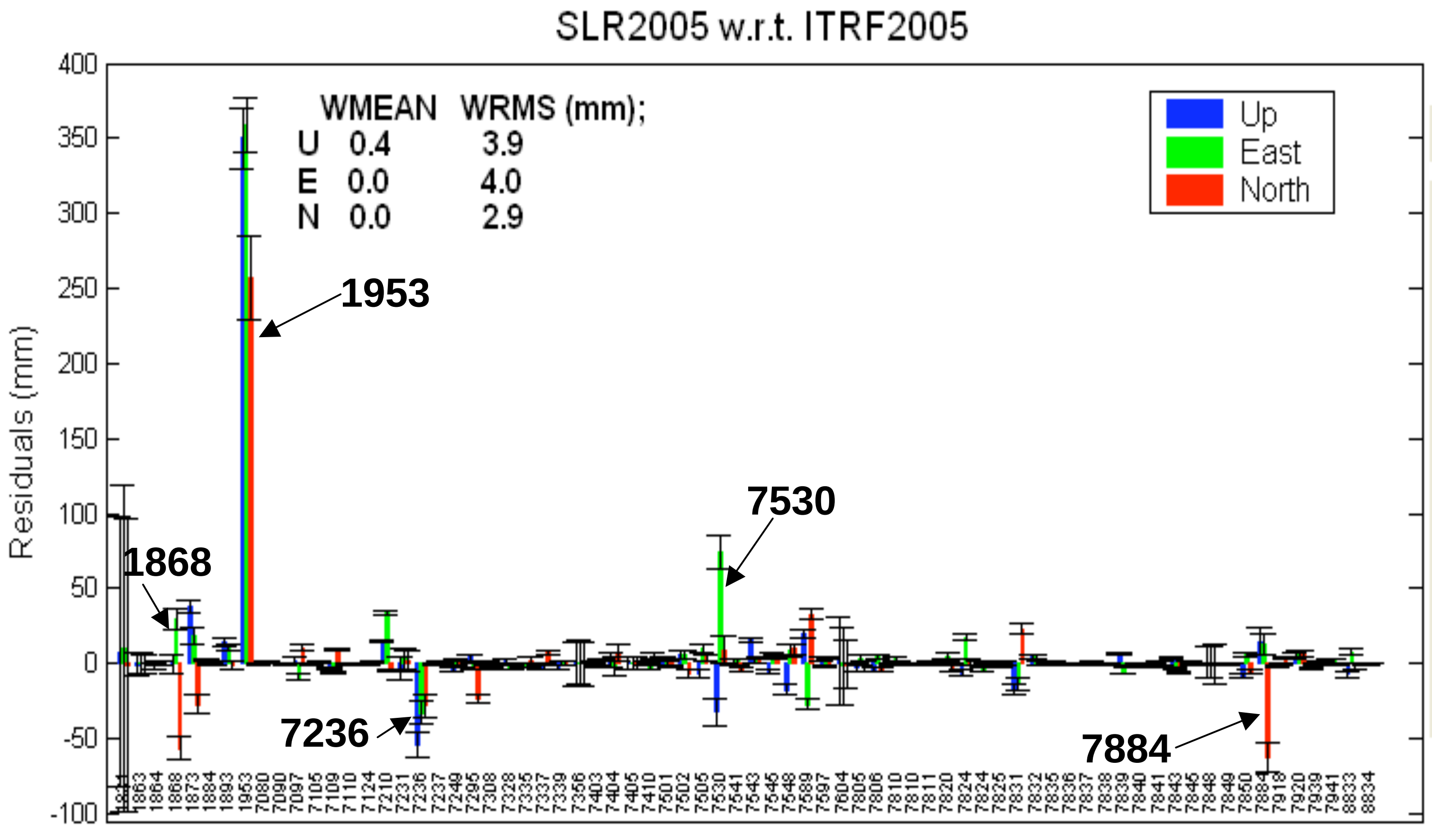
sigma comparison



Sites with 3D sigma difference greater than 0.001 m/yr

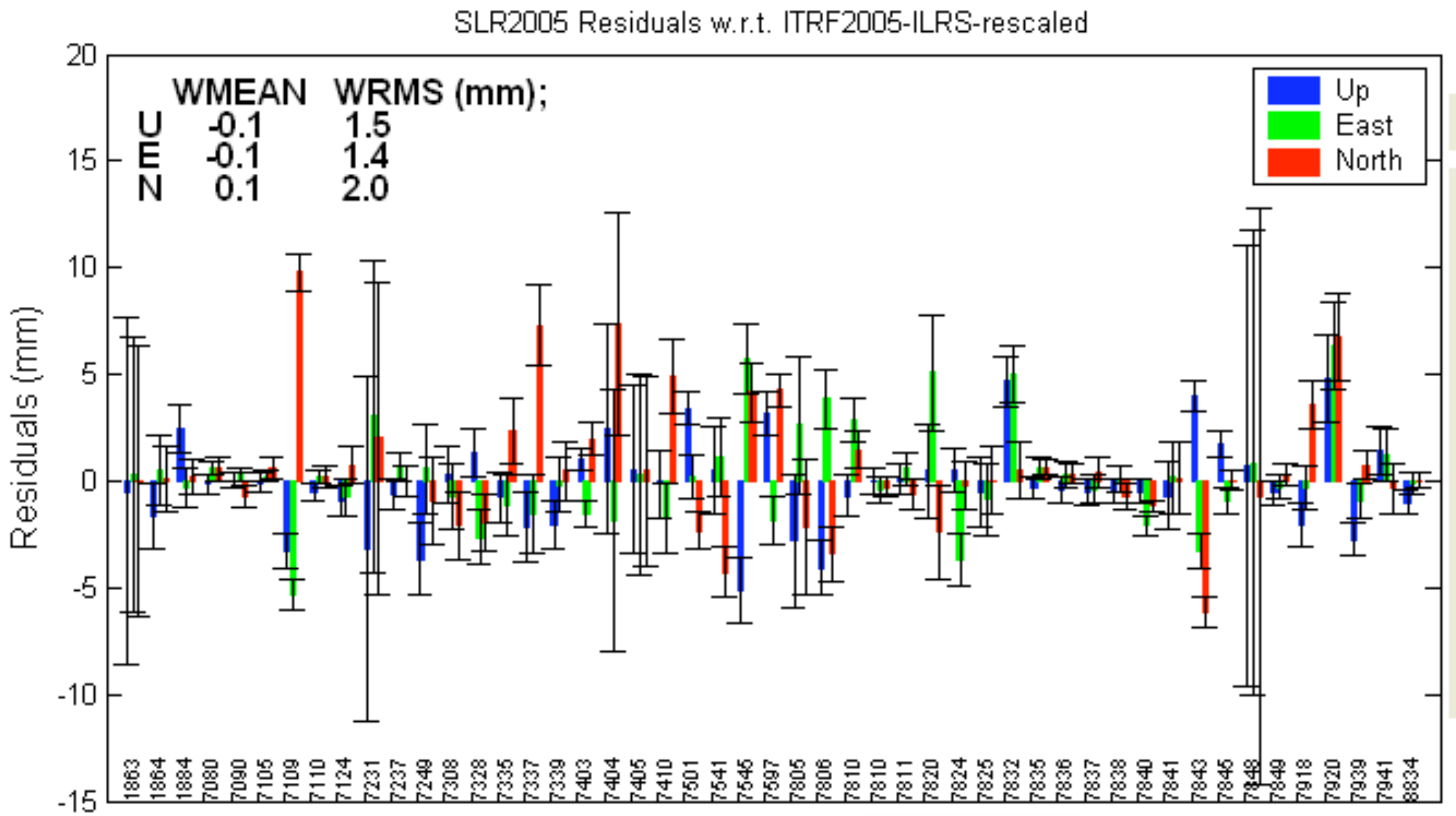


SLR2005 coordinate comparison (1)



All the stations with high residuals have a smaller sigma in SLR2005: a few sites highlighted in the plot

SLR2005 coordinate comparison (2)

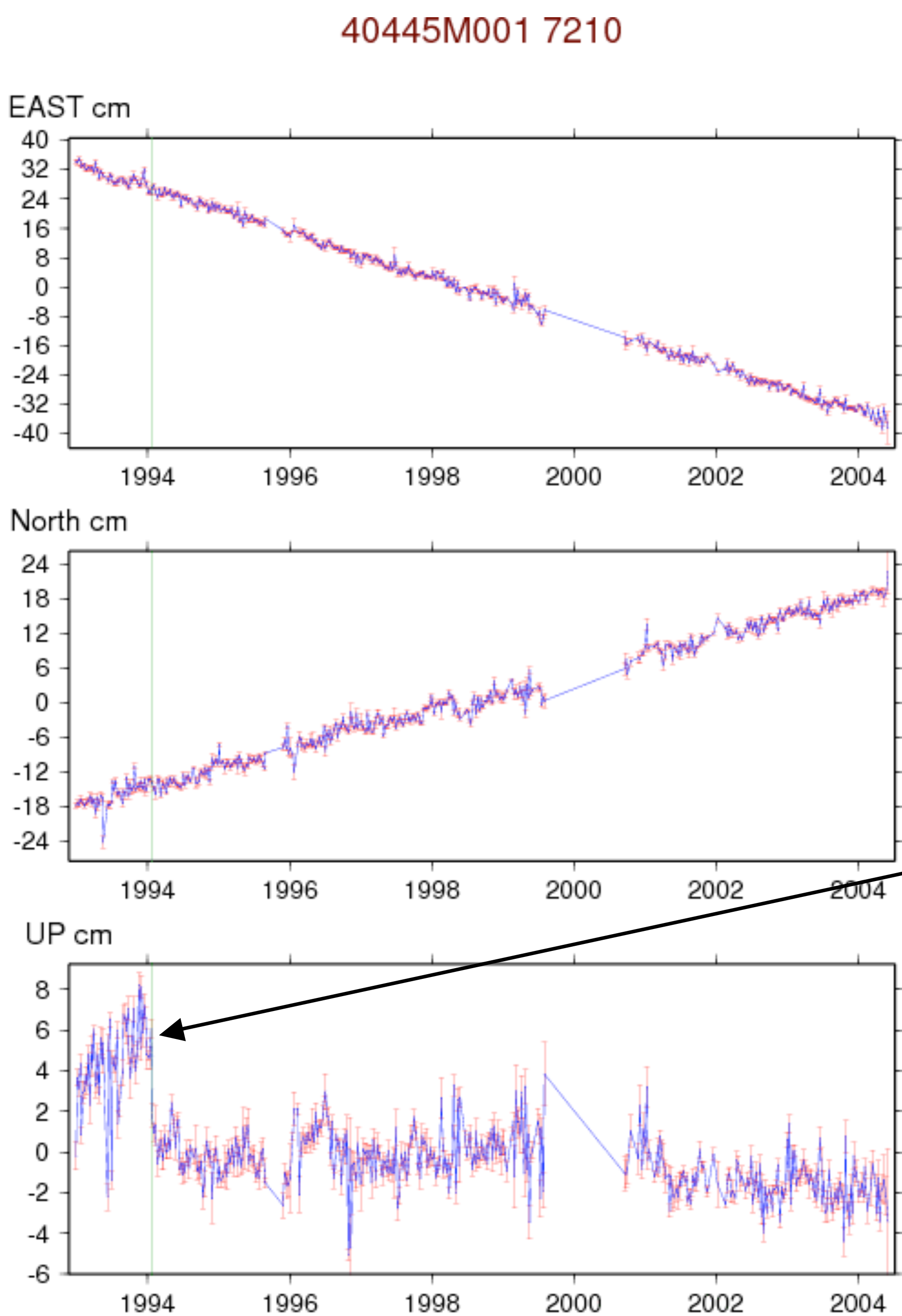


Edited sites: all SOLN > 1 for 7210, 7839, 7840, 7403

sites: 1953, 1868,1873,7884,7236,7530,1831,7589, 7294,7824A , 7502, 7505 7543,7850, 7097,7831,1893,7604, 7839,8833,7548,7356

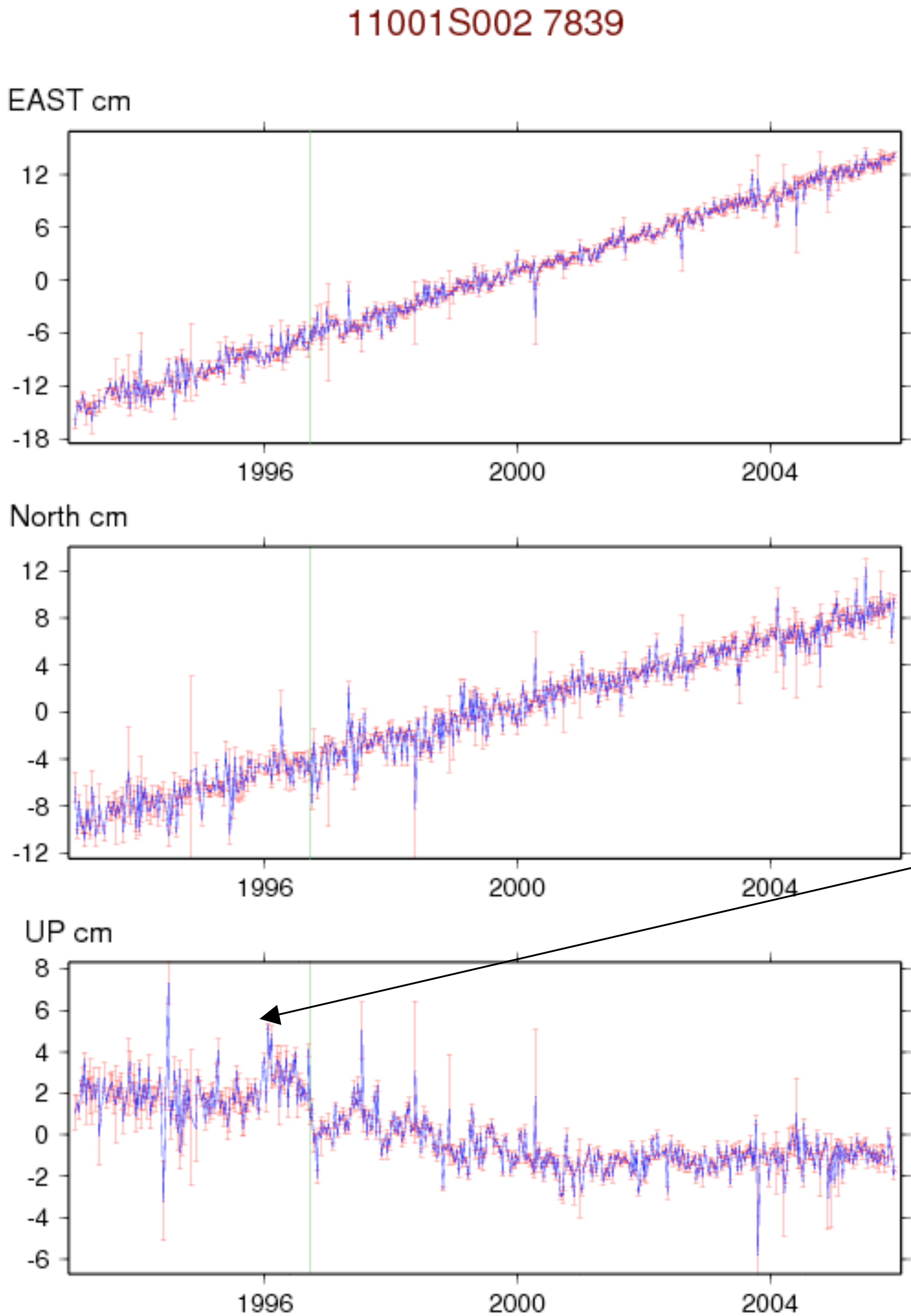
Most of this sites have a longer history in ITRF2000

Stations with jumps



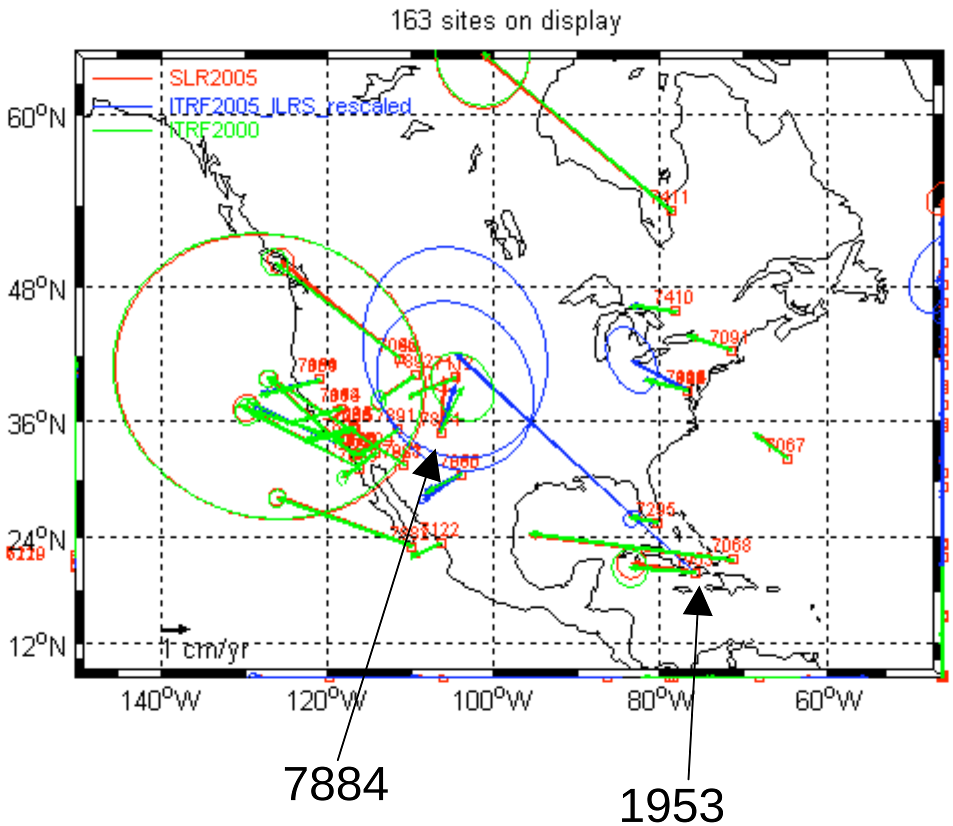
SOLN 1 combined with ITRF2000 to get a better estimate (above all for velocities)

Stations with jumps

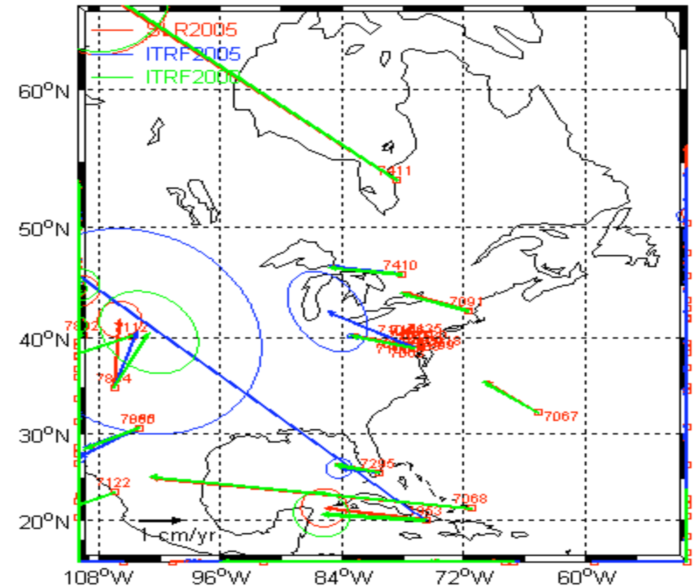


SOLN 1 combined with ITRF2000 to get a better estimate

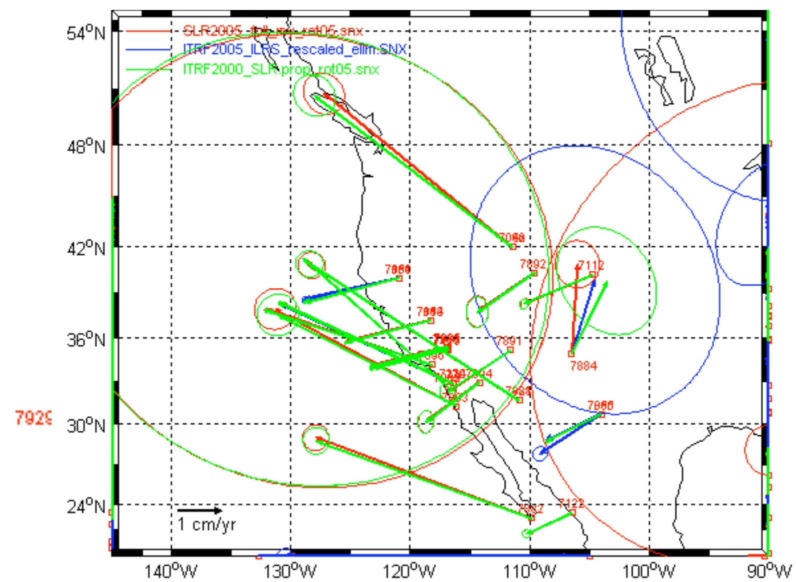
Velocities: North America



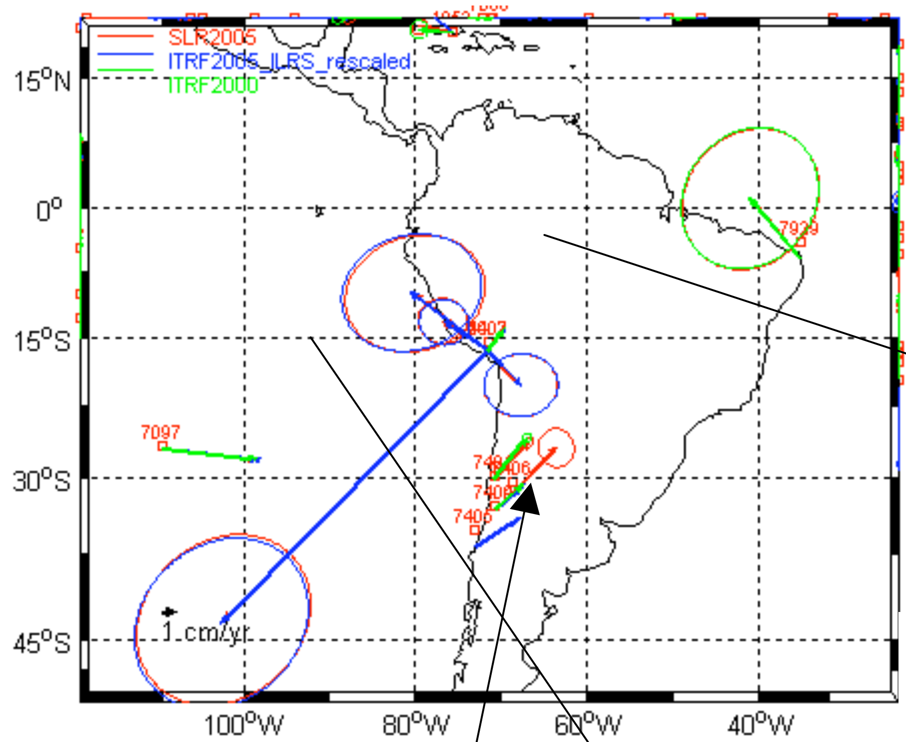
zoom



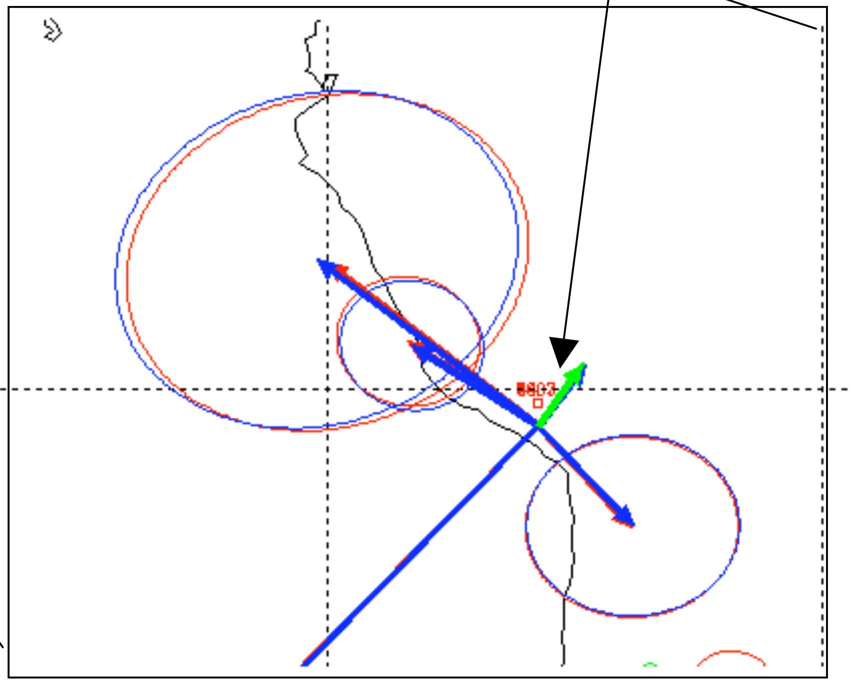
zoom



Velocities: Arequipa

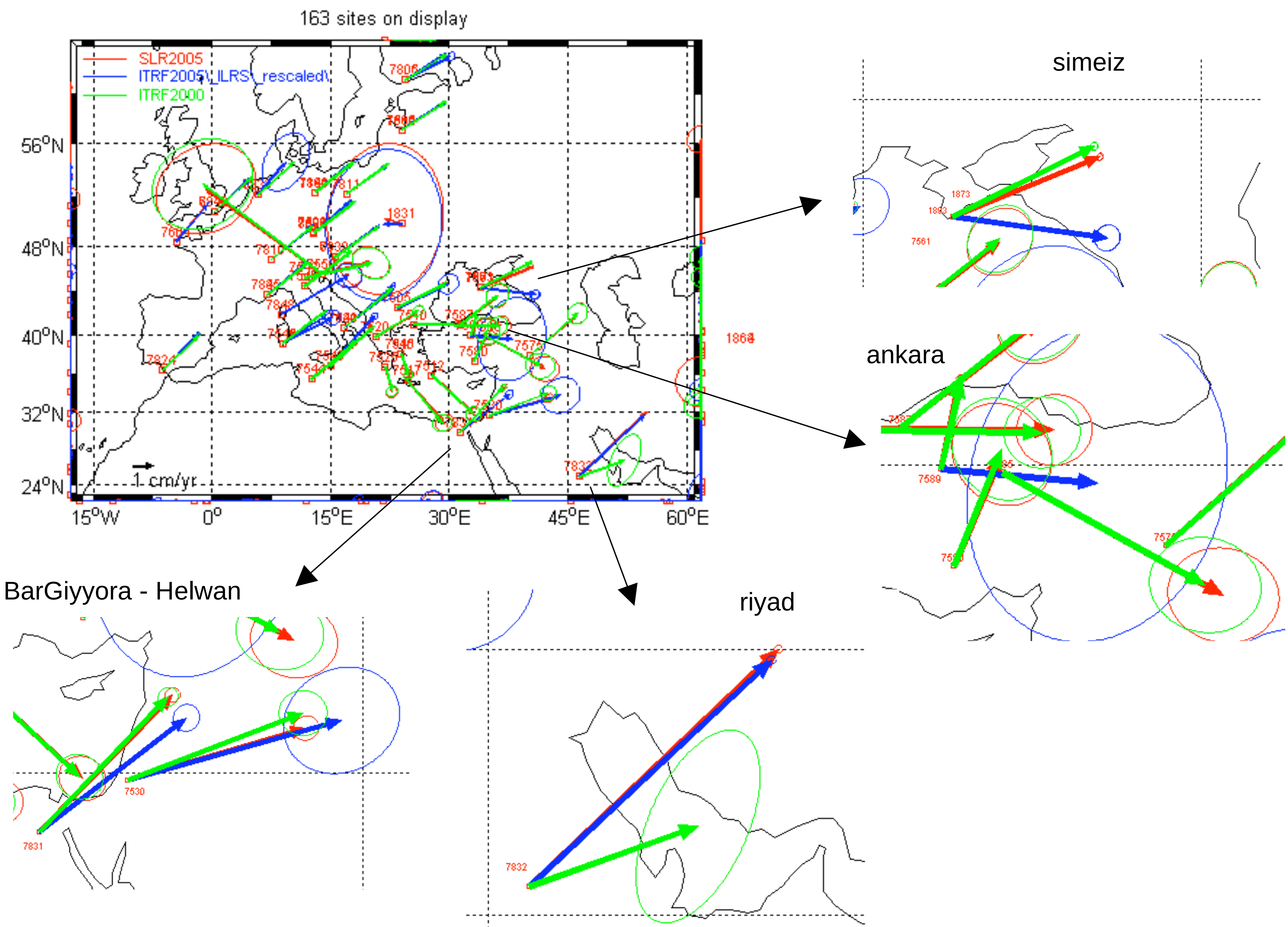


7406 (new)

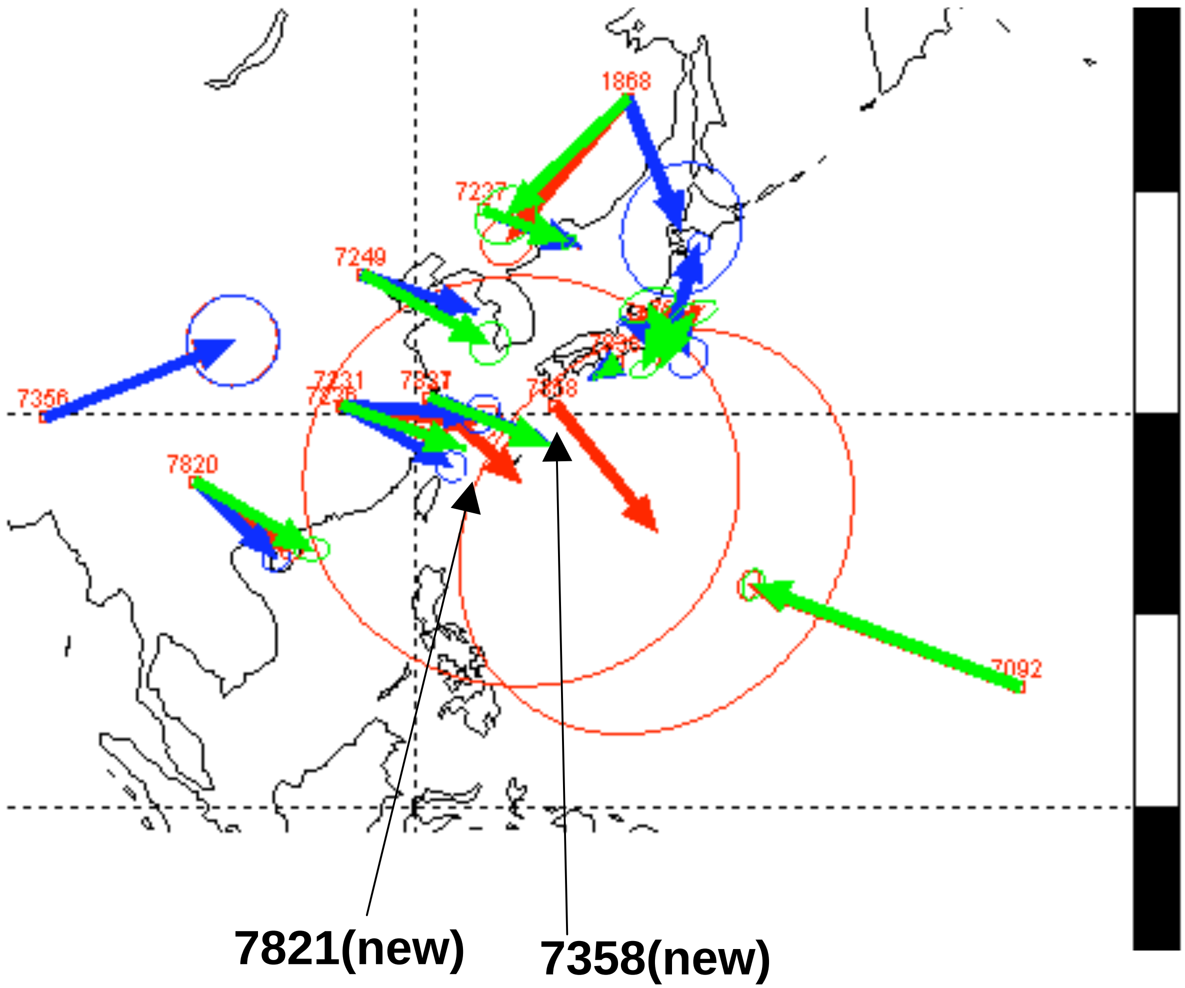


Only ITRF2005 SOLN 1 for 7403 combined

Velocities: Europe



Velocities: Western pacific



OPEN POINTS

- **New sites: eccentricity vector for 7119 (Maui)**
- **Arequipa: weak velocity estimation between jumps in ITRF2005**
- **SOLUTION/EPOCH block to be refined in the SINEX file**
- **SOLUTION/ECCENTRICITY block to be inserted in the SINEX file**

Next ILRS Combination Products

G. Bianco, C. Sciarretta, V. Luceri

ILRS AWG Meeting, July 10, 2007, Perugia, Italia

ILRS Combined Orbital Products

Background

The purpose is to issue a combined set of State Vectors pertaining to the combined weekly EOP/SSC solution for Lageos I/II, Etalon I/II.

Each ILRS AC will provide the usual weekly solution complemented with orbital file(s), in the SP3 format (TBC), with a stated time pace (TBD) in a EF reference frame as realized in the weekly EOP/SSC solution (TBC).

A possible combination scheme

Assumptions

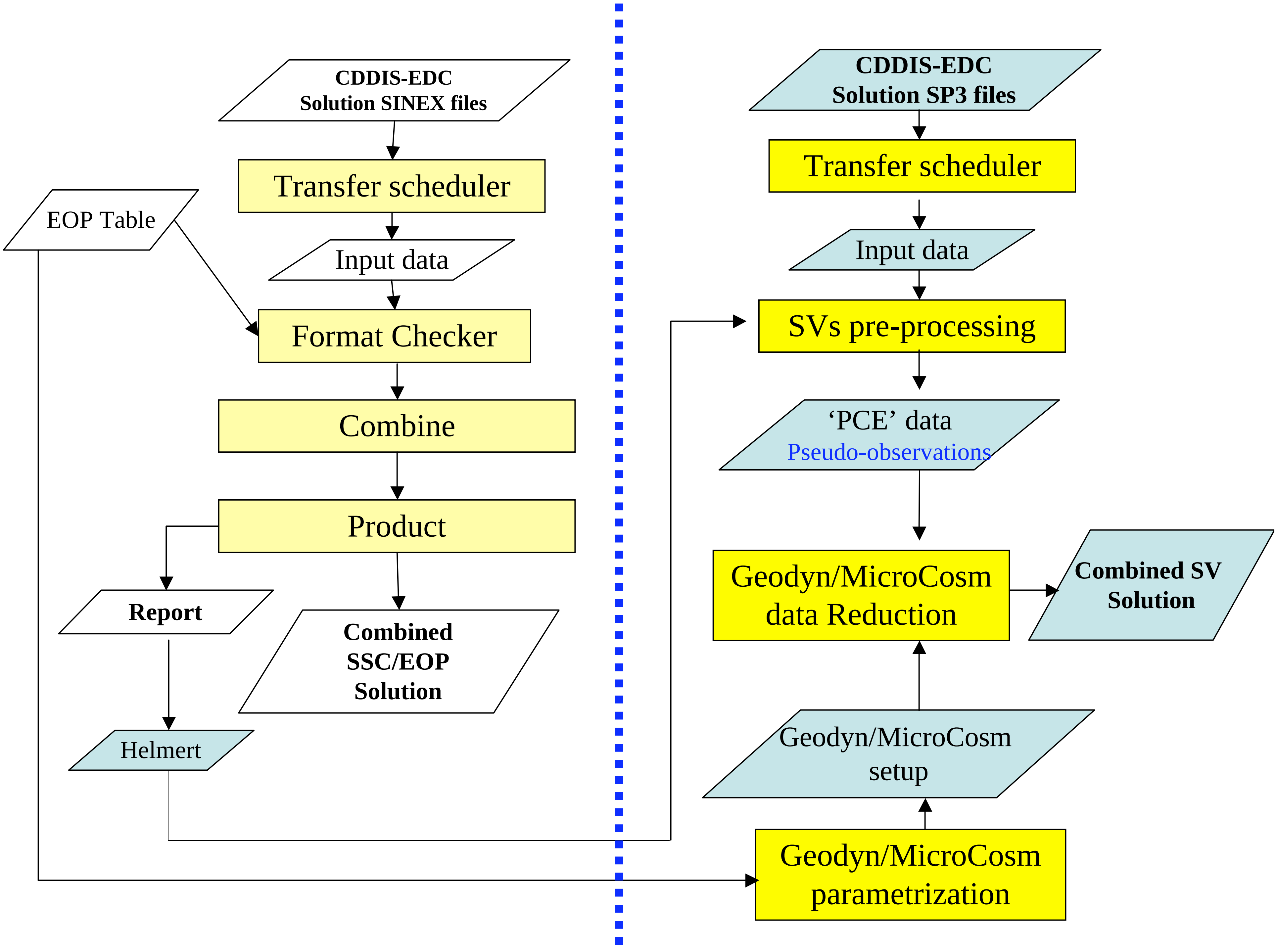
➢Weekly SVs provided by each AC in SP3 format (no information about covariance, ECEF)

➢SV combination procedure following a time scheduling coherent with the present SSC/EOP combination products latency to allow use of relevant information in the input-output flow

Approaches

➢Pure statistical combination (i.e. ‘weighted mean’)

➢SVs as pseudo-observations: physical modeling used to build a reference orbit corrected by means of the provided SVs (preferred by ASI-CGS)


CDDIS-EDC
Solution SINEX files
Transfer scheduler
EOP Table
Input data
Format Checker
Combine
Product
Report
Combined
SSC/EOP
Solution
Helmert
CDDIS-EDC
Solution SP3 files
Transfer scheduler
Input data
SVs pre-processing
'PCE' data
Pseudo-observations
Geodyn/MicroCosm
data Reduction
Combined SV
Solution
Geodyn/MicroCosm
setup
Geodyn/MicroCosm
parametrization

ASI-CGS Combination Procedure - Prototyping phase

ASI CGS just started the definition of a combination procedure, along the lines of the pseudo-observations data reduction, using SP3 test files internally generated.

We plan to present the results from these feasibility tests in Grasse, at the end of September.

The procedure prototyping will enlighten specific criticalities to be taken into account in the operational procedure development; in parallel, discussion within the ILRS AWG, together with other combination proposals, will clarify the SVs product specification as well as the compliance of the single AC SVs generation procedures to different product requirements.

ILRS Combined SSC/SSV Solution

After the production of the whole 1983-2007 set of combined weekly solutions, ILRS should generate an SLR-only, ITRF2005-framed SSV solution and update it systematically at a reasonable frequency by including the SSC weekly solutions being produced on.

This living SSV product has a very important operational impact, as it allows to have the best SLR coordinates at epoch for any site, while the official ITRFxx is frozen.

ASI-CGS has begun to work on this subject in cooperation with INGV (R. Devoti), where similar problems have to be faced to exploit the potentiality of a dense Italian GPS network.

ILRS Combined SSC/SSV Solution

The problem

The problem can be conceptually split in two:

- a static, classic problem of velocity field generation from a batch of not time correlated series of SSC solutions, to be solved taking into account all the available information (e.g full covariance matrices, geophysical and system catalogued ‘jumps’)
- a quick and reliable method to update the SSV solution by adding weekly SSC information in an incremental way

ASI-CGS has developed several SW tools to handle 1., even if modifications are needed to satisfy completely all the aspects; our revision work just started and we plan to be ready when the whole 1983-2007 combined solution set is produced.

ILRS Combined SSC/SSV Solution

About 2., ASI-CGS is approaching the design matrix modeling the mixed position/velocity problem in a recursive way:

$$\left(A_n{}'W_nA_n\right)k^0{}_n = A_n{}'W_n y_n$$

$$A_n = \begin{pmatrix} 1 & t_1 \\ . & . \\ . & . \\ . & . \\ 1 & t_n \end{pmatrix} = \begin{pmatrix} A_{n-1} \\ \hline 1 \quad t_n \end{pmatrix}; \quad k^0{}_n = \begin{pmatrix} x^0{}_n \\ \dot{x}^0{}_n \end{pmatrix}; \quad y_n = \begin{pmatrix} Y_1 \\ . \\ . \\ . \\ Y_n \end{pmatrix}$$

ILRS Combined SSC/SSV Solution

$$\left(A_{n-1}'W_{n-1}A_{n-1} + B_n\right)k^0{}_n = A_{n-1}'W_{n-1}y_{n-1} + z_n$$

$$B_n = \begin{pmatrix} w_n & w_n t_n \\ w_n t_n & w_n t_n{}^2 \end{pmatrix}$$

$$z_n = \begin{pmatrix} w_n \\ w_n Y_n \end{pmatrix}$$

update at step n

to be estimated

$$\left(A_{n-1}'W_{n-1}A_{n-1} + B_n\right)\boxed{k^0{}_n} = \left(A_{n-1}'W_{n-1}A_{n-1}\right)k^0{}_{n-1} + z_n$$

from step n-1

Status of ILRSB

Rainer Kelm
Deutsches Geodätisches Forschungsinstitut

Actual combination

Analysis 1983 -1992

Reanalysis 1993 -2007

Daily Combination

SP3C

Proposals

Actual combination (1)

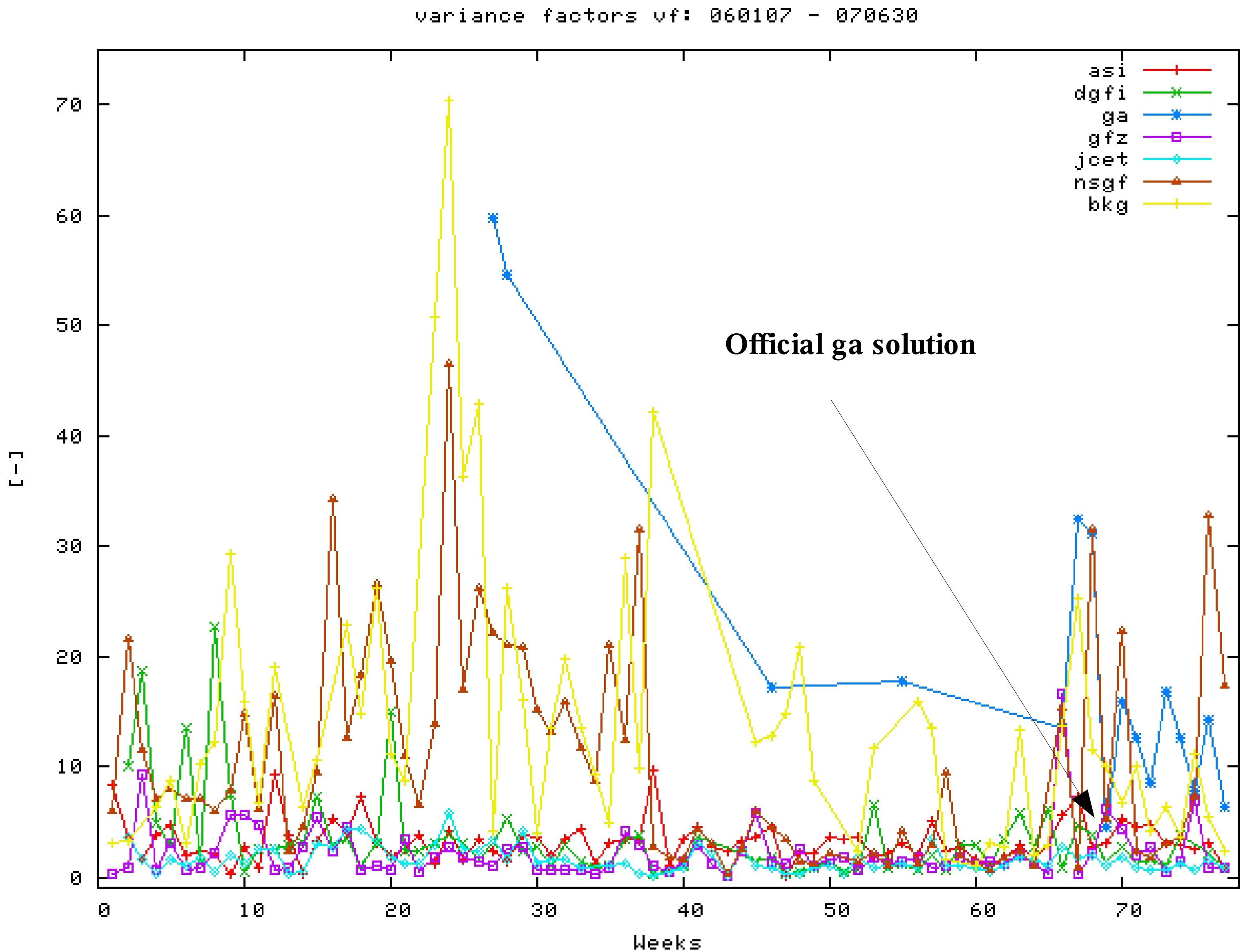
Variance factors and their variances (VCE)
****

asi.pos+eop.070407:	3.21294	0.13082
bkg.pos+eop.070407:	11.79487	0.37012
dgfi.pos+eop.070407:	1.36680	0.06136
ga.pos+eop.070407:	24.41183	0.69992
gfz.pos+eop.070407:	0.35350	0.01154
jcet.pos+eop.070407:	1.58929	0.08698

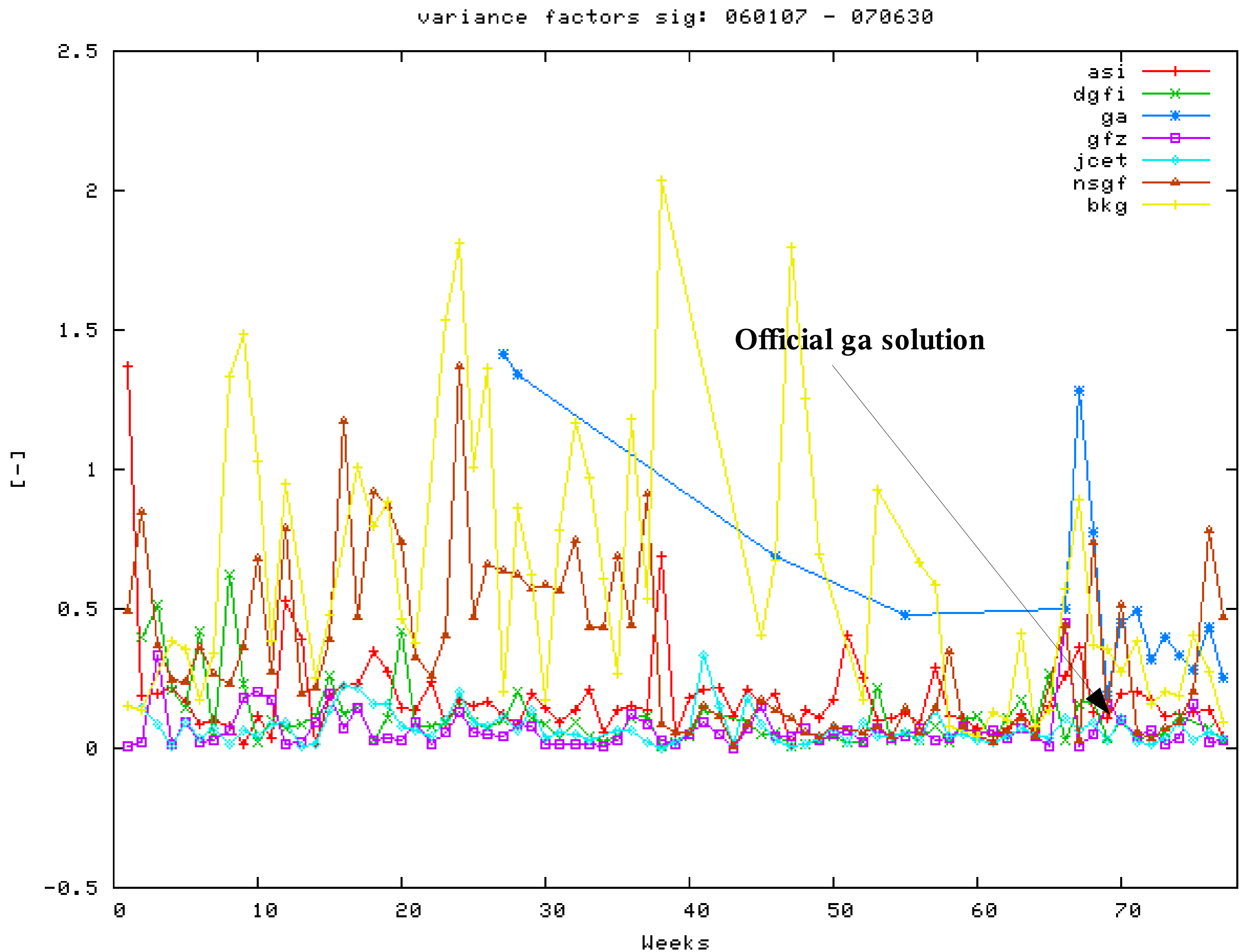
Variance factors and their variances (VCE)
****

asi.pos+eop.070630:	0.82711	0.04672
bkg.pos+eop.070630:	2.28924	0.09567
dgfi.pos+eop.070630:	0.79865	0.03132
ga.pos+eop.070630:	6.35056	0.25073
gfz.pos+eop.070630:	0.79716	0.02614
jcet.pos+eop.070630:	0.80208	0.03596
nsgf.pos+eop.070630:	17.38179	0.46753

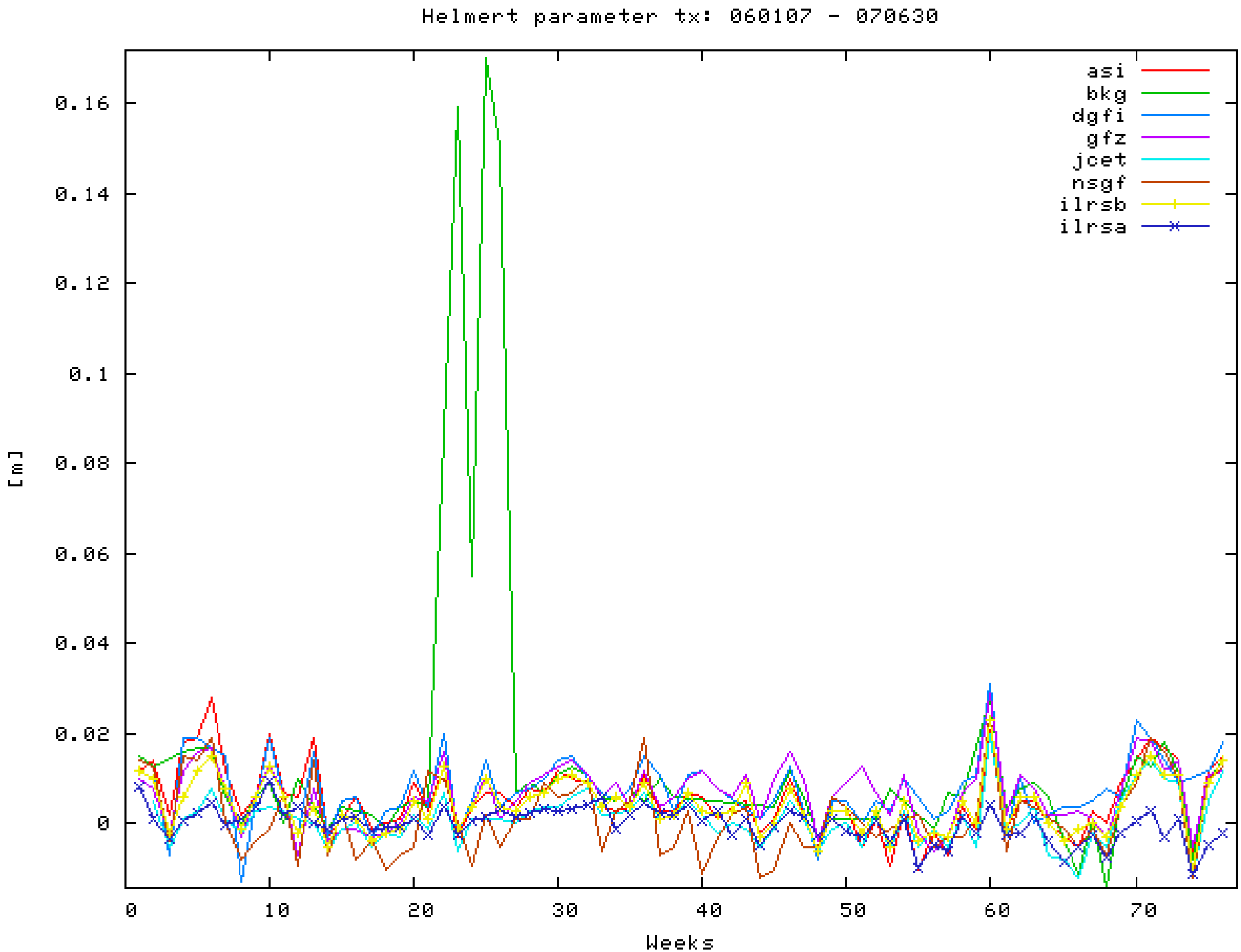
Actual combination (3)



Actual combination (4)

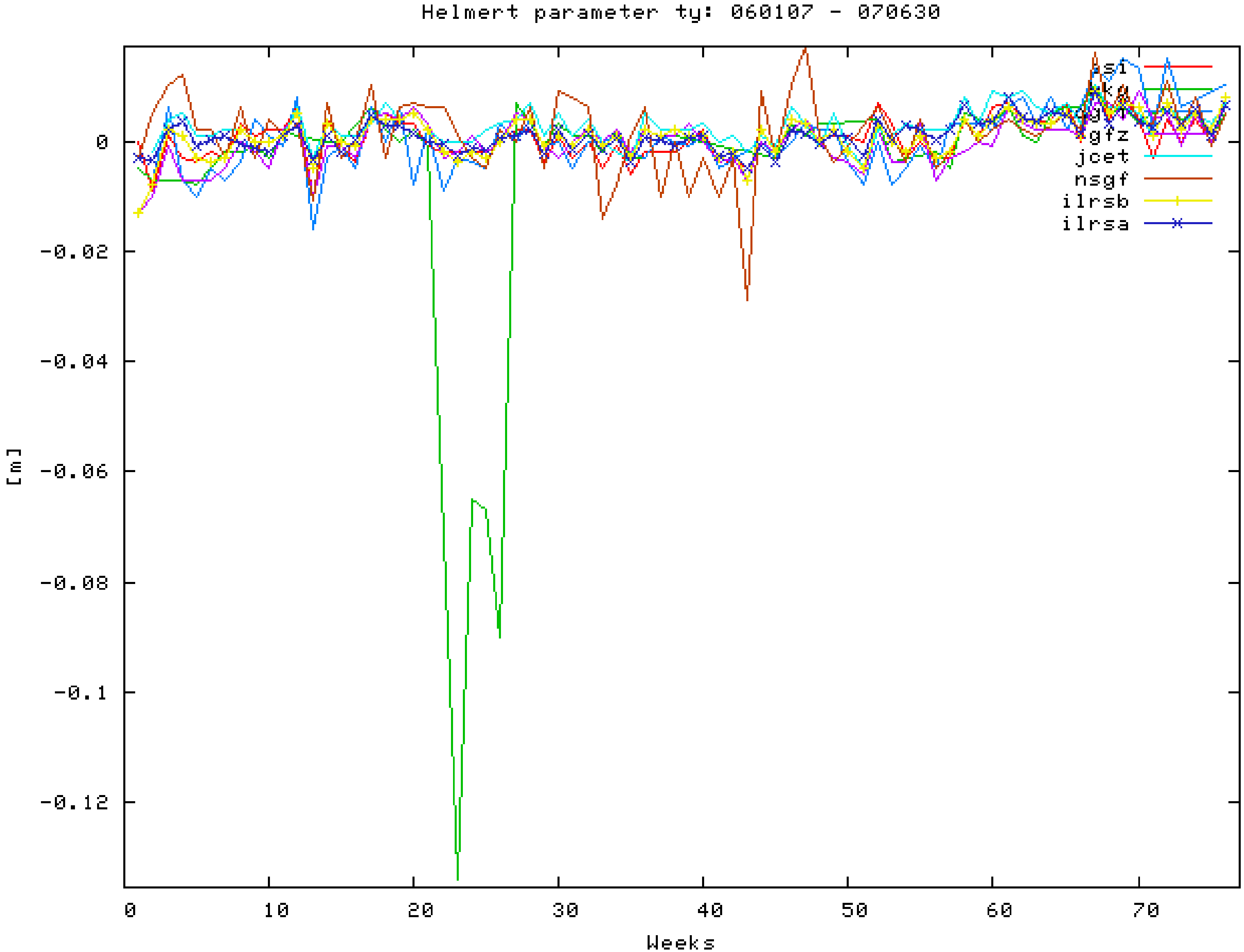


Actual combination (5)

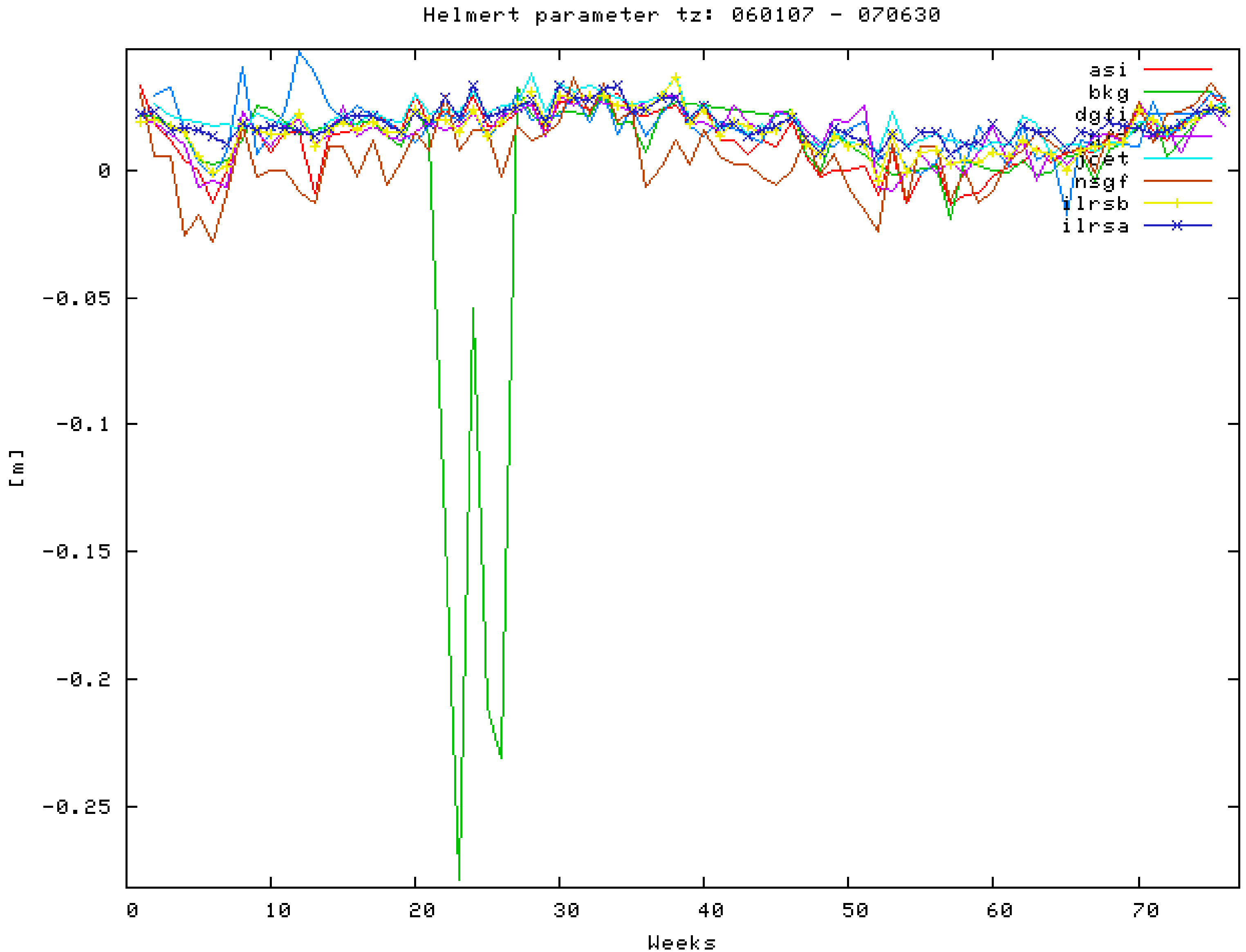


DGFI Forschungsgruppe Satellitengeodäsie

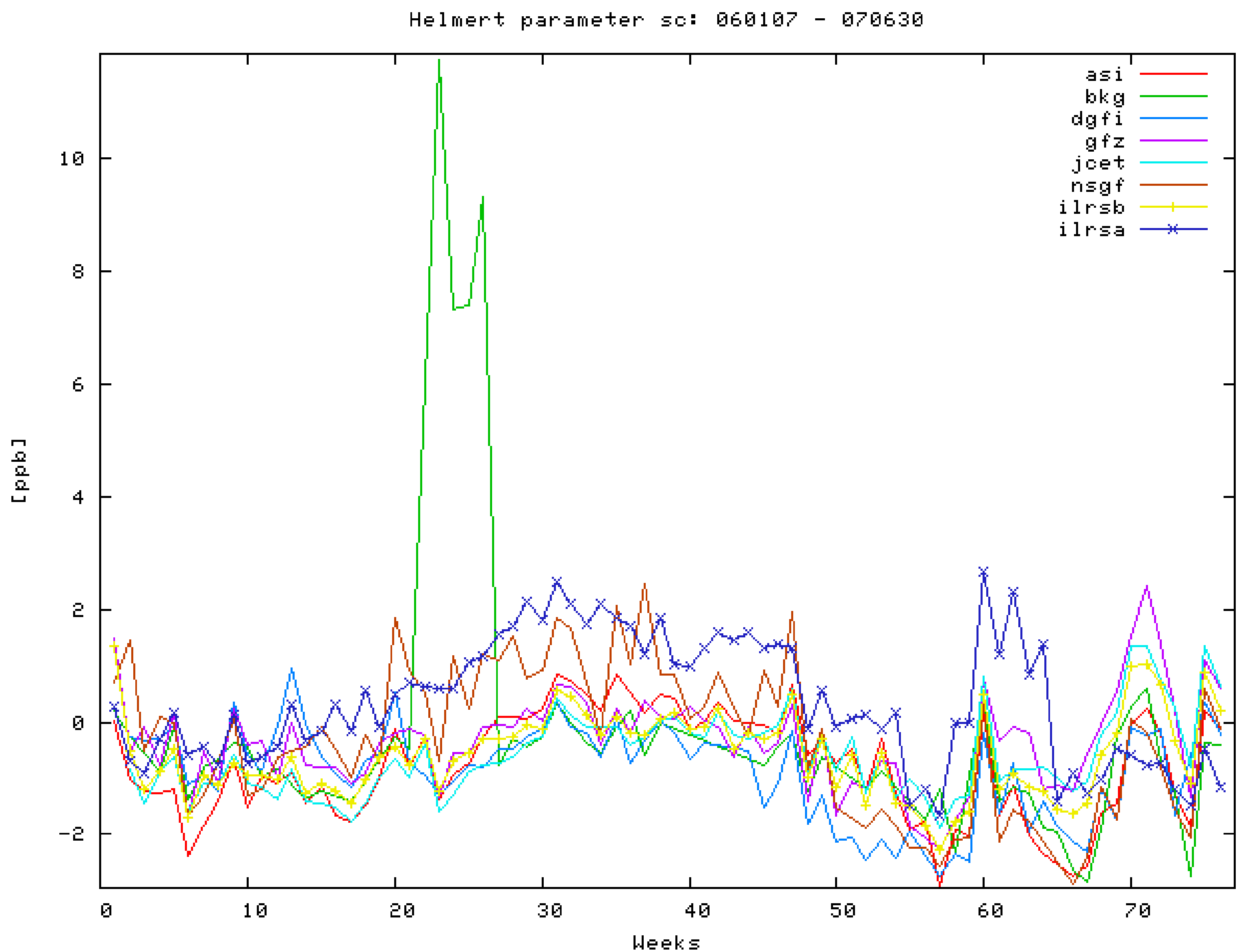
Actual combination (6)



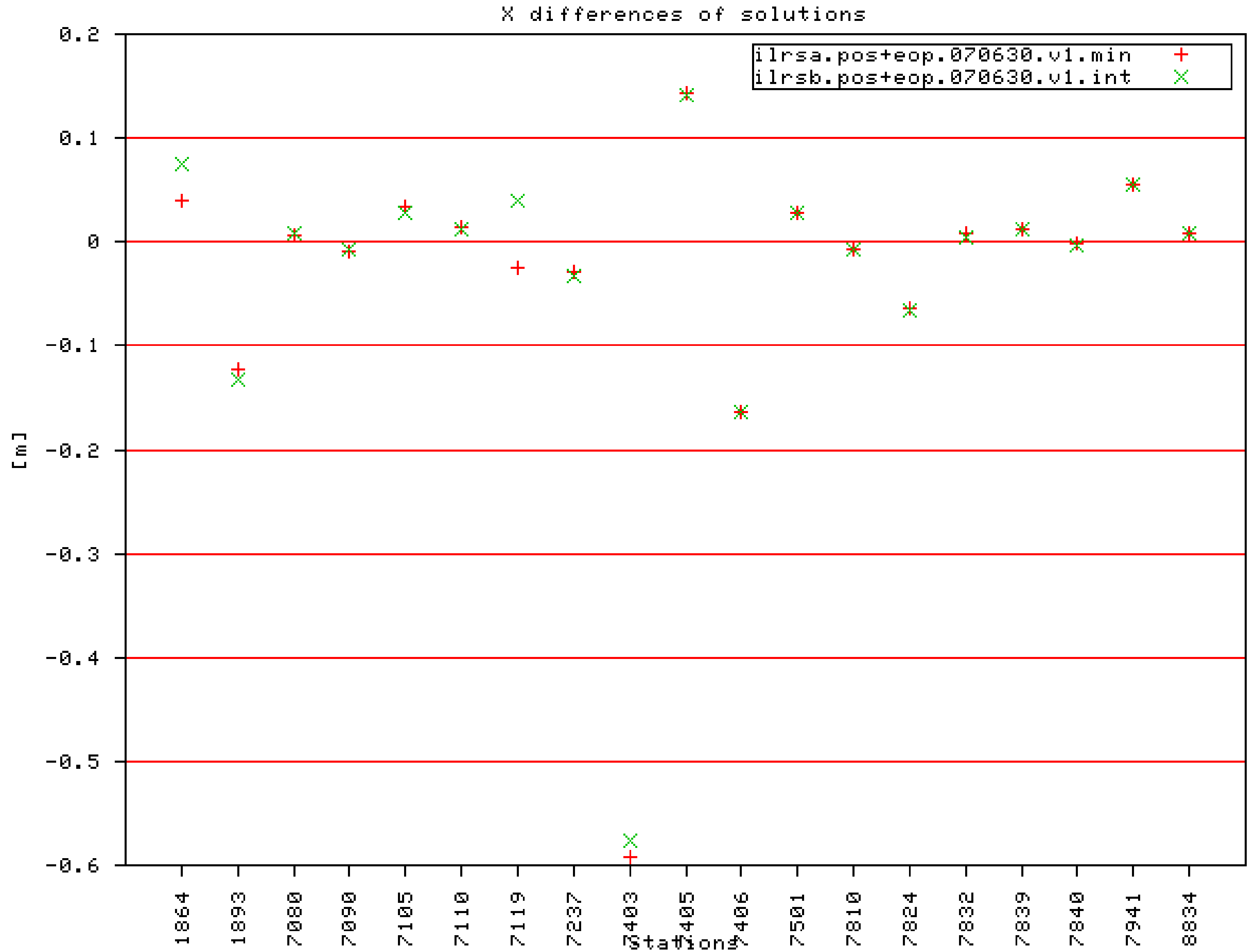
Actual combination (7)



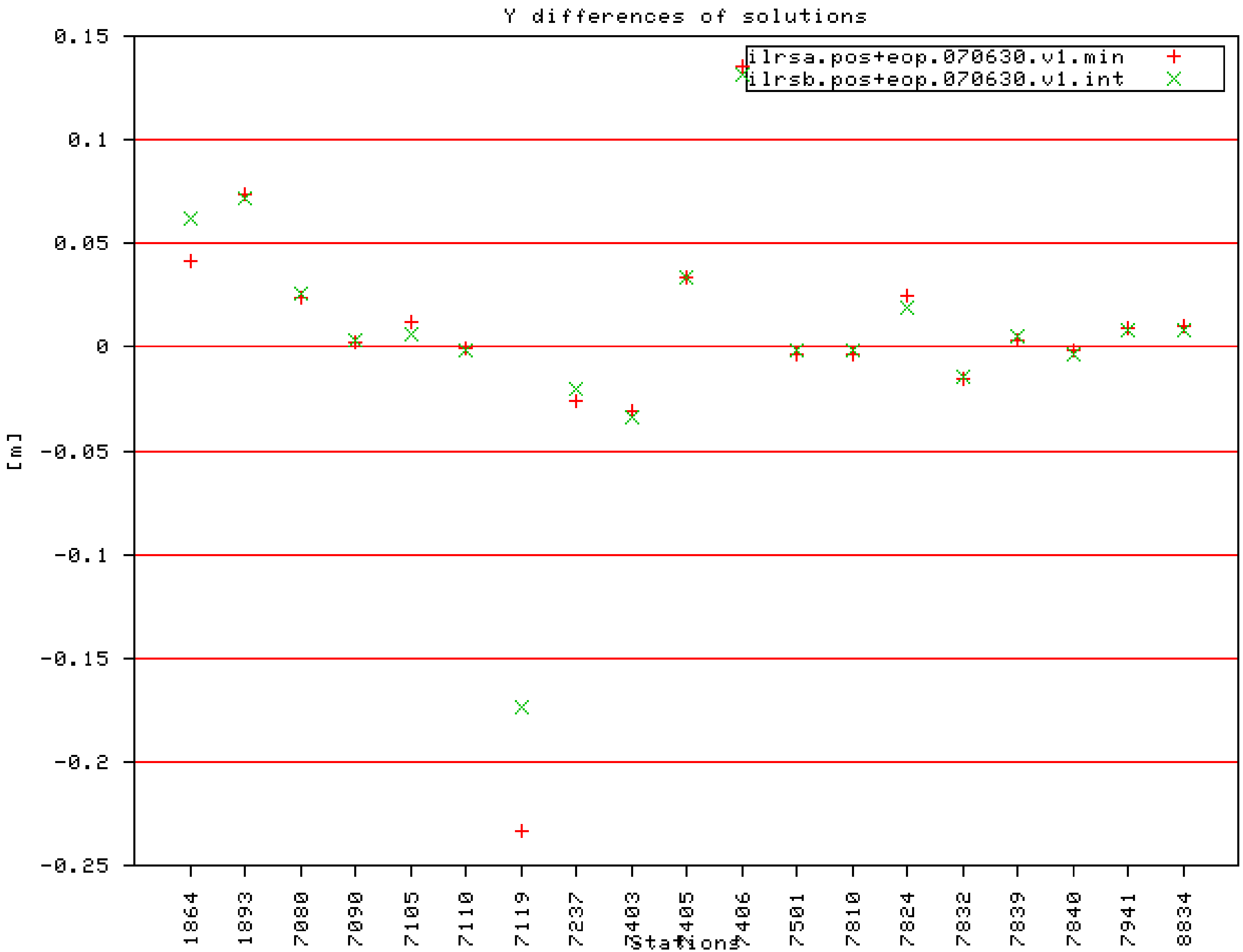
Actual combination (8)



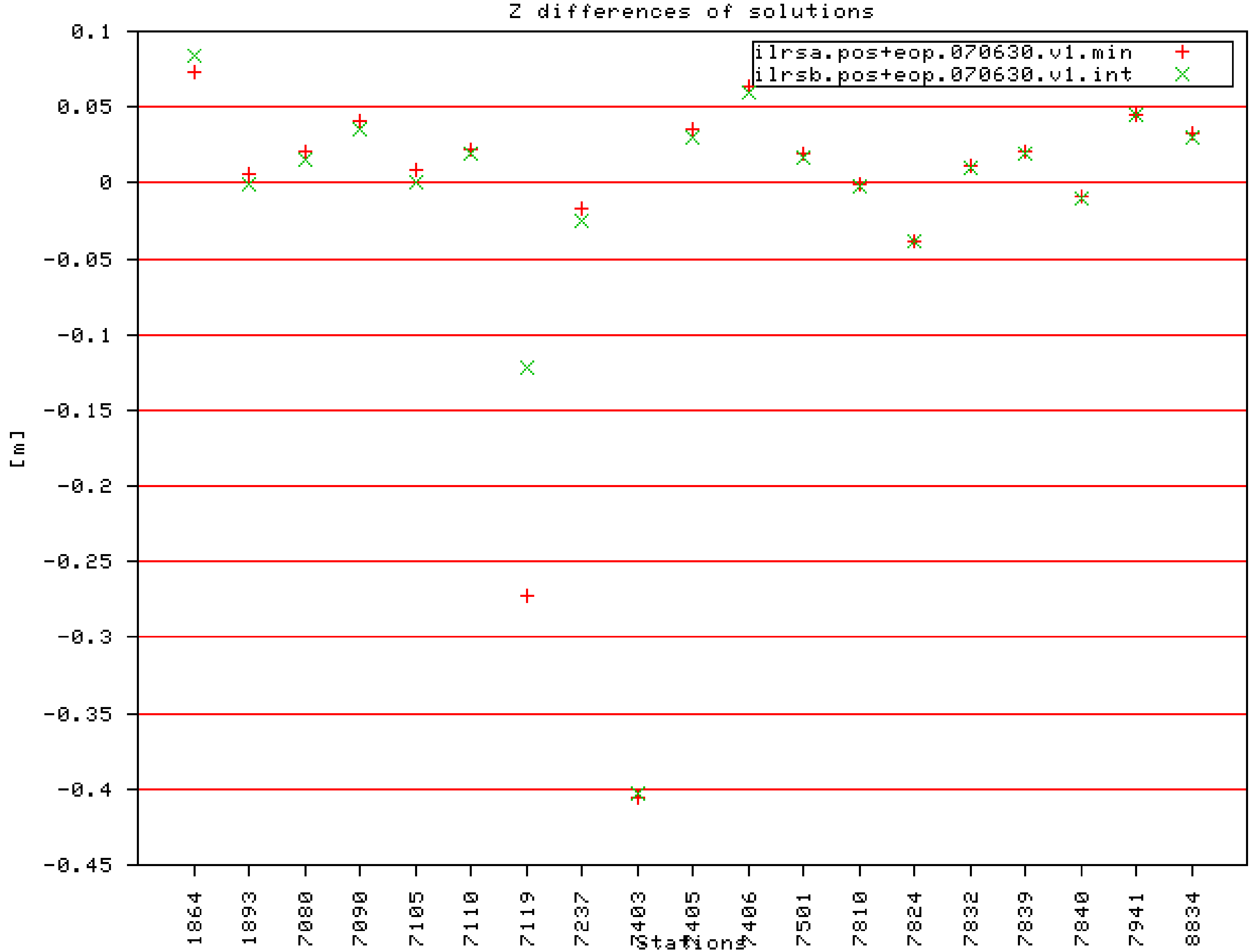
Actual combination (9)



Actual combination (10)

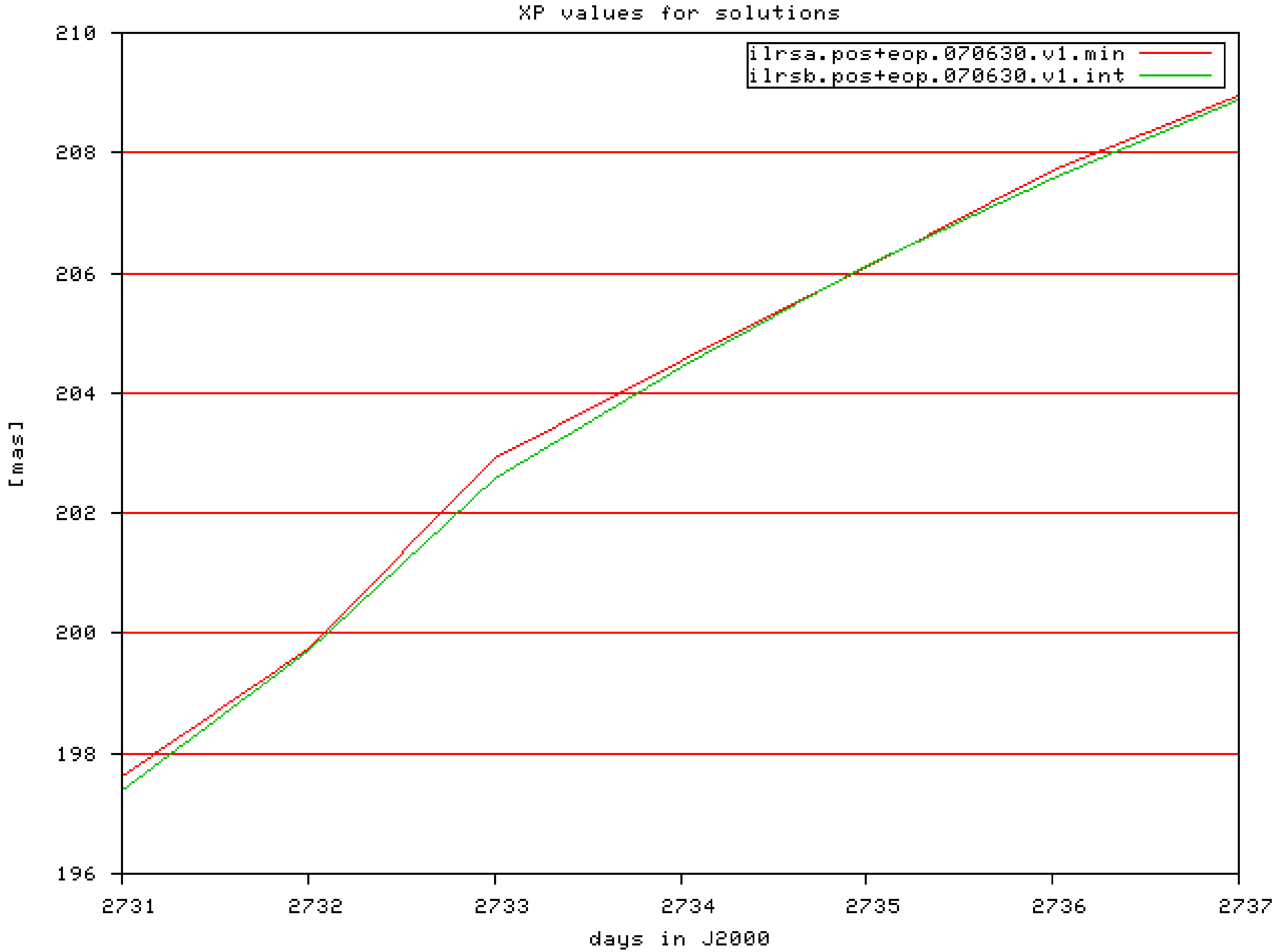


Actual combination (11)

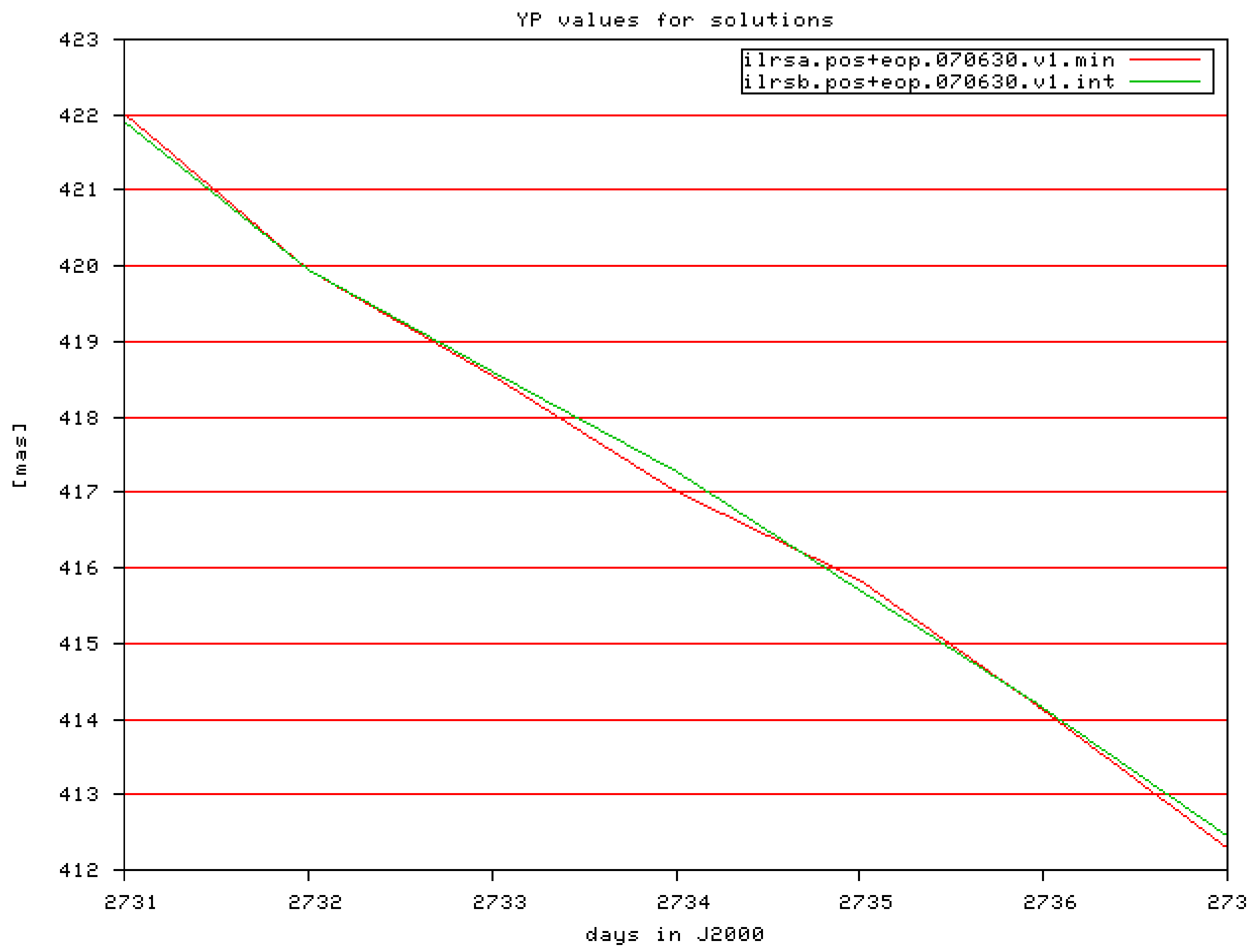


ILRS AWG Meeting Perugia July 10, 2007

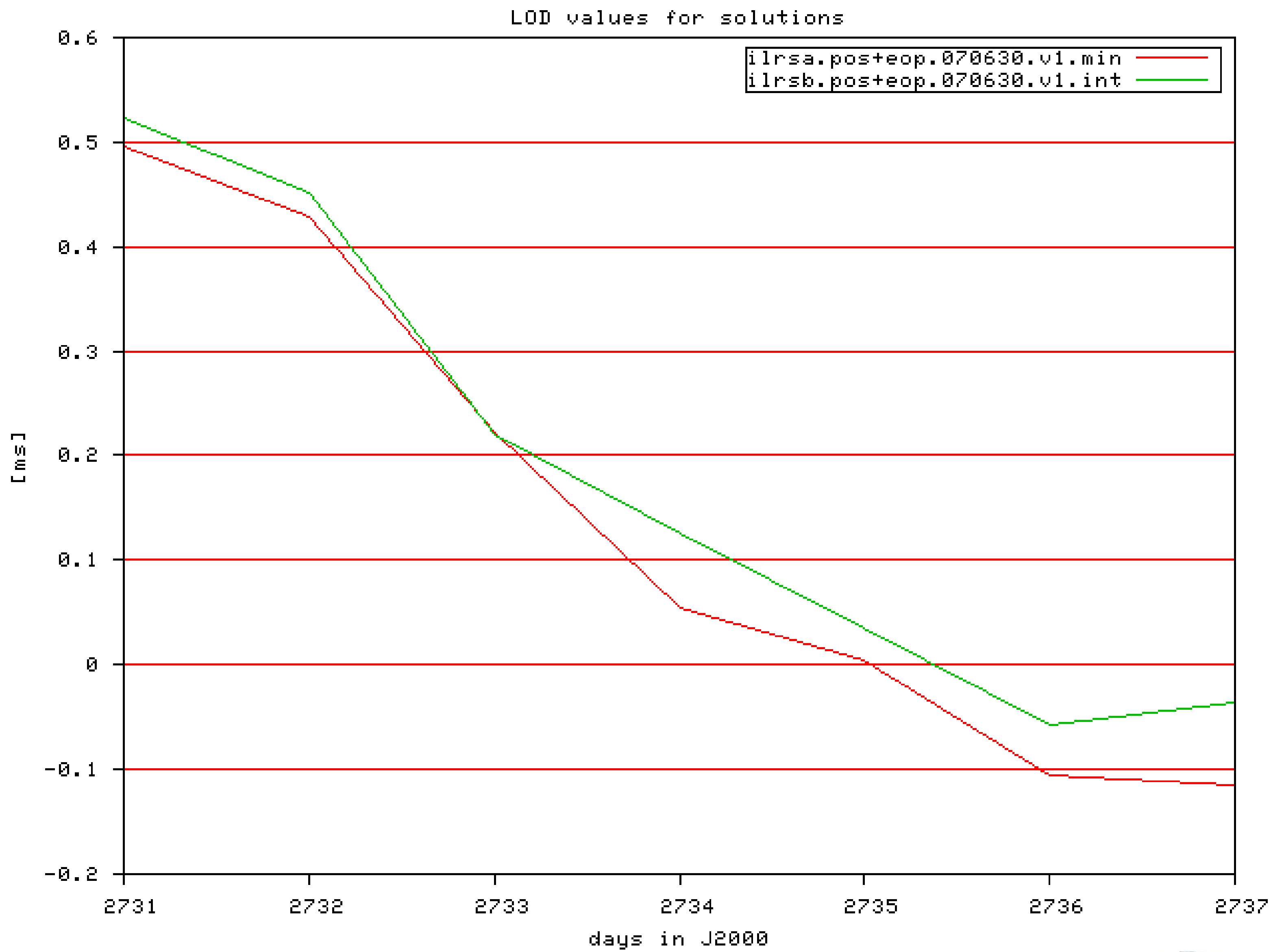
Actual combination (12)



Actual combination (13)



Actual combination (14)



Analysis 1983 - 1992

* Software is updated

* Remarks to test week 890607:
  - BKG, DGFI, and GFZ solutions not available
  - NSGF solution deleted: no rotational rank deficiences
  - ASI: shift of one week – 890615 instead of 890607
  - JCET and NSGF: missing .pos+eop in file name
  - VCE applicable as weighting and outlier analysis method
  - combined solution with GA and JCET solutions

Variance factors and their variances (VCE)
****

ga.pos+eop.831121:	4.64476	0.41227
jcet.pos+eop.831121:	3.79798	0.32881
nsgf.pos+eop.831121:	11.46697	0.70269

Renalysis 1993 - 2007

* waiting for new input solutions

Daily Combination

* waiting for input solutions

SP3C

*   Lageos 1, 2 and Etalon 1 and 2?

*   waiting for test files in SP3C format

*   correlation between xy, xz, xc, yz, yc, and zc (ex.2 of sp3c.txt)?

*   software updating in preperation

Proposals

* only newest version in actual directory at CDDIS and EDC

* two-digit version numbering: 10, 11, 12, ... (proposal of Cecilia a long time ago)

Progress on Systematic Effects in Stanford counters used for Laser Ranging Observations

Graham Appleby, and **Philip Gibbs**

Space Geodesy Facility, Herstmonceux, UK;

ILRS AWG, Perugia 10th July 2007

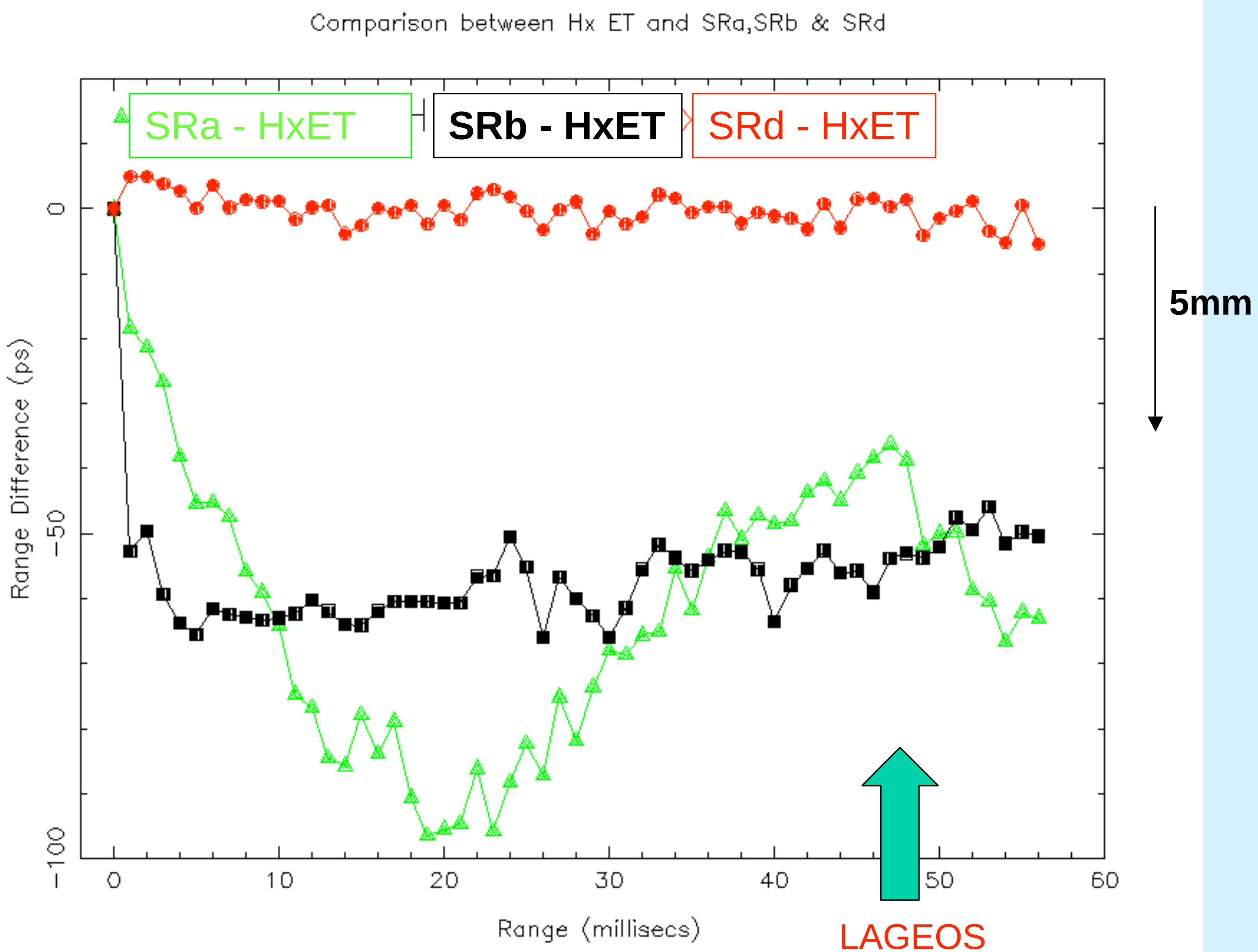
Tests on counter linearity

- Relative to a 'perfect' time-of-flight counter, what are the characteristics of the counters in common use over the last 15+ years?
- Work was started by a careful examination of *Stanford* counters in use at Herstmonceux, relative to a high-spec, ps-level event timer.
- Studied effects at LAGEOS and at local calibration target distances.

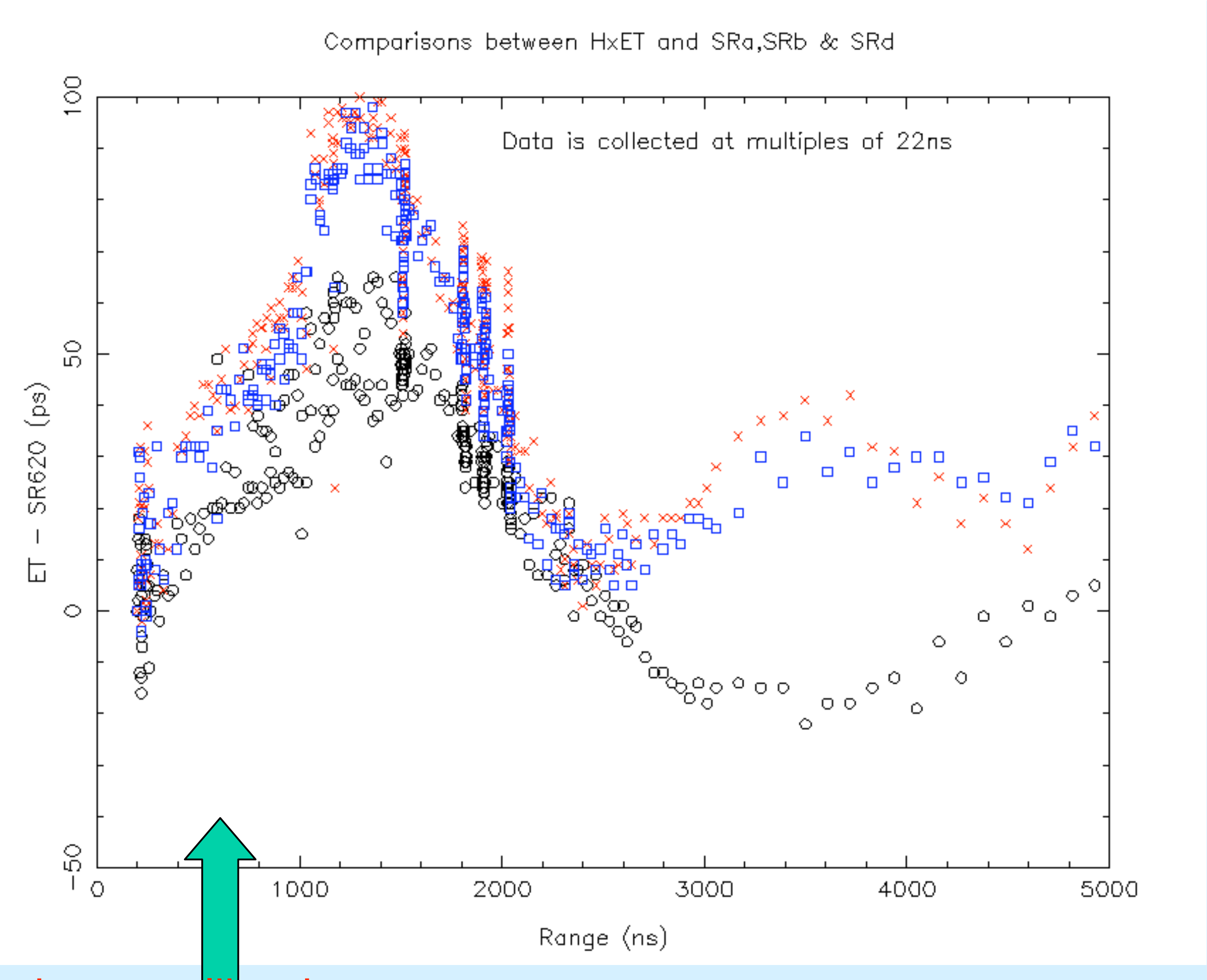
Herstmonceux counters

- A ps-level event timer (HET) has been built in-house from *Thales* clock units;
- A prerequisite for the upcoming kHz operations.

- Extensive use of HET to calibrate existing cluster of *Stanford* counters prior to routine use of HET;
- In particular we wish to **back-calibrate** Hx data 1994-present.



Comparison between Hx ET and SRa,SRb & SRd
SRa - HxET
SRb - HxET
SRd - HxET
0
−50
−100
Range Difference (ps)
0
10
20
30
40
50
60
Range (millisecs)
5mm
LAGEOS



Primary calibration target

Comparisons between HxET and the Stanford counters for calibration boards' distances;
Behaviour very similar to spec;
Errors up to 100ps (15mm), with some systematic detailed structure

Summary of effect on range measurements at Herstmonceux (1994–2007)

- The non-linearity of the Stanfords:
- imparts an average of ~–5.5±2mm error onto the observed **calibration** range;
  - The calibrations are too short;
  - Hence calibrated satellite ranges are **too long by 5.5mm**.
- Value is dependent on the target range and on the particular Stanford;
  - Hence the inherent 2mm uncertainty in this correction

Summary of effect on range measurements at Herstmonceux (1994–2007)

- At distance of LAGEOS, range error is ~ −8 ± 2mm;
  - observed raw LAGEOS ranges are too short
- **So total range error is:**
  - + 5.5 − 8.0 = − 2.5 ± 3mm
  - i.e. need to **add** 2.5mm to LAGEOS ranges

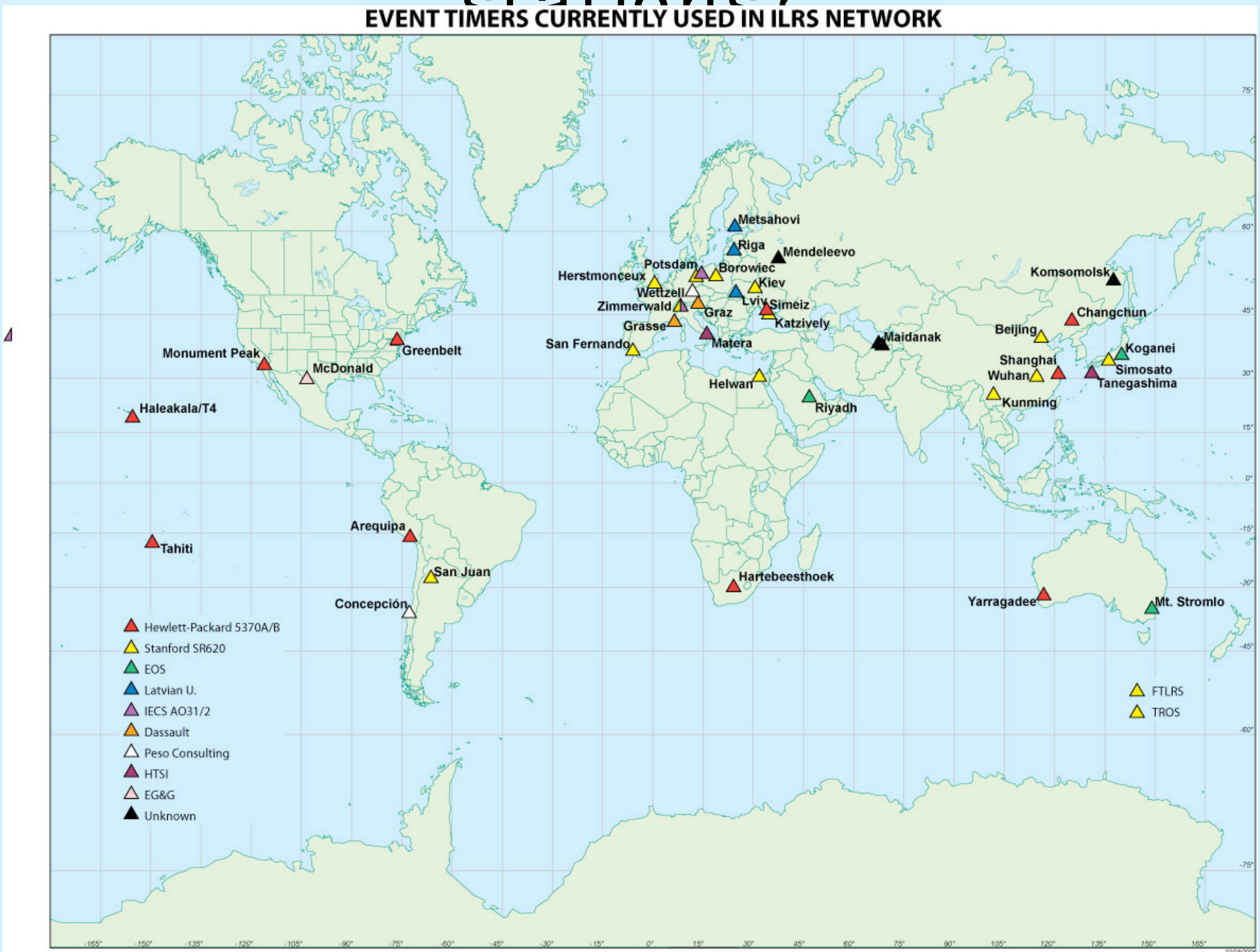
- **This correction applies to the period 1994 October 1 to 2002 January 31**

Summary of effect on range measurements at Herstmonceux (1994–2007)

- From 2002 February 1 the satellite-range-dependent correction has been applied on-site
- The calibration error has **not been applied**
- So for the period 2002 February 1 – 2007 February 10:
  - Subtract 5.5mm from **all satellite ranges** from Herstmonceux

- **From 2007 February 11, range error for all satellites is ~zero, using new event timer**

Effect present in other ILRS stations?



Effect present in other ILRS stations?

- At this stage, we confine our investigation to Stanford counters;
  - Our limited experience with *e.g.* HP timers suggests they do not have problem - used by NASA network
- We have made 'worst case' **estimates** of calibration error and total range error at LAGEOS for all 'Stanford stations'

- Error span is –9 to +11mm, frequent error +10mm
- Uncertainty in these **estimates** is ~5mm

Worse-case error estimates (mm)

Station		ID	Calibration error	LAGEOS error	Total error
BEIL	Beijing	7249	-12	+10	- 2
BORL	Borowiecz	7811	- 9	+ 0 meas	- 9
BREF	Brest	7604	-10	+10	0
GLSV	Kiev	1824	- 6	+10	+ 4
HELW	Helwan	7831	0	+10	+10
KTZL	Katzively, Ukraine	1893	0	+10	+10
KUNL	Kunming, China	7820	- 9	+10	+ 1
POT3	Potsdam	7841	0	+10	+10
POTL	Potsdam	7836	0	+ 5 meas	+ 5
SFEL	San Fernando	7824	0	+ 8 meas	+ 8
SISL	Simosato, Japan	7838	+1	+10	+11
SJUL	San Juan	7406	0	+10	+10
WUHL	Wuhan	7231	0	+10	+10
ZIML	Zimmerwald	7810	-3	+ 8 appl	- 3
Closed sites					
GRSL	Grasse	7835	- 1	10	11

meas = measured on particular Stanford counters; **appl** = applied at station

Comments

- We emphasise the preliminary nature of this table;
  - The plots of the 3 Herstmonceux Stanford counters show large inter-counter differences;

- Calibration of each stations' counter(s) is essential.

- We are currently working on Potsdam counter;
- Want to get others a.s.a.p.;
- Particularly important to calibrate San Juan, San Fernando

Summary/outlook

- We also note that:
- The stations are a subset of the full ILRS network, but do contain some core sites;
- The counters can be calibrated (ongoing) and data reprocessed;
  - Counter characteristics remain static over time;
- Several of the stations have already upgraded to higher-quality counters.

Site range biases 1993-2007

V. Luceri – e-GEOS S.p.A.

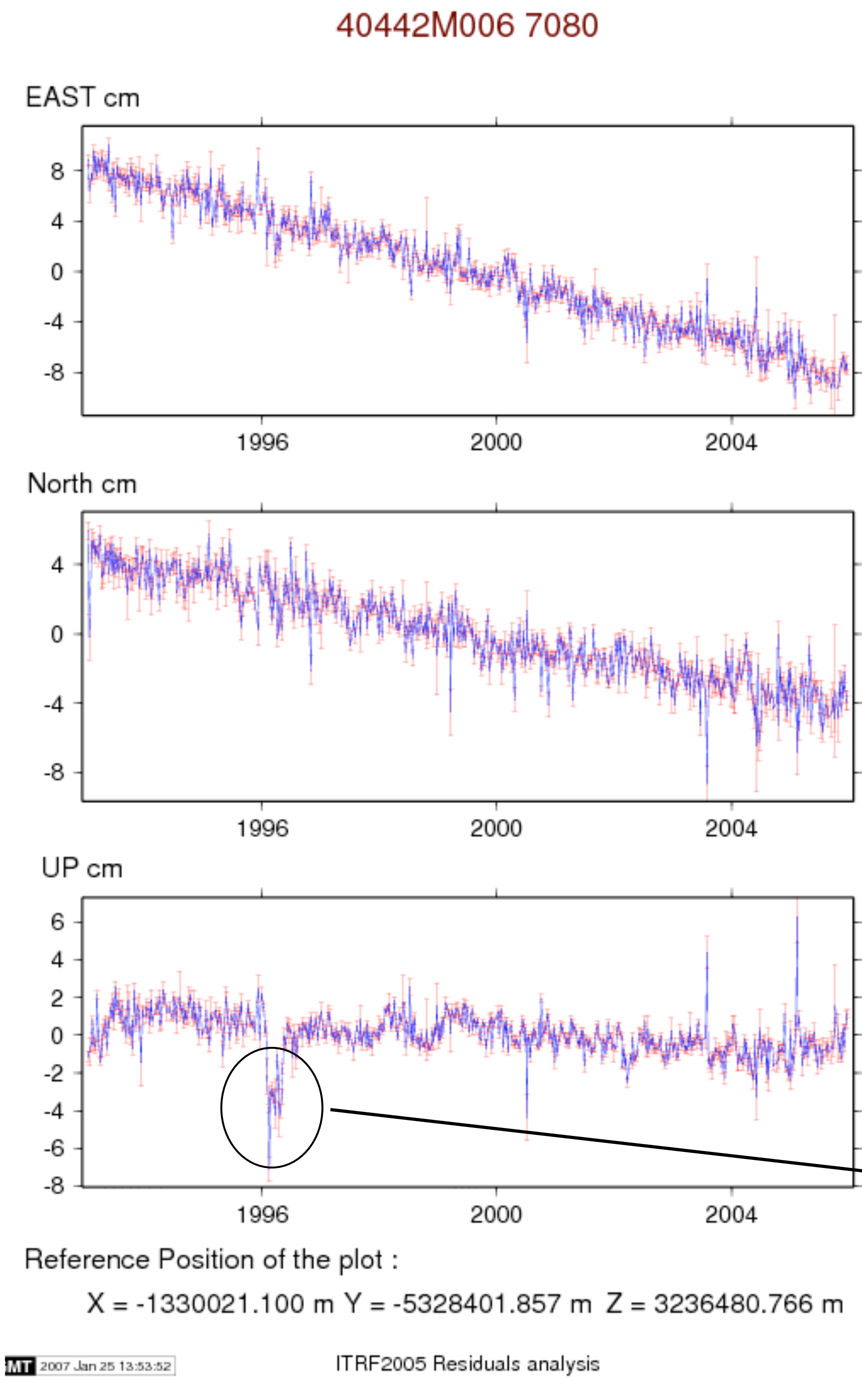
G. Bianco - Agenzia Spaziale Italiana

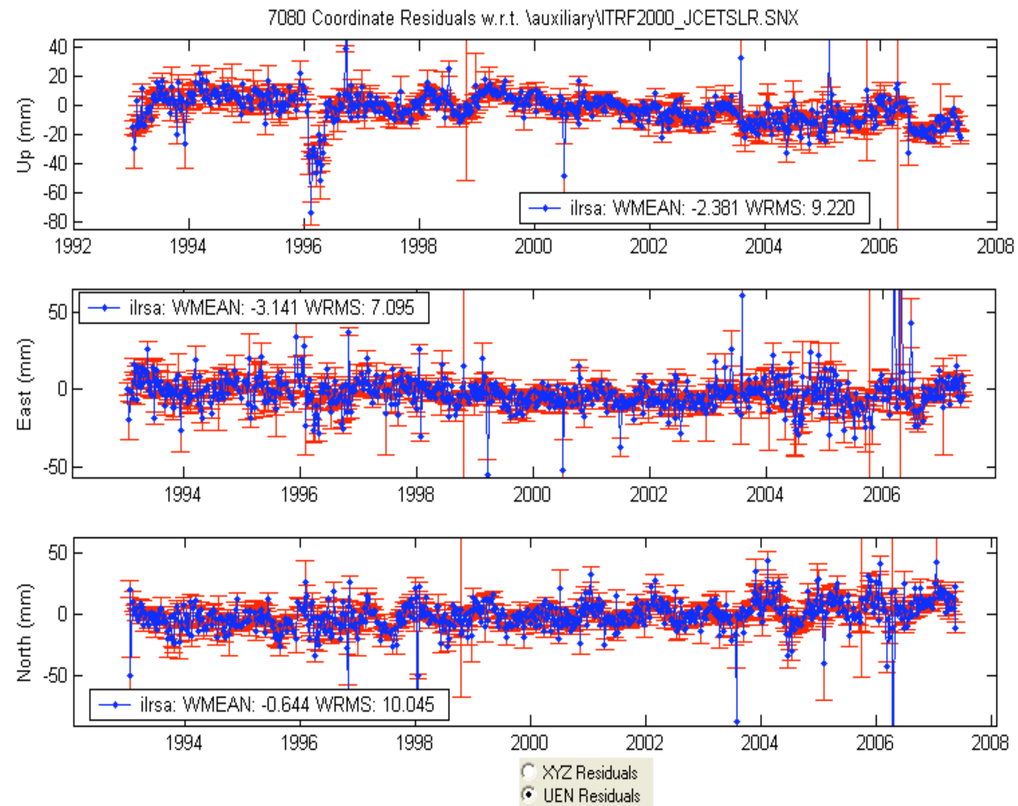
Site list with range biases

Groups of sites	Site No.	Wav	Core NonCore	Solve ?	Model ?	bias in sol V50	SOLUTION PROPOSAL		
CORE SITES	7080	G	C	NO	YES	__	MLRS Barometer Correction Values The correct pressure can be recovered by adding the following corrections to the valu		
							Start Date	**End Date**	**Correction**
							March 6, 1995	January 25, 1996	2.1 mB
							January 26, 1996	April 24, 1996	10.3 mB
							April 25, 1996	May 8, 1996, 20:00	9.7 mB
	7110	G	C	NO	YES	__	**Start Date**	**End Date**	**Correction (one way)**
							August 27, 1996	October 2, 02:50	163,6 mm
	7810	B	C	NO	YES	__	**Start Date**	**End Date**	**Correction (one way)**
							January 1997	July 9, 1997	-7.5 mm
							July 9, 1997	July 17, 1997	60 mm
							July 17, 1997	July 30, 1997	-7.5 mm
							July 30, 1997	Sept 30, 1997	-71.5 mm
							Sept 30, 1997	january 1998	-7.5 mm
							january 1998	May 29, 2002	-25.5
							May 29, 2002	Feb 6, 2006	-7.5 mm
							LAGEOS time bias for pass 97-08-15 23:18:57 23:24:47 microsec 68.0		
	7810	I	C	NO	YES	__	January 1997	Feb 6, 2006	-15 mm
	7832	G	C	NO	NO	__	data before 1998 to be edited out		
	7839	G	C	NO	YES	1993.0 to September 1996	-20 mm from 1993 to september 1996		biased until april 1996? No information
	7840	G	C	NO	YES	__	**Start Date**	**End Date**	**Correction**
							october 1, 1994	february 1, 2002	-1.5 mm (-10 +8.5 mm)
							february 1, 2002	february 10, 2007	8.5 mm
	8834	G	C	NO	YES	1993.0 - 1997.0	beginning	february 1992	-25 mm
							march 1992	may 1996	38 mm
							may 2000	to date	-13 mm
NON-CORE SITES	1864	G	NC	YES	--	1993.0 ->	bias to be estimated over all the period		
	1868	G	NC	YES	--	1993.0 ->	bias to be estimated over all the period		
	1884	G	NC	YES	--	1993.0 ->	data prior august 1994 to be deleted		
	7210	G	NC	NO	YES	1993.0 -2005.0	stepwise bias to be applied (see presentation)		
	7237	G	NC	YES	--	1993.0 ->	bias to be estimated over all the period		
	7811	G	NC	NO	YES	1993.0 -1994.0	data before 1993:202 to be edited		
							stepwise data to be applied (see presentation)		
	1873	G	NC	NO	NO	--	data before 1995.0 to be deleted		
	1893	G	NC	NO	NO	--	data before 1998.0 to be deleted		
	7109	G	NC	NO	NO	--	jump at 1995,0, no info		
	7236	G	NC	NO	NO	--	data after 1998.0 with biases (a few acquisitions until 2000)		
	7249	G	NC	NO	NO	--	data before 1999.0 to be deleted		
	7355	G	NC	NO	NO	--	use data only in 2003		
	7530	G	NC	YES	NO	--	bias to be estimated over all the period		
	7820	G	NC	NO	NO	--	data before 00:291:00000 to be deleted		
	7831	G	NC	NO	NO	--	data in 1999 to be deleted, bias to be estimated in 1993		
	7838	G	NC	NO	NO	--	OK (bad for referencing)		
	7841	G	NC	NO	NO	--	jump at 2004:050 A031 Event Timer replacing SR620 time interval counter		
	7845	G	NC	YES	NO	--	bias to be estimated over all the period		

Black border= sites for EOP

McDonald



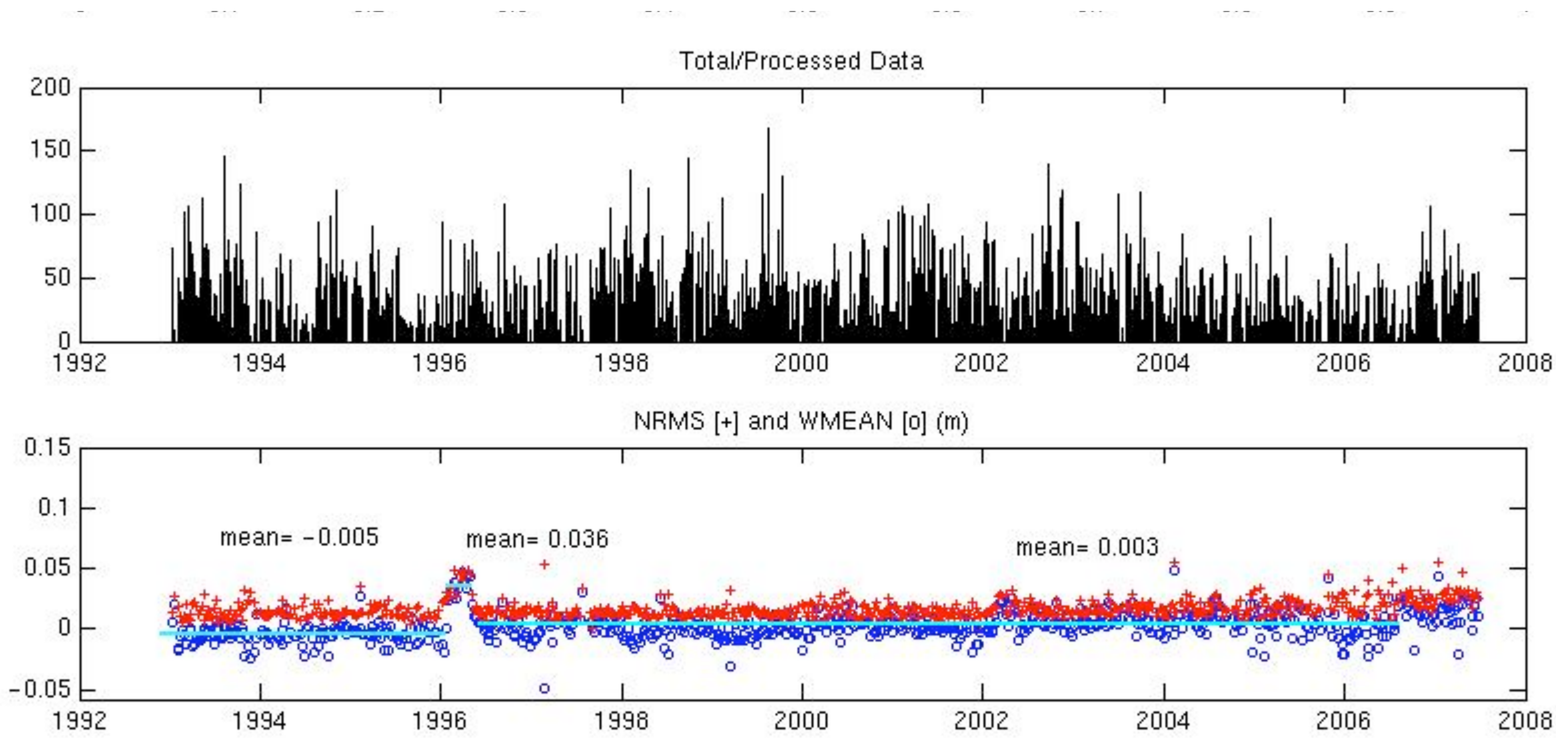


MLRS Barometer Correction Values The correct pressure can be recovered by adding the following corrections to the values recorded in the data files:

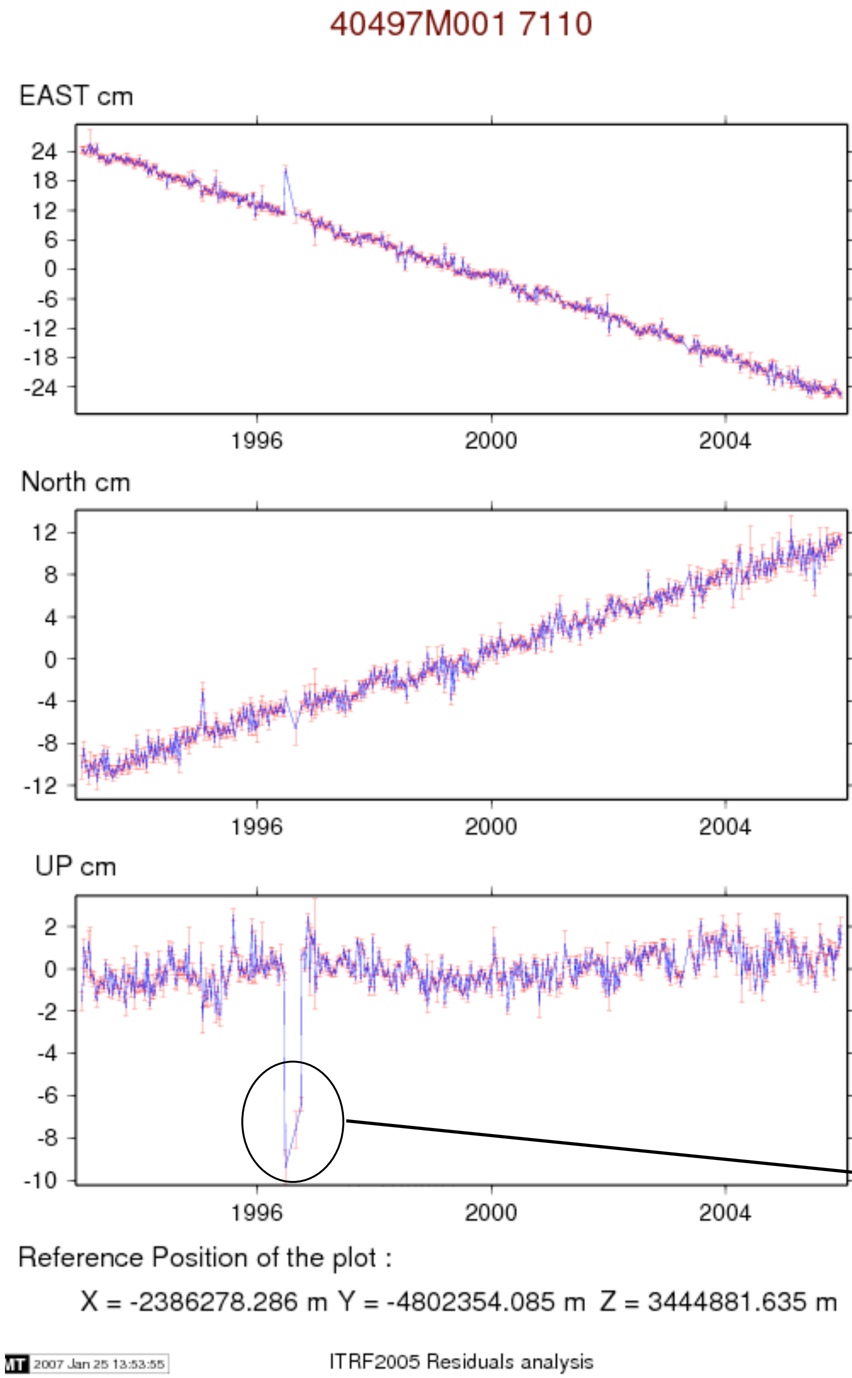
Start Date	End Date	Correction
March 6, 1995	January 25, 1996	2.1 mB
January 26, 1996	April 24, 1996	10.3 mB
April 25, 1996	May 8, 1996, 20:00	9.7 mB

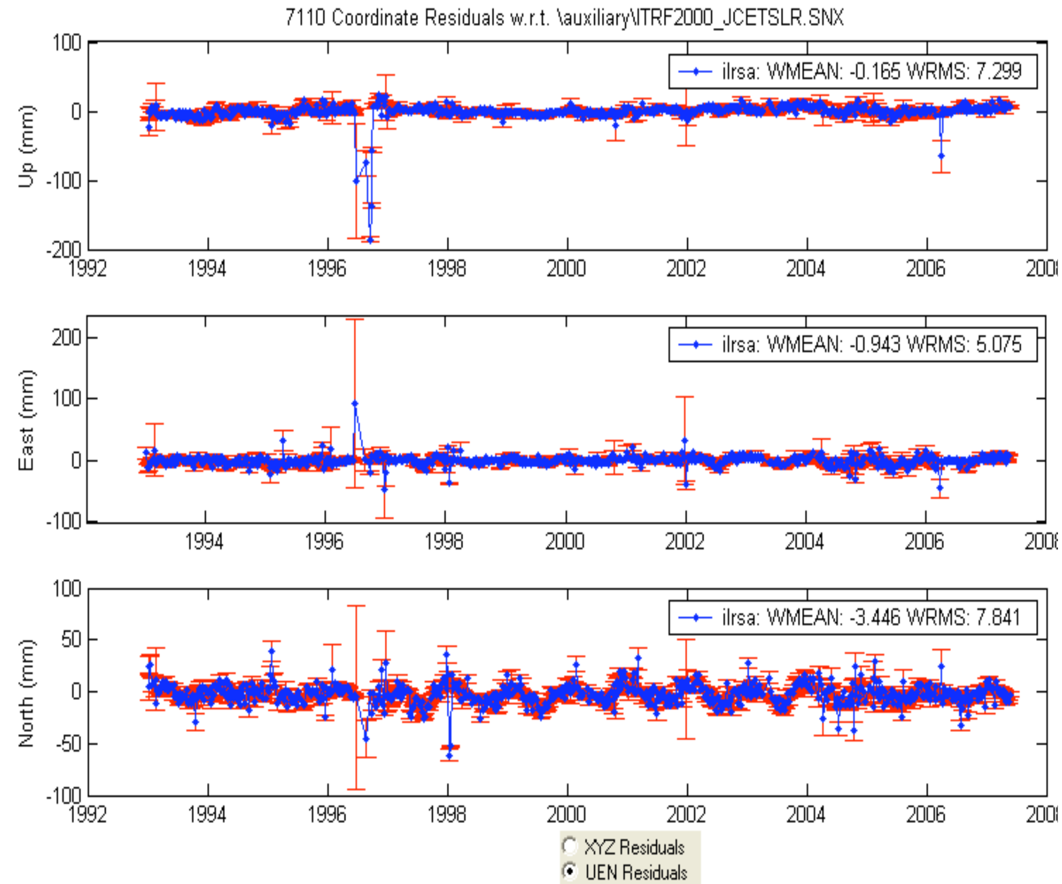
McDonald – Lageos-1

1 point every 7 days



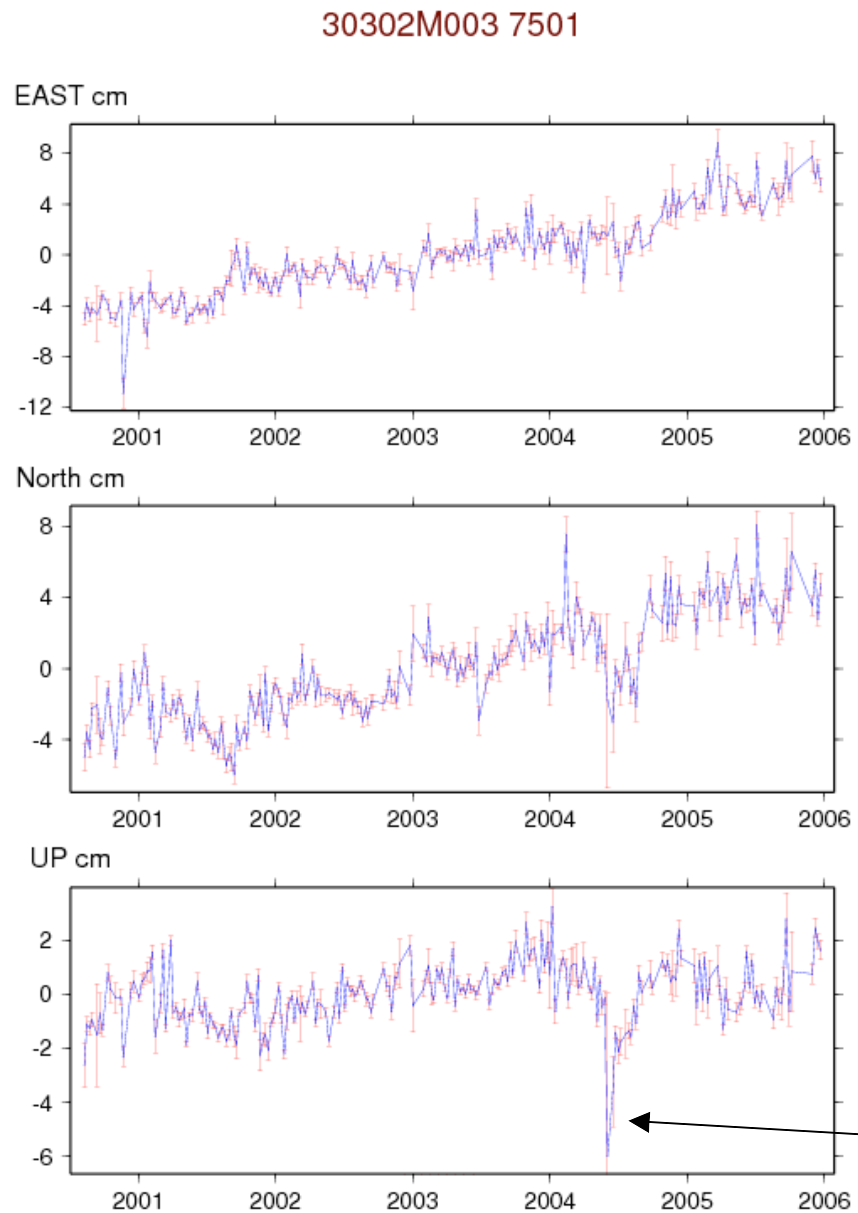
Monument peak





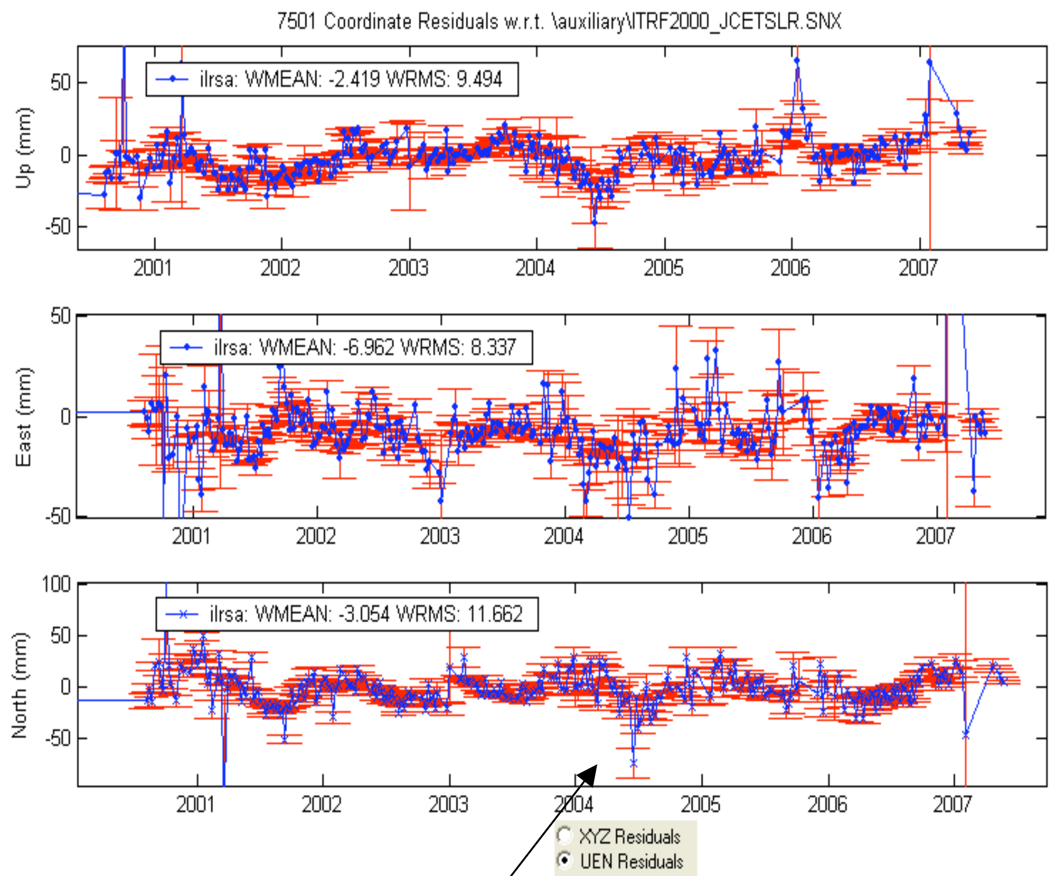
from August 27 through October 02, at 2:50 GMT, 1996 is biased by +16.36cm. To correct for this bias, users should subtract 16.36 cm from the range.

Hartebeesthoek



Reference Position of the plot :

X = 5085401.105 m Y = 2668330.193 m Z = -2768688.774 m



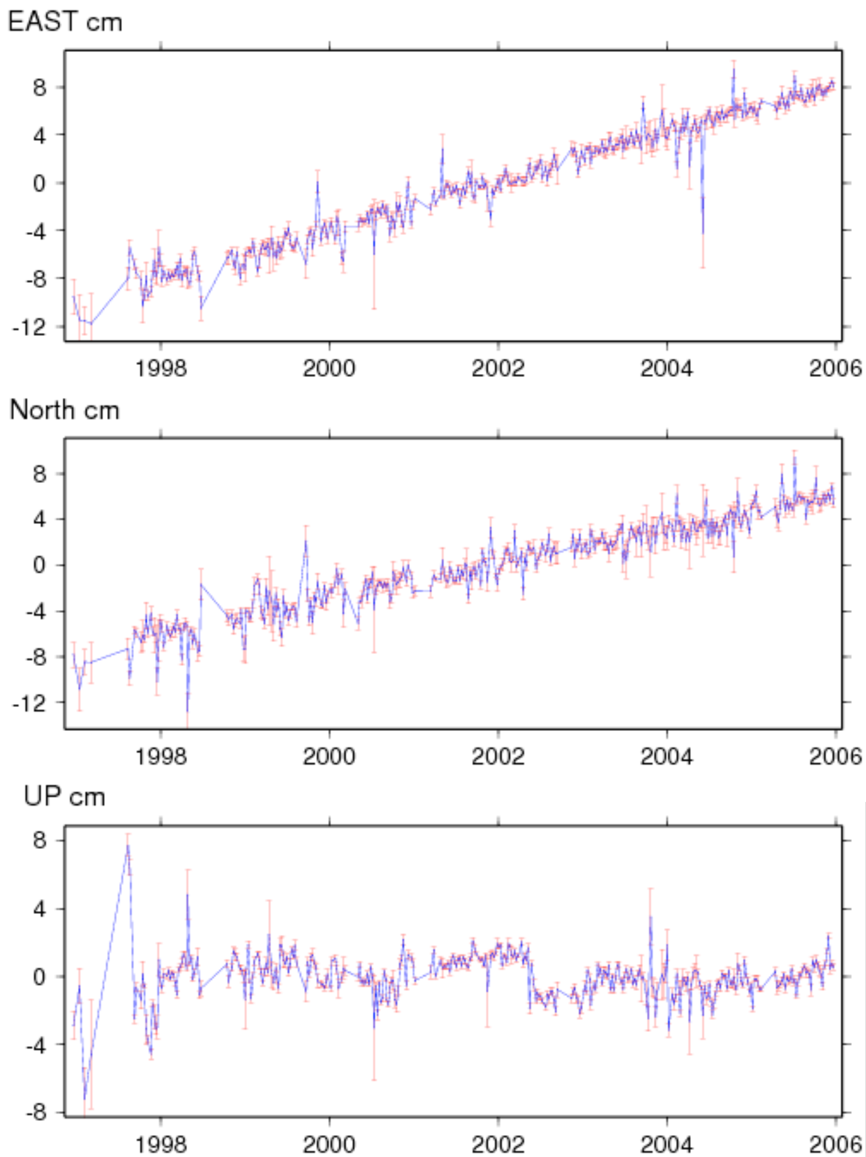
No Lageos-1 data from june to october 2004

2007 Jan 25 13:53:50

ITRF2005 Residuals analysis

Zimmerwald

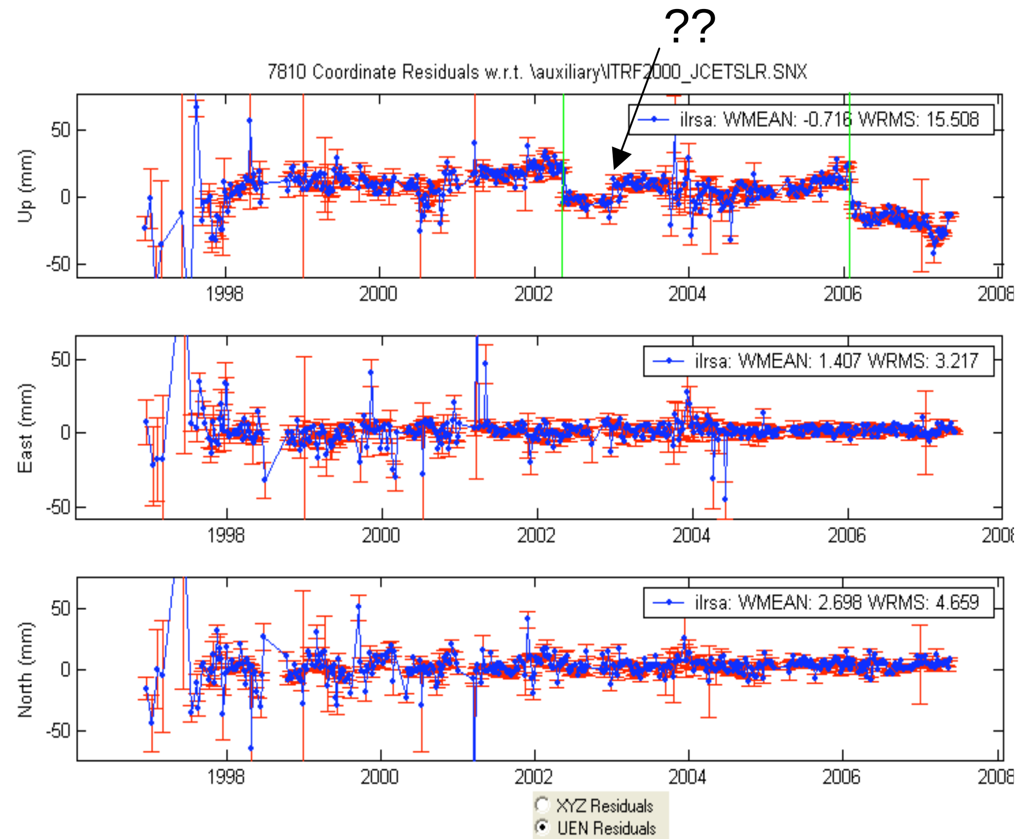
14001S007 7810



Reference Position of the plot :

X = 4331283.615 m Y = 567549.835 m Z = 4633140.324 m

GMT 2007 Jan 25 13:53:37 ITRF2005 Residuals analysis



Start Date	End Date	Correction
July 9, 1997	July 17, 1997	All ranges are too long by 0.45 ns (68 mm 1-way)
July 30, 1997	Sept 30, 1997	All ranges are too short by 0.43 ns (64 mm 1-way)
january 1998	May 29, 2002	All ranges are too short by 0.12 ns (18 mm 1-way)
January 1997	Feb 6, 2006	50 ps too long for 423 (blue) 100 ps too short for 846 (infrared)
LAGEOS time bias for pass 97-08-15 23:18:57 23:24:47 microsec 68.0		

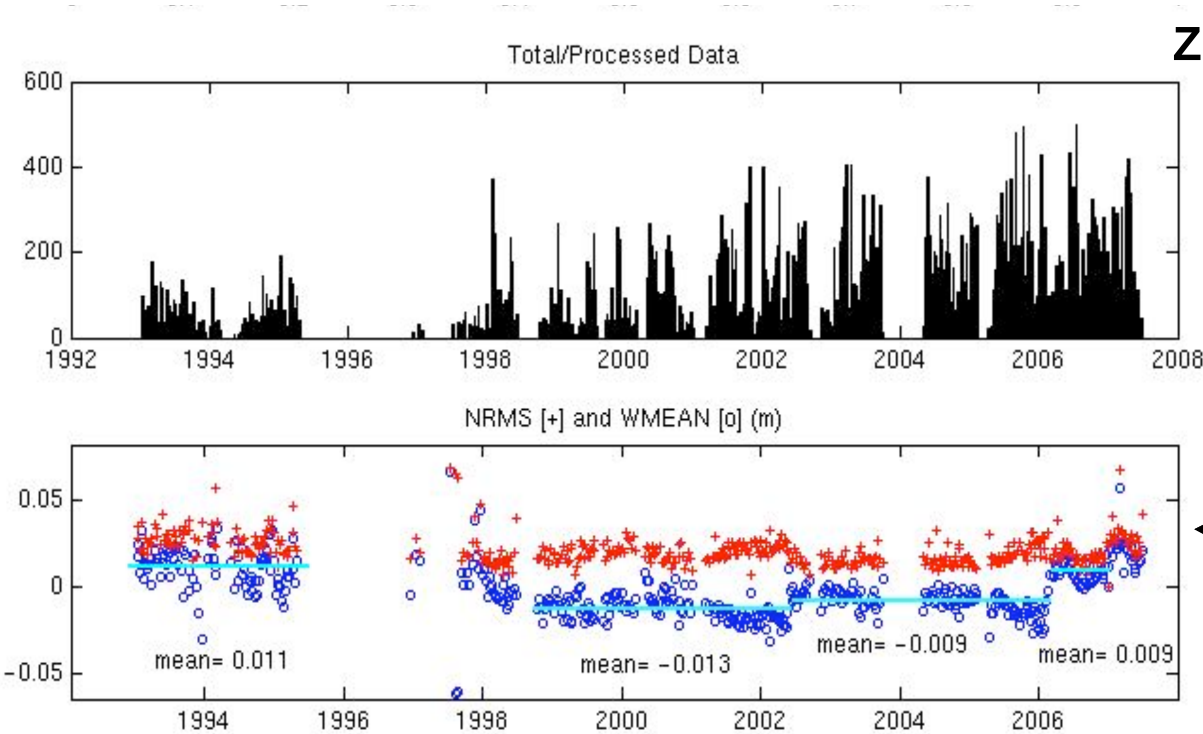
Zimmerwald Range Biases from Zimmerwald web page

Date	Events, might of might not generate a change in the range biases
01 Jan 1997	ZIMLAT: Start of Operation
09 Jul 1997	Begin identified range bias
17 Jul 1997	End range bias
30 Jul 1997	Begin identified range bias
03 Sep 1997	End range bias
01 Jan 1998	Begin identified range bias
29 May 2002 00:00	End range bias
29 May 2002 00:00	Start applying Stanford counter corrections
11 Mar 2003 10:00	Blue: Start using CSPAD
28 Dec 2004 12:00	Blue: Swapped counters: 0236-->3113
28 Dec 2004 12:00	Infrared: Swapped counters: 3113-->0236
03 Feb 2006 15:00	Blue: Riga Event timer replaces Stanford
03 Feb 2006 15:00	Infrared: Applying new Stanford counter corrections
22 Mar 2006 12:00	Infrared: Riga Event timer replaces Stanford
21 Jun 2006 09:10	Blue and IR: Switched to external calibration
06 Mar 2007 17:00	Blue: Temporarily using PM again

Observations between 09 July 1997 and 17 July 1997: All ranges are too long by 0.45 ns = 68 mm
Observations between 30 July 1997 and 03 Sept 1997: All ranges are too short by 0.43 ns = 64 mm
Observations between January 1998 and 29 May 2002, 00:00 UT: All ranges are too short by 0.12 ns = 18 mm.
After february 6, 2006 423 nm: Lageos 1/2 flight times will become shorter by about 50 ps
846 nm: Lageos 1/2 flight times will become longer by about 100 ps

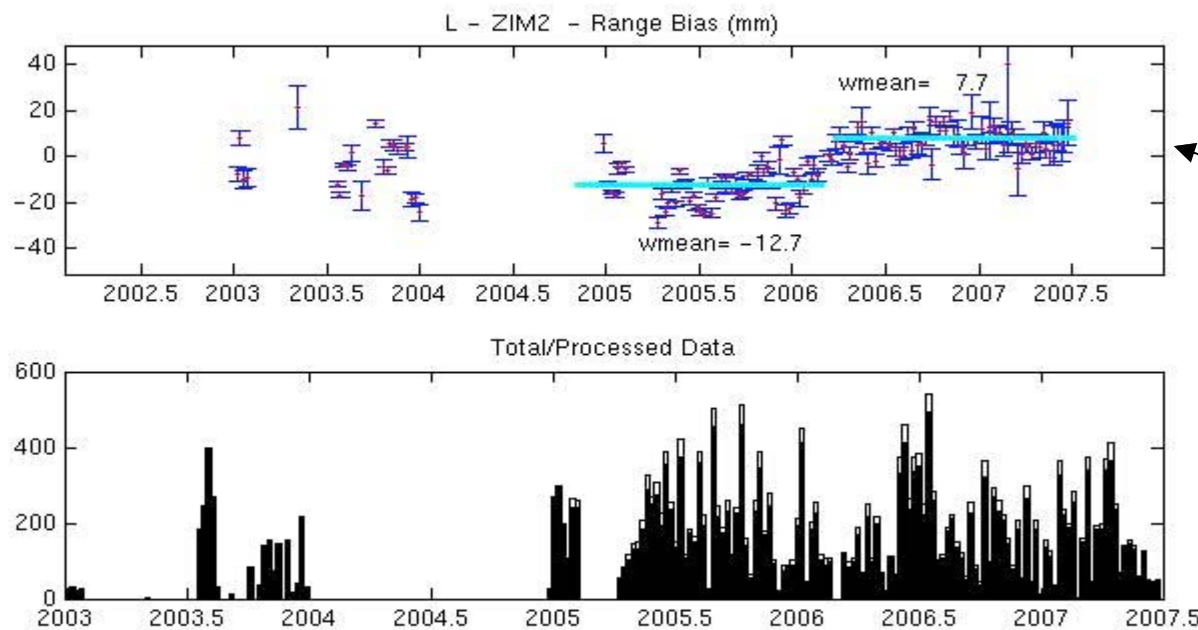
Zimmerwald Lageos-1

1 point every 7 days



Blue, no bias estimated

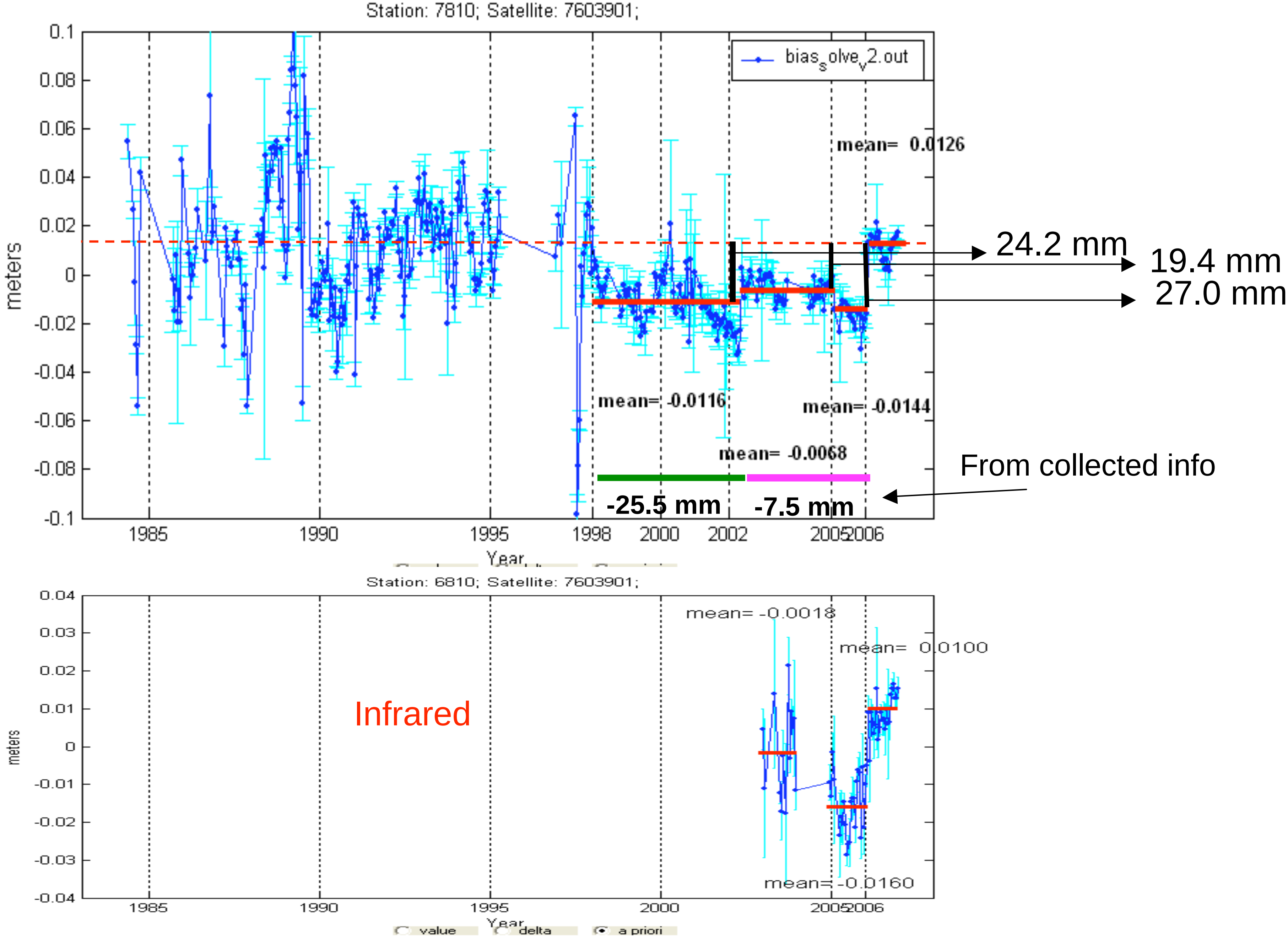
Mean of residuals



Infrared, bias estimated

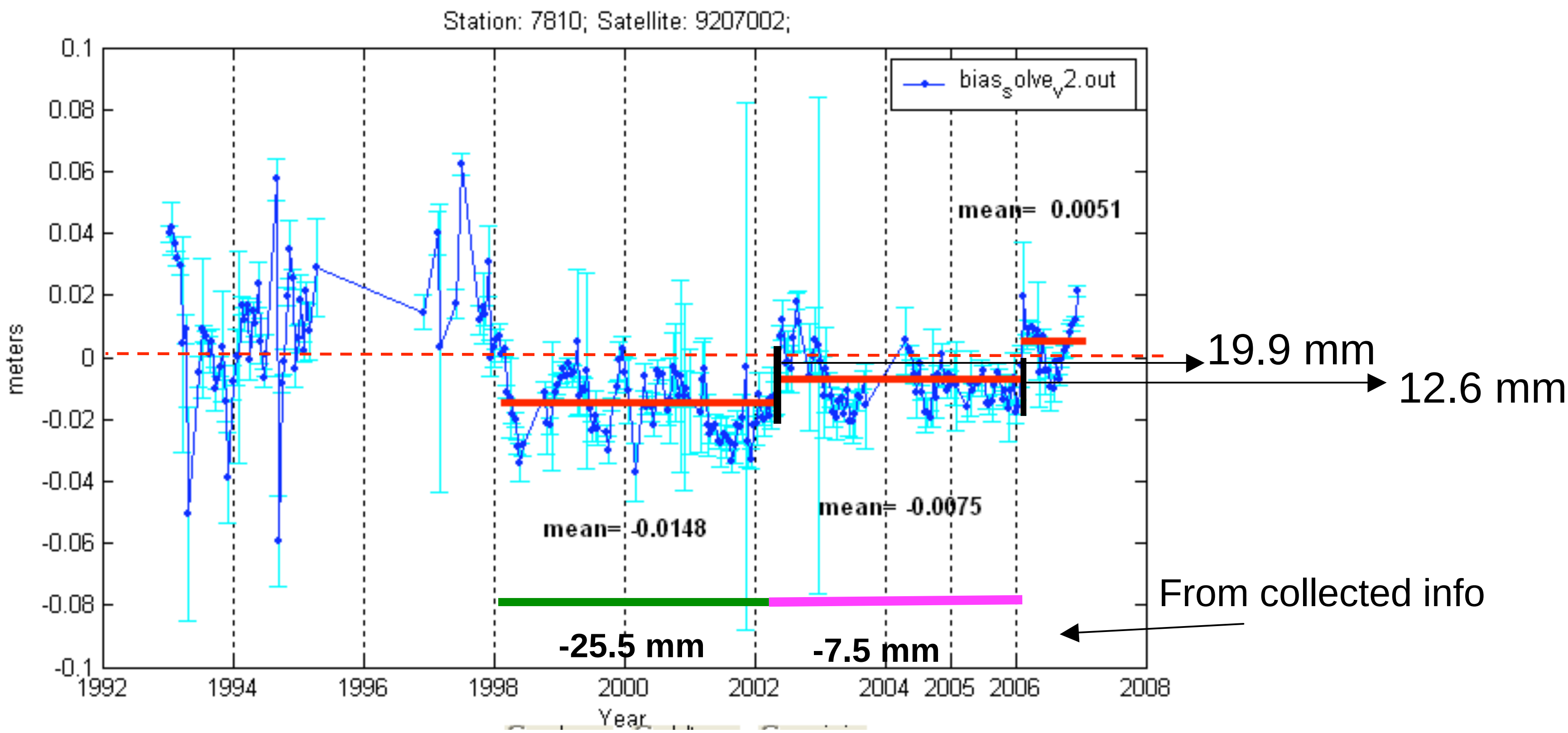
Zimmerwald: Lageos-1 range residuals from solution ASI06

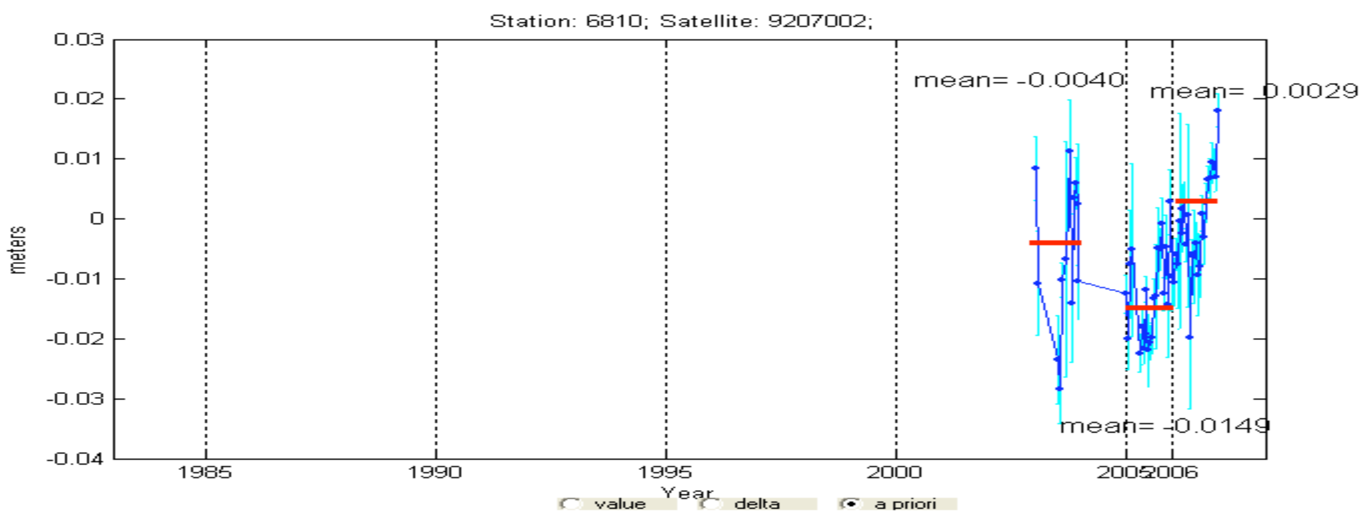
1 point every 15 days



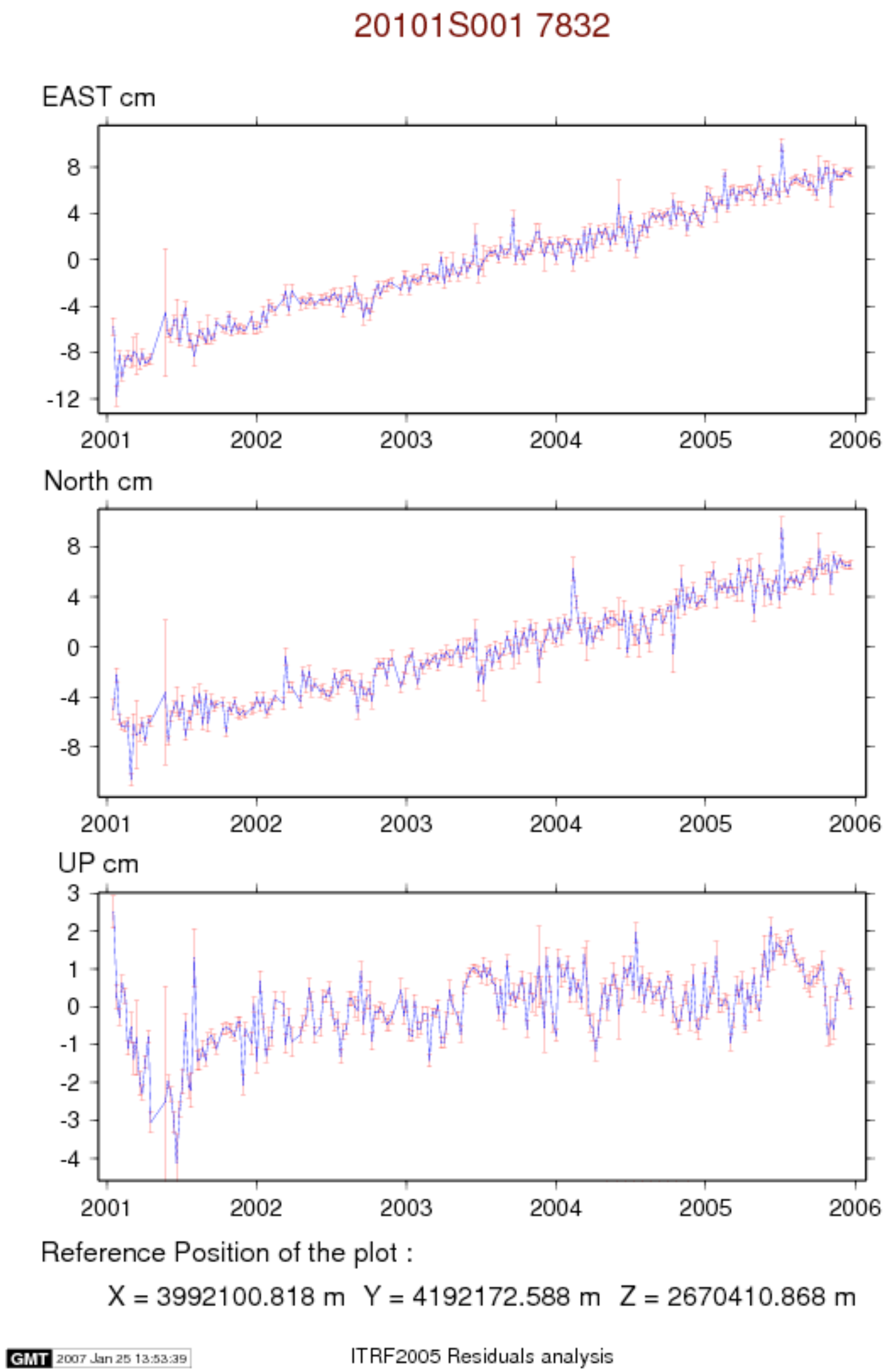
Zimmerwald: Lageos-2 range residuals from solution ASI06

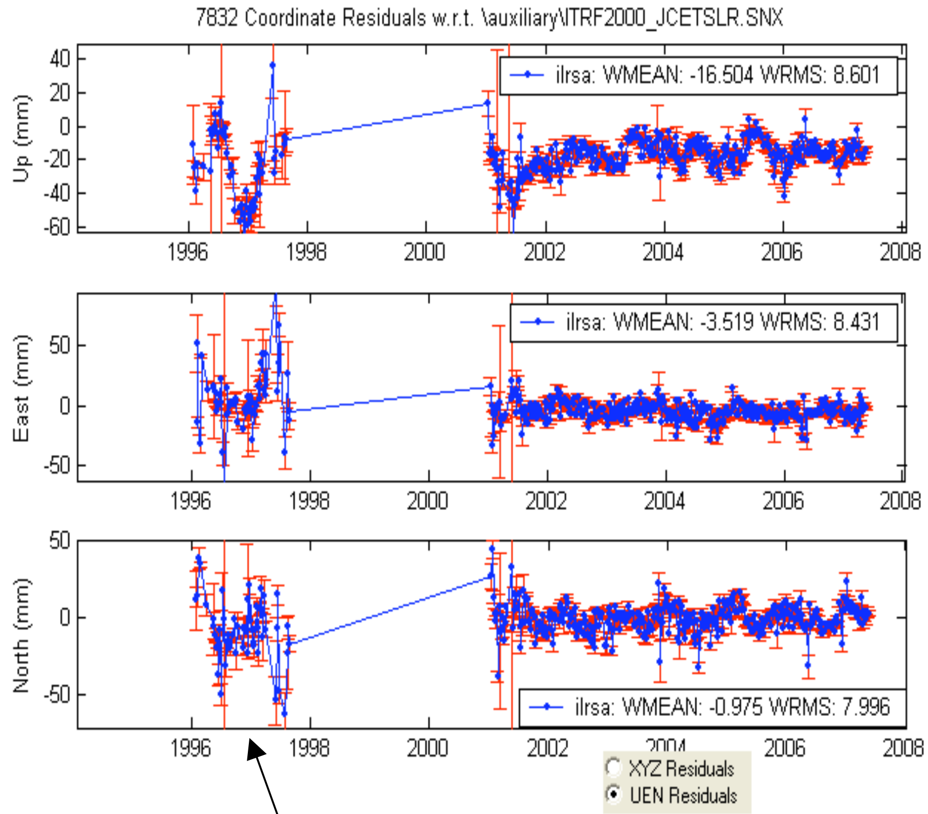
1 point every 15 days





Riyadh

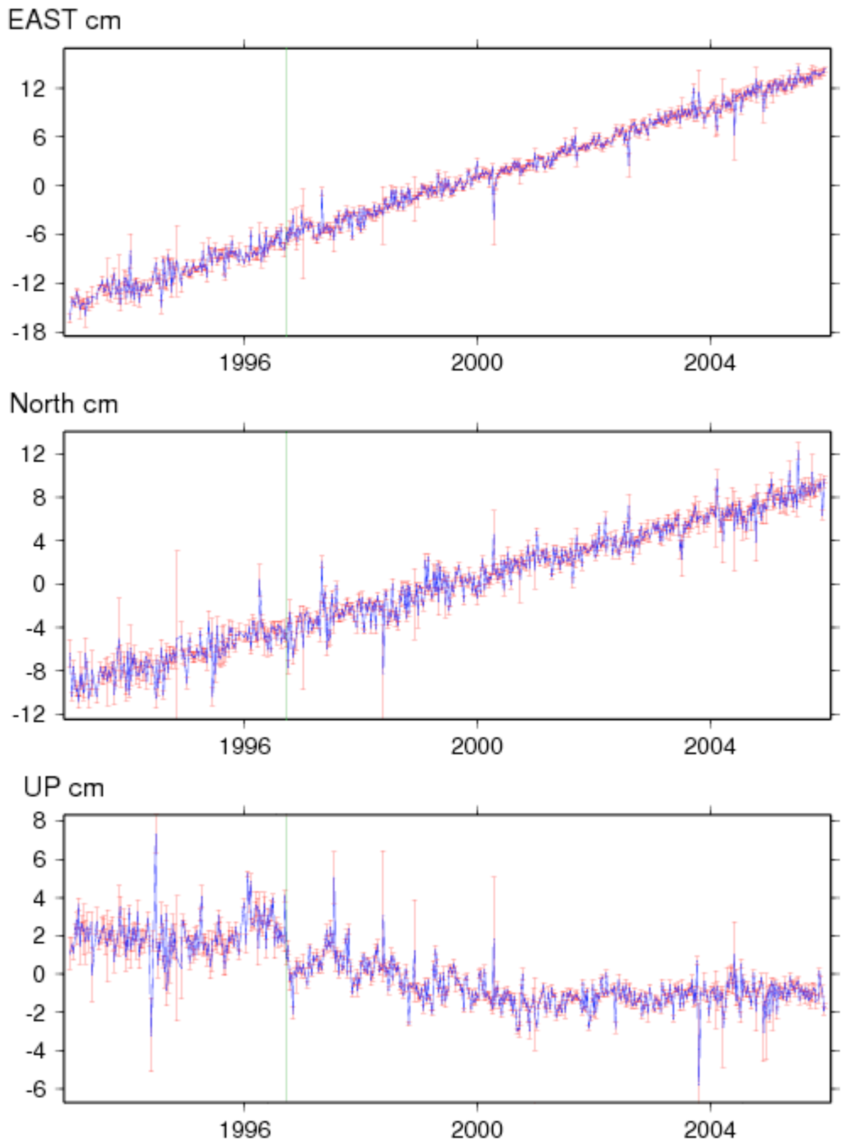




Data not included in ITRF2005.
To be edited in the re-analysis?

GRAZ

11001S002 7839

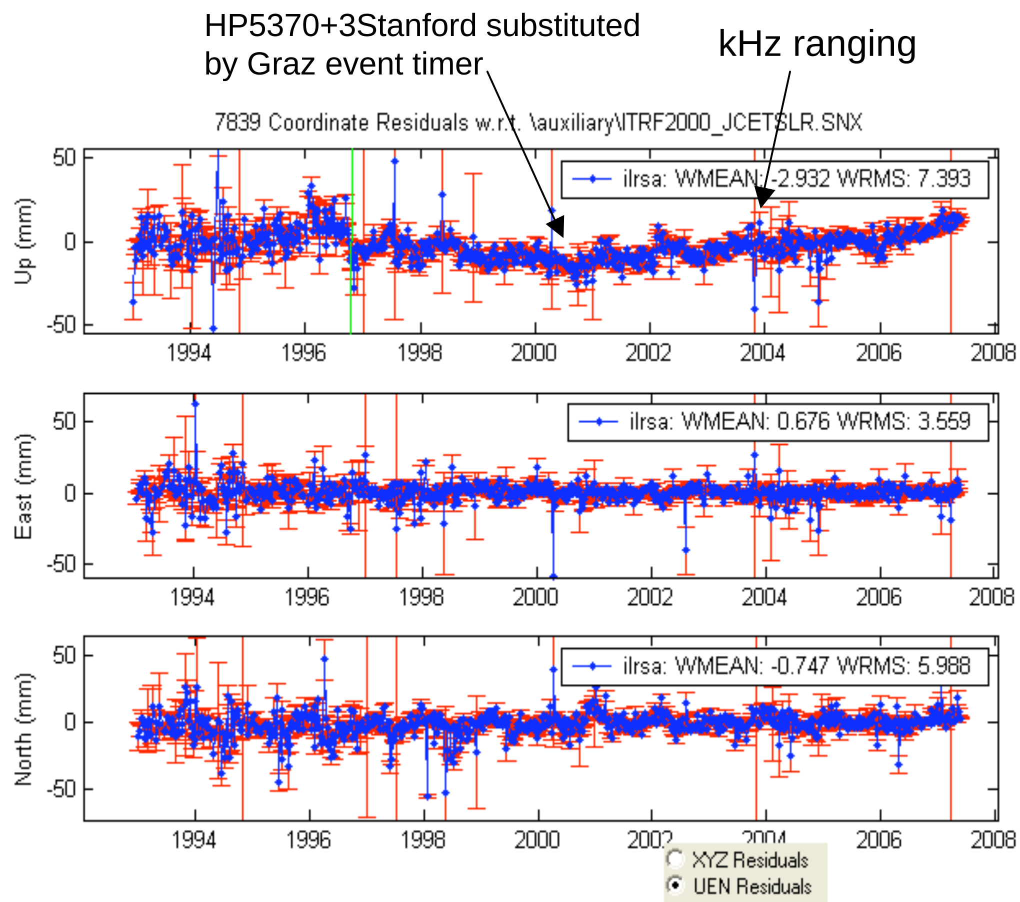


Reference Position of the plot :

X = 4194426.472 m Y = 1162694.080 m Z = 4647246.671 m

GMT 2007 Jan 25 13:53:26

ITRF2005 Residuals analysis



SLRMail 0013: new calibration from april 17, 1996 and no bias to be applied.
Jump probably due to the estimation of the bias until the end of 1996

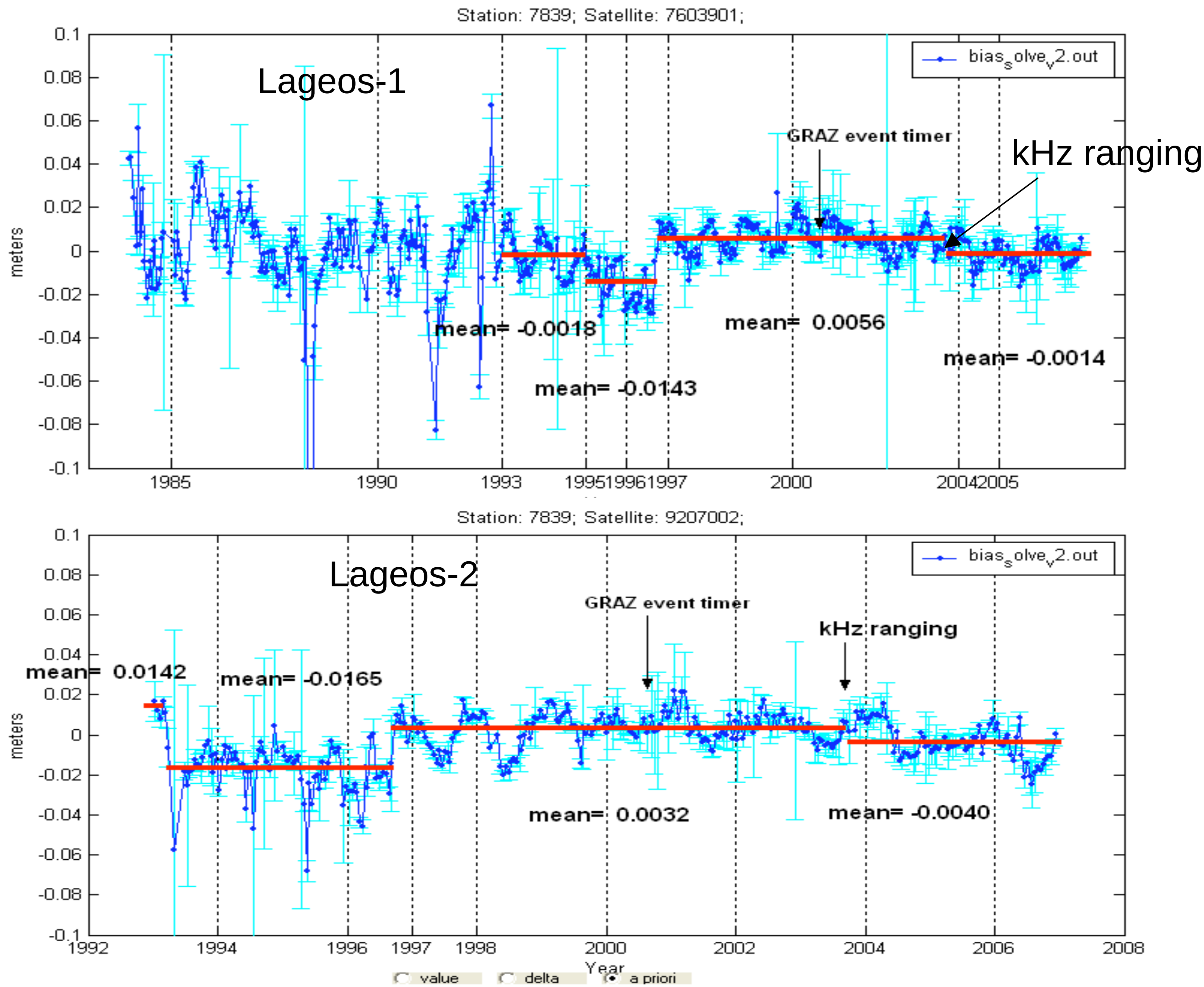
GRAZ

78393402	5	1995289	HP5370A: Trigger Thresholds from 0.25/0.21 to 0.25/0.17 V
78393402	6	1996025	HP5370A+2xSR620 now measure parallel; not yet in results
78393402	7	1996030	All 3 Counter Results now fully used
78393402	1	1996254	Counter #4 (SR620) added for parallel measurements
78393402	5	1996271	Time Walk Compensation: New Adjustment
78393402	6	1996296	3 Counters only; last SR620 removed
78393402	8	1996351	4 Counters again: HP5370A + 3 x SR620
78393402	1	1997030	UTC(TUG) supplies 1 pps, 10 MHz again
78393402	2	1997034	SR620/#1 now as reference counter (instead of HP5370A)
78393402	8	1997114	SR620#3 removed; HP5370A+2xSR620 remain
78393402	9	1997126	SR620#3 added again; Now: HP5370A+3xSR620
78393402	0	2000213	HP5370A + all 3 SR620's replaced by Graz Event Timer

October 9, 2003 kHz ranging

Graz: residuals from solution ASI06

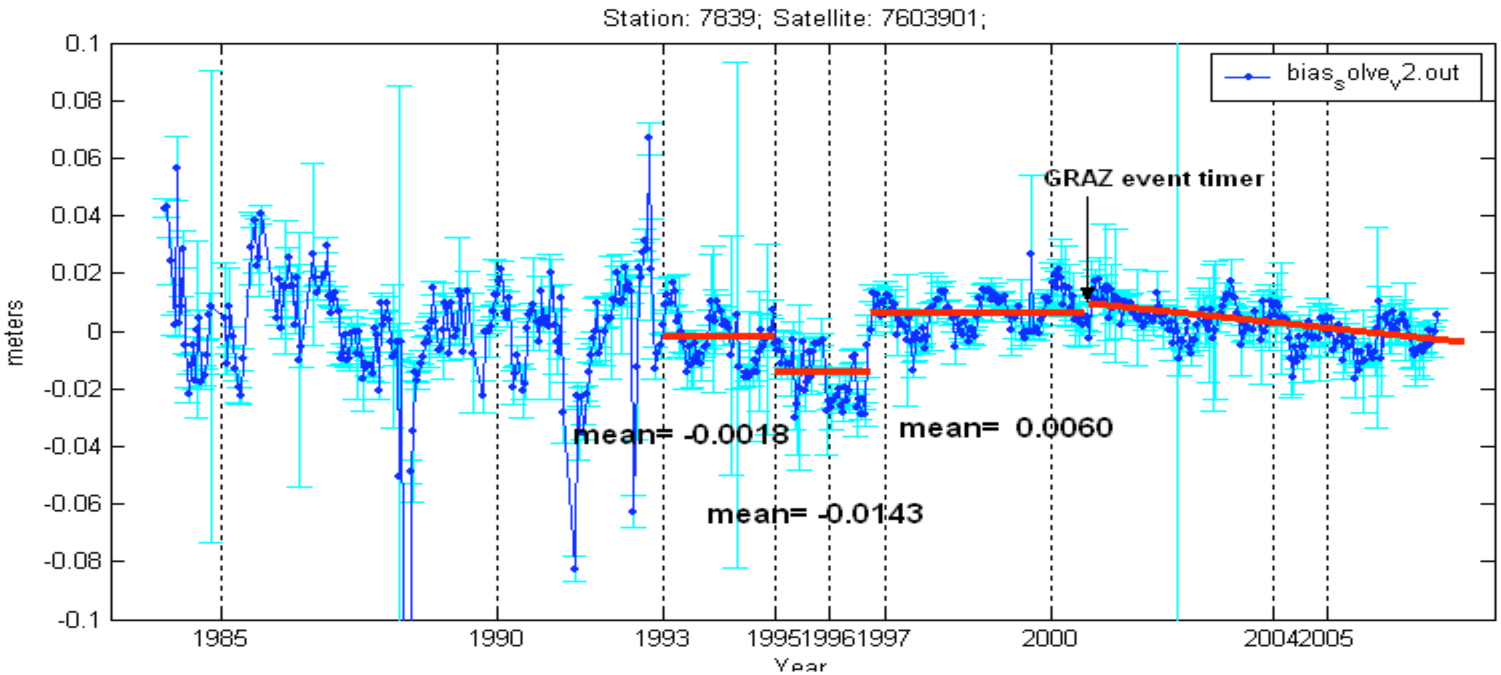
1 point every 15 days

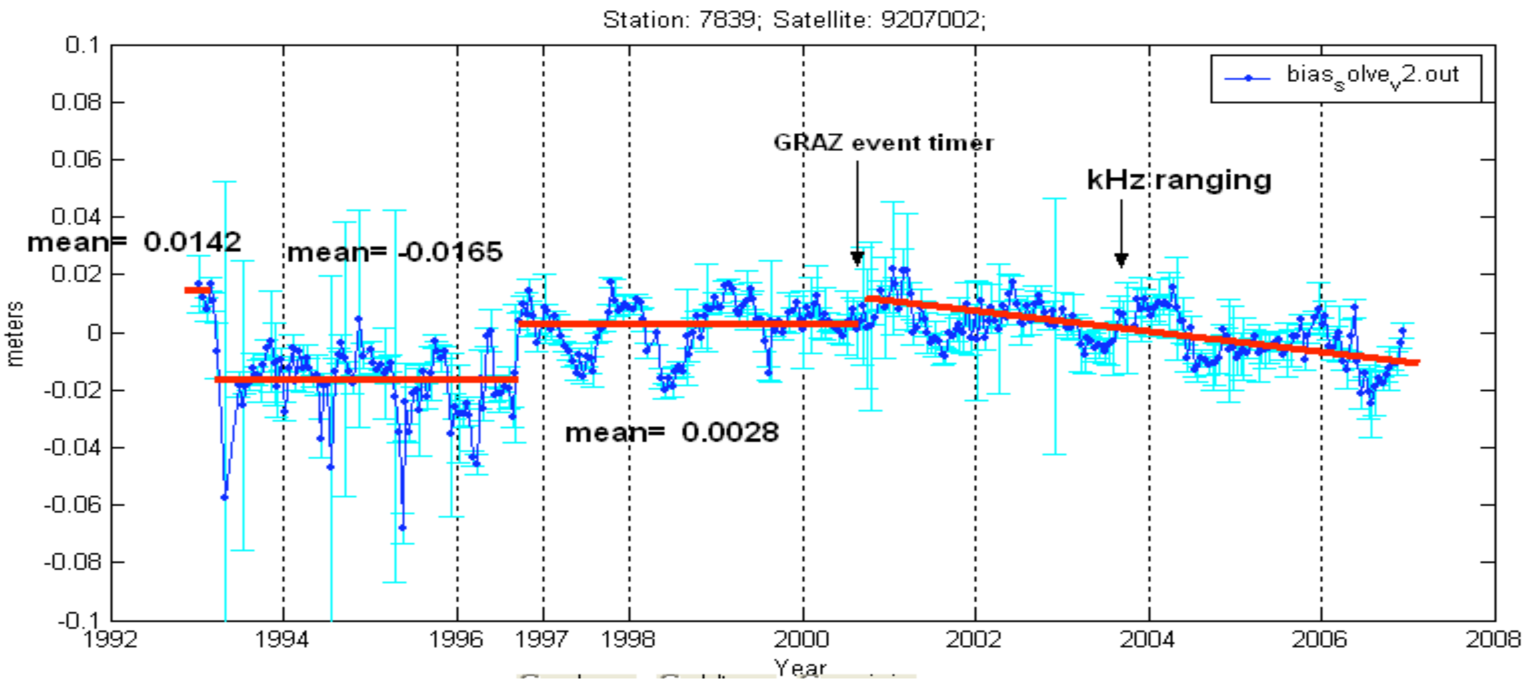


Graz: range residuals from solution ASI06

1 point every 15 days

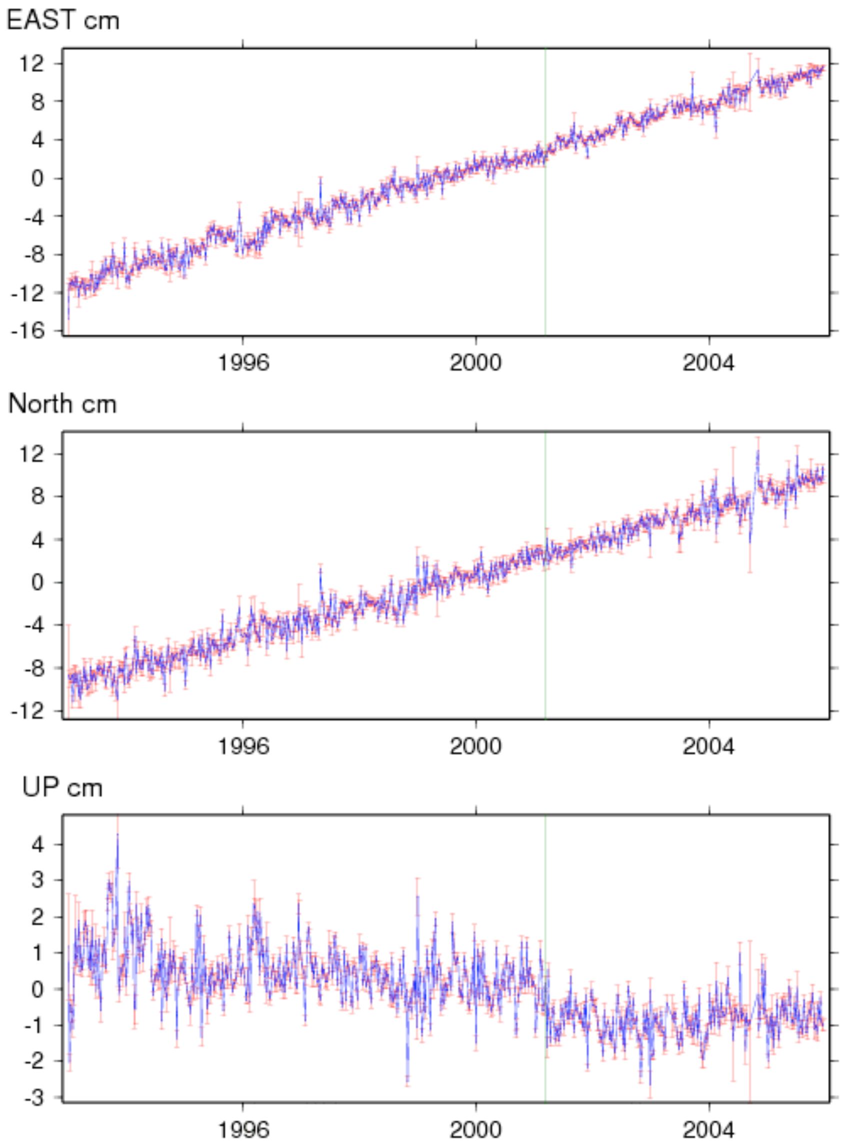
Event timer drift?

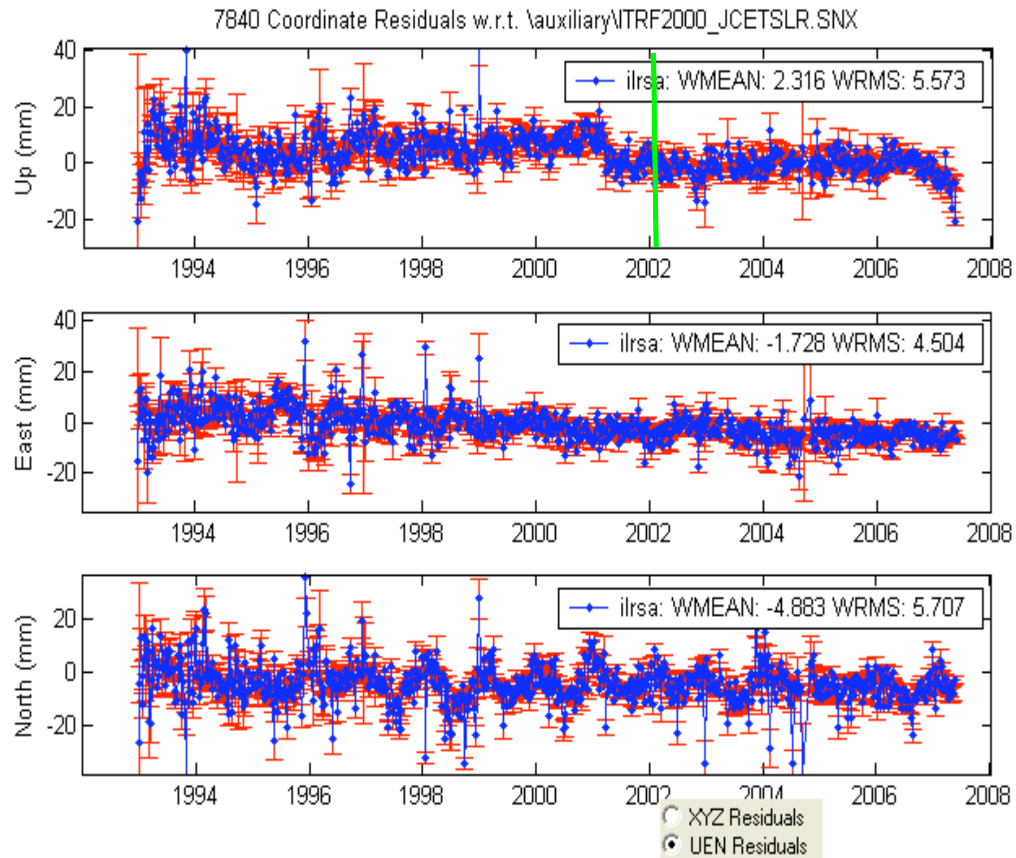




13212S001 7840

Herstmonceux





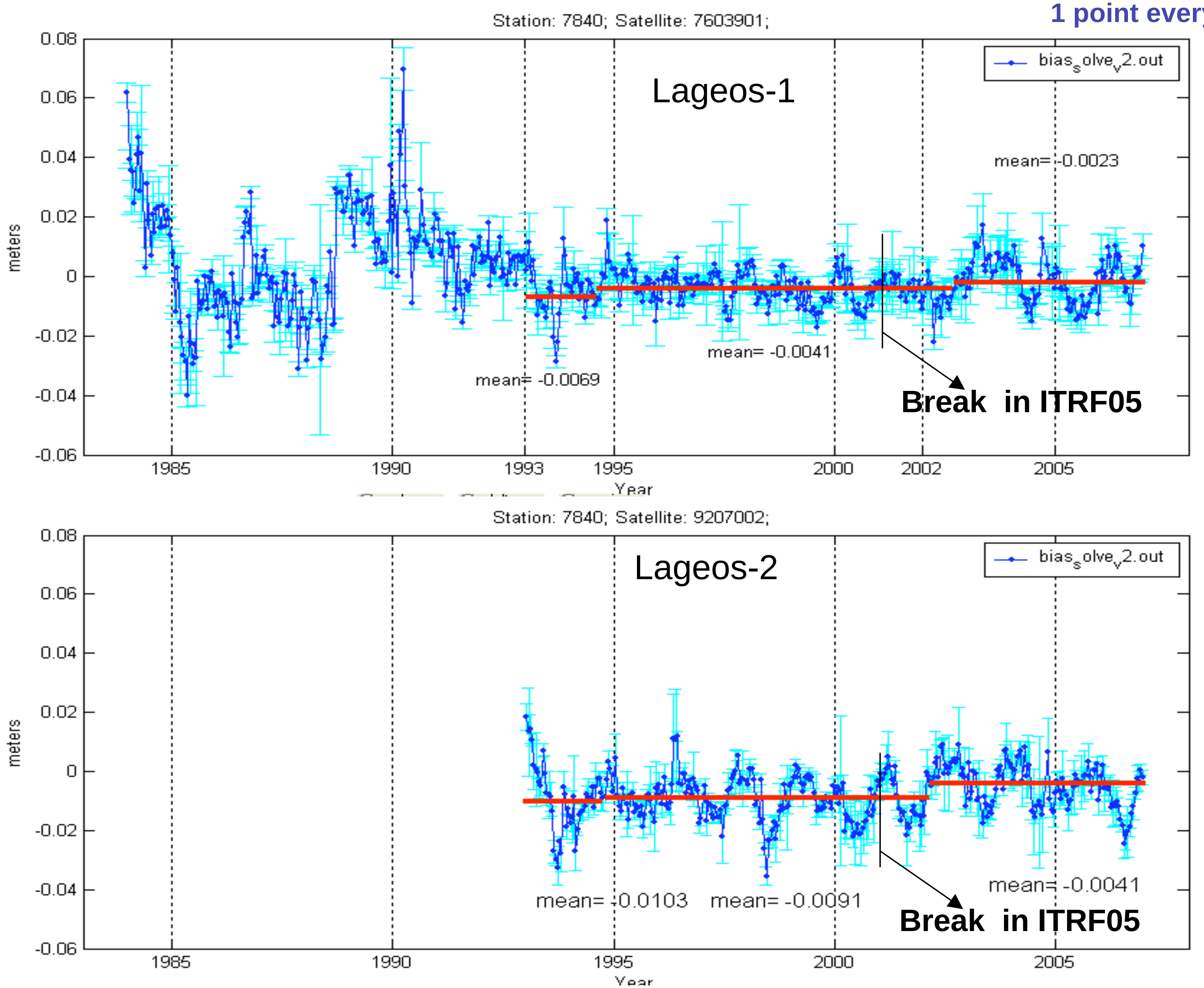
Start Date	End Date	Correction
october 1, 1994	february 1, 2002	-1.5 mm (-10 +8.5 mm)
february 1, 2002	february 10, 2007	8.5 mm

Reference Position of the plot :

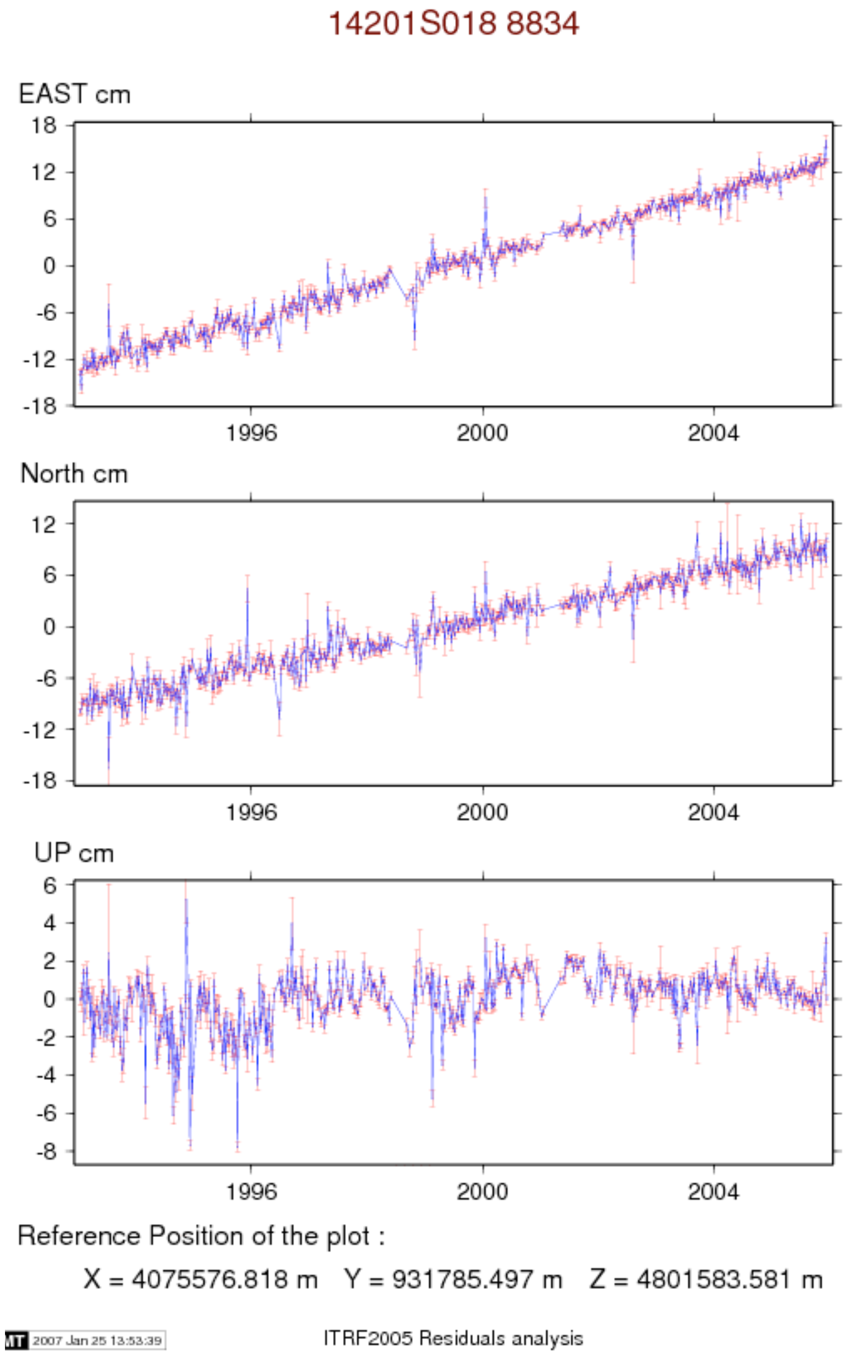
X = 4033463.690 m   Y = 23662.520 m   Z = 4924305.198 m

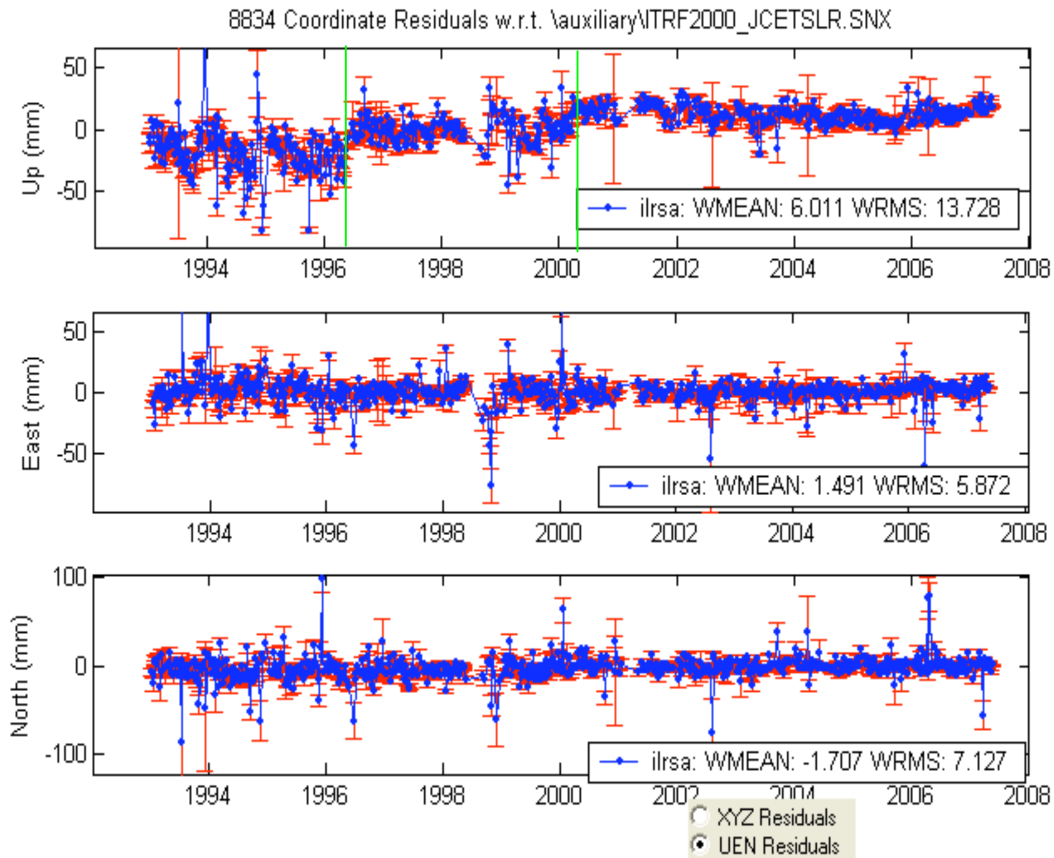
Herstmonceux: range residuals from solution ASI06

1 point every 15 days



Wettzell

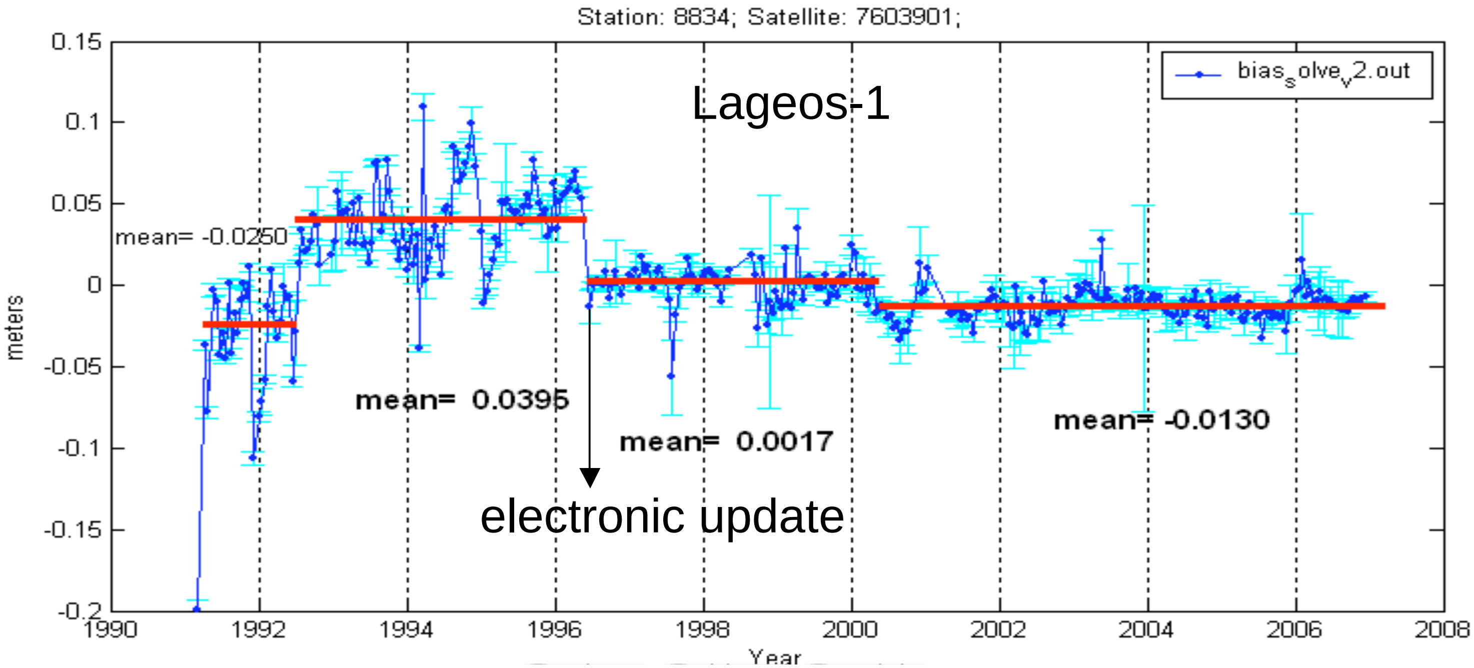


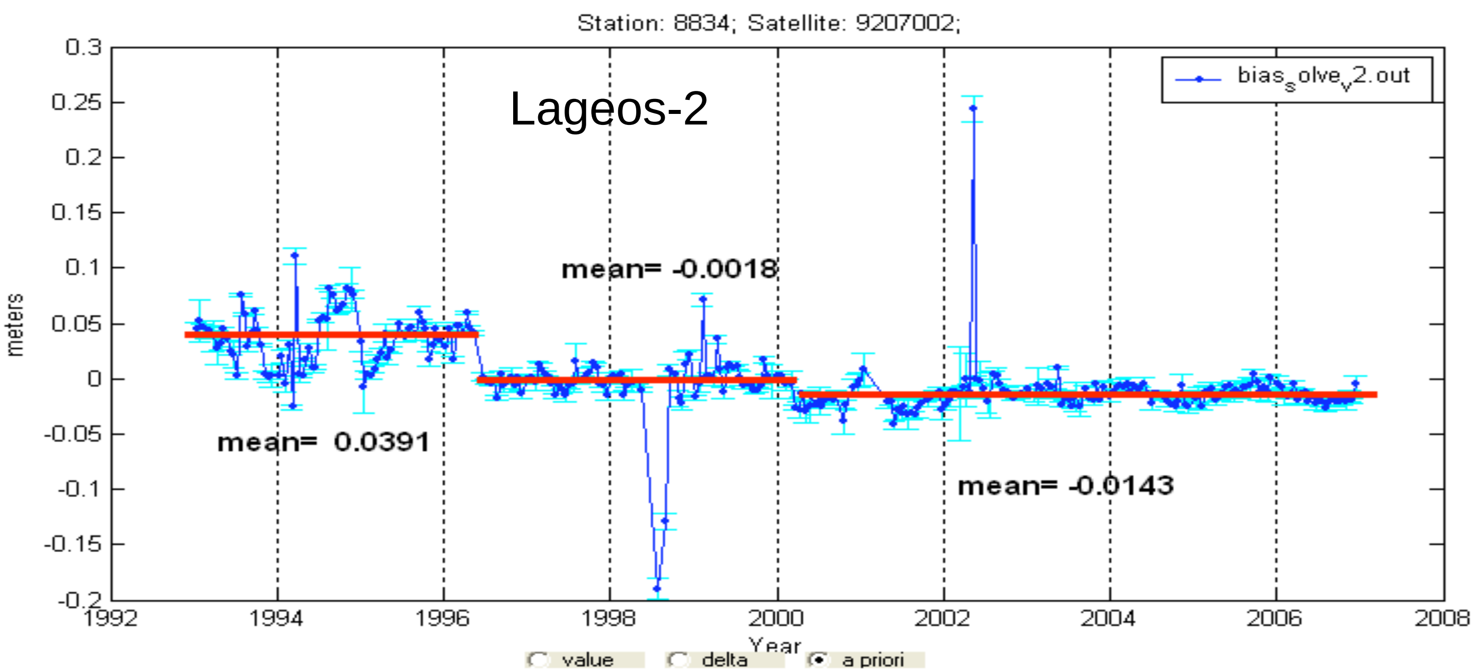


Jump probably due to the estimation of the bias until the end of 1996

Wettzell: range residuals from solution ASI06

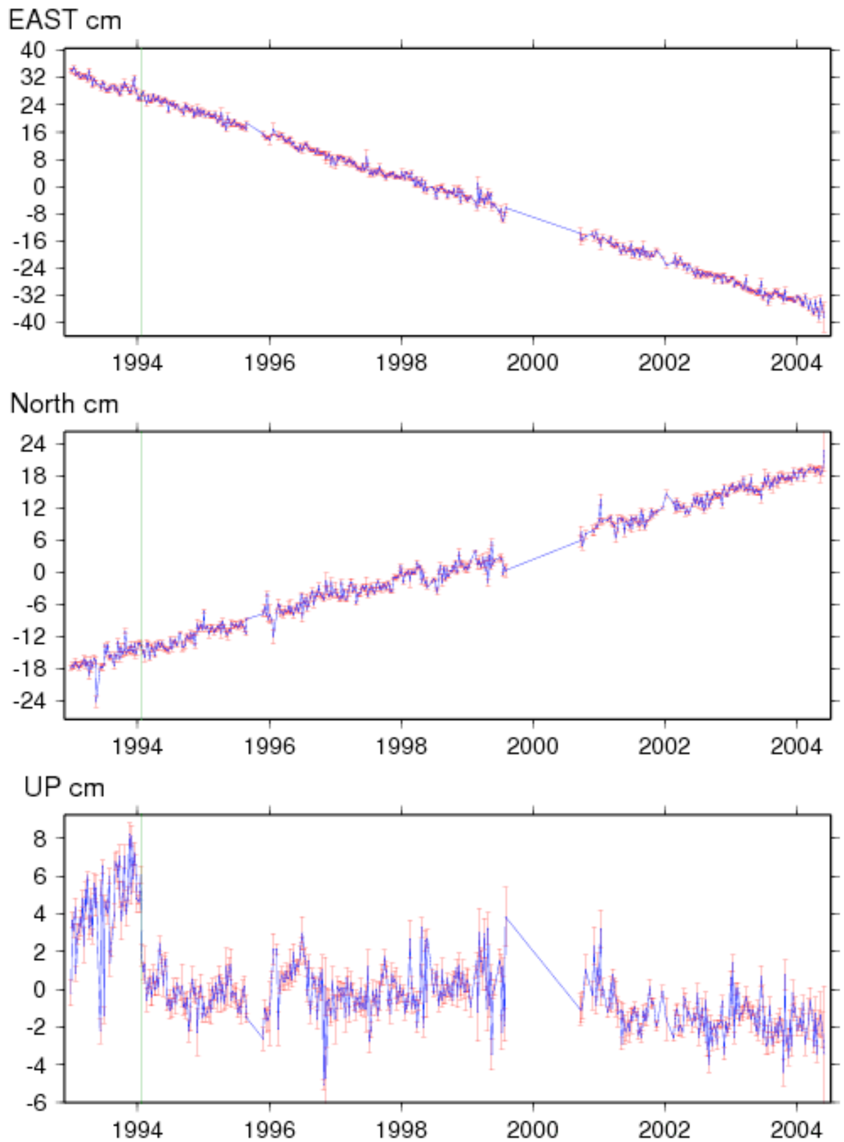
1 point every 15 days





40445M001 7210

Haleakala

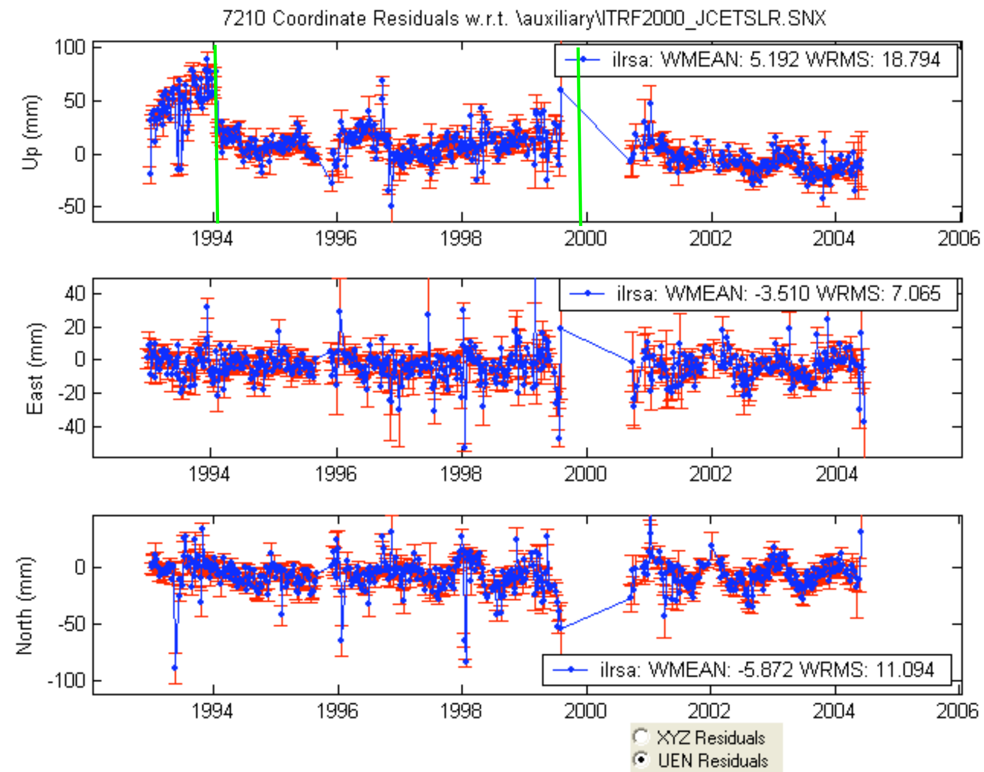


Reference Position of the plot :

X = -5466006.635 m Y = -2404427.332 m Z = 2242187.803 m

GMT 2007 Jan 25 13:53:53

ITRF2005 Residuals analysis

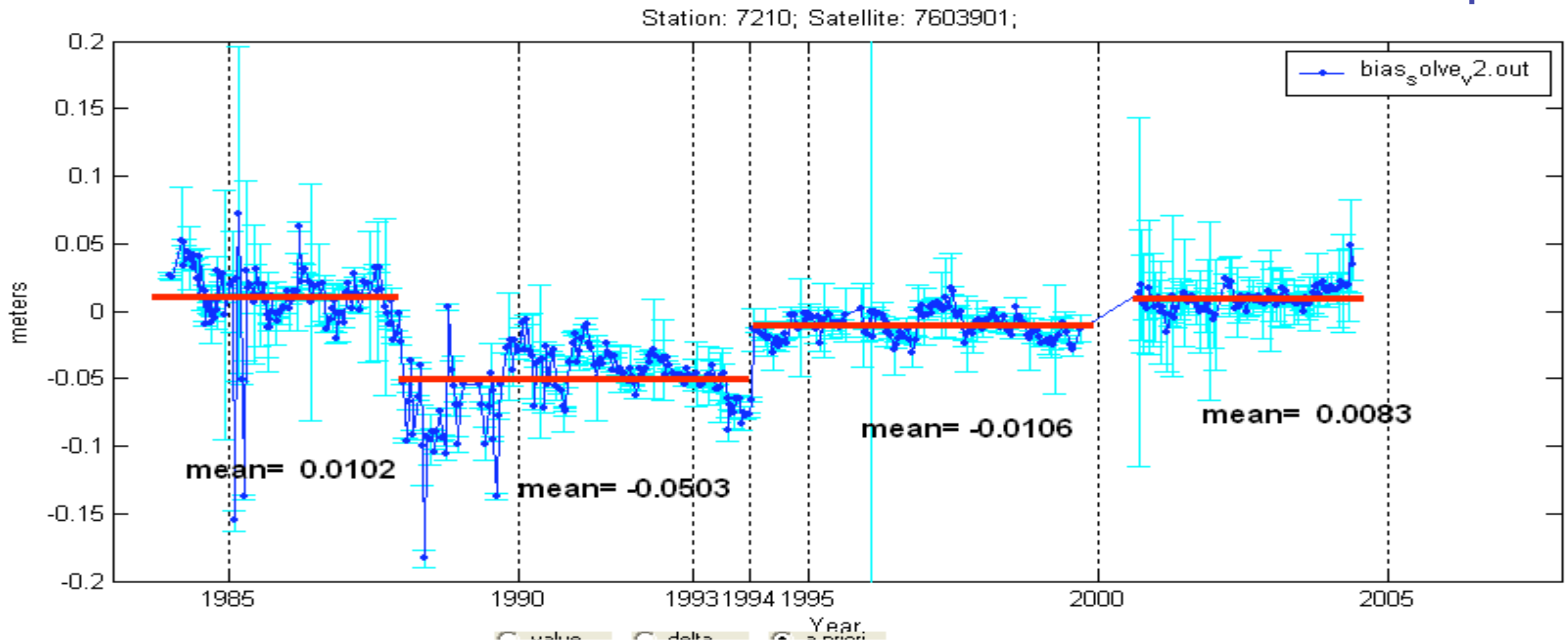


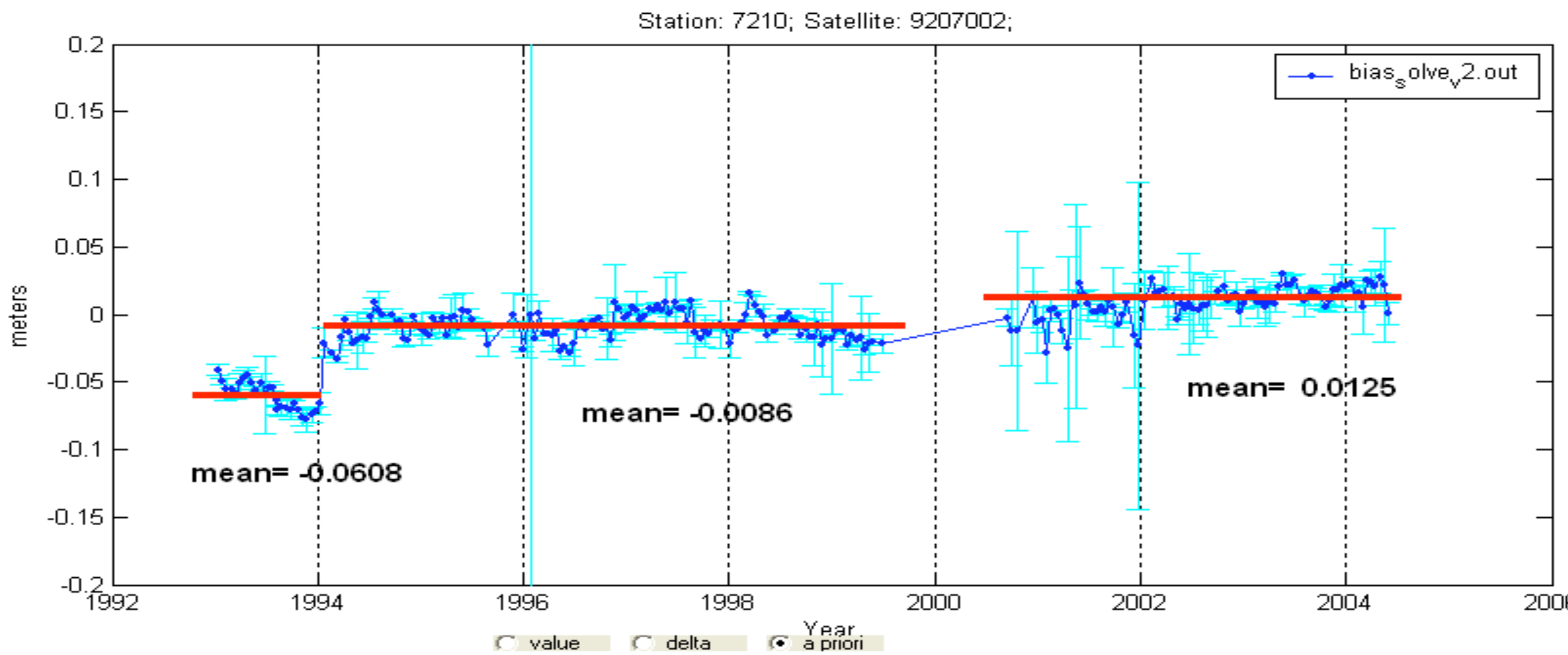
1994:021 HP5370A FREQUENCY INPUT SWITCHED TO EXTERNAL

1999:233 True Time GPS steered rubidium

Haleakala: range residuals from solution ASI06

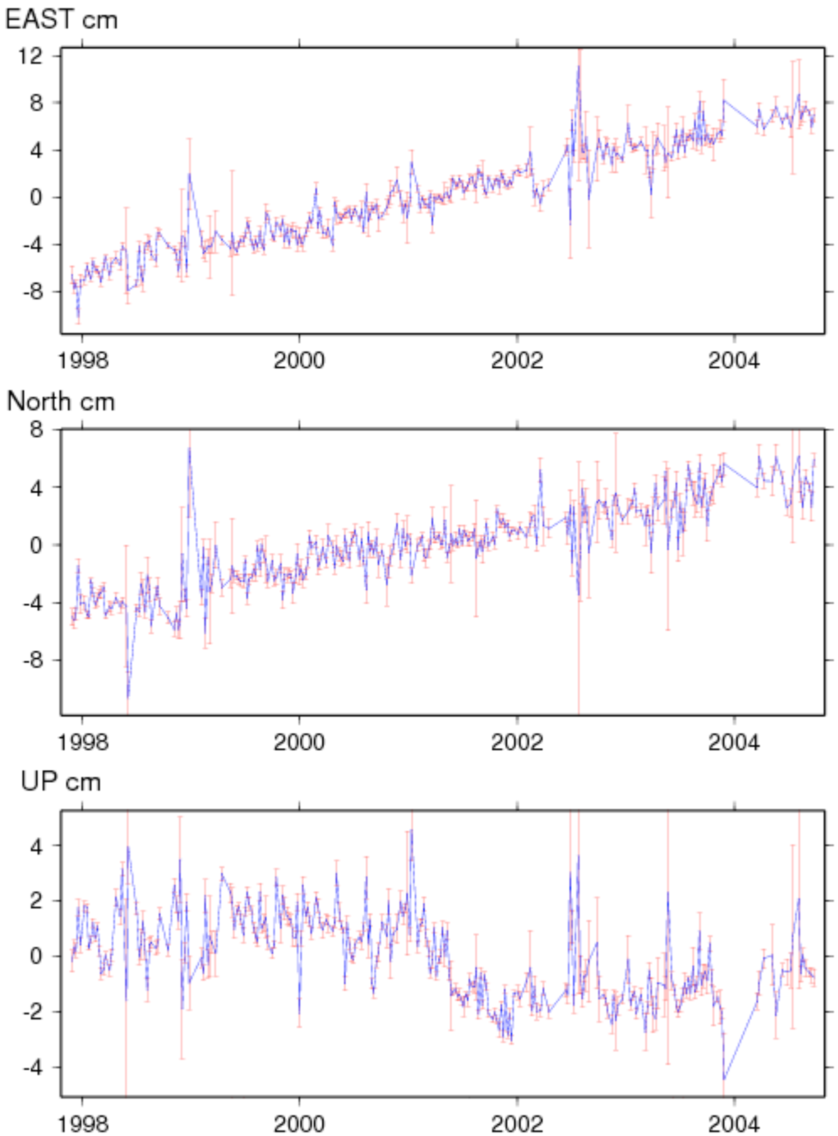
1 point every 15 days





Grasse

10002S002 7845



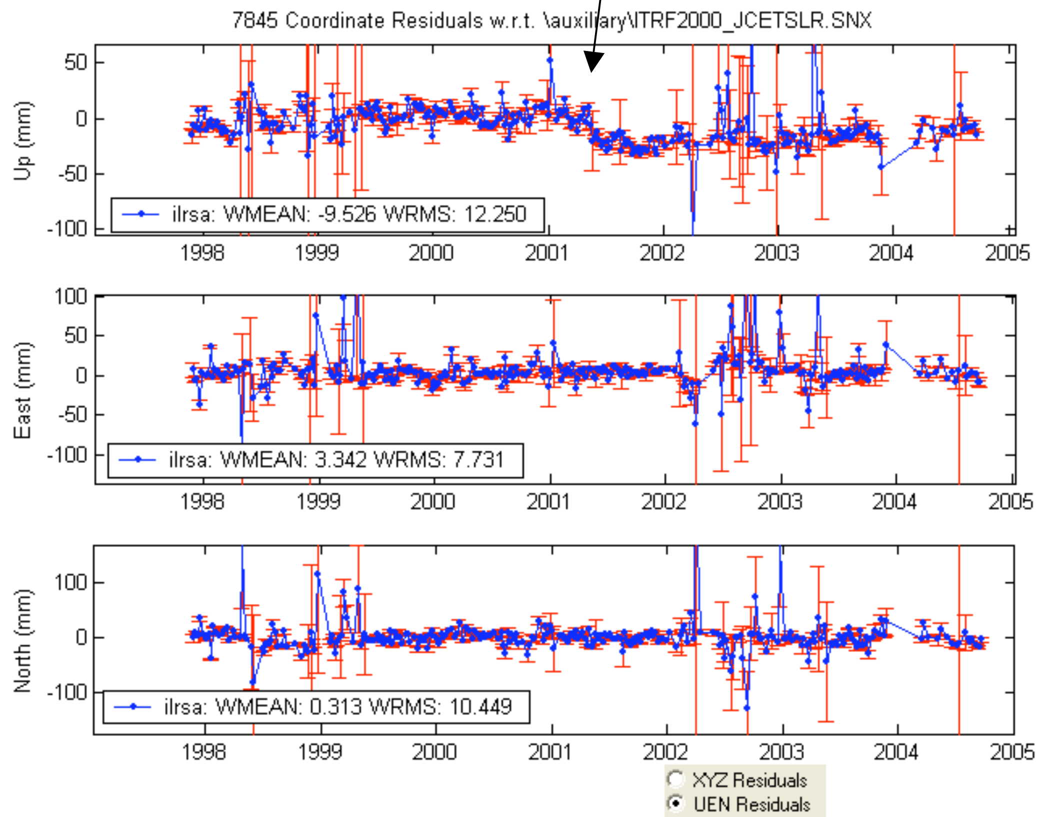
Reference Position of the plot :

X = 4581692.125 m   Y = 556196.104 m   Z = 4389355.109 m

2007 Jan 25 13:53:24

ITRF2005 Residuals analysis

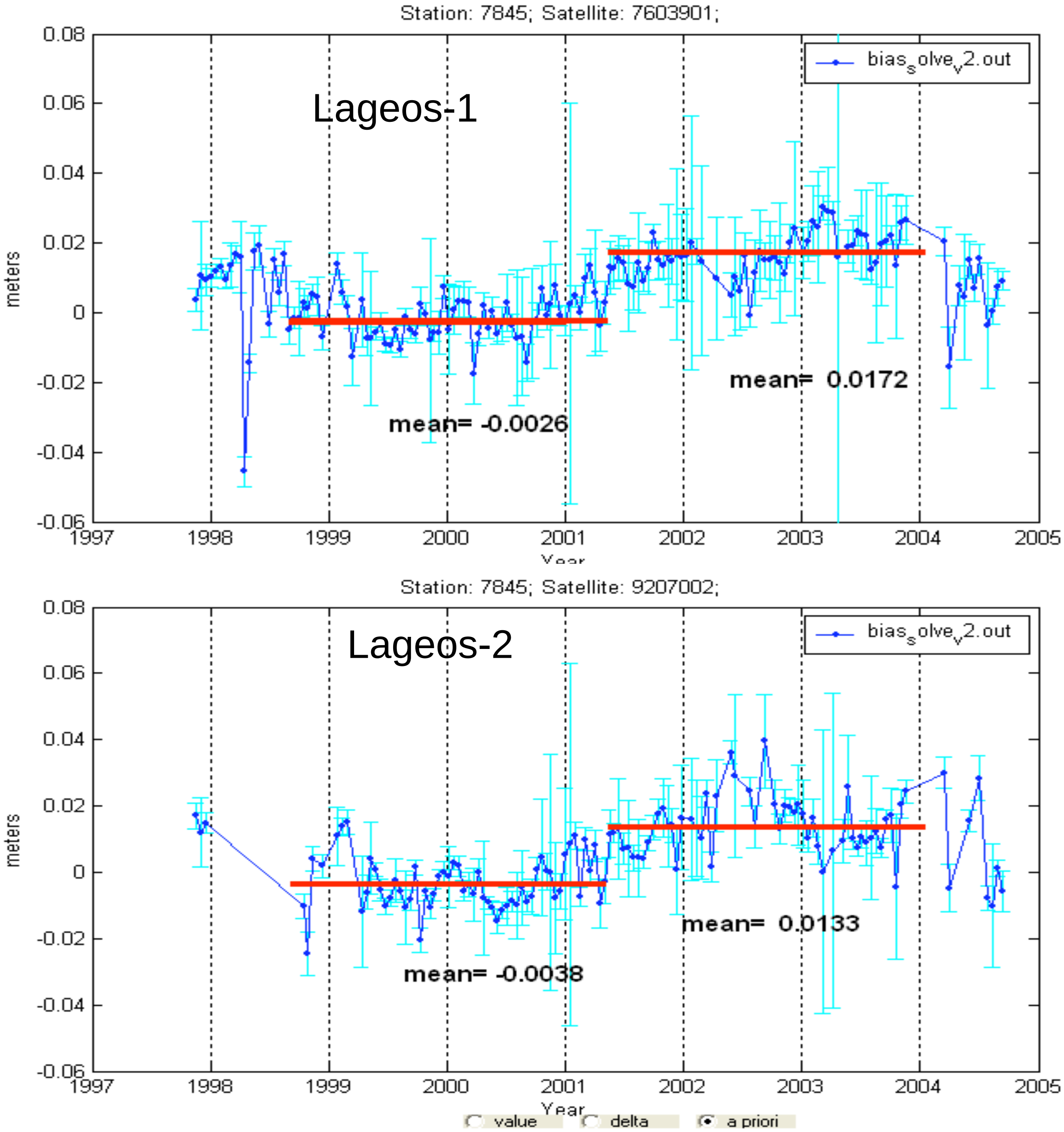
Mid-june 2001 new laser



2001:152 laser change

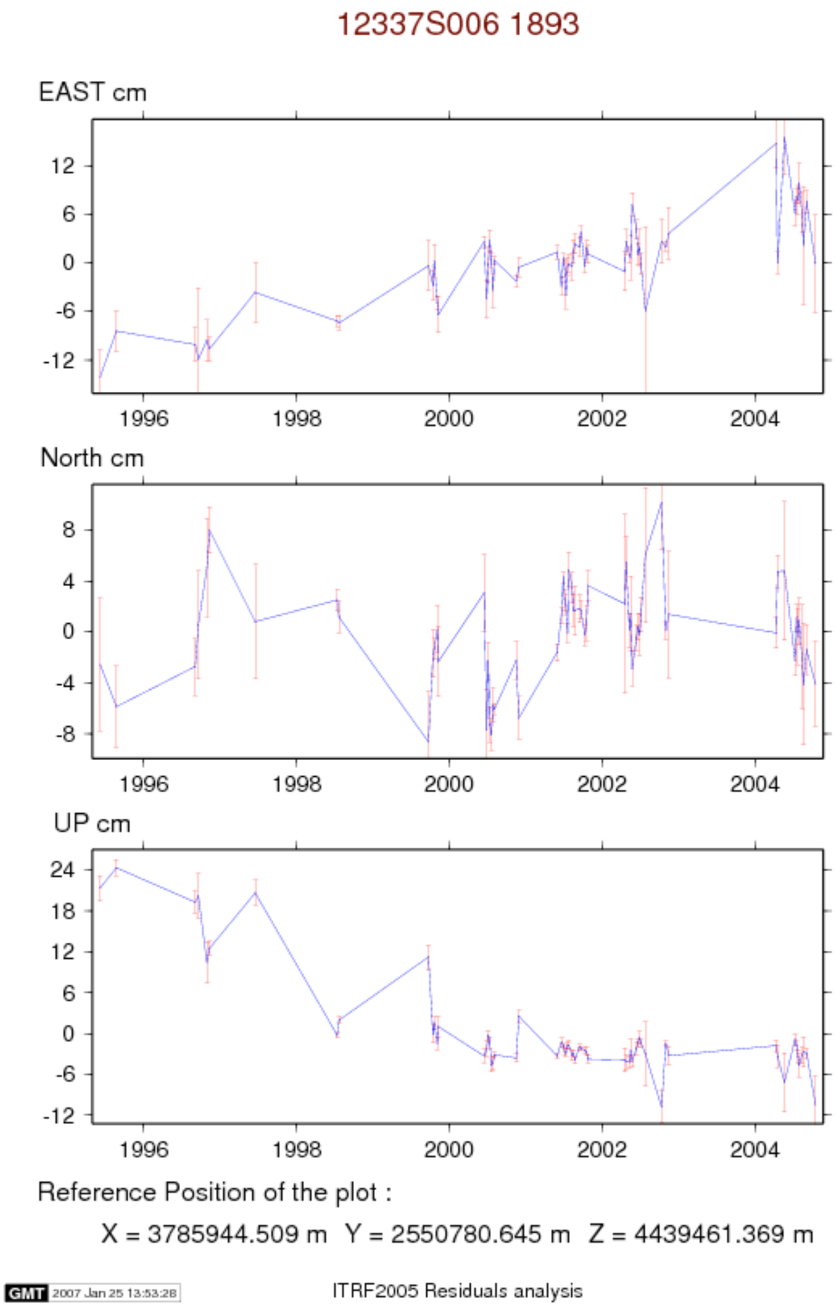
Grasse: range residuals from solution ASI06

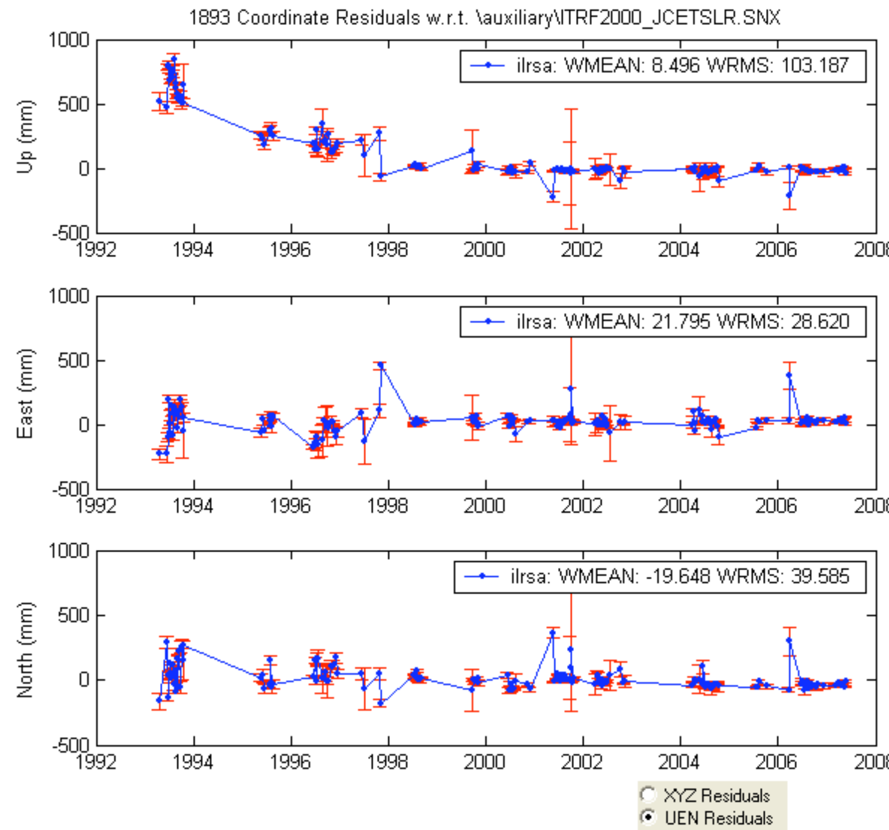
1 point every 15 days



2001:152 laser change

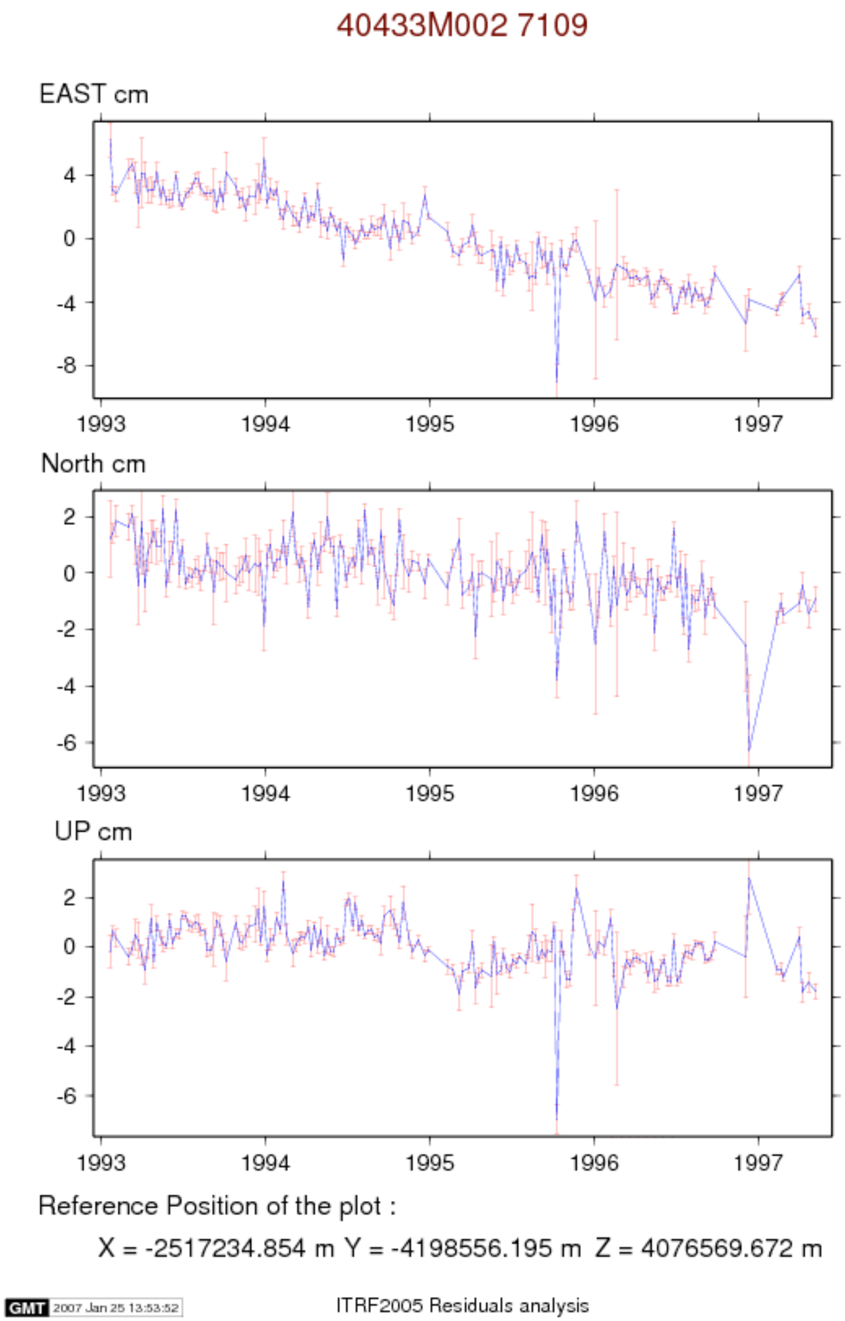
Katsively



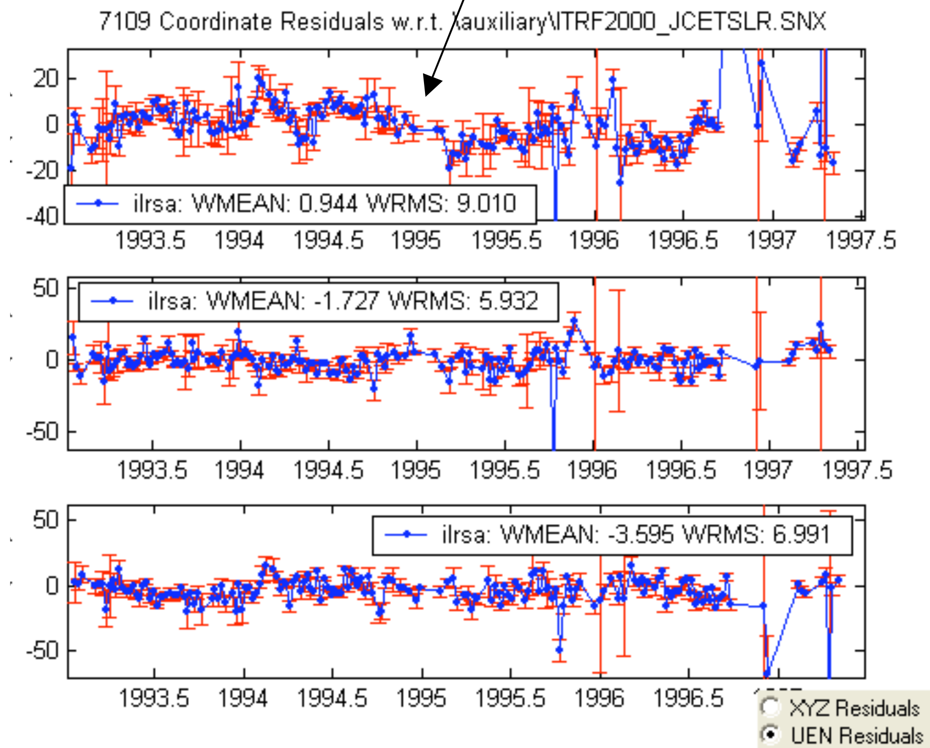


From ILRS web page: data before 1998.0 with biases (70 cm in 1993, 35 from 95 to 97)

Quincy



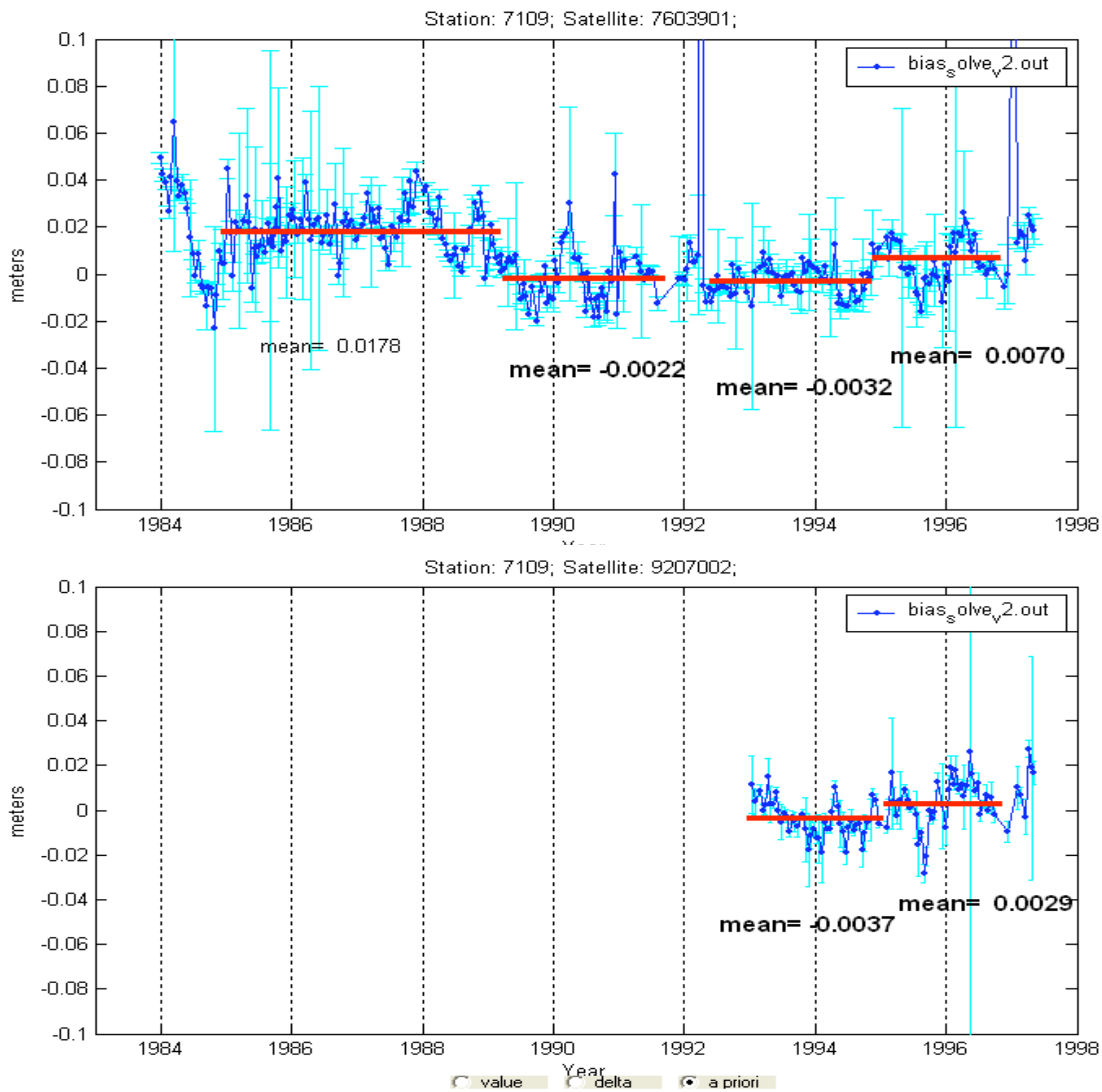
Paroscientific barometer



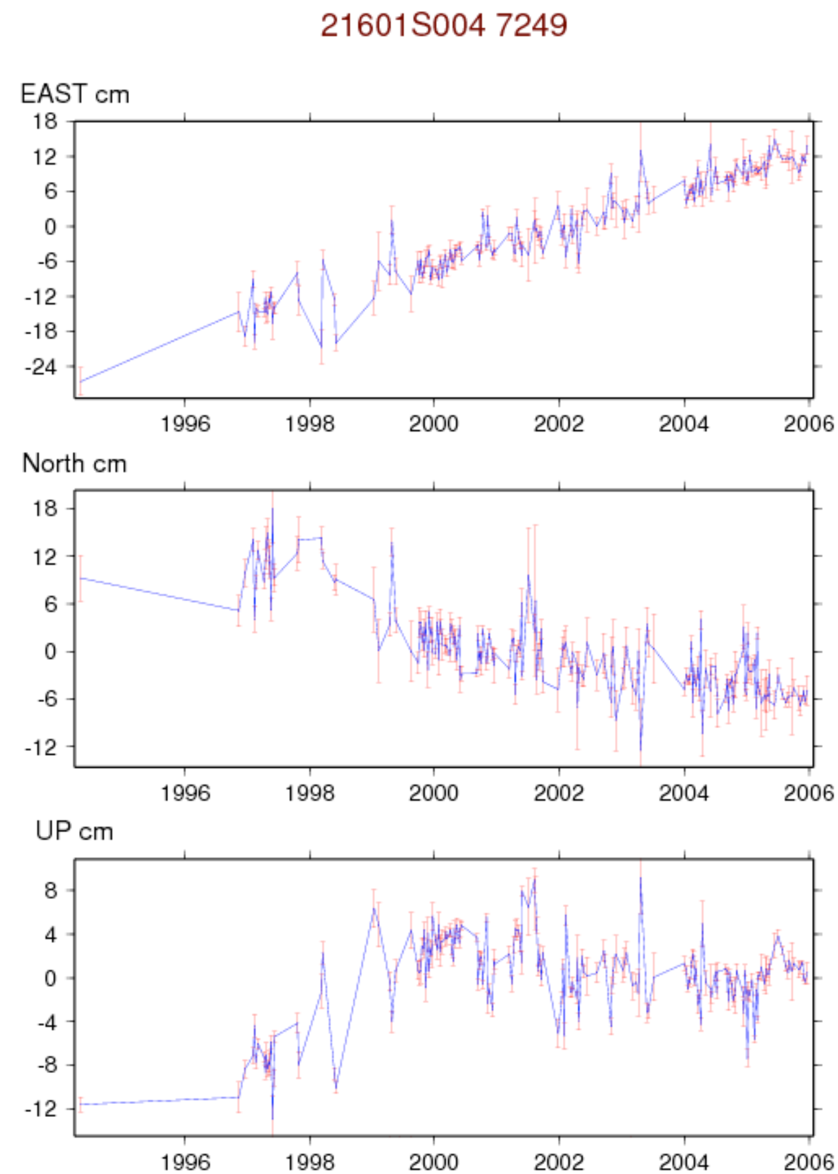
1995:001 Paroscientific barometer

Quincy: range residuals from solution ASI06

1 point every 15 days



Bejing

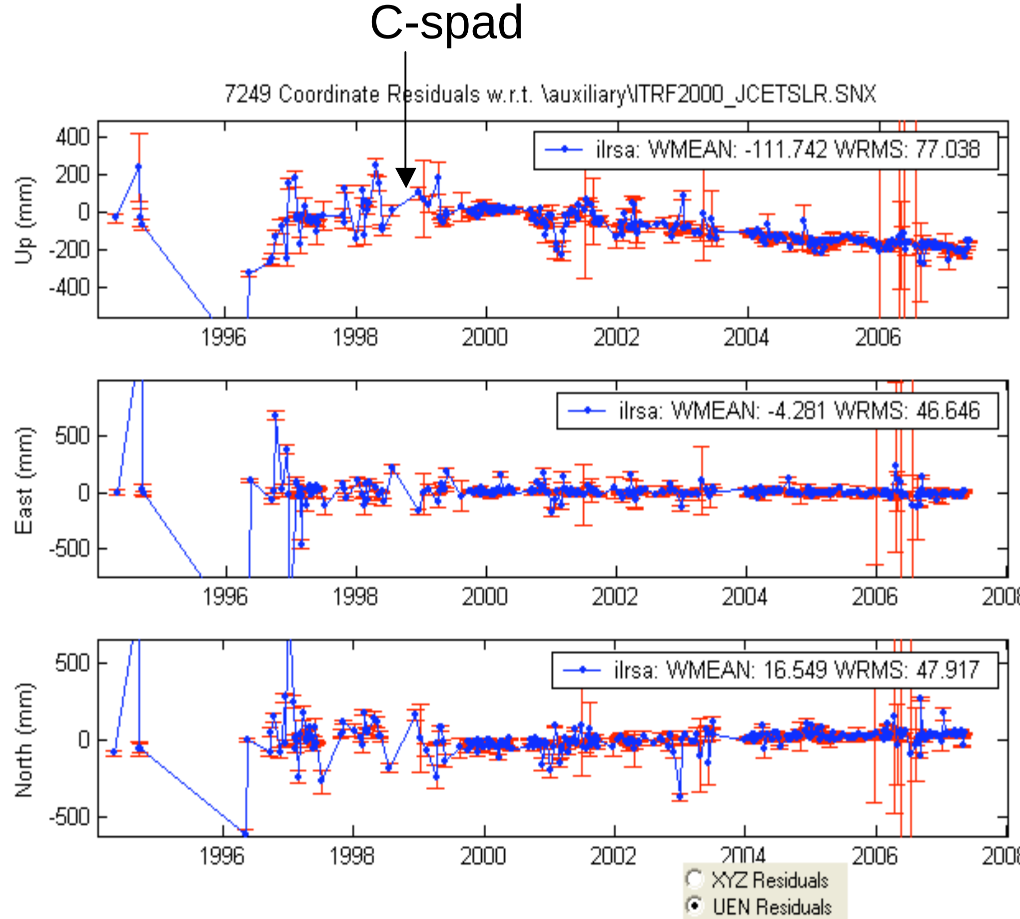


Reference Position of the plot :

X = -2148760.503 m Y = 4426759.573 m Z = 4044509.654 m

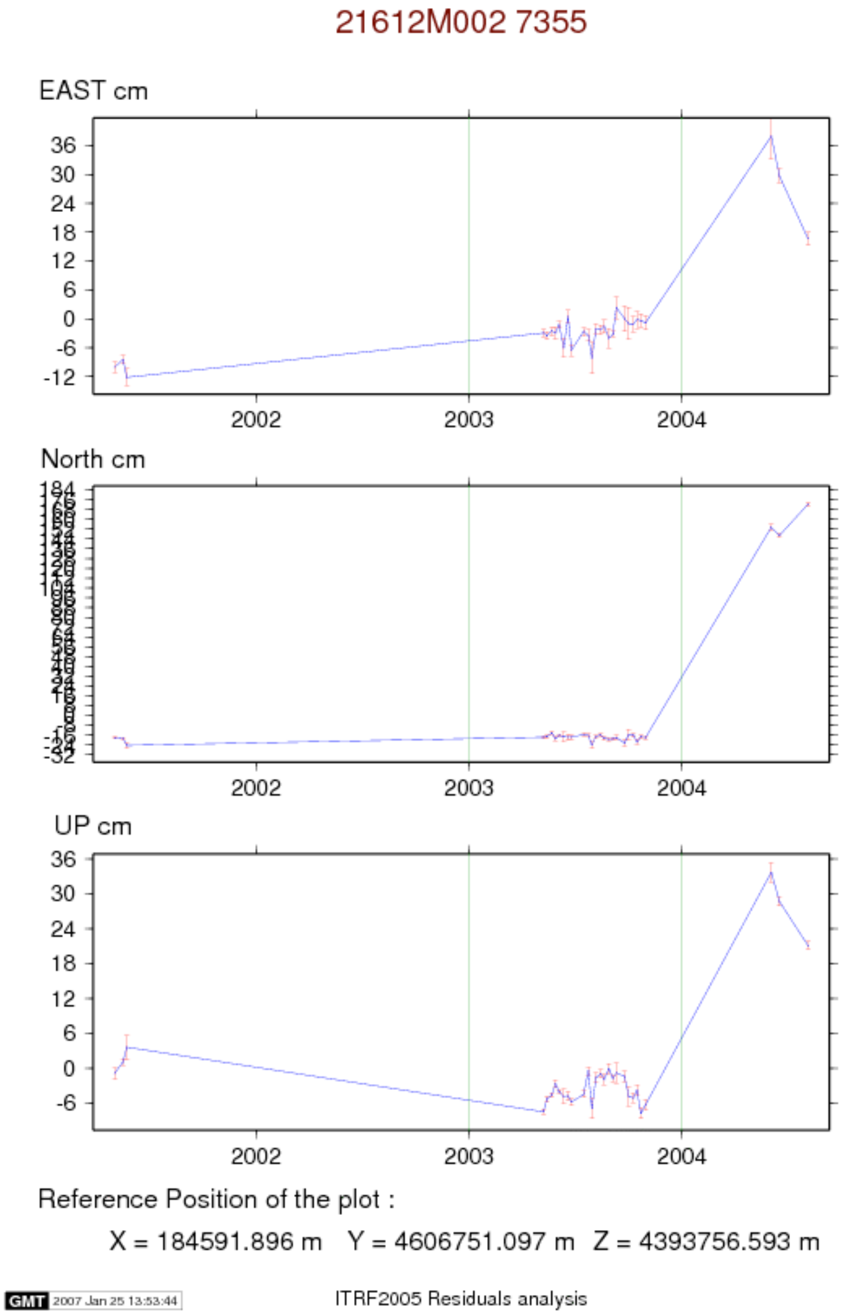
2007 Jan 25 13:53:40 ITRF2005 Residuals analysis

C-spad



data before 1999.0 to be deleted?

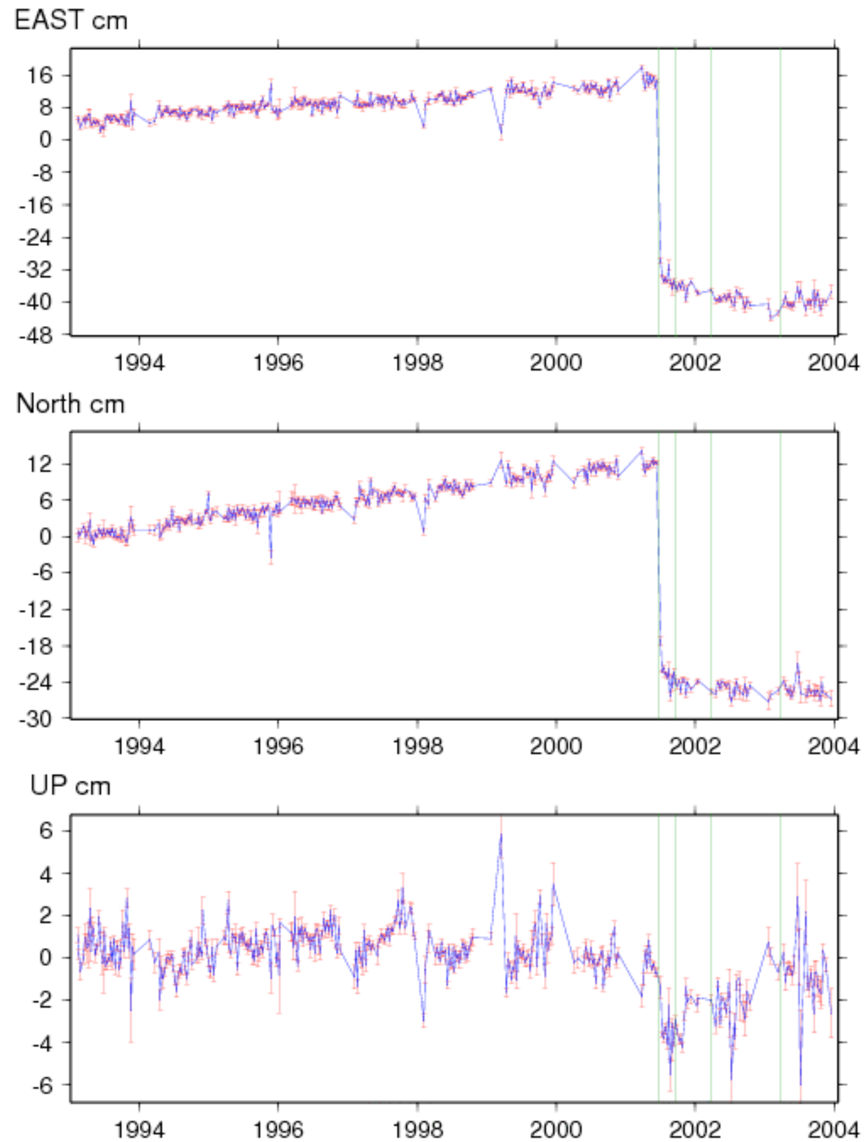
Urumqui

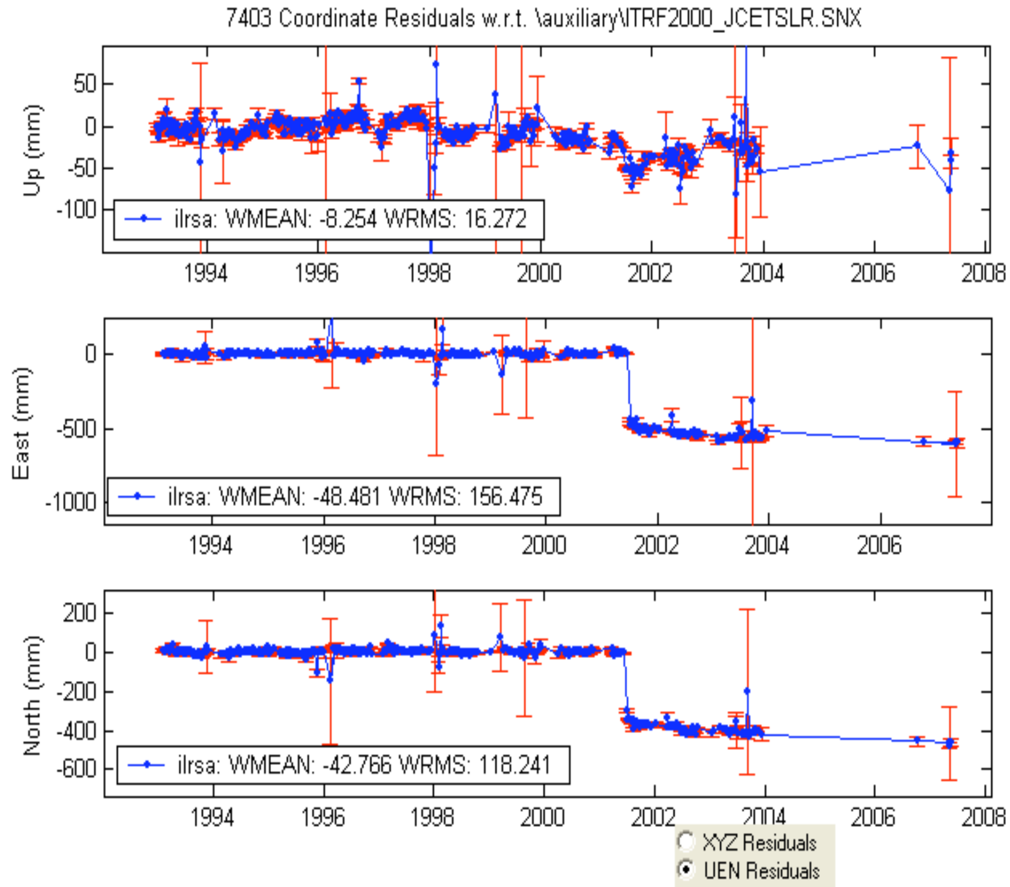


Only 2003 data?

42202M003 7403

Arequipa

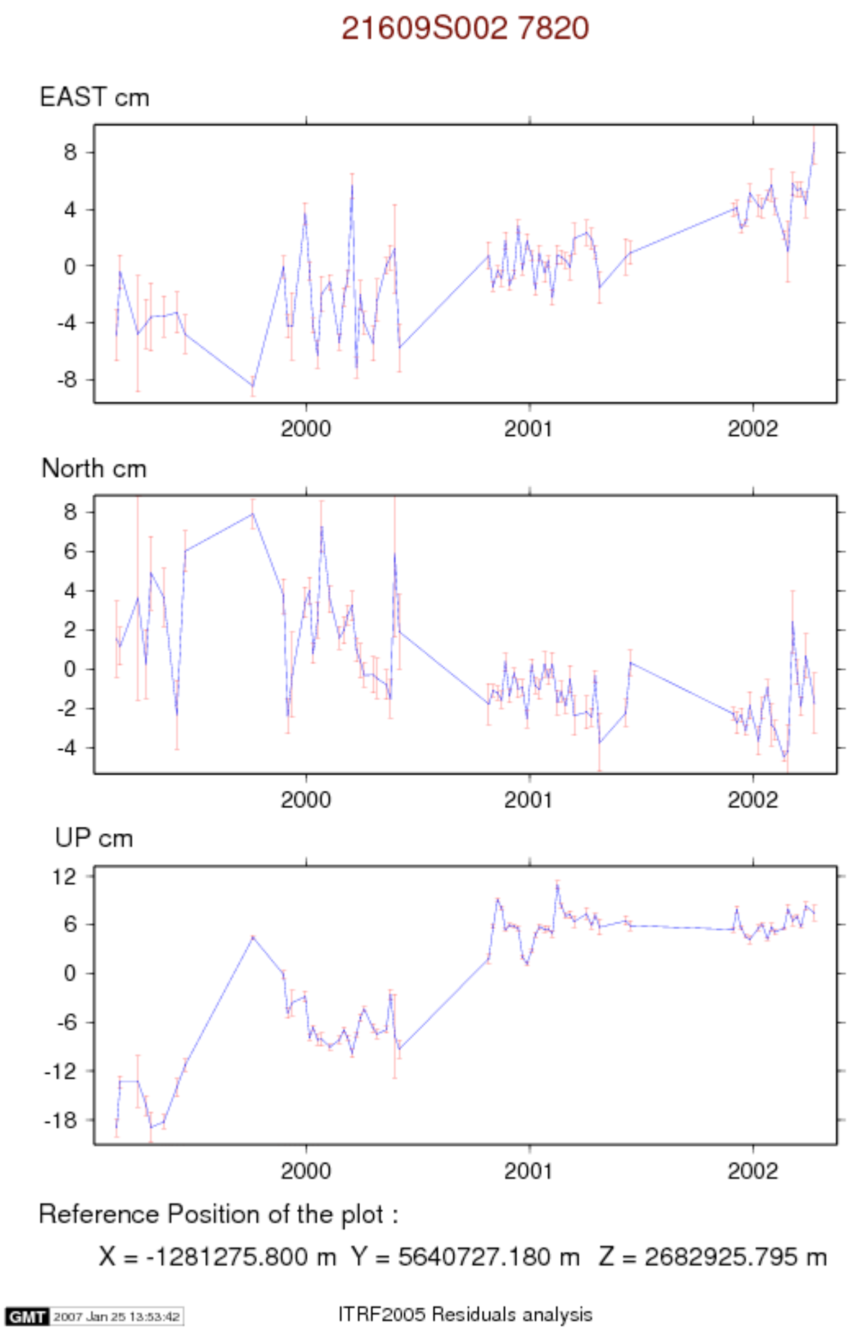


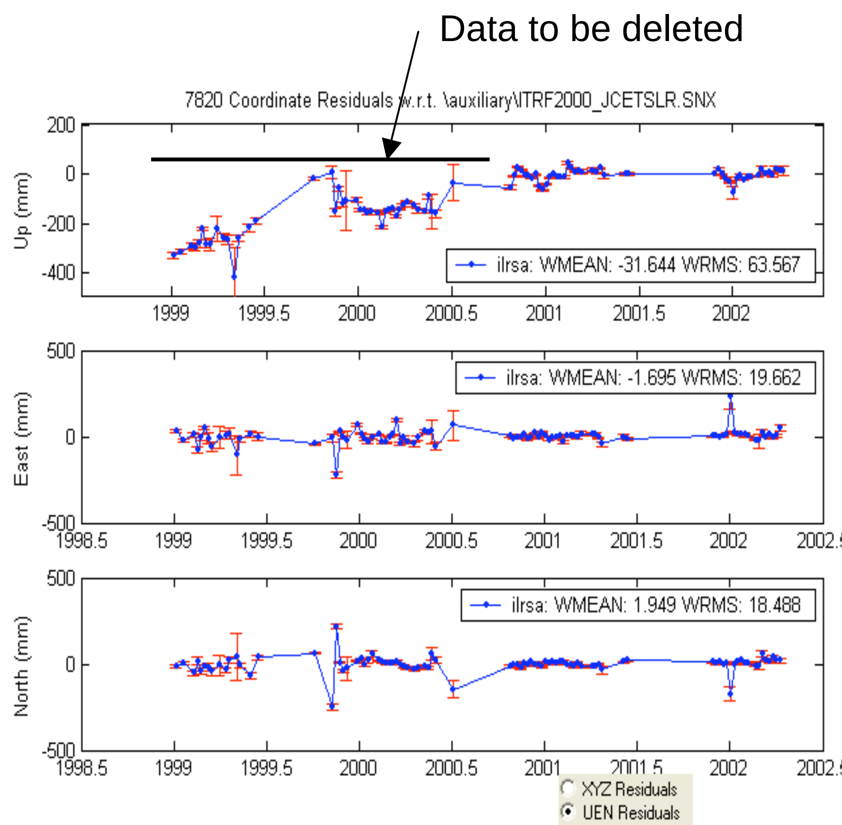


Reference Position of the plot :

X = 1942808.023 m Y = -5804069.709 m Z = -1796915.514 m

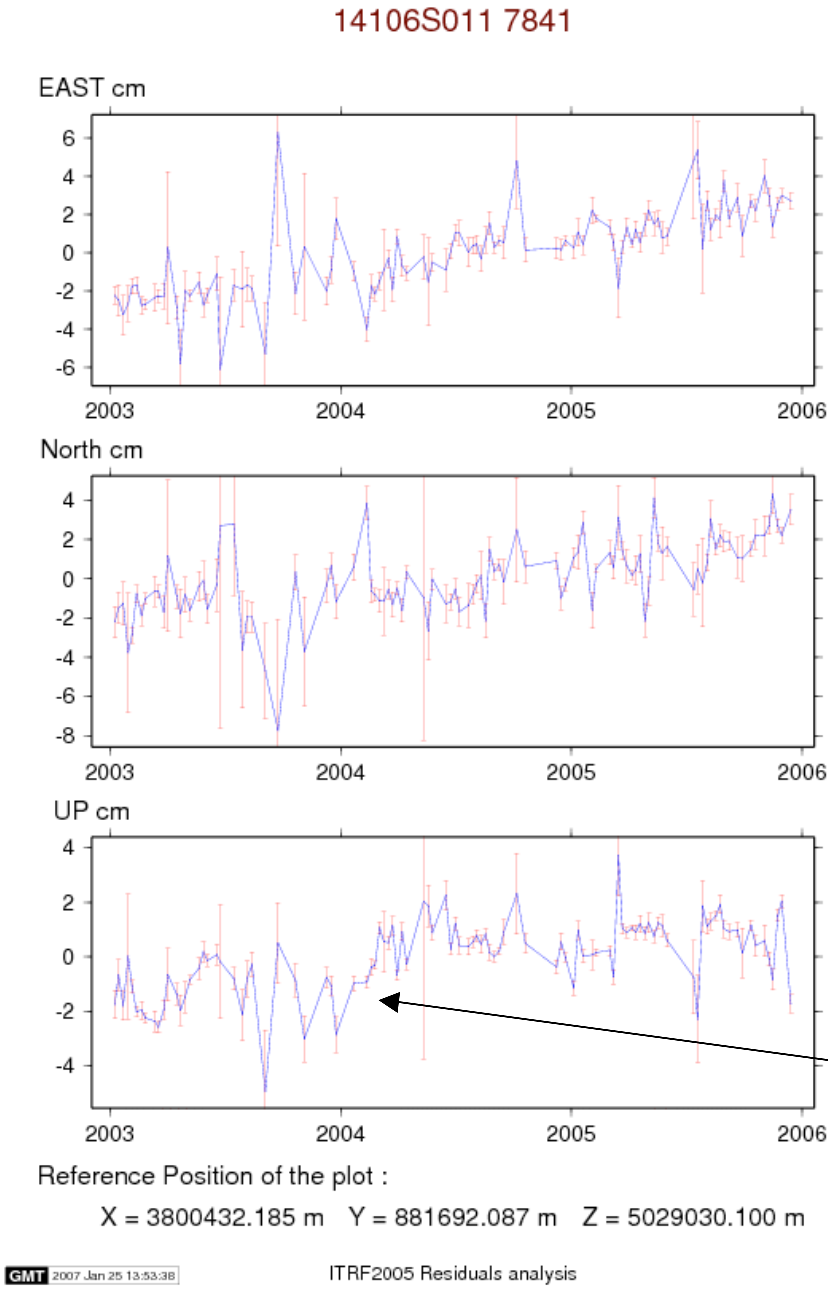
Kunming





From ILRS web site: All data prior to 00:291:00000 had a scale bias due to a frequency error. A frequency error will drift and is not recoverable.

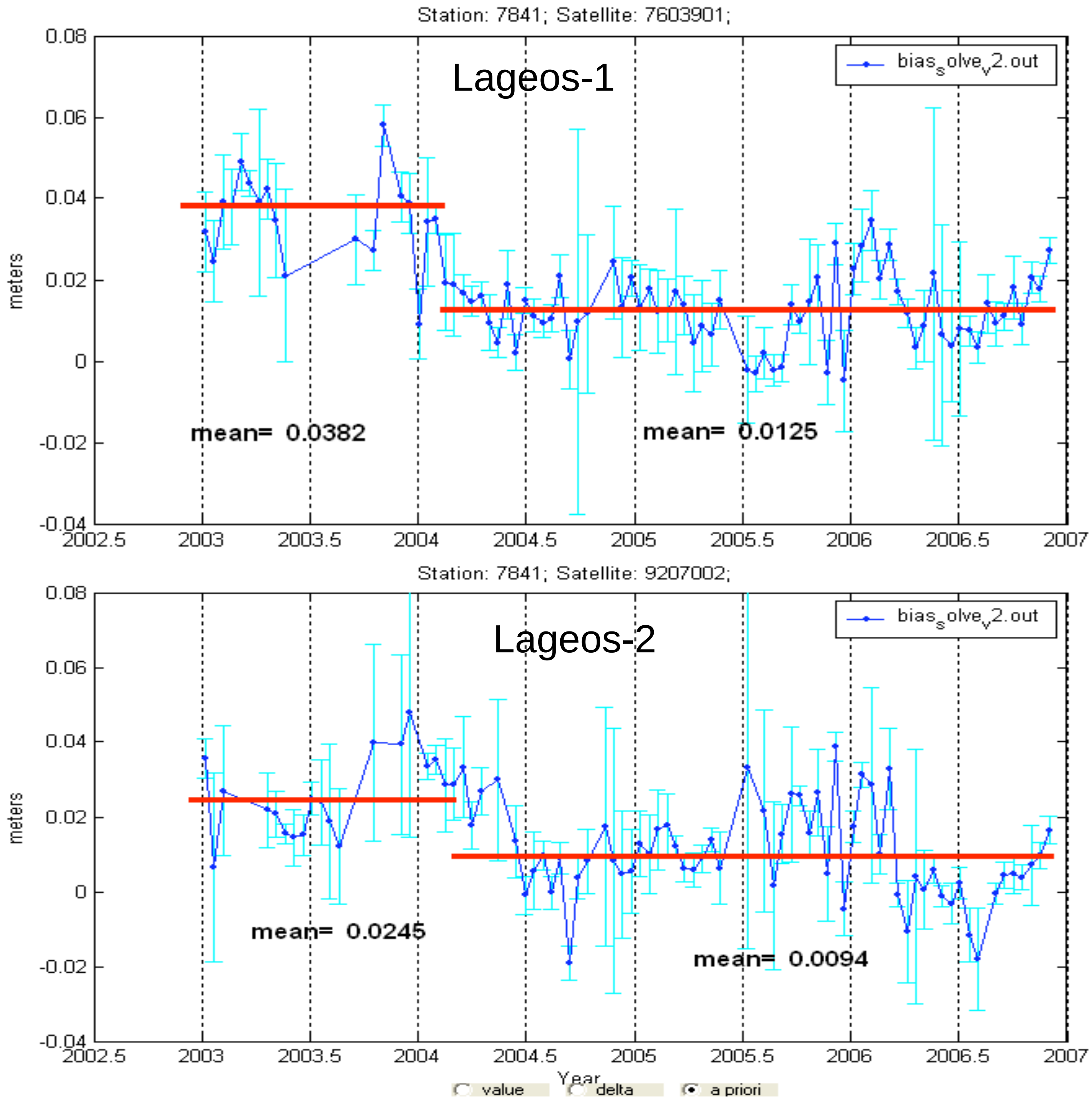
Potsdam



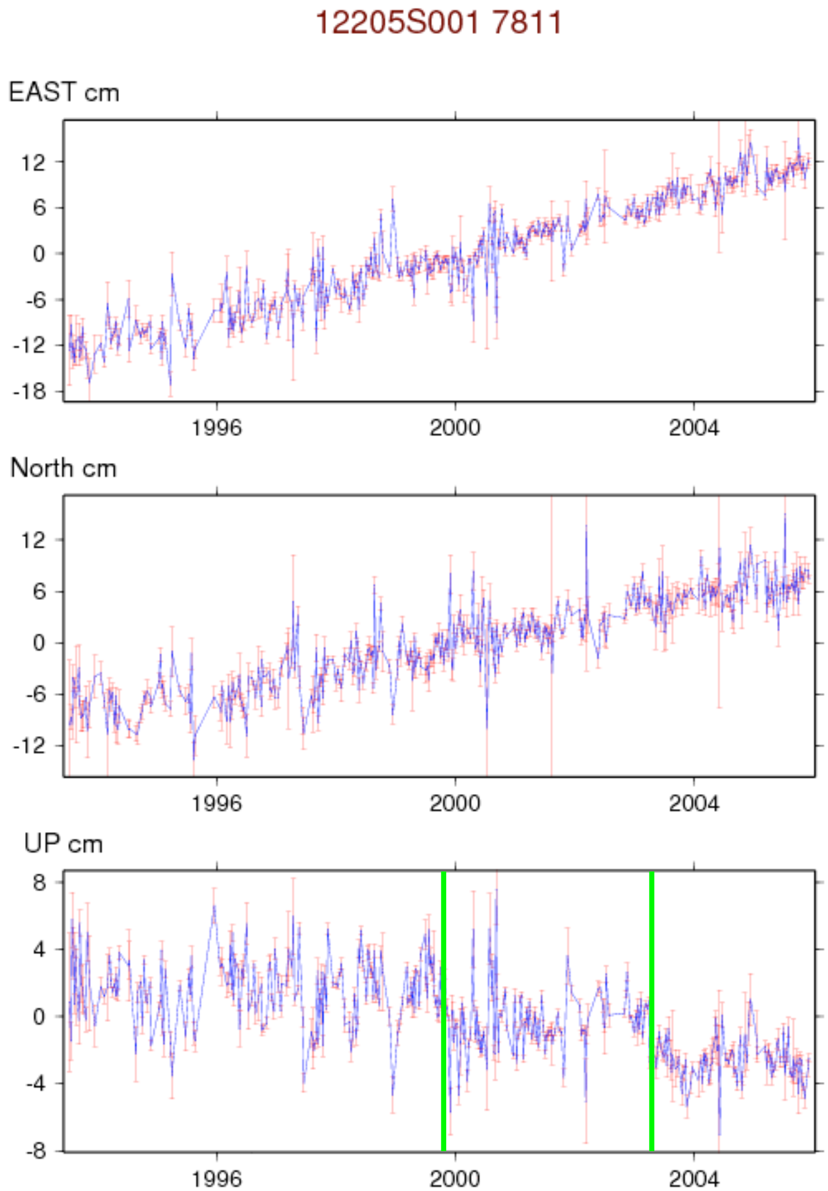
2004:050 A031 Event Timer replacing SR620 time interval counter

Potsdam: range residuals from solution ASI06

1 point every 15 days



Borowiec



Reference Position of the plot :

X = 3738332.784 m Y = 1148246.542 m Z = 5021816.063 m

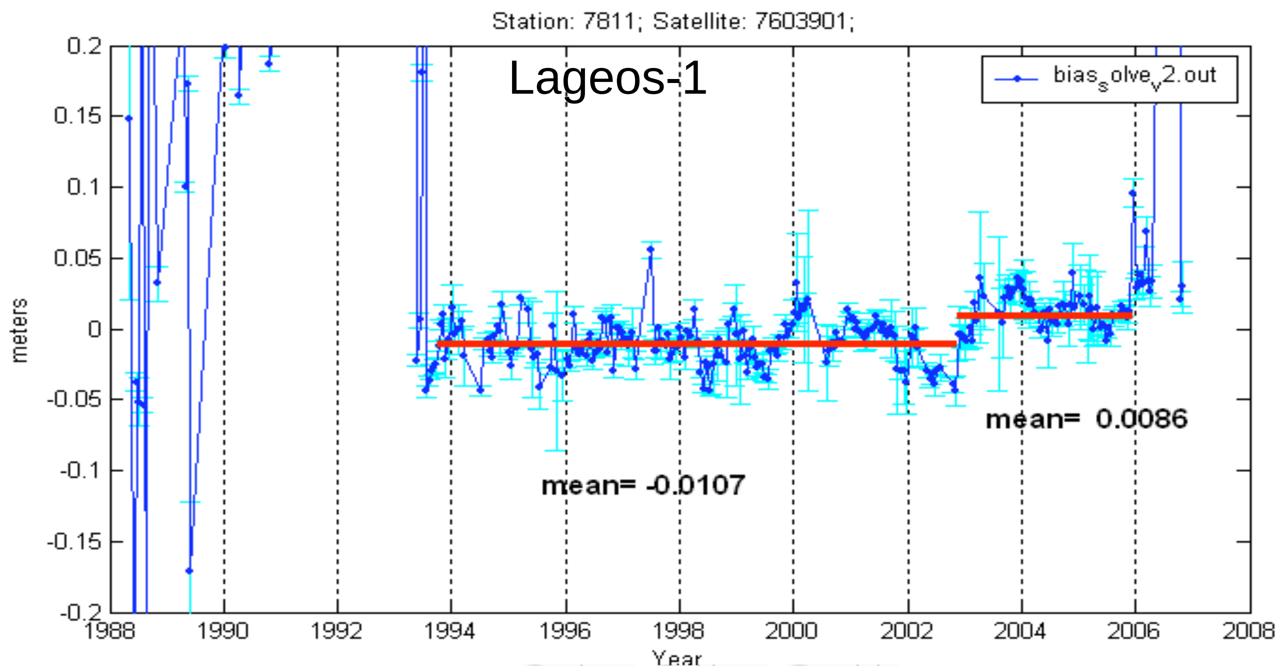
GMT 2007 Jan 25 13:53:27

ITRF2005 Residuals analysis

1993:202 Rb-frequency standard for PS-500 Timer
(elimination of large range bias!)
2003:088 Discriminator B6 replaced by discriminator
TENNELEC TC454 in stop channel

Borowiec: range residuals from solution ASI06

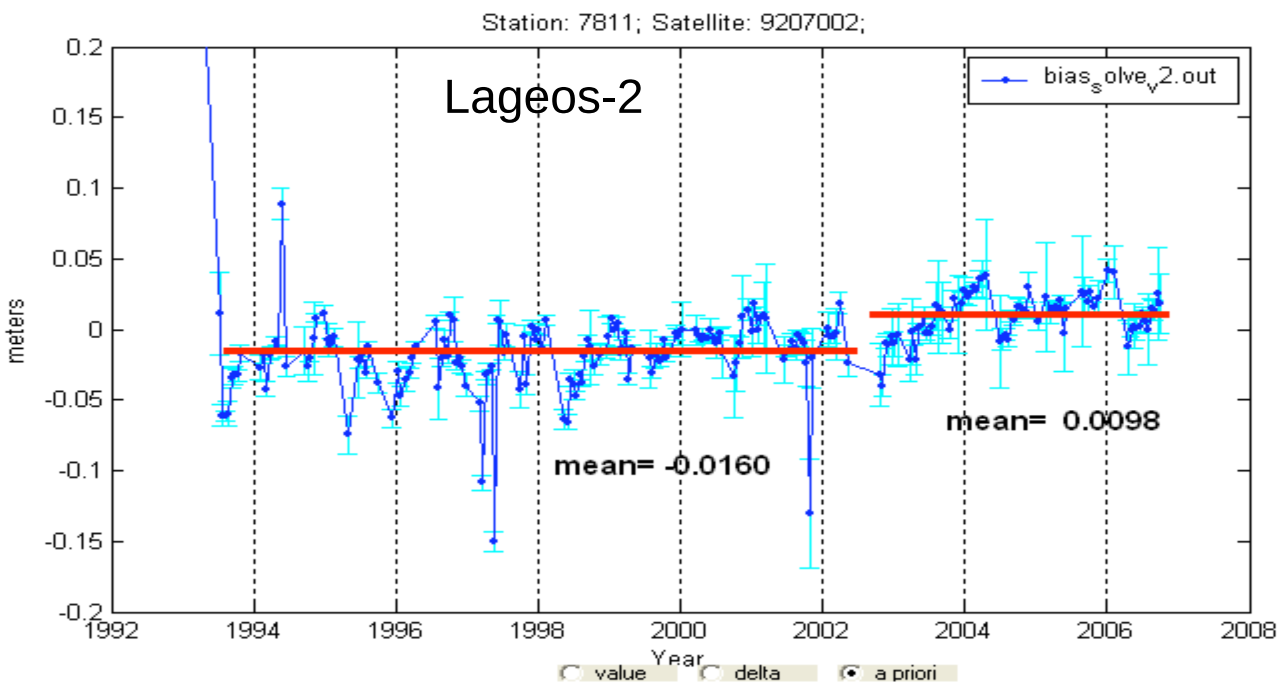
1 point every 15 days



1993:202 Rb-frequency standard for PS-500 Timer (elimination of large range bias!)

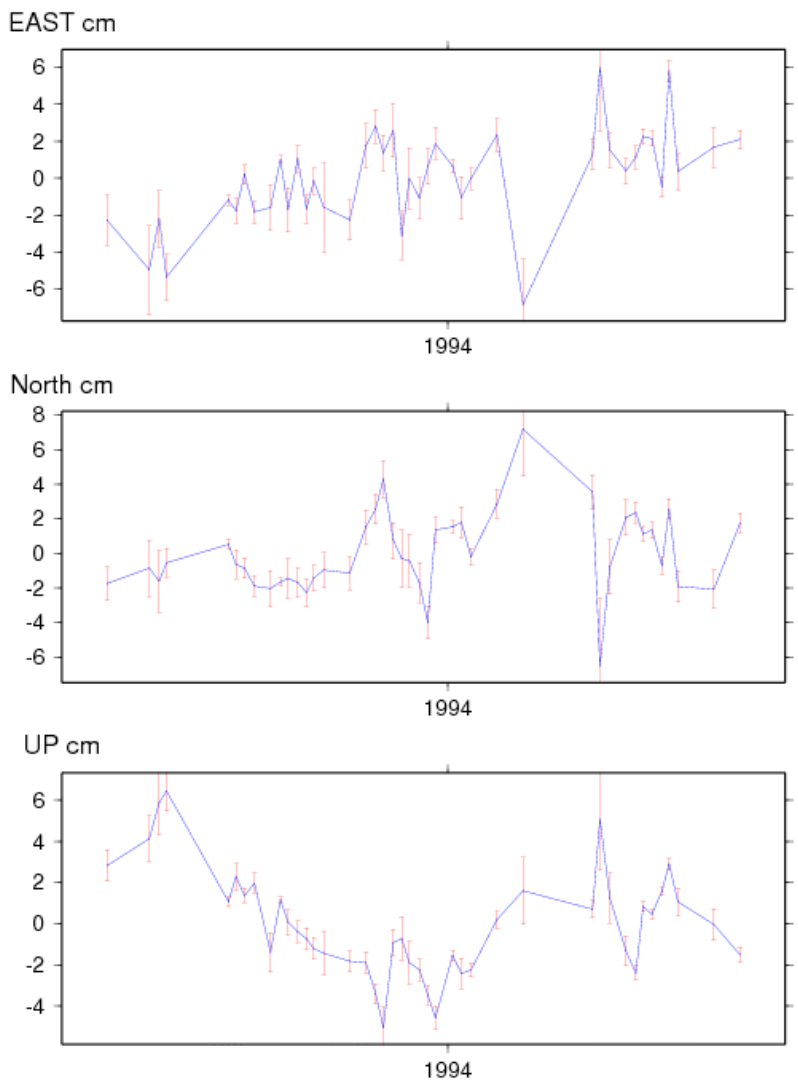
2003:088 Discriminator B6 replaced by discriminator TENNELEC TC454 in stop channel

Data before 1993:202 to be edited



Bar Giyyora

20702M001 7530

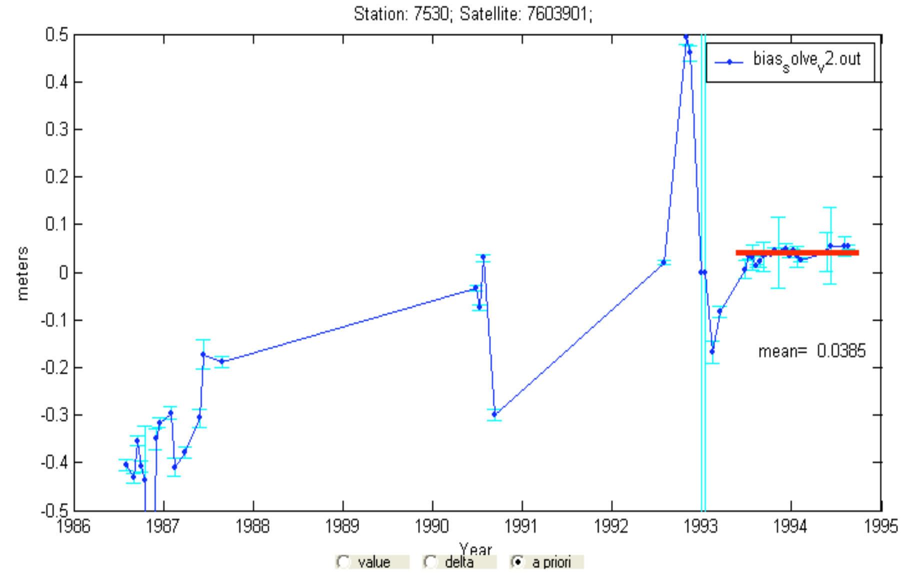


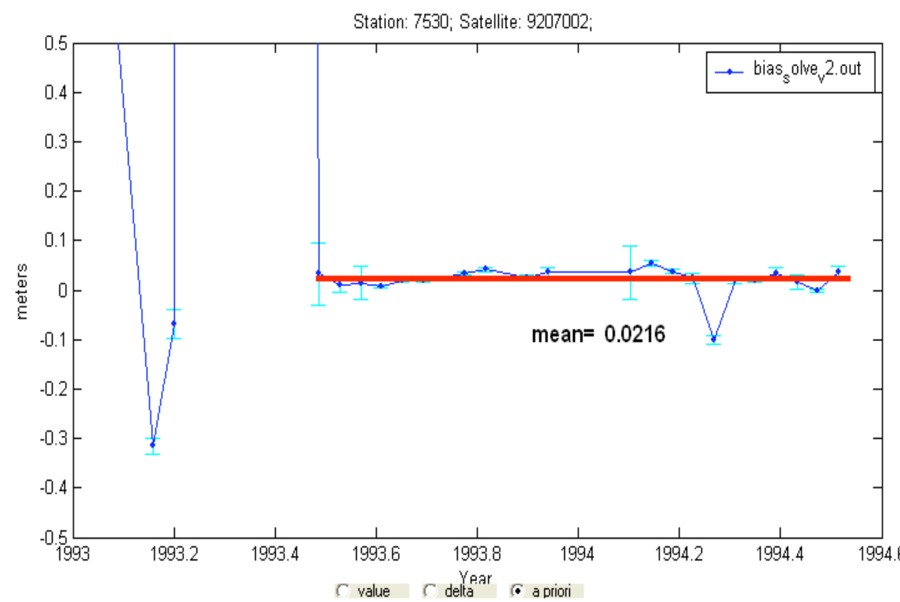
Reference Position of the plot :

X = 4443965.852 m   Y = 3121945.276 m   Z = 3334693.766 m

GMT 2007 Jan 25 13:53:39

ITRF2005 Residuals analysis





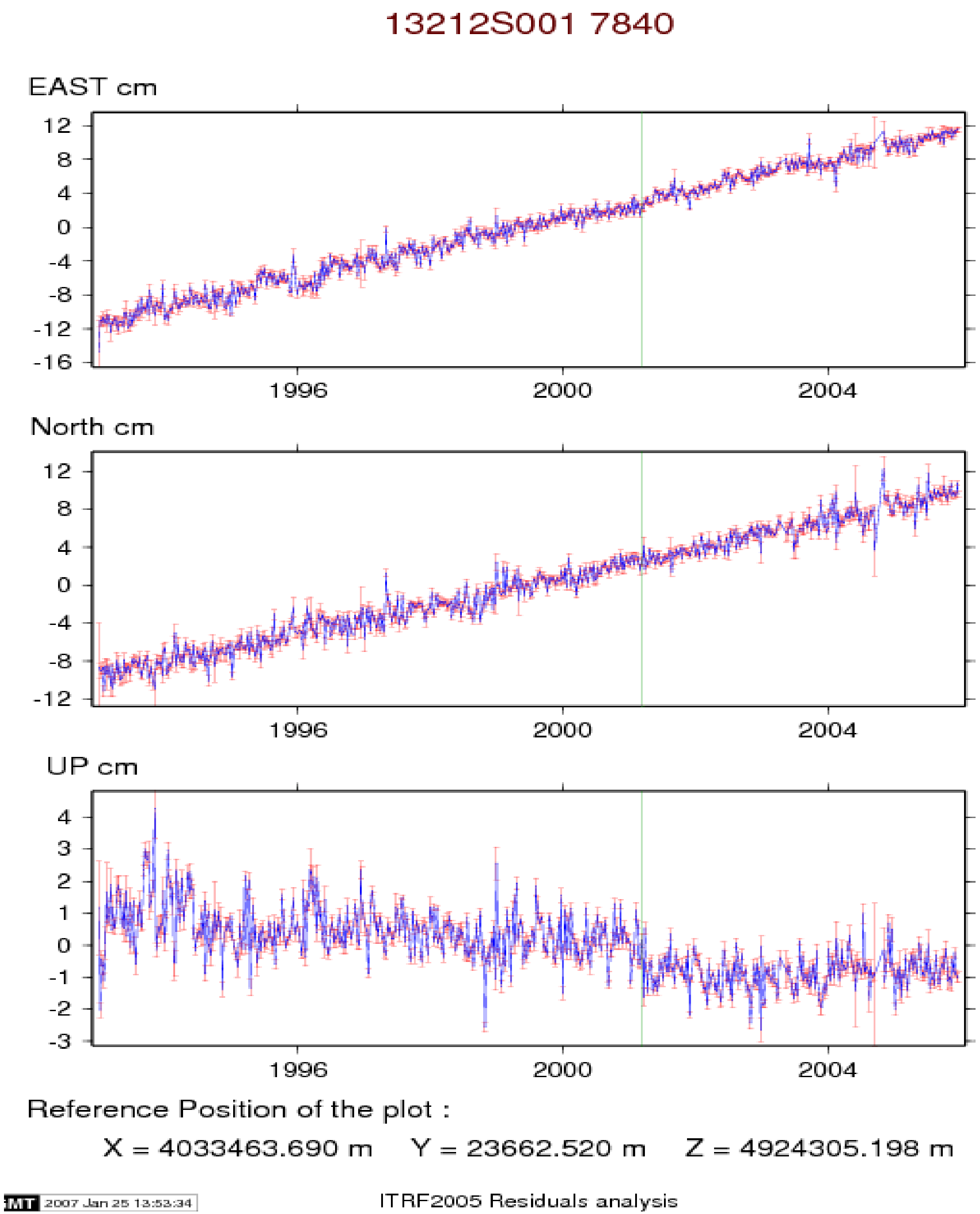
Site range biases

V. Luceri – e-GEOS S.p.A.

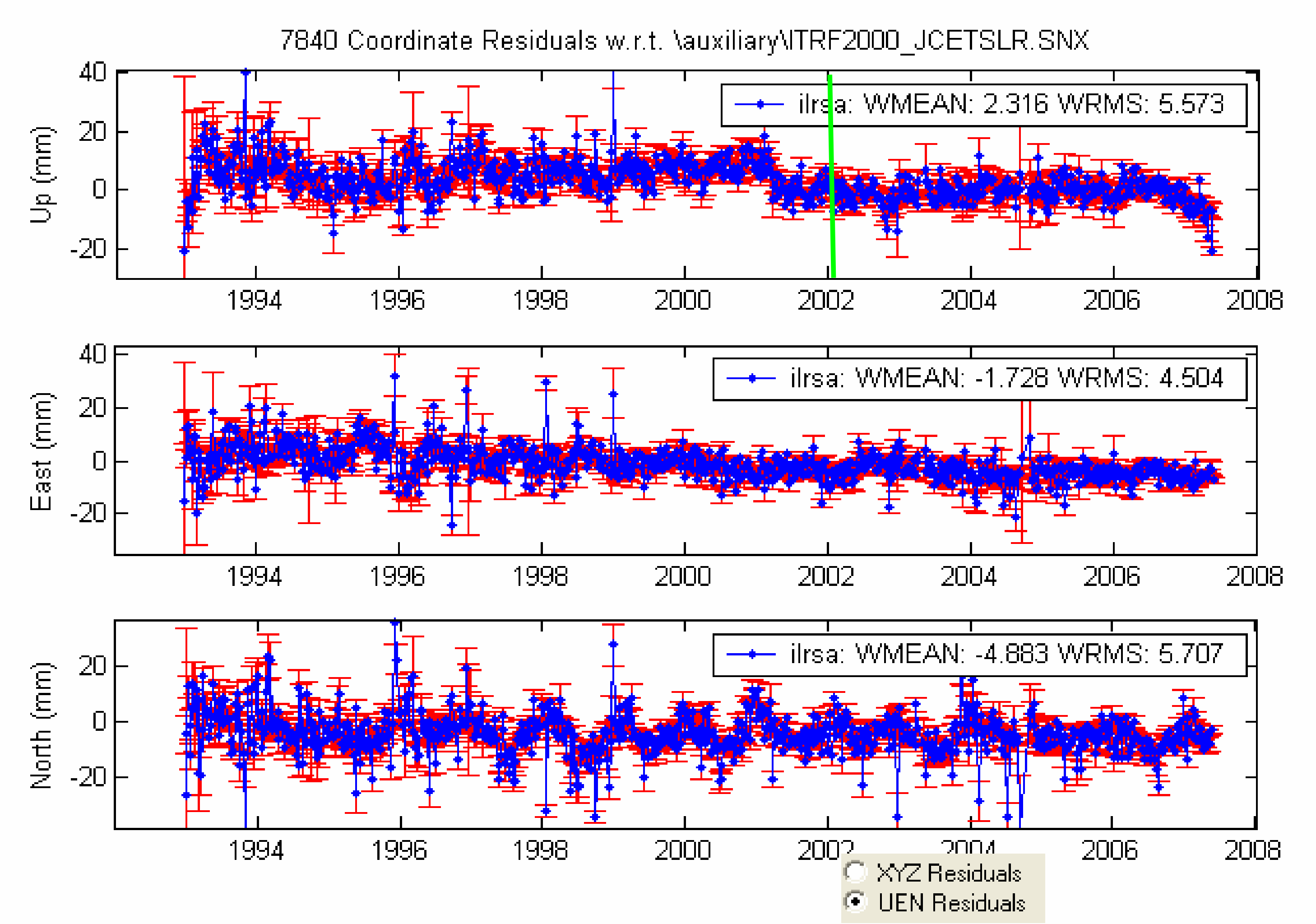
Bias estimation

- The biases are estimated with a long arc solution from jan 1983 to jul 2007 (ASI06)
- The solution is loose and SSC/SSV are estimated over the entire time span
- One bias estimate every 15 days after the SSC/SSV/EOP adjustment

Herstmonceux coordinate time series from ITRF web page



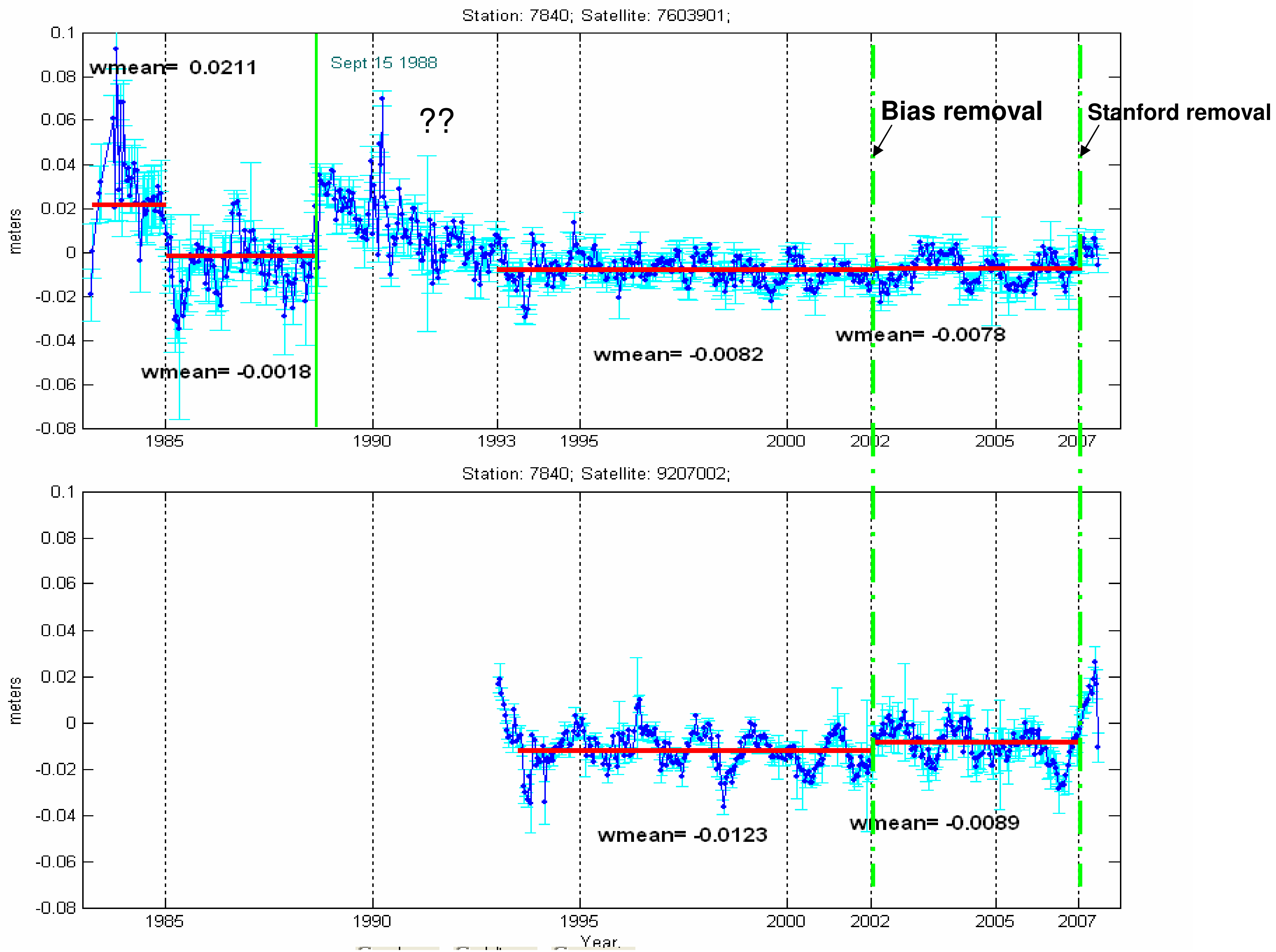
Herstmonceux: ILRSA UEN residuals w.r.t. ITRF2000



Correction reported by the station

Start Date	End Date	Correction to be subtracted
october 1, 1994	february 1, 2002	-2.5 mm
february 1, 2002	february 10, 2007	5.5 mm

Herstmonceux: range biases from solution ASI06



Remarks

- 8 mm jump at feb 1, 2002 not visible
- Jump at feb 2007 still not detectable
- Lageos-2 drift after feb 2007
- Biases from sep 15 1988 to 1993.0 have a drift
- Info on the biases before 1993?