Astronomisches Institut 2013: Aktivitäten und Projekte

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Astronomisches Institut

Zimmerwald SLR

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Astronomisches Institut

Hardware Entwicklungen (1)

Kuppelrevision: Da die Beobachtungszeiten in den letzten Jahren gesteigert wurden, müssen die flexiblen Kranseile nun in einem kürzeren Intervall regelmässig gewechselt werden.

Kompressor: Das Hauptrückschlagventil zwischen Kompressor und Speicher musste nach einem Haarriss gewechselt werden.

ZIMLAT-Teleskop: Die grossen Hauptlager für die Azimut und Elevationsachse sowie der Derotatorplattform wurden mit einem Spezialfett nachgefettet.

Neue Gesamtüberwachung der Laserkuppel mit SPS: Zunächst wurde die Hardware der neuen speicherprogrammierbare Steuerung (SPS) aufgebaut. Anschliessend wurde begonnen, diese in das bestehende System zu integrieren. Eine Ethernet Remote IO Einheit der SPS für allgemeine Überwachung wurde installiert.

Hardware Entwicklungen (2)

sCMOS Trackingkamera für SLR Beobachtungen: Neue Satelliten, die mit konventionellen Methoden schwer zu finden sind, wie z.B. Ziele ohne Retroreflektoren oder Satelliten auf exzentrischen Orbits, erzwingen wieder den Einsatz einer Kamera zeitsimultan zur SLR Beobachtung.

Laser-Chiller: Die für den SLR Betrieb erforderliche Laserkopf-Kühlung fiel im November 2012 aus und wurde zur Überprüfung an den Hersteller gesandt. Das Gerät funktionierte jedoch auch nach der Reparatur nicht einwandfrei. Die geräteinterne Wasserdurchfluss-Überwachung stellte immer wieder die Kühlung ab und verhinderte damit den SLR Messbetrieb.

Laser Probleme

Quasi gleichzeitig wurden im November 2012 der Chiller und der Laserkopf des Doppelpass-Verstärkers defekt. Eine Kausalität zwischen beiden Defekten kann bis heute weder ausgeschlossen noch bewiesen werden.

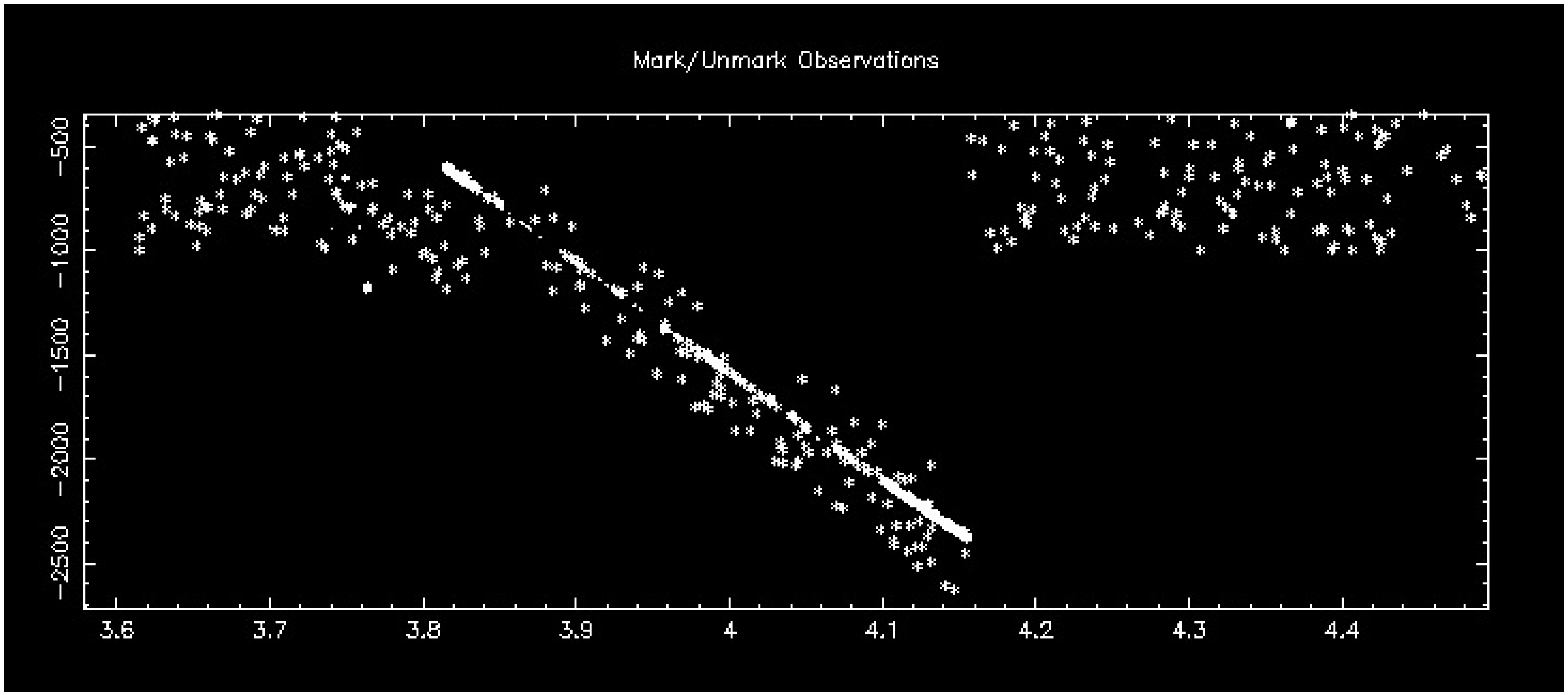
Normalerweise führt eine nutzungsbedingte Degeneration der Dioden nur zu einer Leistungsreduktion, nicht aber zu einem Ausfall. Im November 2012 sind nun mehrere Dioden quasi gleichzeitig unbrauchbar geworden. Durch die fehlende Verstärkung war die Energie des Ausgangspulses zu niedrig, um selbst einfachste SLR Beobachtungen noch durchführen zu können. Die Laserfirma konnte einen temporären Ersatzkopf einbauen, der mit weniger Dioden bestückt ist. Zwar konnten die Beobachtungen nach dem Tausch wieder aufgenommen werden, allerdings steht seitdem eine geringere Pulsenergie zur Verfügung. Ein neu bestellter Laserkopf hätte im September 2013 geliefert und eingebaut werden sollen, die Auslieferung verzögert sich jedoch. Ein genauer Liefertermin ist bis heute trotz mehrfacher Anfragen nicht bekannt.

Spezielle Experimente

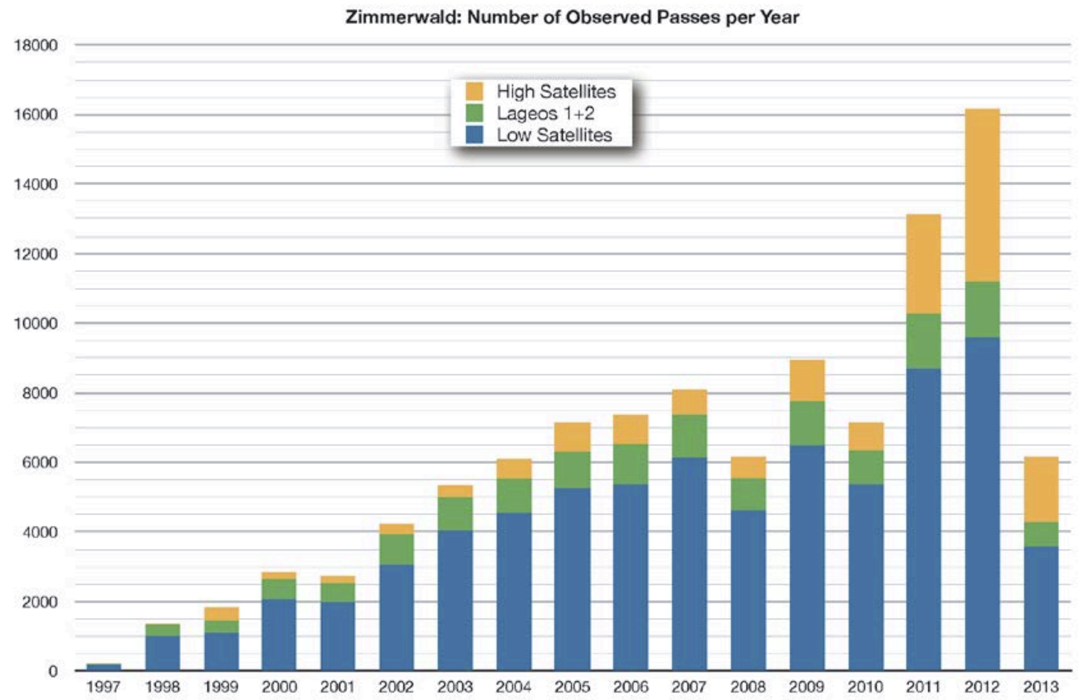
Geostationäre Satelliten: Am 24.9.2013 konnten erstmals Echos von einem geostationären Satelliten empfangen werden. Es handelt sich hierbei um den Satelliten IRNSS-1A des im Aufbau befindlichen indischen Navigations-systems. Zimmerwald war die erste europäische Station und die dritte Station weltweit, die Echos empfangen konnte (nach Yarragadee und Changchun in China).

Bistatic Experiment mit Graz: Die Experimente mit der SLR Station Graz Lustbühel wurden fortgesetzt. Als Ziele wurden in diesem Jahr nicht nur der Satellit ENVISAT, sondern auch Space Debris Objekte ausgewählt, die in niedrigen Bahnhöhen (bis ca. 3000 km) fliegen. Am 18.6.2013 weltweit erstmals gelungen, einige dieser diffus an den Oberflächen von Space Debris Objekten reflektierten Photonen in Zimmerwald mit Hilfe des ZIMLAT Teleskops zu detektieren, z.B. die nachfolgend gezeigte Raketenoberstufe CZ-2C.

Bistatic Experiment

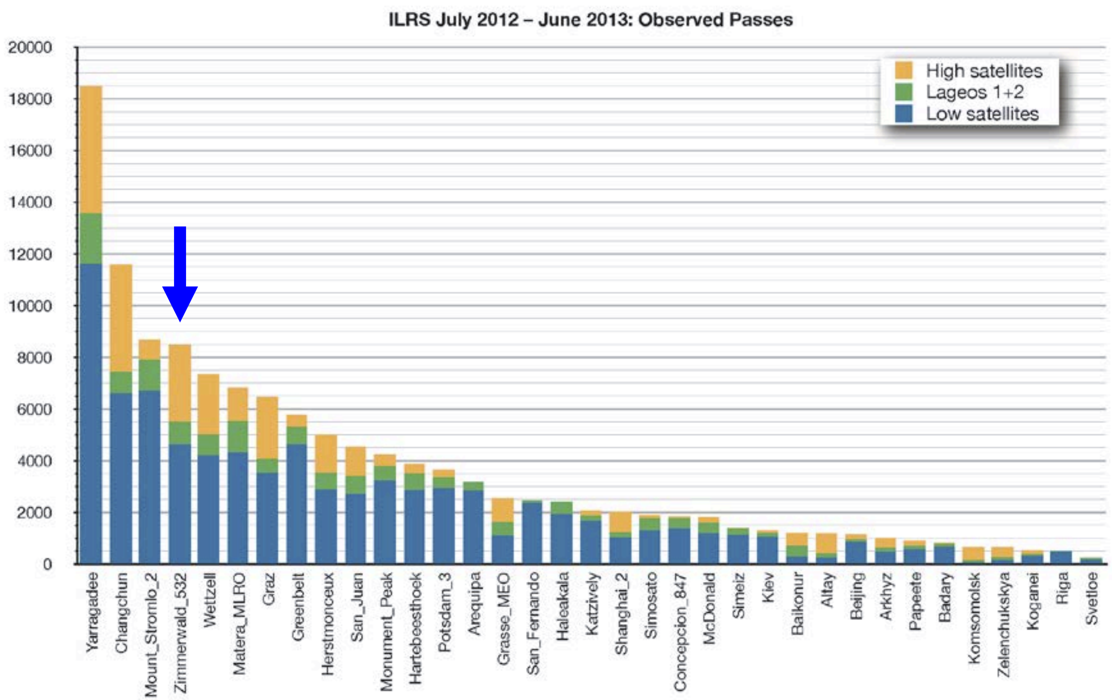


Beobachtete Durchgänge



Der Ausfall des Lasers und das ausgesprochen schlechte Wetter sind für den massiven Einbruch in der Beobachtungsstatistik verantwortlich.

Beobachtete Durchgänge



Aufgrund der geschilderten Umstände war Zimmerwald 2013 nicht mehr die produktivste Station der nödlichen Hemisphäre

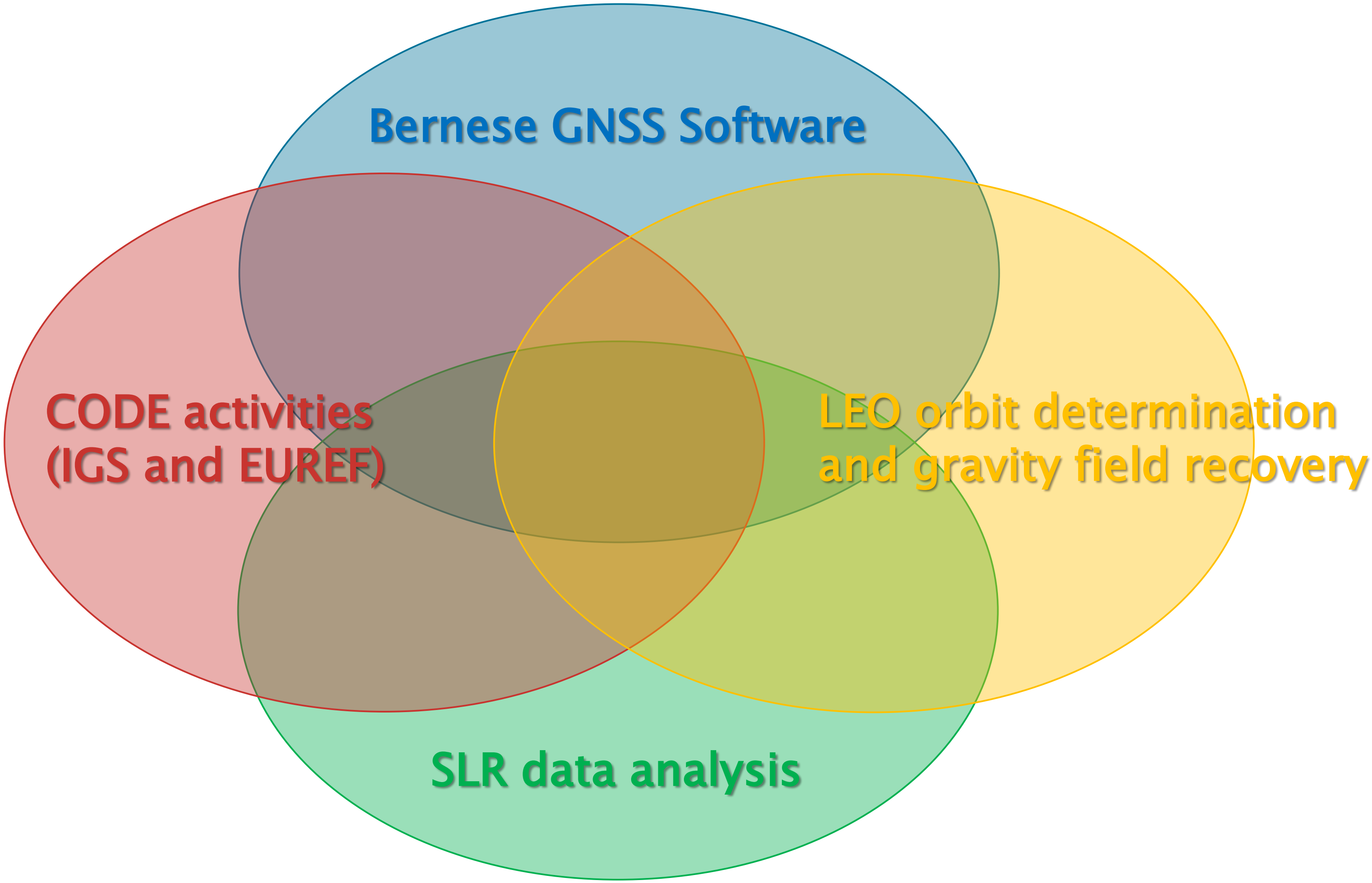
Aktivitäten der Forschungsgruppe Satellitengeodäsie am AIUB

R. Dach und Adrian Jäggi

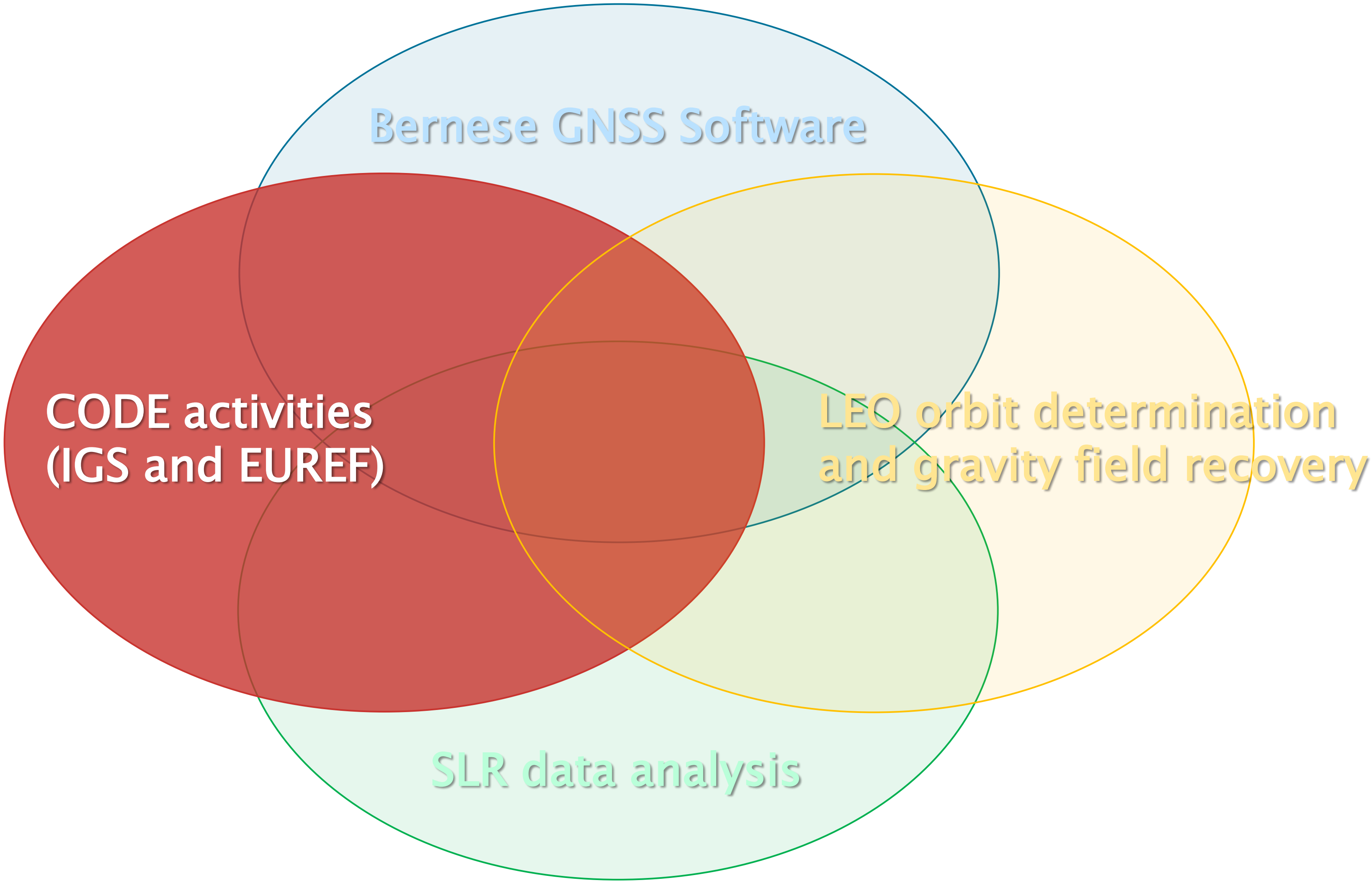
D. Arnold, C. Baumann, S. Bertone,
H. Bock, Y. Jean, S. Lutz, U. Meyer,
E. Orliac, L. Prange , S. Schaer,
~~D. Thaller~~, K. Sosnica, P. Walser

Astronomisches Institut

Satellite Geodesy Research Group



Satellite Geodesy Research Group



New processing line for the CODE-analysis center

Station/data quality monitoring

- in the evening a PPP procedure based on the submitted CODE rapid products starts
  - about 300 stations are included
  - four solutions are generated:
    GPS+GLONASS: code+phase (classical PPP) and phase-only
    GPS-only, GLONASS-only: phase-only
- Evaluation of the resulting time series is primary intended as a preparation for the upcoming final procedure:

```
==========================================================================
 SERIES OF PROBLEMATIC STATIONS FROM GNS-SOLUTION:
==========================================================================


                                    13300   13301   13302   13303   13304   13305   13306


 UNSA 41514M001   N    3.84         -6.82    1.34    4.28    0.39   -0.70    4.07   -2.15
 UNSA 41514M001   E   11.41        -24.45   -0.24    3.88    7.43   -1.04   10.15    2.92
 UNSA 41514M001   U   12.51        -17.15    5.06   23.07   -2.67   -8.84    0.33    1.05

 WUHN 21602M001   N    5.36         -3.28   -0.28    5.44    9.23   -1.33    6.43    1.94
 WUHN 21602M001   E   11.51          0.23    1.48  -10.64   18.67    5.73   16.34   -5.53
 WUHN 21602M001   U   17.85         12.65   -5.74  -18.65  -33.19   11.65   -5.41   10.26
```

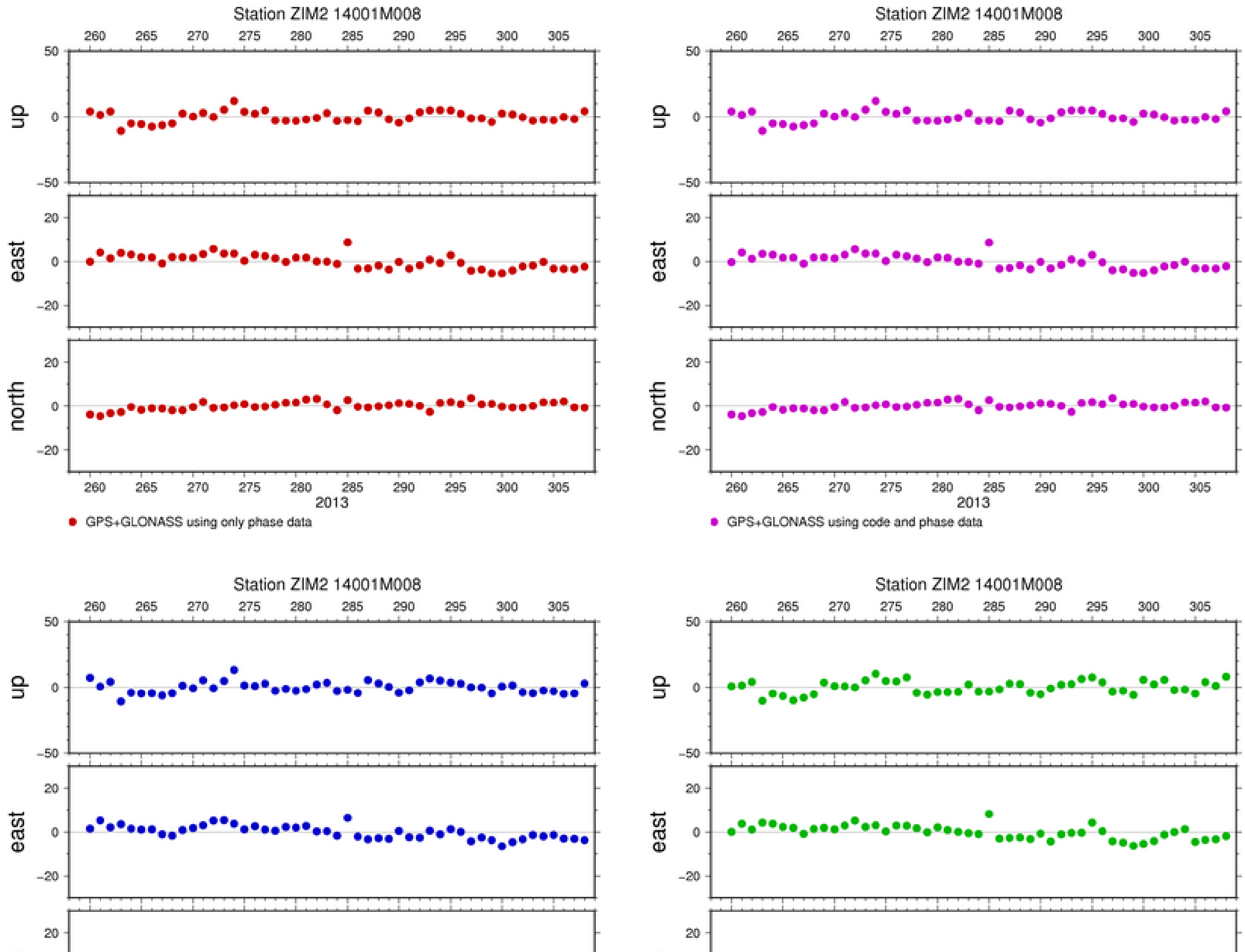
Time series from the recent PPP solutions

Go to: [most recent PPP solution](#).


```
List of solutions:

GNS:   GPS+GLONASS   phase        static PPP
GPS:   GPS           phase        static PPP
GLO:   GLONASS       phase        static PPP
```

Stability of the recent PPP solutions:



CODE-contribution to IGS final solution and repro2-initiative

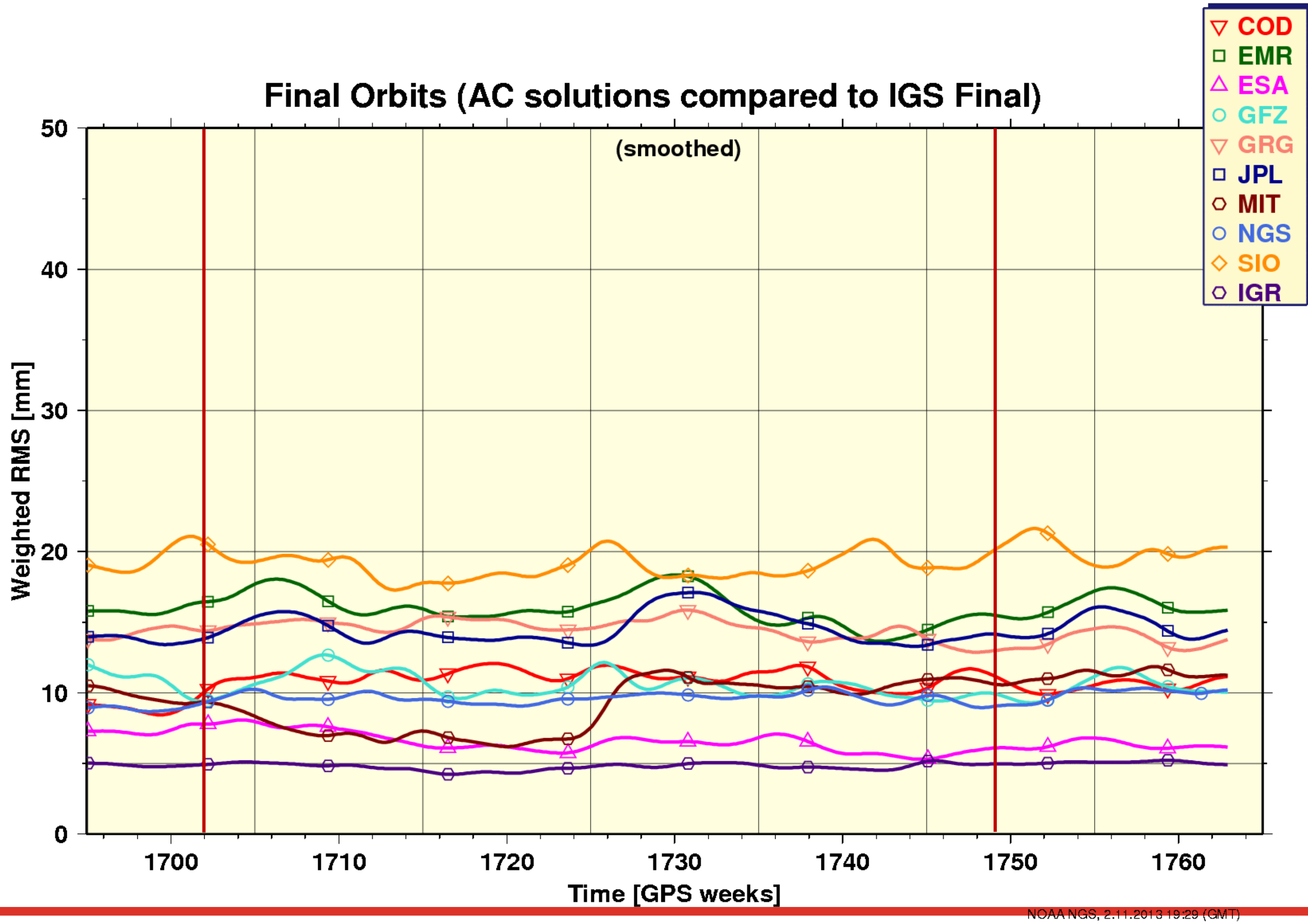
Modeling updates in CODE's processing

- Update in orbit modeling according to IERS- and IGS-guidelines:
  - JPL-ephemeris: DE405 to DE421
  - Albedo model according to Rodriguez-Solano et al. 2012
  - Antenna thrust (GPS: block-specific; GLONASS: assumed to 100W)
  - No a priori RPR model anymore
- Observation type selection based on RINEX3 type definition

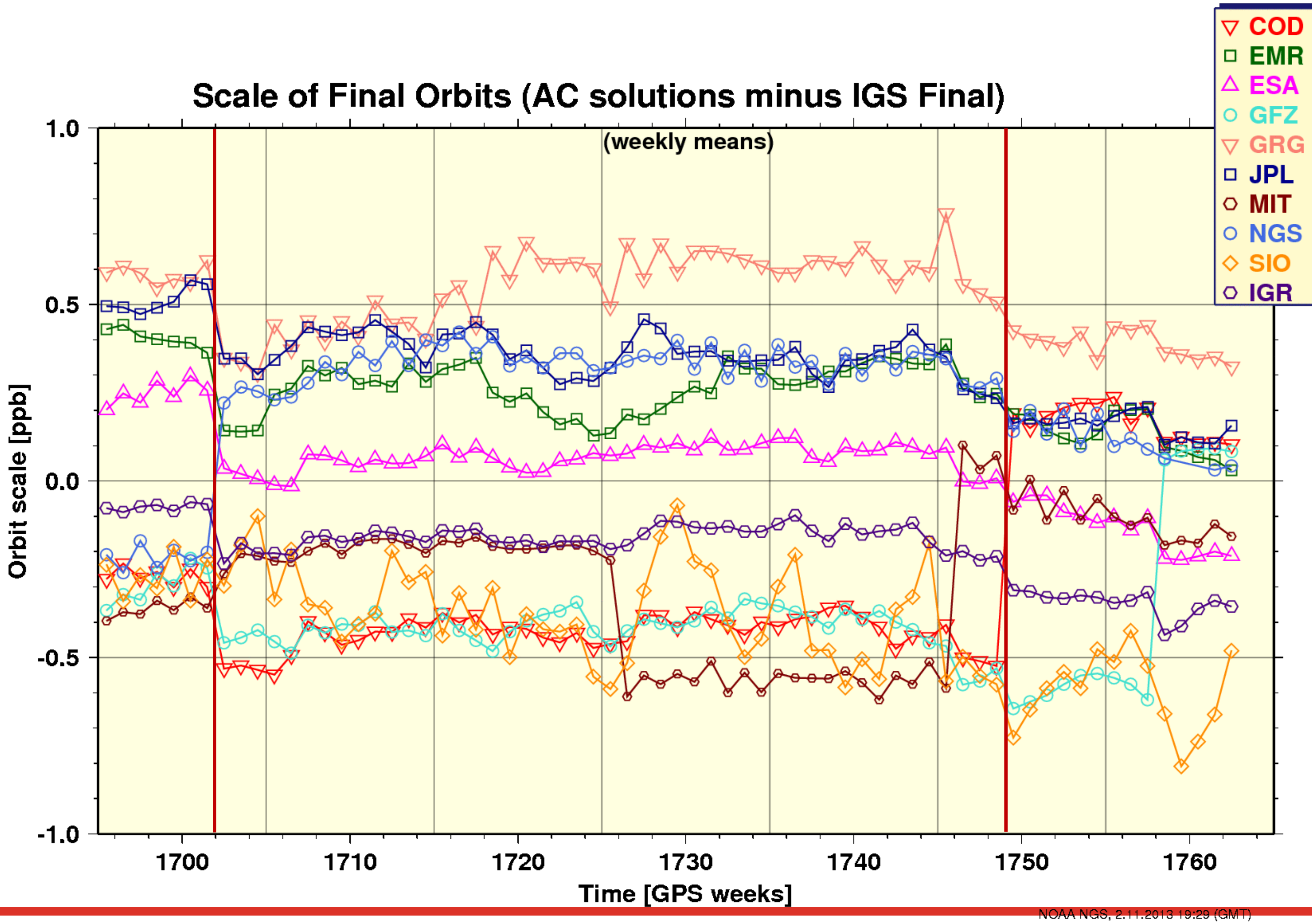
- Minimum accuracy code in the precise orbit files is 1 (instead of 0 for the best satellites).
- Modified reference clock selection for the CLKFINAL-highrate and ultra-highrate solutions

- Major event in July: outage of the VMF1-server in Vienna (automated switch to GPT/GMF)

Modeling updates in CODE's processing



Modeling updates in CODE's processing



CODE contribution to IGS–repro02

- considering the updates in the orbit modeling as defined by the IGS in particular for IGS–repro02
- pure one–day and three–day long–arc solution
- GLONASS considered since January 2002
- computation has been performed at CODE–partner TU Müchen coordinated with AIUB (mainly performed by P. Steigenberger).

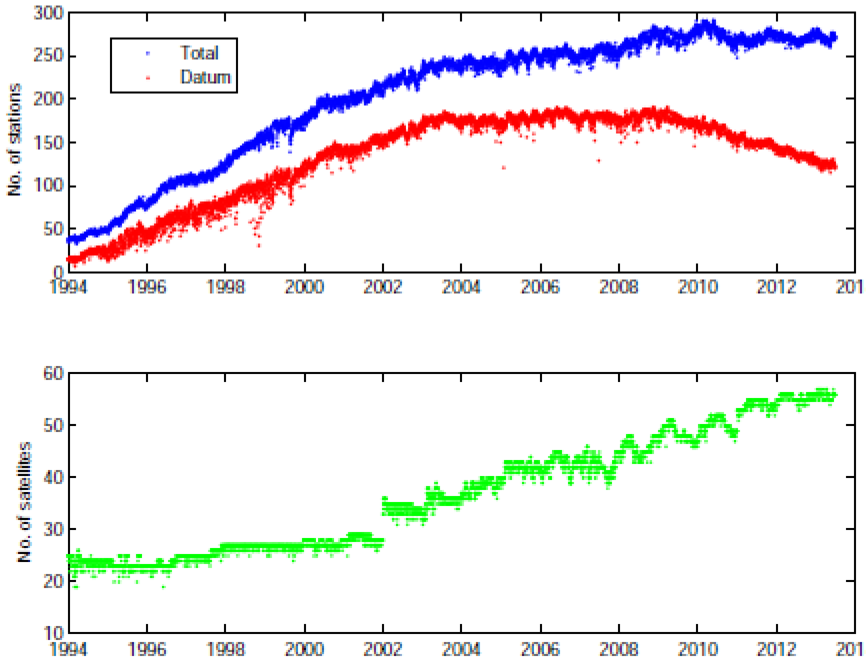


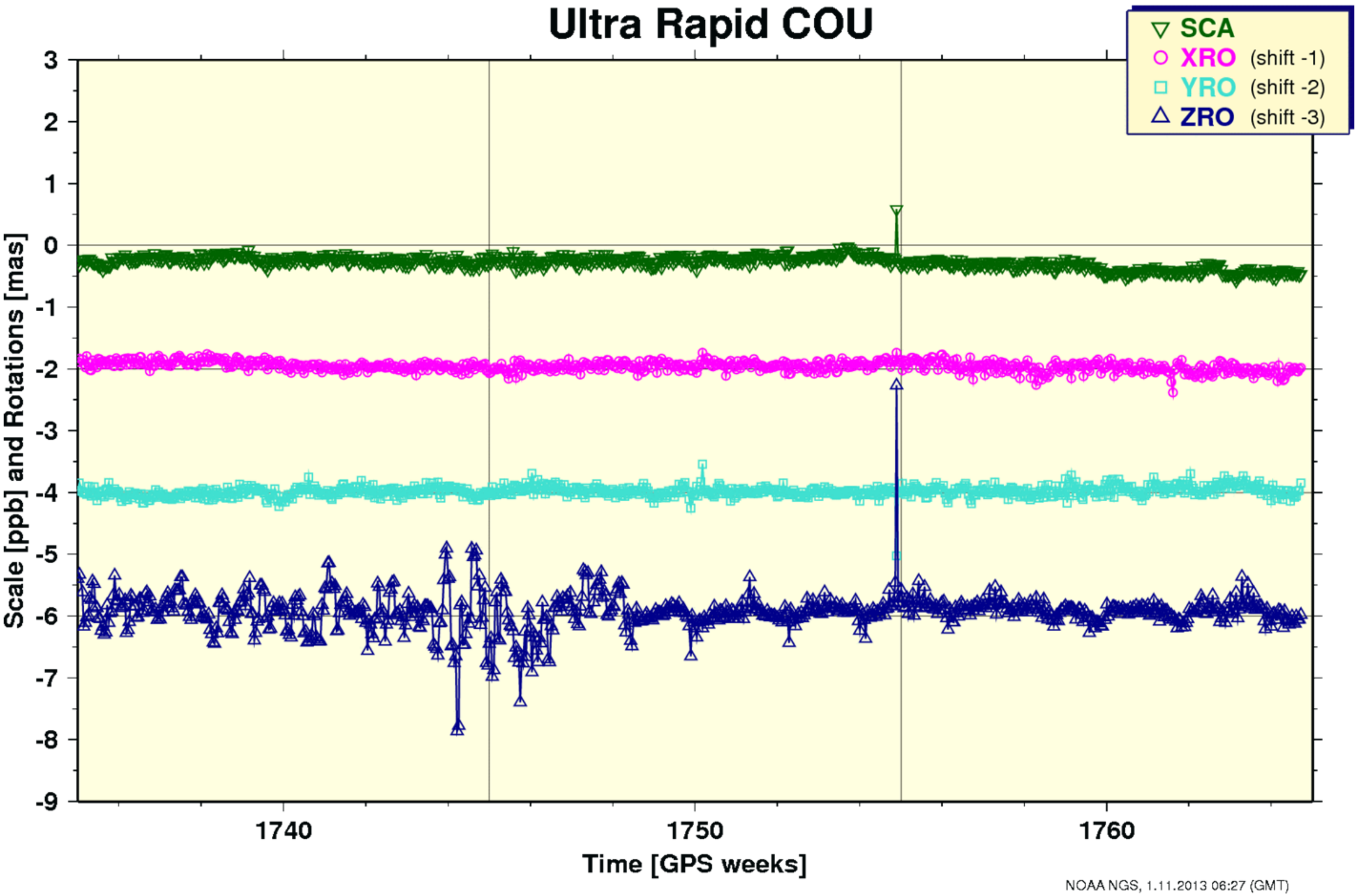
Figure 2: Total number of stations, number of datum stations, and number of satellites.

CODE-contribution to IGS ultra-rapid solution

Update of CODE's ultra-rapid product

- **Problem**
  Large z-rotations in the comparisons of our orbits w.r.t. the combined IGS ultra-rapid product and the solutions of other ACs
- **1st step**
  - Consistent use of Earth rotation parameters (ERP) for the integration and prediction of the orbits and the transformation to the terrestrial frame
  - Submitted since 11-Jul-2013 (GPS week 1748)

CODE's ultra-rapid orbits w.r.t the IGS ultra-rapid product



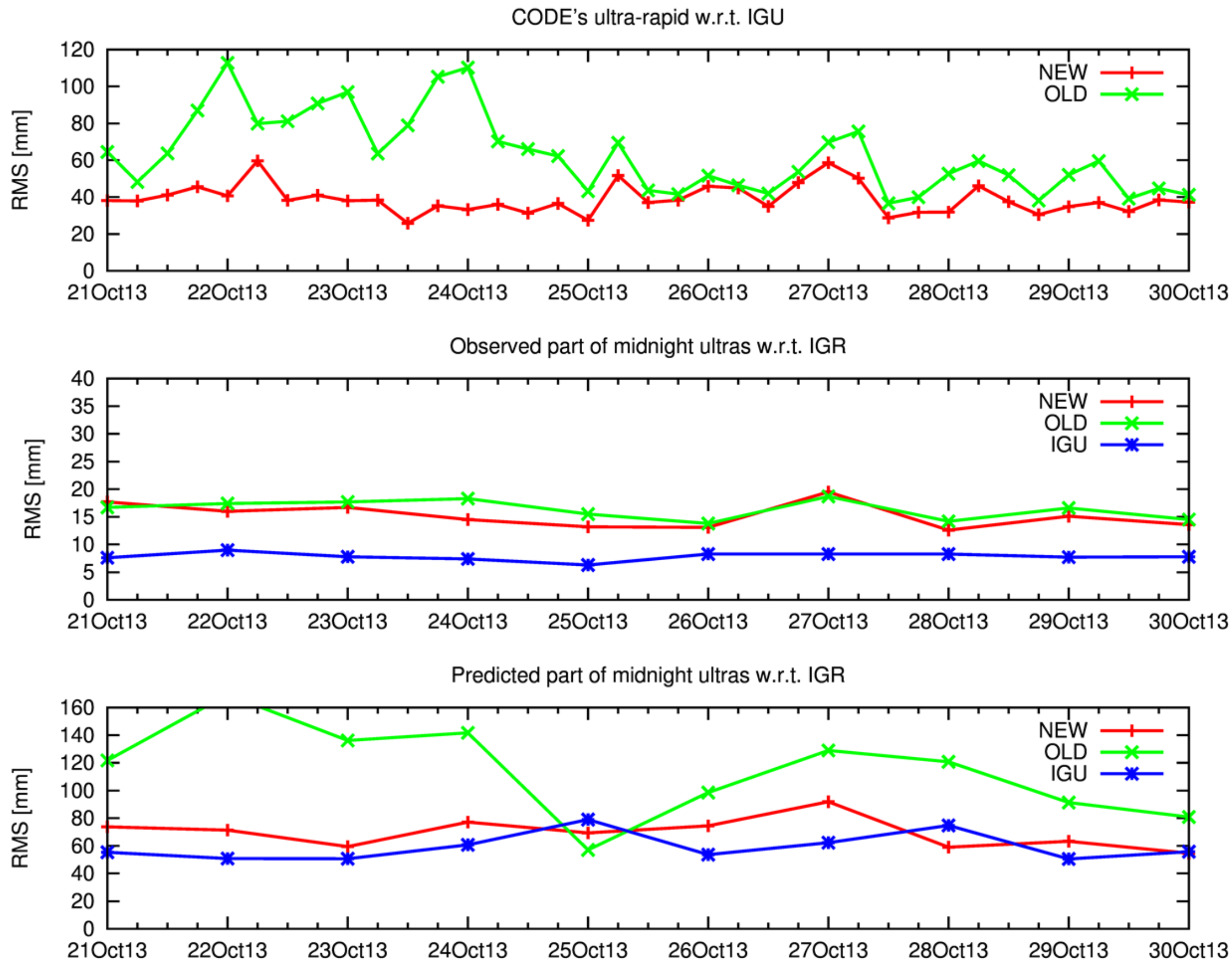
Update of CODE's ultra-rapid product

- Problem
  Large z-rotations in the comparisons of our orbits w.r.t. the combined IGS ultra-rapid product and the solutions of other ACs
- 1st step
  - Consistent use of Earth rotation parameters (ERP) for the integration and prediction of the orbits and the transformation to the terrestrial frame
  - Submitted since 11-Jul-2013 (GPS week 1748)
- 2nd step: Redesign of the procedure
  - Best possible orbit representation in the observed time intervall (48h+) on NEQ-level and followed by an orbit integration including the orbit prediction
  - Not yet submitted

2nd step: Redesign of the procedure

- Best possible orbit representation in the observed time interval (48h+) with stochastic orbit parameters every 12 hours (12UT and 00UT)
- ERP parameterization with 24h linear pieces in the observed part and linear extrapolation for the predicted part
- Prediction of the orbits with 9 empirical parameters integrated over the last observed 48 hours
- Not yet submitted

RMS of the orbit comparisons in the terrestrial frame without transformation parameters



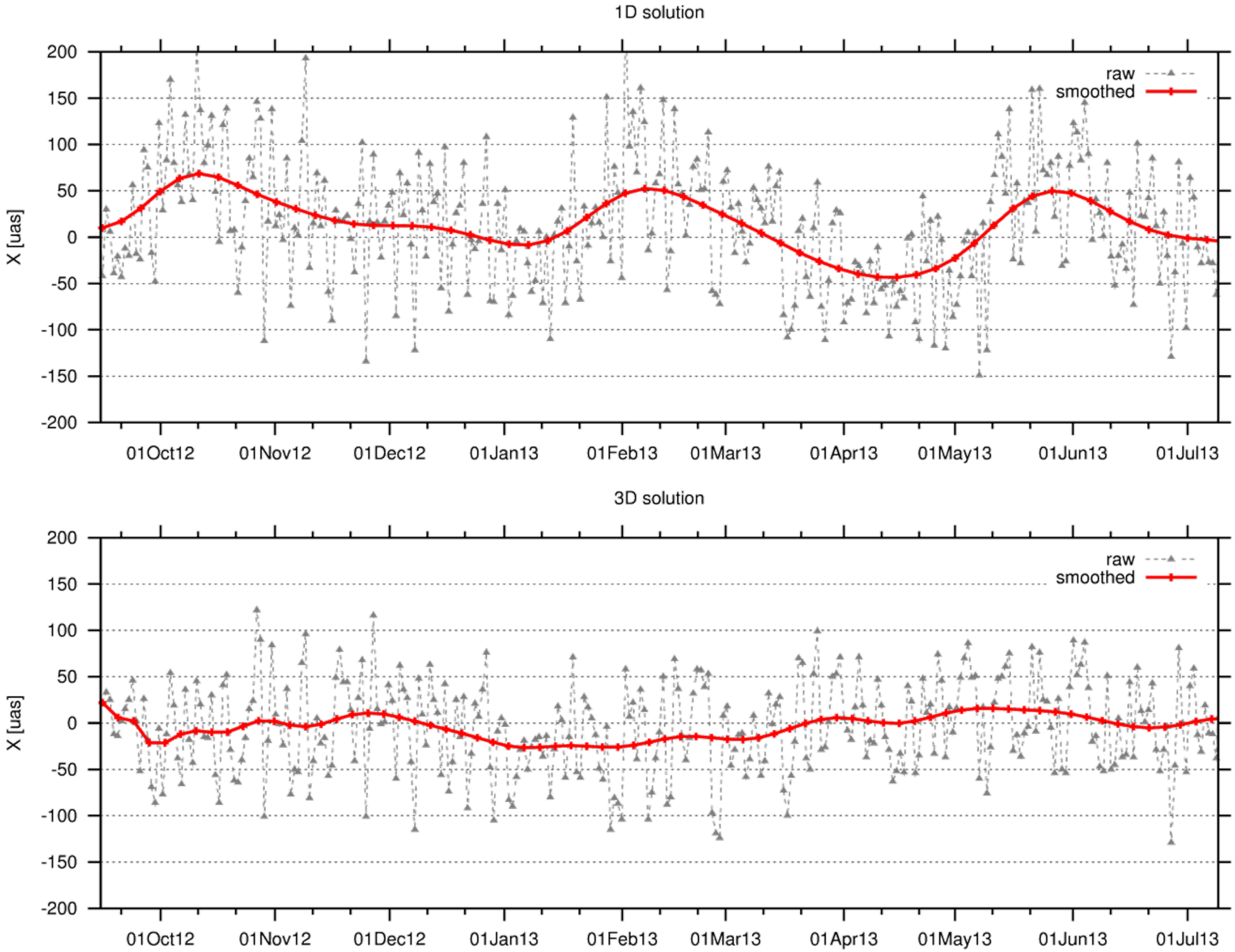
Clean one-day solution versus three-day long-arc solution (experience at CODE)

CODE's final series

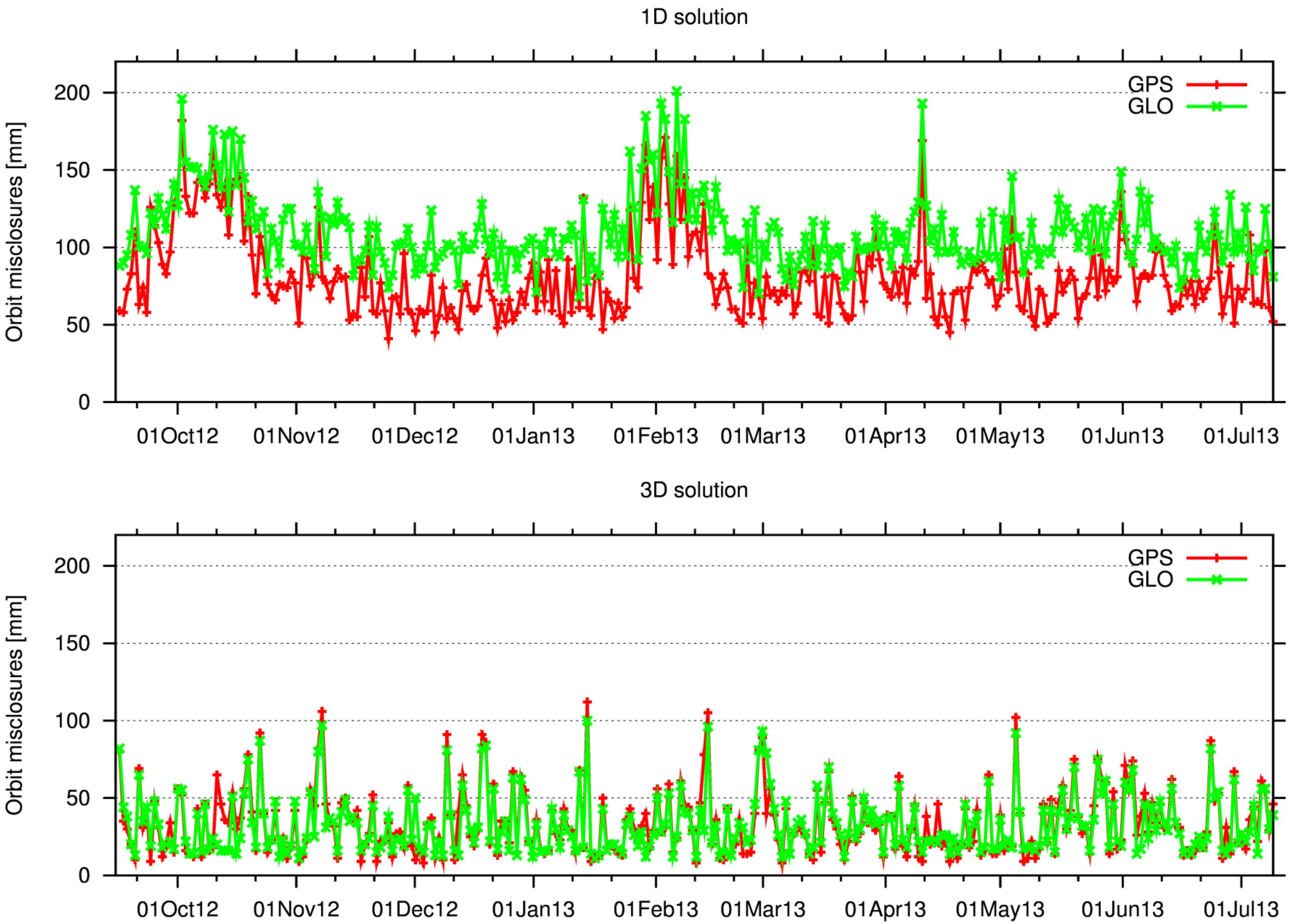
- Since GPS week 1706 (16-Sep-2012), CODE has been generating two consistent sets of combined GPS+GLONASS solutions for the IGS final product series:
  - A clear-cut 1-day solution (used for the official combined GPS-only products of the IGS)
  - A solution based on overlapping 3-day orbital arcs and on a continuous, 24-h piece-wise linear ERP representation (used for the combined GLONASS-only products of the IGS)

- Where does the arc-length play an important role?
  - Continuity at day boundaries (00 UT)
  - GNSS specific frequencies
  - Correlation between orbital elements and ERPs
  - Estimation of ERP rates

Differences of the estimated X pole with respect to Bulletin A



Mean orbit misclosures of all non-eclipsing GPS&GLONASS satellites in the terrestrial frame



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Modeling GNSS Orbits, Earth Rotation and Station Coordinates at the CODE Analysis Center

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Abstract Prior to GPS week 1706, starting on September 16, 2012, the daily products of the CODE (Center for Orbit Determination in Europe) analysis center of the IGS (International GNSS Service) were based on overlapping three-day arcs for GPS and GLONASS satellites and on continuous, piecewise linear Earth Rotation Parameters (ERPs) (linear within each day and continuous at the interior day boundaries). The product referred to the estimated weekly set of coordinates. The ERPs were made continuous over the entire week. The associated CODE product series was labeled as "COD". This traditional CODE series was slightly modified and continued with a slight modification (see Sec. 5.1) after has to be fixed to one value of the a priori pole file for each individual solution of the COD and COF series.

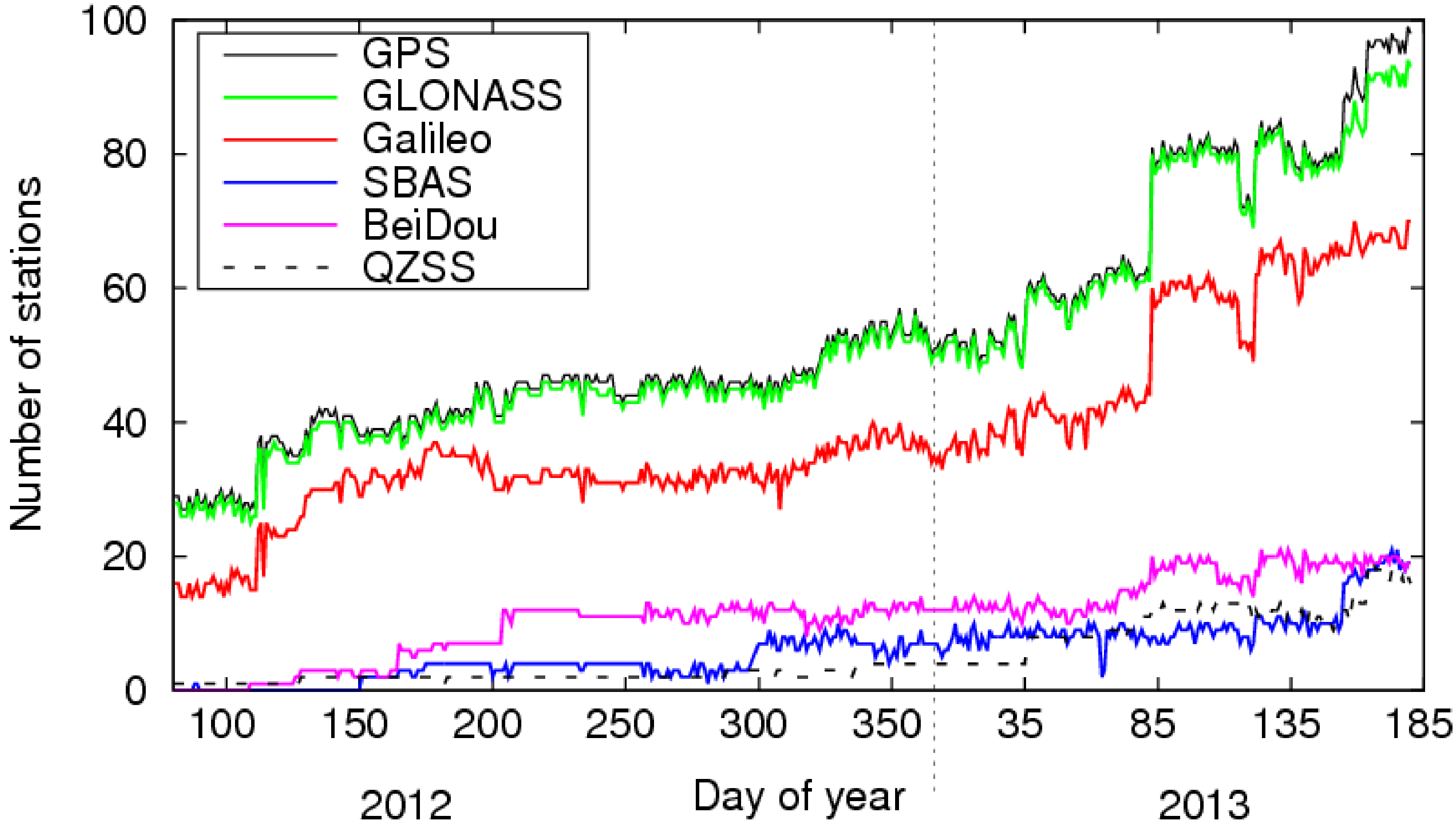
(Dis)continuity at the day boundaries of the three-day solutions in one or more of the physical models (Earth rotation, orbits, troposphere) are defining elements of the mathematical models underlying the adjustment. They have to be declared as defining elements, therefore they are neither "right" nor "wrong".

Our study is primarily motivated by the modifications of the principal CODE product required by GPS week 1702 and implemented in GPS week 1706. The CODE product is a combined GPS/GLONASS prod-

CODE-contribution to IGS Multi-GNSS Experiment (MGEX)

MGEX data monitoring

Satellite systems being monitored (RINEX3 files):



New RINEX file monitoring at CODE

EUREF
Symposium 2013
29 – 31 May 2013, Budapest (Hungary)

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Introduction

The availability of consistent tracking data is a prerequisite to process the signals of the Global Navigation Satellite Systems (GNSS) and to generate best possible analysis products. In this context, the Center for Orbit Determination in Europe (CODE) has developed an extensive monitoring of the RINEX observation files in order to improve the reliability of the derived products.
In the frame of the Multi-GNSS Experiment (MGEX) of the International GNSS Service (IGS), CODE has extended its file monitoring procedure to the new signals and GNSS defined in RINEX-3 to handle the increasing number of satellites, systems and observation types. This procedure has also been applied to the RINEX-3 files from the EUREF Permanent Network (EPN).
Daily updated GNSS specific summaries for all stations and satellites can be found at:
ftp://ftp.unibe.ch/aiub/mgex
There is a README.TXT explaining the content of these summaries.

New procedure

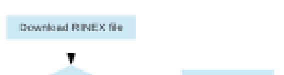
- Perl routines for reading the entire RINEX files and for writing extensive meta-data files in XML format (standard packages)
- Evaluation and comparison of the RINEX data
- Generation of daily and monthly summaries
- Possibility to filter stations according to given properties (equipment, satellite systems, observation types, ...)

Structure of XML file

- **FILE section**: Information on download (e.g., download time, availability at data centers) and RINEX file specifications
- **HEADER section**: All relevant parts from the RINEX file header with consistency tests, e.g., with respect to the RINEX format description or external files (rcvr_ant.tab of IGS for receiver and antenna types)
- **RDATA section**: Information on epochs (first, last, number, event flags, etc.), number of observation types and combinations for each satellite, loss of lock and S/N ratio summaries
- **XML section**: Information on the XML file itself

Update of datapool

Data download can be optimized using specific criteria stored in the XML files to compare with already existing RINEX files in the datapool.



RINEX-3 data sources

For global multi-GNSS activities, RINEX-3 files are freely available from the stations of the IGS-MGEX network, other IGS stations, as well as from some EPN stations:
ftp://igs.bkg.bund.de/EUREF/obs_v3

EPN stations providing RINEX-3

At present, there are about 20 stations of the EUREF Permanent Network (EPN) not participating in MGEX but delivering GNSS observation data in RINEX-3 format.
The following statistics are based on daily RINEX-3 files of these EPN stations for day 141 of 2013 (21-May-2013).

Map of the EPN stations providing RINEX-3.

```
  5.0%  JAVAD TRE_G3TH DELTA   MAKKRINEX 2.0.10850   3.02     E  G  R
 20.0%  LEICA GR10             GR10 V3.00            3.01     E  G  R
 10.0%  LEICA GR25             BNC 2.6               3.01     E  G  R
 20.0%  LEICA GR25             BNC 2.6               3.01     E  G  R  S
  5.0%  LEICA GR25             BNC 2.6               3.01        G  R
  5.0%  LEICA GR25             GR25 V2.62            3.01     E  G  R  S
 10.0%  LEICA GR25             GR25 V3.00            3.01     E  G  R
 10.0%  LEICA GRX1200GGPRO     BNC 2.4               3.00        G  R
 15.0%  TRIMBLE NETR9          NetR9 4.80            3.02  C  E  G  R  S
```

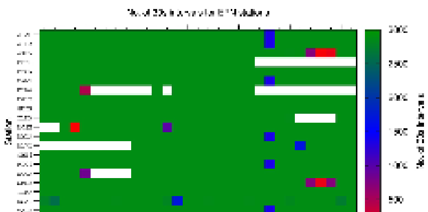
Variety of receiver types, programs creating the RINEX files, RINEX format versions and satellite systems given in the RINEX-3 files of the EPN stations. About half of the files are created using BKG Ntrip Client (BNC). Unfortunately, some stations do not provide any Galileo (E) tracking data.

```
C
100.0%  C2I C6I C7I                         L2I L6I L7I
E
 35.3%      C1X     C5X C7X C8Q                 L1X     L5X L7X L8Q
 35.3%  C1C     C5Q                         L1C     L5Q
 17.6%      C1X     C5X C7X     C8X             L1X     L5X L7X     L8X
 11.8%      C1X     C5X                         L1X     L5X                      In RINEX-2:
G
 50.0%  C1C             C2W     C2X C5X     L1C         L2W     L2X     L5X      C1 C2    C5 L1 L2 L5
 30.0%  C1C         C2S C2W C5Q             L1C     L2S L2W         L5Q          C1 C2    C5 L1 L2 L5
 10.0%  C1C     C2P                         L1C             L2P                  C1    P2    L1 L2
  5.0%  C1C             C2W         C5X     L1C         L2W             L5X      C1 C2    C5 L1 L2 L5
  5.0%  C1C C1W         C2W     C2X C5X     L1C L1W     L2W     L2X     L5X      C1 C2    C5 L1 L2 L5
R
 45.0%  C1C         C2P                     L1C         L2P
 35.0%  C1C     C2C C2P                     L1C     L2C L2P
 20.0%  C1C C1P C2C C2P                     L1C L1P L2C L2P
S
100.0%  C1C                                 L1C
```

Multitude of code and phase observation types for the different satellite systems stored in the RINEX-3 files. Together with new signals emitted by the GNSS satellites, the stations' tracking capabilities have been extended. The ambiguousness of the reported types in RINEX-2 is minimized in RINEX-3 but the selection of the optimal set of observables for the processing has become a challenging task.

Completeness of daily observation files

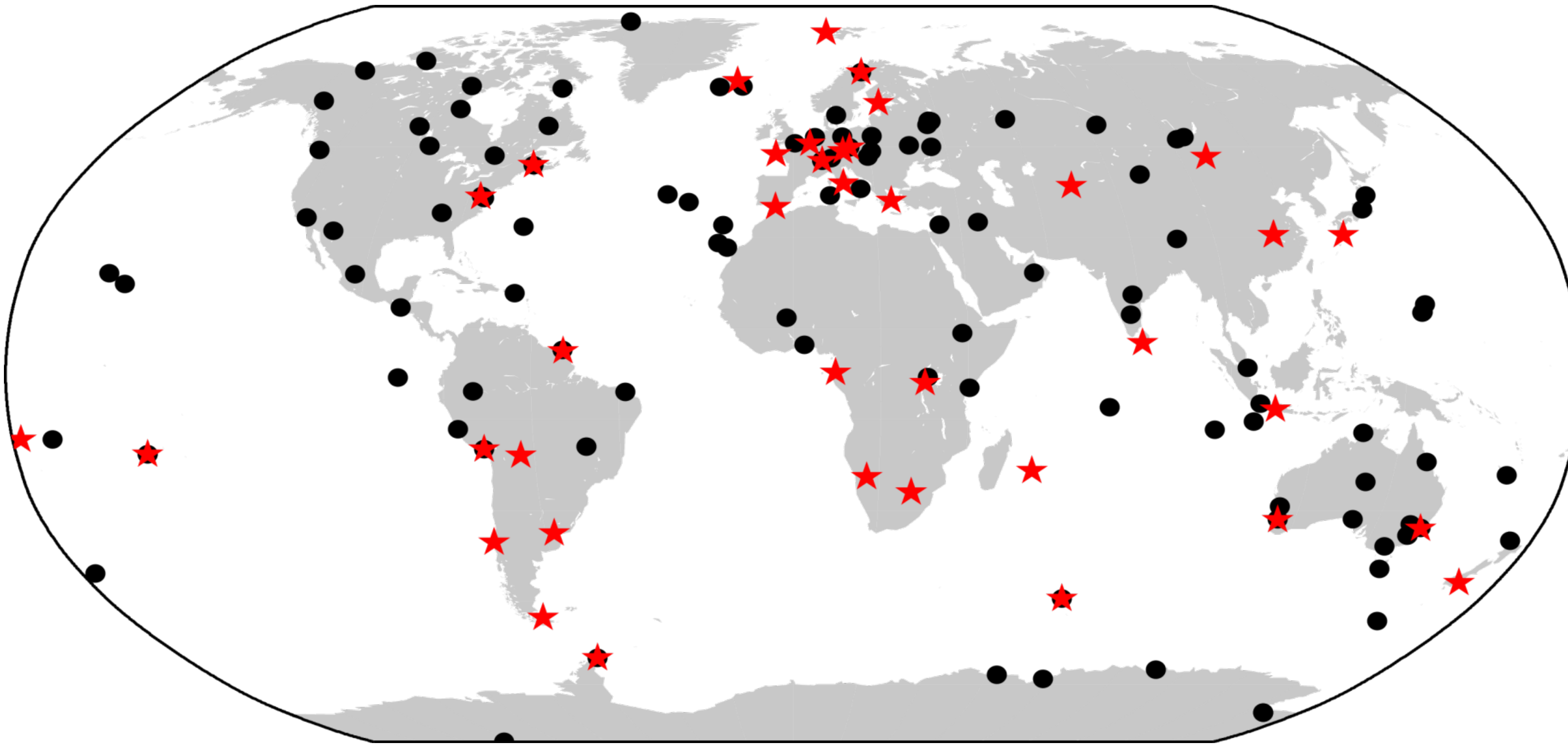
One indicator for the qualitiy of an observation file is the number of available epochs with tracking data within the nominal time span. Missing epochs cannot be compensated later on. In addition to the number of epochs at 30 seconds intervals, the number of epochs with event flags etc. can be extracted from the XML files for evaluation purposes. Furthermore, observations with loss of lock indicators are summarized over



AIUB

MGEX station distribution

Number and distribution of tracking stations contributing to the CODE MGEX orbit solution (status mid 2013)



● GPS: 145-150 GLONASS: 125 ★ Galileo: 30-40

=> 22000 – 25000 SD obs. per Sat/d

=> 18000 – 20000 SD obs. per Sat/d

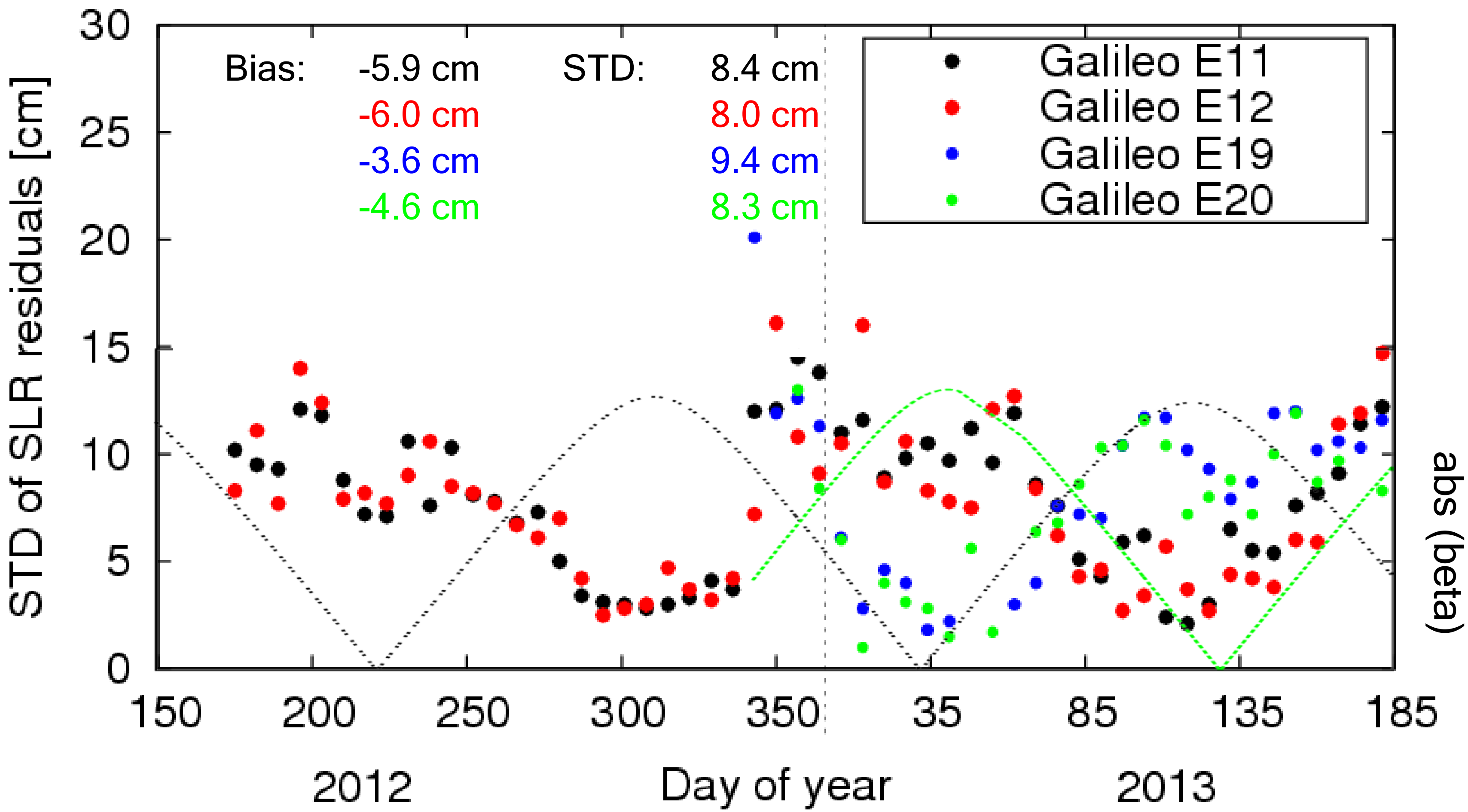
=> 4000 – 6500 SD obs. per Sat/d

MGEX orbit solution: overview

GNSS considered:	GPS + GLONASS + Galileo (up to 60 satellites)
Processing mode:	post-processing
Timespan covered:	GPS-weeks 1689-1746 (DOY 12/146-13/180)
Number of stations:	150 (GPS + GLONASS), 30 - 40 (Galileo)
Processing scheme:	double-difference network processing (observable: phase double differences)
Signal frequencies:	L1+ L2 (GPS + GLONASS), E1 (L1) + E5a (L5) (Galileo)
Orbit characteristic:	3-day long arcs
Reference frame:	IGS08 (until week 1708); IGb08 (since week 1709)
IERS conventions:	IERS2003 (until 1705); IERS2010 (since 1706)
Product list:	daily orbits (SP3) and ERPs
Distribution:	ftp://cddis.gsfc.nasa.gov/gnss/products/mgex/
Designator:	comwwwwd.???.Z

MGEX orbit validation: SLR residuals

STD of SLR residuals per week: correlation with beta angle

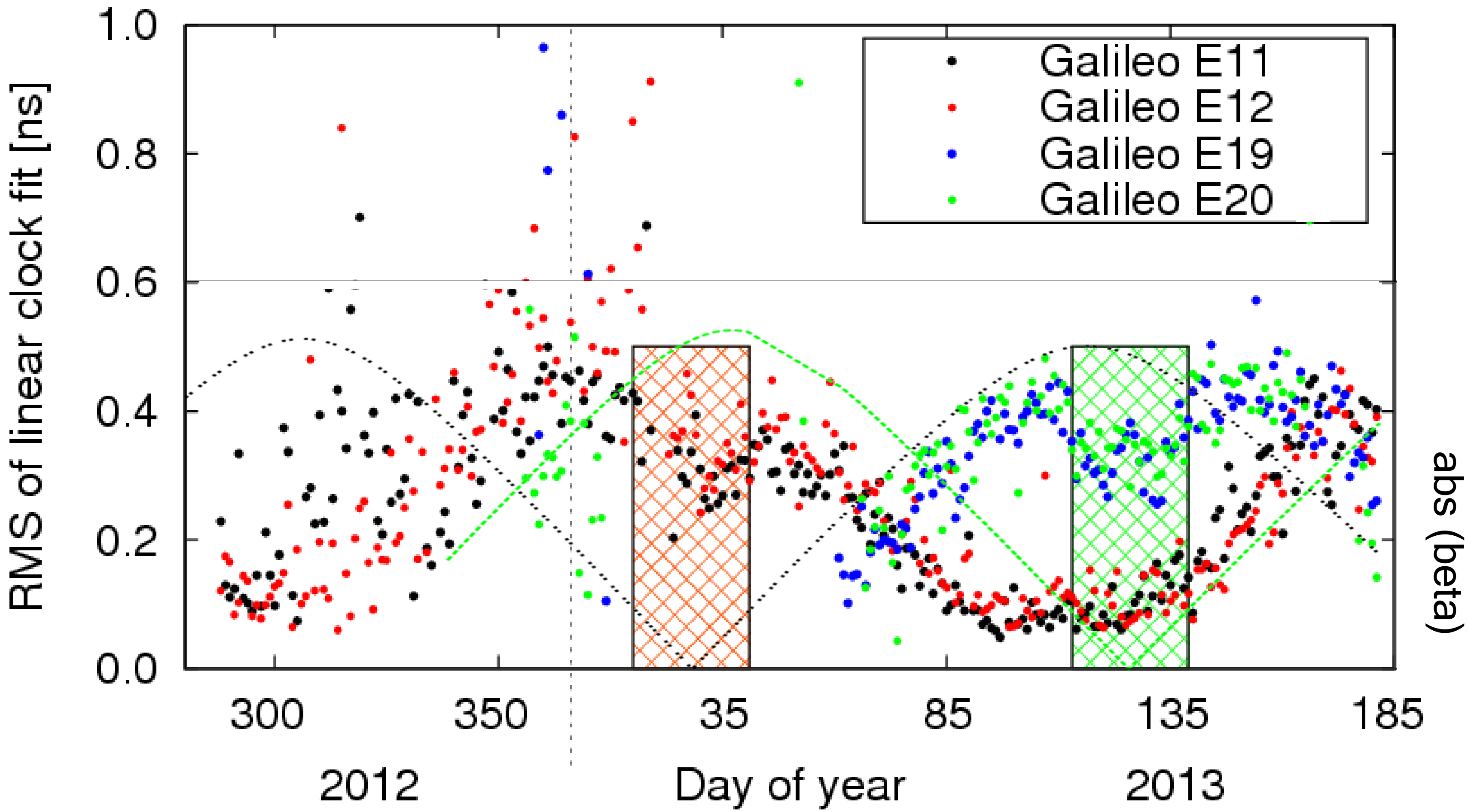


MGEX clock solution

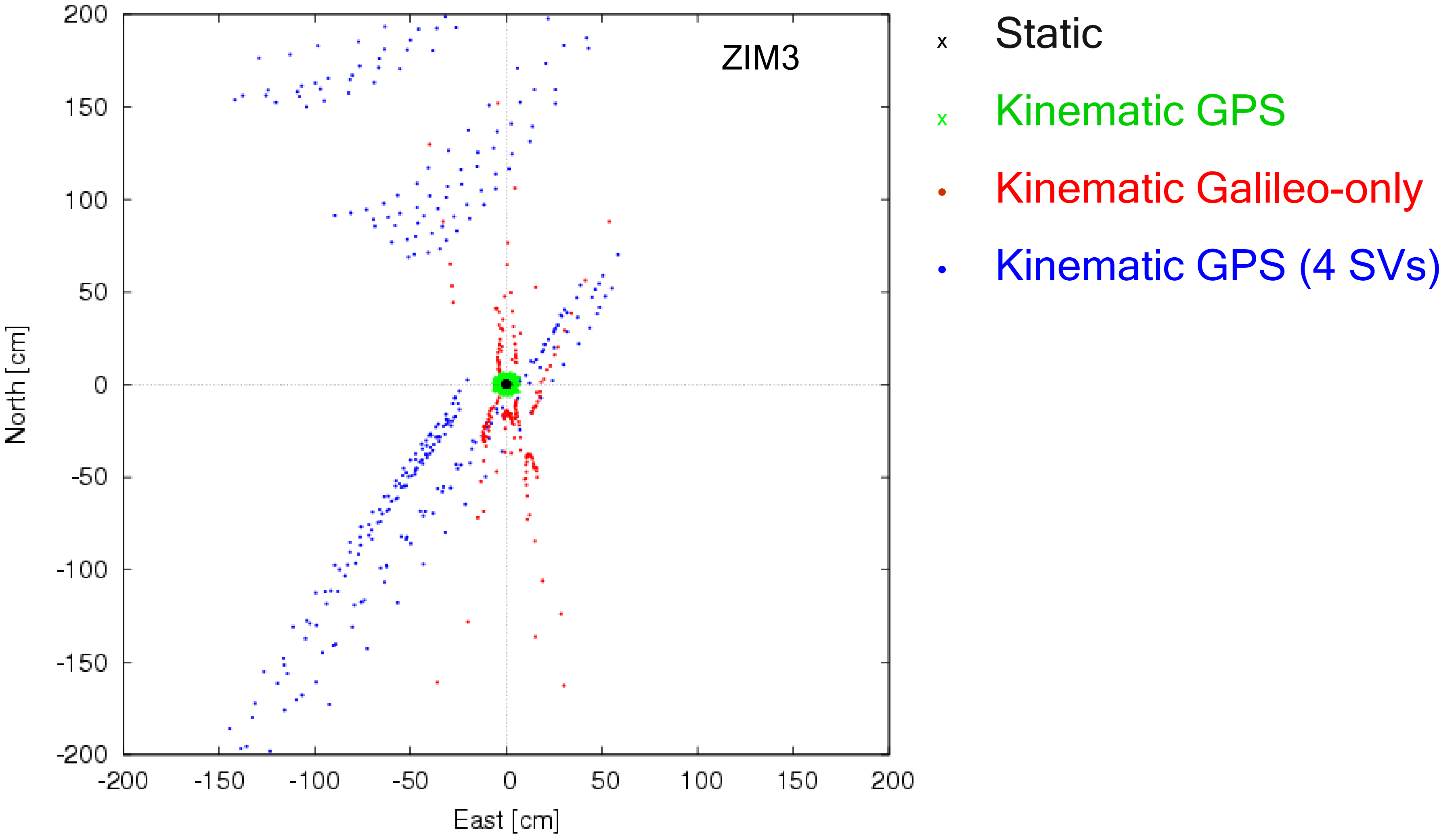
GNSS considered:	GPS + Galileo (up to 36 satellites)
Processing mode:	post-processing
Timespan covered:	GPS-weeks 1710-1746 (DOY 12/288-13/180)
Number of stations:	150 (GPS), 30 -40 (Galileo)
Processing scheme:	zero-difference network processing (observable: code+phase undifferenced)
Signal frequencies:	L1+L2 (GPS); E1(L1)+E5a (L5) (Galileo)
A priori information:	orbits, ERPs, coordinates, and troposphere from CODE MGEX orbit solution introduced as known
Reference frame:	IGb08
IERS conventions:	IERS2010
Product list:	epoch-wise (300s) satellite and station clock corrections in daily clock RINEX files; daily GPS-Galileo inter-system biases for mixed stations in Bernese DCB and BIAS-SINEX (BIA) format
Distribution:	ftp://cddis.gsfc.nasa.gov/gnss/products/mgex/
Designator:	comwwwwd.???.Z

MGEX clock solution: linear clock fit

Galileo IOV: impact of sun eclipse and beta angle



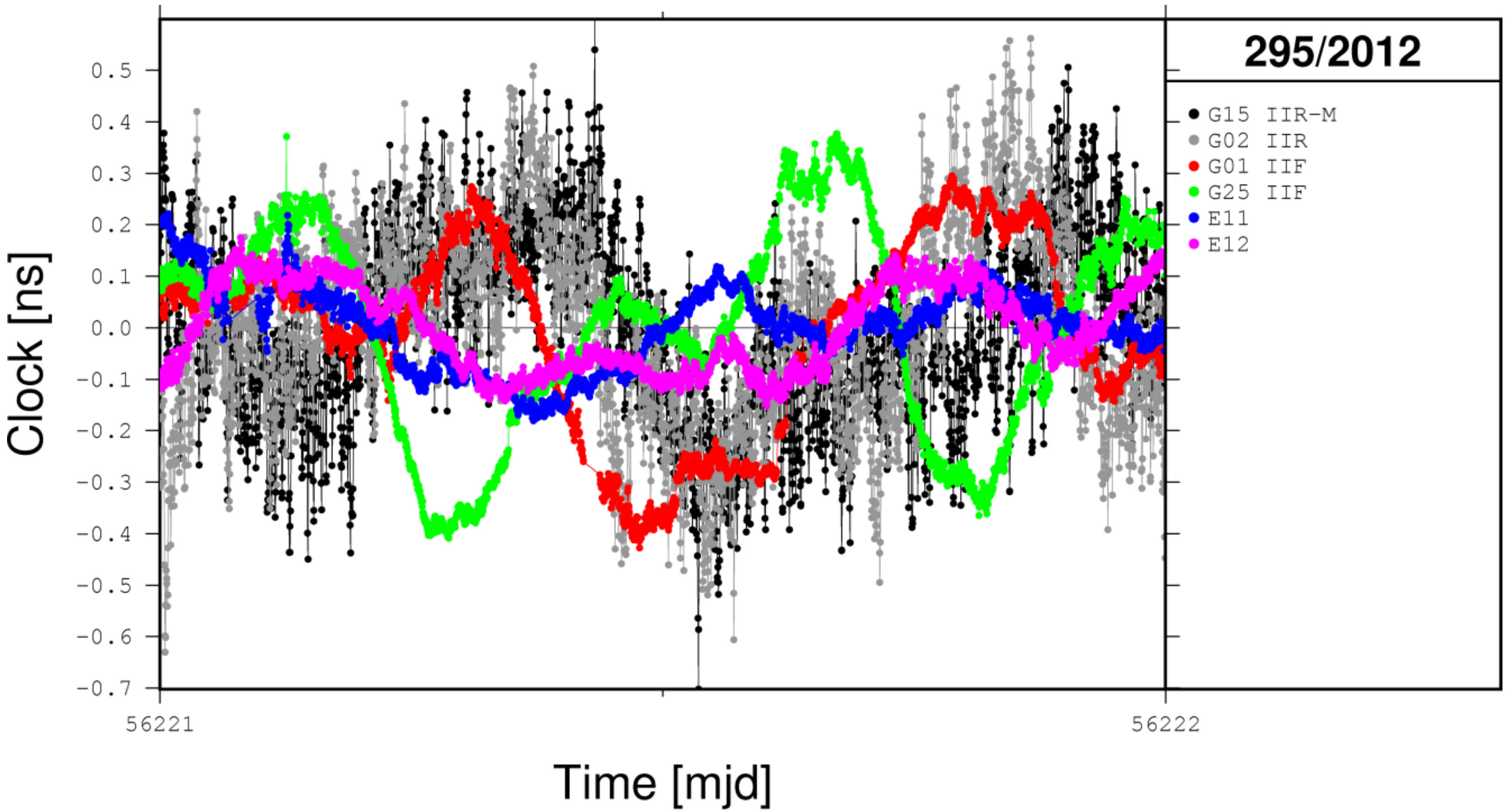
MGEX: Galileo-only PPP (DOY 75 - 84)



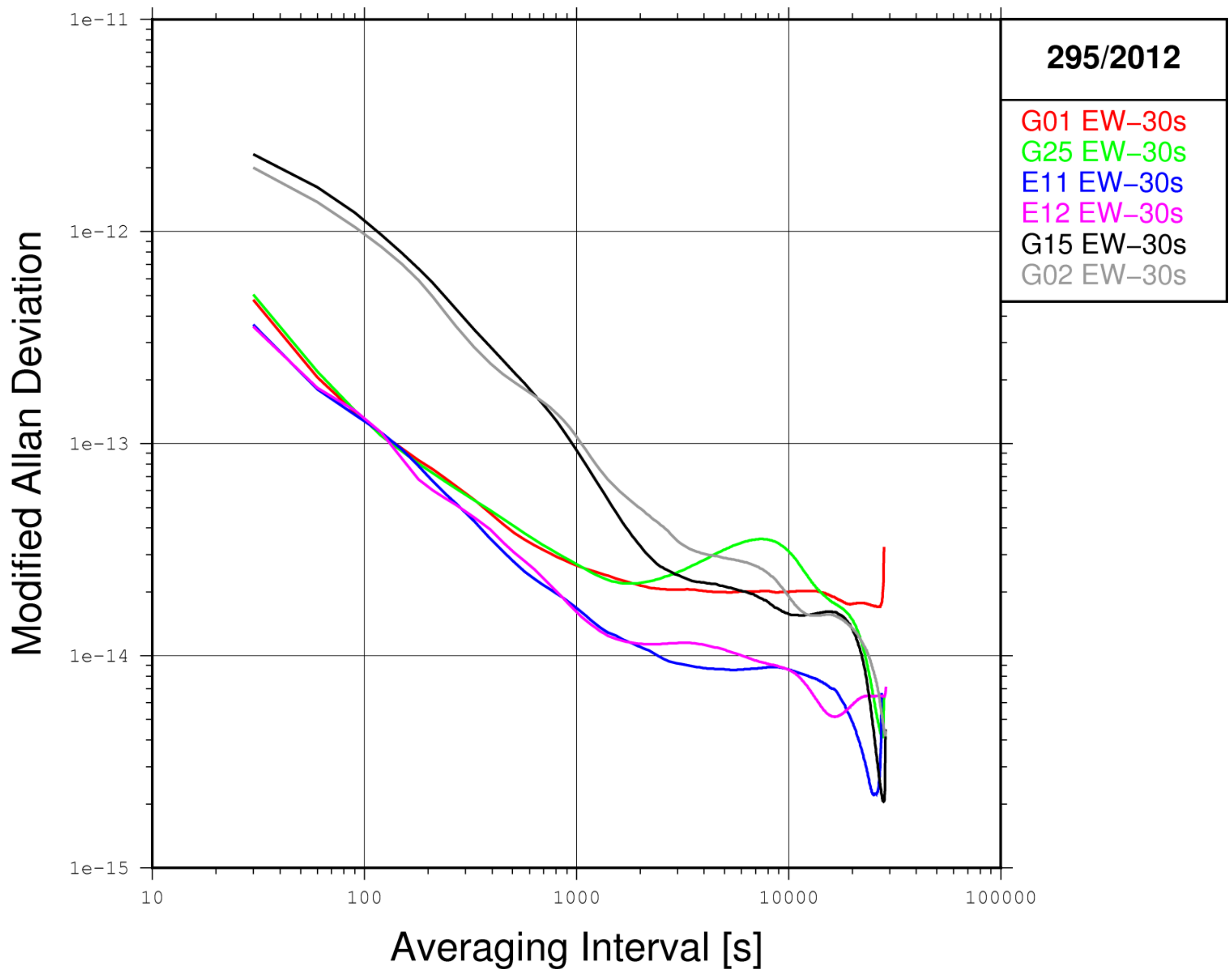
Satellite and Station Clock Modeling for GNSS

(ESA-project with ETH and TU Munich)

30 s Pure MGEX Solution (295/2012)



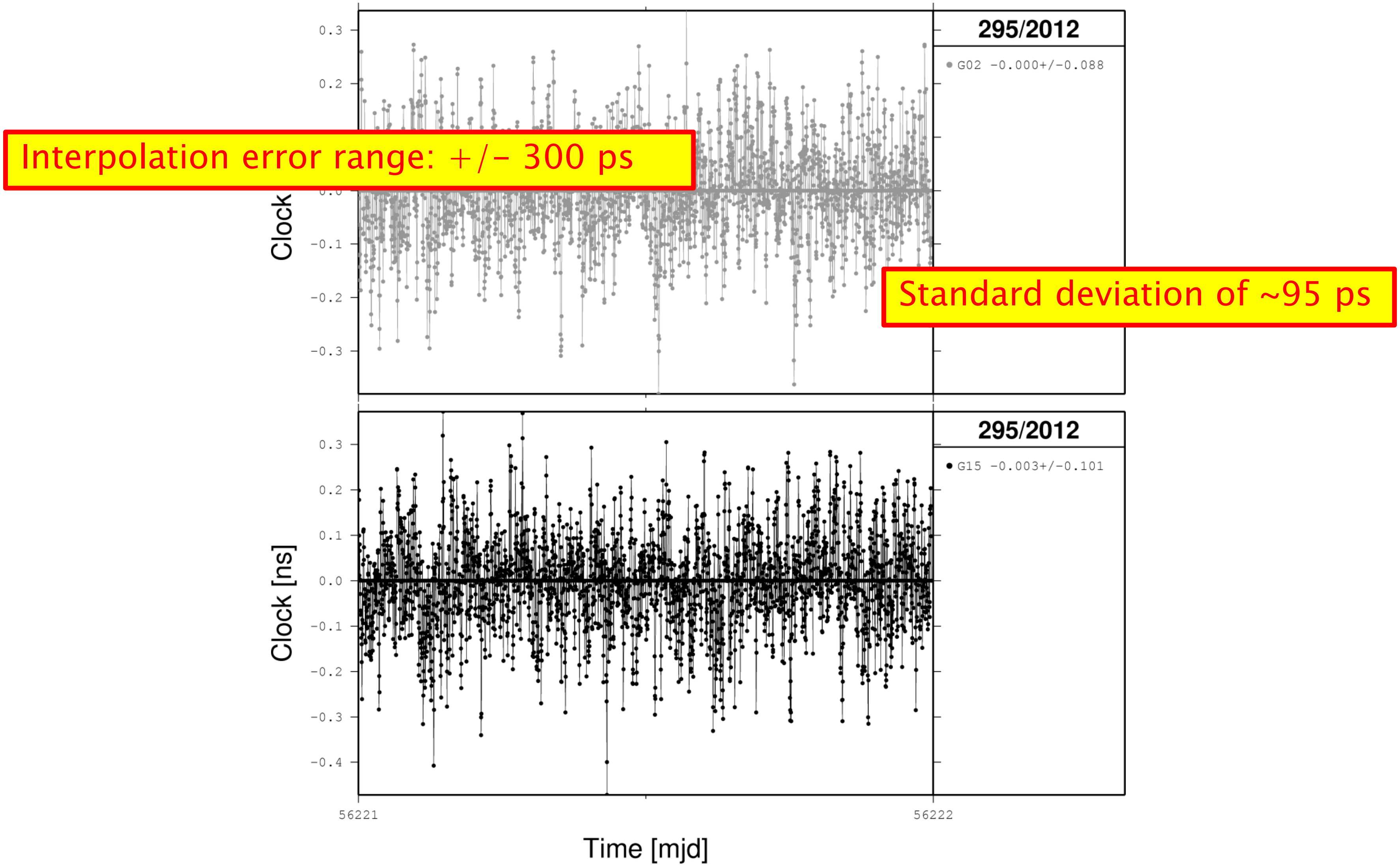
30 s (pure) MGEX Solution – 295/2012



Clock Interpolation

- 30 s estimated clocks are compared to linearly interpolated clocks over 300 s estimates (extracted from the same 30 s solution)
- The main motivation is to assess whether or not when processing 30 s data, the satellite clock could be estimated at 300 s only and interpolated in between, with an acceptable degradation of the solution
- Should be feasible if the RMS of the interpolation error is in the range of the phase measurements noise level (~10 ps for inosphere-free linear combination)

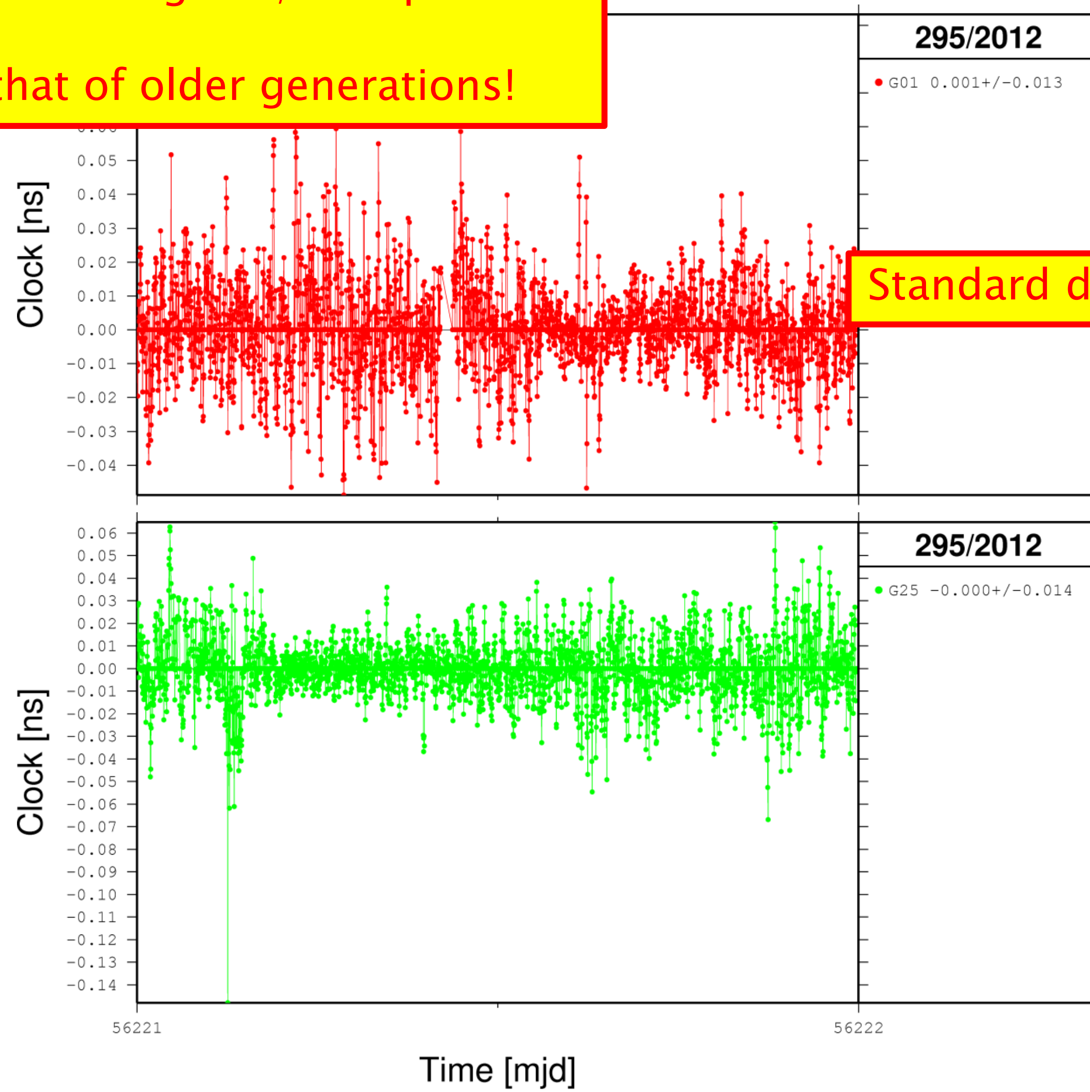
Clock Interpolation



Clock Interpolation

Interpolation error range: +/- 30 ps

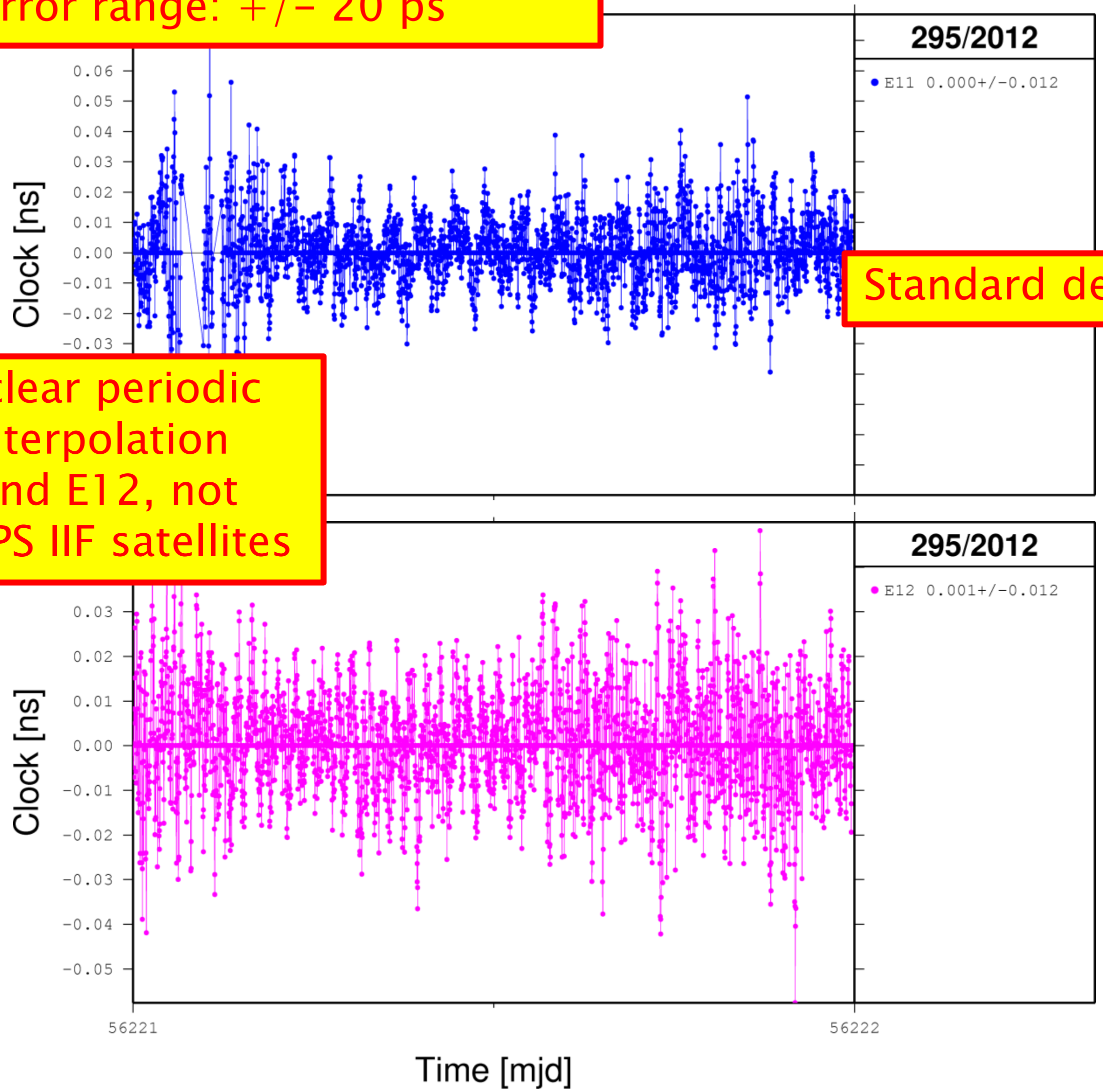
10 times less that of older generations!



Standard deviation of ~13 ps

Clock Interpolation

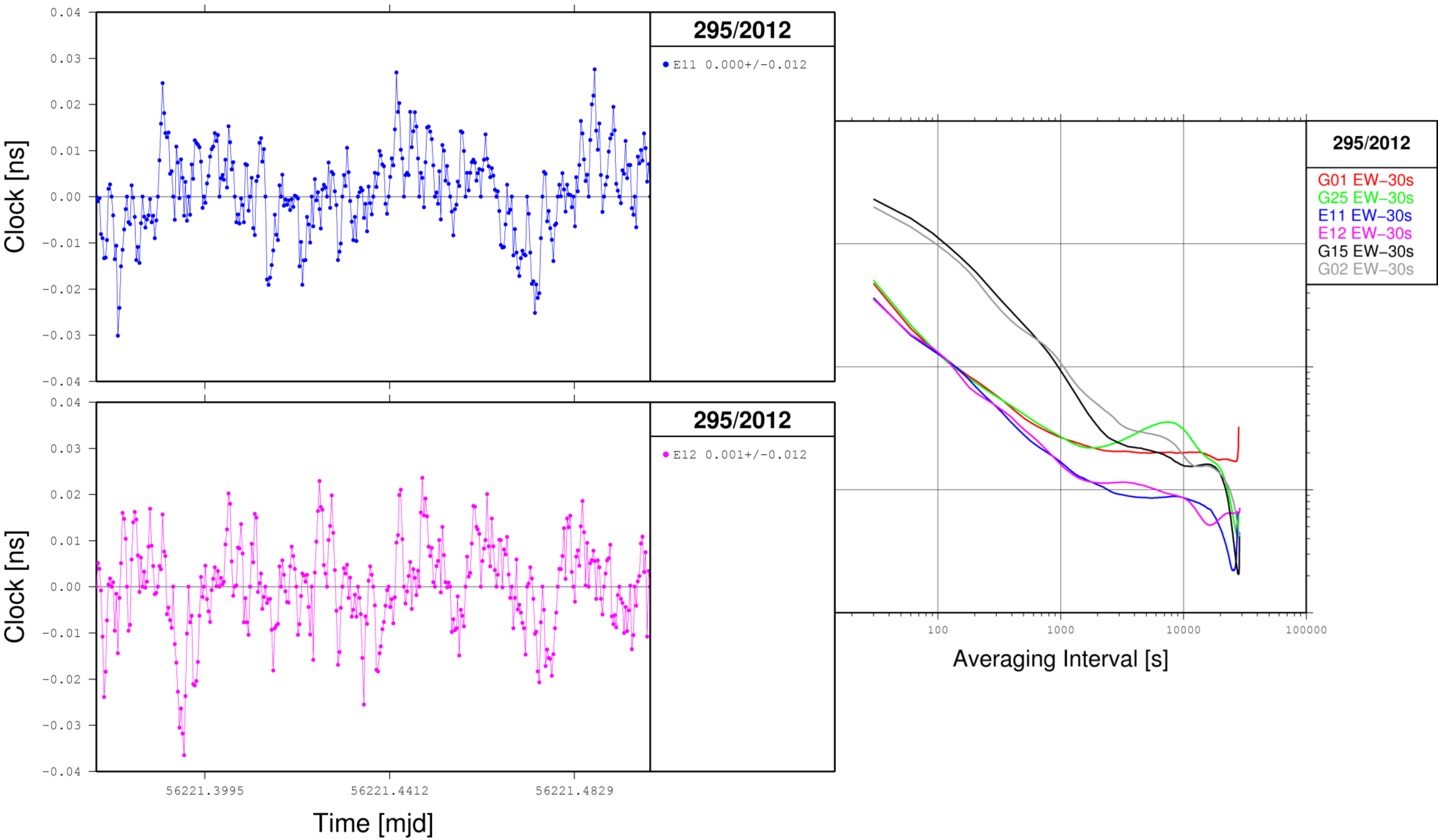
Interpolation error range: +/- 20 ps



Standard deviation of ~12 ps

But there is a clear periodic signal in the interpolation error for E11 and E12, not seen for the GPS IIF satellites

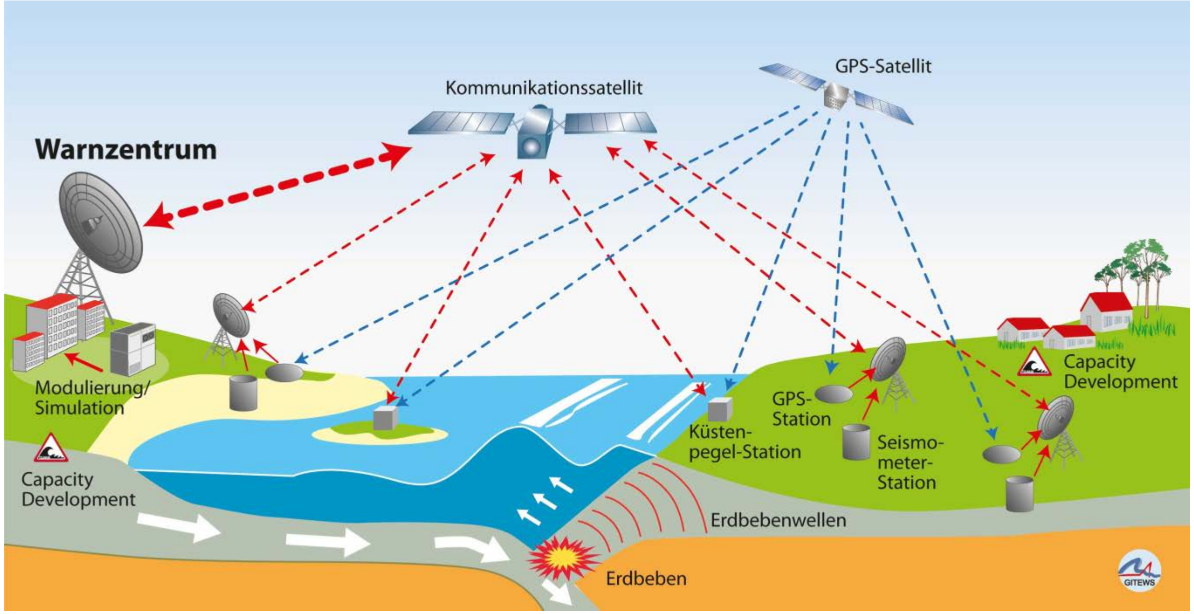
Clock Interpolation – Zoom into 09-12 h of 295/2012



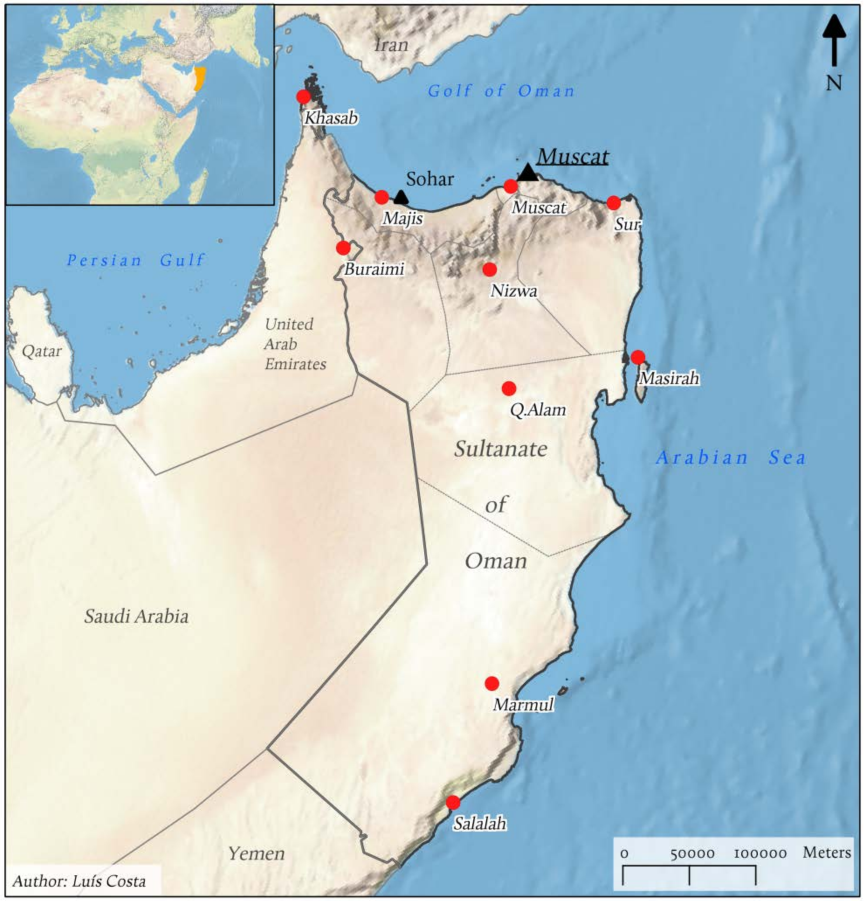
Tsunami Early Warning System for the Sultanate of Oman

GNSS based tsunami early warning systems

- After the disastrous tsunami on December 26, 2004 in the Indian Ocean, a lot of effort has been undertaken to establish tsunami early warning systems.
- One of the first reactions: The German Indonesian Tsunami Early Warning System (GITEWS). Initiated by German government, realized by GFZ Potsdam.
- A similar system shall be established in the Sultanate of Oman. SpaceTech GmbH coordinates the buildup of the GNSS sector, in coopera-tion with GFZ Potsdam and AIUB.



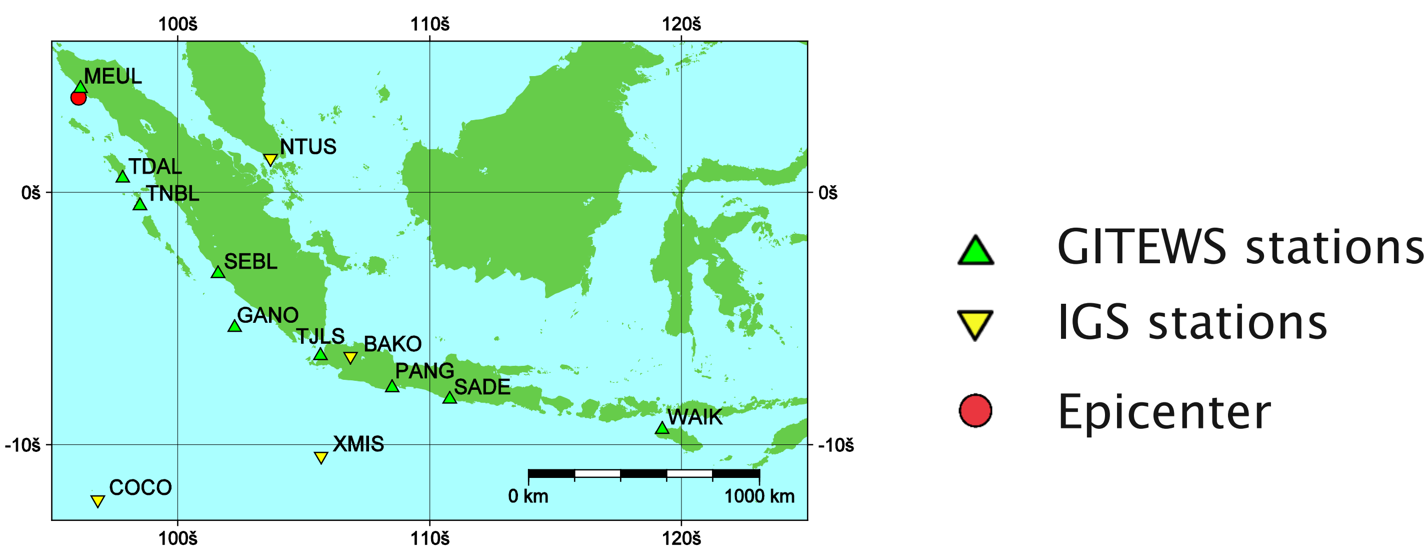
National Multi-Hazard Early Warning System (NMHEWS)



- Seismic stations, GNSS stations, meteorological stations, tide gauges.
- GNSS network: 10 permanent stations. Only GPS data will be processed. Cross-validate possibility of a tsunami after a nearby submarine Earthquake.
- Requirement: Obtain displacement vectors with a delay less than 2 minutes. (our procedure needs 1 minute)

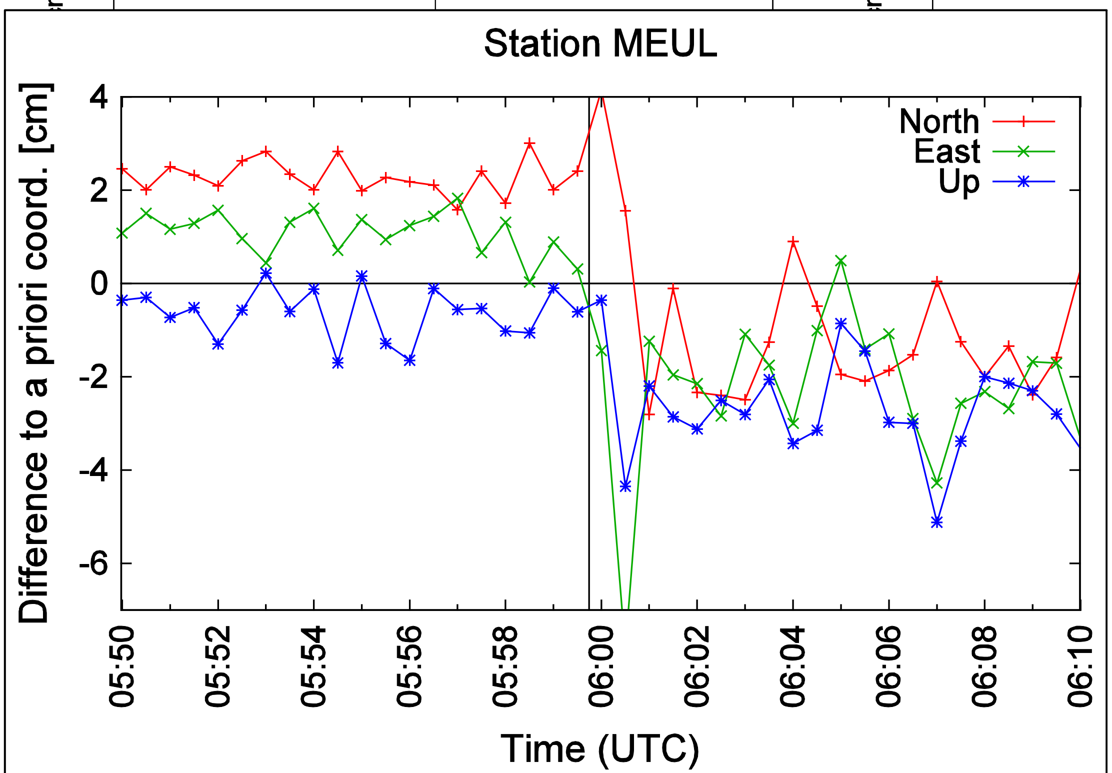
Testing with data from GITEWS

- May 9, 2010 at 05:59:44 UTC: 7.2 magnitude Earthquake off the island of Sumatra. The GITEWS was operational.
- Apply our processing strategy to (GPS only, 30 s sampling) data from 9 GNSS stations located at tide gauges. Selected 4 additional IGS reference stations.



Testing with data from GITEWS

- Kinematic coordinates of tide gauge stations during Earthquake, using CODE final orbits and ERPs (vertical line: time of Earthquake):



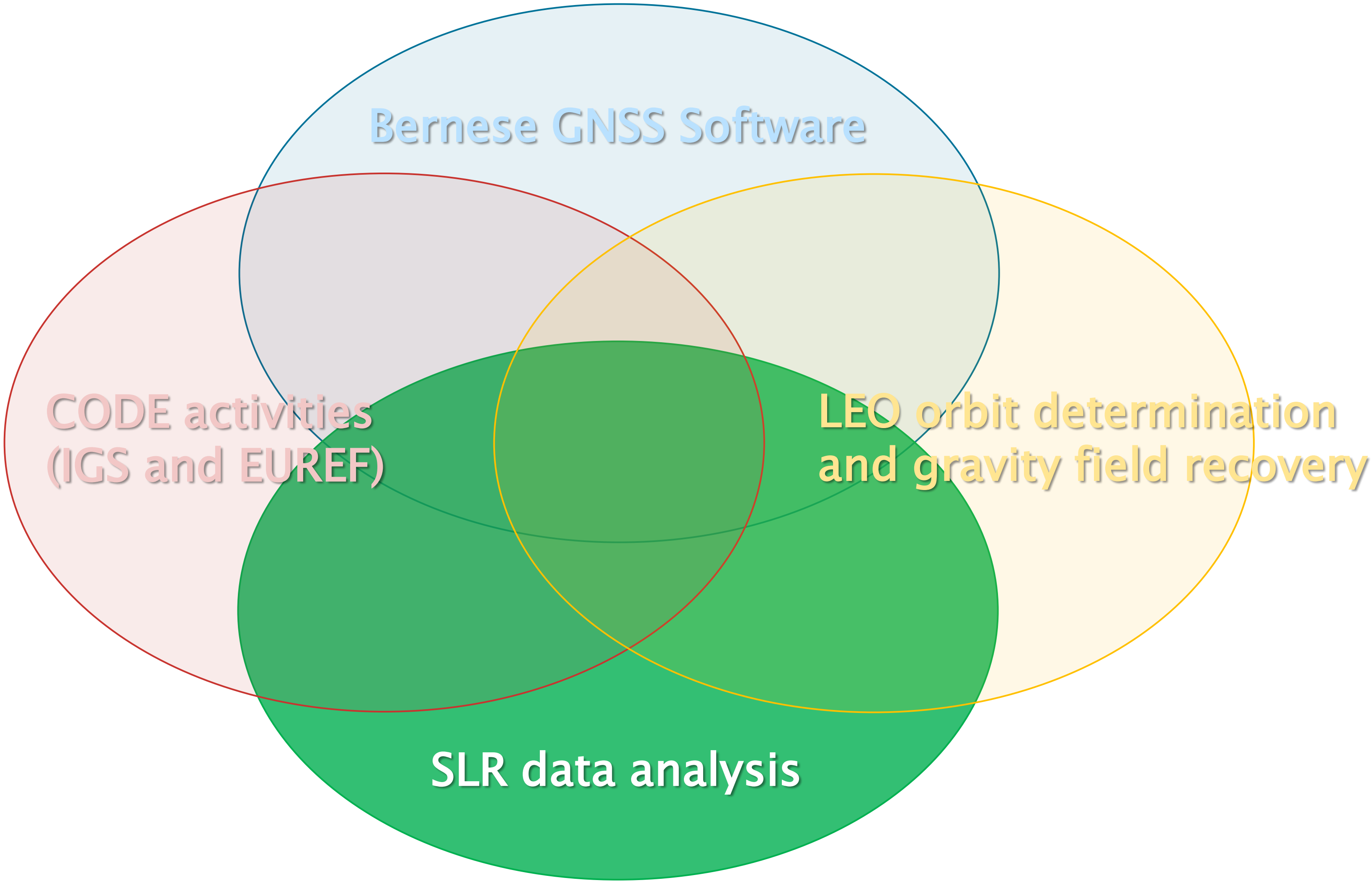
Displacement:

$\Delta N = -3.7$ cm

$\Delta E = -3.2$ cm

$\Delta U = -2.1$ cm

Satellite Geodesy Research Group

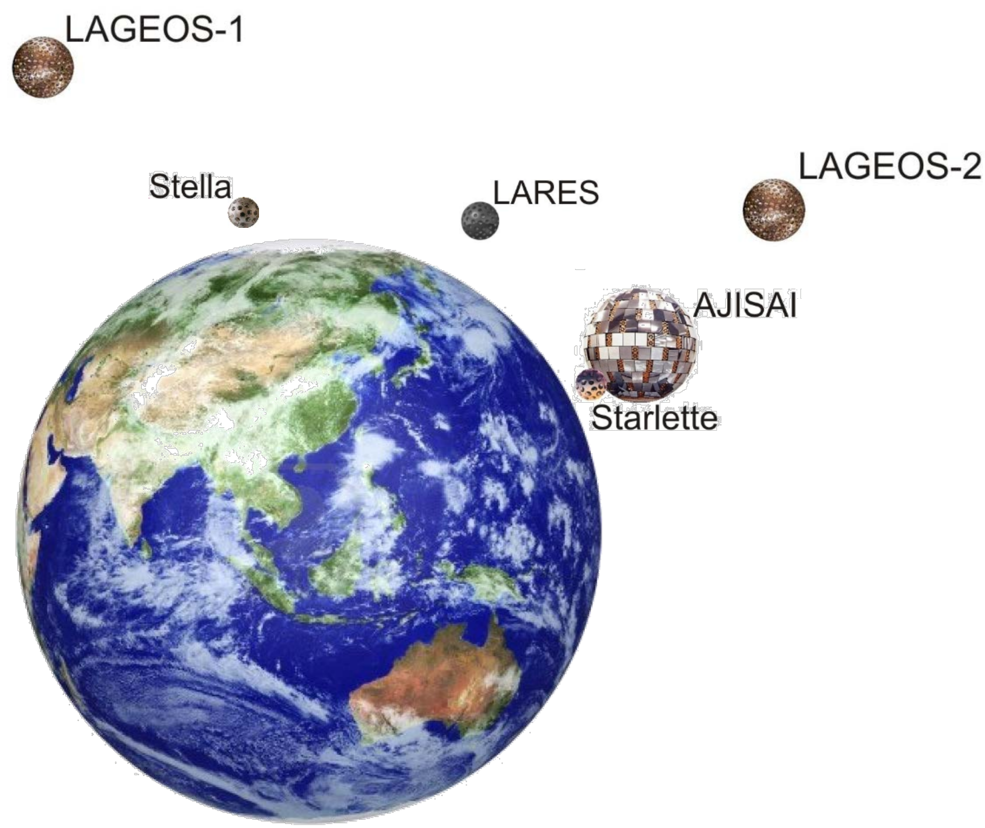


Satellite Laser Ranging (SLR) Solutions

Motivation

Current ILRS products:

- LAGEOS-1/2 & Etalon-1/2 solutions only,
- On average ~3000 normal points to LAGEOS-1/2 and ~300 normal points to Etalon-1/2 per week,
- The impact of Etalon-1/2 on the solution is virtually negligible



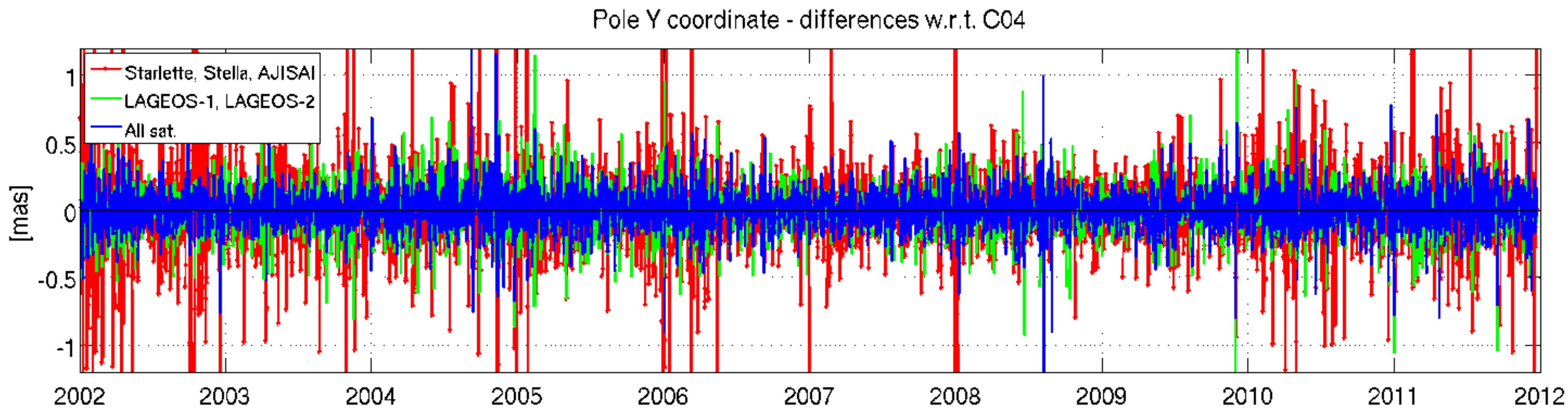
SLR solutions in the Bernese GNSS Software

Parameter		LAGEOS	LEO
Station Coordinates		Weekly	Weekly
Earth Rotation Parameters		PWL daily	PWL daily
Geocenter Coordinates		Weekly	Weekly
Gravity field		Up to d/o 4	Up to d/o 4
Range Biases		**Selected stations**	**All stations**
Orbit	Osculating Elements	Weekly	Weekly
	Constant along-track S0	**Weekly**	-
	Air Drag Scaling Factor	-	**Daily**
	Once-per-rev SS, SC	**Weekly**	**Daily**
	Once-per-rev WS, WC	**Weekly** (when not estimating gravity field)	**Daily**
	Pseudo-Stochastic Pulses	-	**Once-per-rev in along-track**

Bernese GNSS Software, v.5.3

10 years of processed data (2002-2012)

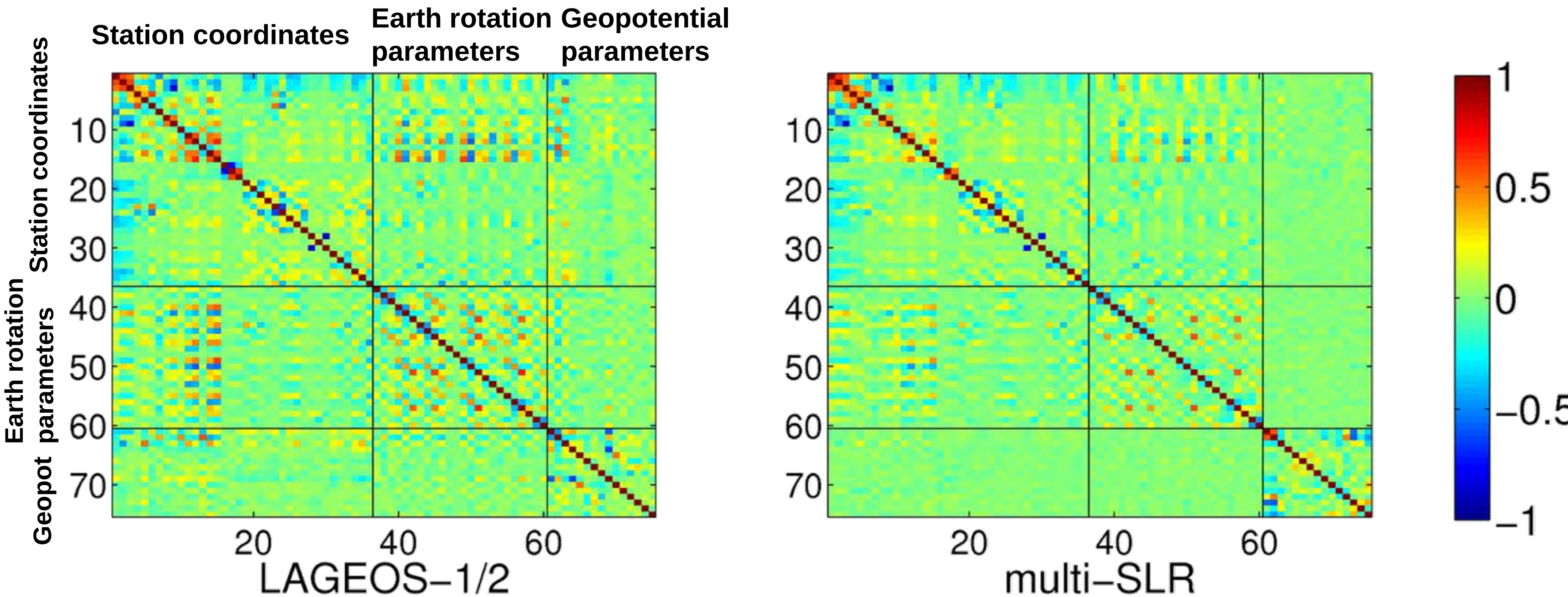
Earth Rotation Parameters (w.r.t. IERS−08−C04)



Solution type		X pole [μas] bias	WRMS	Y pole [μas] bias	WRMS	LoD [μs] bias	WRMS	Repeatability [mm] Up	North	East
LAGEOS-1/2	gravity up to 4/4	4.1	160.0	-8.0	155.2	6.1	57.0	11.1	10.2	12.3
LAGEOS-1/2	no gravity	45.8	168.5	-54.1	153.5	77.3	120.5	10.9	10.0	12.4
SLR-LEO	gravity up to 4/4	38.3	267.9	-7.8	217.6	-38.5	105.6	15.3	15.4	15.2
SLR-LEO	no gravity	190.1	437.5	-61.1	315.9	189.6	359.3	15.8	15.6	16.8
multi-SLR	gravity up to 4/4	6.4	148.9	8.5	140.3	6.3	56.3	11.3	11.2	11.7
multi-SLR	no gravity	83.7	153.1	63.3	156.7	75.8	121.7	11.1	11.3	11.8

Simultaneous estimation of all parameters
(gravity field+station coord+ERPs+orbits)
is beneficial for SLR solutions
(in particular for combined L1/L2/Sta/Ste/Aji solutions).

Correlations

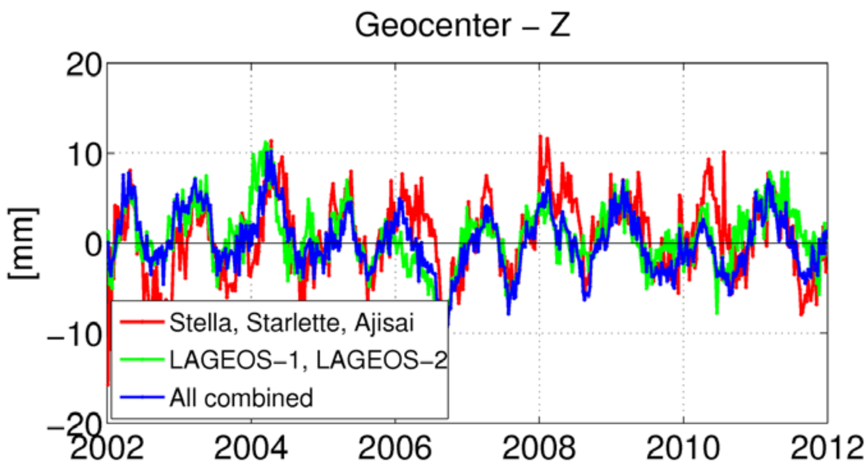


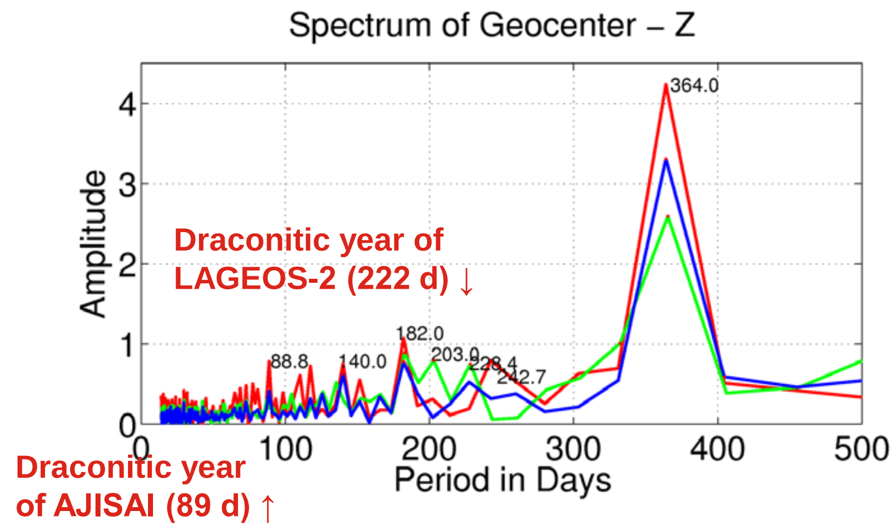
Correlation coefficients between selected parameters.

Estimated parameters (ERPs, geopotential, station coordinates) can be substantially decorrelated when using many SLR satellites, due to:

- better observation geometry,
- larger number of SLR observations,
- different orbital characteristics (altitudes, inclination angles, eccentricities).

Geocenter coordinates





The origin of the reference frame (geocenter coordinates) is best defined by the SLR technique. The X and Y components can be also recovered by other techniques, e.g., DORIS, GNSS, but the Z component is strongly affected by the deficiencies in the solar radiation pressure modeling, and thus, can only be established by the SLR solutions.

The LAGEOS-1/2 solutions or the Star+Ste+Aji solutions show very small orbit modeling deficiencies (draconitic year of LAGEOS-2 and Ajisai).

All amplitudes related to draconitic years are substantially reduced in the combined solutions.

Scale

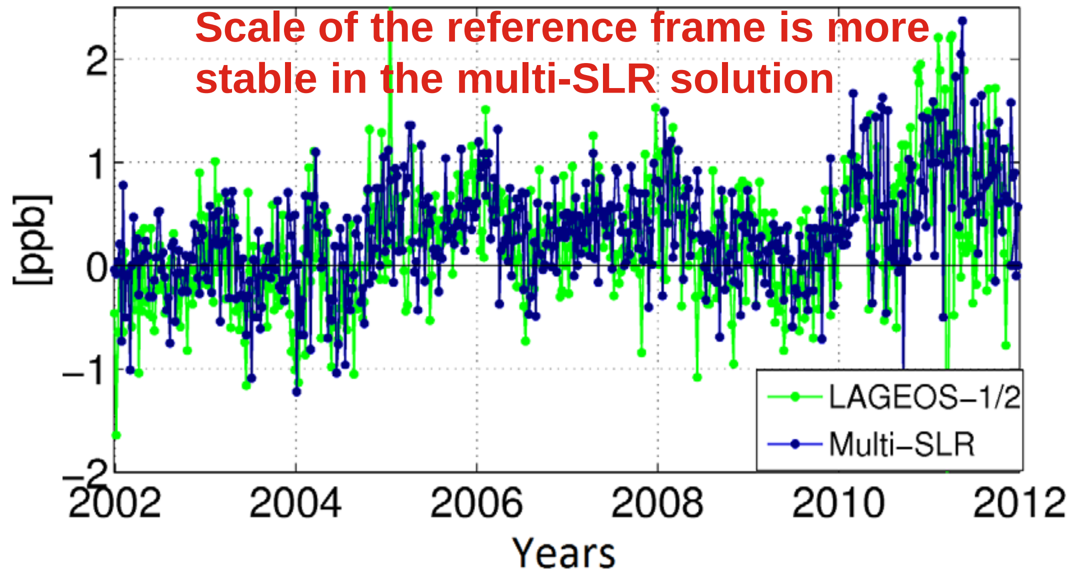
TRF scale estimated from the Helmert 7-parameter transformation of weekly SLR solutions

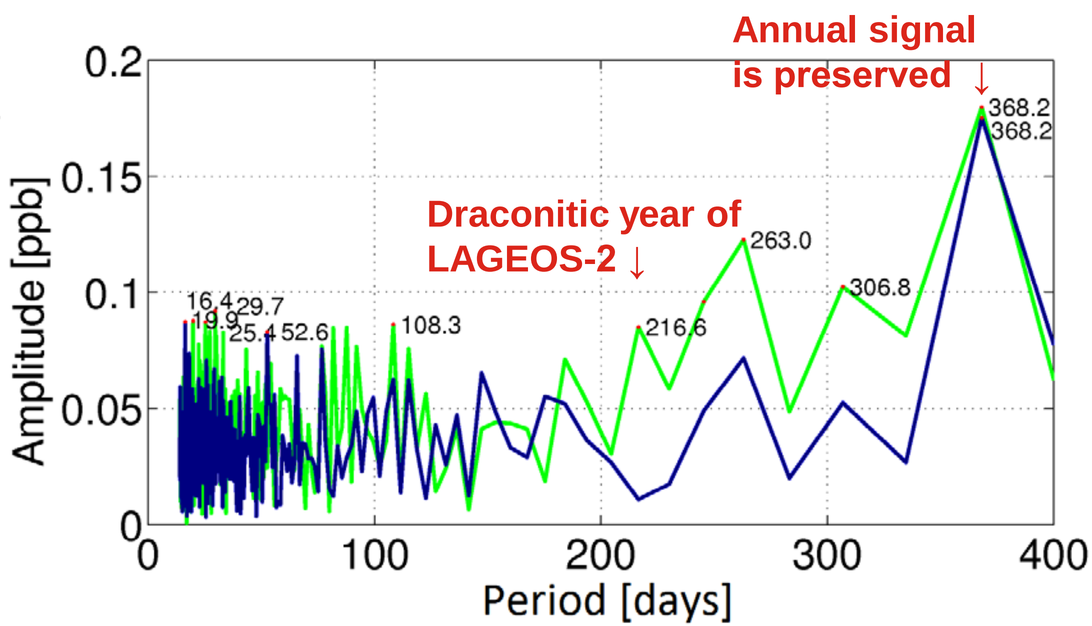
Orbit modeling deficiencies related to non-gravitational forces appear as the periods of the draconitic year.

Draconitic year is a time interval between two consecutive passes of the Sun through the orbital plane of a satellite (in the same direction).

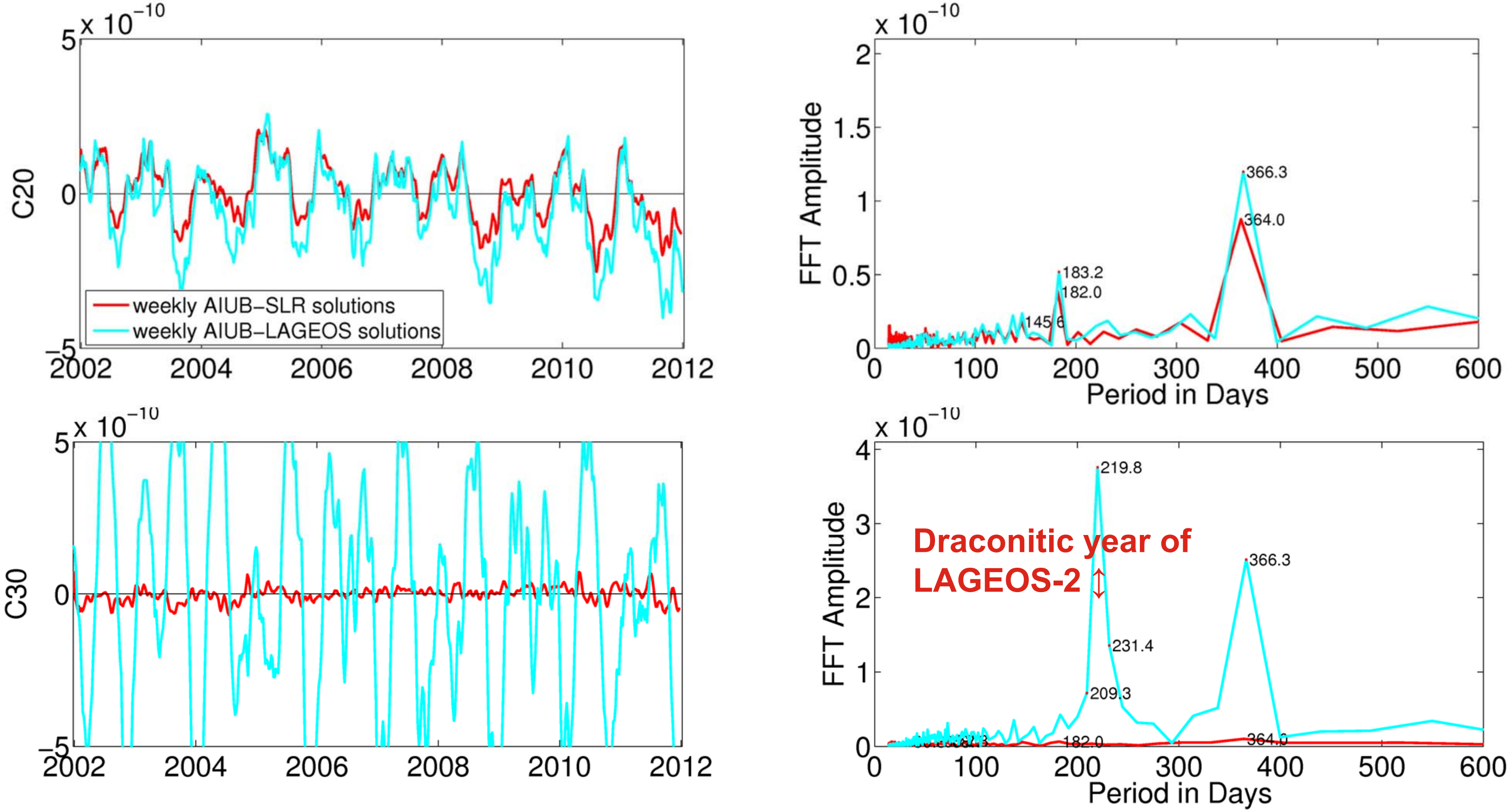
Draconitic years of geodetic satellites:

- 222 days: LAGEOS-2
- 560 days: LAGEOS-1
- 89 days: AJISAI
- 73 days: Starlette
- 182 days: Stella
- 133 days: LARES.





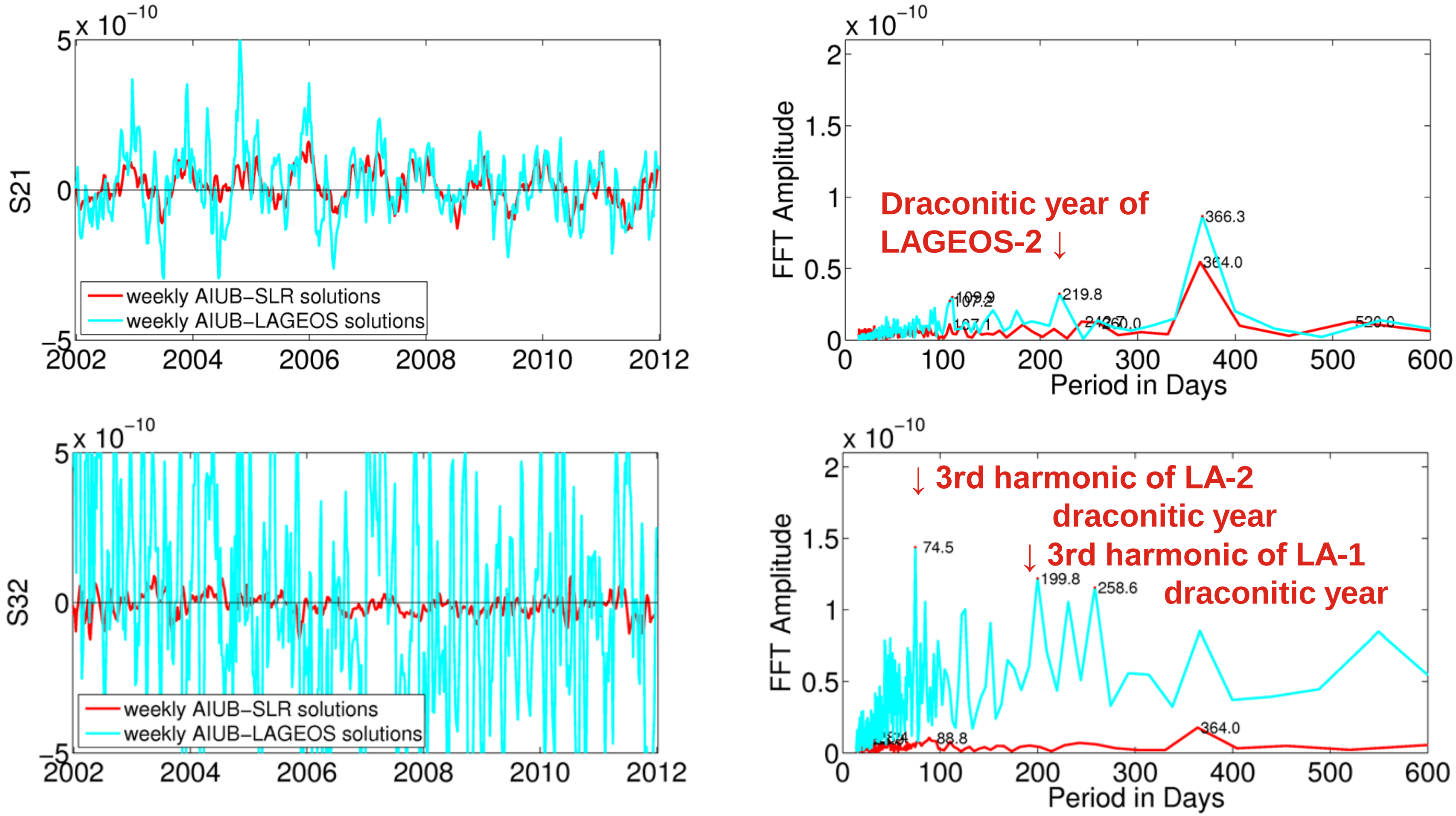
Gravity field parameters



C_{20} can be well-established from LAGEOS-1/2 solutions, but the amplitude of annual signal is by 20% larger than in the multi-SLR solutions.

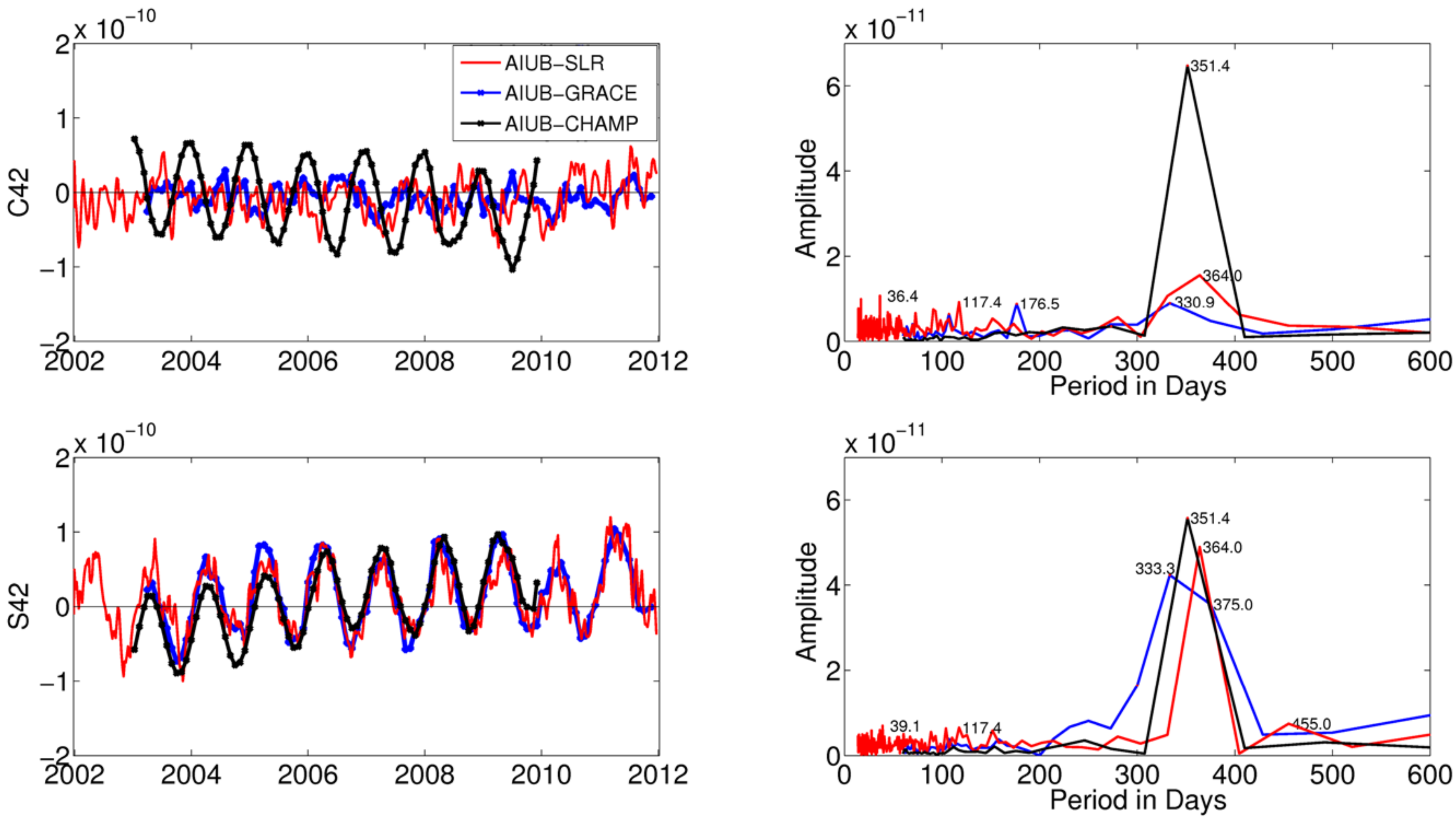
C_{30} from LAGEOS-1/2 shows a clear alias period with draconitic year of LA-2.

Gravity field parameters



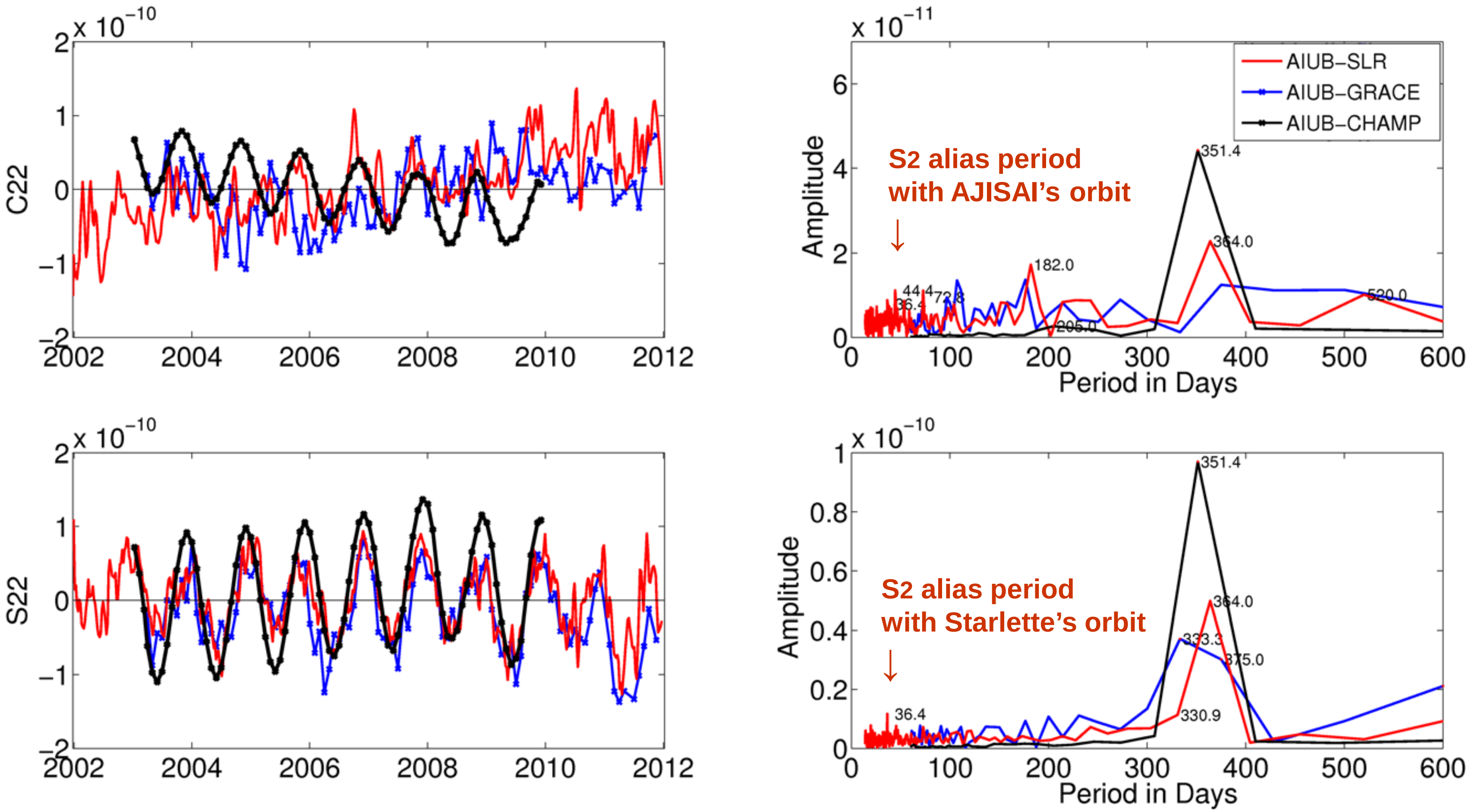
Gravity field parameters (besides C20) can be much better established from the multi–SLR solutions (in particular for degree higher than 2). LAGEOS–1/2 solution reveals variations related to the draconitic years or their harmonics.

SLR vs. CHAMP vs. GRACE



Some coefficients derived by SLR, CHAMP, and GRACE solutions perfectly agree. CHAMP solutions show usually larger amplitudes.

SLR – specific issues

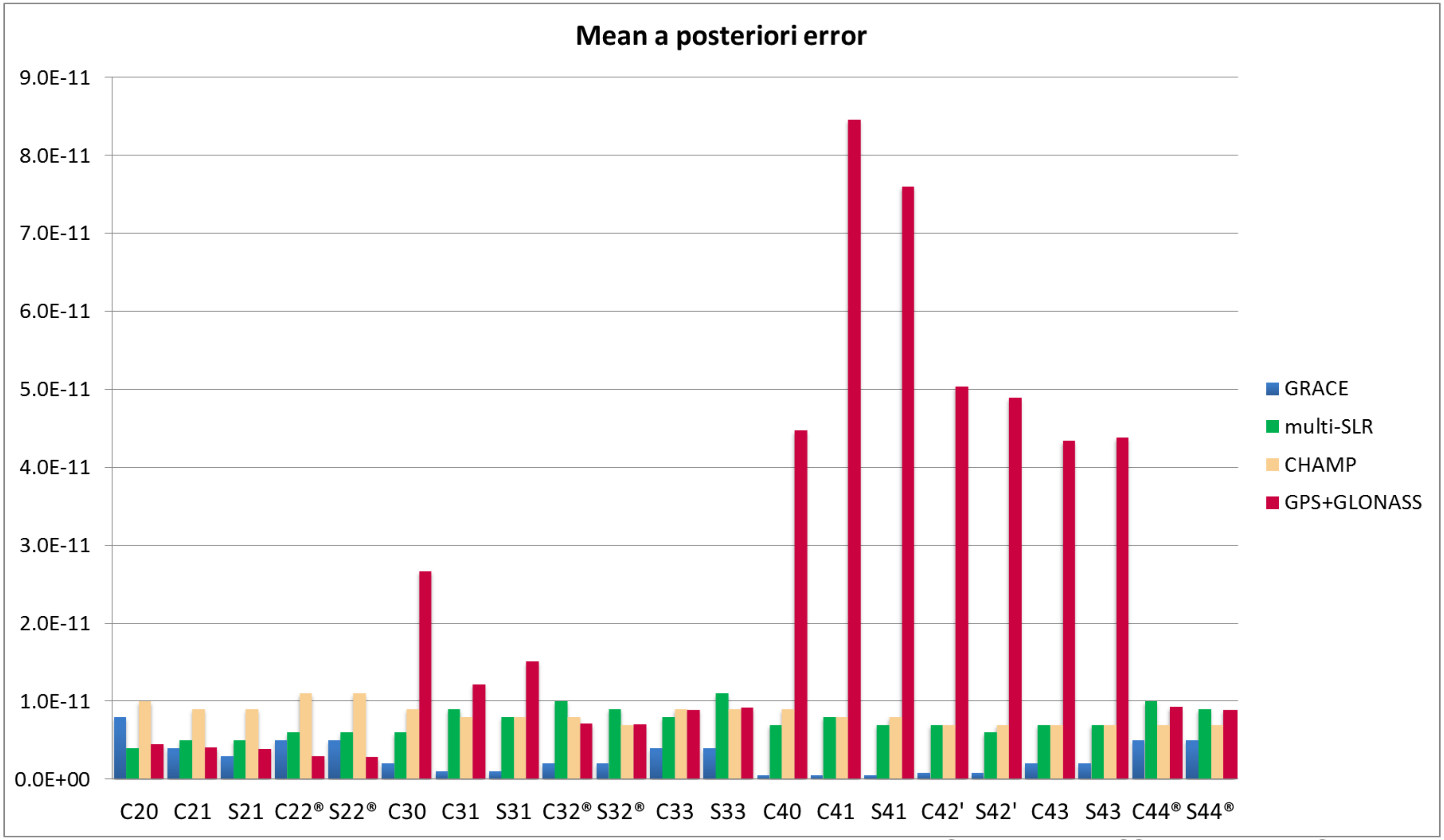


S2 alias period affects not only GRACE solutions, but also has a minor impact on SLR satellites, which is detected by high-precision SLR data.

GPS+GLONASS Gravity Field Solutions

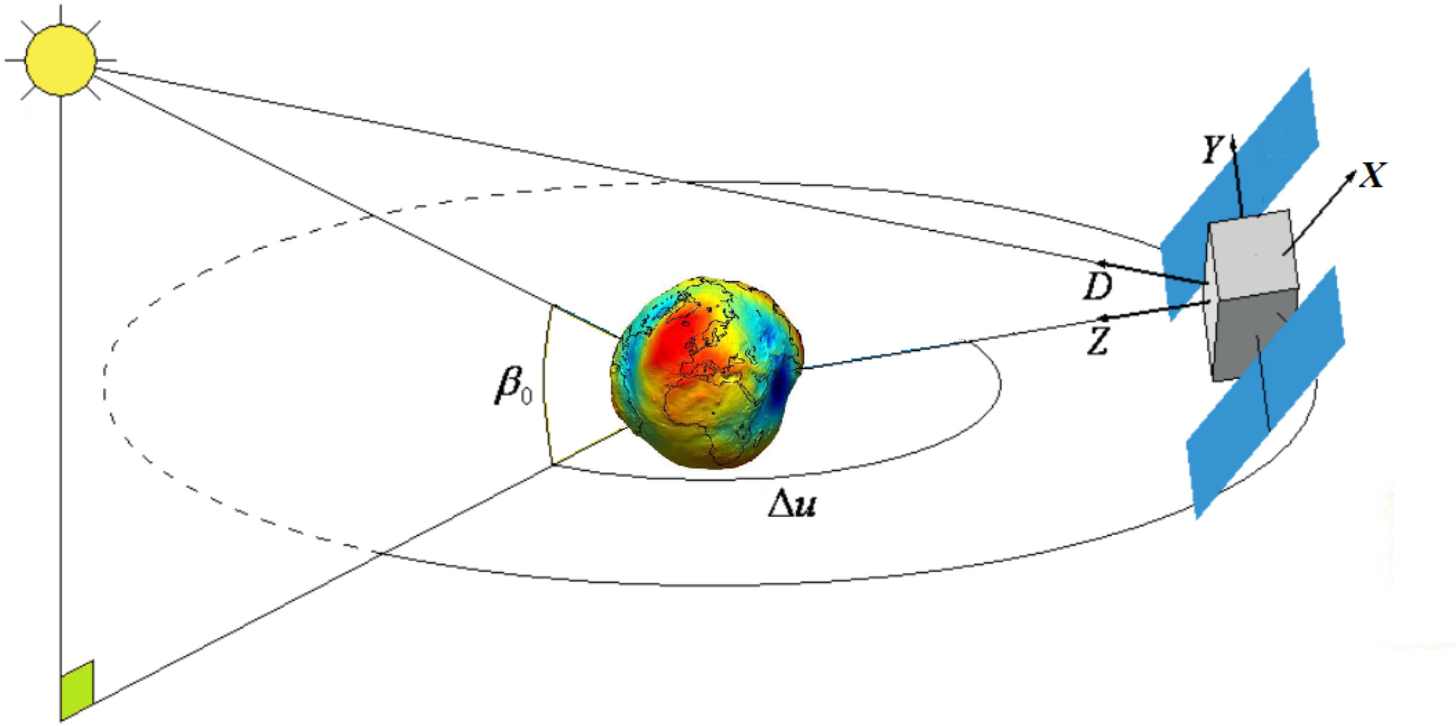
Sensitivity of GPS resonant orbits

Sośnica et al.: Earth gravity field recovery using GPS, GLONASS, and SLR satellites.
18th International Workshop on Laser Ranging, Fujiyoshida, Japan



GNSS satellites are very sensitive to gravity field coefficients of degree 2. For coefficients above degree 3, GNSS are only sensitive to resonant gravity field parameters (®).

GNSS orbit modeling



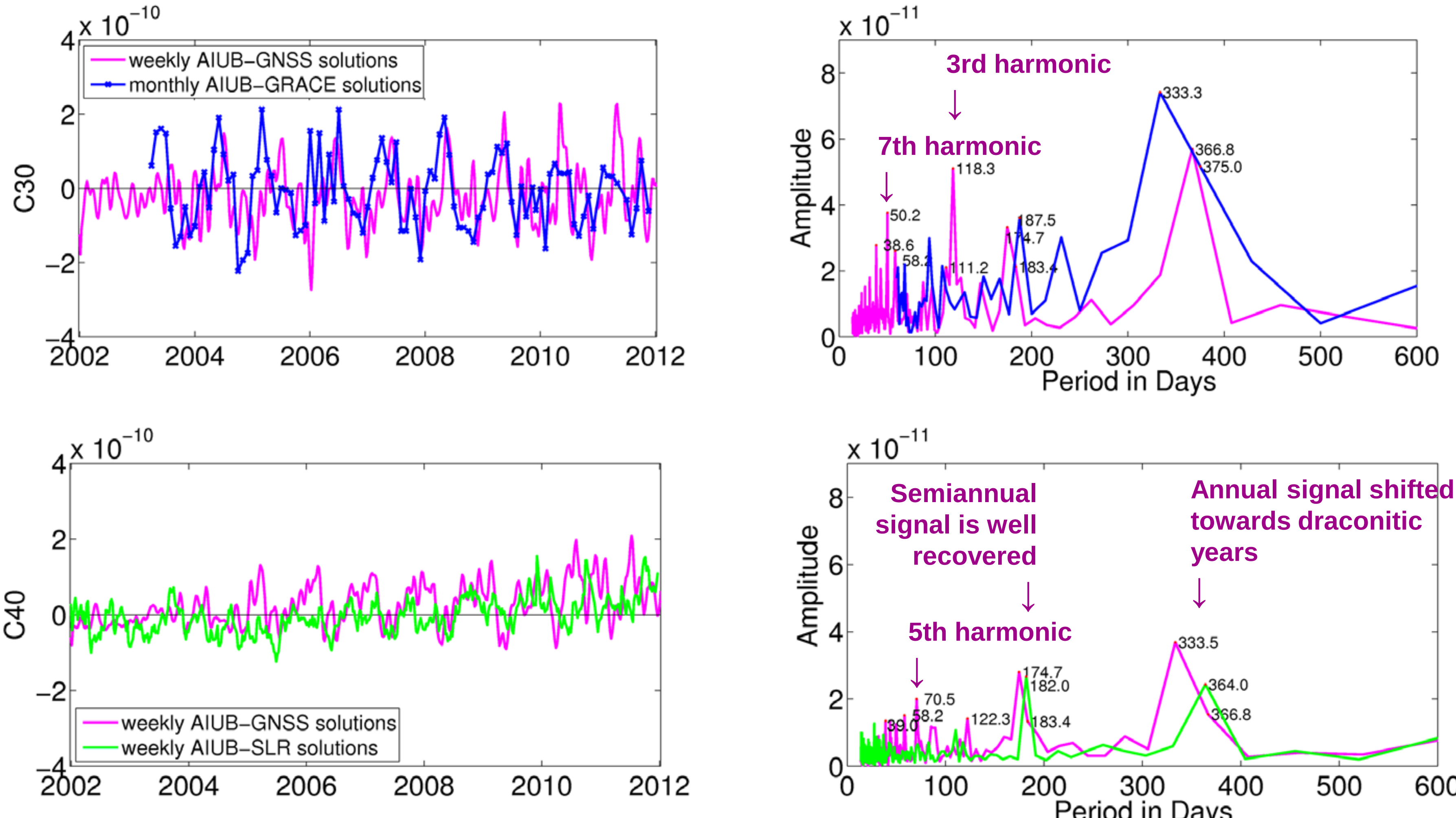
GNSS dynamic orbit parameters estimated in standard CODE solutions:

$D = D_0$

$Y = Y_0$

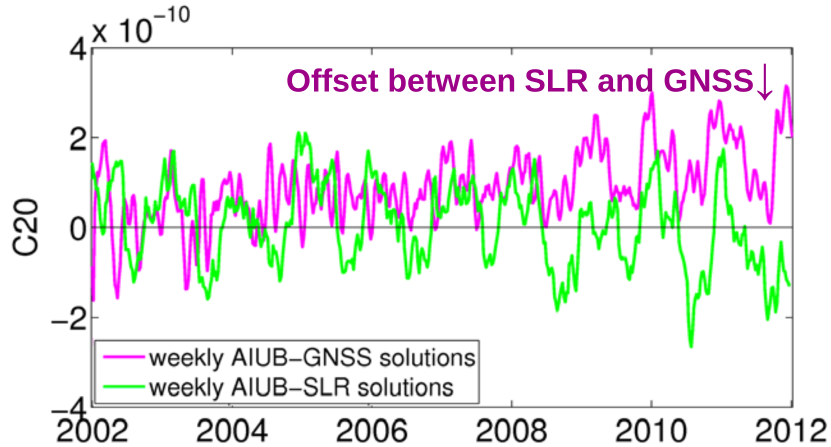
$X = X_0 + X_S \sin \Delta u + X_C \cos \Delta u$

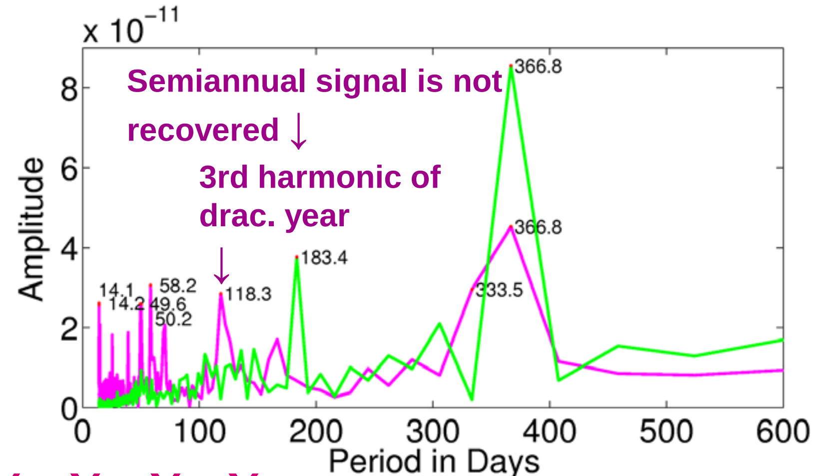
Zonal spherical harmonics from GPS and GLONASS



Zonal harmonics can be quite well recovered by GNSS

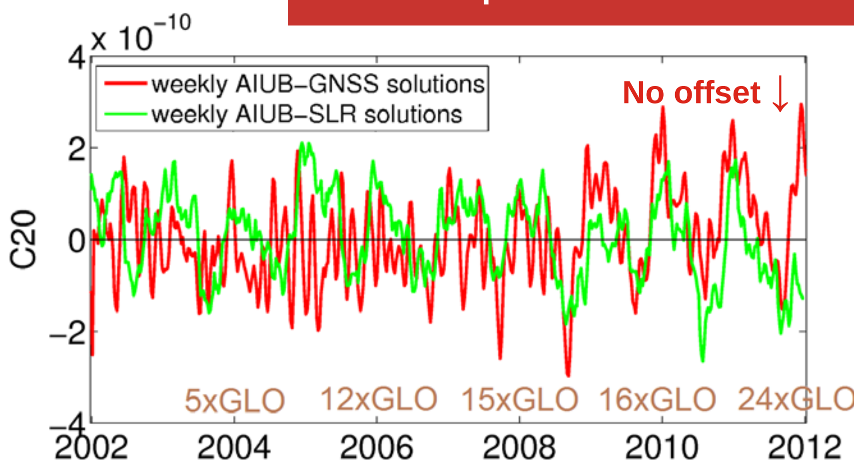
C_{20} from GPS and GLONASS

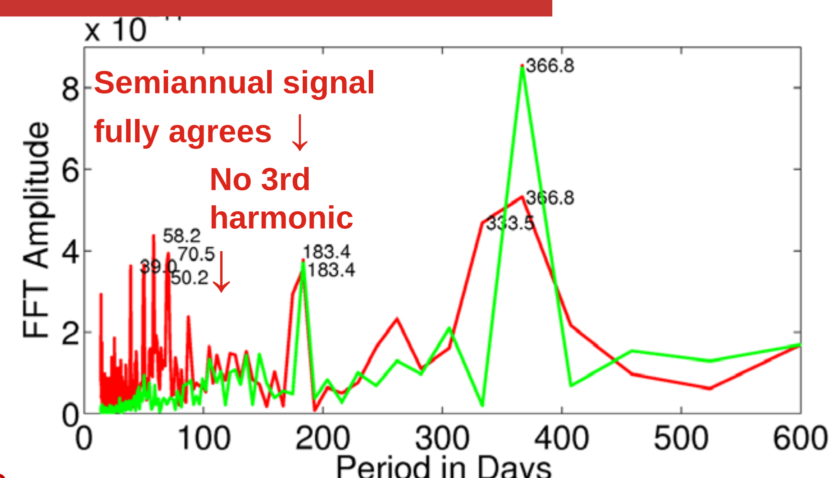




GNSS dynamic orbit parameters :D_0, Y_0, X_0, X_S, X_C

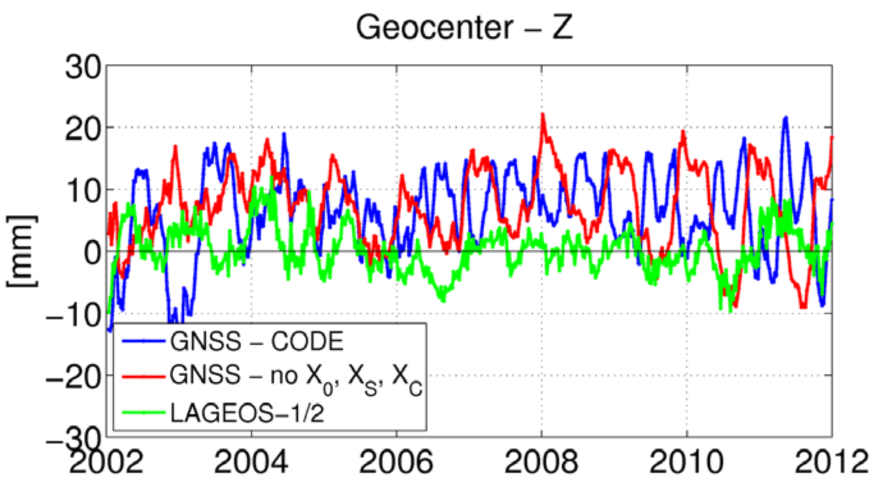
All parameters in X are correlated with C_{20}

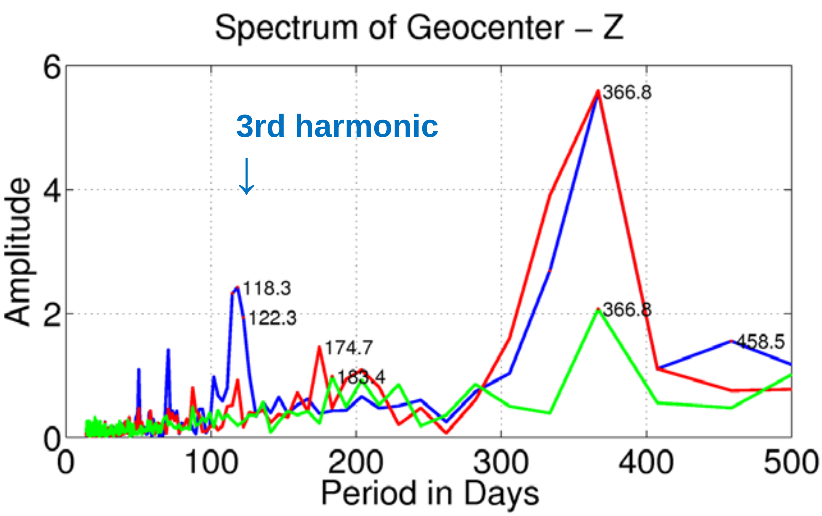




GNSS dynamic orbit parameters :D_0, Y_0

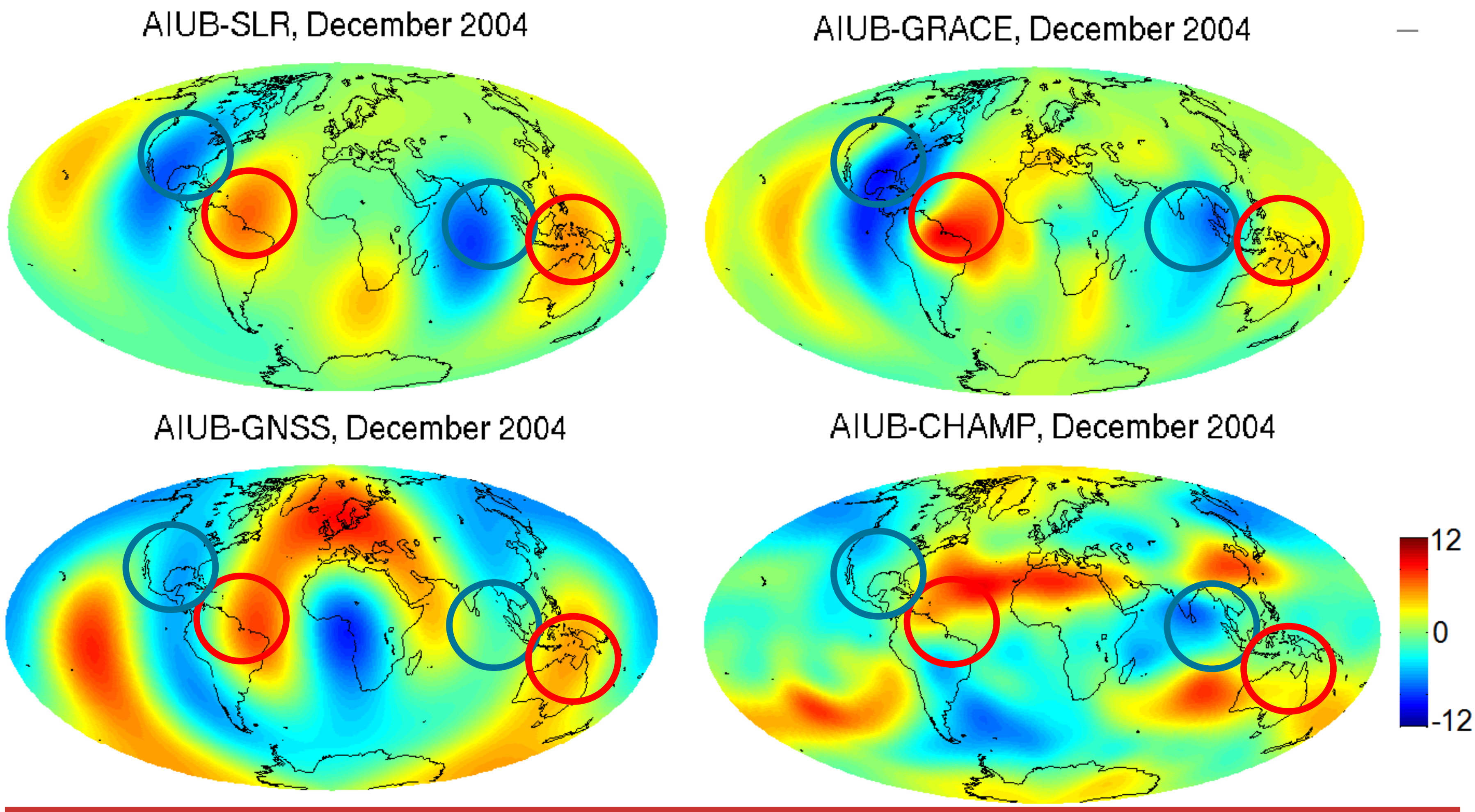
Geocenter coordinates from GNSS and SLR





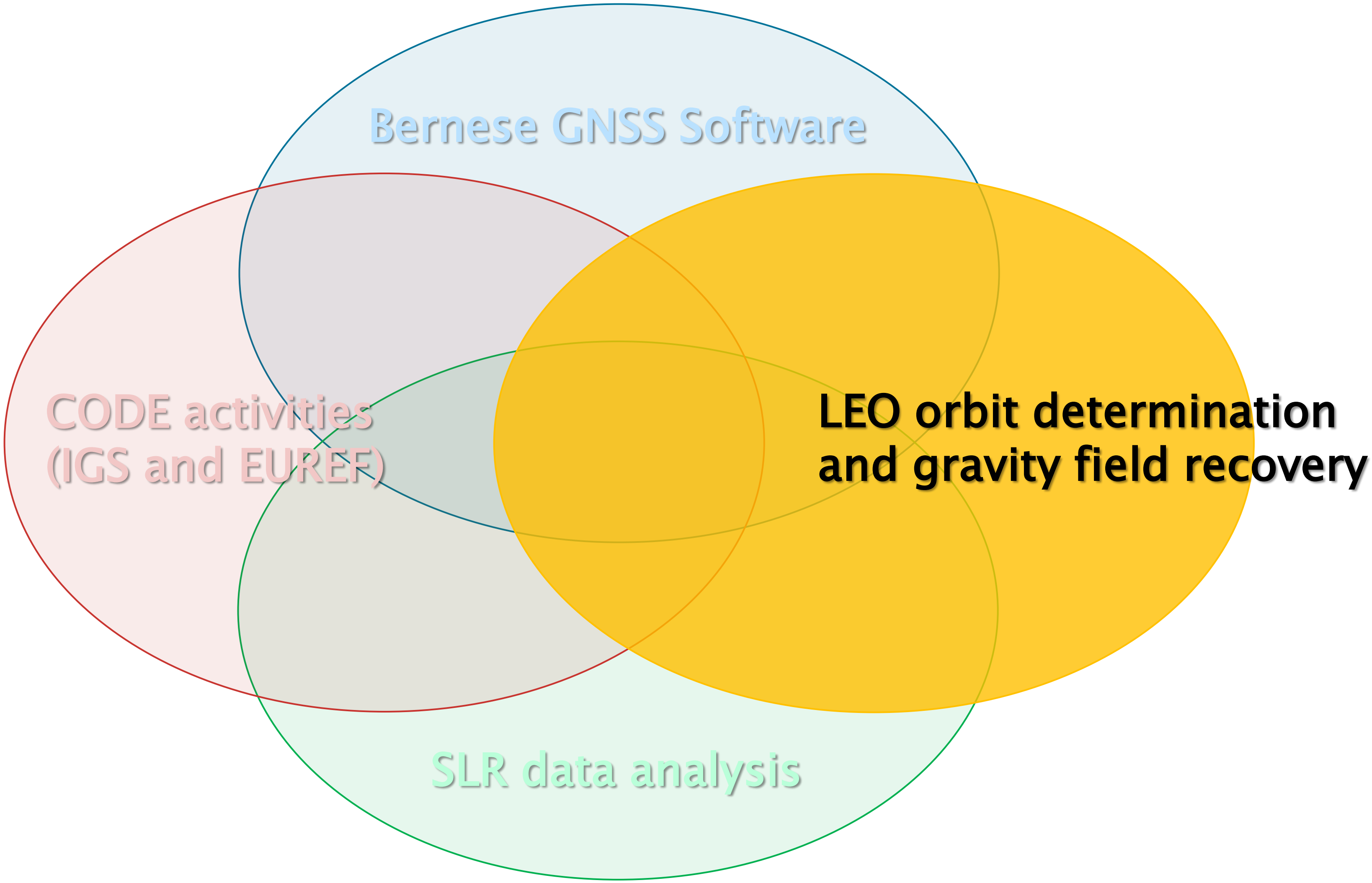
Z geocenter component from GNSS is extremely sensitive to orbit modeling; the exclusion of dynamic orbit parameters in the X direction entirely changes the signal!

Low–degree geoid variations



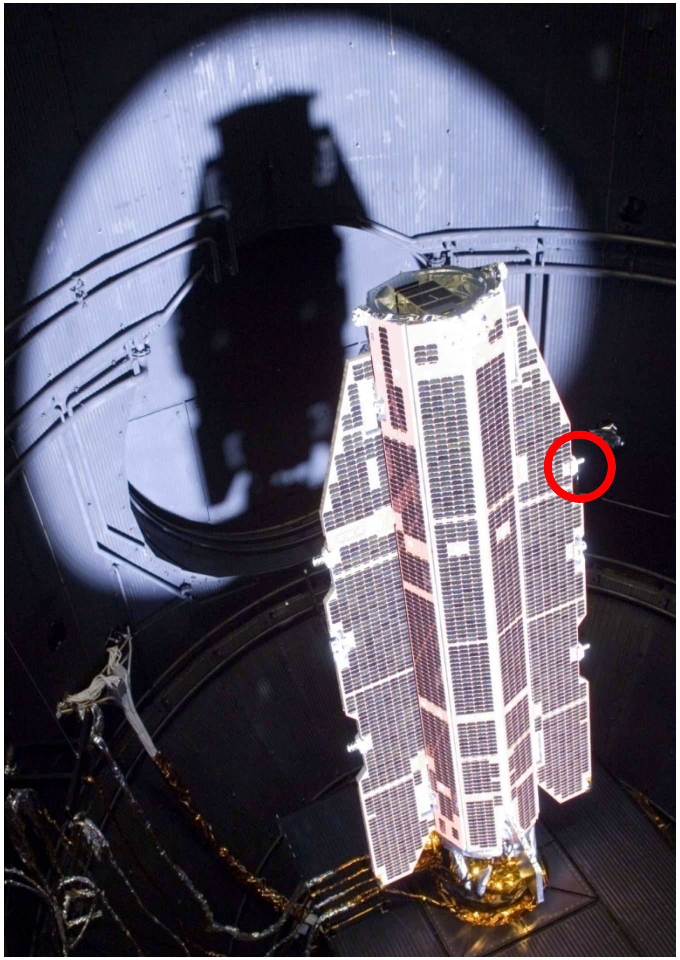
Low–degree gravity field parameters from SLR solutions fit well to GRACE results. CHAMP and GNSS solutions are affected by orbit modeling issues, but many similarities to other solutions can be found.

Satellite Geodesy Research Group



GOCE-HPF:
Berechnung genauer Bahnen und Schwerefeldbestimmung

Background and motivation

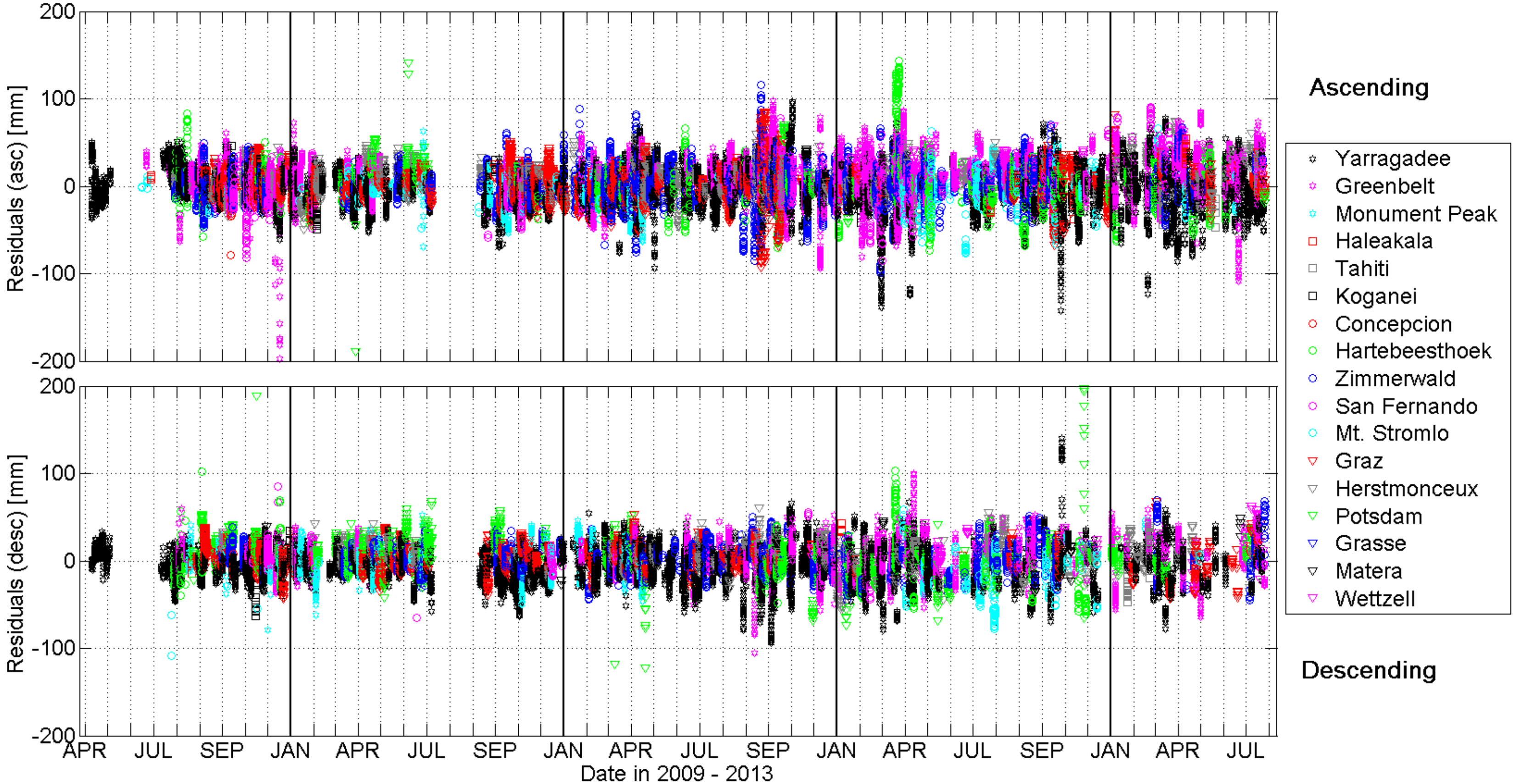


Courtesy:ESA

- AIUB is responsible for the determination of the Precise Science Orbit (SST_PSO) product within the GOCE HPF consortium
- The kinematic orbit product (SST_PKI) is used for the determination of the low degrees of the Earth's gravity field => GPS-only gravity field solutions
- The "Celestial Mechanics Approach" (CMA) developed at AIUB allows it to directly test the performance of the GPS-only gravity field solutions

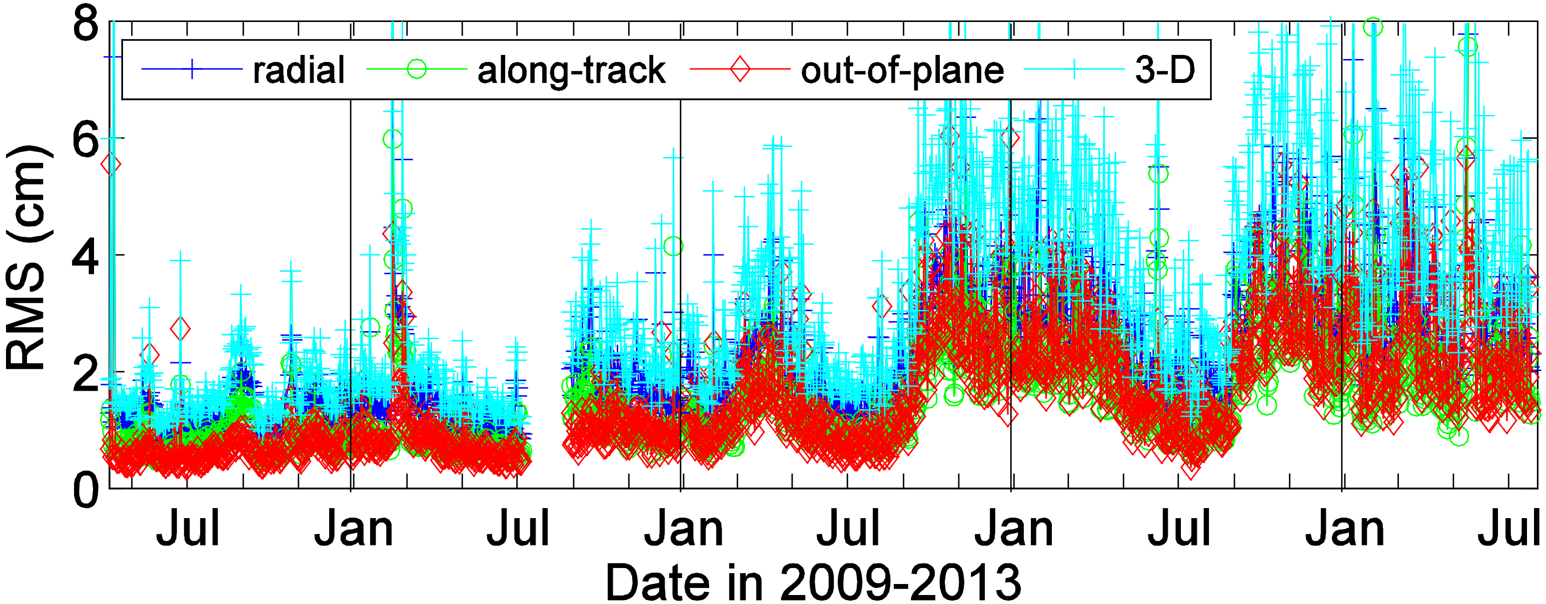
GOCE orbit determination – SLR validation

Kinematic orbits – SST_PKI



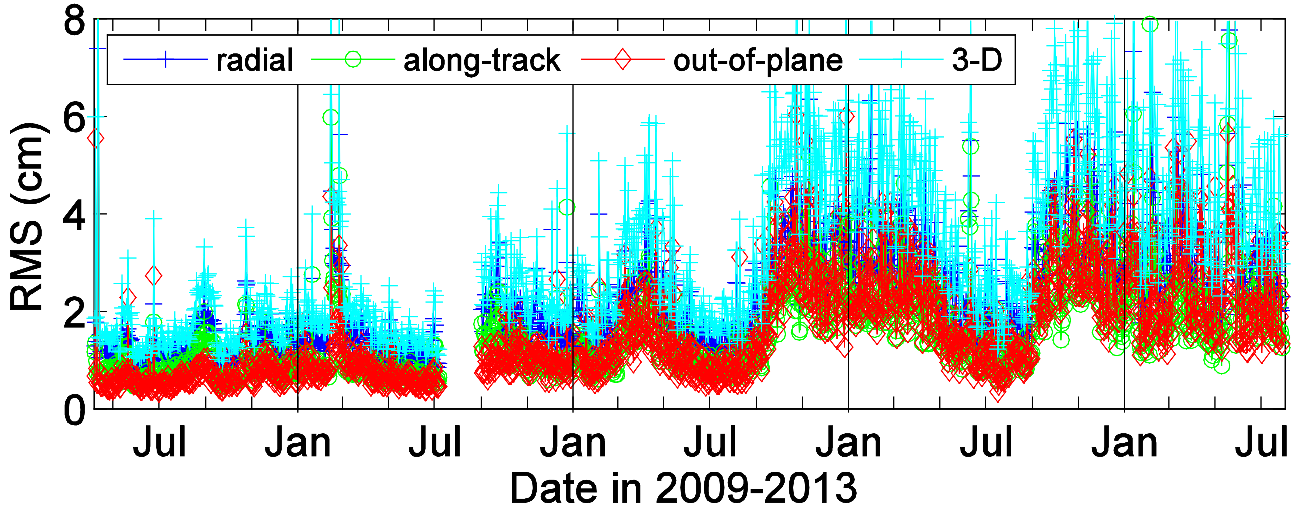
Mean: 0.08 cm **RMS: 2.36 cm**

GOCE orbit determination – results

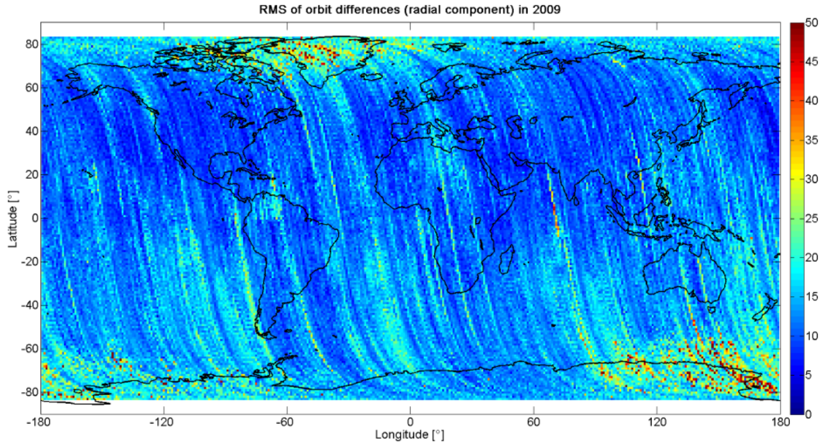


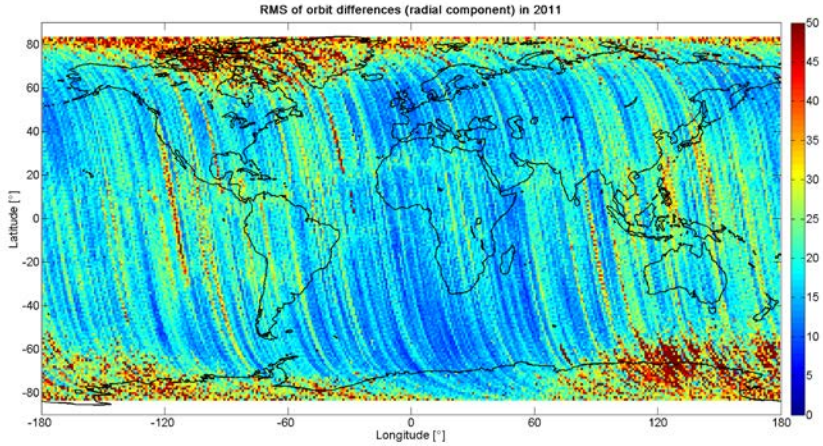
- RMS of the differences between reduced-dynamic and kinematic orbits
- RMS values are growing during the mission

GOCE orbit determination – results

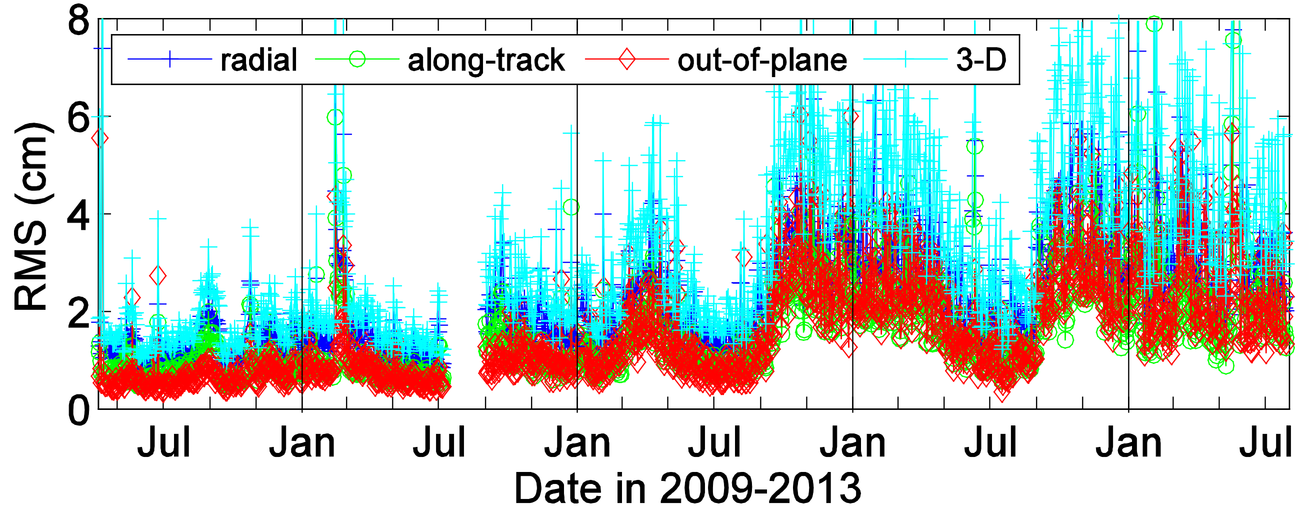


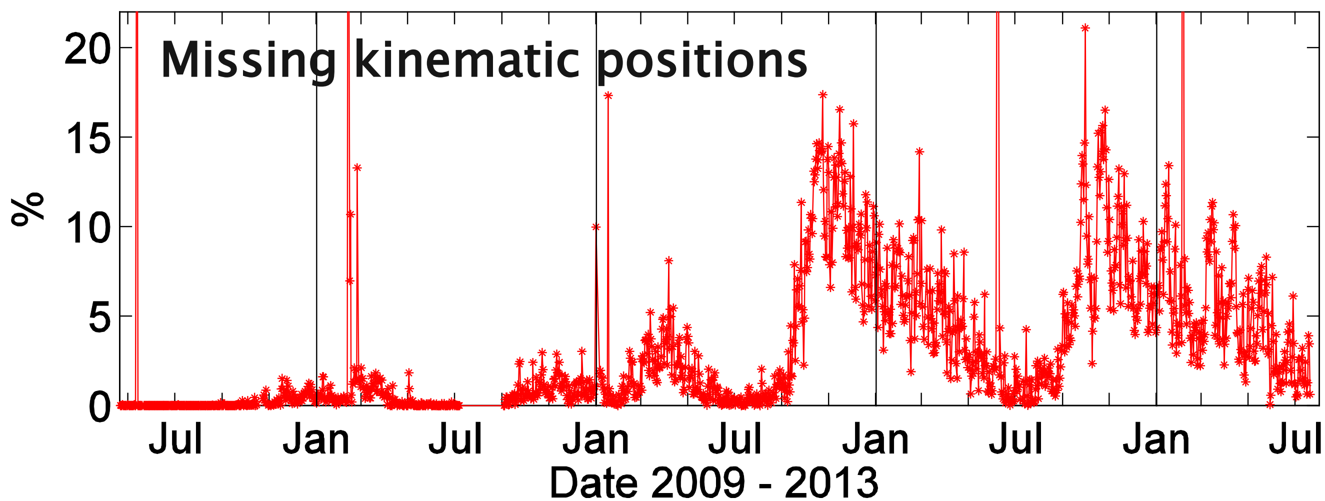
2009 **Radial RMS (ascending arcs)** **2011**





GOCE orbit determination – results





GPS-only gravity field determination

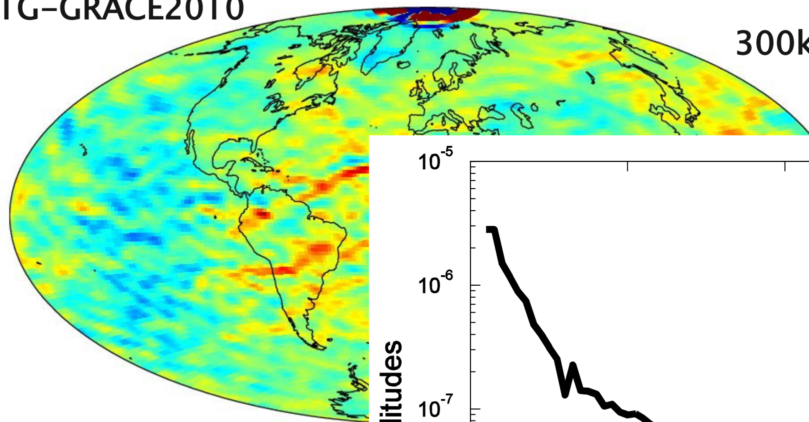
- Celestial Mechanics Approach
- Pseudo-observations: kinematic GOCE positions (SST_PKI) with variance-covariance information (SST_PCV)   (+ common-mode accelerometer data)
- Parameters:
  - 6 initial orbit elements
  - Constant and once-per-revolution terms in R, S, and W
  - Pseudo-stochastic pulses in R, S, and W every 6 min (σ= 0.1mm/s)
  - Gravity field parameters up to degree/order 120

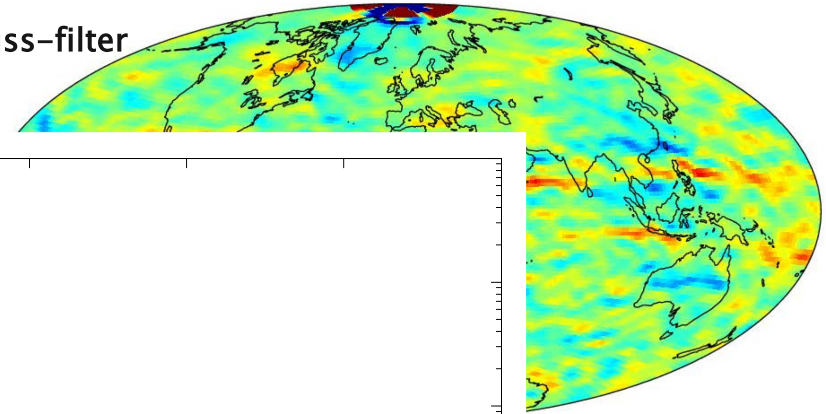
Impact of accelerometer data

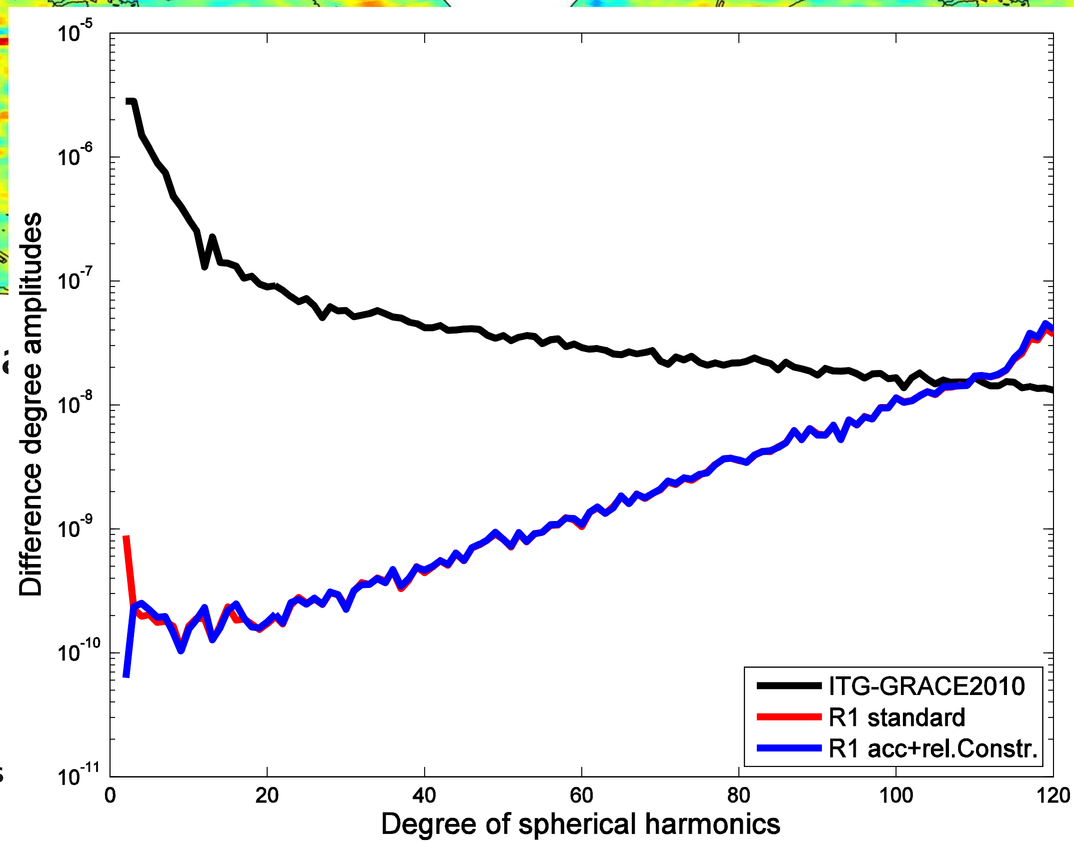
Geoid differences to ITG-GRACE2010

Colour scale -0.05 .... 0.05 m

300km Gauss-filter







Sta

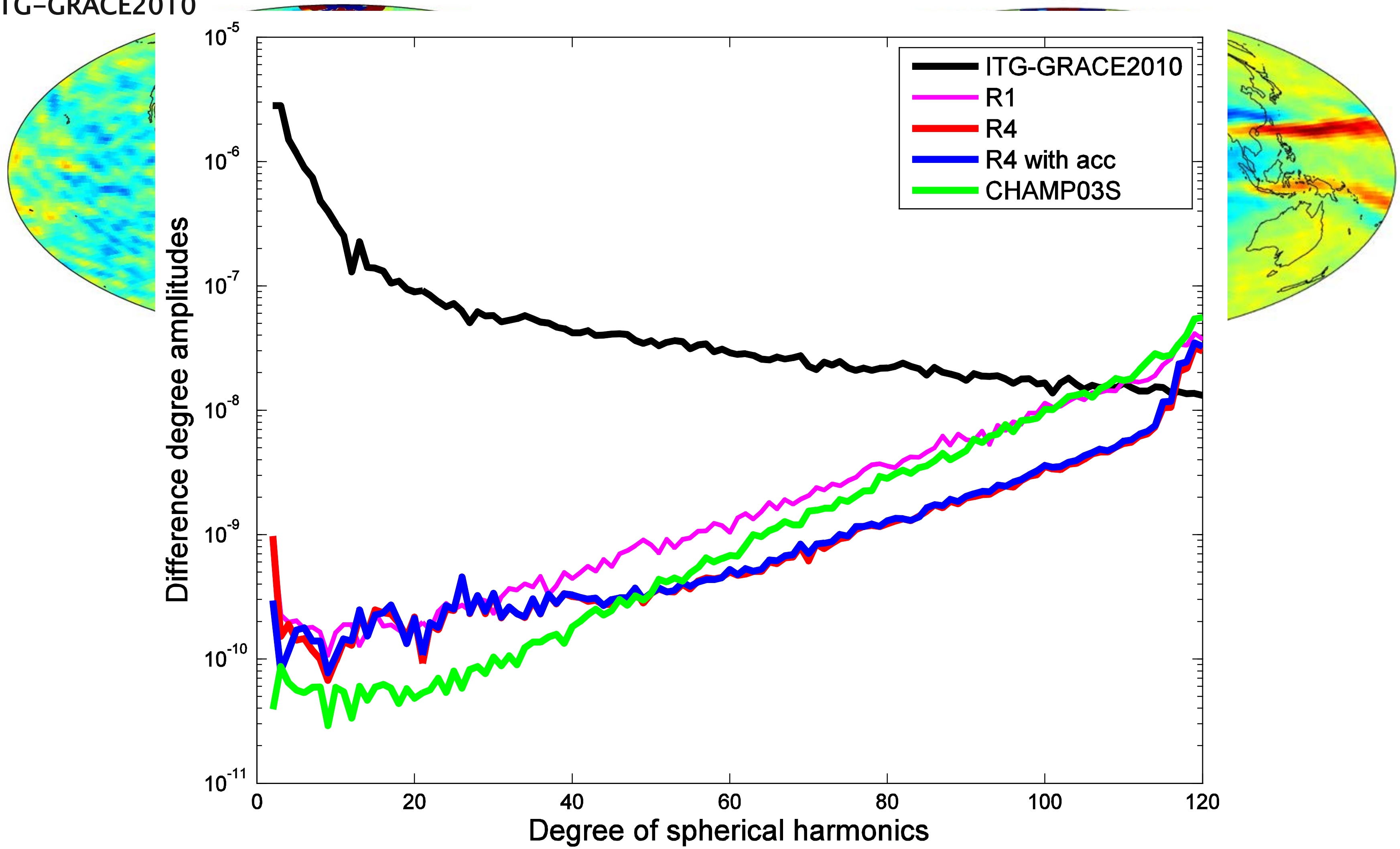
rometer data

Zonal and near-zonal terms excluded according to Van Gelderen and Koop, 1997

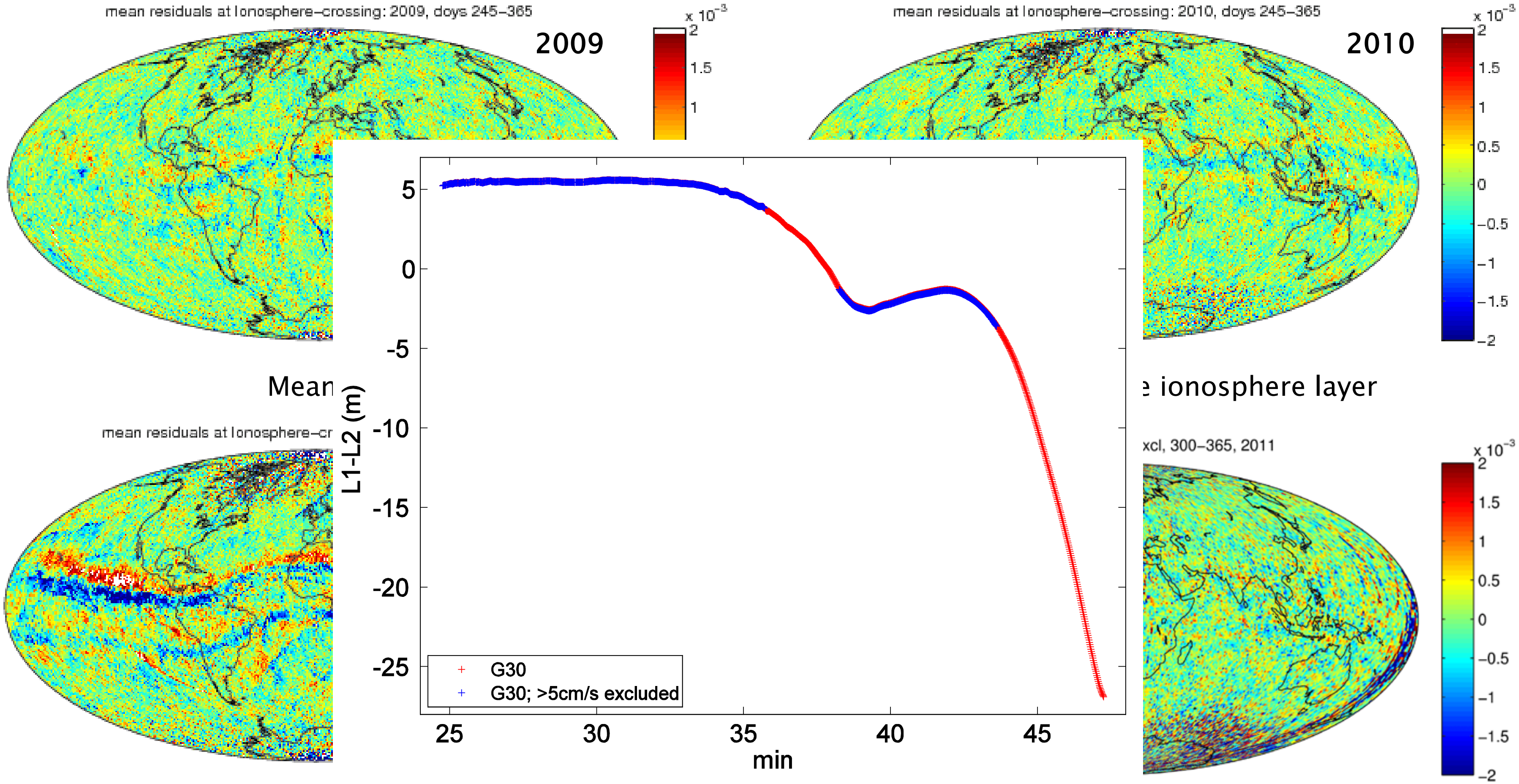
Release 1 and Release 4 solutions

Geoid differences to ITG-GRACE2010

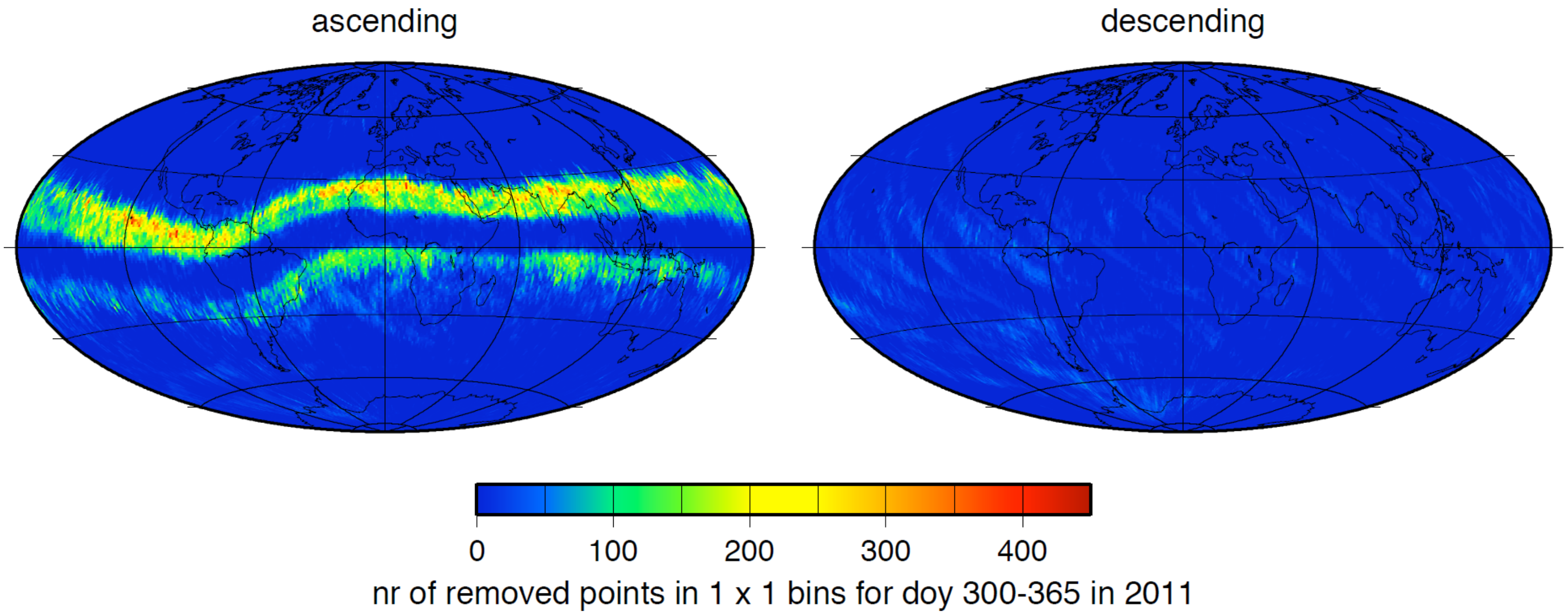
Colour scale -0.05 .... 0.05 m



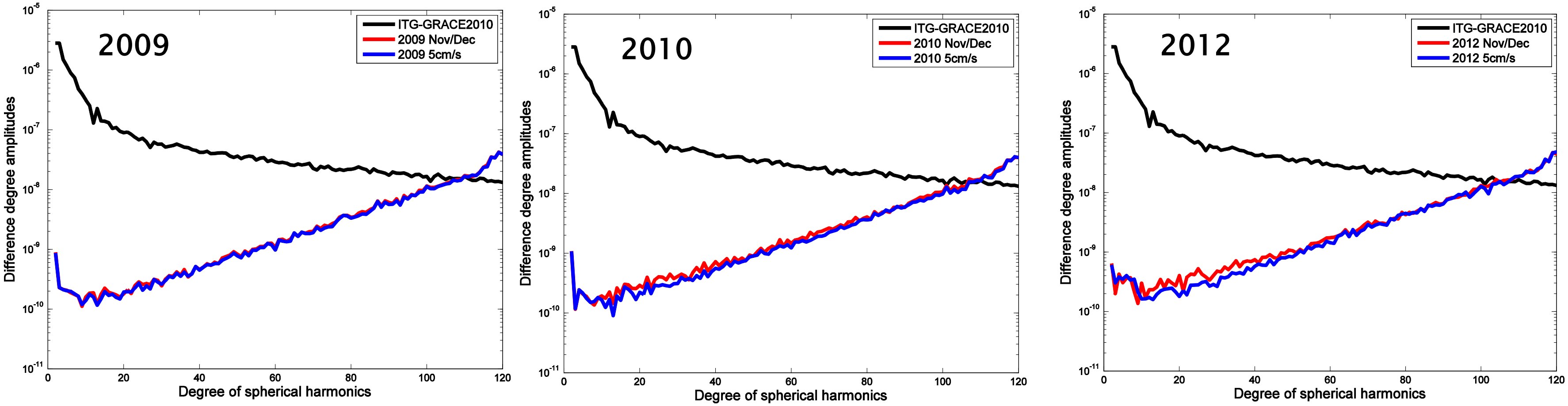
Phase observation residuals

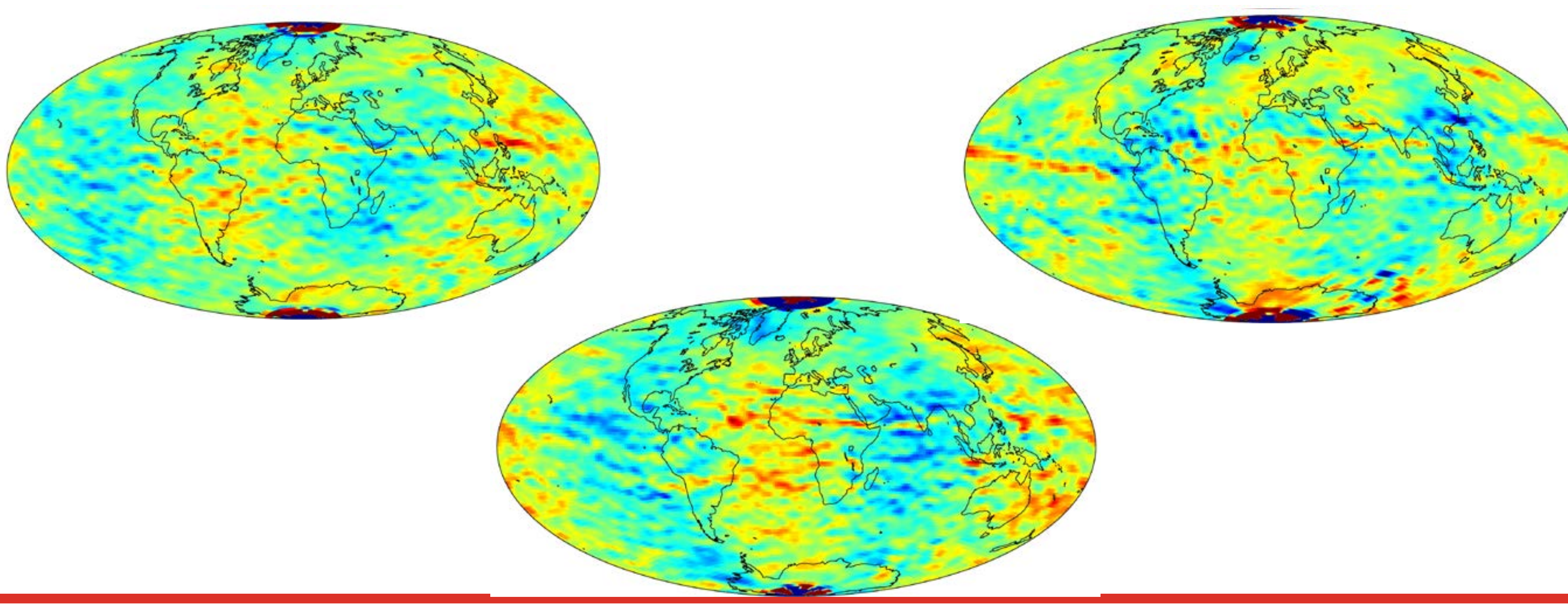


Number of removed observations



Removal of systematic orbit errors





Summary

- AIUB is providing the Precise Science Orbit product for the GOCE satellite
- The Celestial Mechanics Approach is applied to derive GPS-only gravity field models from the GPS-derived precise kinematic orbits
- Systematic orbit errors around the geomagnetic equator are mapped into the gravity field solutions
- Removal of GPS observations, which are affected by a ionosphere change of >5cm/s from one observation epoch to the next
- Systematic errors are removed but orbit quality suffers => more investigations necessary

GOCE – the last days

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Erfolgreicher Satellit der ESA verglüht in den kommenden Tagen

Er wird demnächst in die Erdatmosphäre eintreten und verglühen: Der 2009 gestartete Satellit GOCE (Gravity Field and steady-state Ocean Circulation Explorer) der europäischen Raumfahrtorganisation ESA. Danach wird die äusserst erfolgreiche, erste Hauptmission des «Living Planet Programme» der ESA definitiv beendet sein, zu der das Astronomische Institut der Universität Bern massgeblich beigetragen hat.

Seit März 2009 kreist GOCE im Erdorbit in gut 250 Kilometern Höhe. Mit seinen Messungen hat der Satellit unter anderem dazu beigetragen, die Höhensysteme einzelner Länder zu vereinheitlichen. Damit können etwa unterschiedliche Höhenangaben von Bergen korrigiert und Probleme bei Bauvorhaben besser gelöst werden.

Der Forschungssatellit lieferte auch Grundlagen, um Veränderungen des Meeresspiegels und der Ozeanströmungen zu untersuchen, was für weltweite Klimamodelle massgeblich ist. 2011 hatte GOCE zudem Schallwellen gemessen, die das schwere Erdbeben vor Japan am 11. März produziert hatte, und wurde nach Angaben der ESA so zum ersten Seismometer im All.

In einem Zusammenschluss von zehn europäischen Institutionen und Universitäten war das Astronomische Institut der Universität Bern (AIUB) täglich für die präzise Bahnbestimmung aus den Daten des Bordempfängers des Global Positioning System (GPS) zuständig.

Bern weltweit führend in der GPS-Datenauswertung

Bereits sechs Jahre vor Beginn der GOCE-Mission begannen am Astronomischen Institut der Universität Bern die Vorbereitungsarbeiten für das Projekt. «Für ein relativ kleines Institut wie das AIUB war die Beteiligung an einem ESA-Projekt mit derart langer Laufzeit ein absoluter Glücksfall», sagt Prof. Adrian Jäggi, Direktor des AIUB.

Download

Der GOCE-Satellit im Flug – dank der «Bernese GPS Software», welche seine Bahn bis auf zwei Zentimeter genau bestimmte, wussten die Berner Forschenden immer, wo er sich gerade befand. Bild: ESA.

» Astronomisches Institut der Universität Bern (AIUB)
» GOCE-Mission der ESA
» Bernese GPS Software

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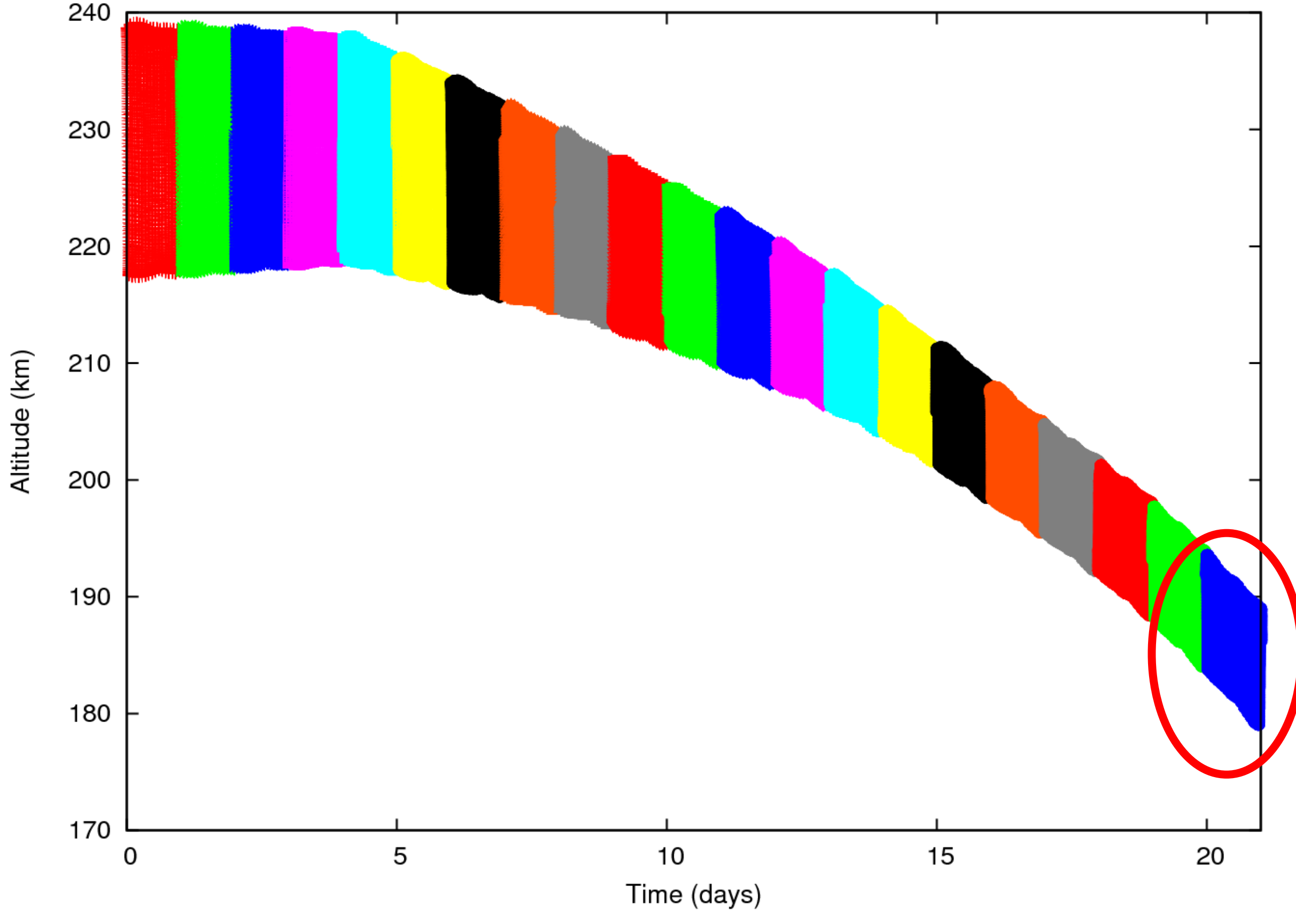
Astronomisches Institut der Universität Bern

GOCE – the last days



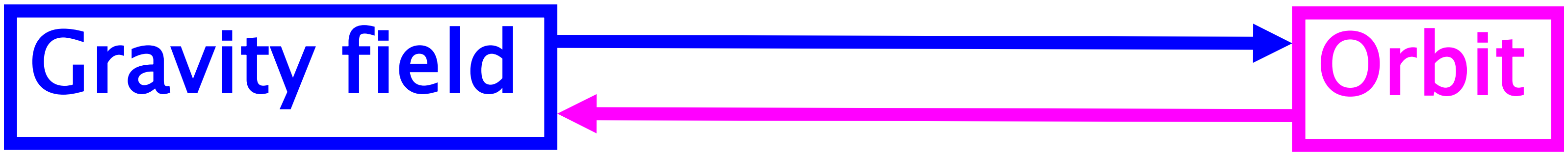
Wednesday, 6.11.2013

Schwerefeldbestimmung mit GRACE

Motivation

- Signal and Noise in monthly fields (GRACE)
- Separation of Orbit and Gravity field estimation
- How does it work?
- Discussion

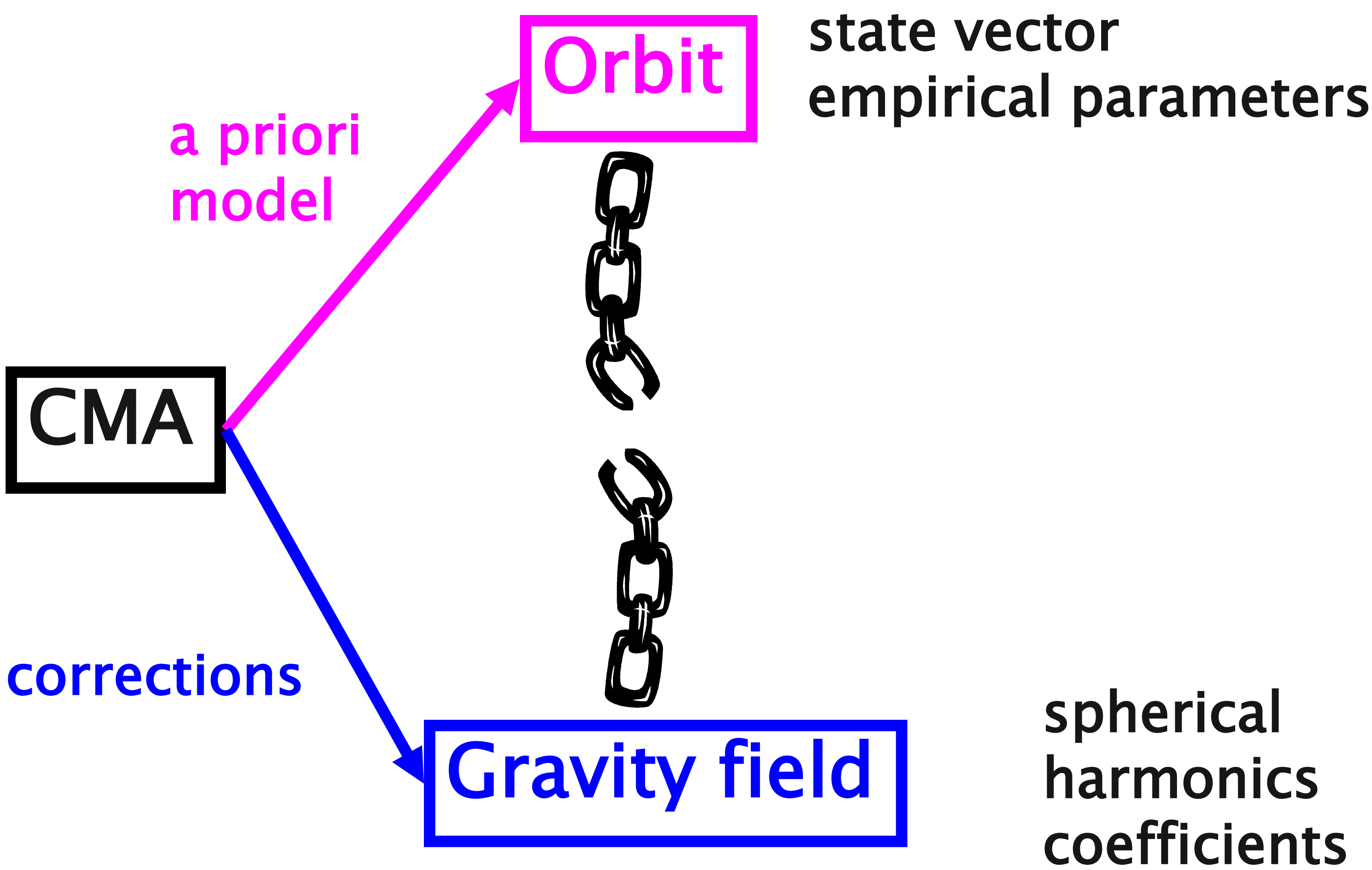
Gravity field and Orbit



Non–linear parameter estimation problem

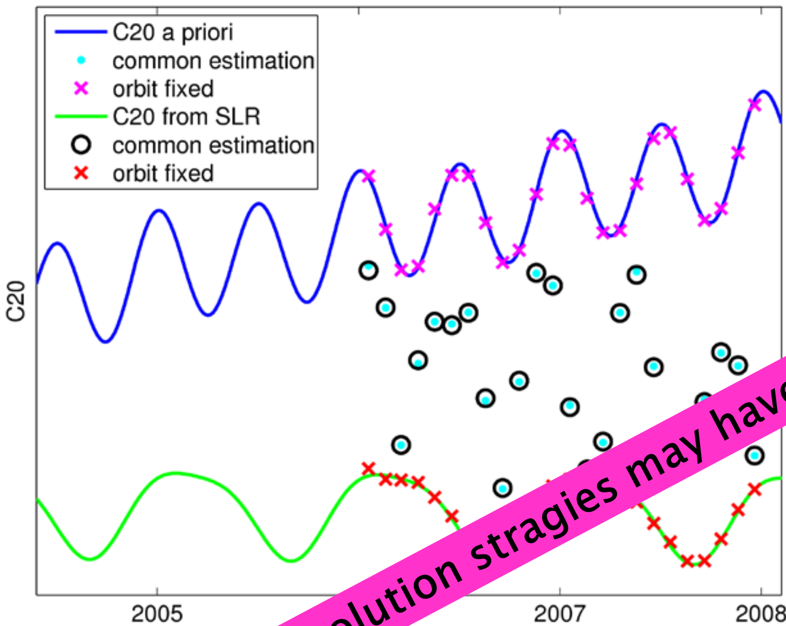
- A priori model (linearization)
- Observations
- Regularization (a priori knowledge via pseudo–observations)

Impact of different processing strategies

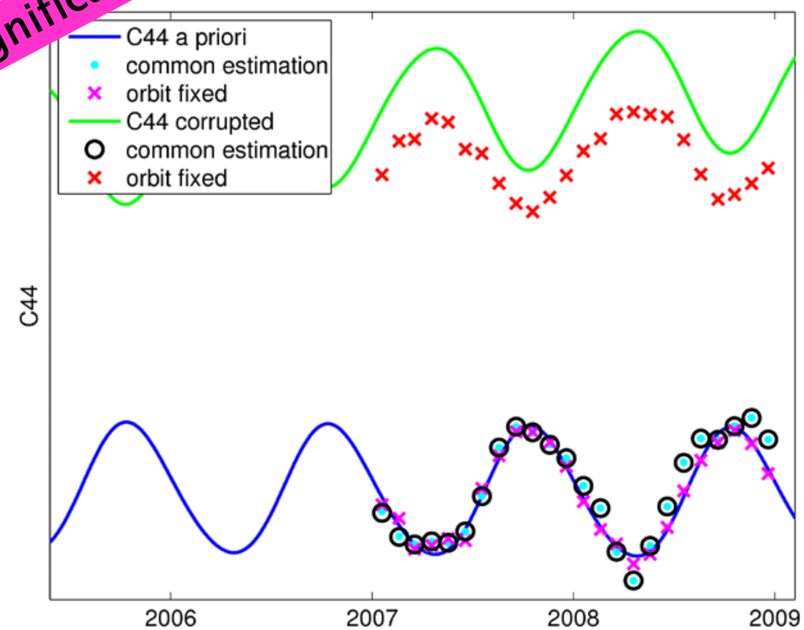


Impact of different processing strategies

C20

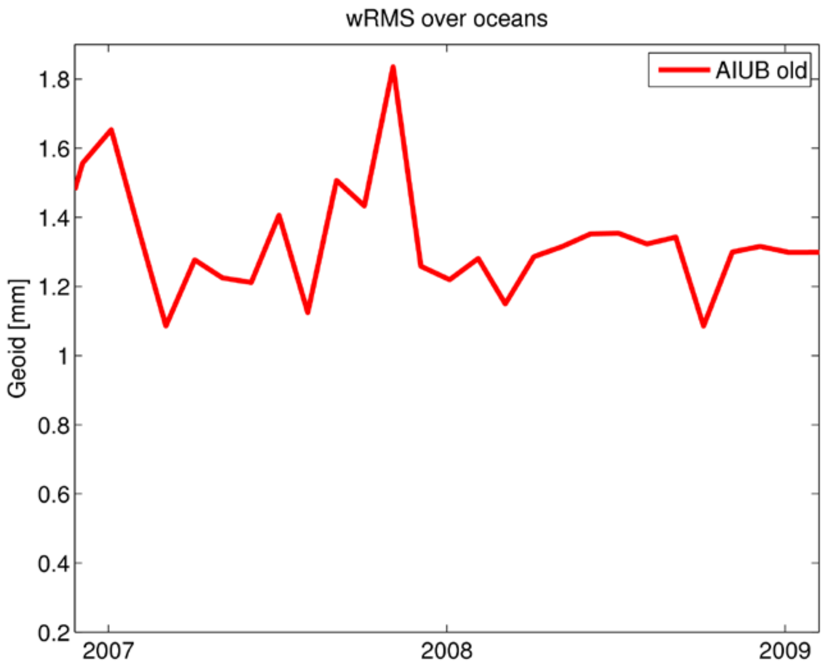


C44

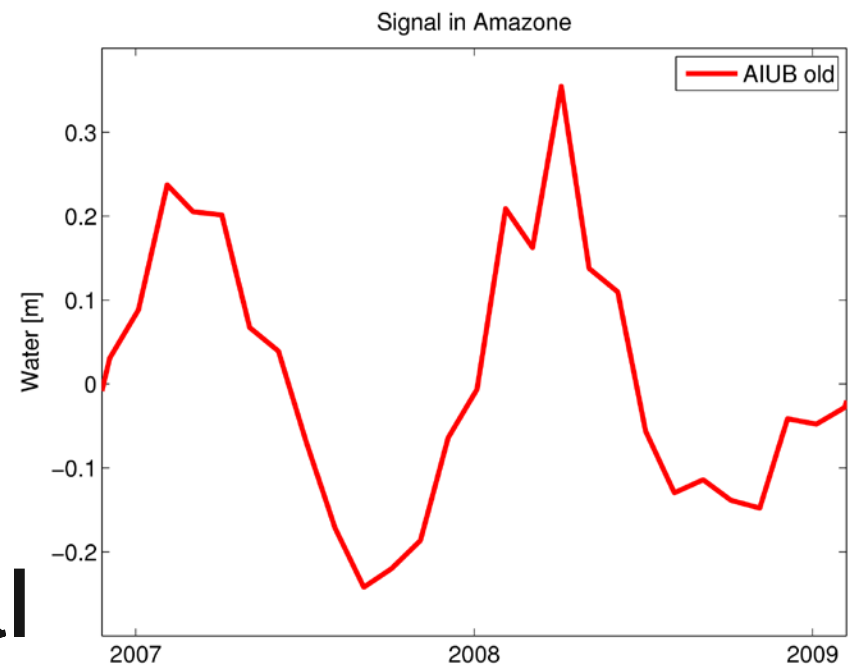


Different solution stragies may have a significant impact on signal and noise

Separation of Orbit and Gravity field

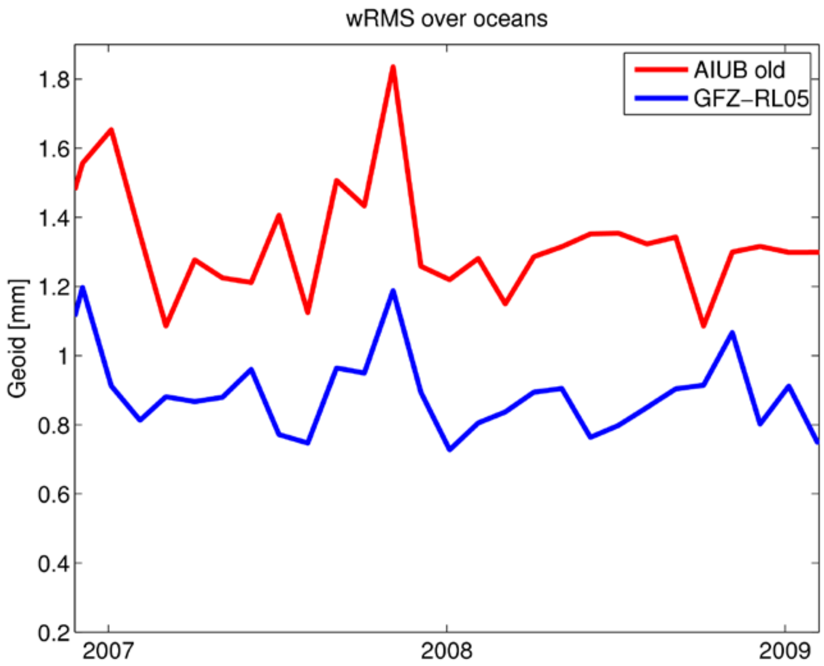


noise

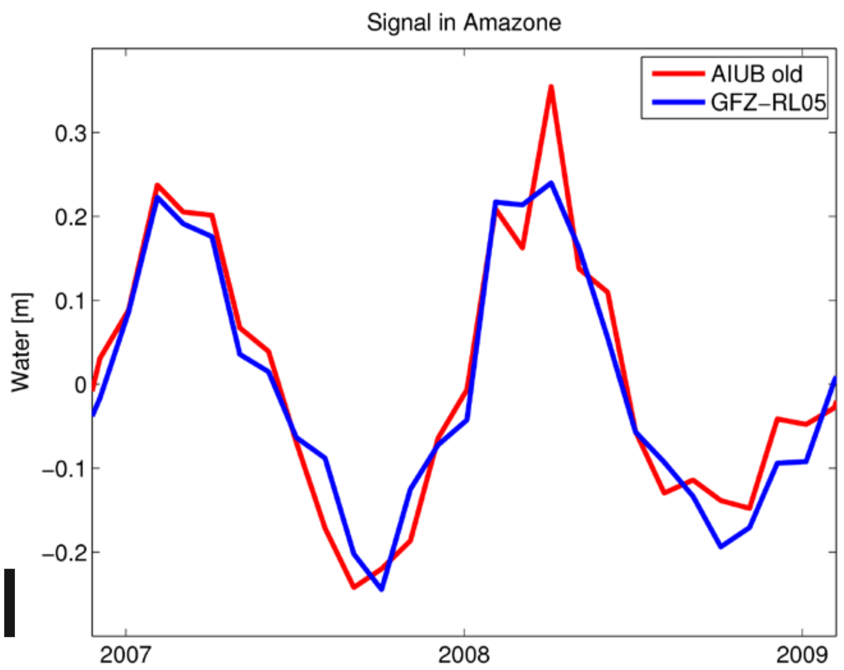


signal

Separation of Orbit and Gravity field

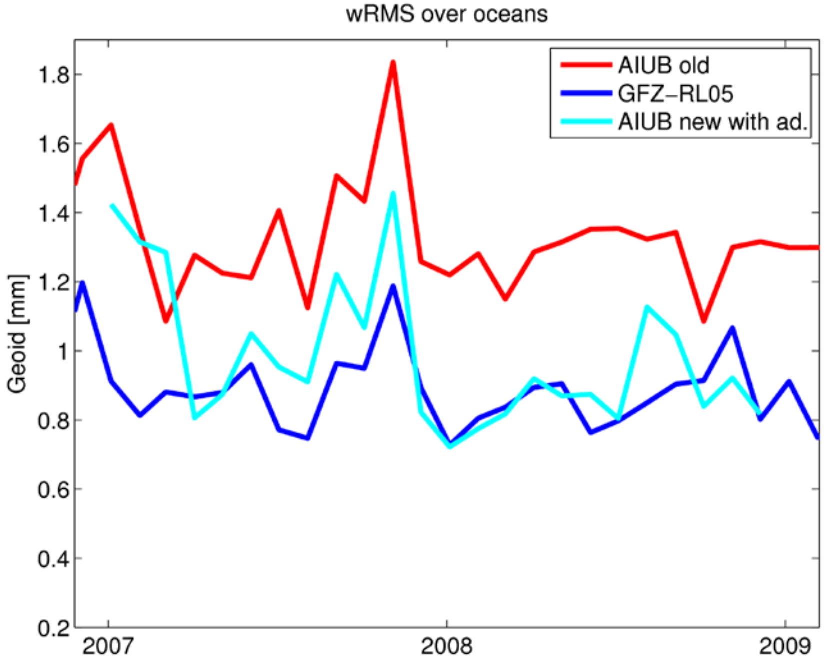


noise

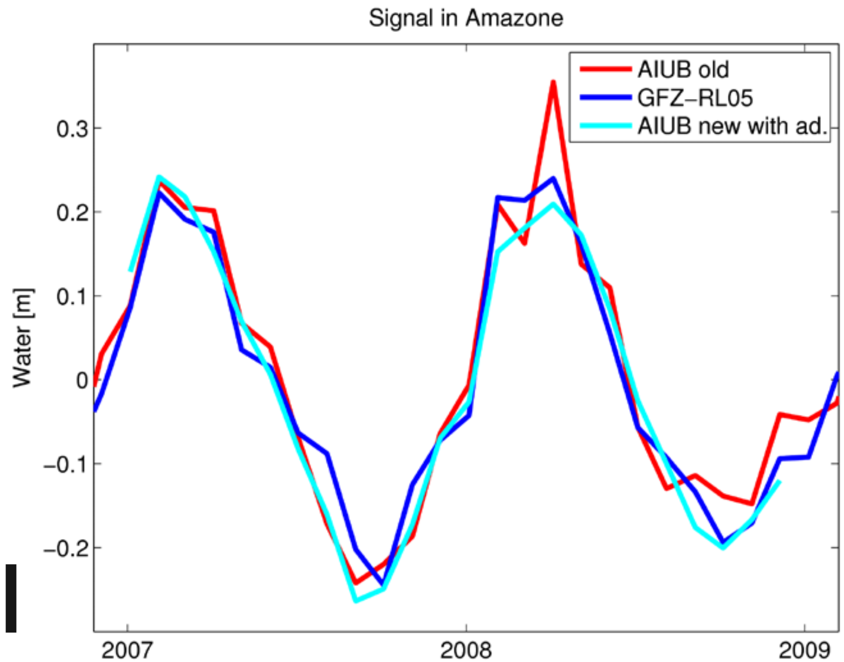


signal

Separation of Orbit and Gravity field

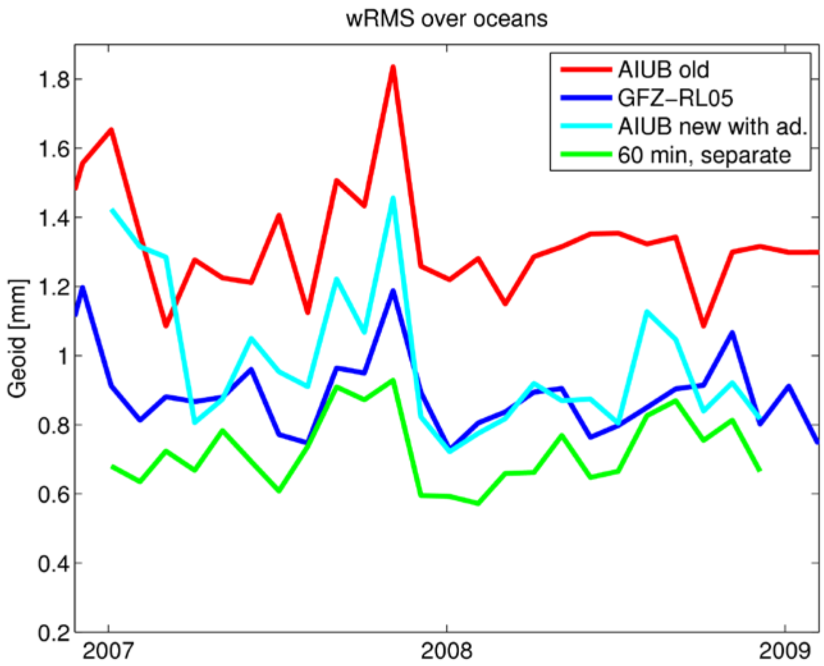


noise

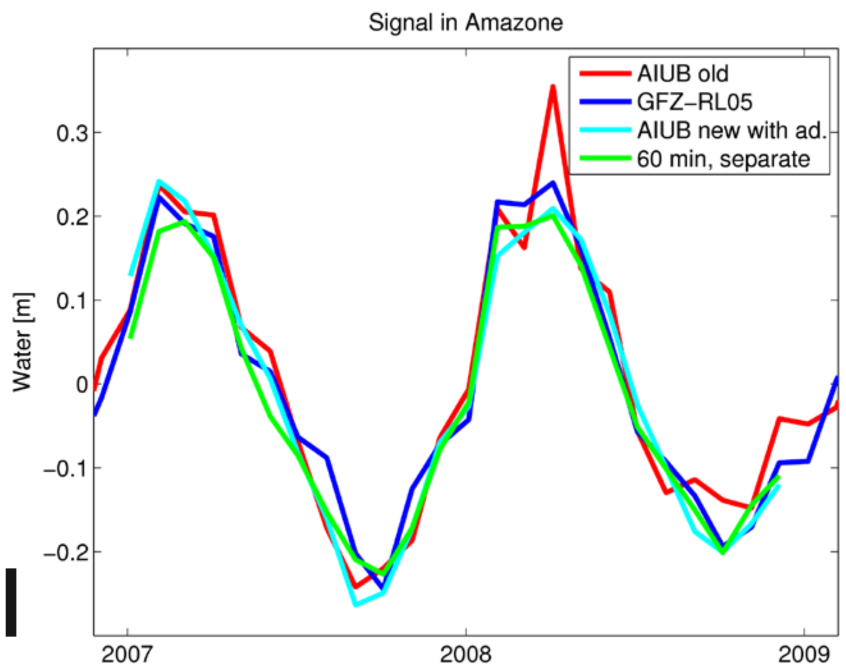


signal

Separation of Orbit and Gravity field

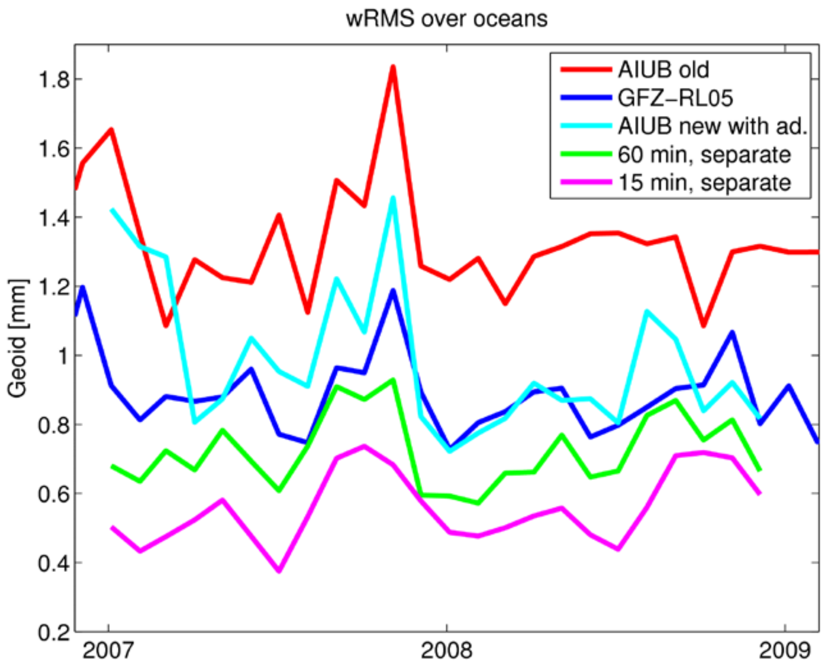


noise



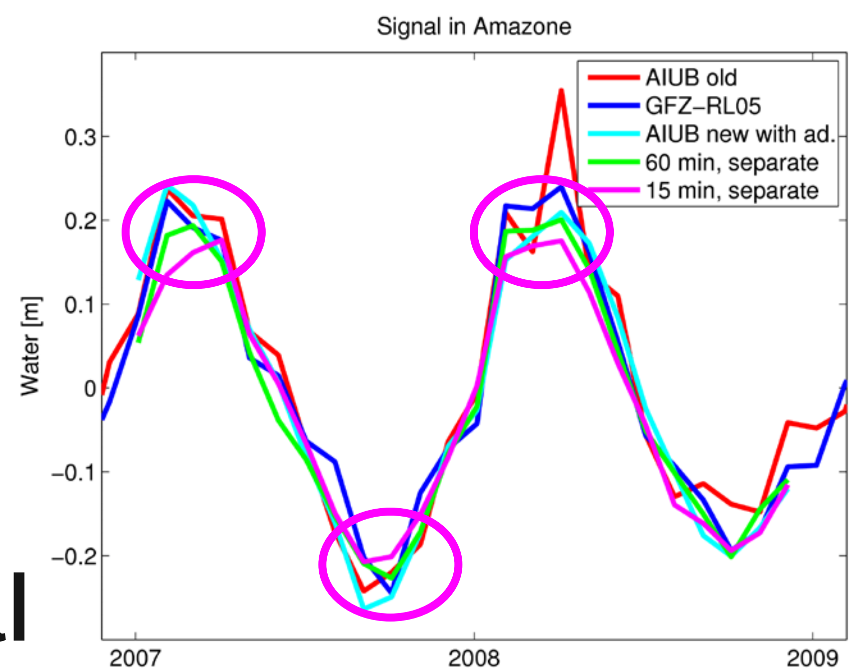
signal

Separation of Orbit and Gravity field



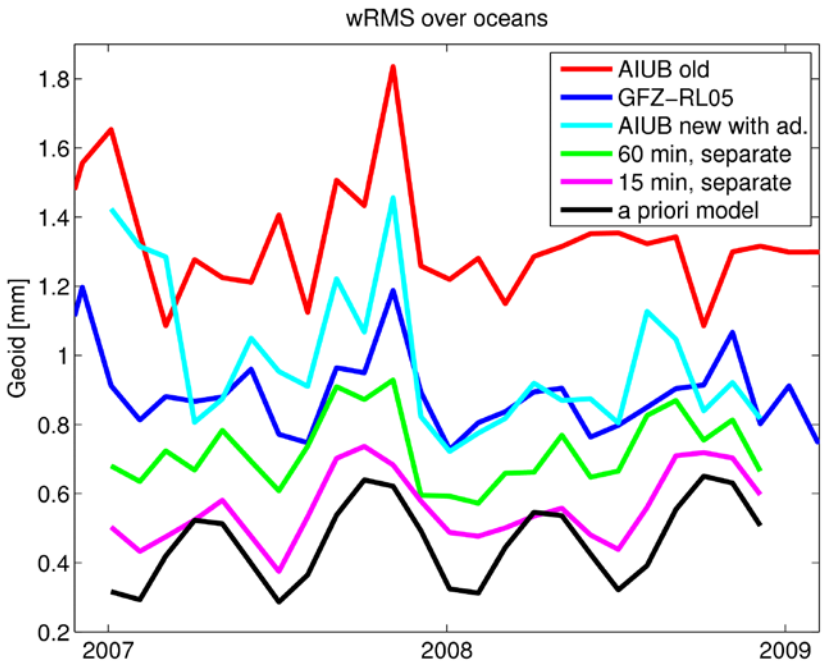
noise

signal loss

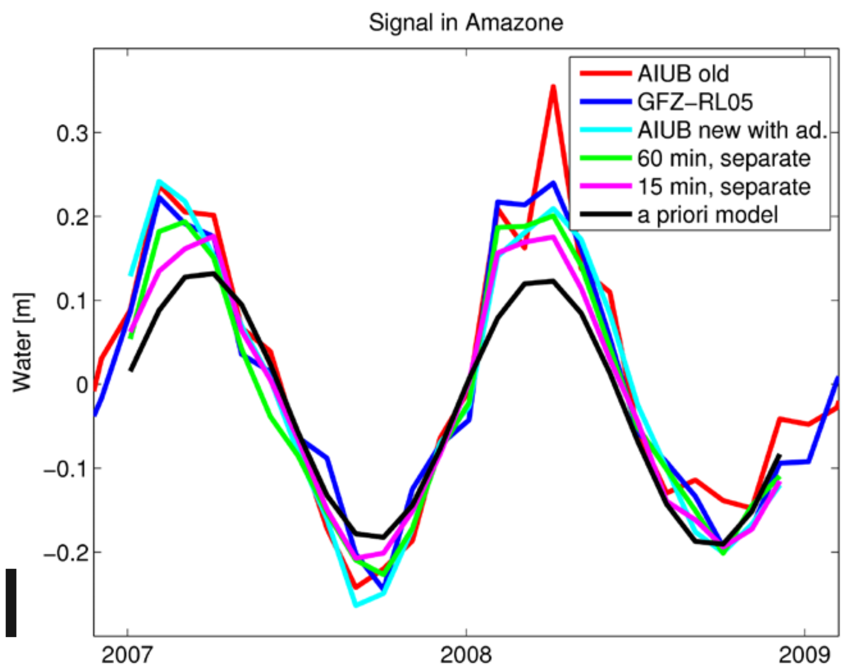


signal

Separation of Orbit and Gravity field

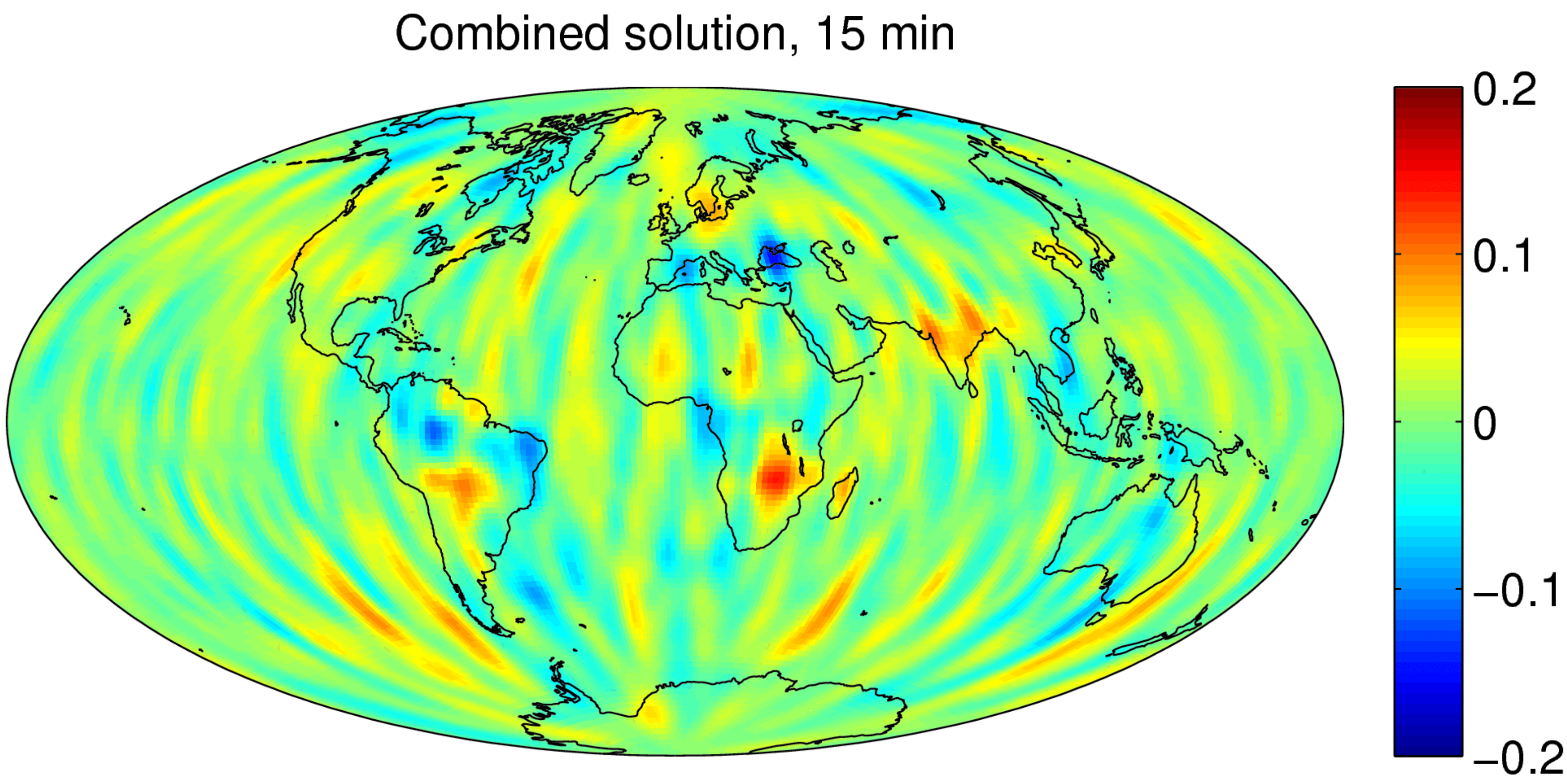


noise

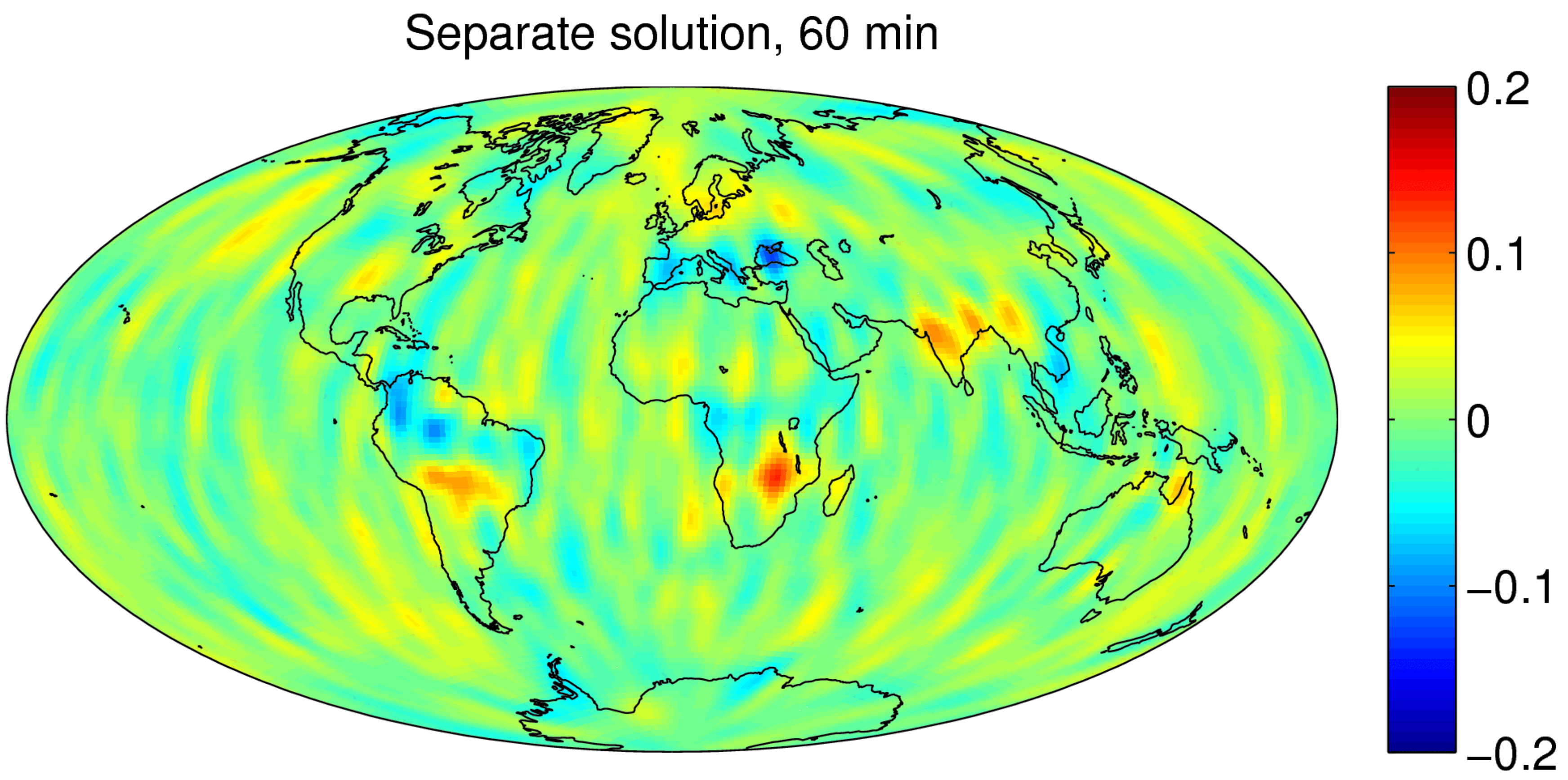


signal

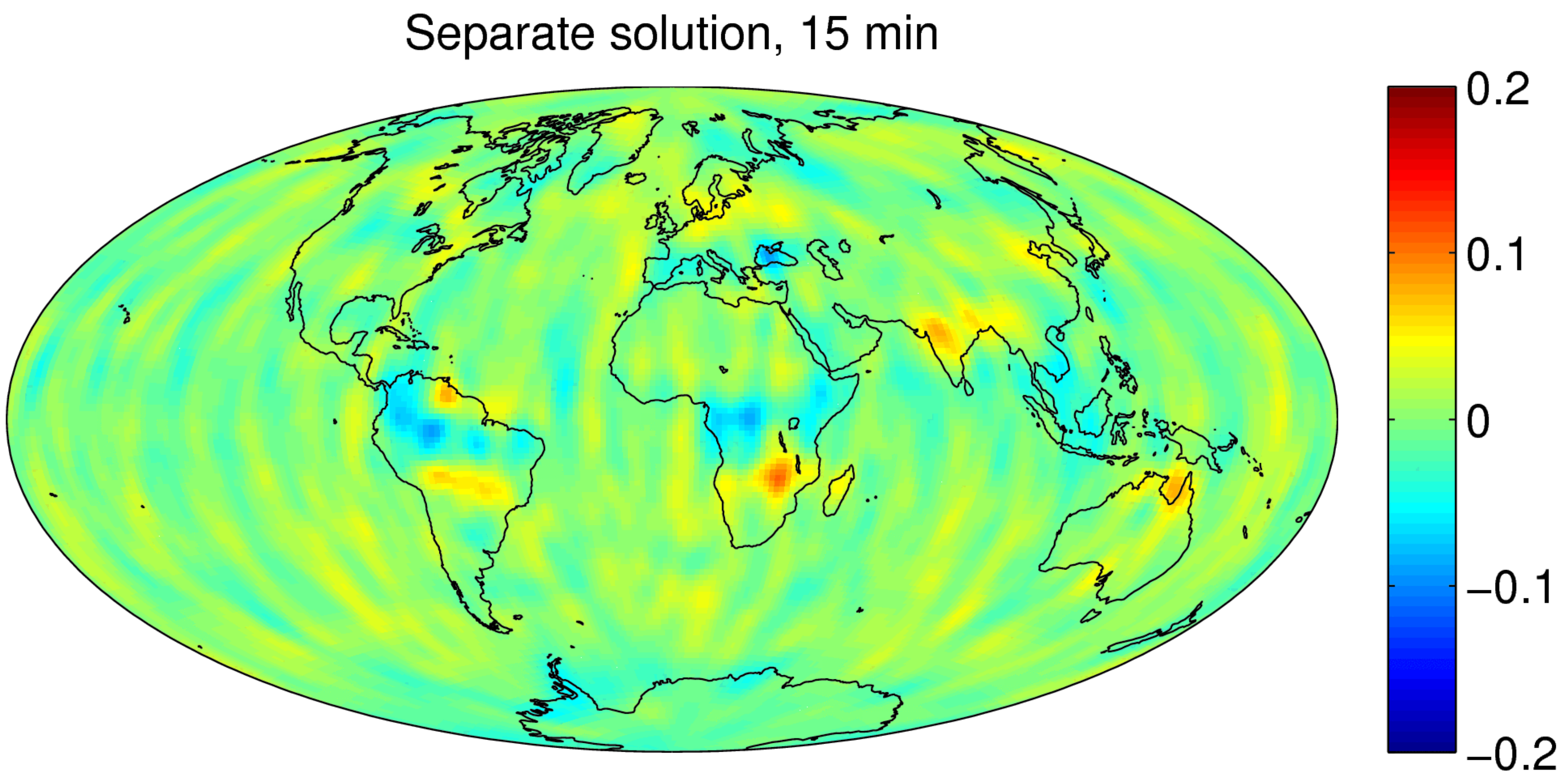
Monthly field – a priori model



Monthly field – a priori model



Monthly field – a priori model



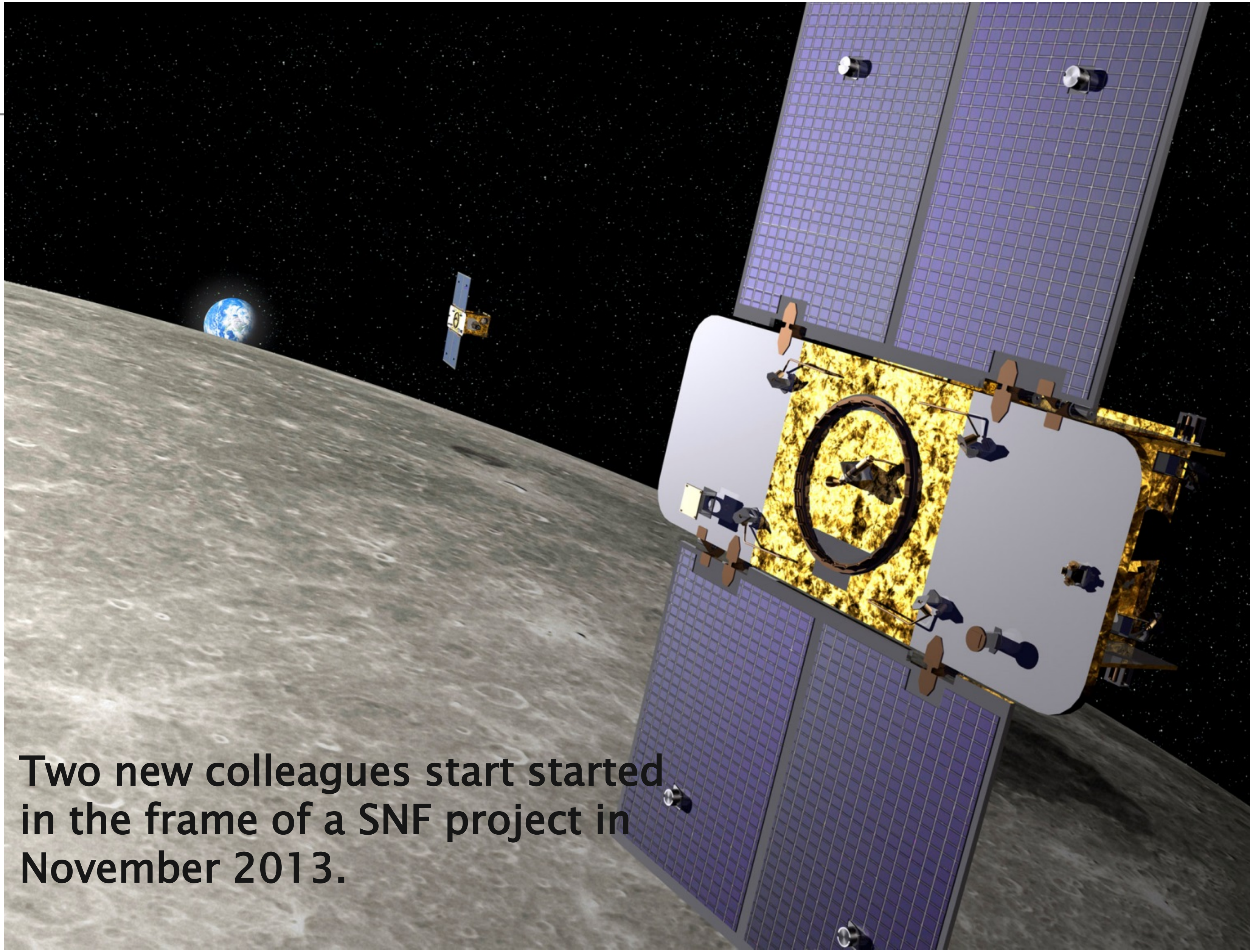
Discussion

Is it good or bad?

- Is it correct?
  - Not really
- Is it helpful?
  - Yes
- Is it dangerous?
  - Yes

⇒ GFZ announced an alternative Release 05a (trends for Greenland ice mass loss were heavily biased towards the a priori model)

GRAIL: Bestimmung des Schwerefeldes des Mondes


Two new colleagues start started
in the frame of a SNF project in
November 2013.

Vielen Dank für Ihre Aufmerksamkeit

Publikationen der Forschungsgruppe Satellitengeodäsie:
http://www.bernese.unibe.ch/publist