

# Astronomisches Institut 2013: Aktivitäten und Projekte

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*Astronomisches Institut*

# Zimmerwald SLR

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*Astronomisches Institut*

# Hardware Entwicklungen (1)

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- 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)

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**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

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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

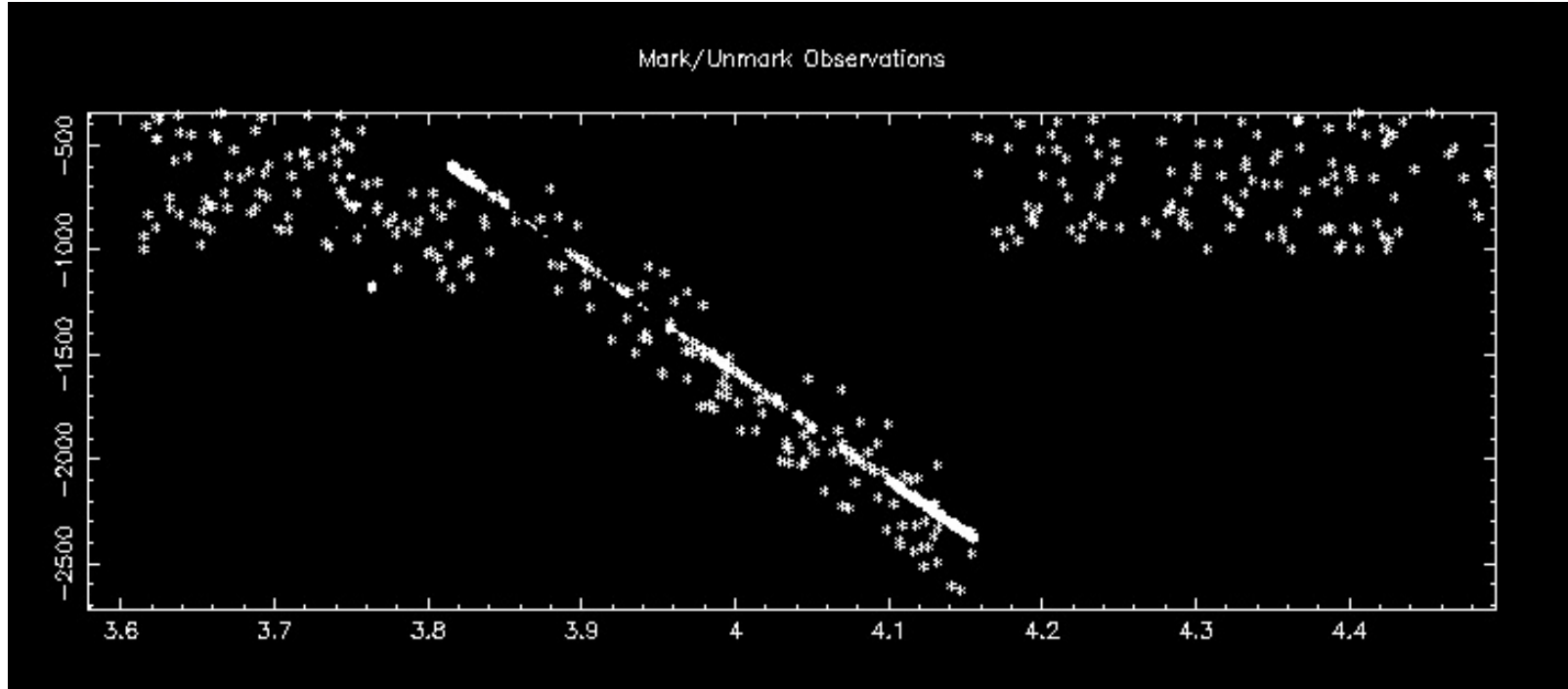
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**Geostationäre Satelliten:** Am 24.9.2013 konnten **erstmalig Echos von einem geostationären Satelliten** empfangen werden. Es handelt sich hierbei um den Satelliten IRNSS-1A des im Aufbau befindlichen indischen Navigationssystem. Zimmerwald war die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

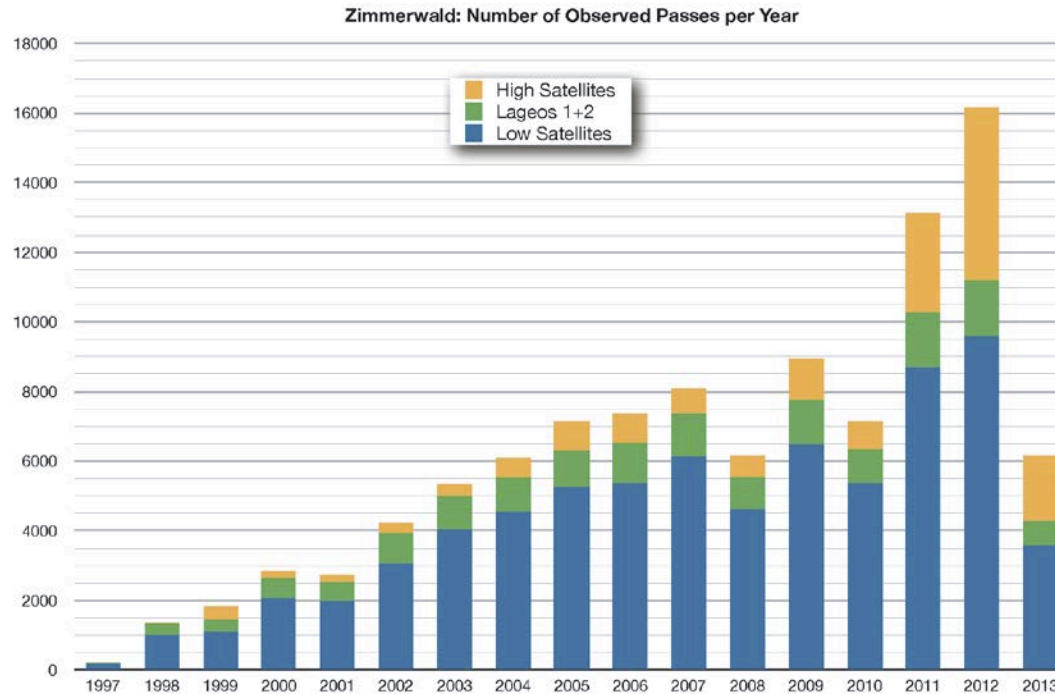
**Bistatic Experiment mit Graz:** Die Experimente mit der SLR Station Graz Lustbühel wurden fortgesetzt. Als Ziele wurden in diesem Jahr nicht nur der Satellit ENVISAT, sondern auch **Space Debris Objekte** ausgewählt, die in **niedrigen Bahnhöhen (bis ca. 3000 km)** fliegen. Am 18.6.2013 **weltweit erstmalig 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

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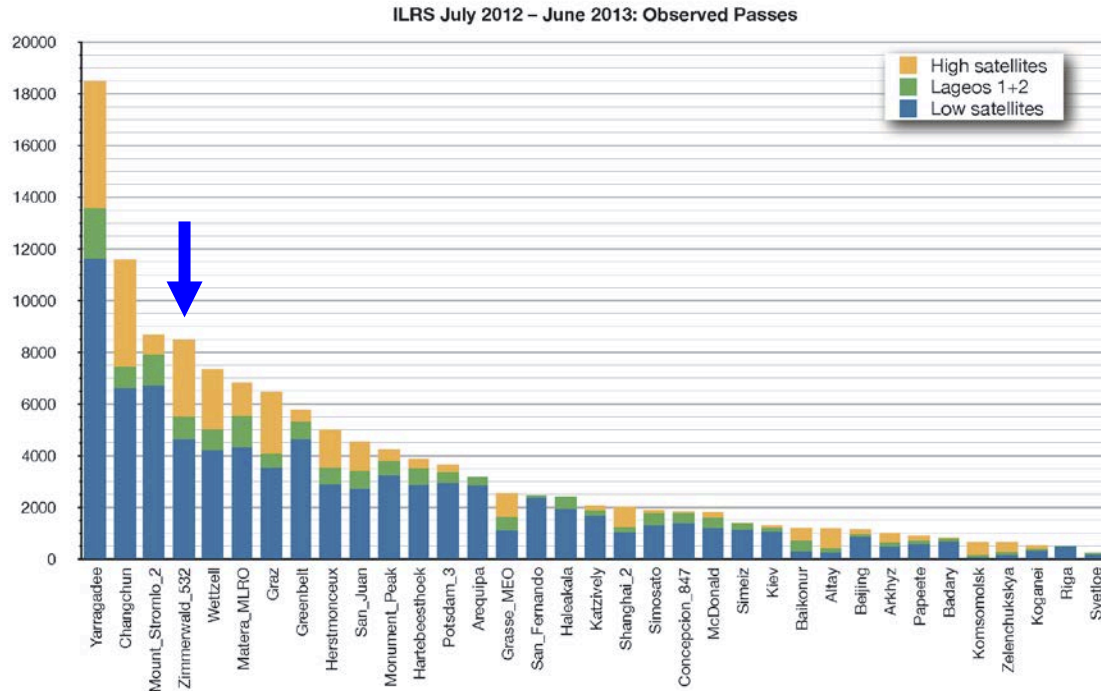
# Beobachtete Durchgänge



**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 nördlichen Hemisphäre**

# Aktivitäten der Forschungsgruppe Satellitengeodäsie am AIUB

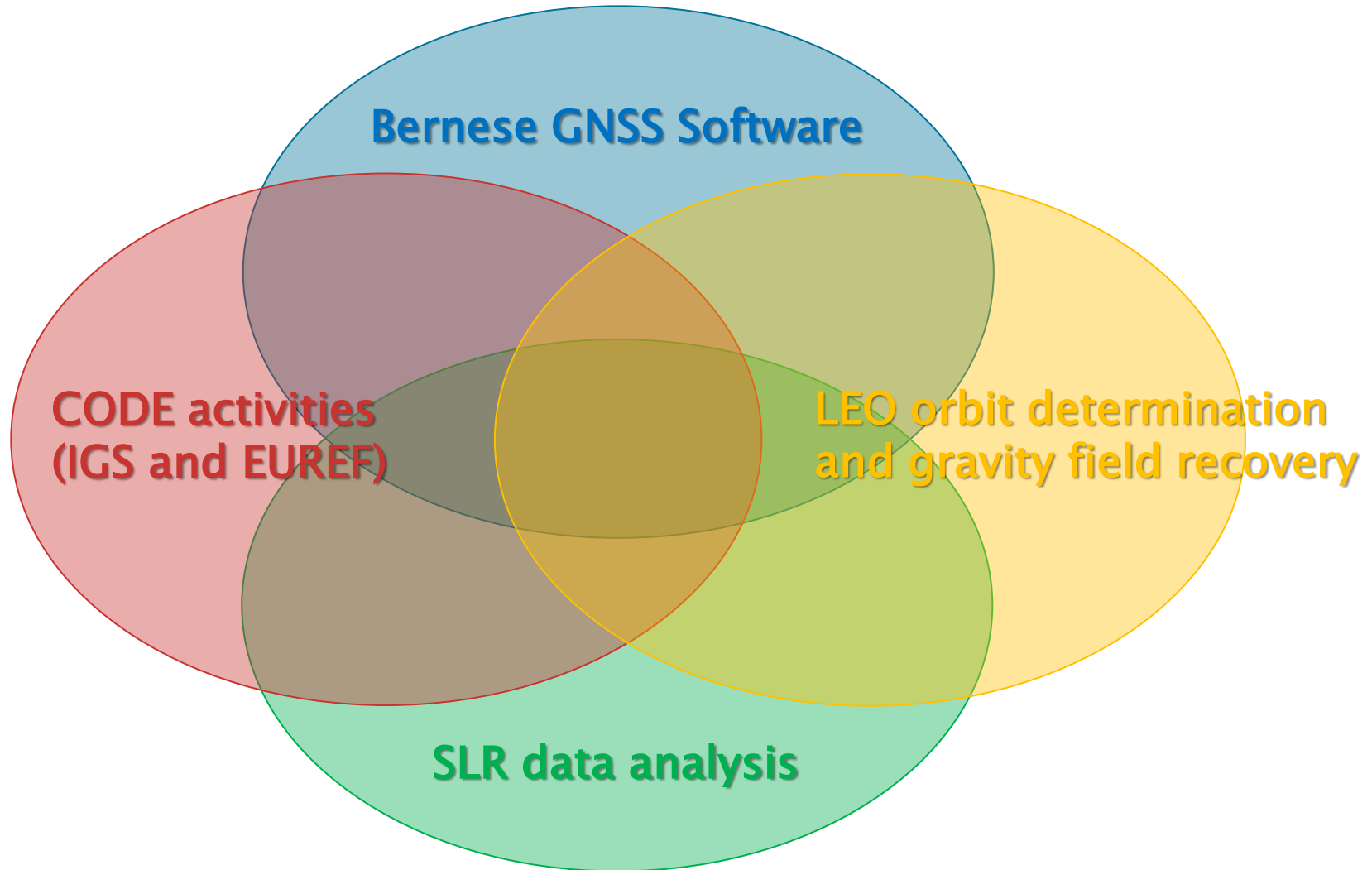
R. Dach und Adrian Jäggi

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*

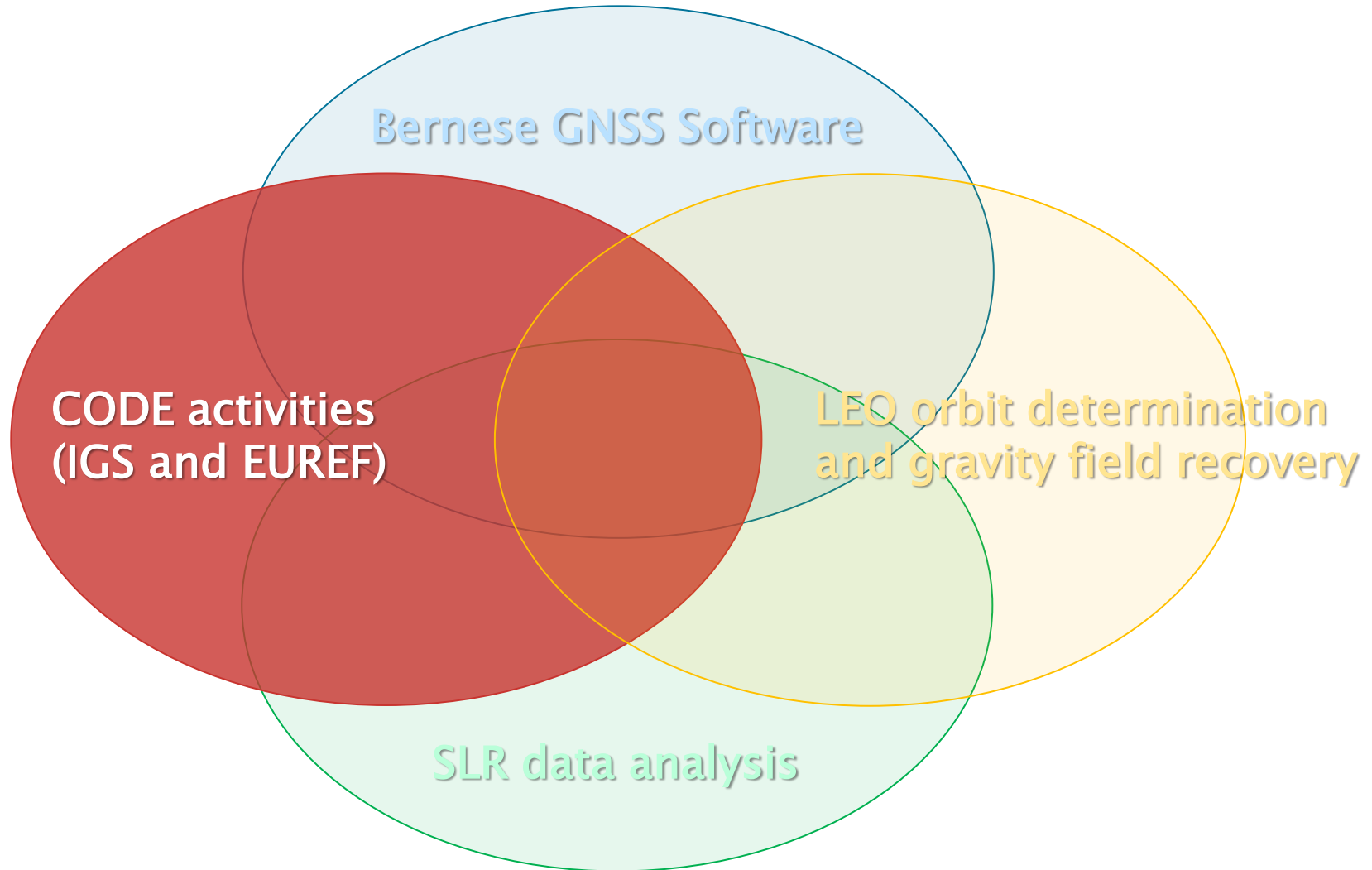
# Satellite Geodesy Research Group

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# Satellite Geodesy Research Group

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# New processing line for the CODE-analysis center

# Station/data quality monitoring

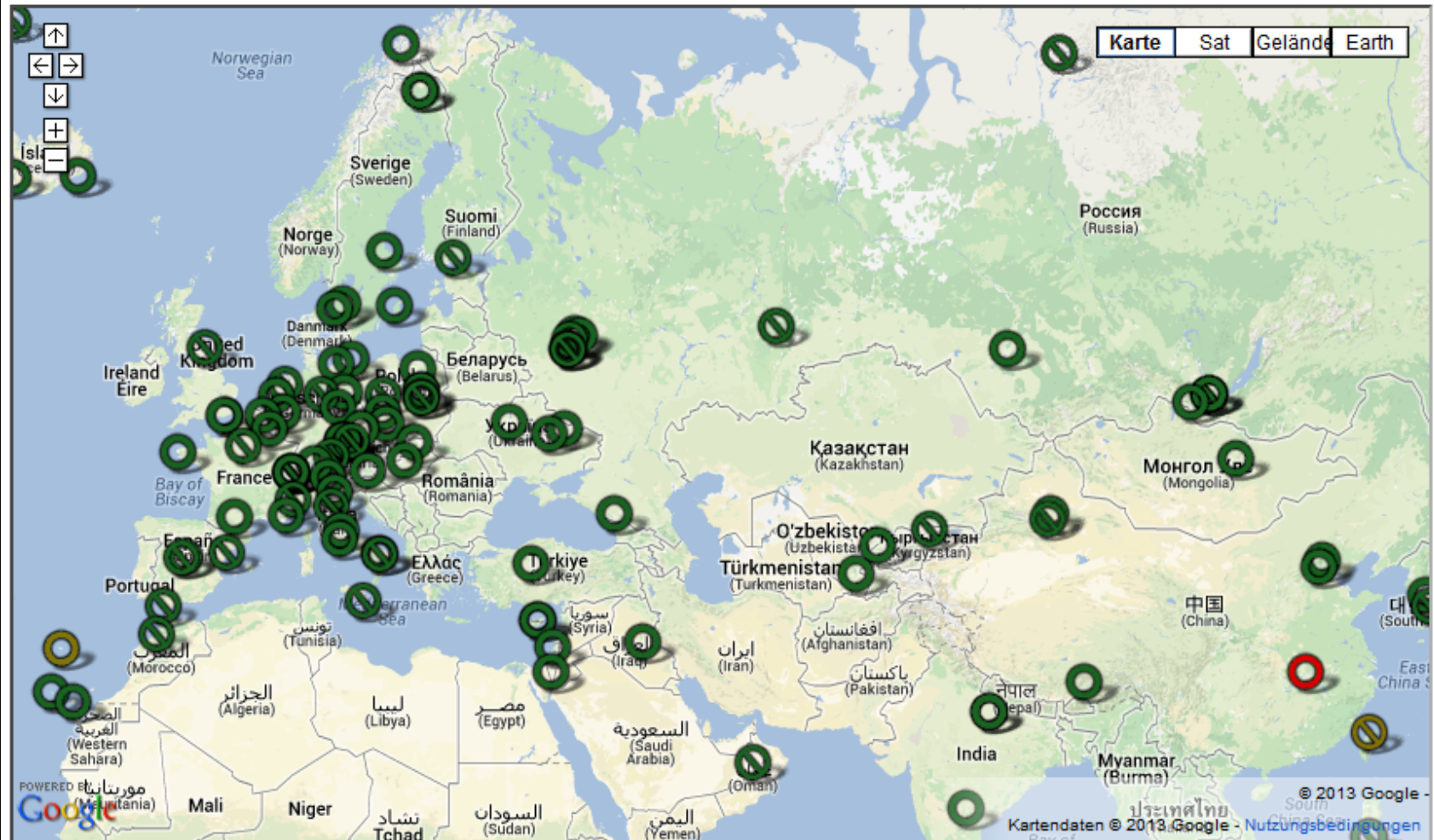
- in the evening a PPP procedure based on the submitted CODE rapid products starts
  - about **300 stations** are included
  - **four solutions** are generated:  
GPS+GLONASS: **code+phase** (classical PPP) and **phase-only**  
GPS-only, GLONASS-only: **phase-only**
- Evaluation of the resulting time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

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SERIES OF PROBLEMATIC STATIONS FROM GNS- SOLUTION:
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				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	<b>-24.45</b>	-0.24	3.88	7.43	-1.04	<b>10.15</b>	2.92
UNSA	41514M001	U	12.51	-17.15	5.06	<b>23.07</b>	-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	<b>-10.64</b>	<b>18.67</b>	5.73	<b>16.34</b>	-5.53
WUHN	21602M001	U	17.85	12.65	-5.74	<b>-18.65</b>	<b>-33.19</b>	11.65	-5.41	10.26

# Time series from the recent PPP solutions

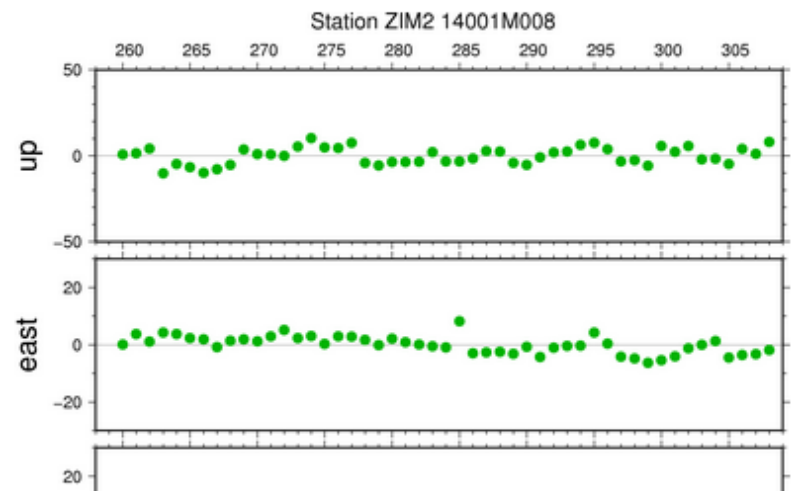
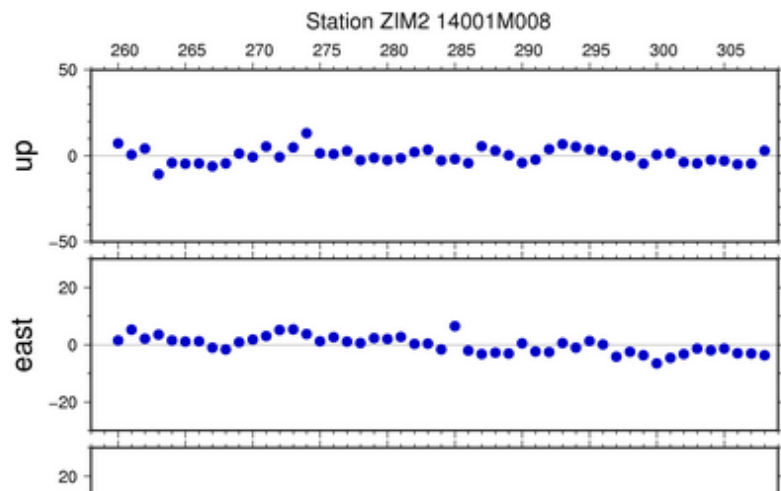
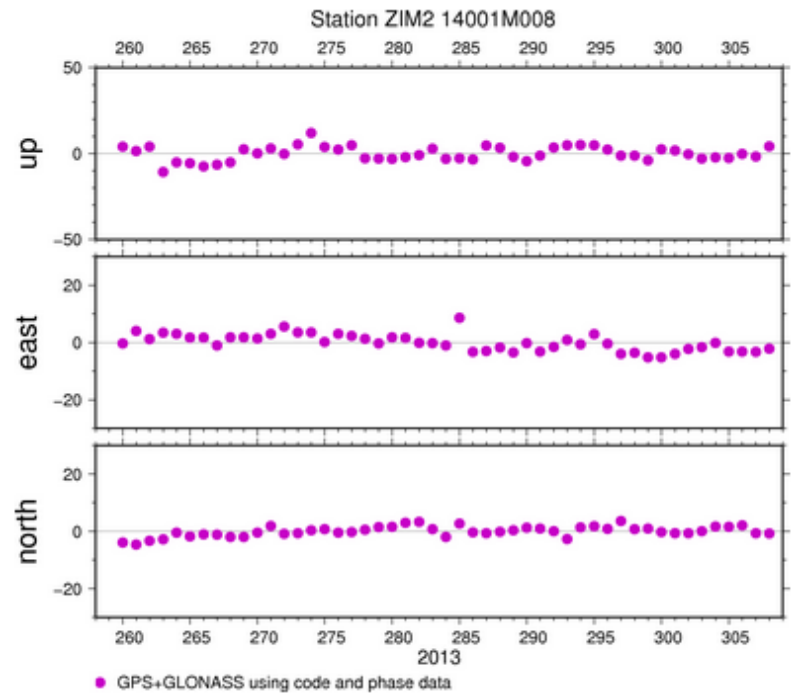
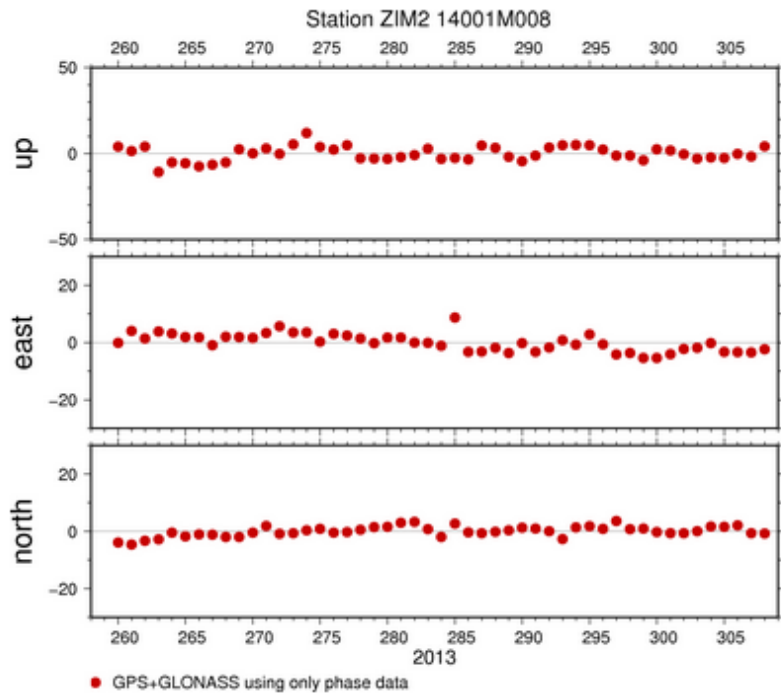
Go to: [most recent PPP solution](#).



## List of solutions:

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

# Stability of the recent PPP solutions:





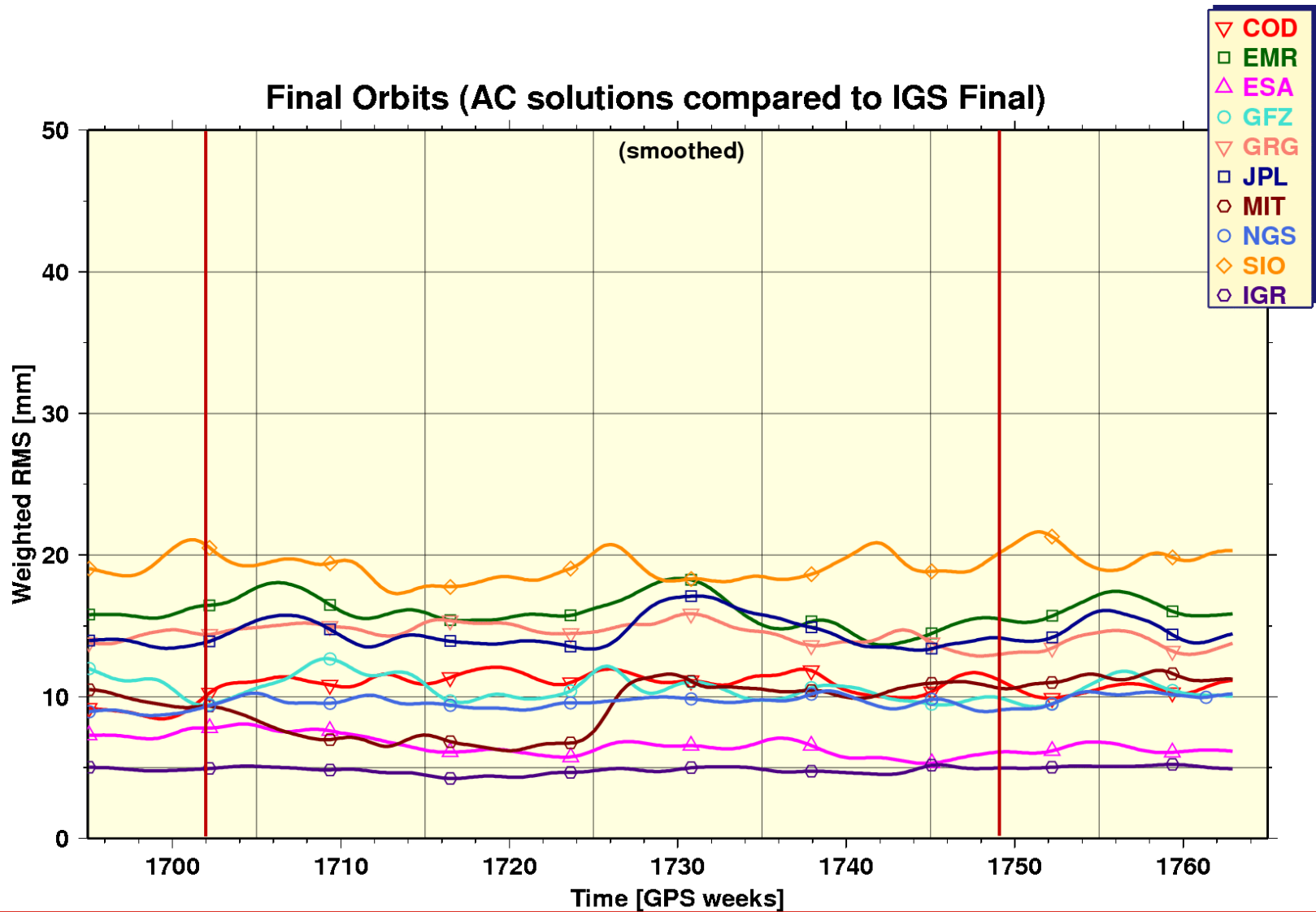
# CODE-contribution to IGS final solution and repro2-initiative

# Modeling updates in CODE's processing

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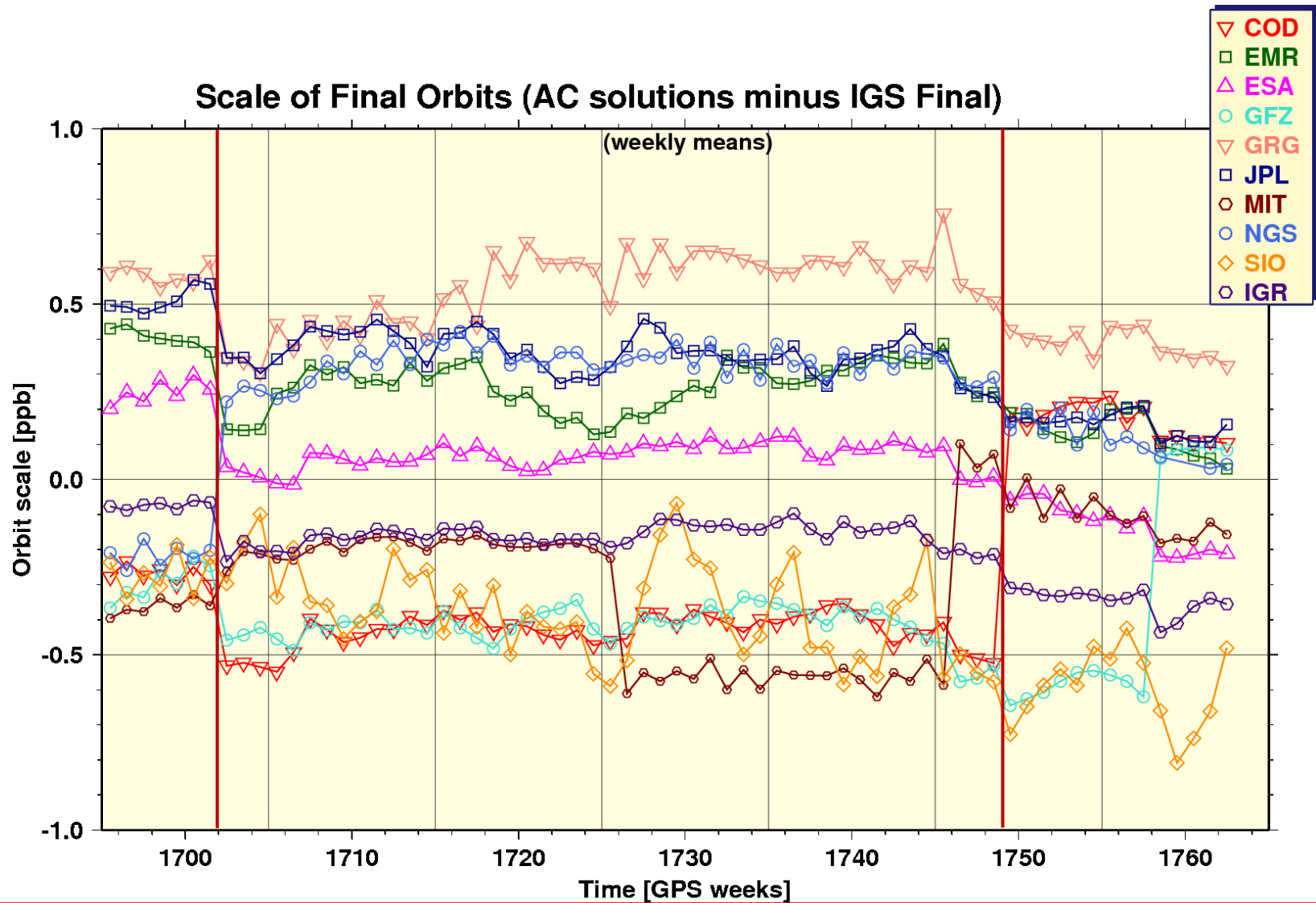
- **Update in orbit modeling according** to IERS- and IGS-guidelines:
  - JPL-ephemeris: DE405 to DE421
  - Albedo model according to Rodriguez-Solano et al. 2012
  - Antenna thrust (GPS: block-specific; GLONASS: assumed to 100W)
  - No a priori RPR model anymore
- **Observation type** selection based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



NOAA NGS, 2.11.2013 19:29 (GMT)

# Modeling updates in CODE's processing



NOAA NGS, 2-11-2013 19:29 (GMT)

# 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 München coordinated with AIUB (mainly performed by P. Steigenberger).

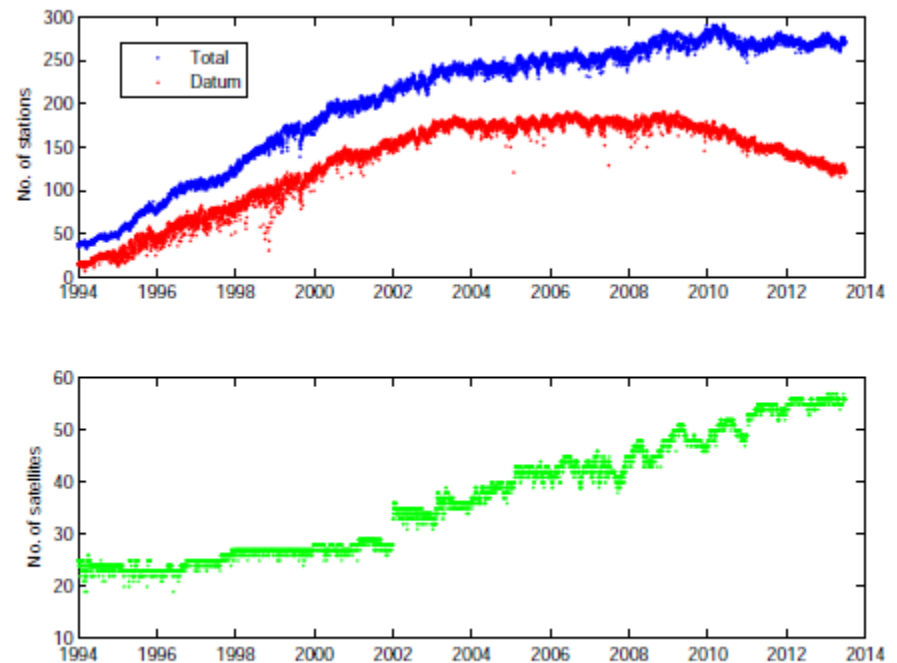


Figure 2: Total number of stations, number of datum stations, and number of satellites.

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# CODE–contribution to IGS ultra–rapid solution

# Update of CODE's ultra-rapid product

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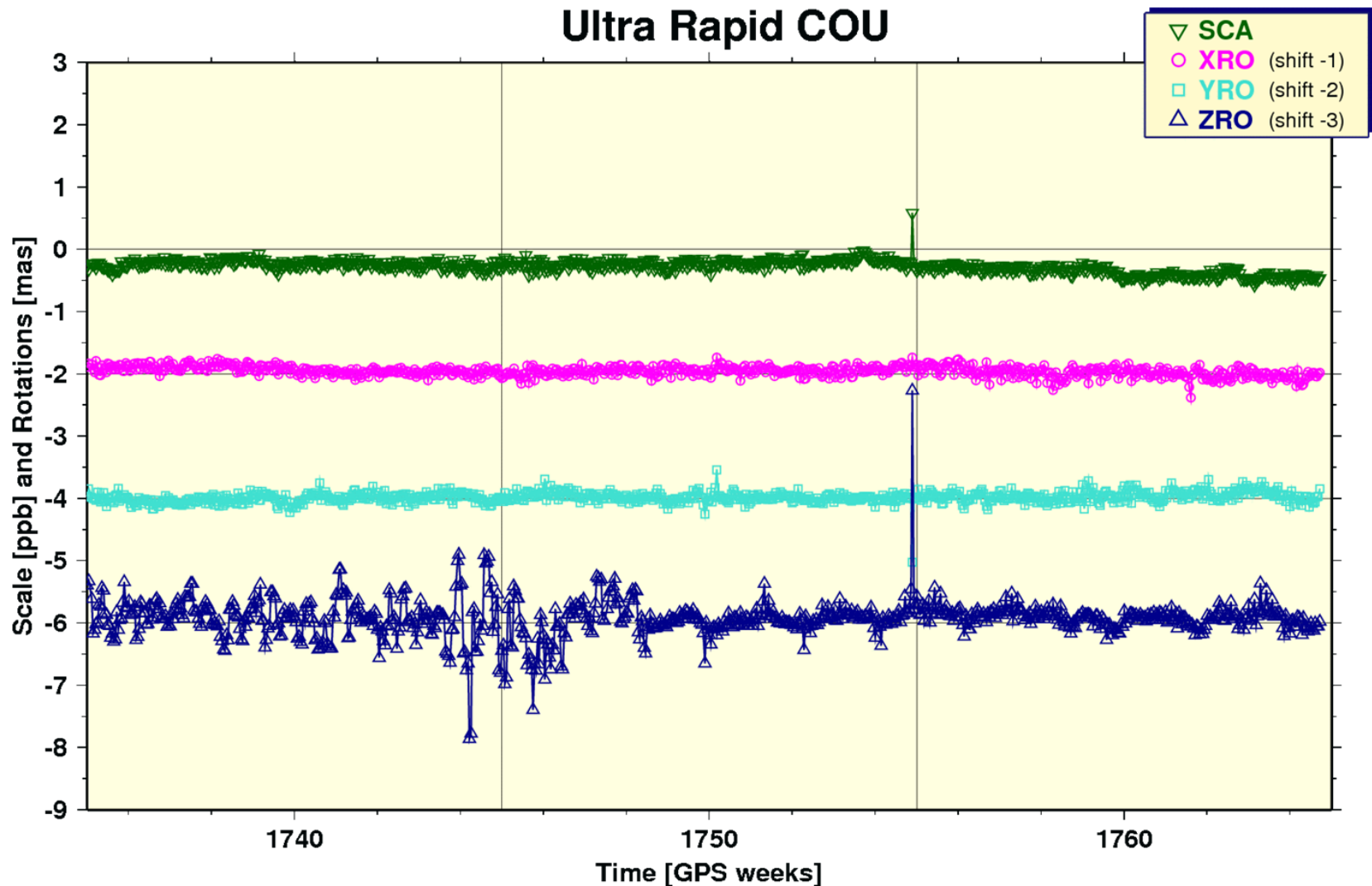
- **Problem**

Large z-rotations in the comparisons of our orbits w.r.t. the combined IGS ultra-rapid product and the solutions of other ACs

- **1<sup>st</sup> 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



NOAA NGS, 1.11.2013 06:27 (GMT)



# Update of CODE's ultra-rapid product

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- **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

- **1<sup>st</sup> 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)

- **2<sup>nd</sup> step: Redesign of the procedure**

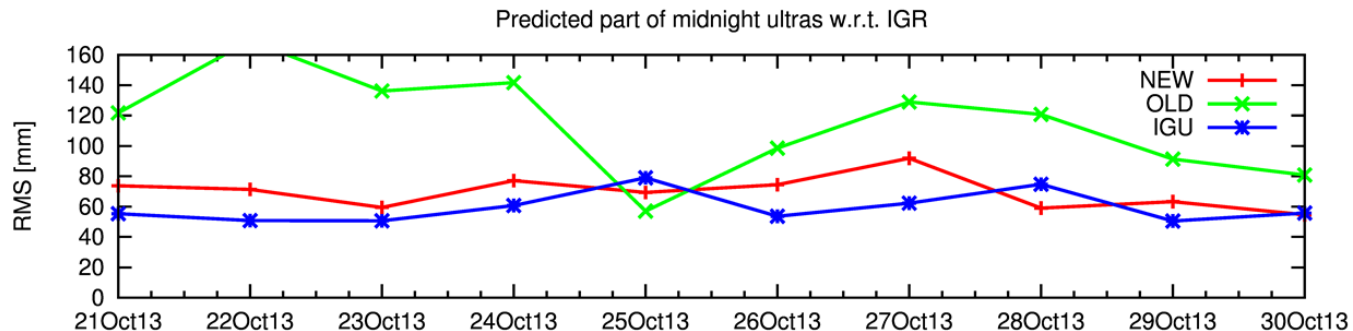
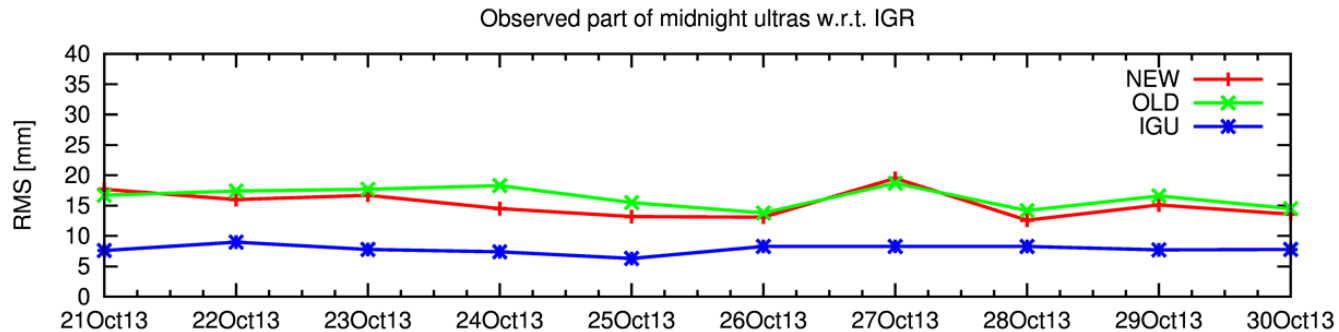
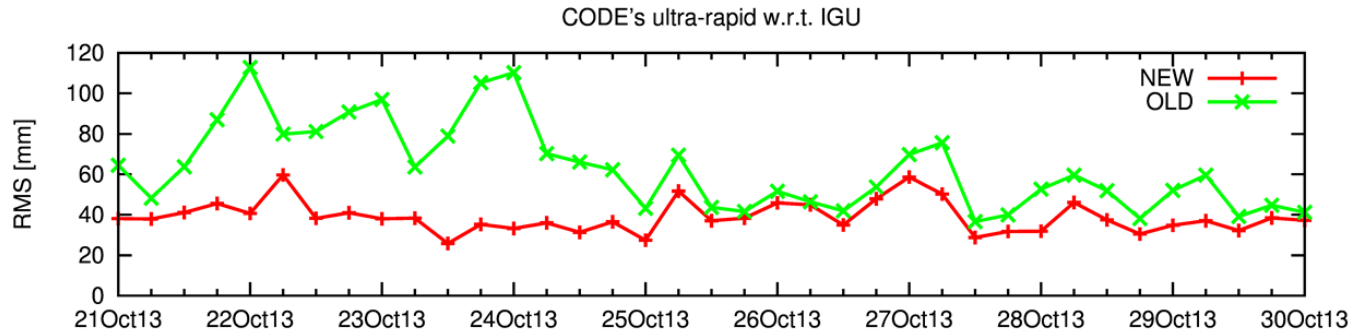
- Best possible orbit representation in the observed time interval (48h+) on NEQ-level and followed by an orbit integration including the orbit prediction
- Not yet submitted

## 2<sup>nd</sup> step: Redesign of the procedure

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- 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



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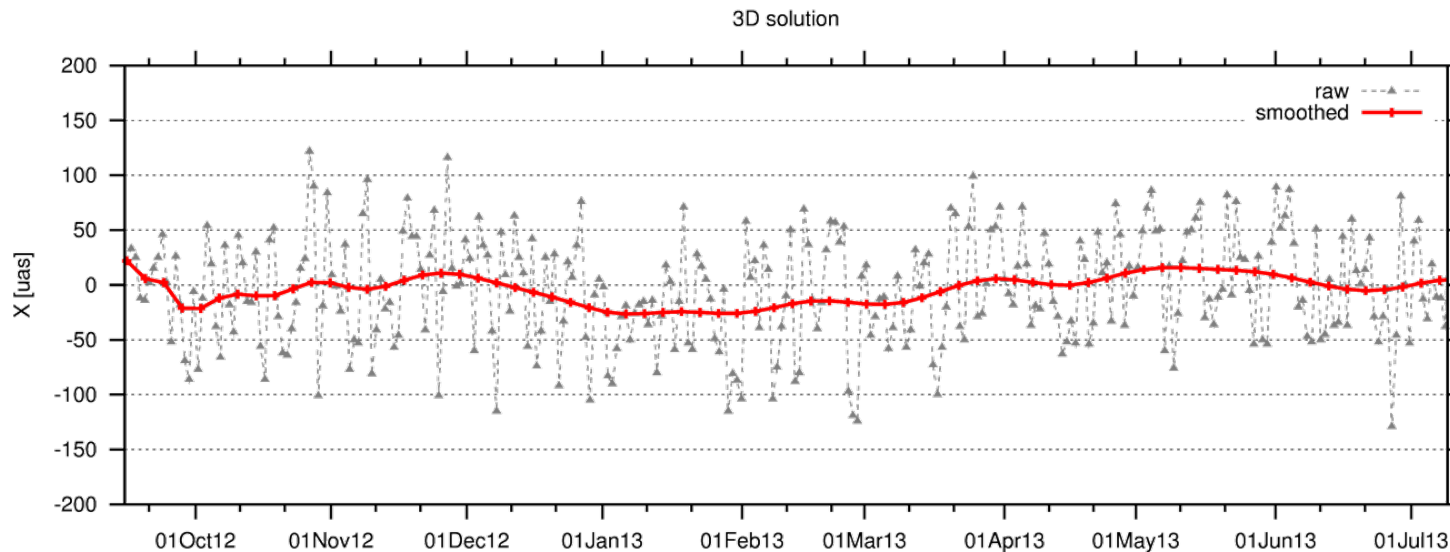
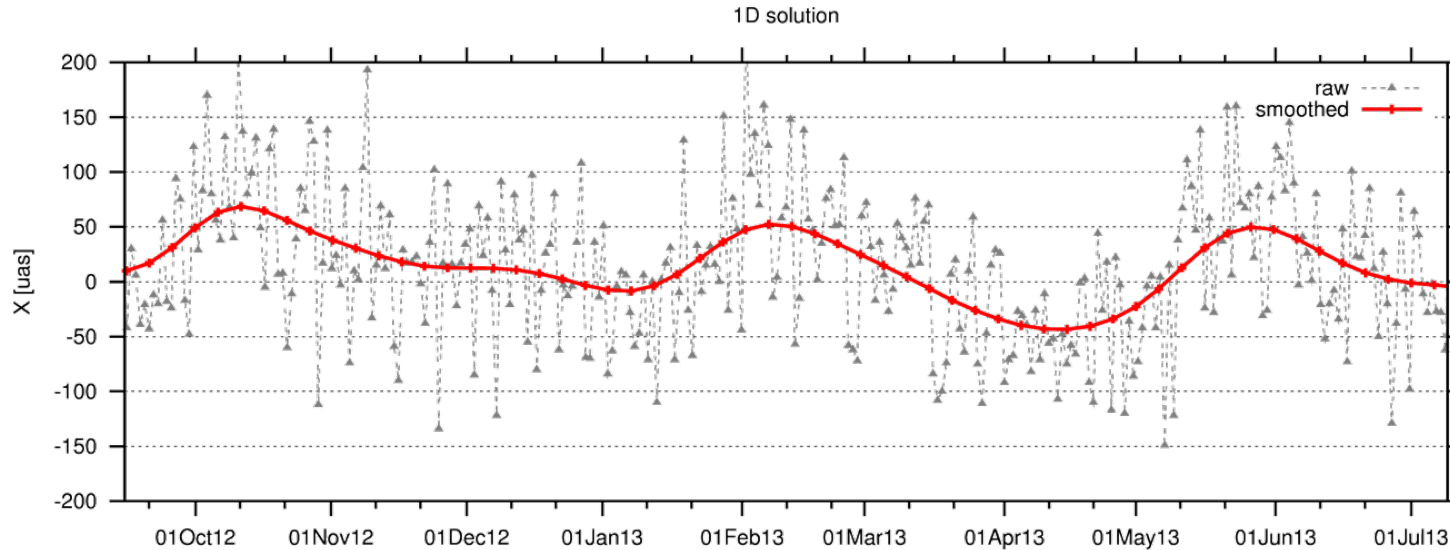
# Clean one-day solution versus three-day long-arc solution (experience at CODE)

# CODE's final series

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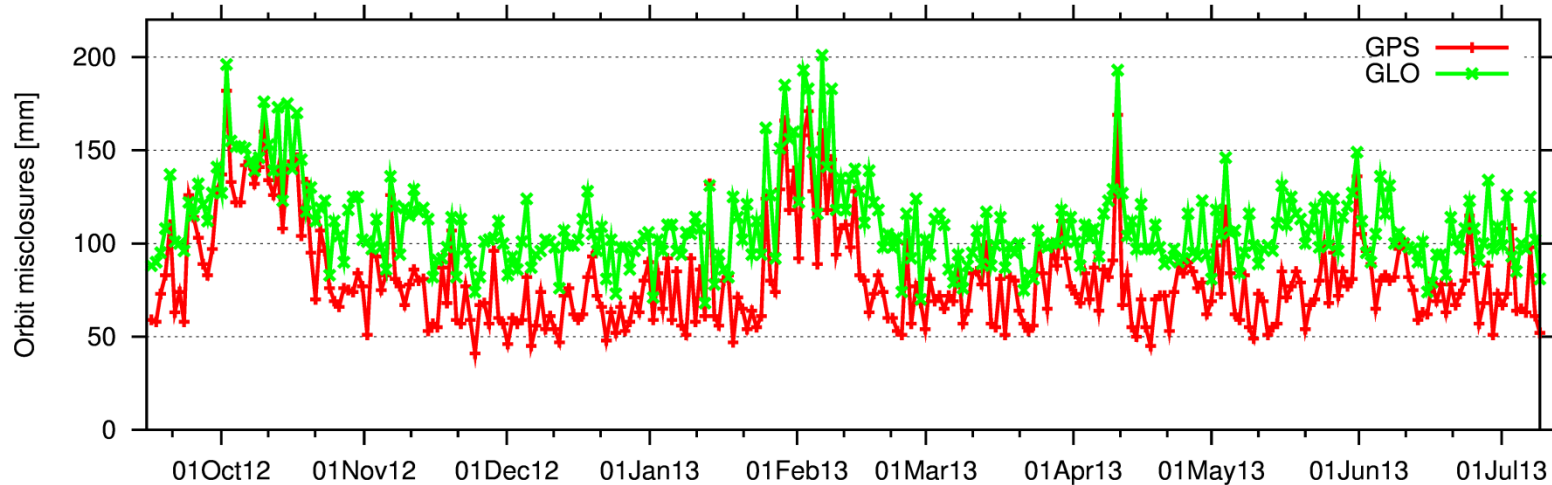
- Since GPS week 1706 (16-Sep-2012), CODE has been generating **two consistent sets of combined GPS+GLONASS** solutions for the IGS final product series:
  - A clear-cut **1-day solution** (used for the official combined GPS-only products of the IGS)
  - A solution based on overlapping **3-day orbital 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

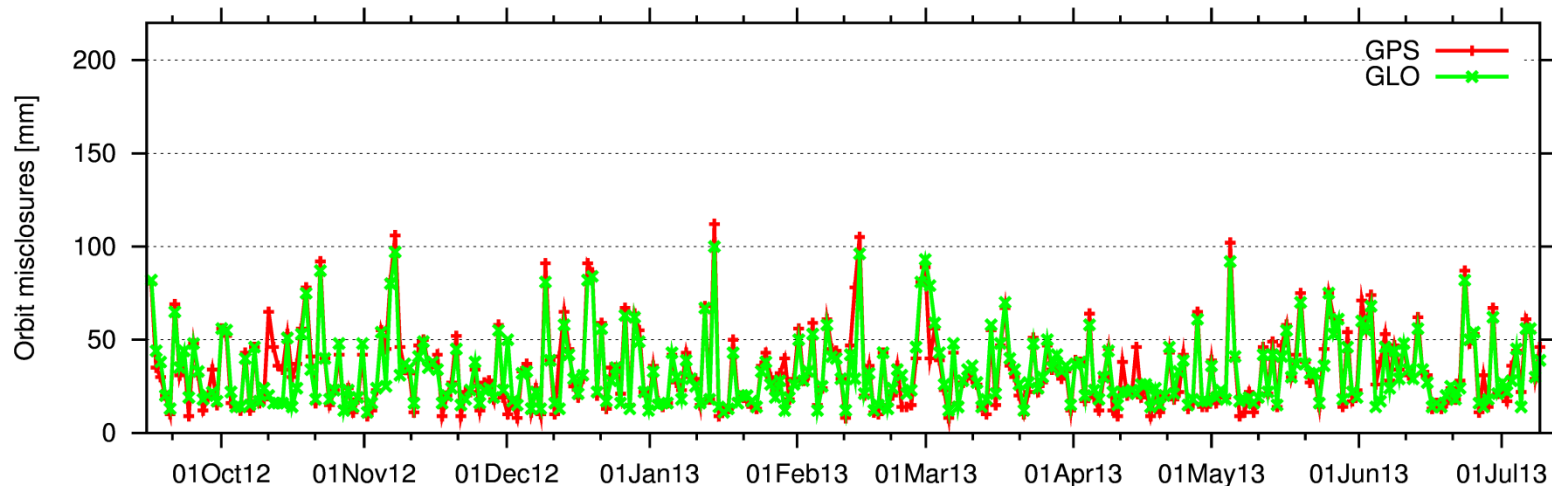


# Mean orbit misclosures of all non-eclipsing GPS&GLONASS satellites in the terrestrial frame

1D solution



3D solution



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

S. Lutz (AIUB), M. Meindl (ETH Zurich), G. Beutler (AIUB),  
T. Springer (ESA), R. Dach (AIUB), D. Thaller (BKG Frankfurt),  
A. Jäggi (AIUB), S. Schaer (swisstopo)

Received: 07-Nov-2013 / Accepted: date

**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-

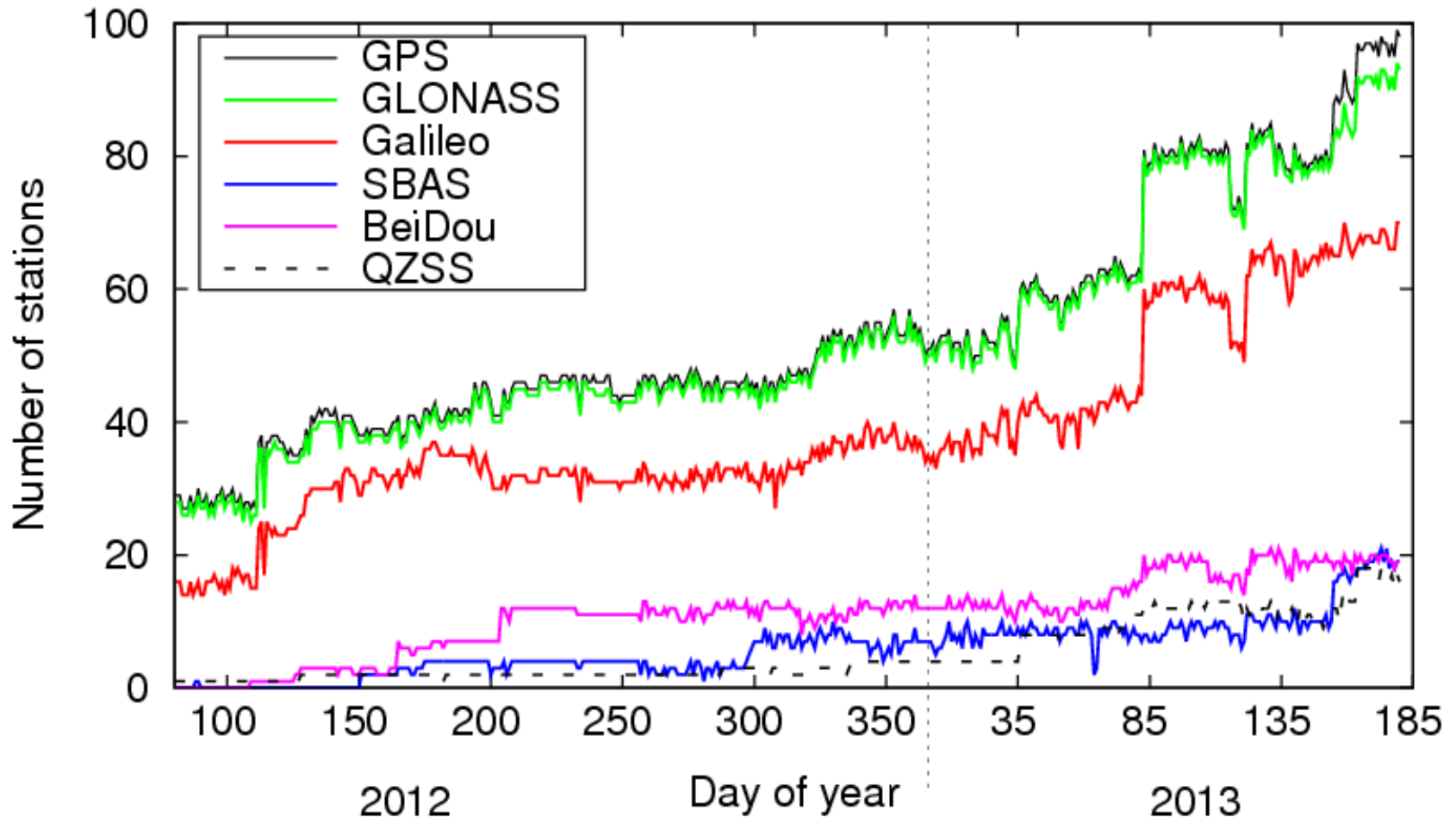


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# CODE-contribution to IGS Multi-GNSS Experiment (MGEX)

# MGEX data monitoring

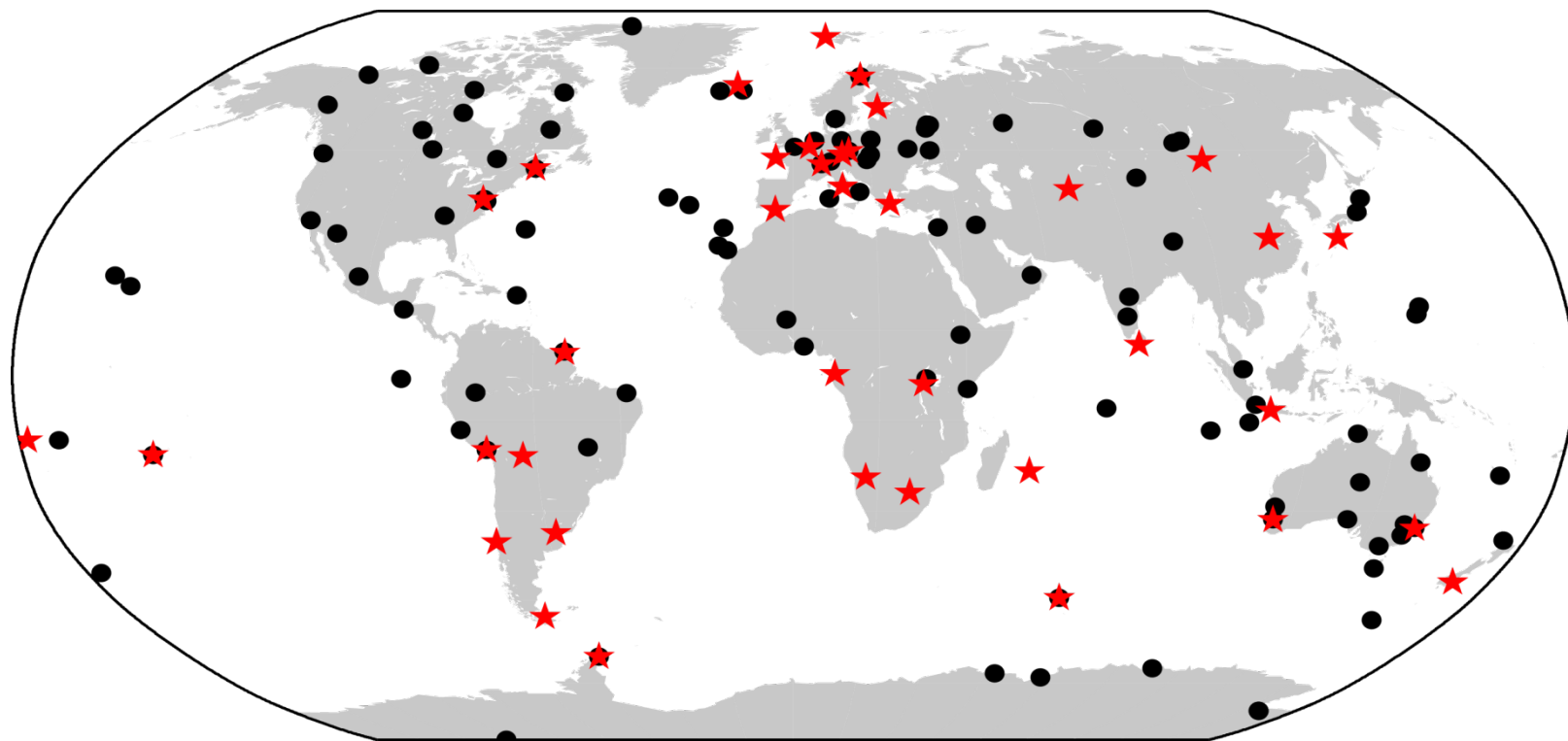
Satellite systems being monitored (RINEX3 files):





# 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

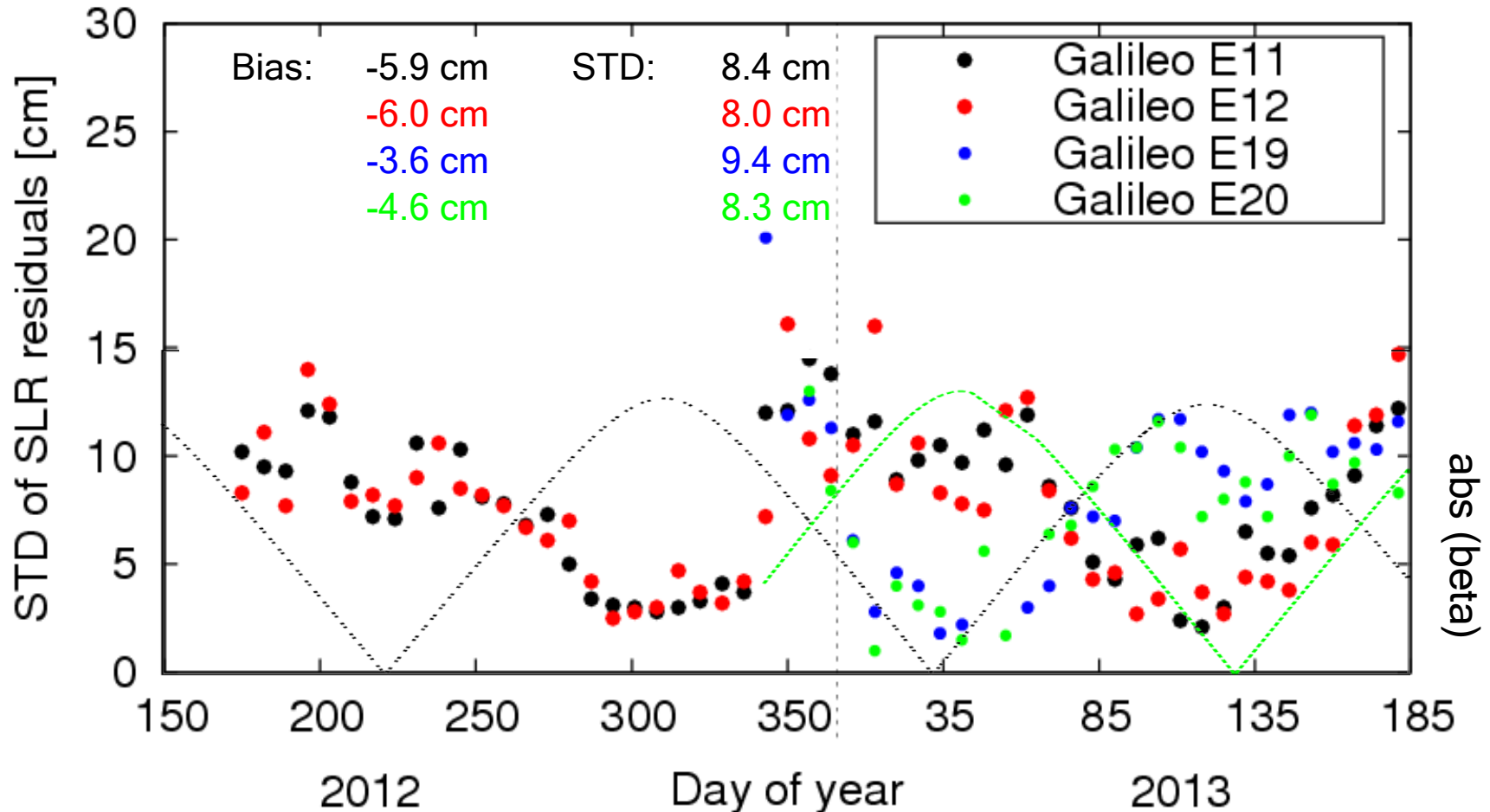
# MGEX orbit solution: overview

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GNSS considered:	<b>GPS + GLONASS + Galileo</b> (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:	<a href="ftp://cddis.gsfc.nasa.gov/gnss/products/mgex/">ftp://cddis.gsfc.nasa.gov/gnss/products/mgex/</a>
Designator:	comwwwwd.???.Z

# MGEX orbit validation: SLR residuals

STD of SLR residuals per week: correlation with beta angle



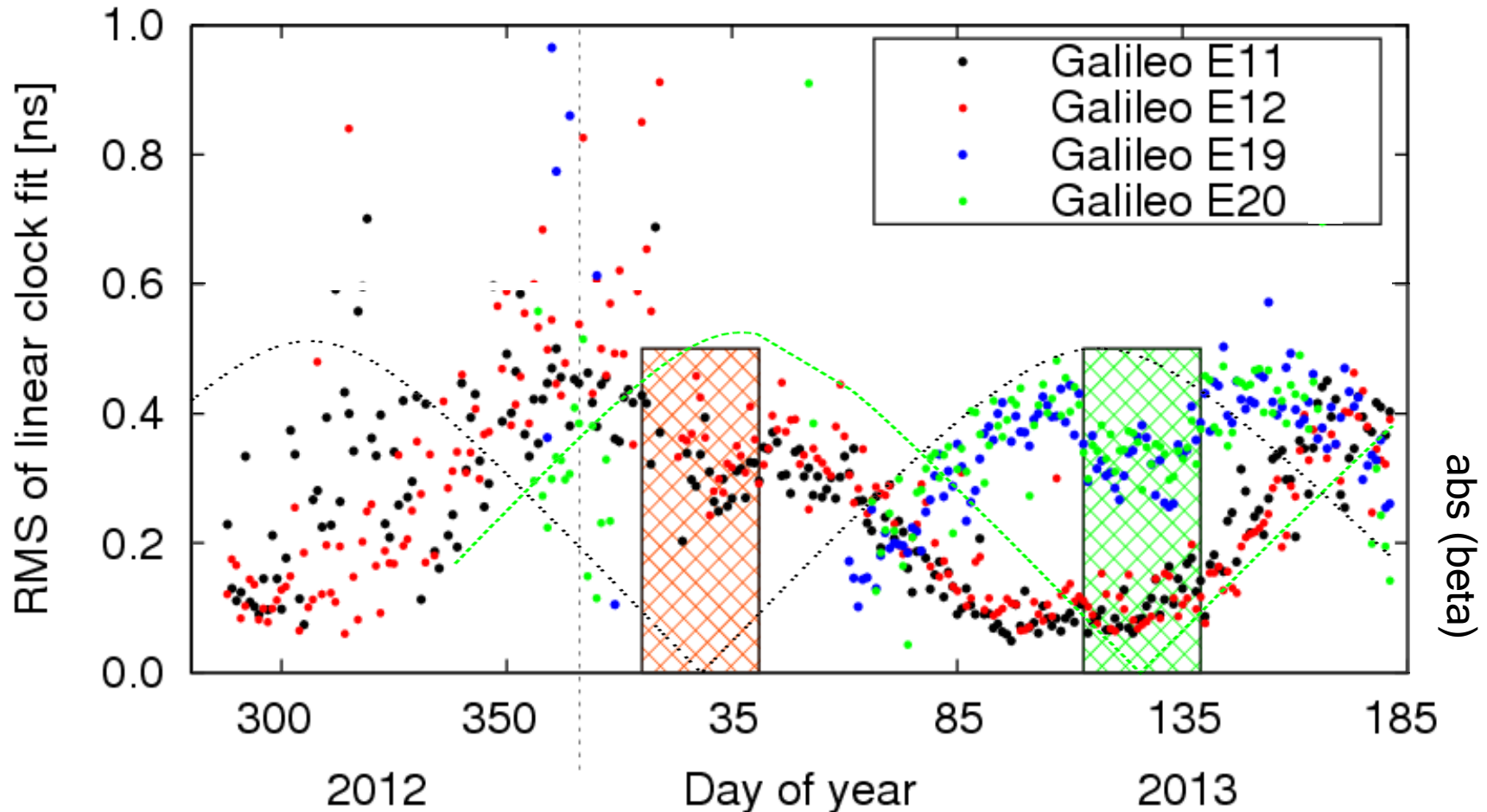
# MGEX clock solution

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GNSS considered:	<b>GPS + Galileo</b> (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:	<a href="ftp://cddis.gsfc.nasa.gov/gnss/products/mgex/">ftp://cddis.gsfc.nasa.gov/gnss/products/mgex/</a>
Designator:	comwwwwd.???.Z

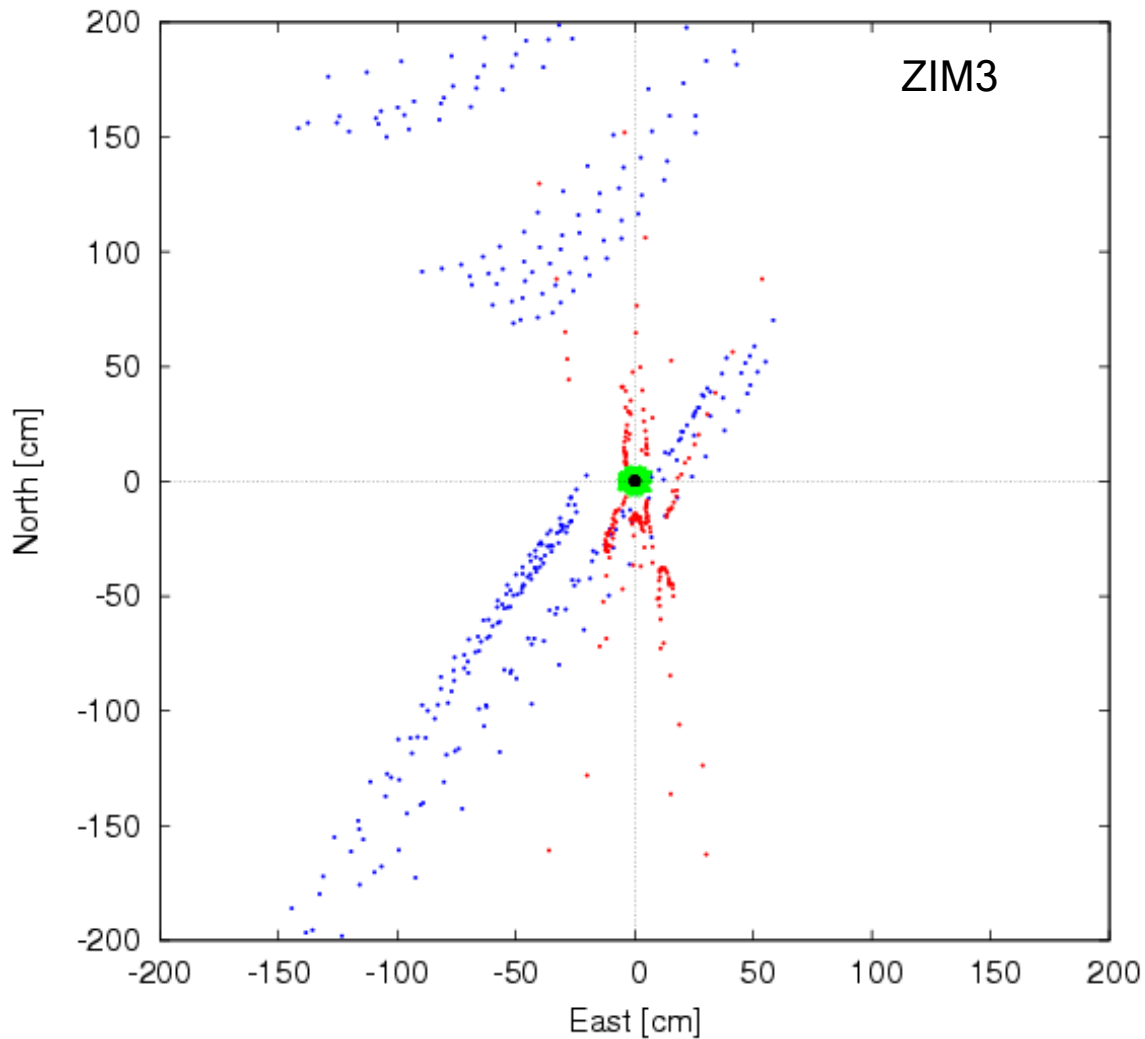
# MGEX clock solution: linear clock fit

## Galileo IOV: impact of sun eclipse and beta angle





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



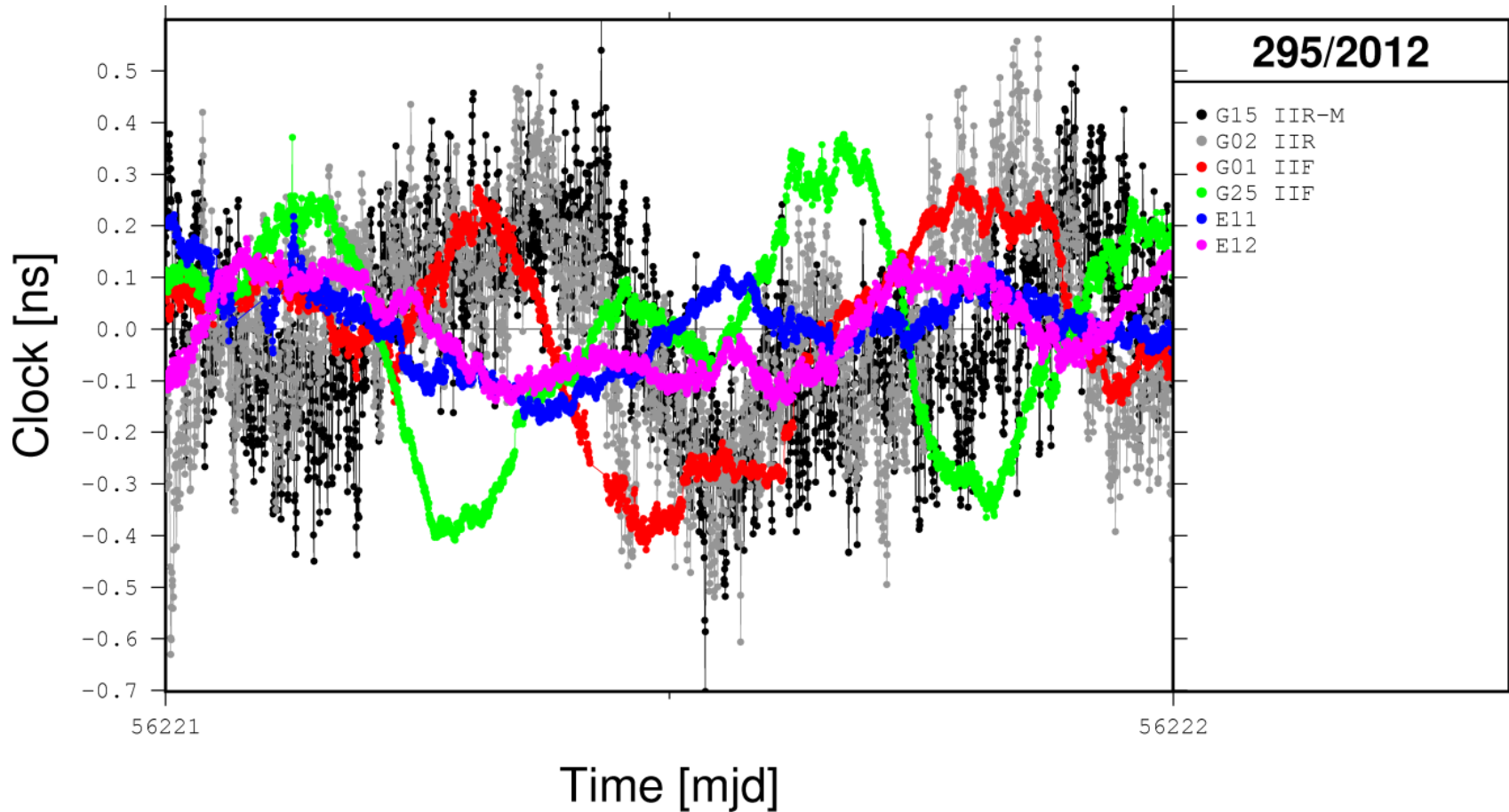
- x Static
- x Kinematic GPS
- Kinematic Galileo-only
- Kinematic GPS (4 SVs)

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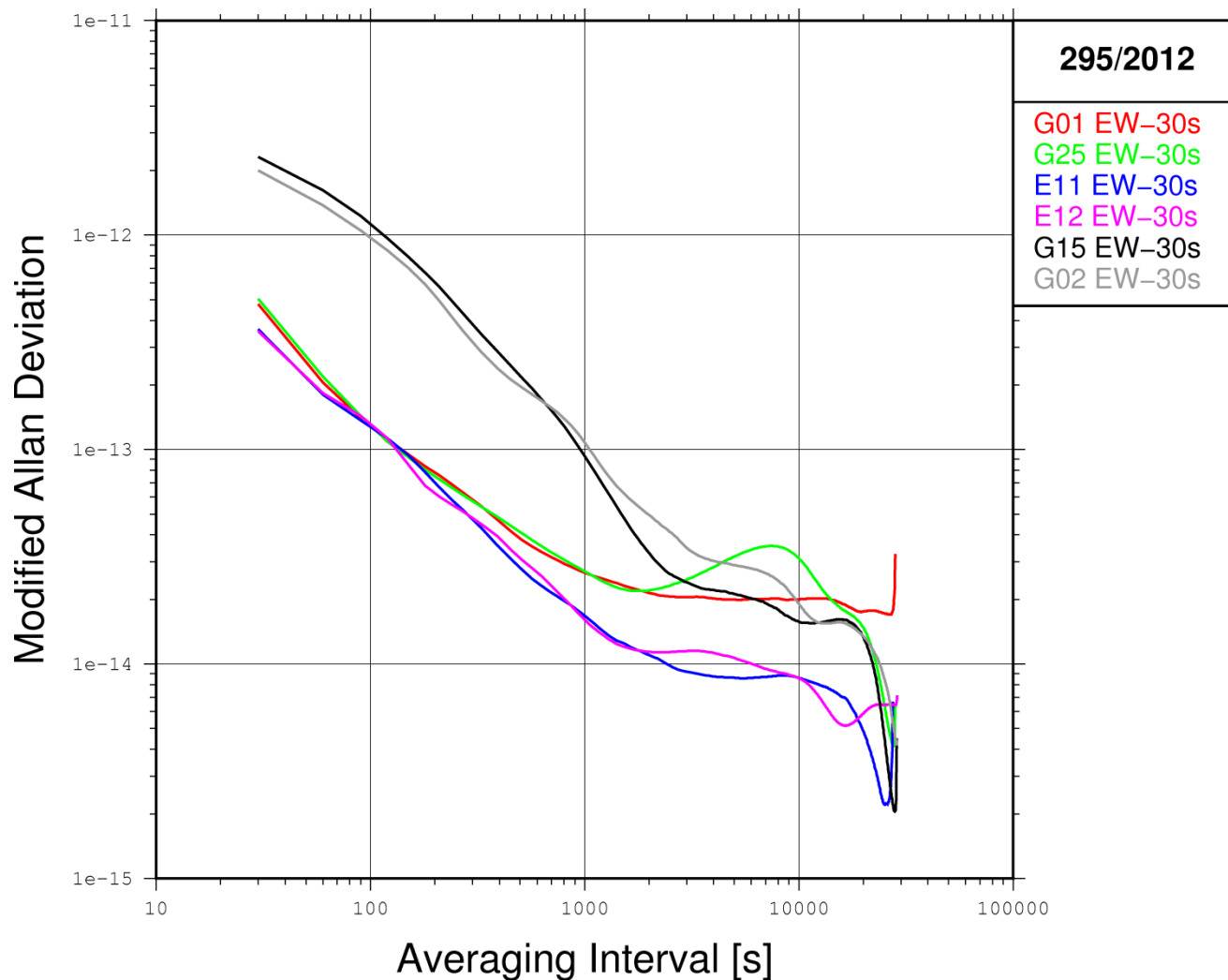
# Satellite and Station Clock Modeling for GNSS

*(ESA–project with ETH and TU Munich)*

# 30 s Pure MGEX Solution (295/2012)



# 30 s (pure) MGEX Solution – 295/2012

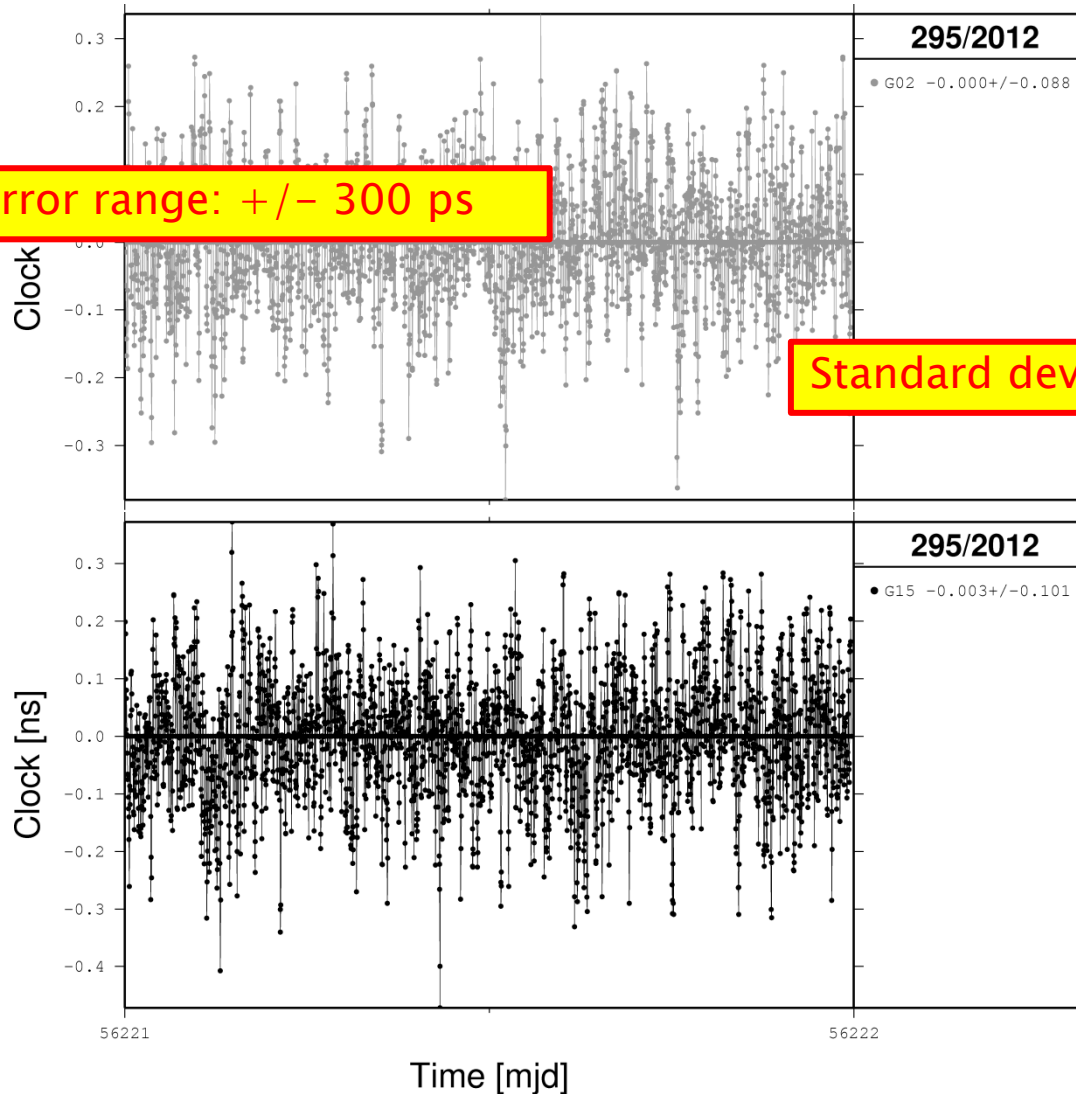


# Clock Interpolation

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- 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 ( $\sim 10$  ps for ionosphere-free linear combination)

# Clock Interpolation



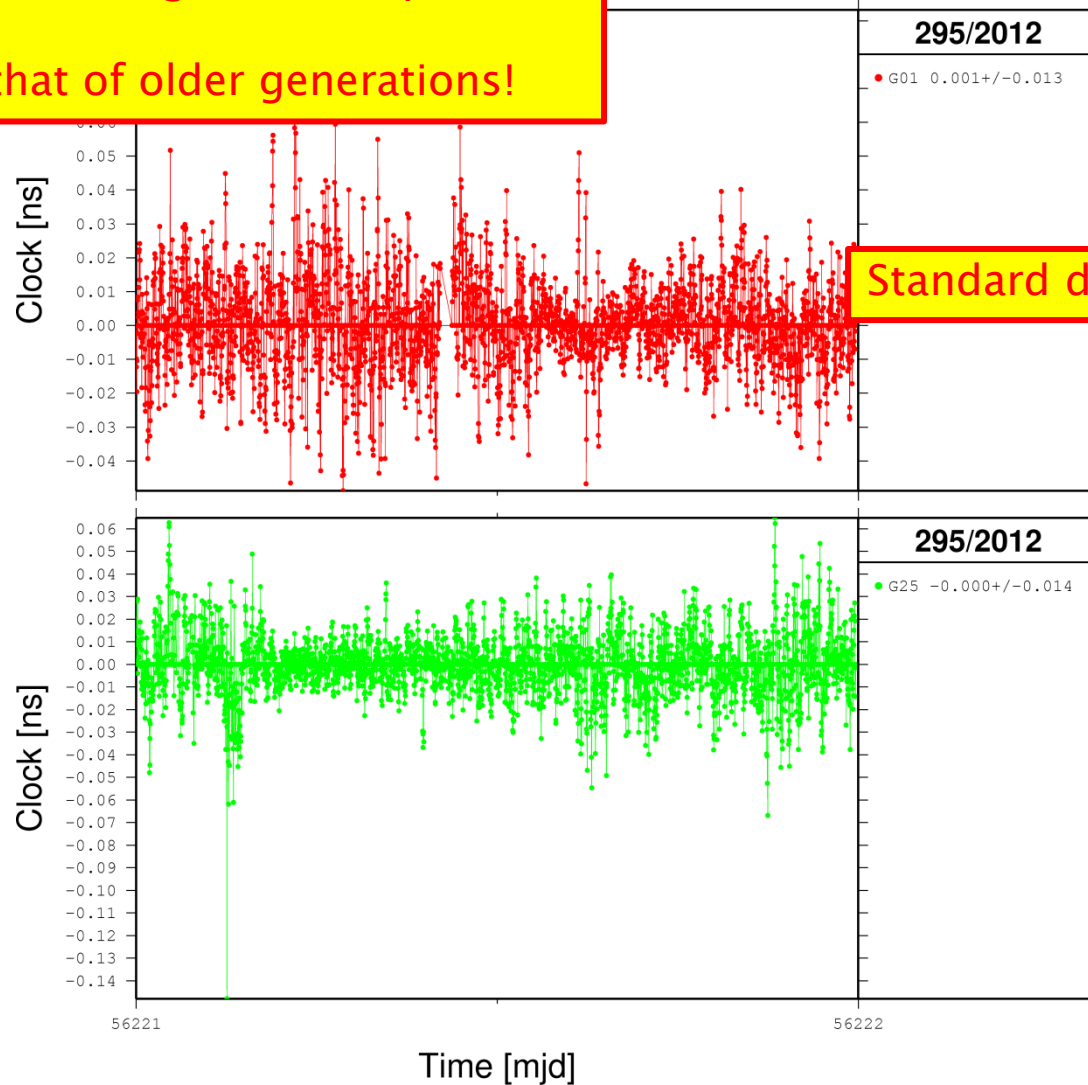
Interpolation error range:  $\pm 300$  ps

Standard deviation of  $\sim 95$  ps

# Clock Interpolation

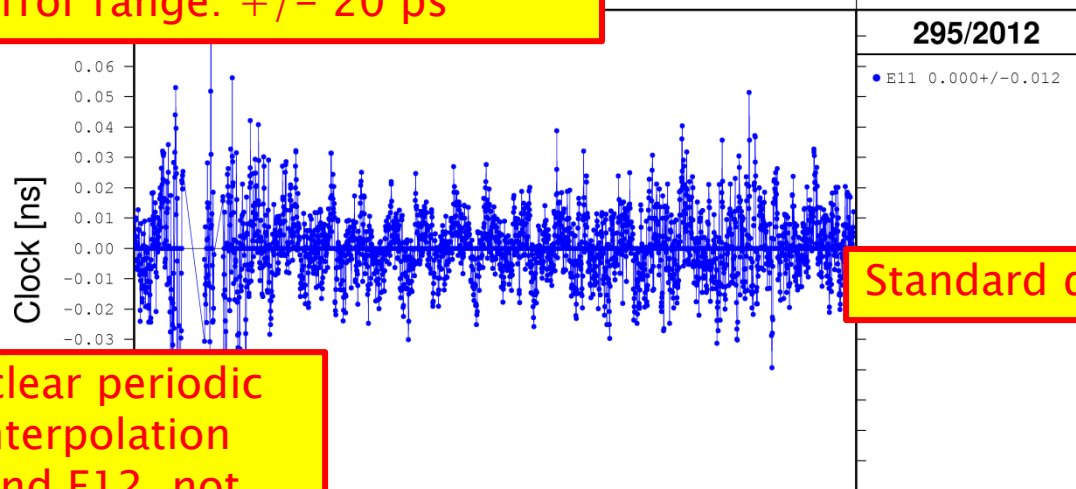
Interpolation error range:  $\pm 30$  ps

10 times less than that of older generations!



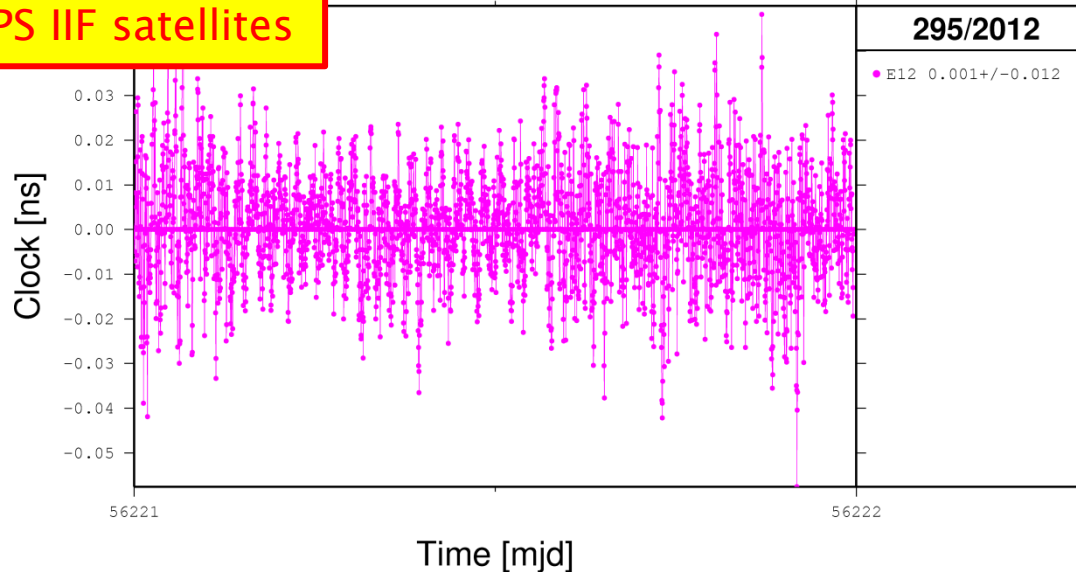
# Clock Interpolation

Interpolation error range:  $\pm 20$  ps



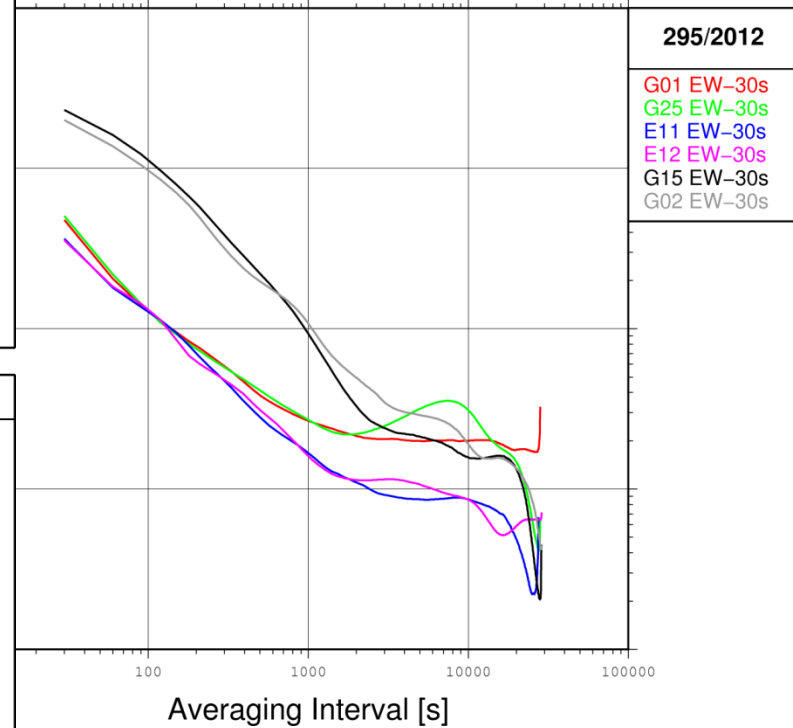
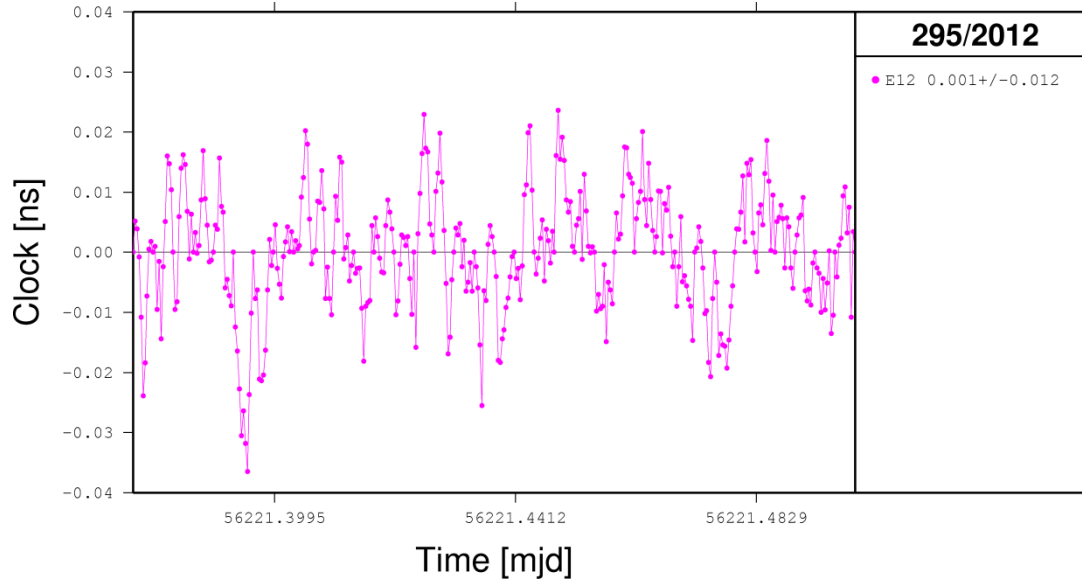
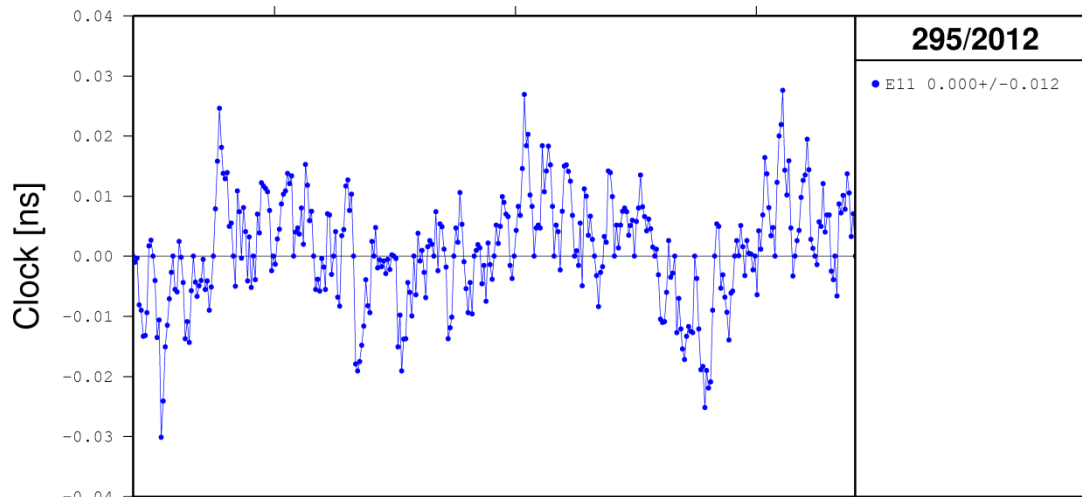
Standard deviation of  $\sim 12$  ps

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

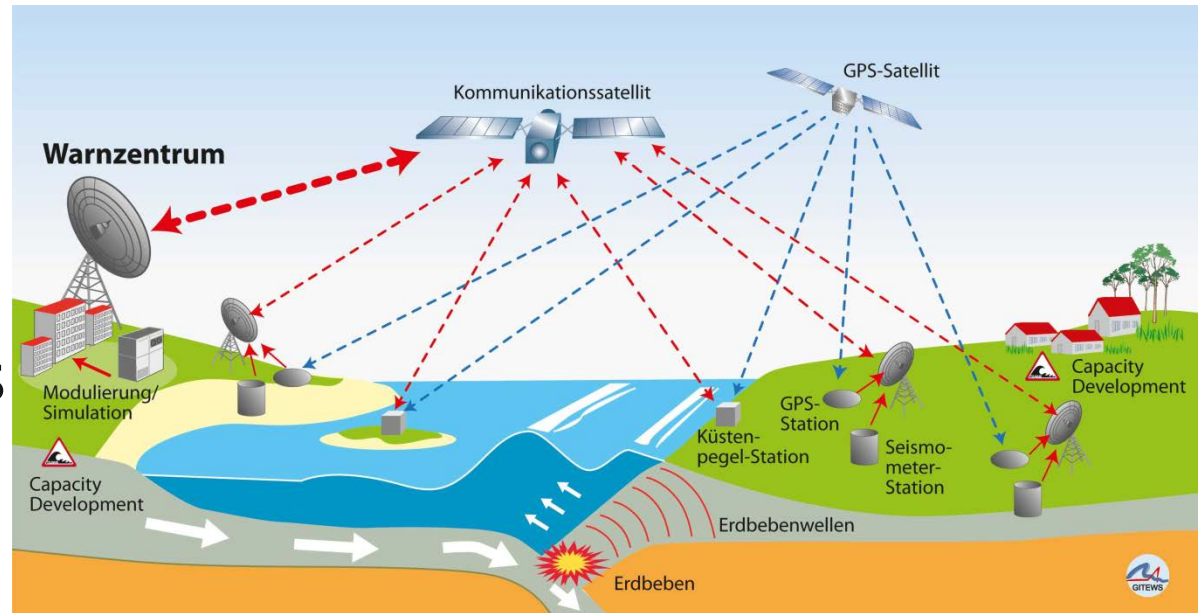


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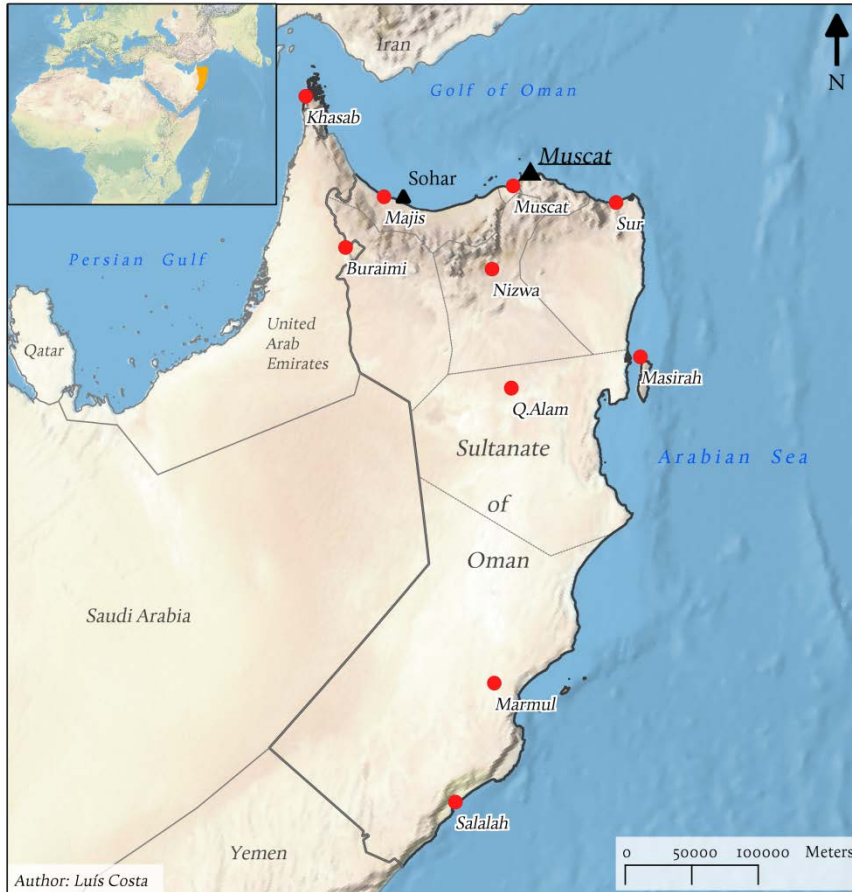
# Tsunami Early Warning System for the Sultanate of Oman

# 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 cooperation with **GFZ Potsdam** and **AIUB**.



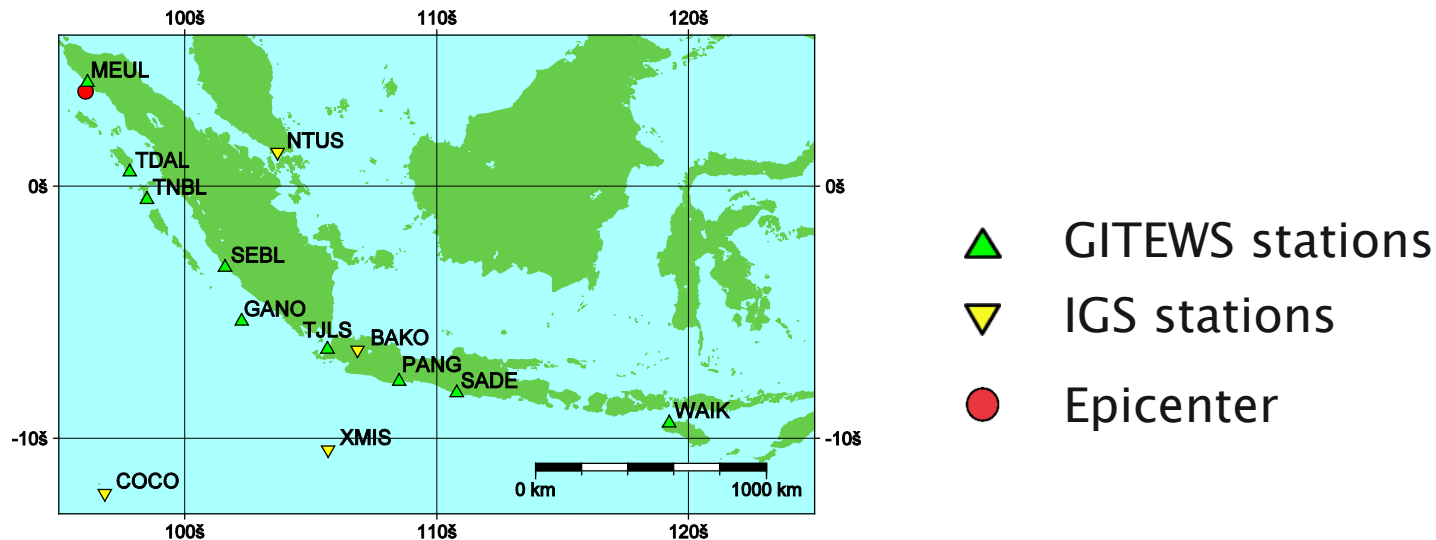
# National Multi-Hazard Early Warning System (NMHEWS)



- 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**)

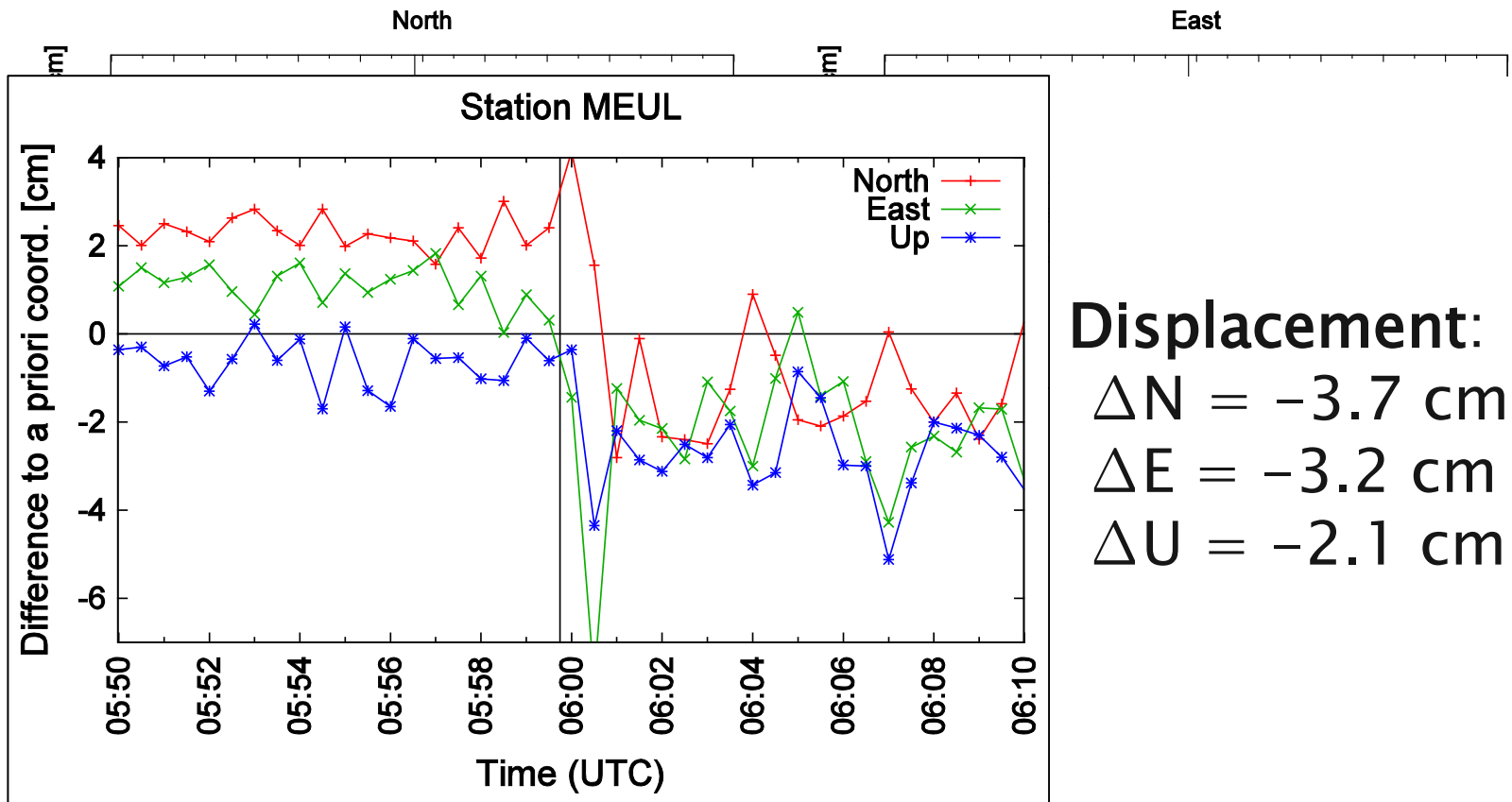
# Testing with data from GITEWS

- 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.



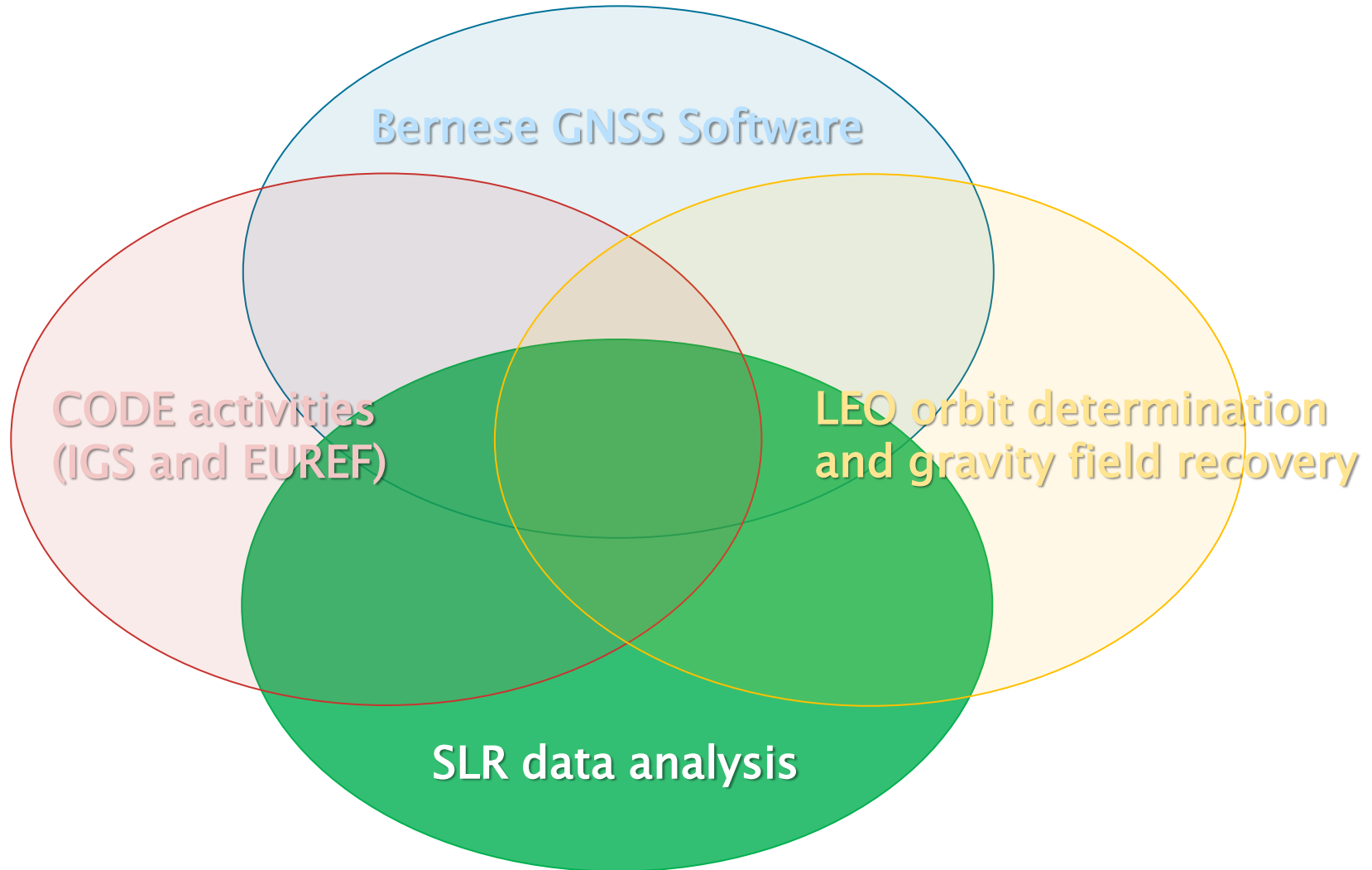
# Testing with data from GITEWS

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



# Satellite Geodesy Research Group

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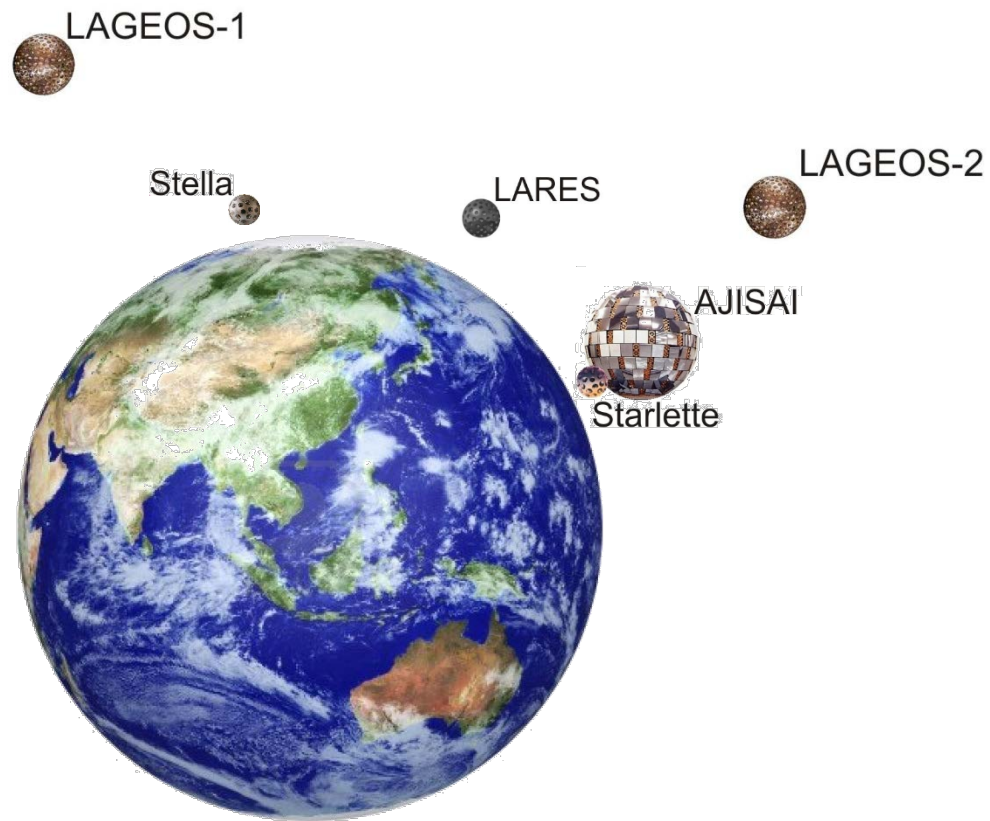
# Satellite Laser Ranging (SLR) Solutions



# 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



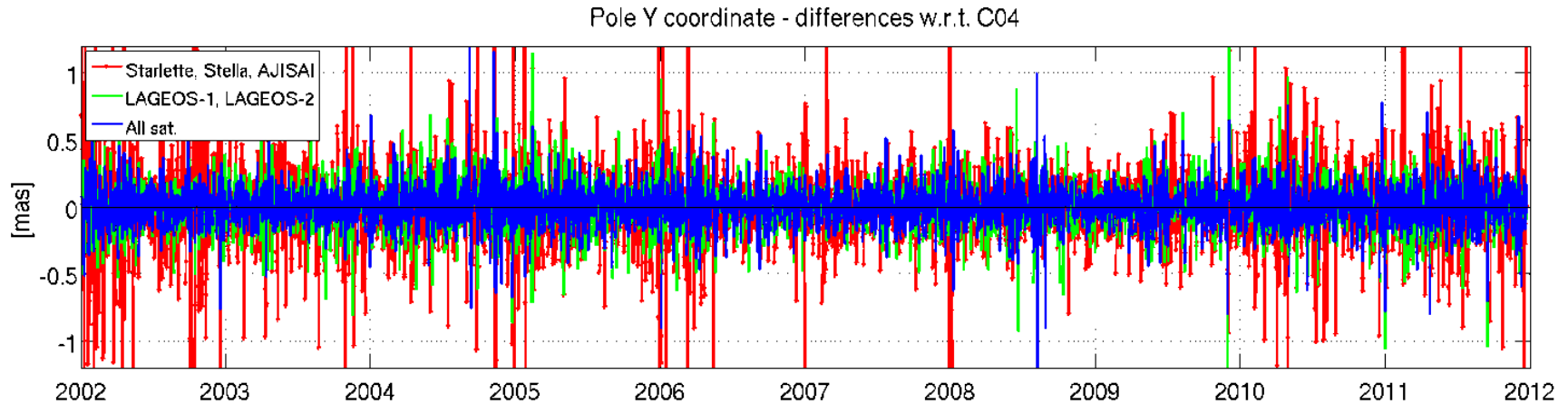
# SLR solutions in the Bernese GNSS Software

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)

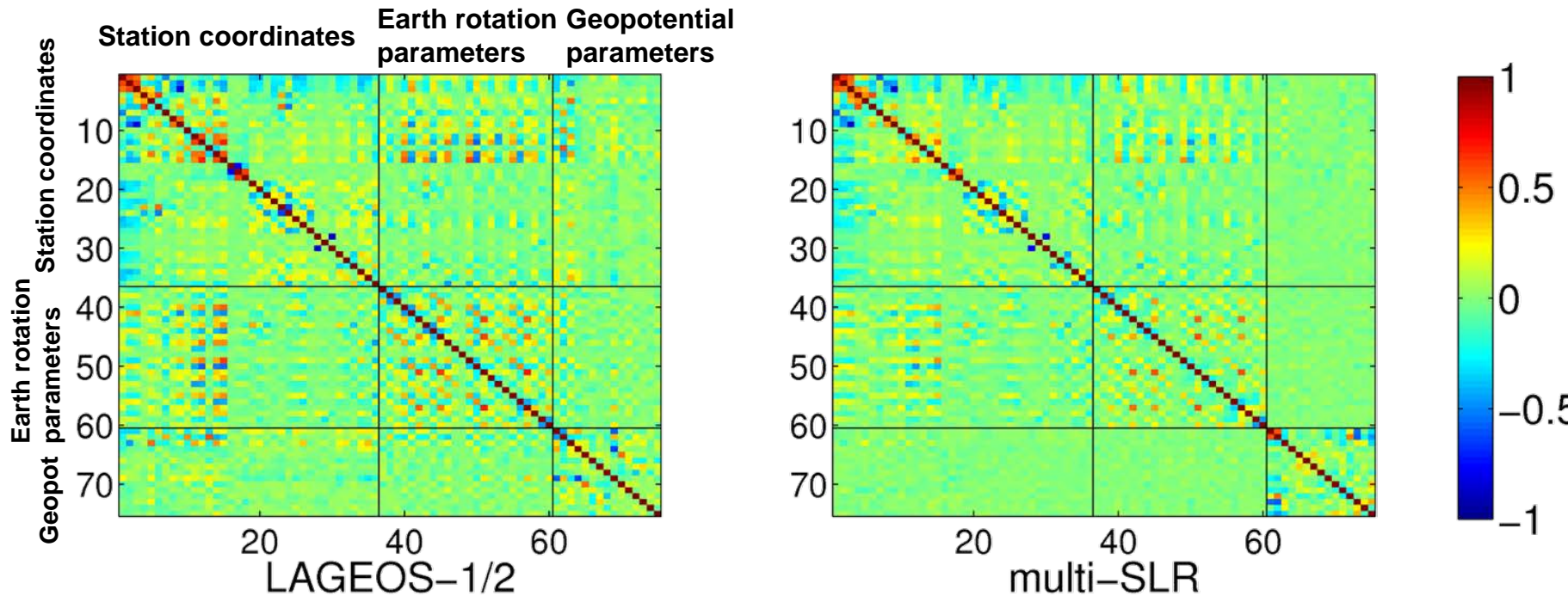
# Earth Rotation Parameters (w.r.t. IERS-08-C04)



Solution type		X pole [ $\mu\text{as}$ ]		Y pole [ $\mu\text{as}$ ]		LoD [ $\mu\text{s}$ ]		Repeatability [mm]		
		bias	WRMS	bias	WRMS	bias	WRMS	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

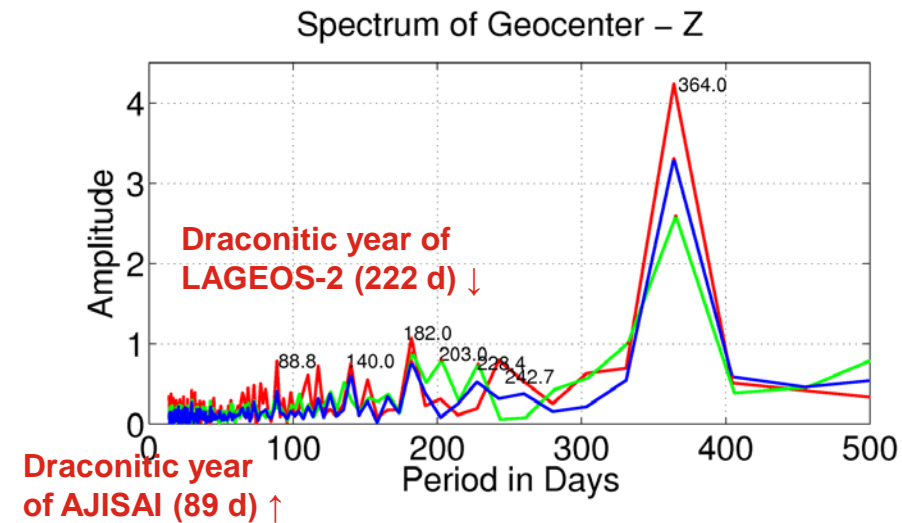
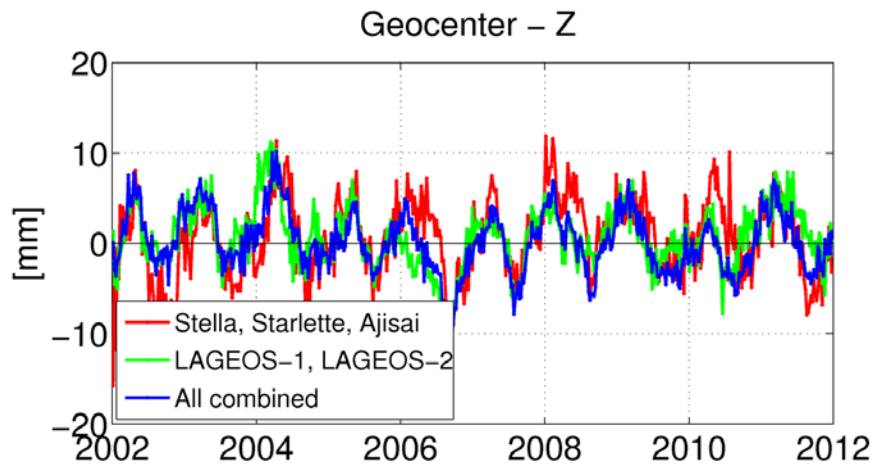


Correlation coefficients between selected parameters.

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

# Scale

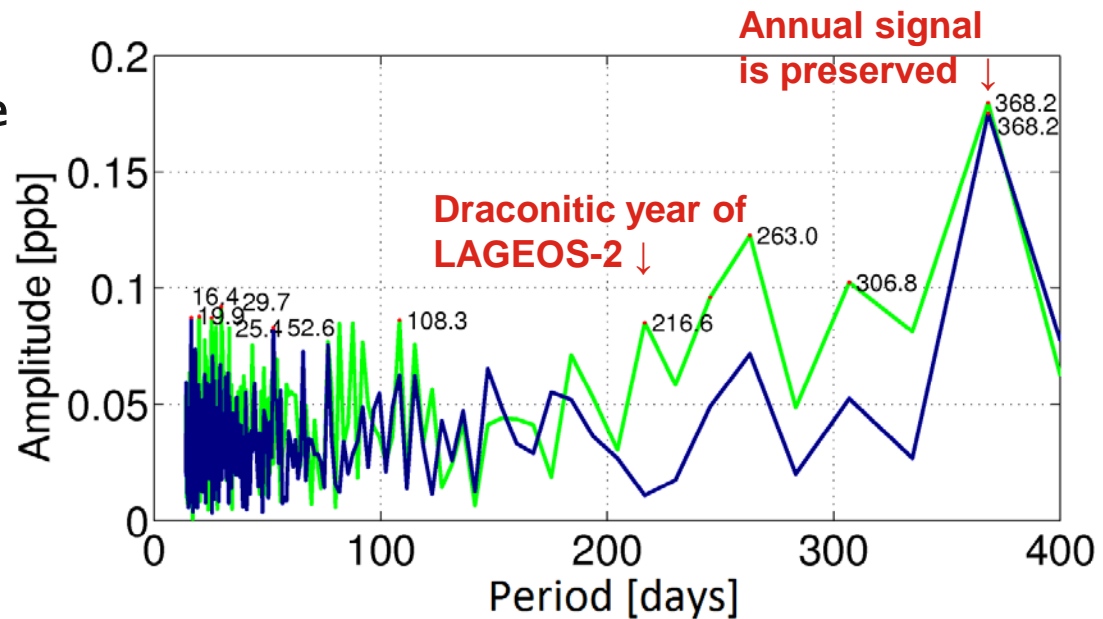
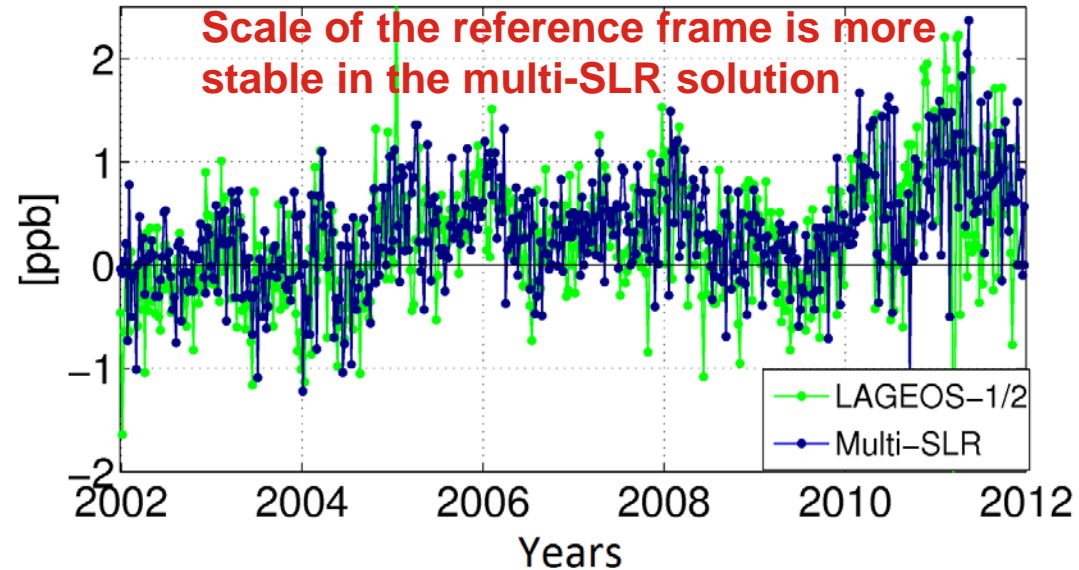
**TRF scale** estimated from the Helmert 7-parameter transformation of weekly SLR solutions

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

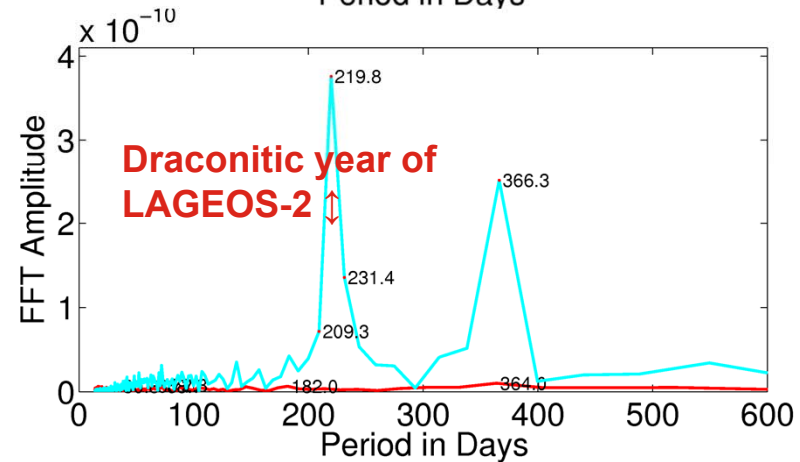
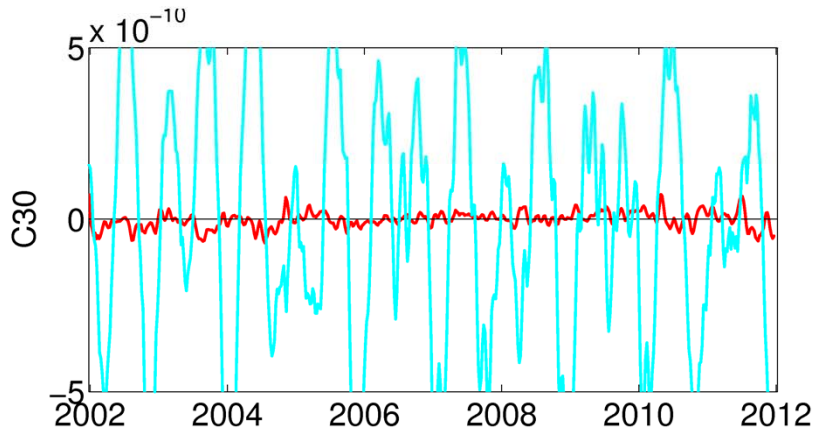
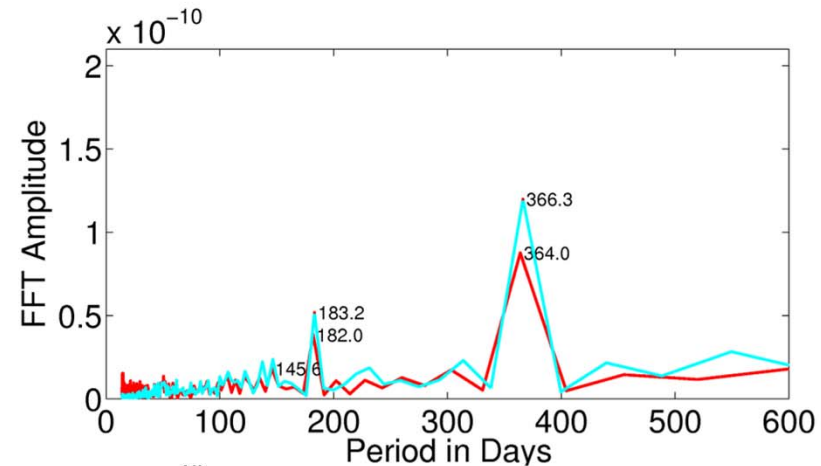
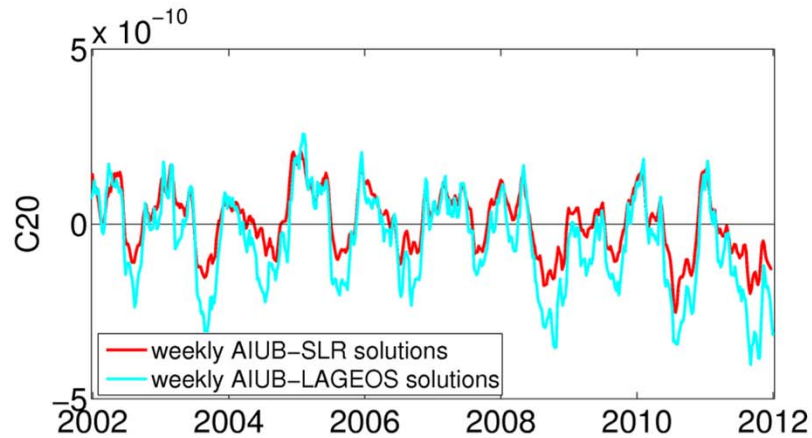
Draconitic year is a time interval between two consecutive passes of the Sun through the orbital plane of a satellite (in the same direction).

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.



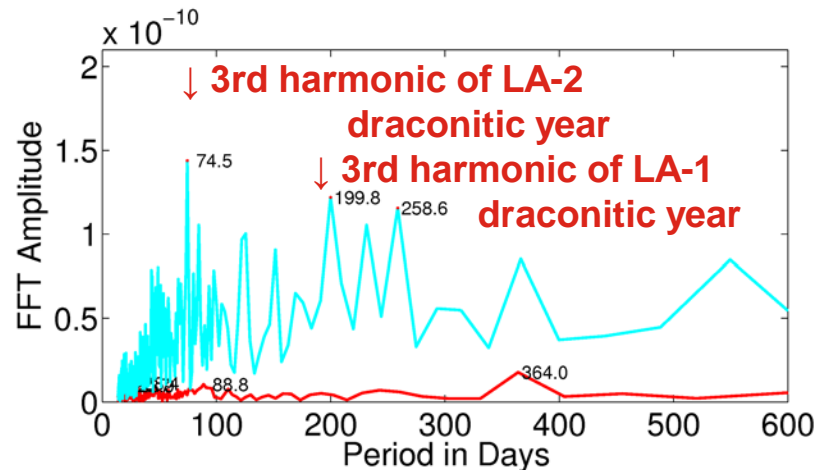
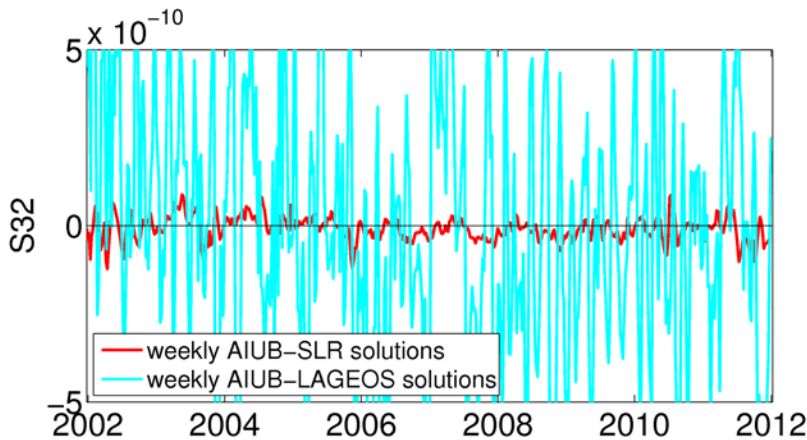
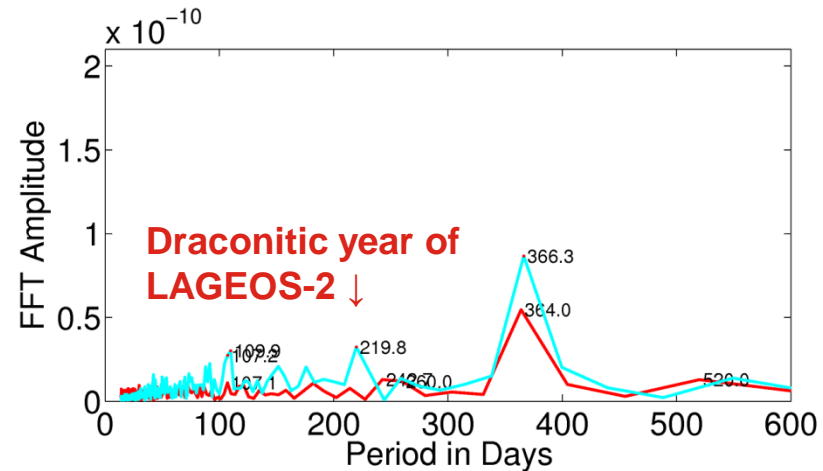
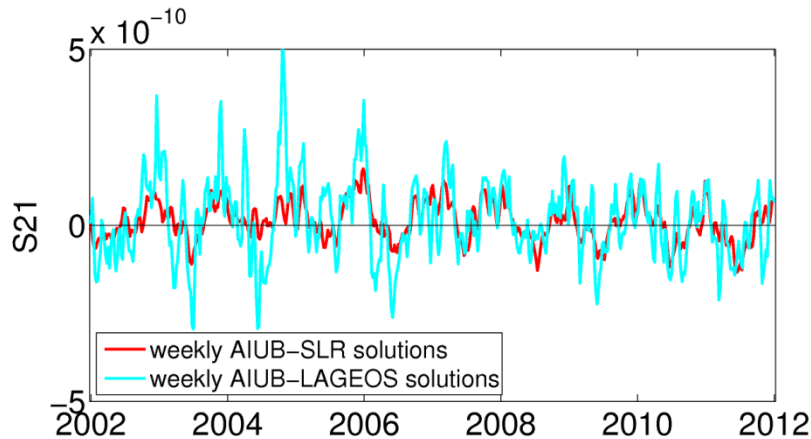
# Gravity field parameters



$C_{20}$  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.

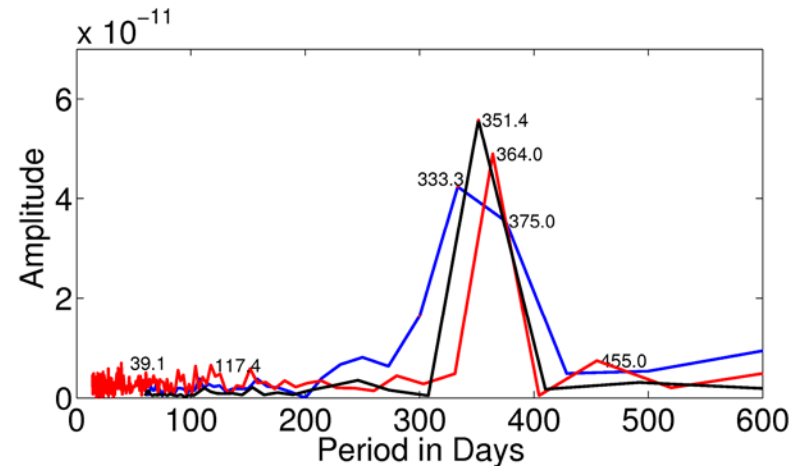
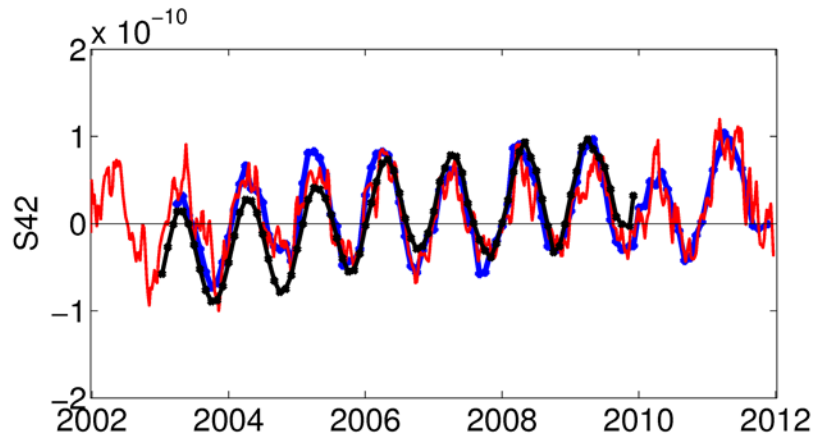
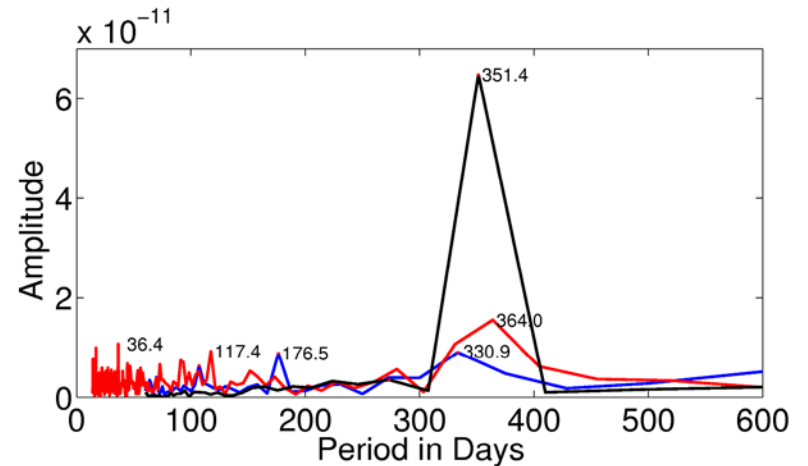
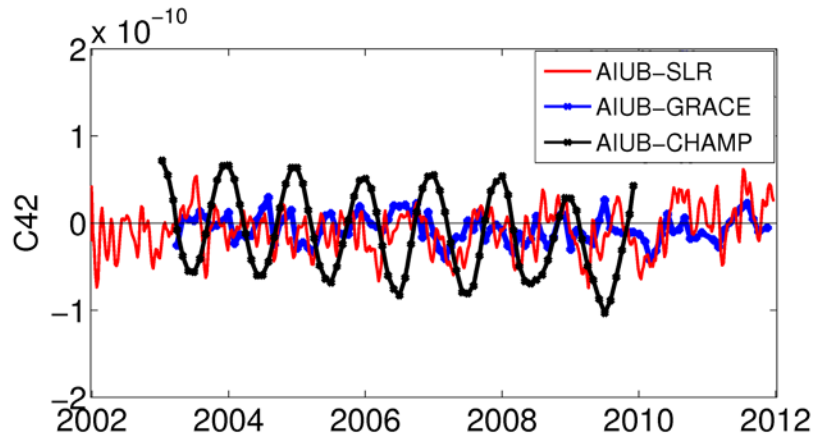
# Gravity field parameters



Gravity field parameters (besides  $C_{20}$ ) 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.

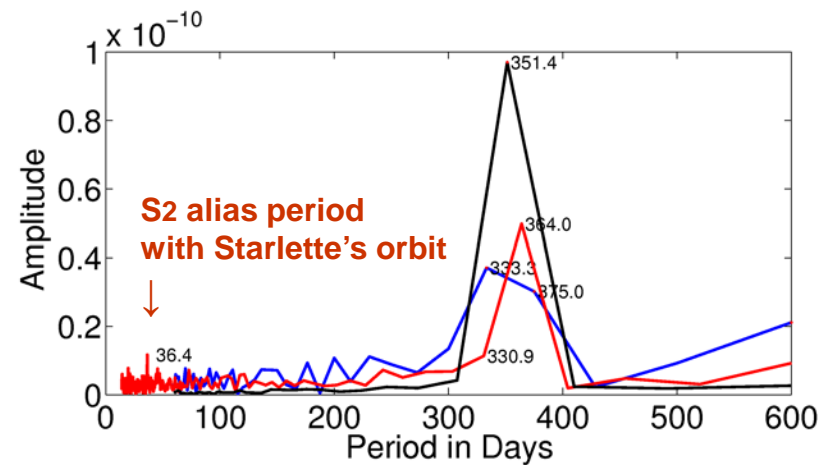
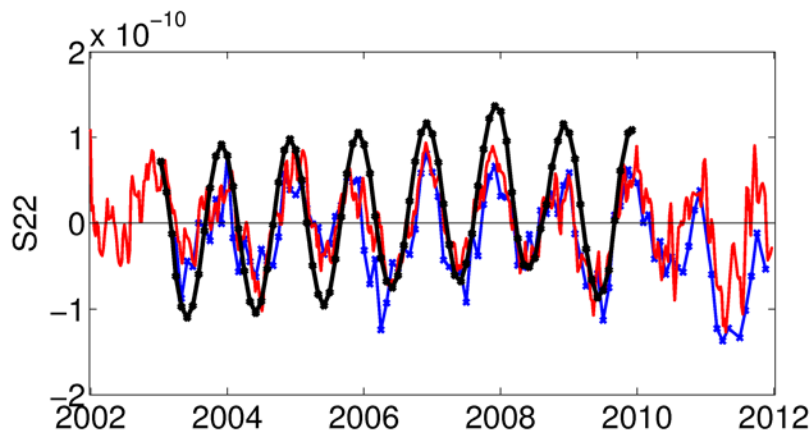
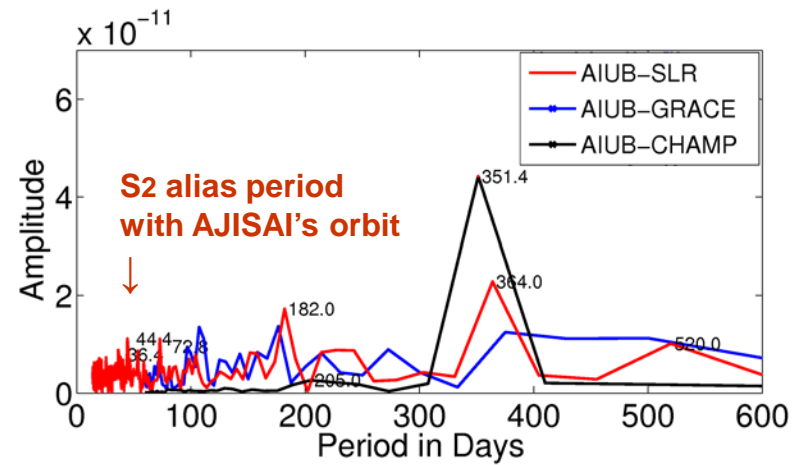
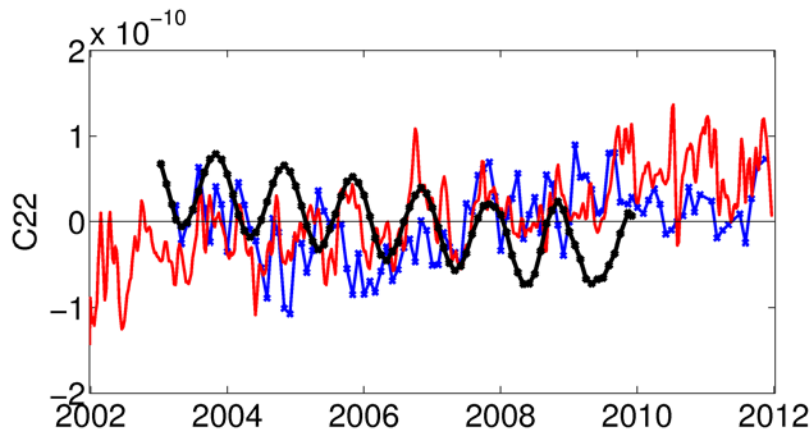


# SLR vs. CHAMP vs. GRACE



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

# SLR – specific issues

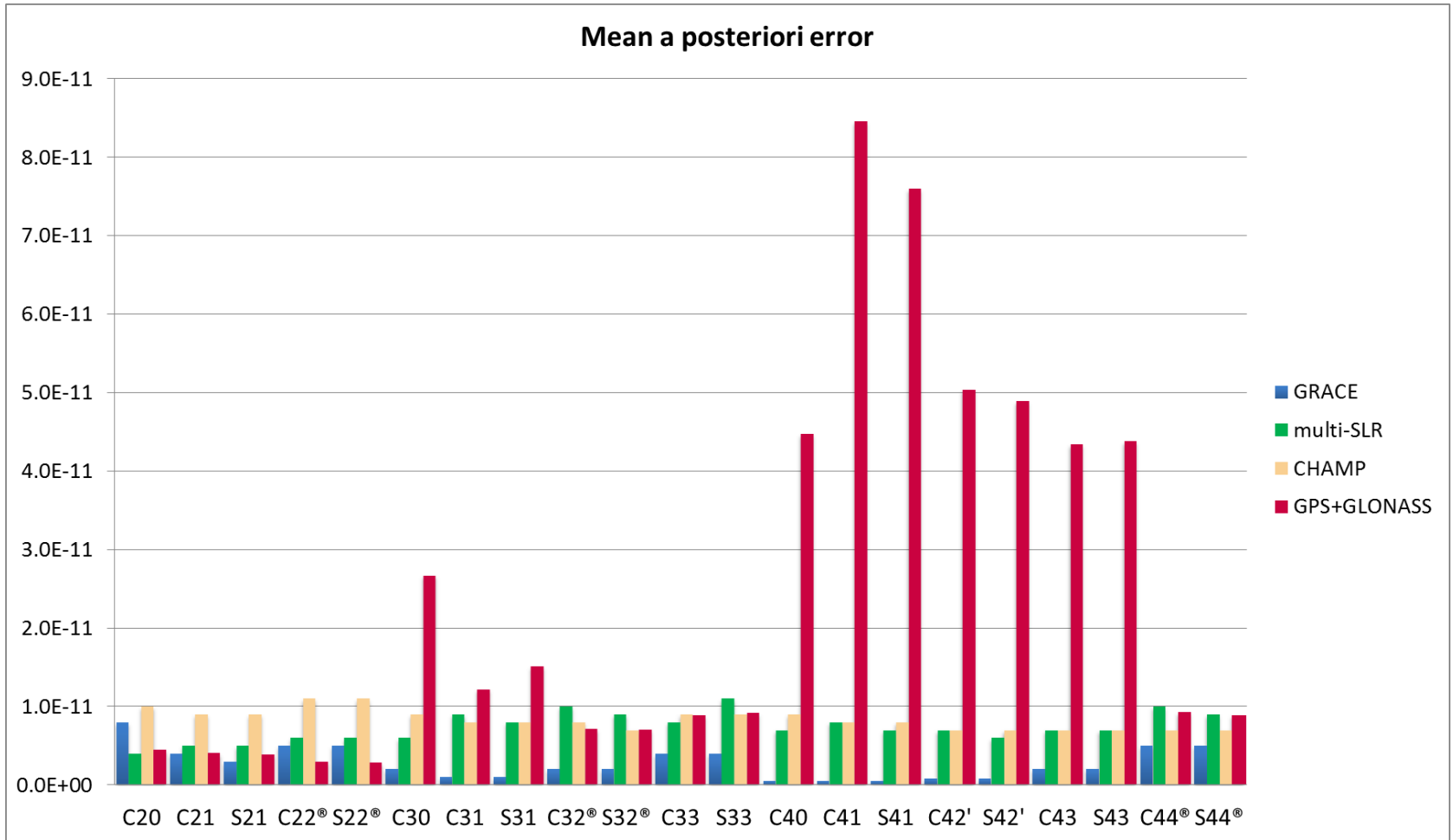


S2 alias period affects not only GRACE solutions, but also has a minor impact on SLR satellites, which is detected by high-precision SLR data.

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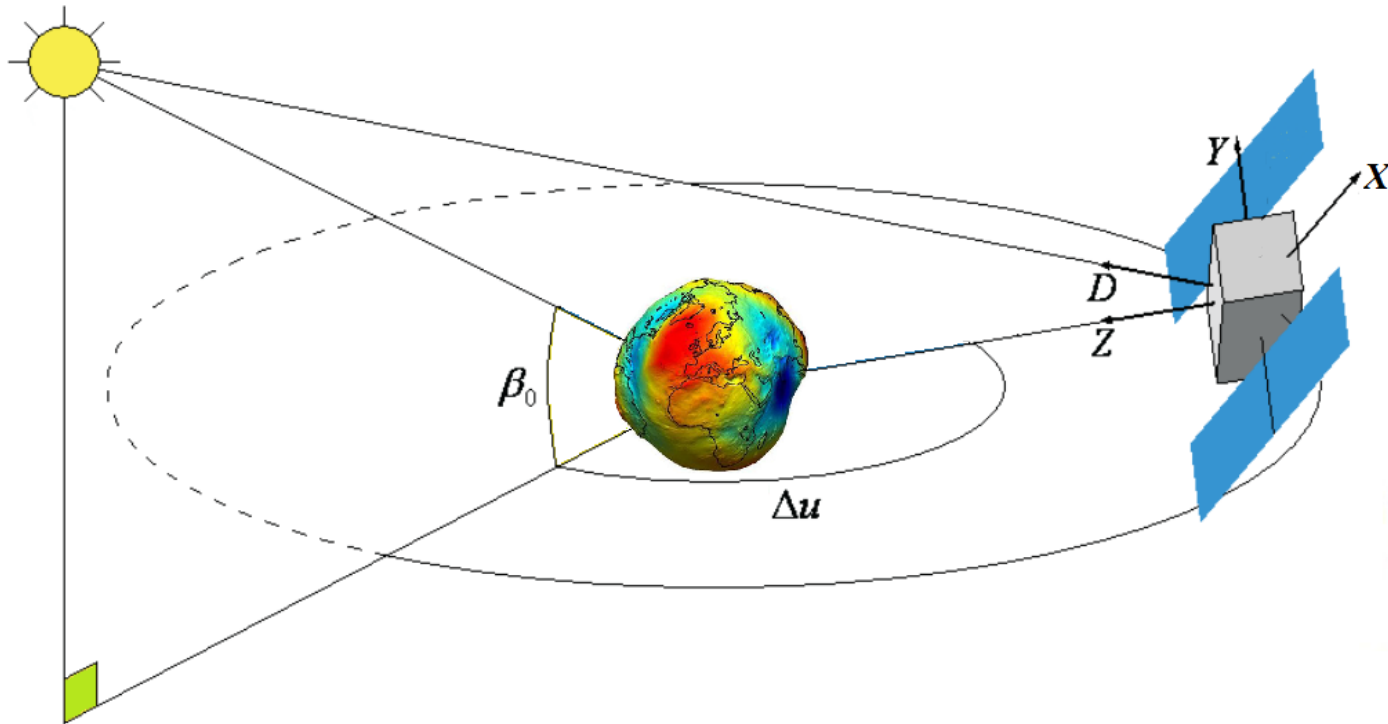
# GPS+GLONASS Gravity Field Solutions

# Sensitivity of GPS resonant orbits



**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



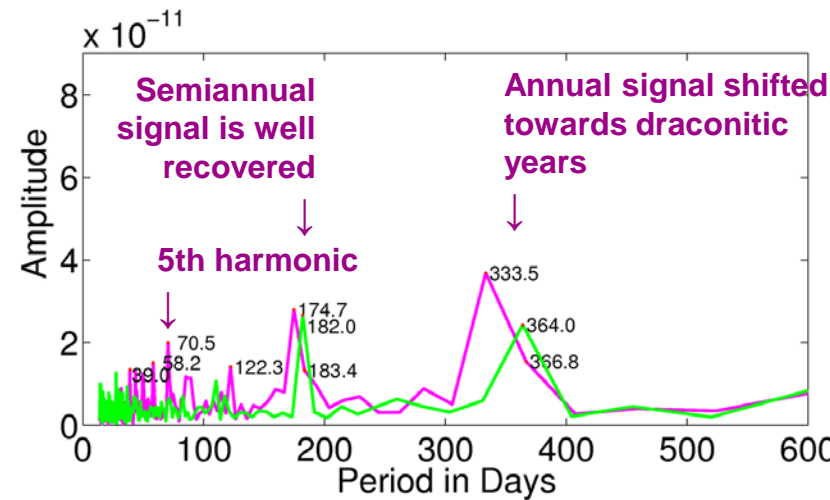
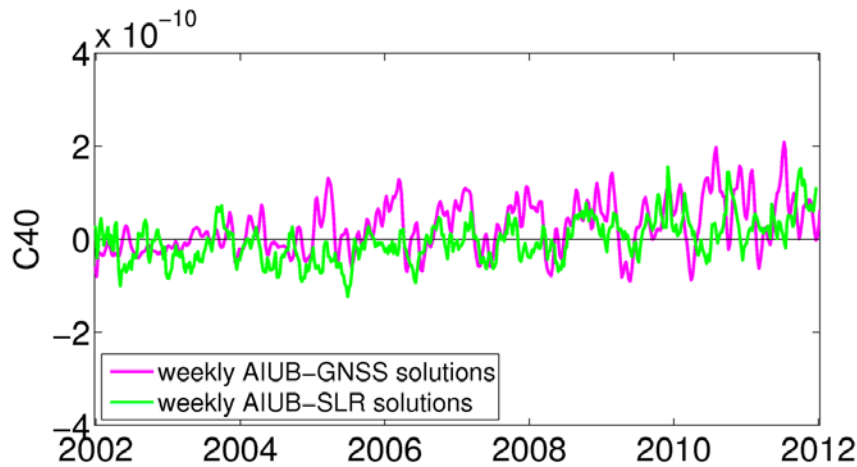
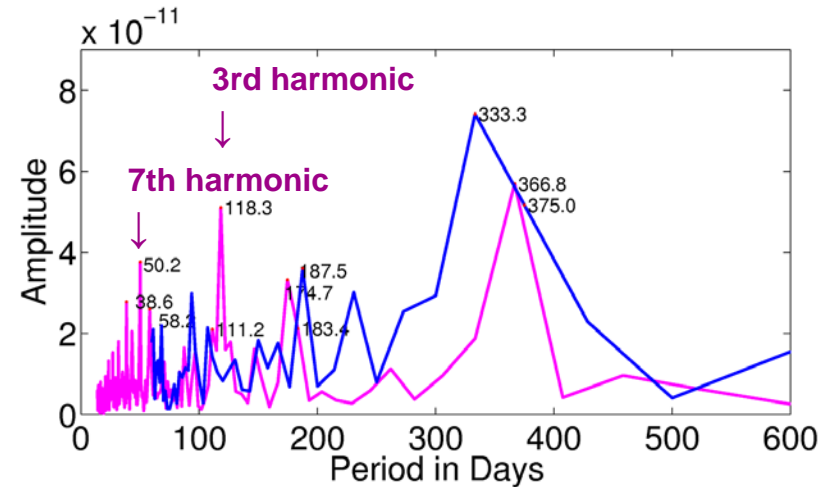
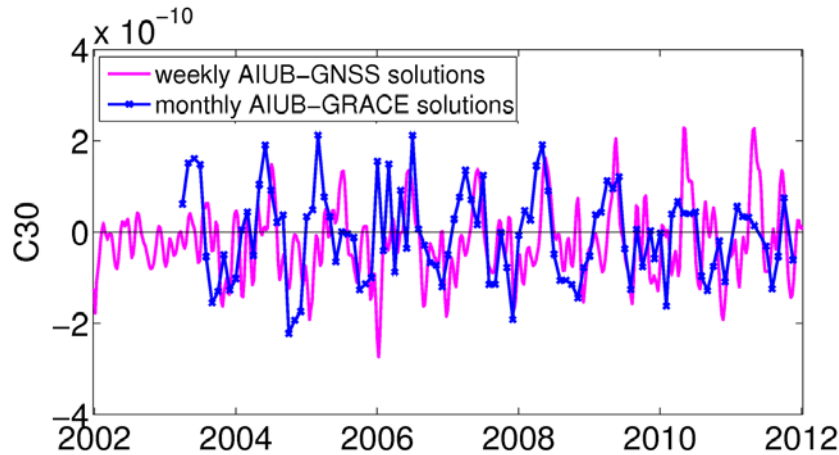
**GNSS** dynamic orbit parameters estimated in standard CODE solutions:

$$D = D_0$$

$$Y = Y_0$$

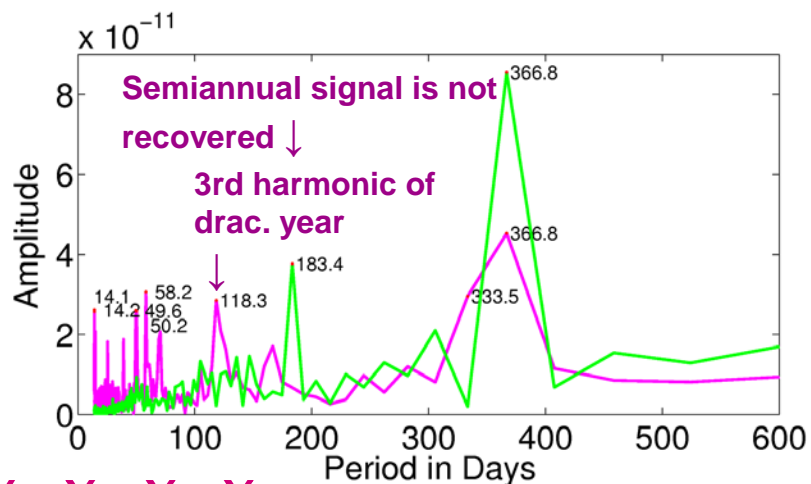
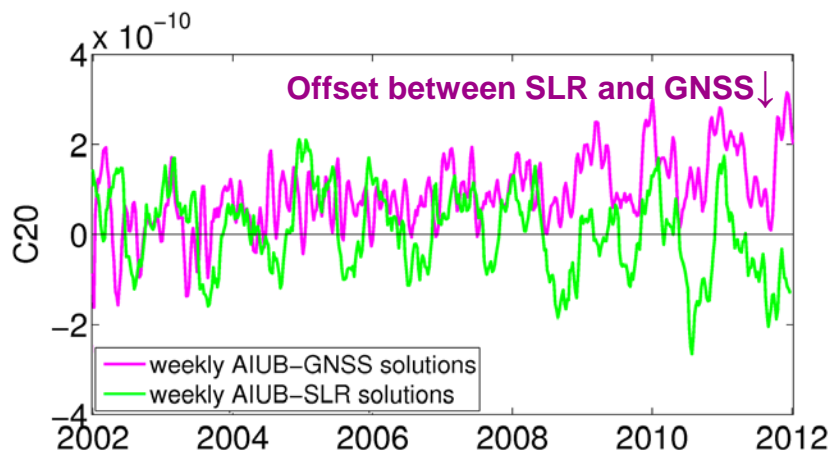
$$X = X_0 + X_s \sin \Delta u + X_c \cos \Delta u$$

# Zonal spherical harmonics from GPS and GLONASS



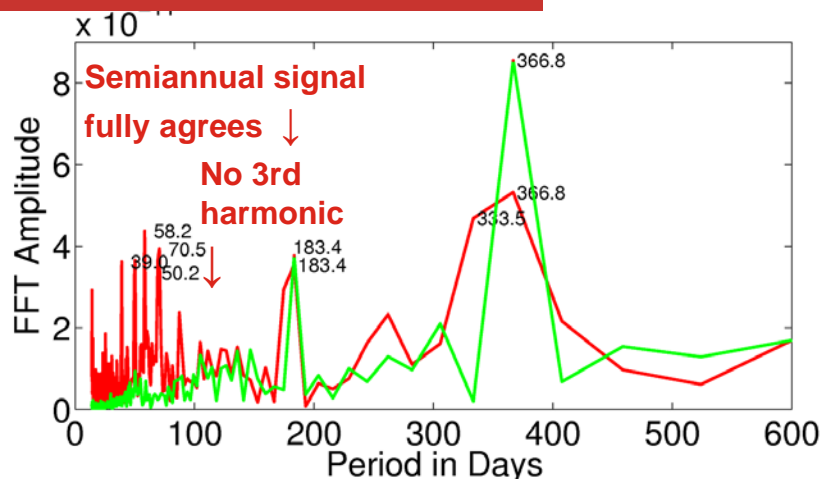
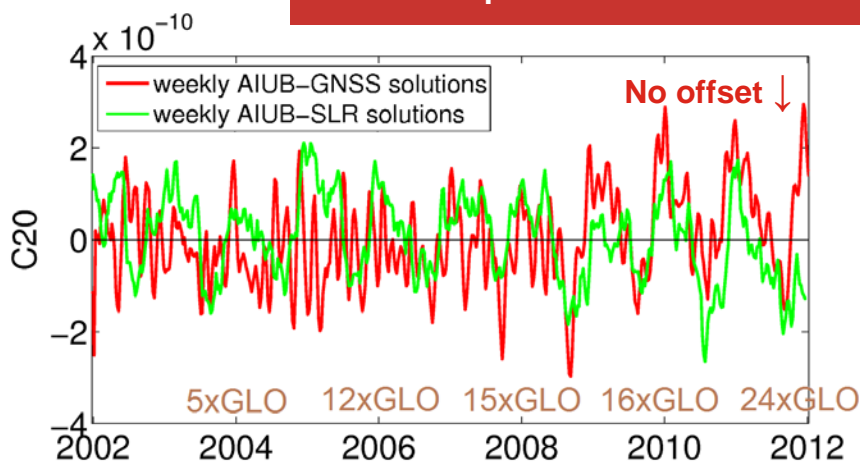
Zonal harmonics can be quite well recovered by GNSS

# C<sub>20</sub> from GPS and GLONASS



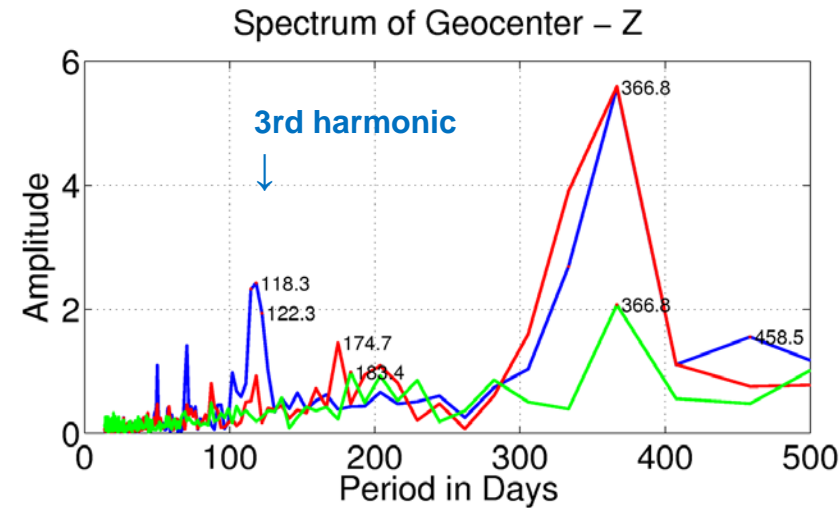
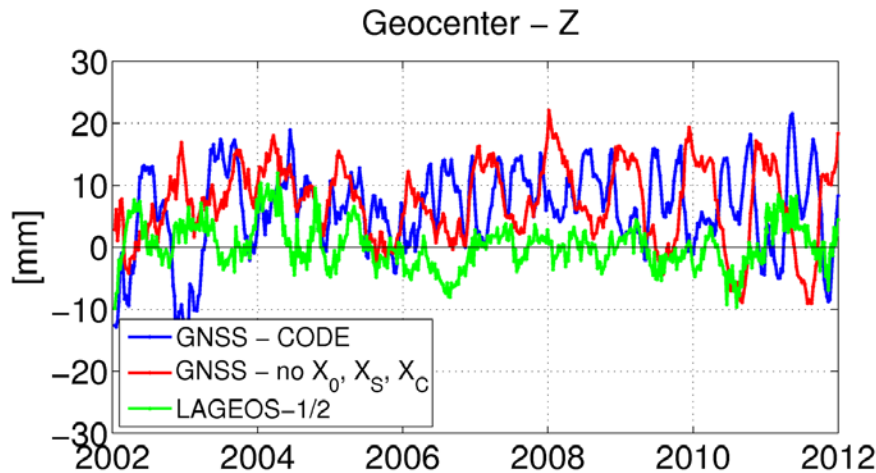
**GNSS dynamic orbit parameters :D<sub>0</sub>, Y<sub>0</sub>, X<sub>0</sub>, X<sub>s</sub>, X<sub>c</sub>**

All parameters in X are correlated with C<sub>20</sub>



**GNSS dynamic orbit parameters :D<sub>0</sub>, Y<sub>0</sub>**

# Geocenter coordinates from GNSS and SLR



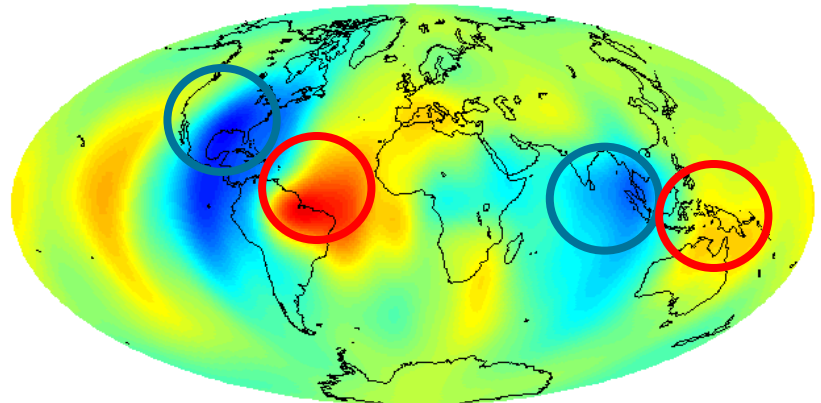
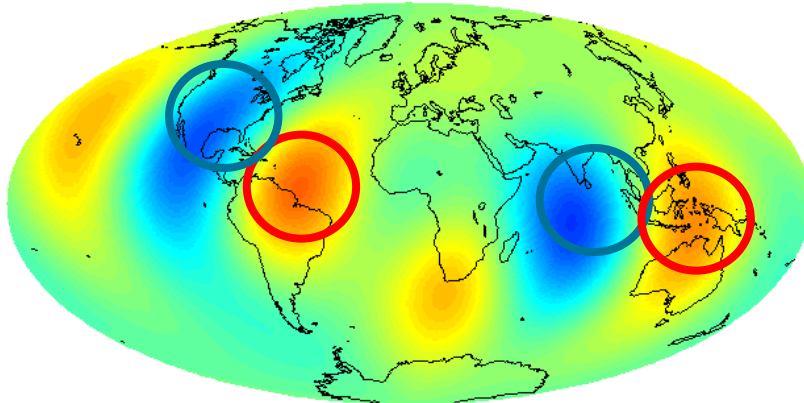
Z geocenter component from GNSS is extremely sensitive to orbit modeling; the exclusion of dynamic orbit parameters in the X direction entirely changes the signal!



# Low-degree geoid variations

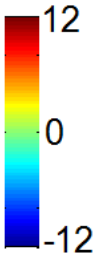
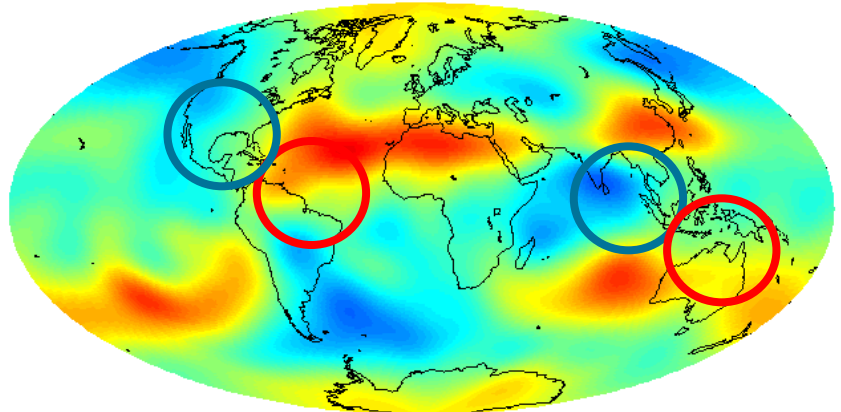
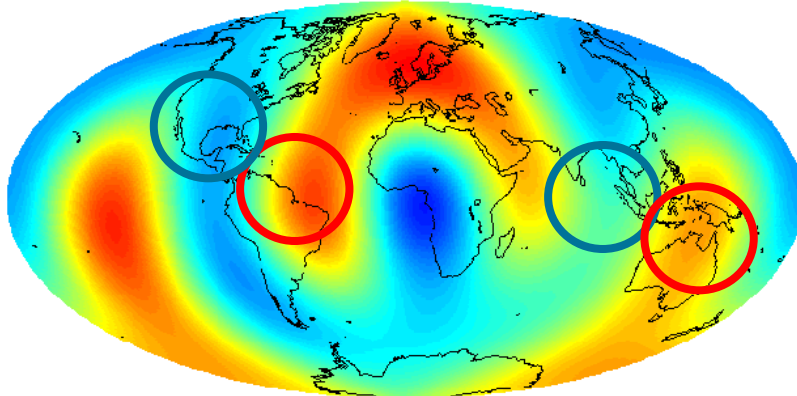
AIUB-SLR, December 2004

AIUB-GRACE, December 2004



AIUB-GNSS, December 2004

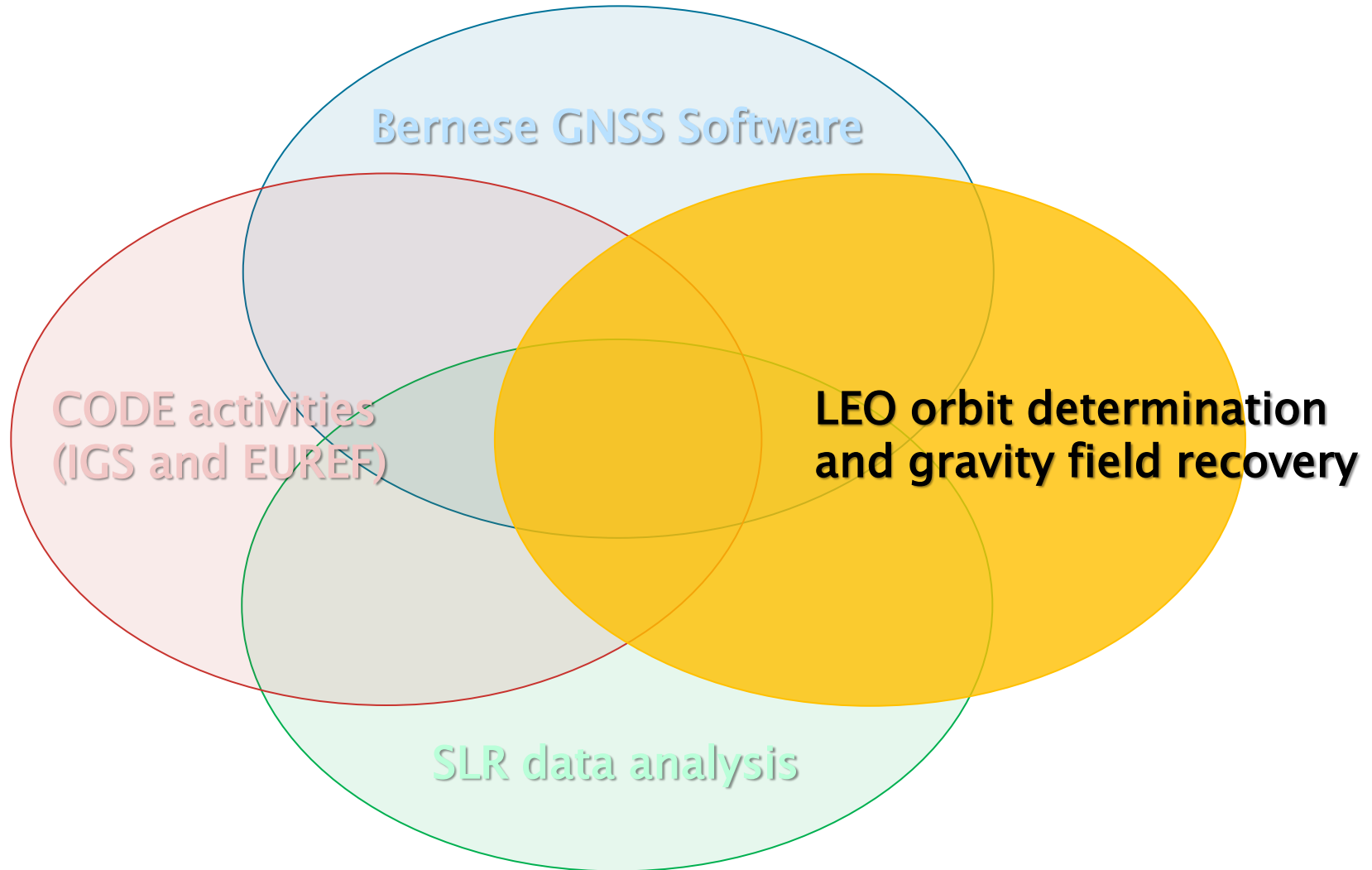
AIUB-CHAMP, December 2004



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

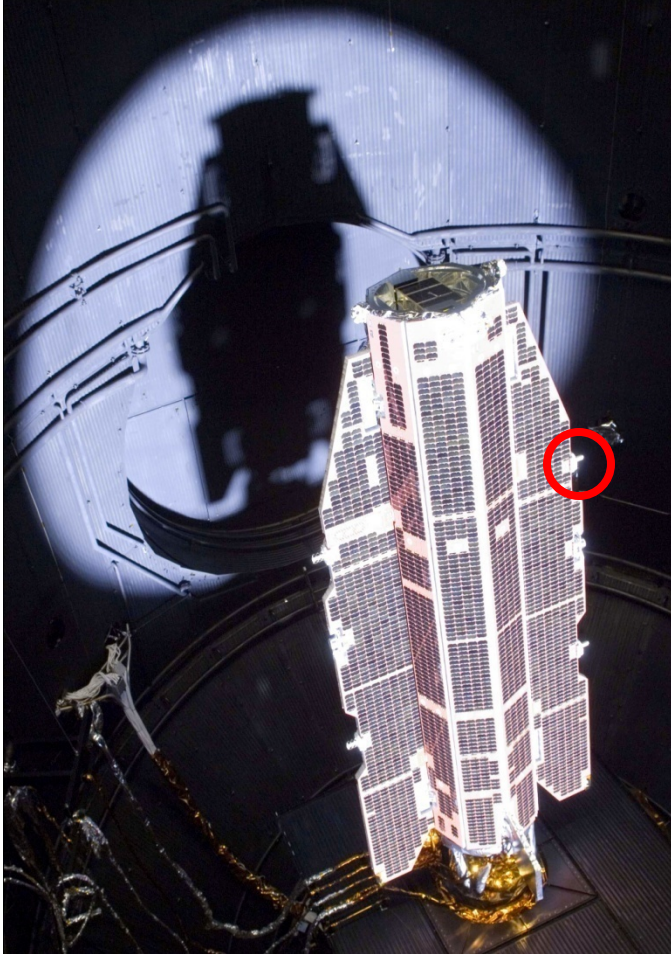
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# GOCE-HPF: Berechnung genauer Bahnen und Schwerefeldbestimmung

# Background and motivation

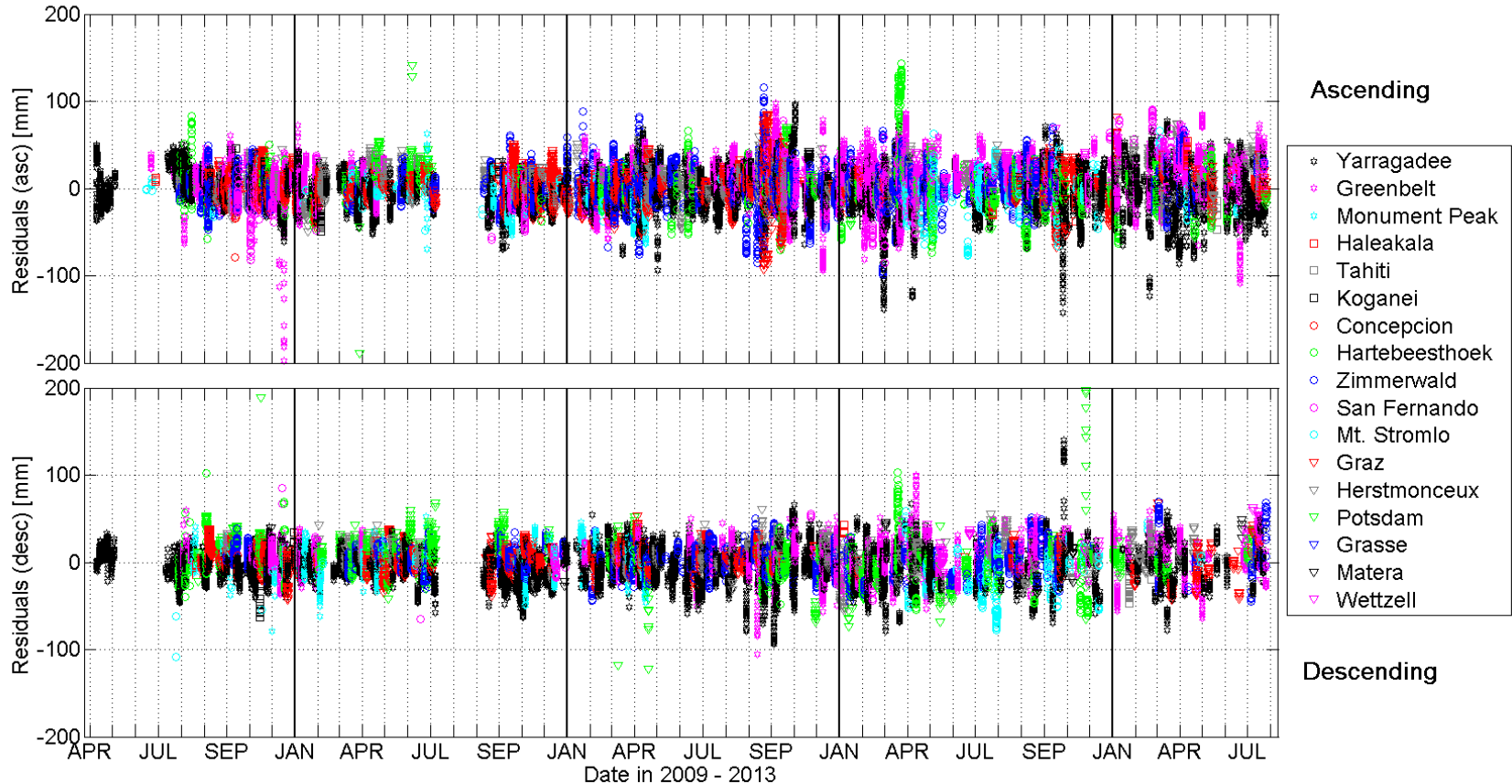


Courtesy:ESA

- 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

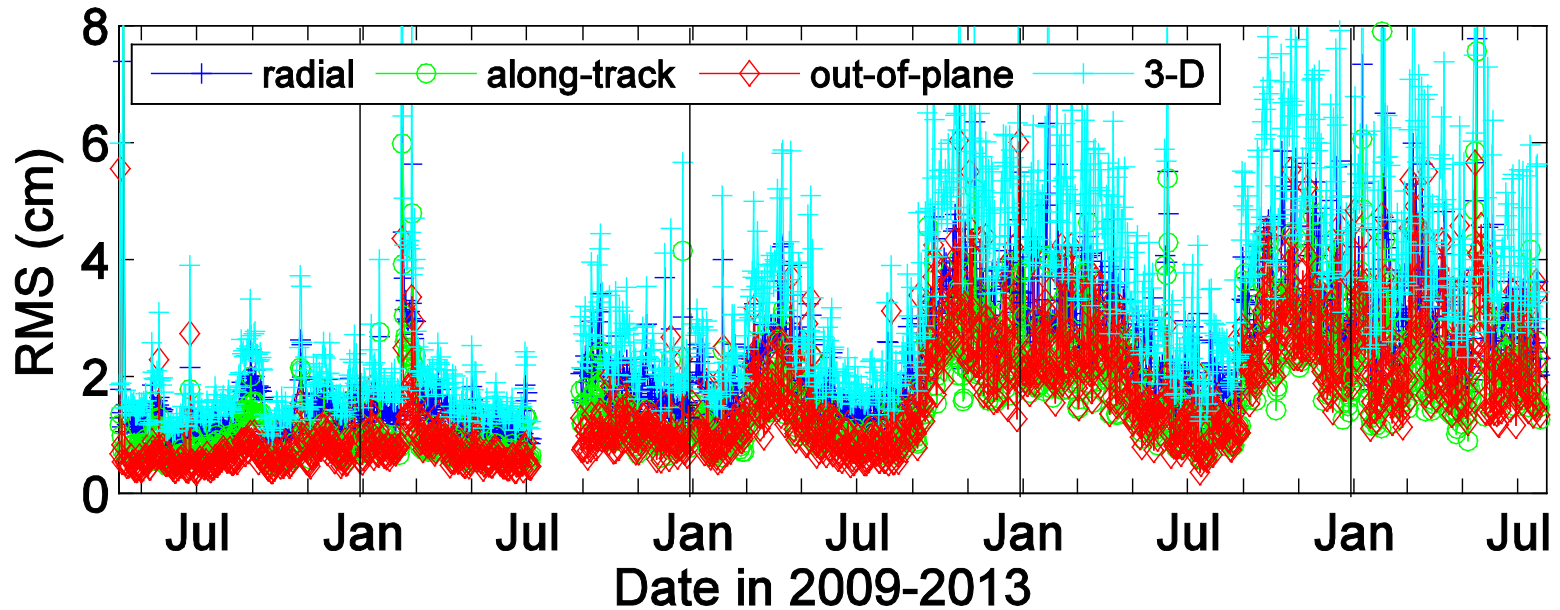
## Kinematic orbits – SST\_PKI



Mean: 0.08 cm

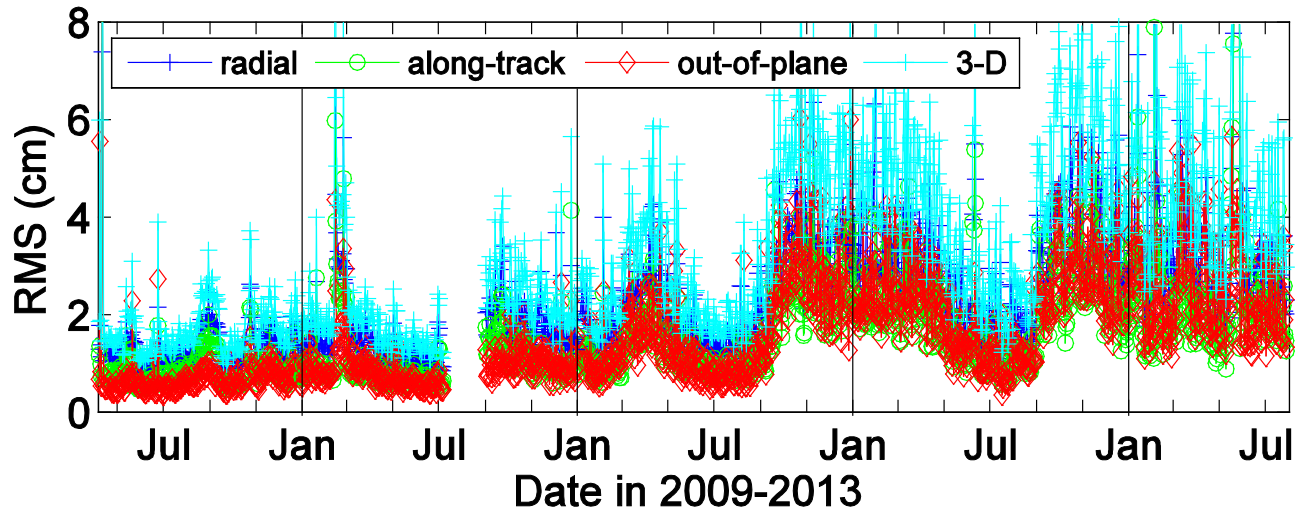
RMS: 2.36 cm

# GOCE orbit determination – results



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

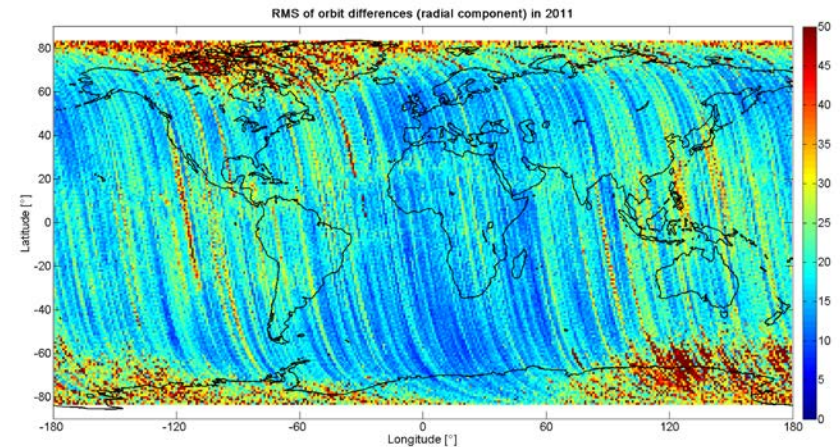
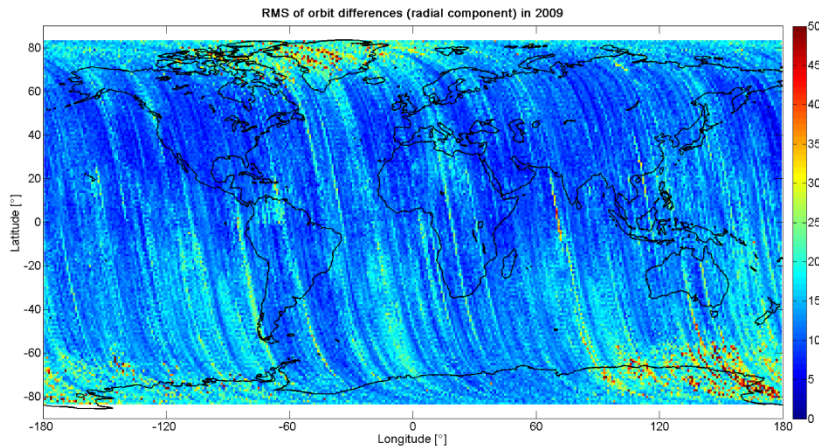
# GOCE orbit determination – results



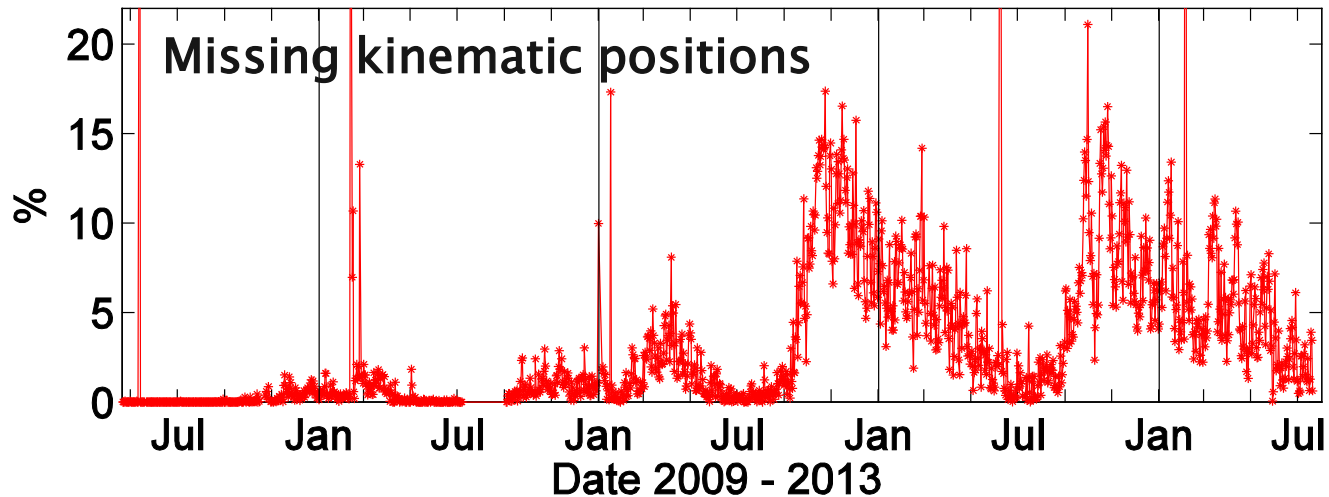
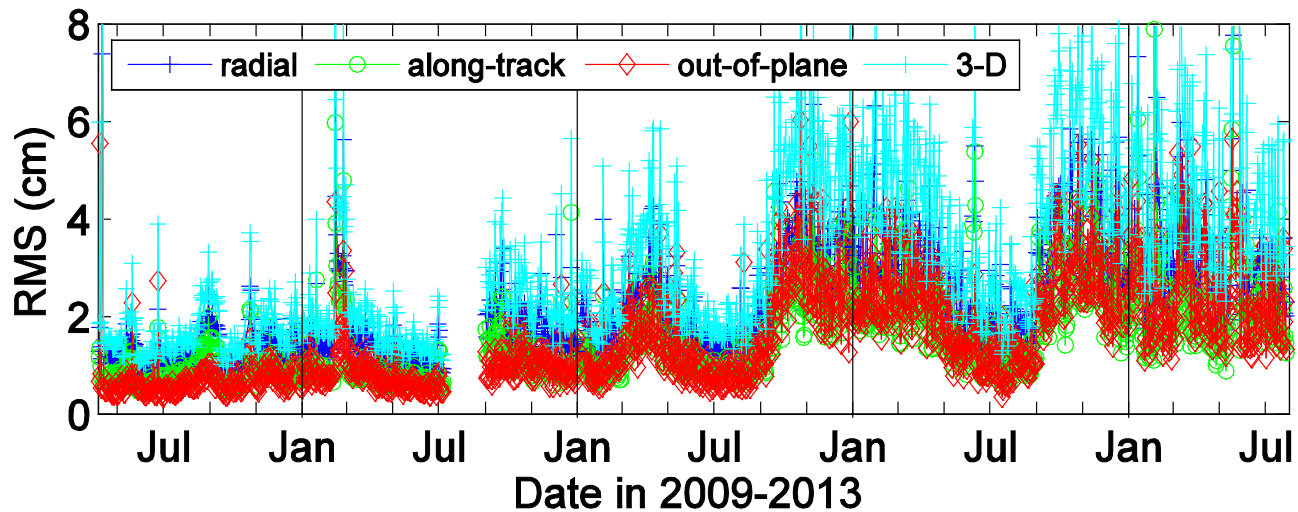
2009

Radial RMS (ascending arcs)

2011



# GOCE orbit determination – results





# GPS-only gravity field determination

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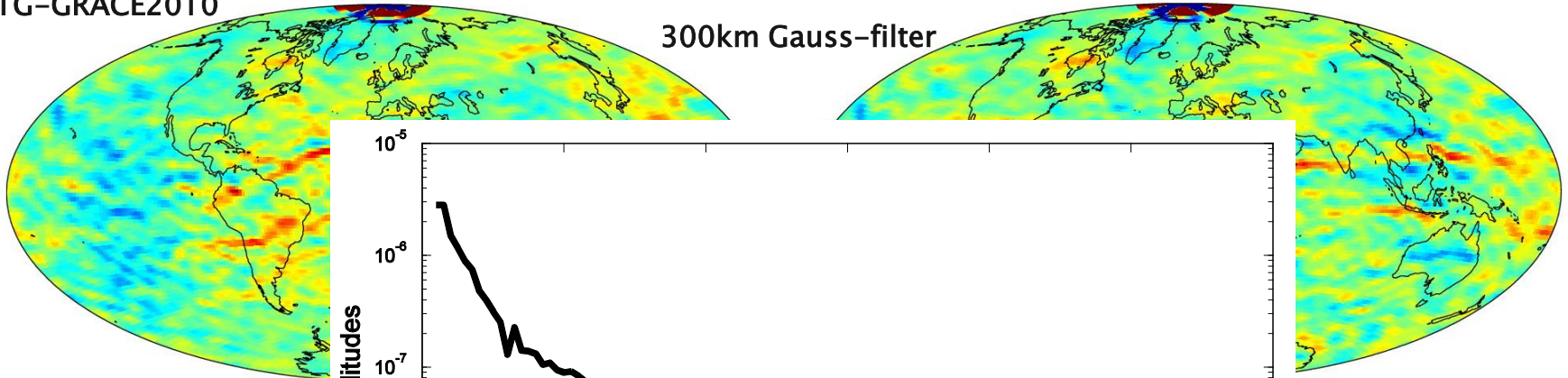
- **Celestial Mechanics Approach**
- **Pseudo-observations: kinematic GOCE positions (SST\_PKI) with variance-covariance information (SST\_PCV) (+ common-mode accelerometer data)**
- **Parameters:**
  - **6 initial orbit elements**
  - **Constant and once-per-revolution terms in R, S, and W**
  - **Pseudo-stochastic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

# Impact of accelerometer data

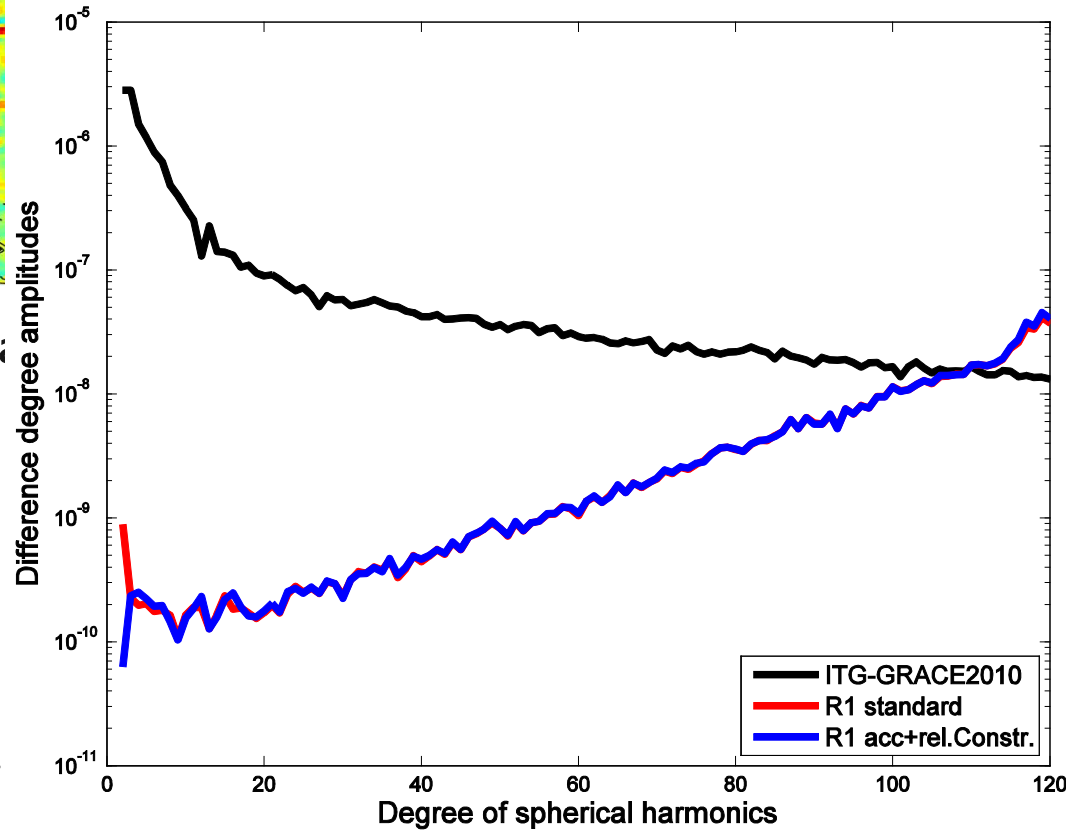
Geoid differences to  
ITG-GRACE2010

Colour scale -0.05 ... 0.05 m

300km Gauss-filter



St:



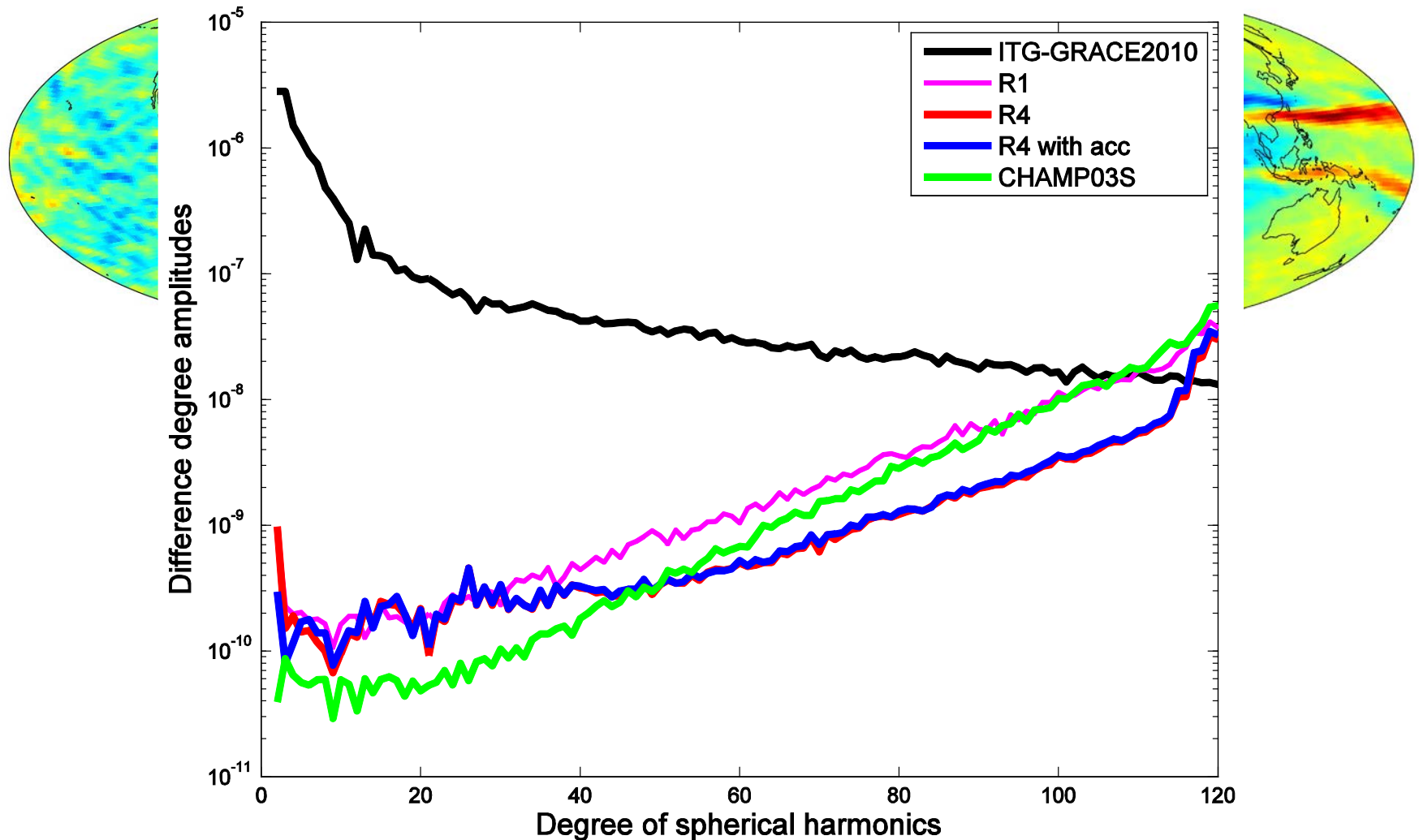
ometer data

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

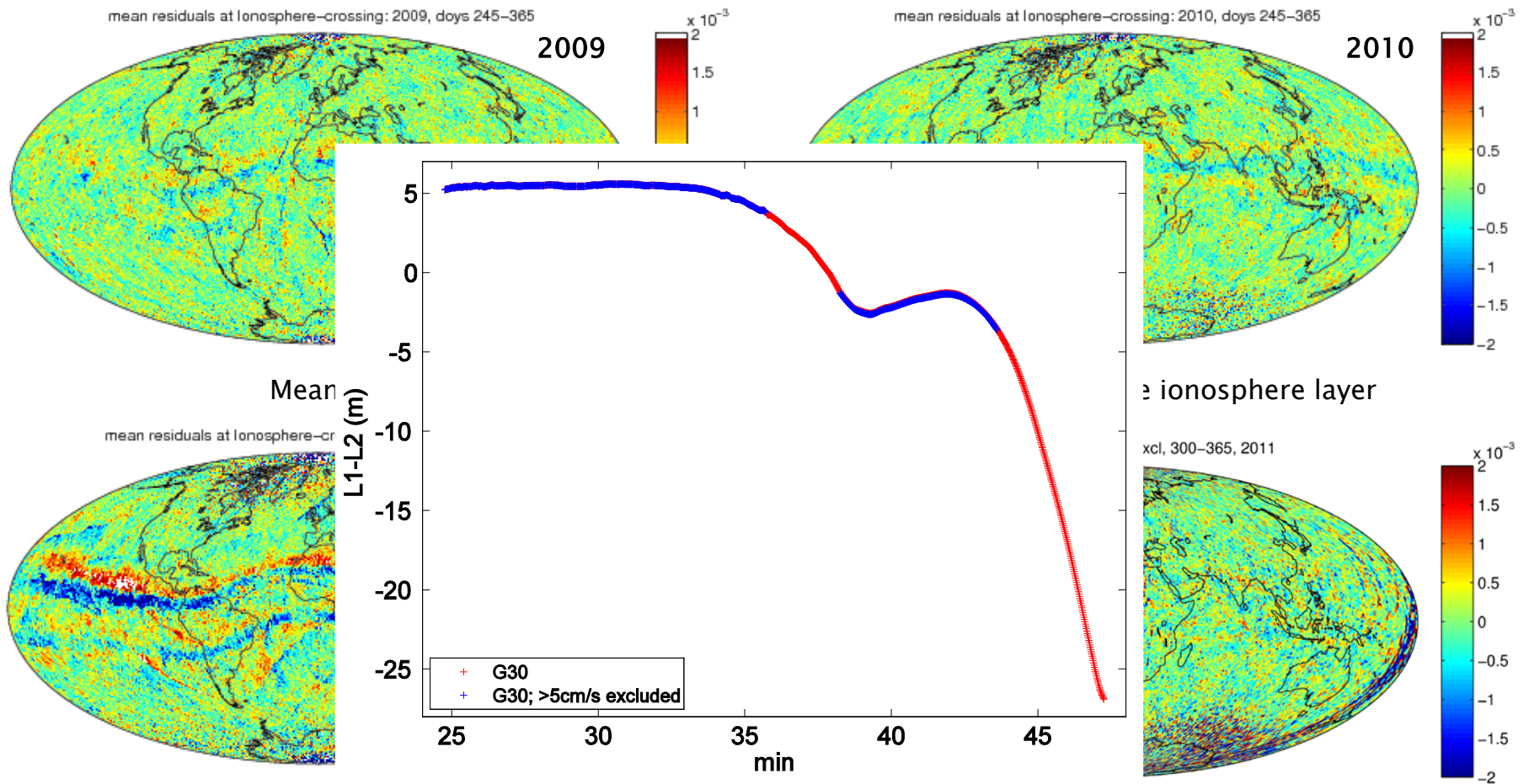
# Release 1 and Release 4 solutions

Geoid differences to  
ITG-GRACE2010

Colour scale -0.05 .... 0.05 m



# Phase observation residuals

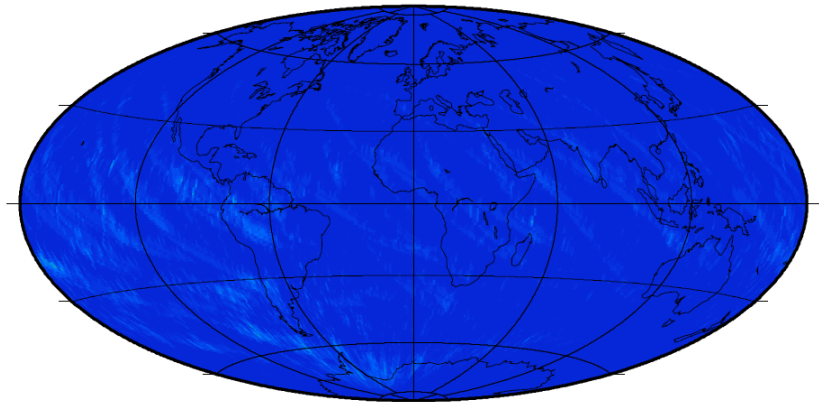
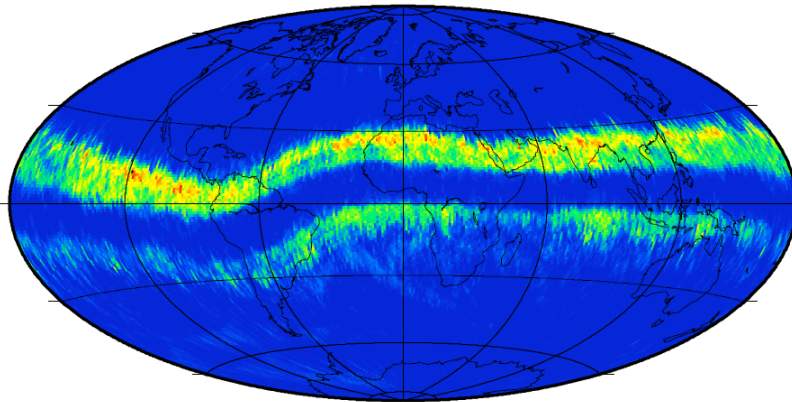


# Number of removed observations

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ascending

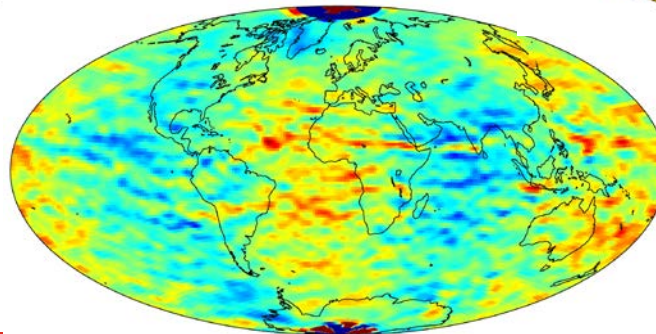
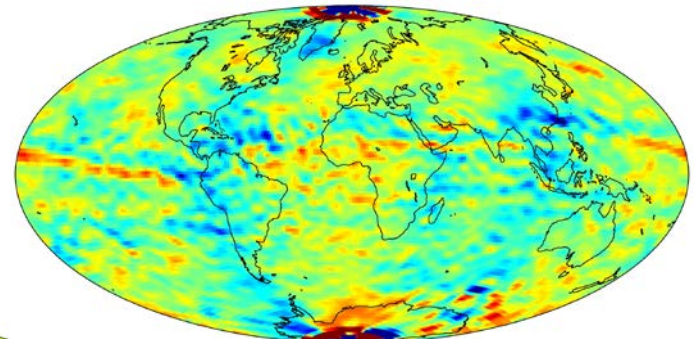
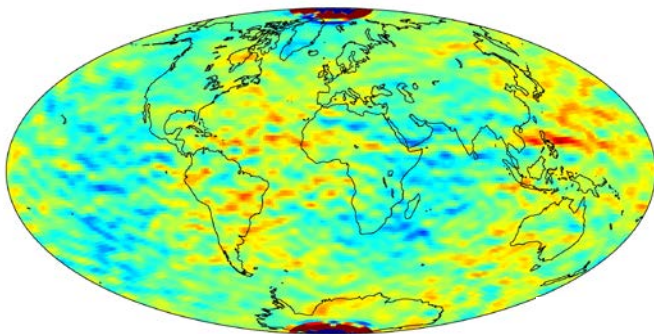
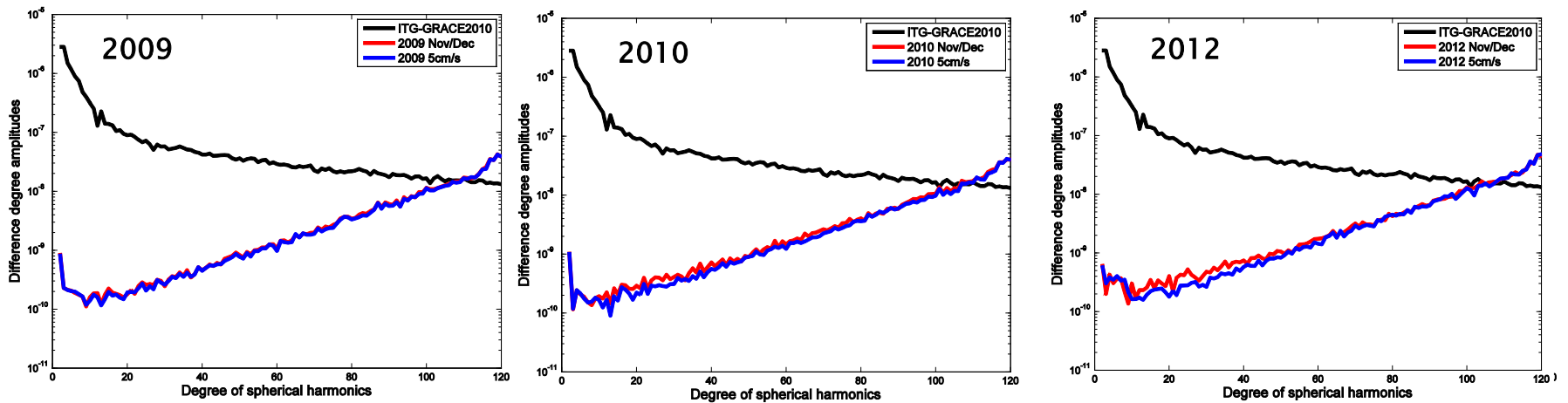
descending



0 100 200 300 400

nr of removed points in 1 x 1 bins for doy 300-365 in 2011

# Removal of systematic orbit errors



# Summary

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- 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  $>5\text{cm/s}$  from one observation epoch to the next
- Systematic errors are removed but orbit quality suffers => more investigations necessary

# GOCE – the last days

home universitaet > rektorat > abteilung kommunikation > medien > medienmitteilungen > alle news > 2013 > erfolgreicher satellit der esa  
Studium | Campus | Bibliotheken | Forschung | Organisation | Arbeiten an der Uni | Öffentlichkeit

Suchen | Kontakt | Lageplan | Sitemap | Drucken

Abteilung  
Kommunikation



## Erfolgreicher Satellit der ESA verglöh in den kommenden Tagen

Er wird demnächst in die Erdatmosphäre eintreten und verglöh: 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.

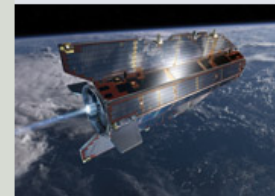
### Bern weltweit führend in der GPS-Datenauswertung

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.

u<sup>b</sup>

UNIVERSITÄT  
BERN

### 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

### Kontaktpersonen

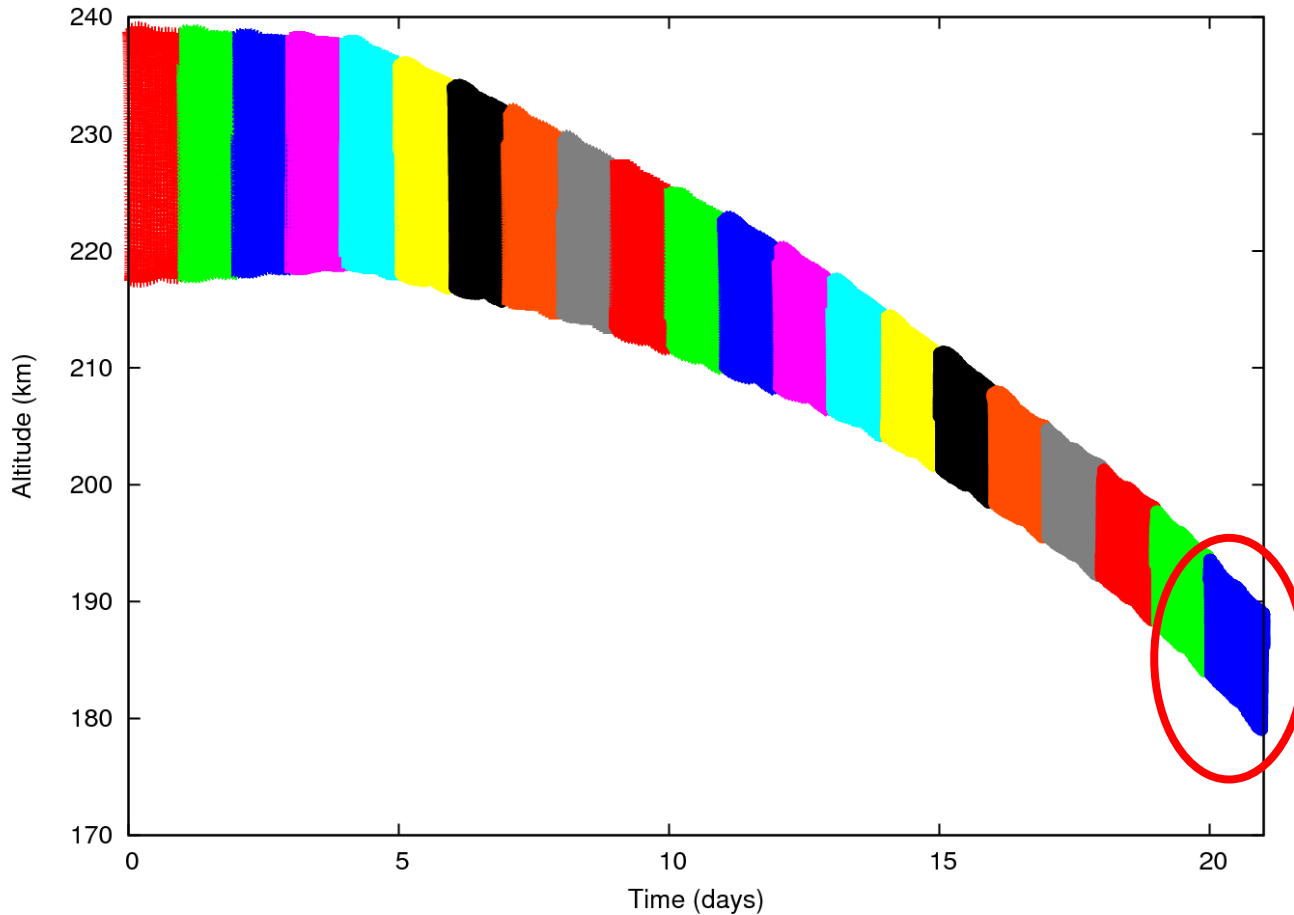
Dr. Heike Bock  
Astronomisches Institut der  
Universität Bern

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[E-Mail](#)

Prof. Dr. Adrian Jäggi  
Astronomisches Institut der  
Universität Bern



# GOCE - the last days



Wednesday,  
6.11.2013

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# Schwerefeldbestimmung mit GRACE

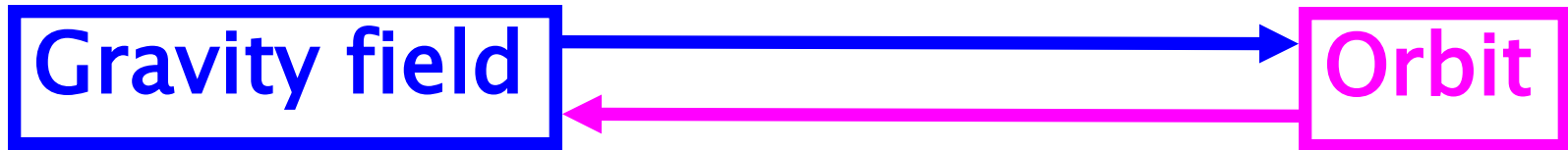
# Motivation

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

# Gravity field and Orbit

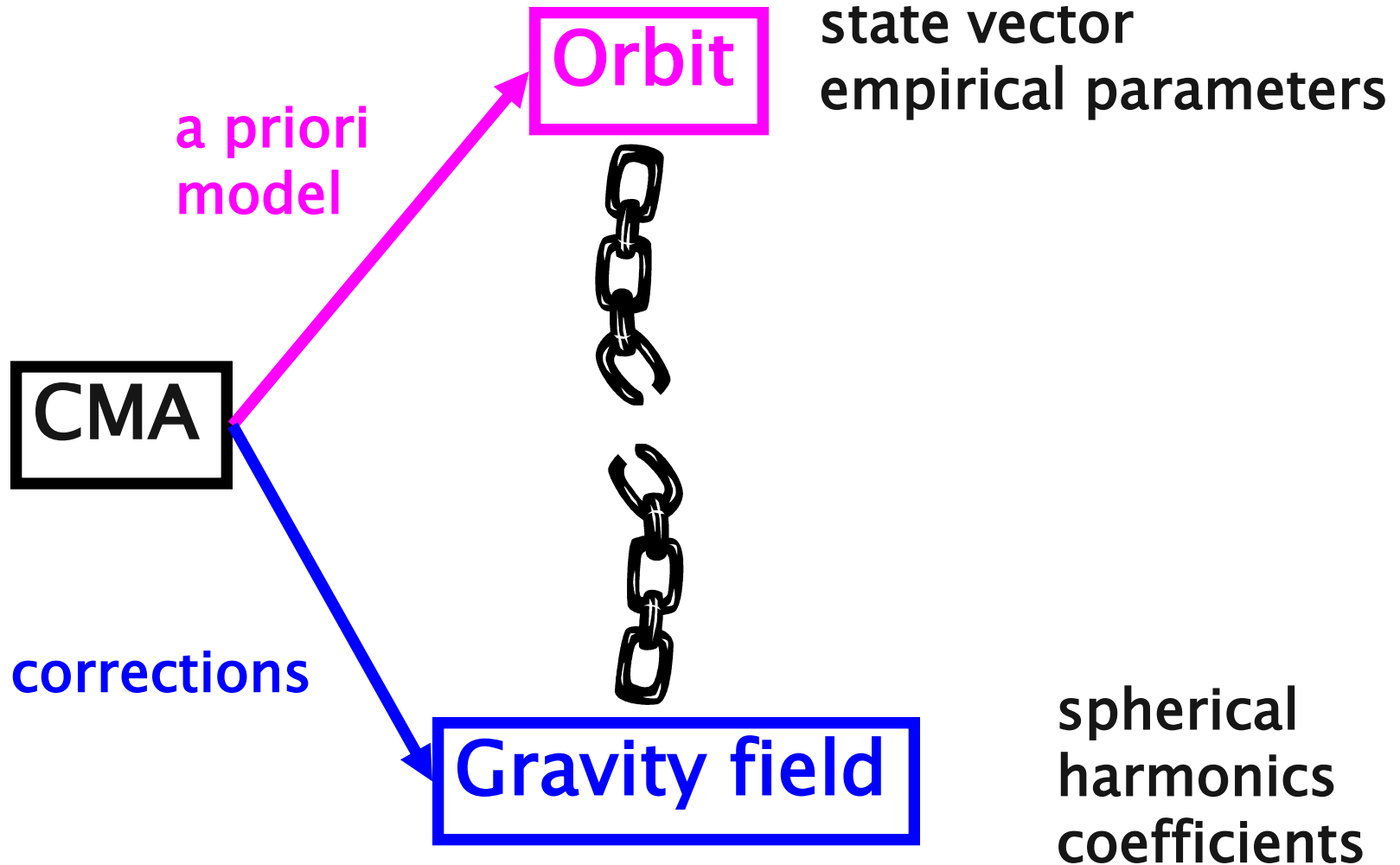
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## Non-linear parameter estimation problem

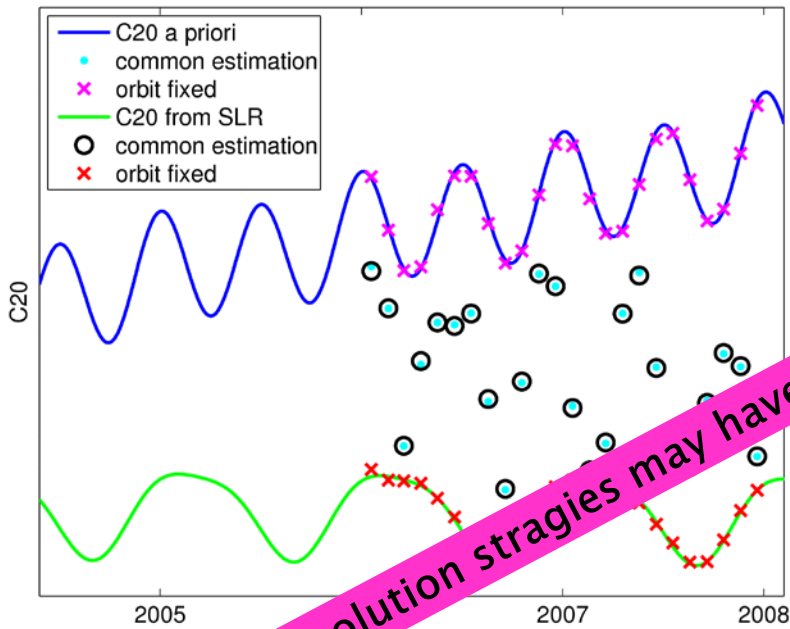
- A priori model (linearization)
- Observations
- Regularization (a priori knowledge via pseudo-observations)

# Impact of different processing strategies

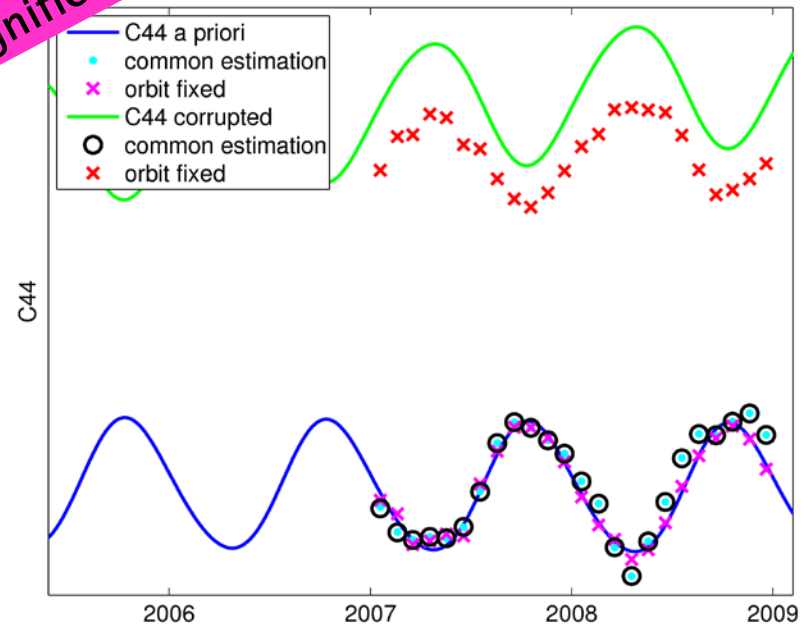


# Impact of different processing strategies

## C20

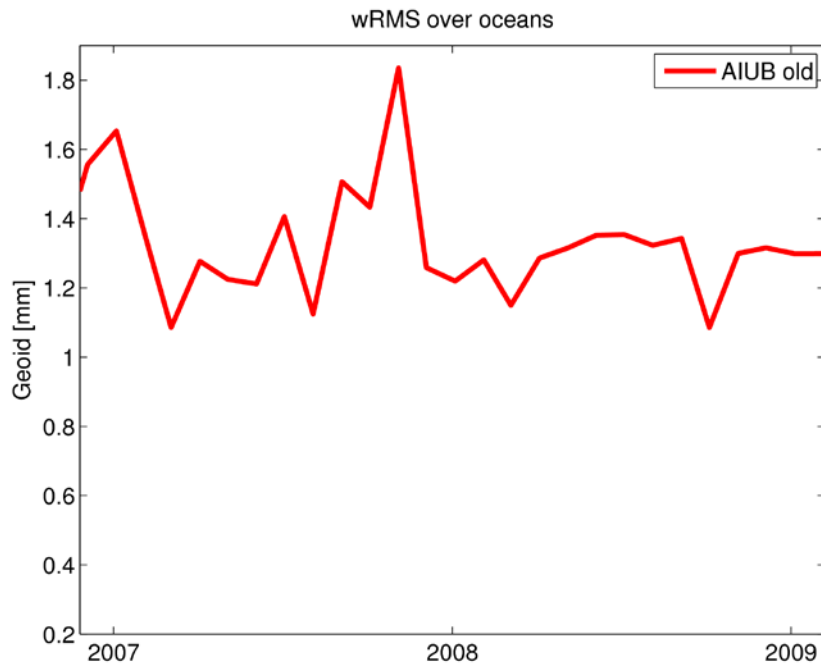


## C44



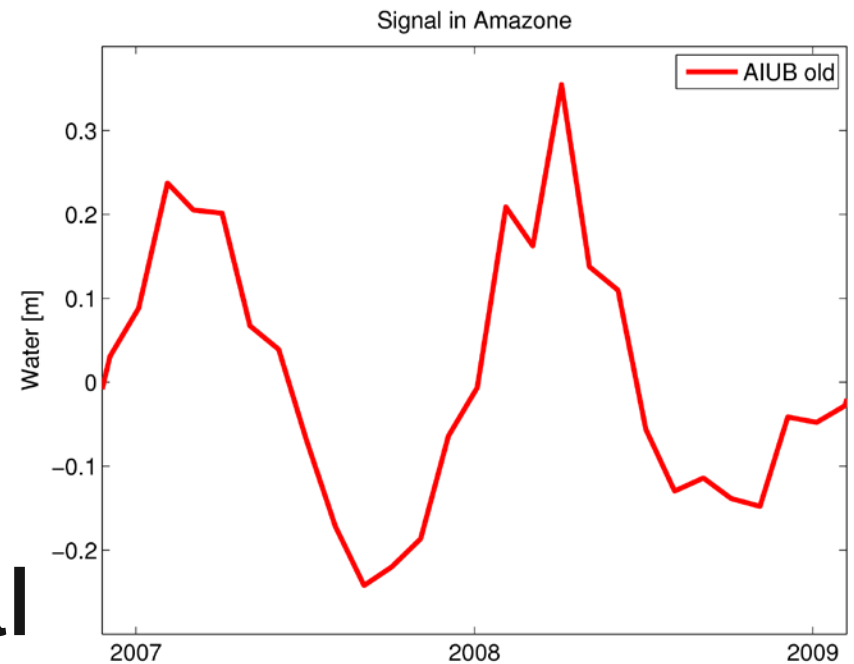
Different solution strategies may have a significant impact on signal and noise

# Separation of Orbit and Gravity field

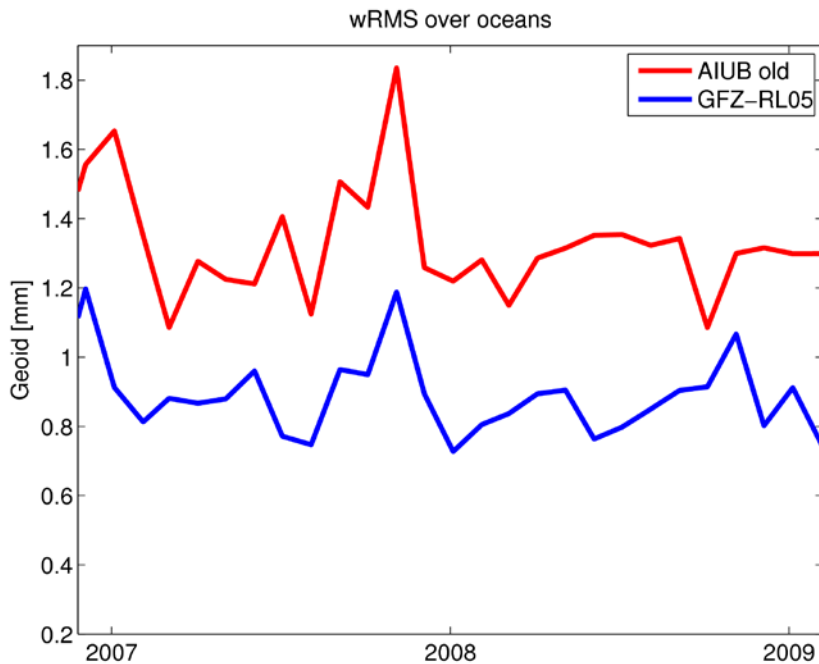


noise

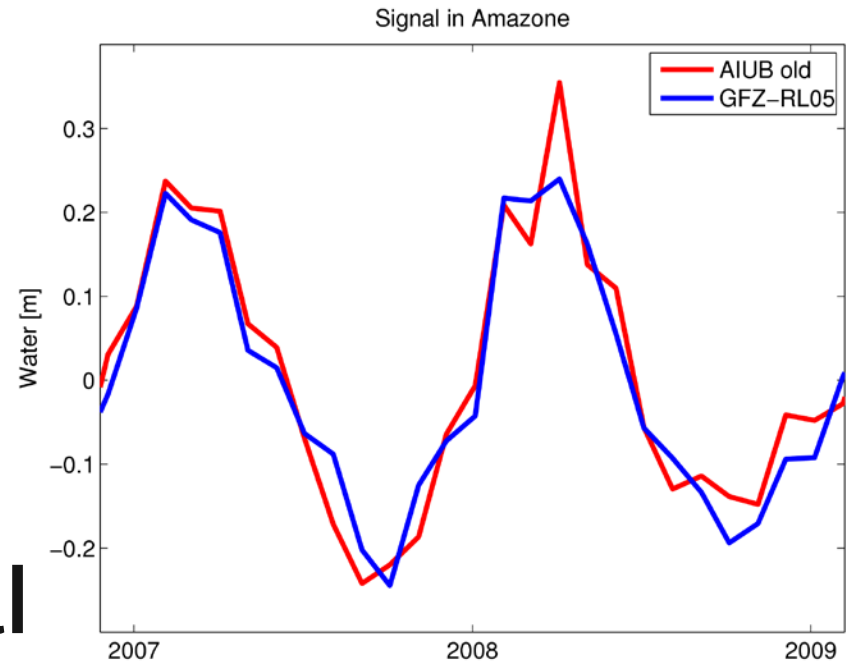
signal



# Separation of Orbit and Gravity field



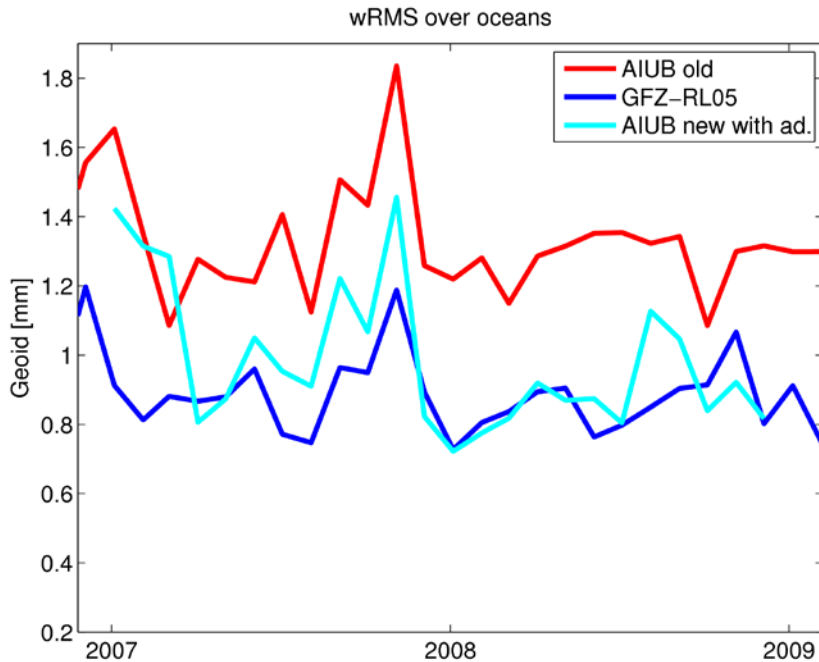
noise



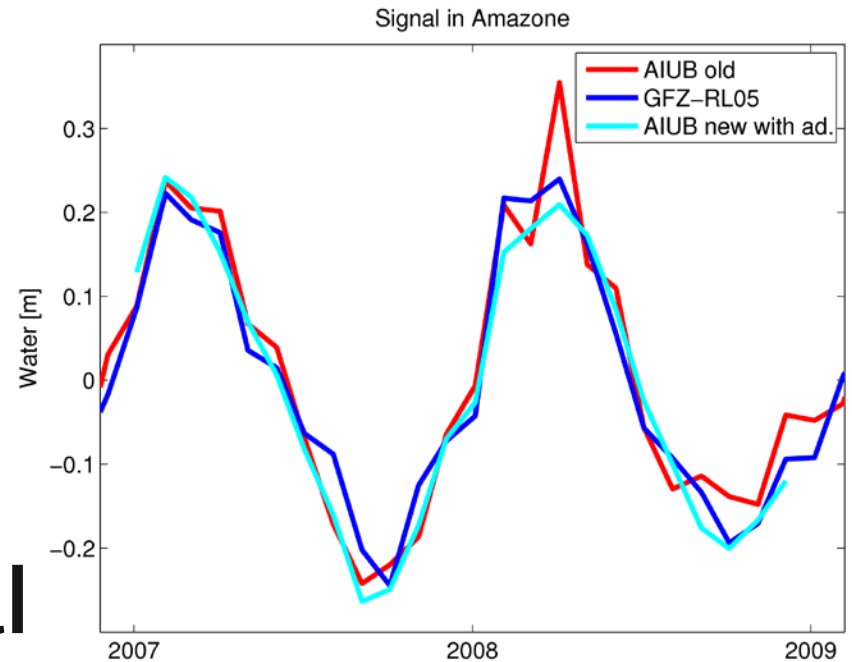
signal



# Separation of Orbit and Gravity field

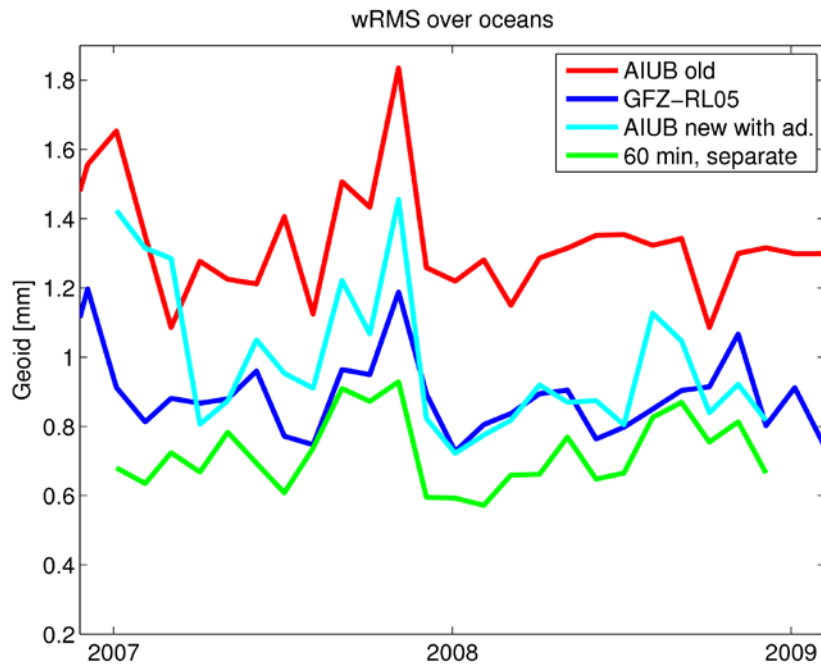


noise

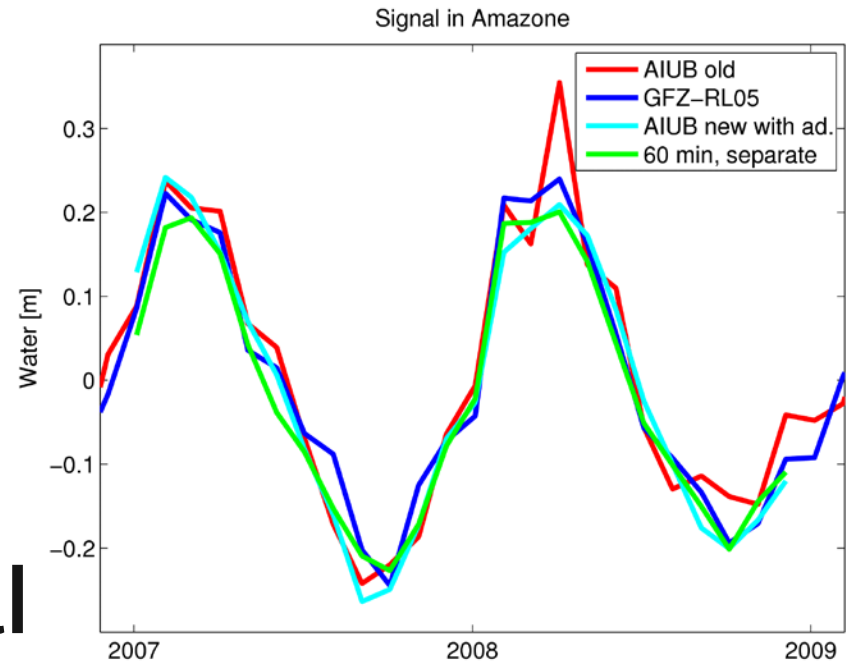


signal

# Separation of Orbit and Gravity field

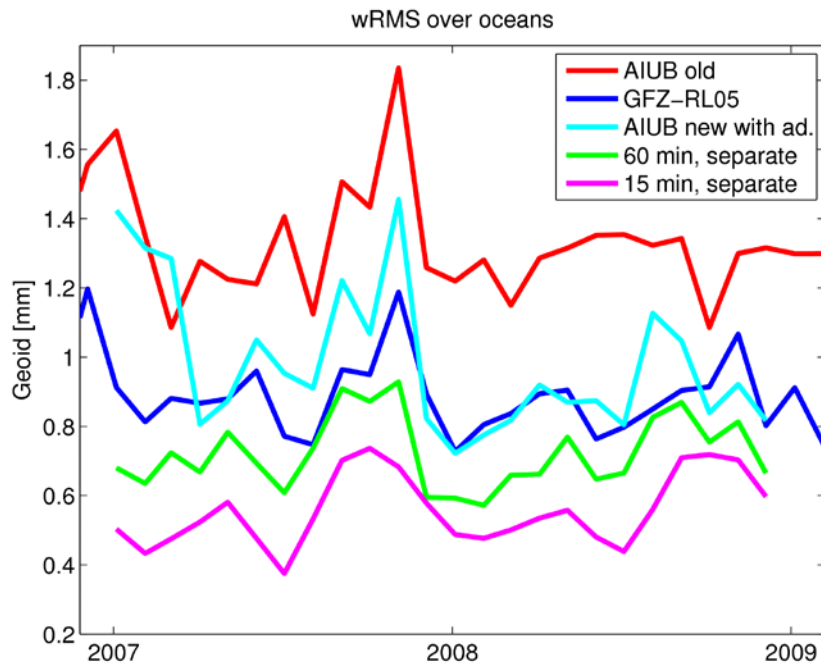


noise



signal

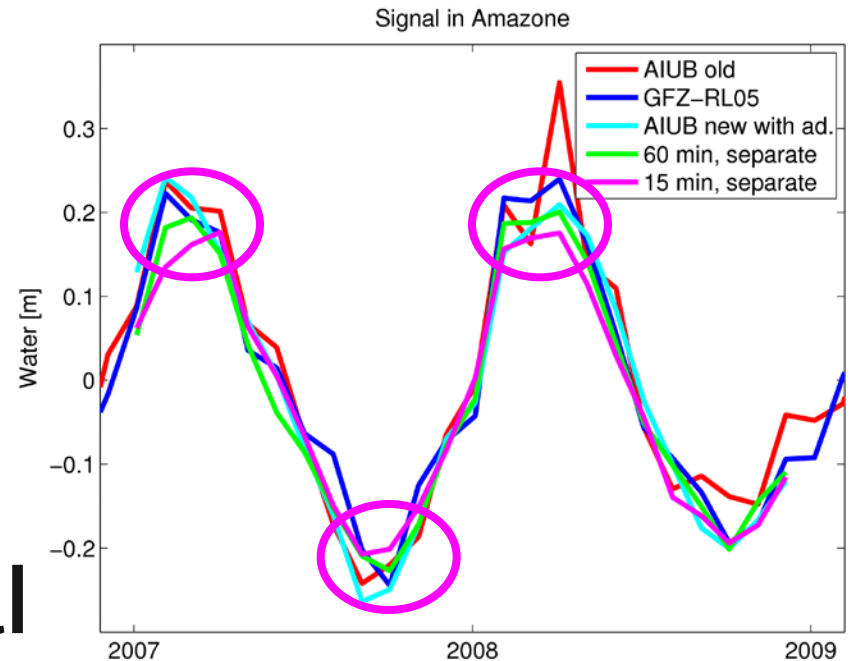
# Separation of Orbit and Gravity field



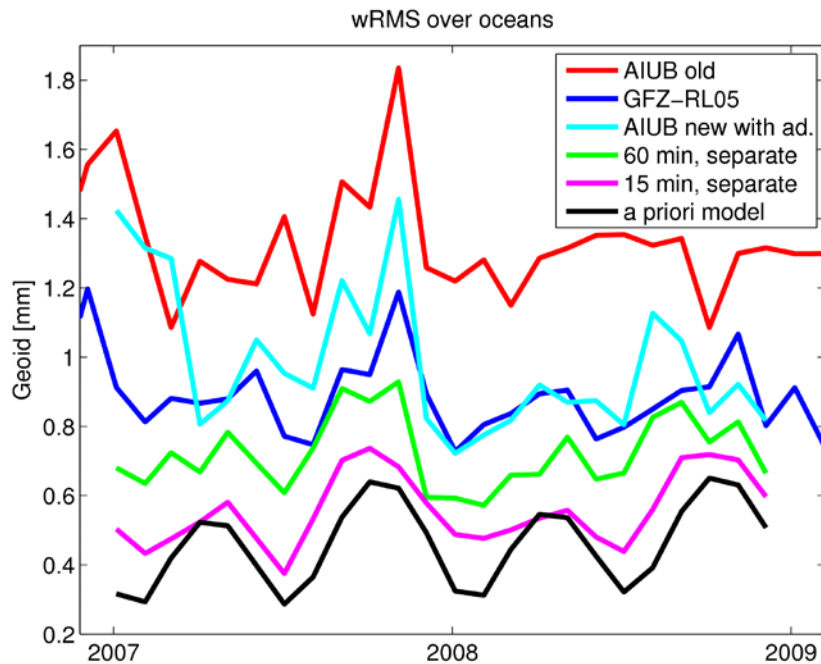
noise

signal loss

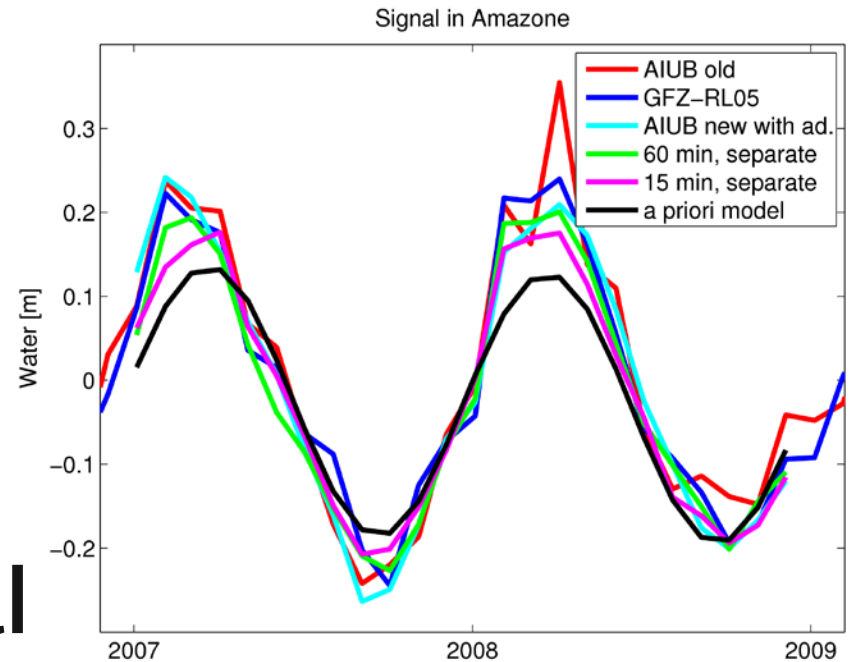
signal



# Separation of Orbit and Gravity field



noise

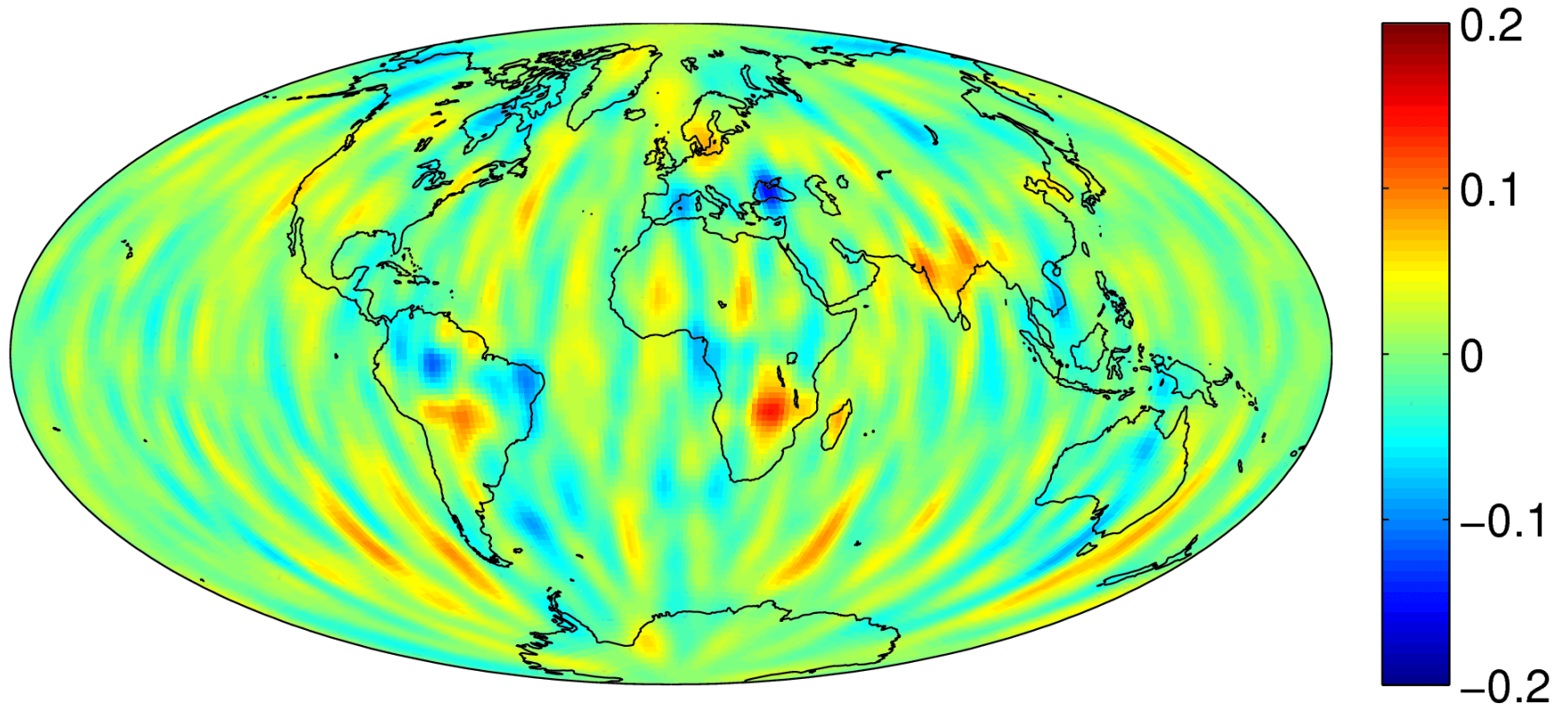


signal

# Monthly field – a priori model

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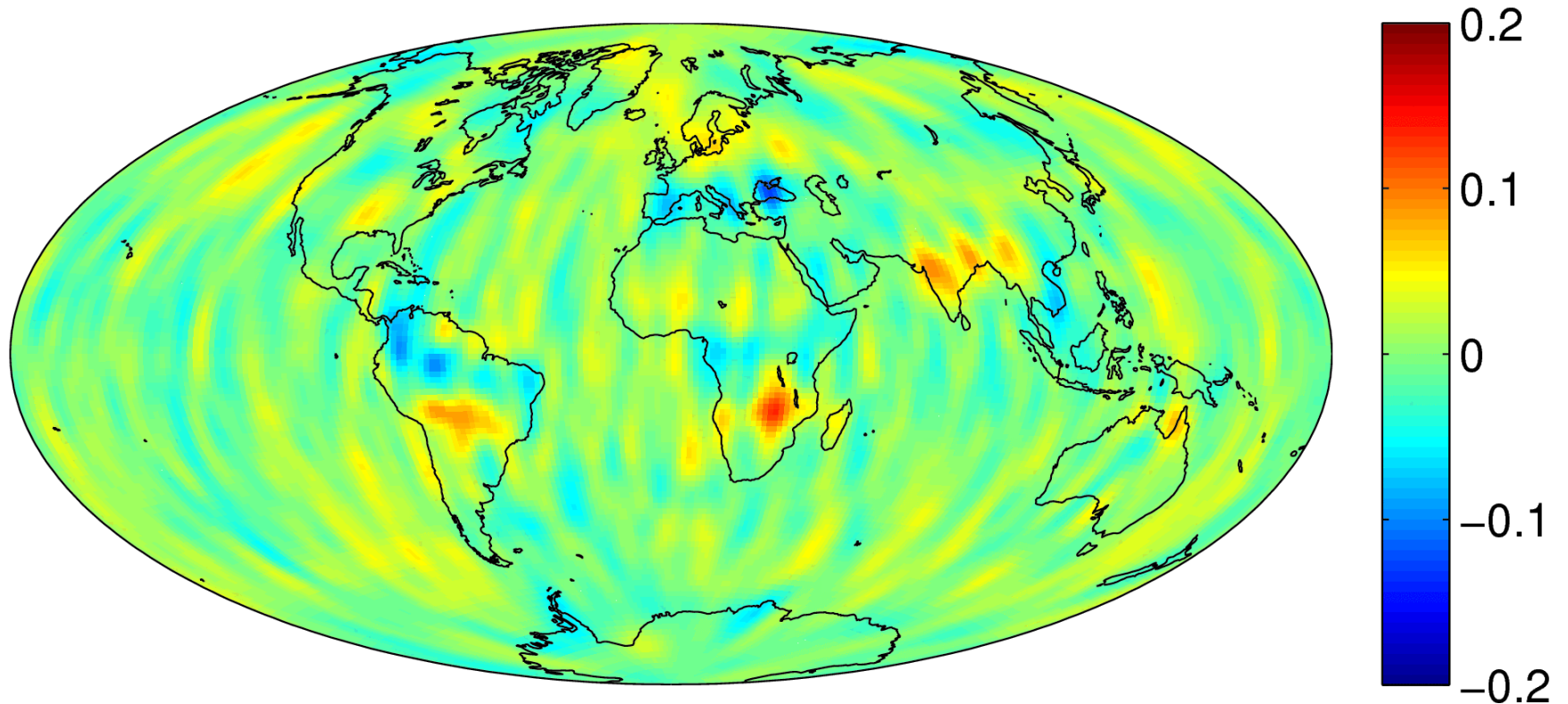
Combined solution, 15 min



# Monthly field – a priori model

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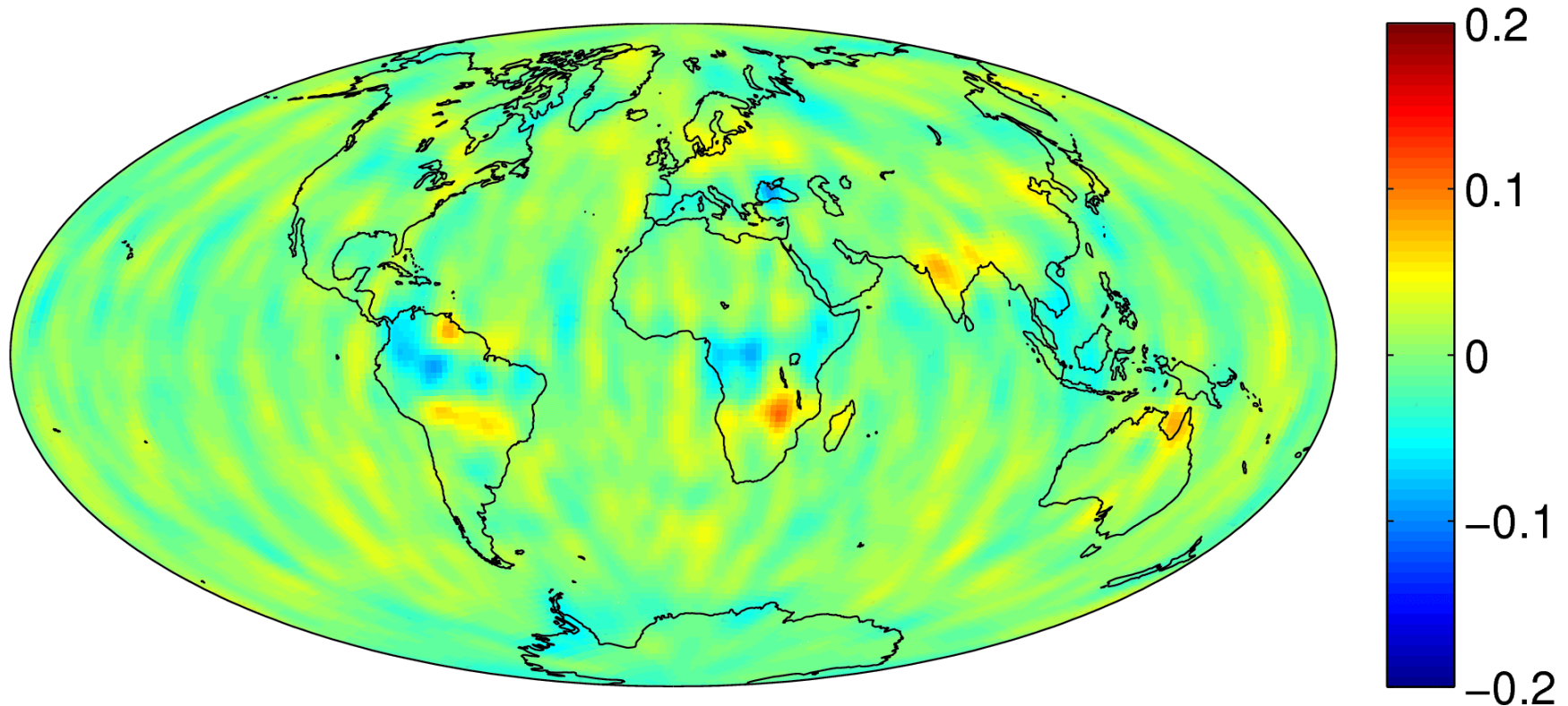
Separate solution, 60 min



# Monthly field – a priori model

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Separate solution, 15 min



# Discussion

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## Is it good or bad?

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

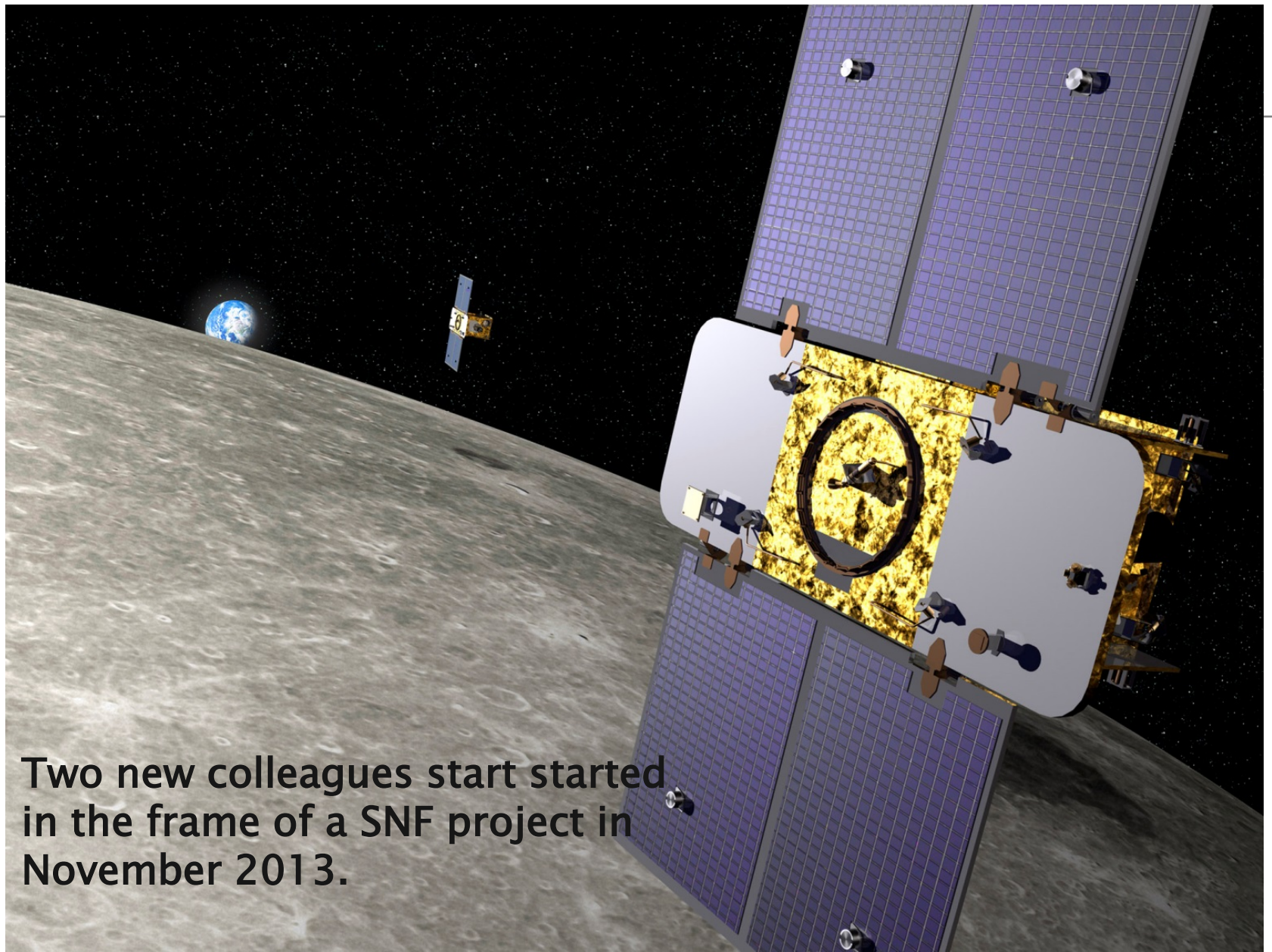
⇒ GFZ announced an alternative Release 05a  
(trends for Greenland ice mass loss were  
heavily biased towards the a priori model)

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# GRAIL: Bestimmung des Schwerefeldes des Mondes



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

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**Vielen Dank  
für Ihre Aufmerksamkeit**



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