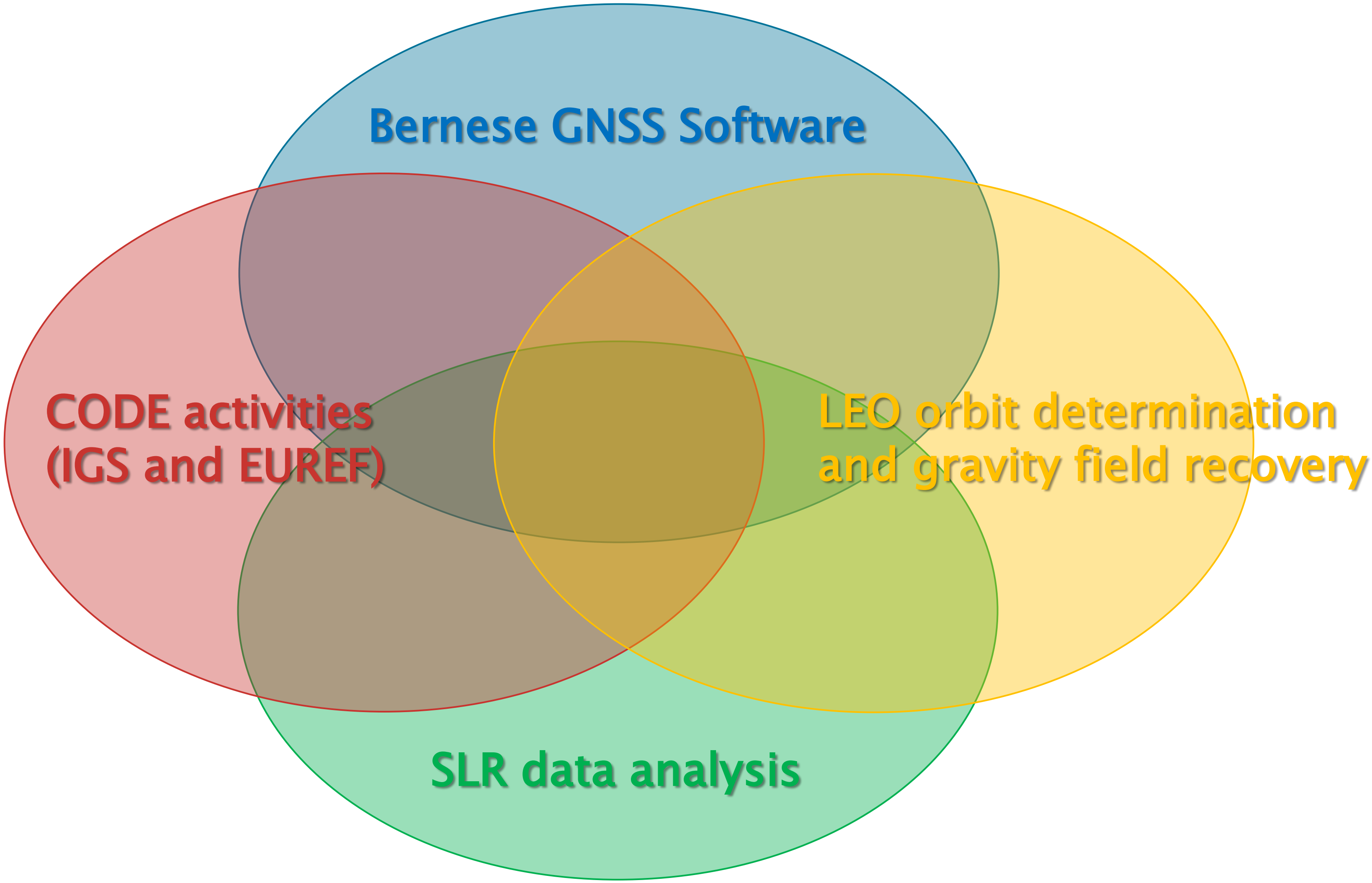
Astronomisches Institut 2015: Aktivitäten und Projekte

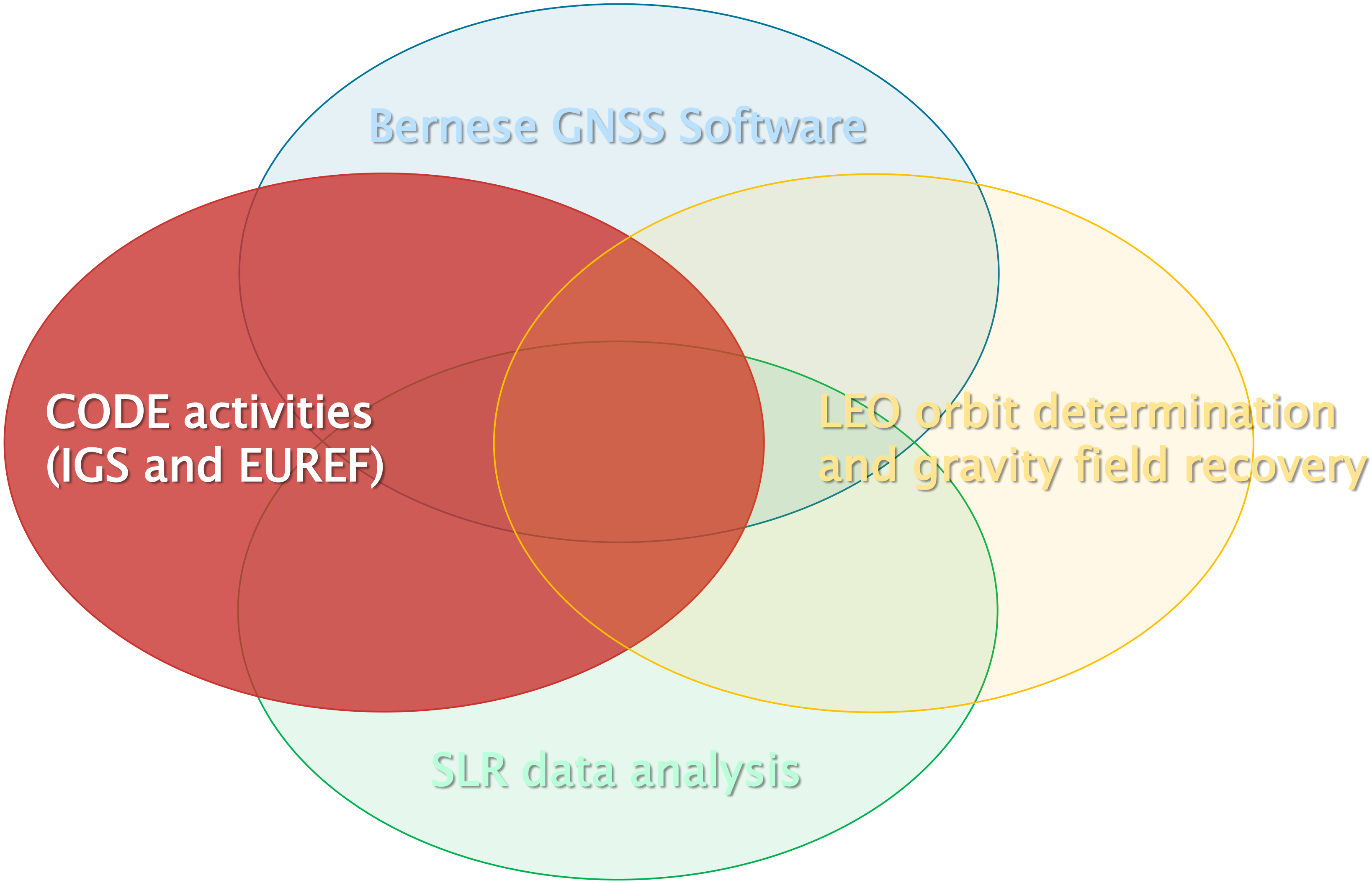
A. Jäggi, R. Dach, T. Schildknecht

Astronomisches Institut

Satellite Geodesy Research Group



Satellite Geodesy Research Group



Updates from the CODE analysis center

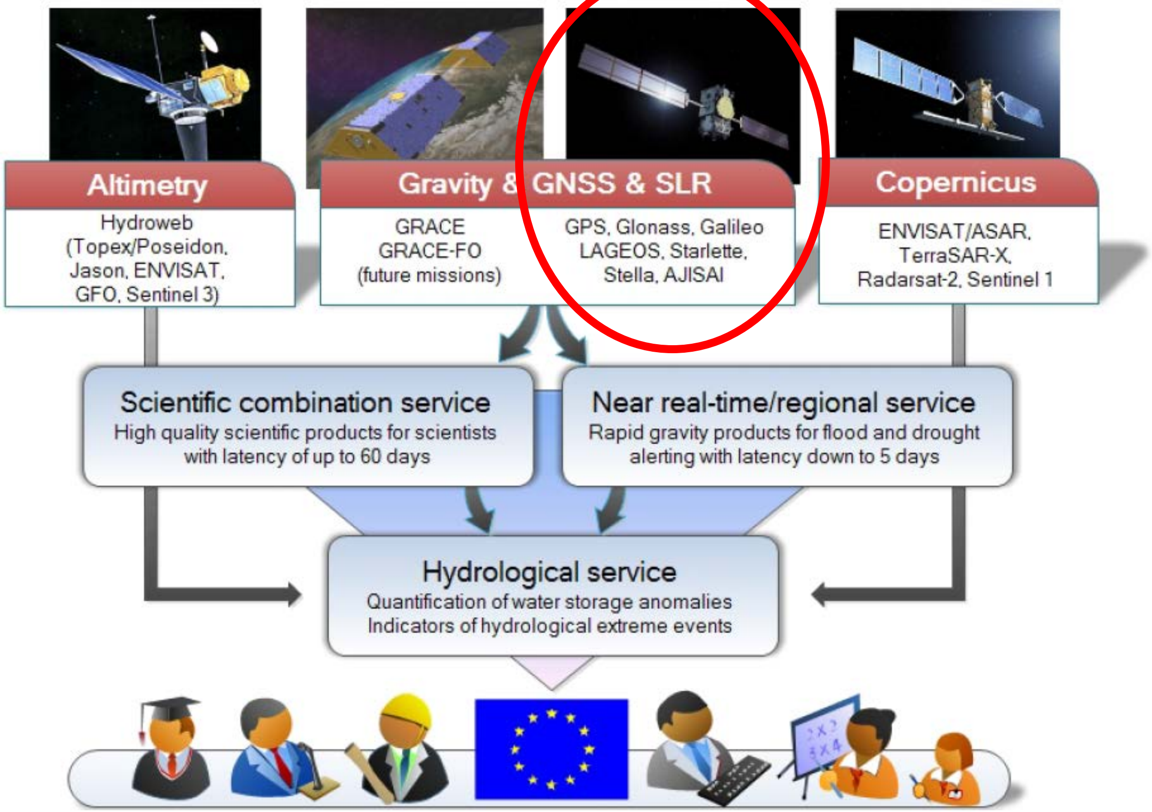
News from the CODE analysis center

- Fix interpolation bug for VMF1 coefficients (Feb.15)
- Prepared to include also RINEX3 files (with long filenames) into the processing.
- XML statistics on the content of RINEX files.
- (many other technical details)...
- Since Summer 2015 the CODE rapid clock product includes GPS and GLONASS clock corrections.

GNSS reprocessing with the new empirical CODE orbit model in the frame of the H2020 project EGSIEM

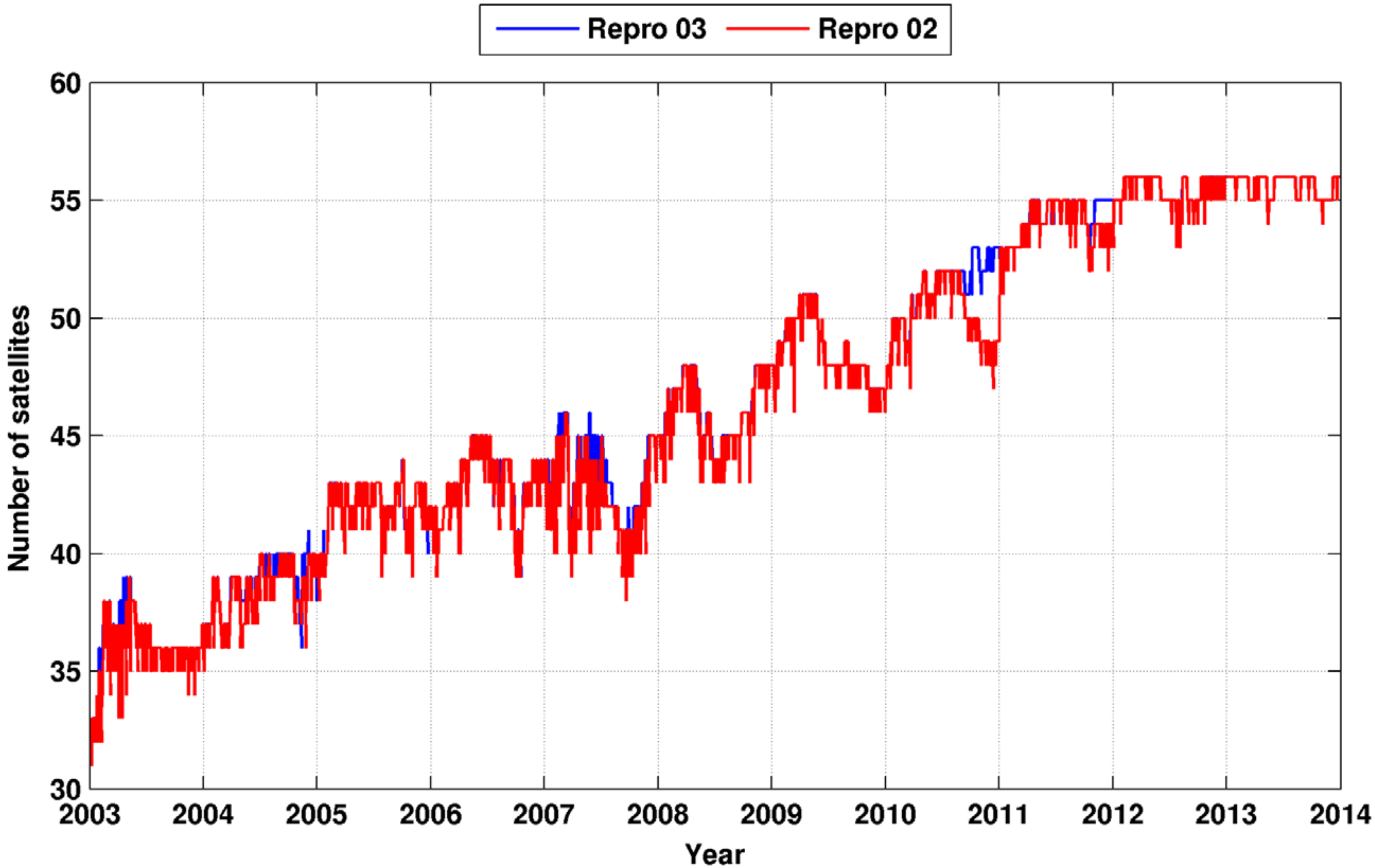
EGSIEM project overview

- **Three dedicated services shall be established**

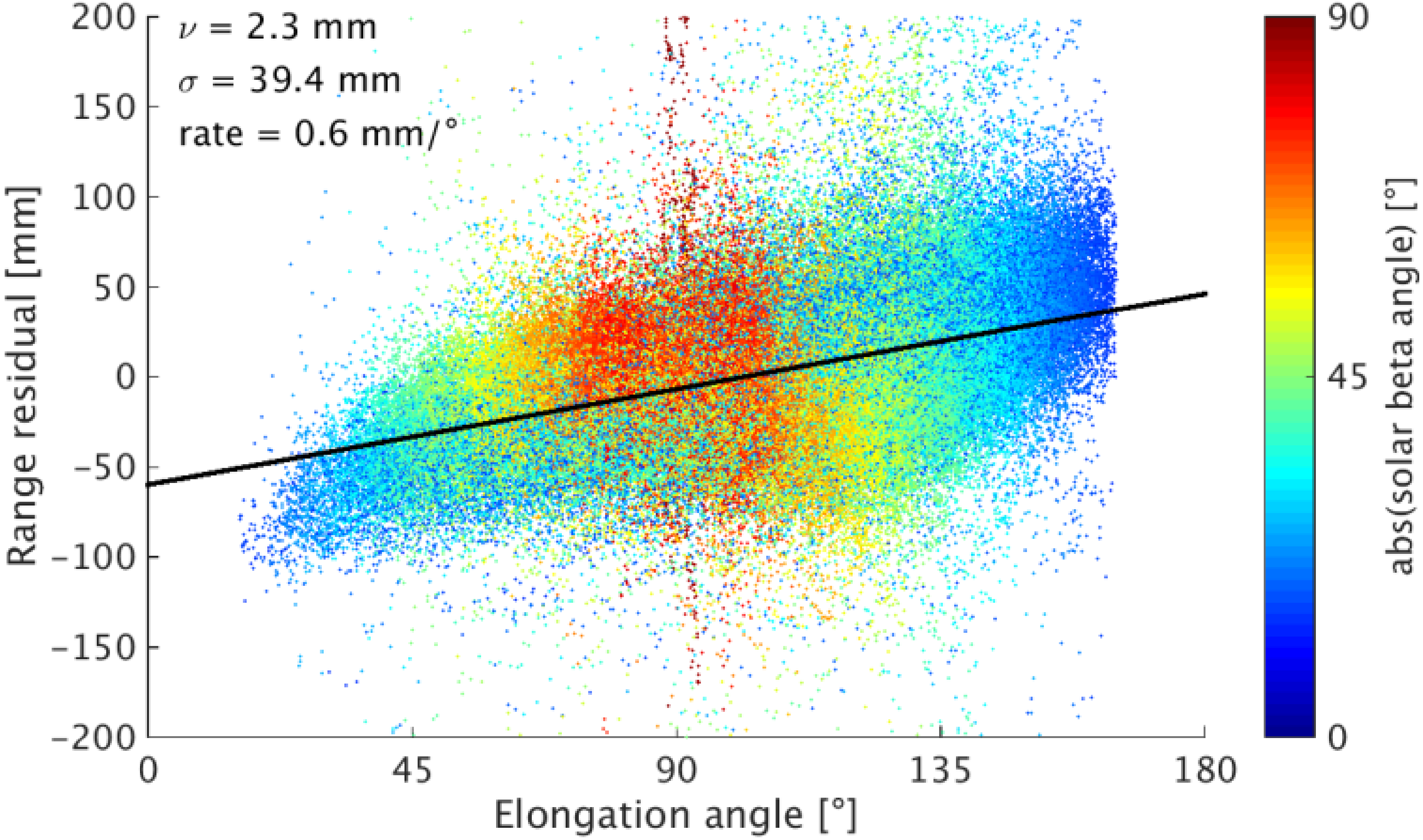


Services will be tailored to the needs of governments, scientists, decision makers, stakeholders and engineers. Special visualisation tools will be used to inform, update, and attract also the large public.

Contains more satellites

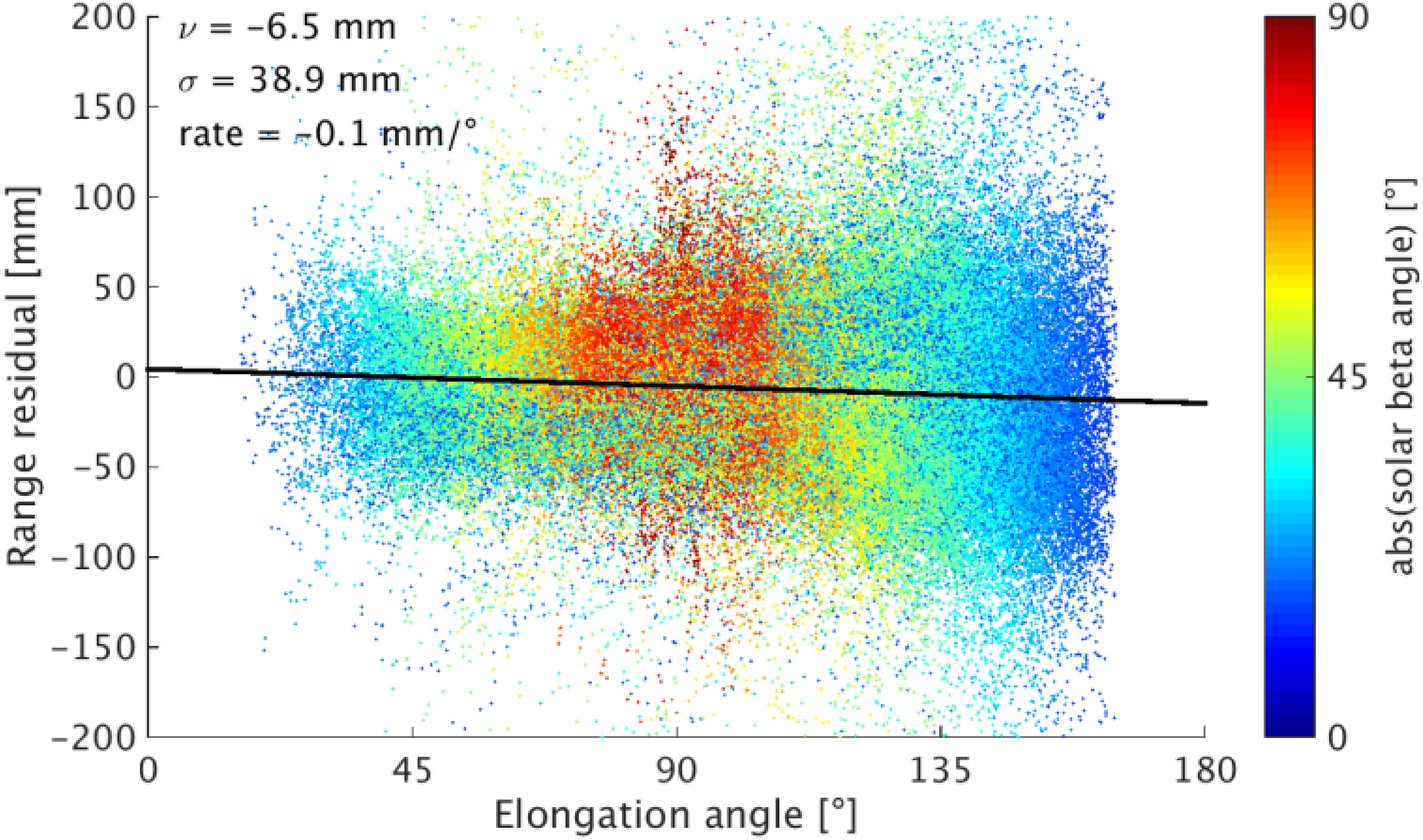


SLR Validation



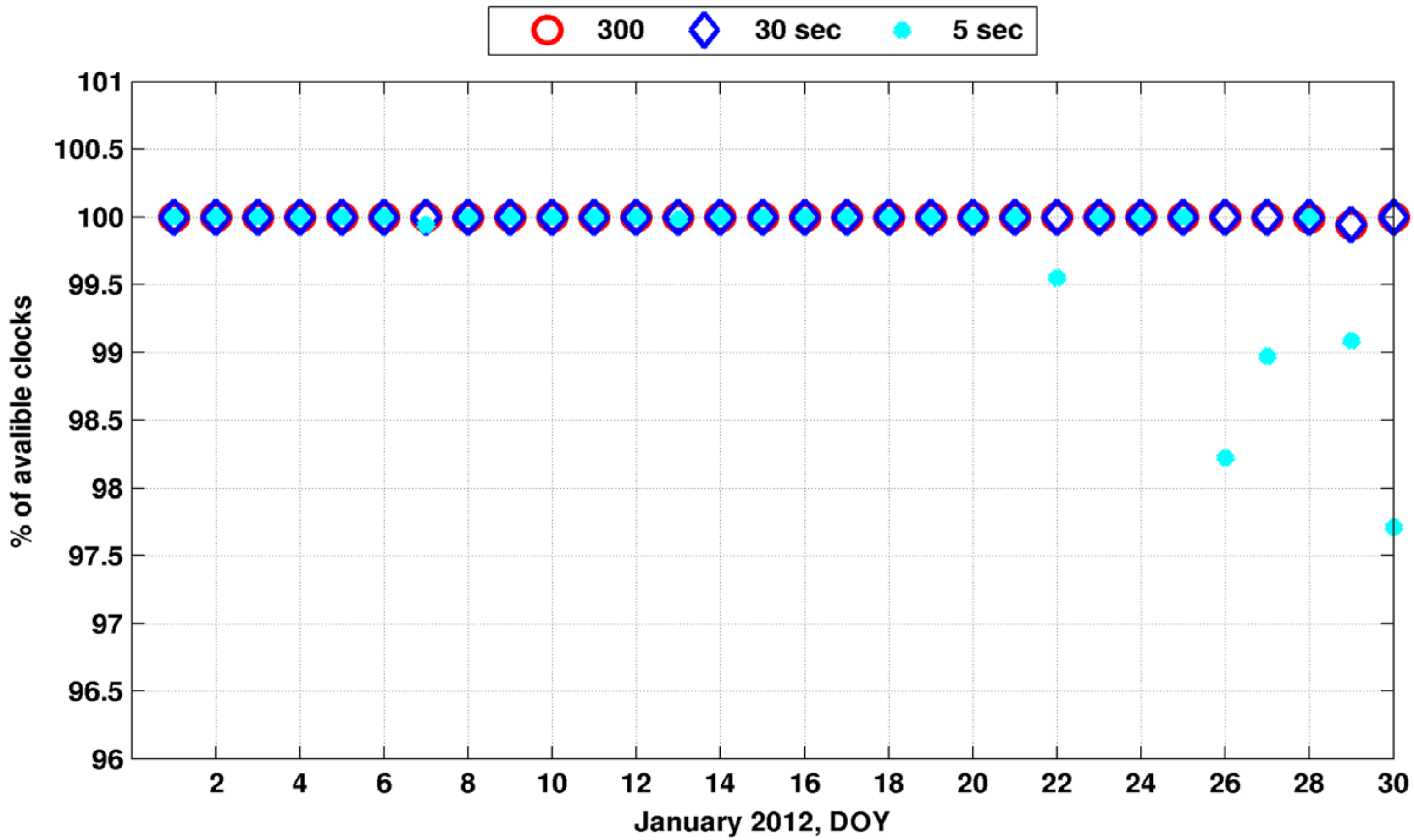
SLR residuals w.r.t. 1-day GLONASS-M orbits between 2003 and 2014 using the old ECOM. Mean value (ν), standard deviation (σ), and the rate of the linear trend per degree of elongation angle are computed w.r.t. all residuals whose absolute value is smaller than 150mm. Furthermore, all residuals having an absolute beta angle smaller than 15° have been not taken into account due to uncontrolled attitude during eclipses.

SLR validation

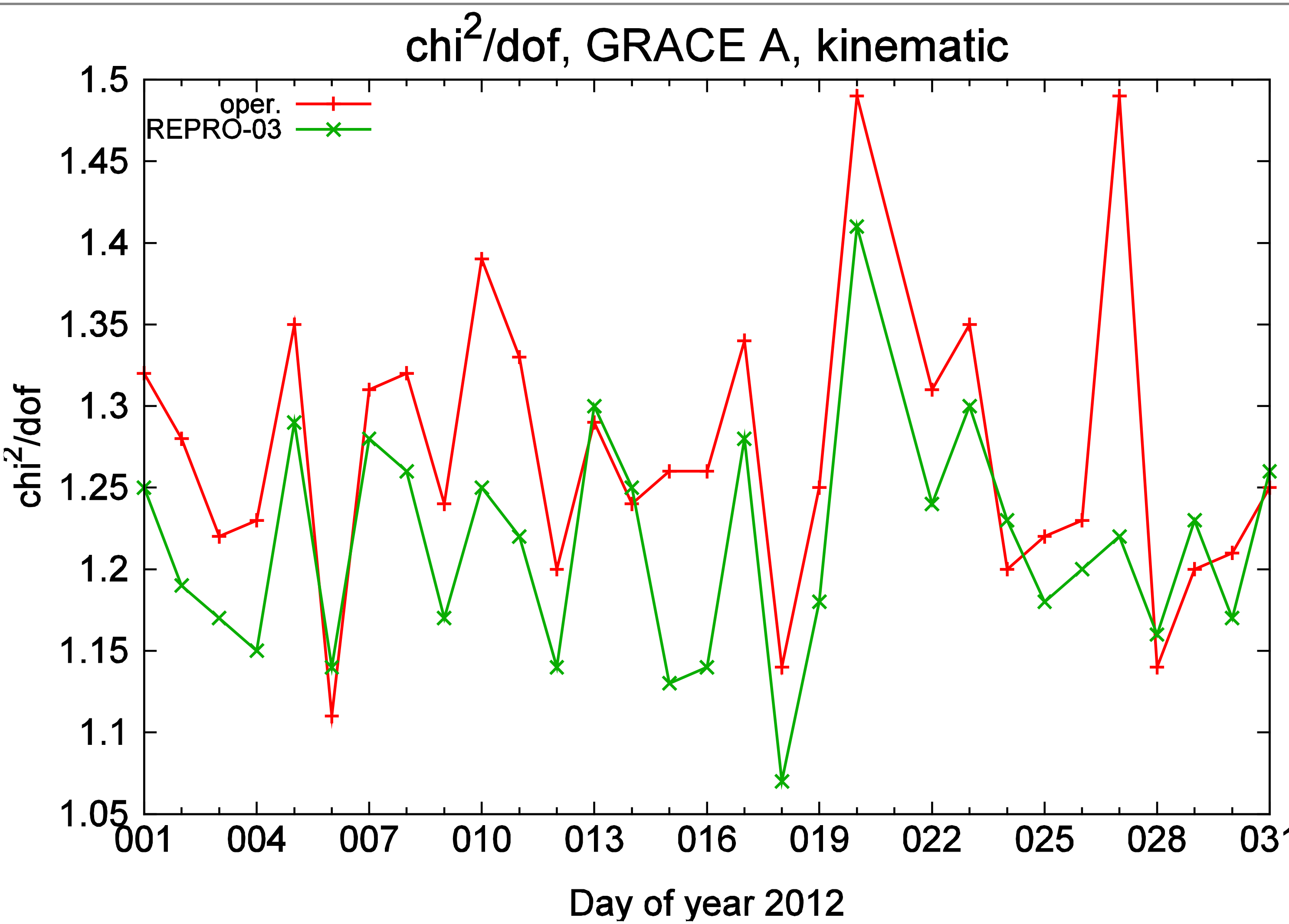


SLR residuals w.r.t. 1-day GLONASS-M orbits between 2003 and 2014 using the new ECOM. Mean value (ν), standard deviation (σ), and the rate of the linear trend per degree of elongation angle are computed w.r.t. all residuals whose absolute value is smaller than 150mm. Furthermore, all residuals having an absolute beta angle smaller than 15° have been not taken into account due to uncontrolled attitude during eclipses.

Completeness of clock corrections



GRACE Orbit Determination



χ^2 value of the kinematic orbit determination of GRACE-A for January 2012 when using the operational orbits and clocks and the current reprocessing products, respectively.

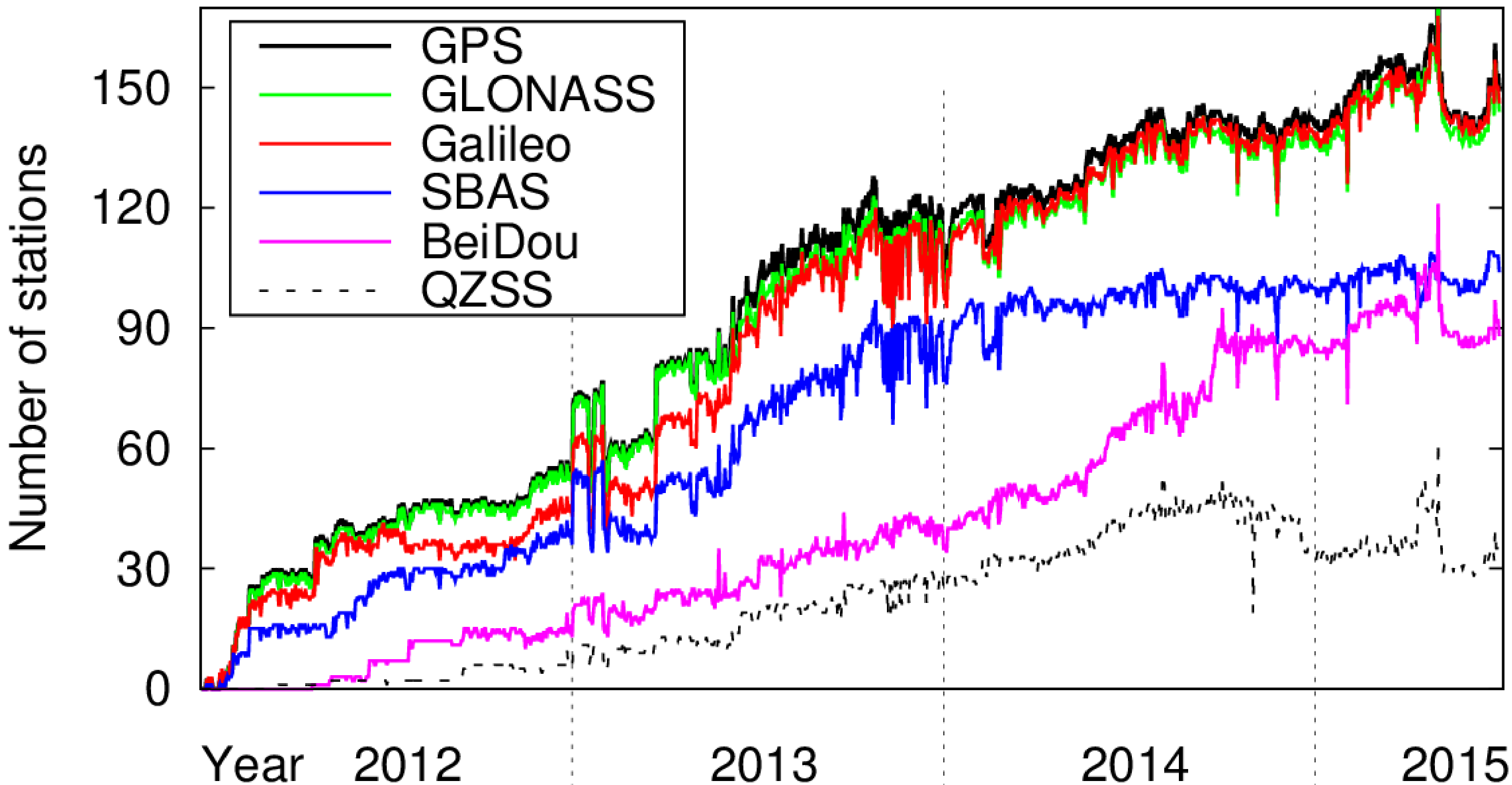
CODE contribution to IGS MGEX

CODE MGEX changes

- Revised station selection; limitation to 130 sites
- GLONASS clocks added
- New GNSS added: BeiDou (MEO, IGSO) and QZSS => orbits and clocks for 5 GNSS provided
- New ECOM SRP model considered since early 2015
- Reprocessing of data from 2014 with old and new ECOM
- Change to routine-like processing and weekly submission with about 2 weeks latency

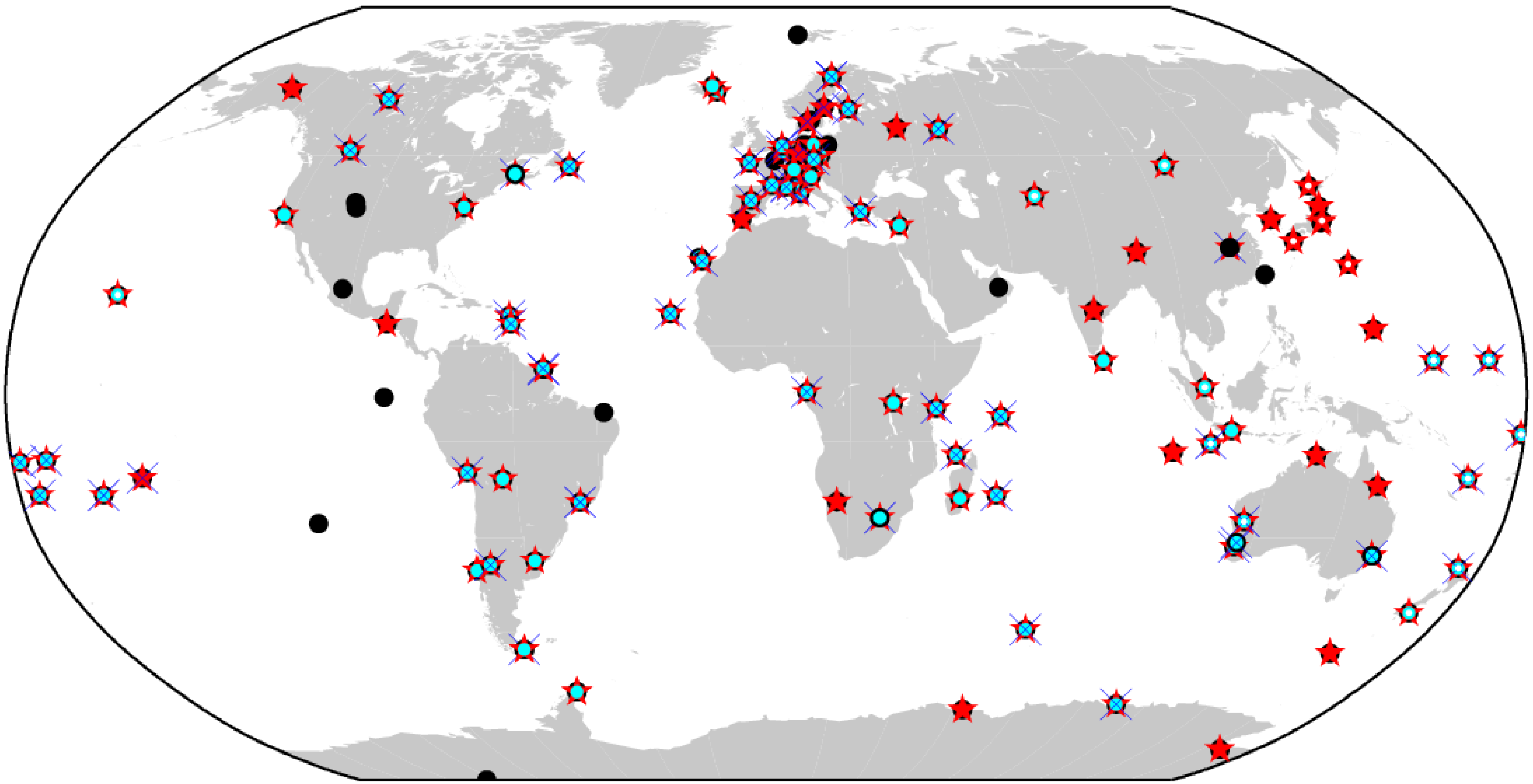
CODE MGEX data monitoring

Satellite systems being monitored (RINEX3 files):



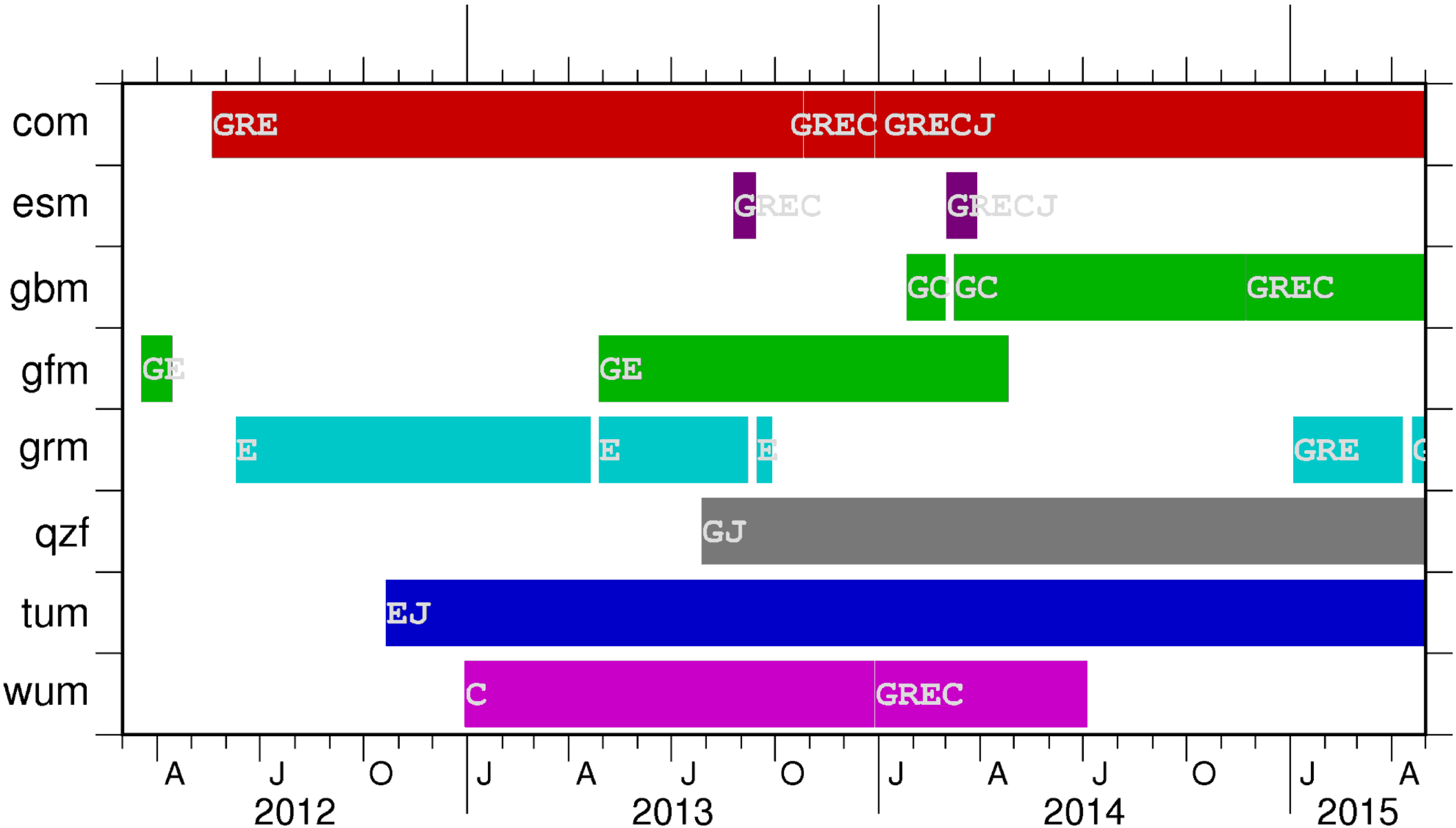
MGEX station distribution

Station distribution for orbit solution (DOY 030/2015)



● GPS ★ GLONASS ● Galileo X BeiDou o QZSS

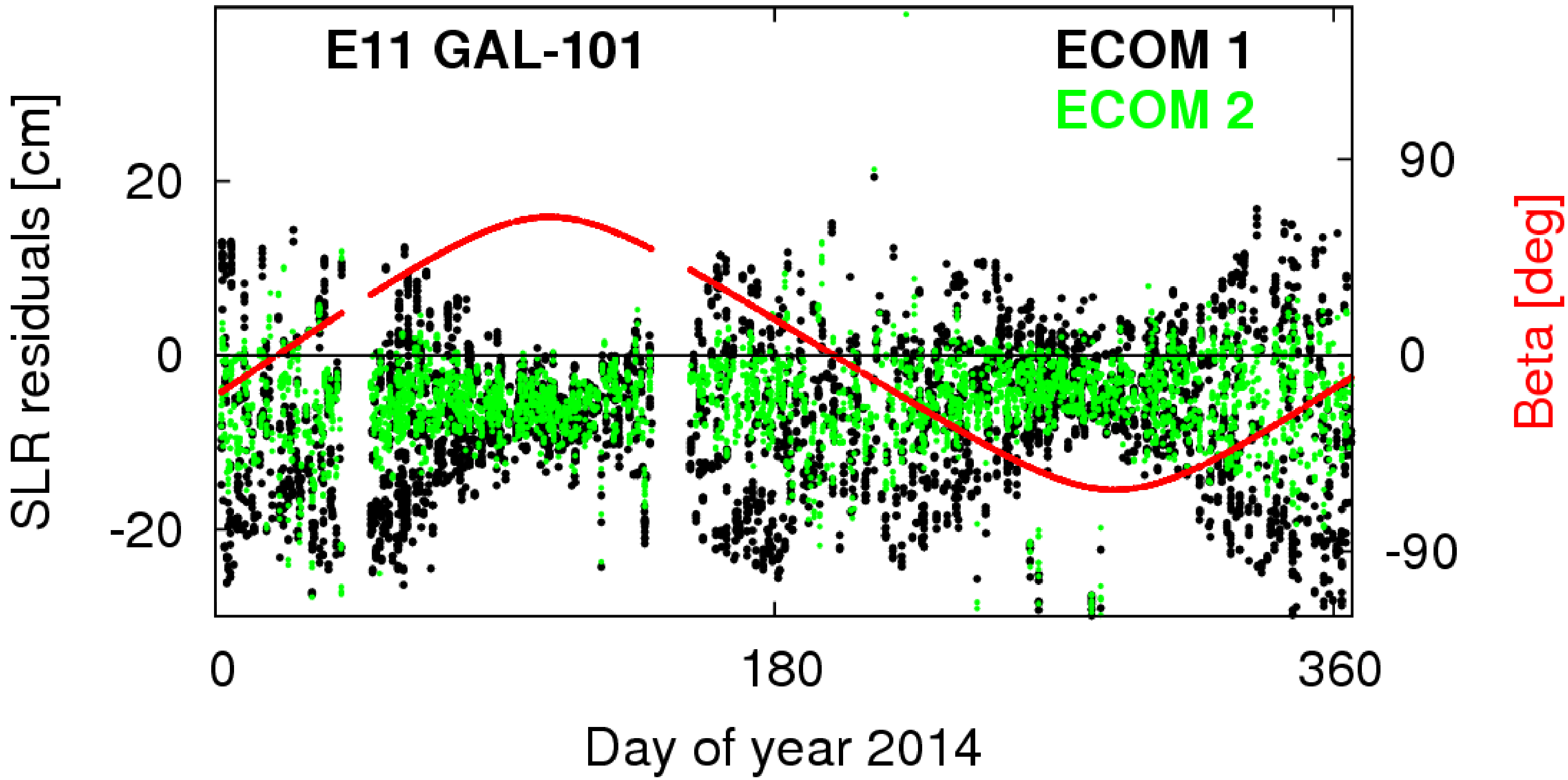
MGEX products availability



Status: 01-May-2015

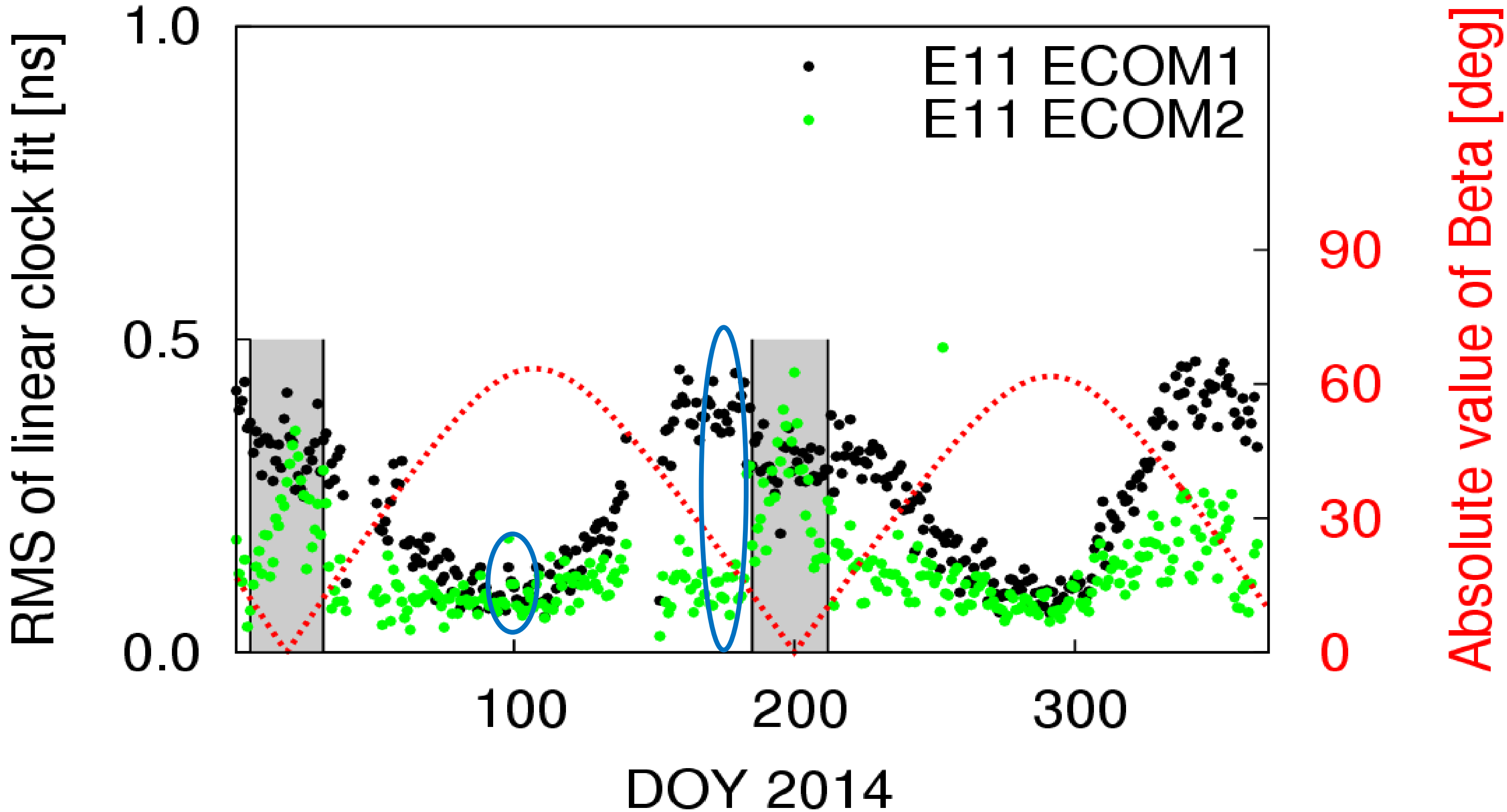
Satellite system IDs according to the content of the precise orbit files at ftp://cddis.gsfc.nasa.gov/pub/gps/products/mgex/

Impact of new ECOM on Galileo orbits



=> Significant reduction of size and dependency of SLR residuals on the Beta-angle (elevation of the Sun above the orbital plane)

Impact of new ECOM on Galileo clock corrections



=> Significant reduction of Beta angle dependency

=> Pronounced signal remains during eclipse season or close-by (=> impact of mis-modelled attitude?)

AIUB contribution to TGVF/OVF

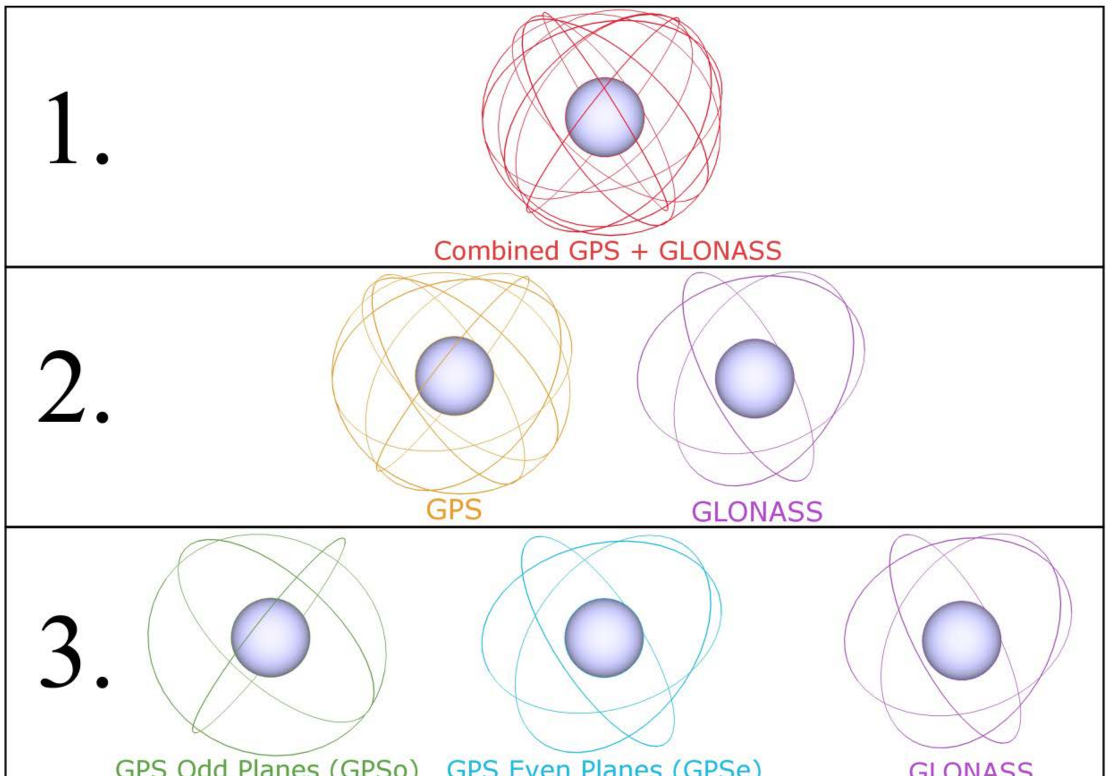
TGVF-OVF fact sheet

- AIUB is part of the GGSP consortium – provider of the TGVF-OVF and the GTRF (Galileo Terrestrial Reference Frame)
- AIUB contribution includes PF3, PF3-TROPO, and PF3-IONO facilities
- RAPID (latency 1 day) and FINAL (latency less than 2 weeks) product lines for SINEX, orbit, clock, troposphere, ionosphere, bias products and SLR validations
- Consideration of GPS and Galileo (including FOC)
- Several updates of station network (ESA, MGEX, and IGS stations) and GTRF within the last year

GNSS-specific characteristics in Earth rotation and geocenter parameter series

Efficient and consistent solution

1. Set up general normal equations with:
   - Plane specific ERP
   - Satellite specific GCC
2. Solve the daily NEQ three times:

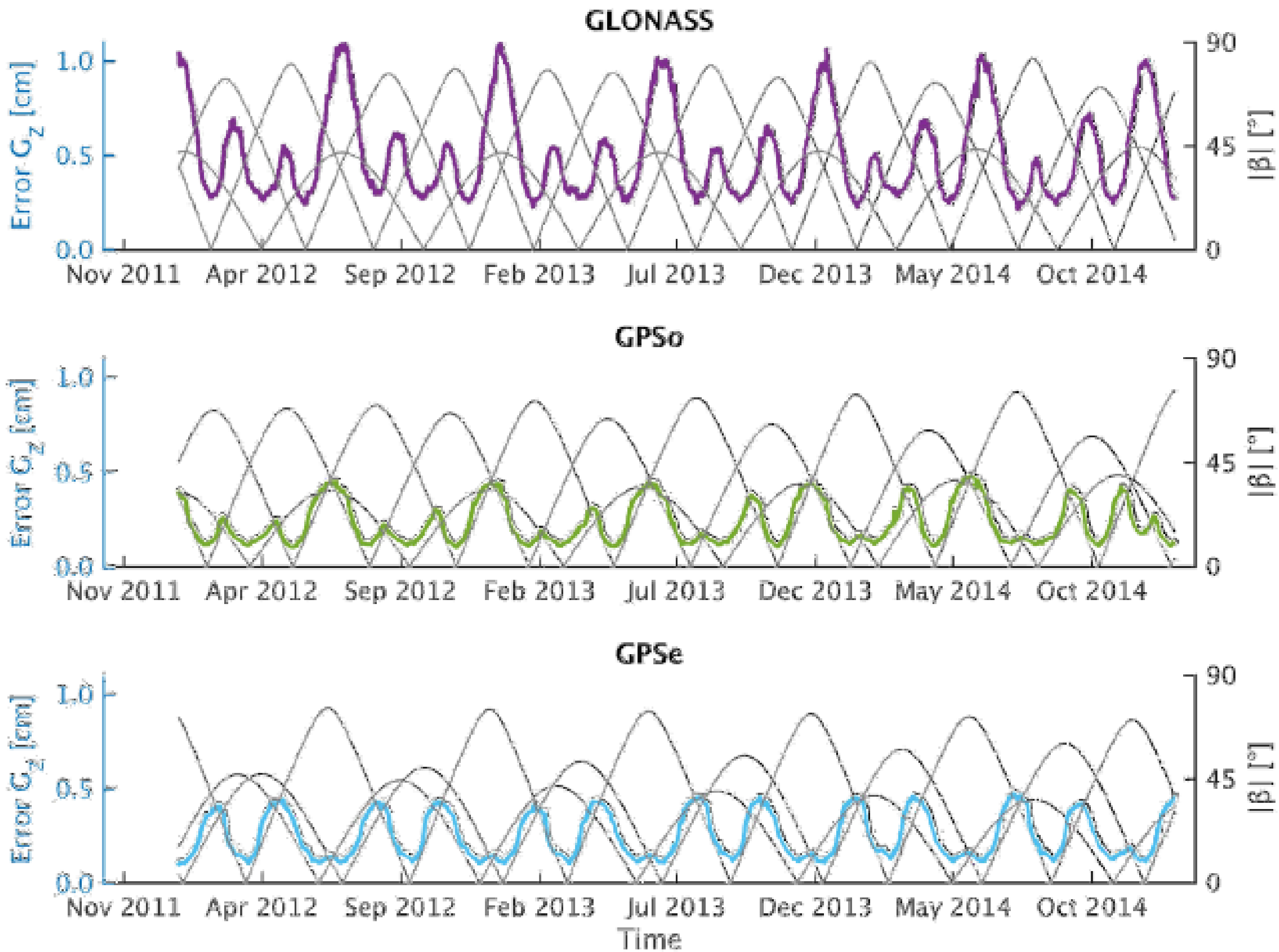


Usual multi-GNSS solution

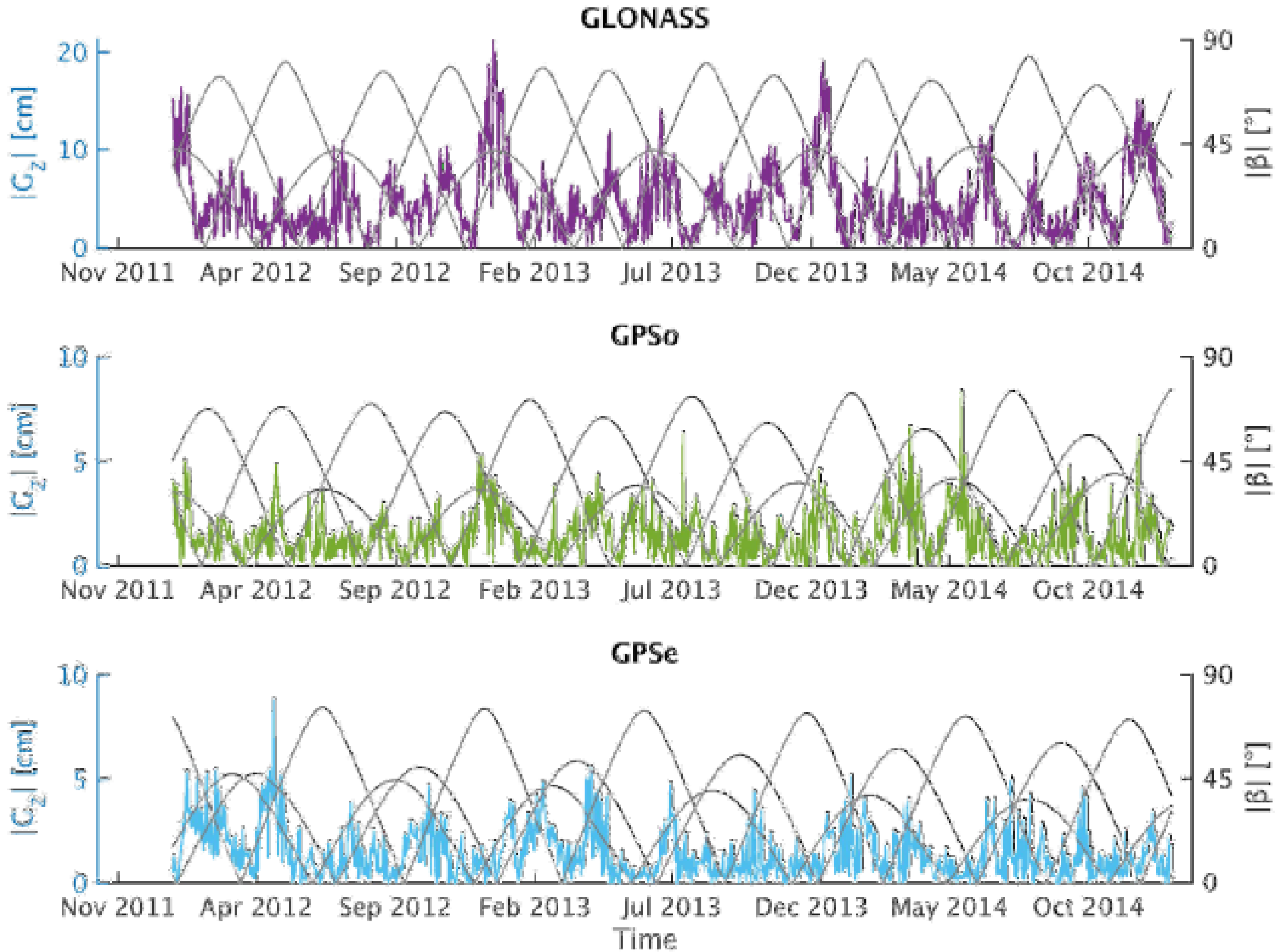
Equivalent to GPS-only, GLONASS-only solution

Special solutions

Geocenter solutions



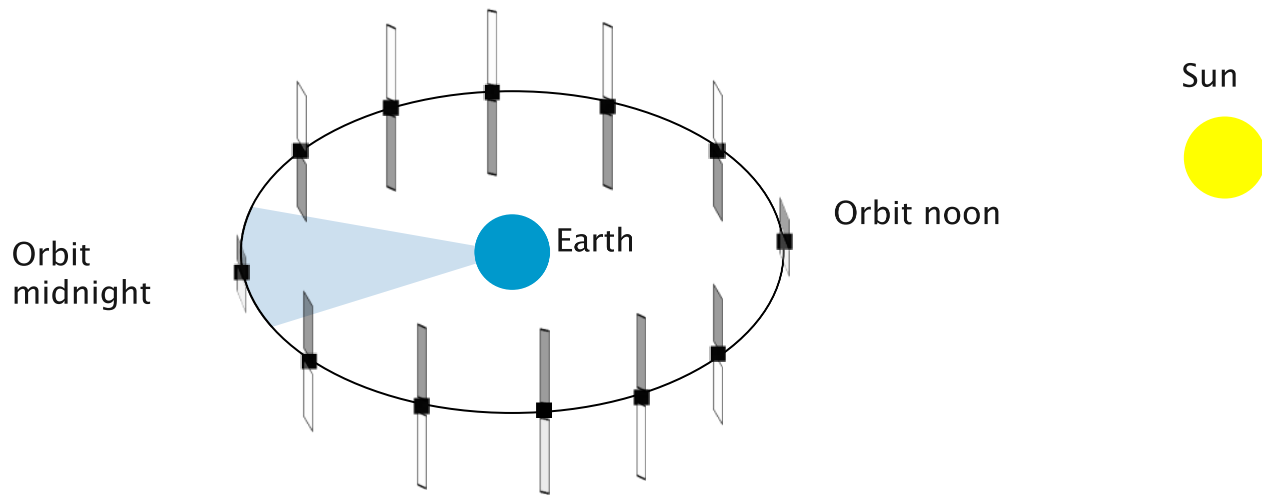
Geocenter solutions (formal errors)



Attitude Modelling

GNSS Attitude Modelling in BSW

- GNSS satellites operate in ‘yaw steering’ mode:
  - Antenna array points towards the Earth
  - Solar panels points towards the Sun



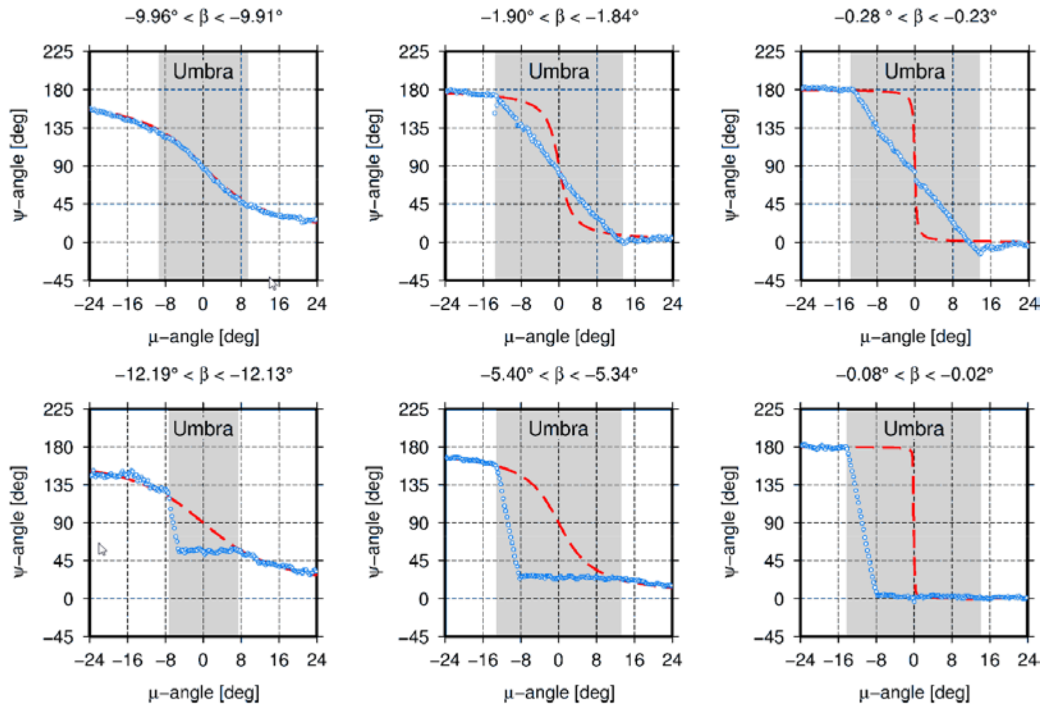
- Nominal yaw attitude is not always reachable
  - Shadow crossing (for some satellite types)
  - Limited hardware yaw rates (at orbit noon and orbit midnight)

GNSS Attitude Modelling in BSW

- **Actual satellite attitude is different from nominal**

GPS Block IIF

GLONASS-M



Nominal yaw angle

Estimated yaw angle

Dilssner et al. (2011)

- **Imperfections in SRP modelling**
- **Degradation of the estimated satellite orbits, clocks, station coordinates, tropospheric estimates, etc.**

GNSS Attitude Modelling in BSW

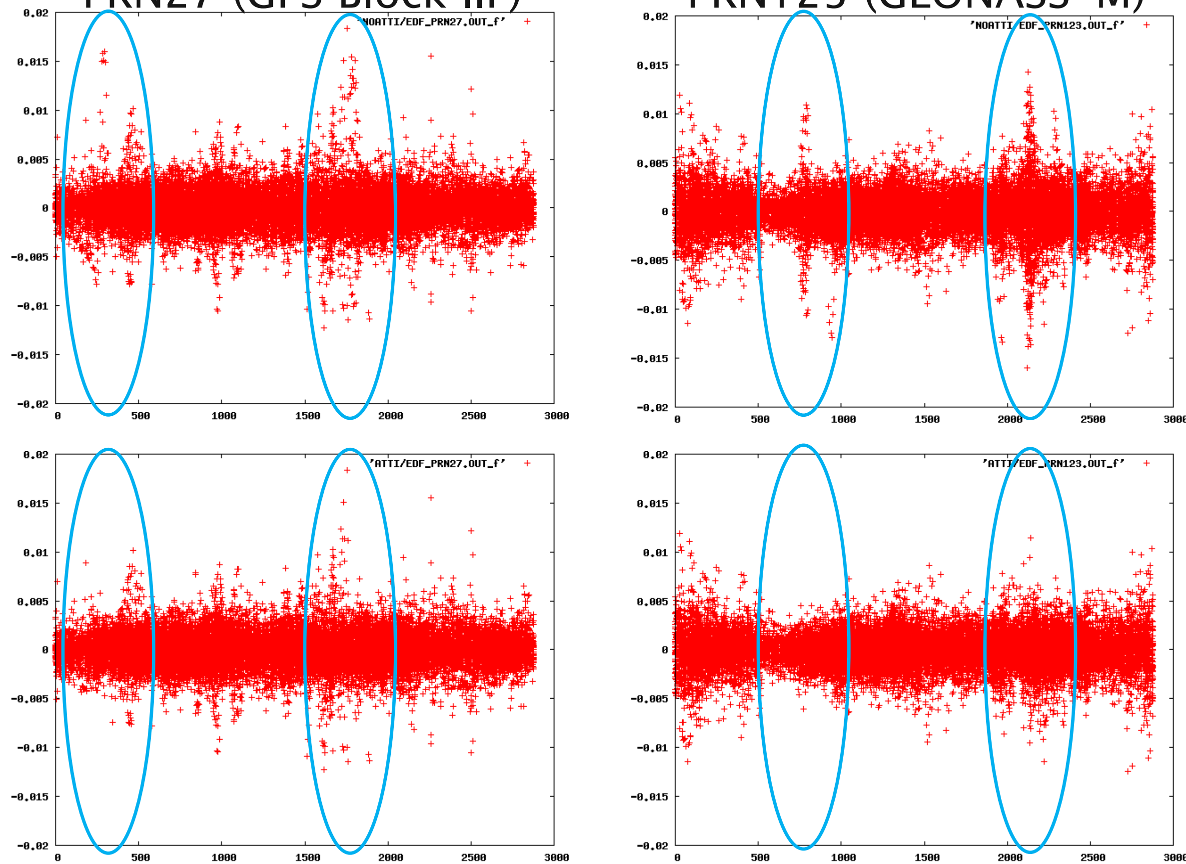
- **Improved satellite attitude modelling for GPS (Kouba, 2009; Dilssner, 2010) and GLONASS (Dilssner et al., 2011)**

Example:
2 January 2015

PRN27 (GPS Block IIF) | PRN123 (GLONASS-M)

Nominal attitude modelling

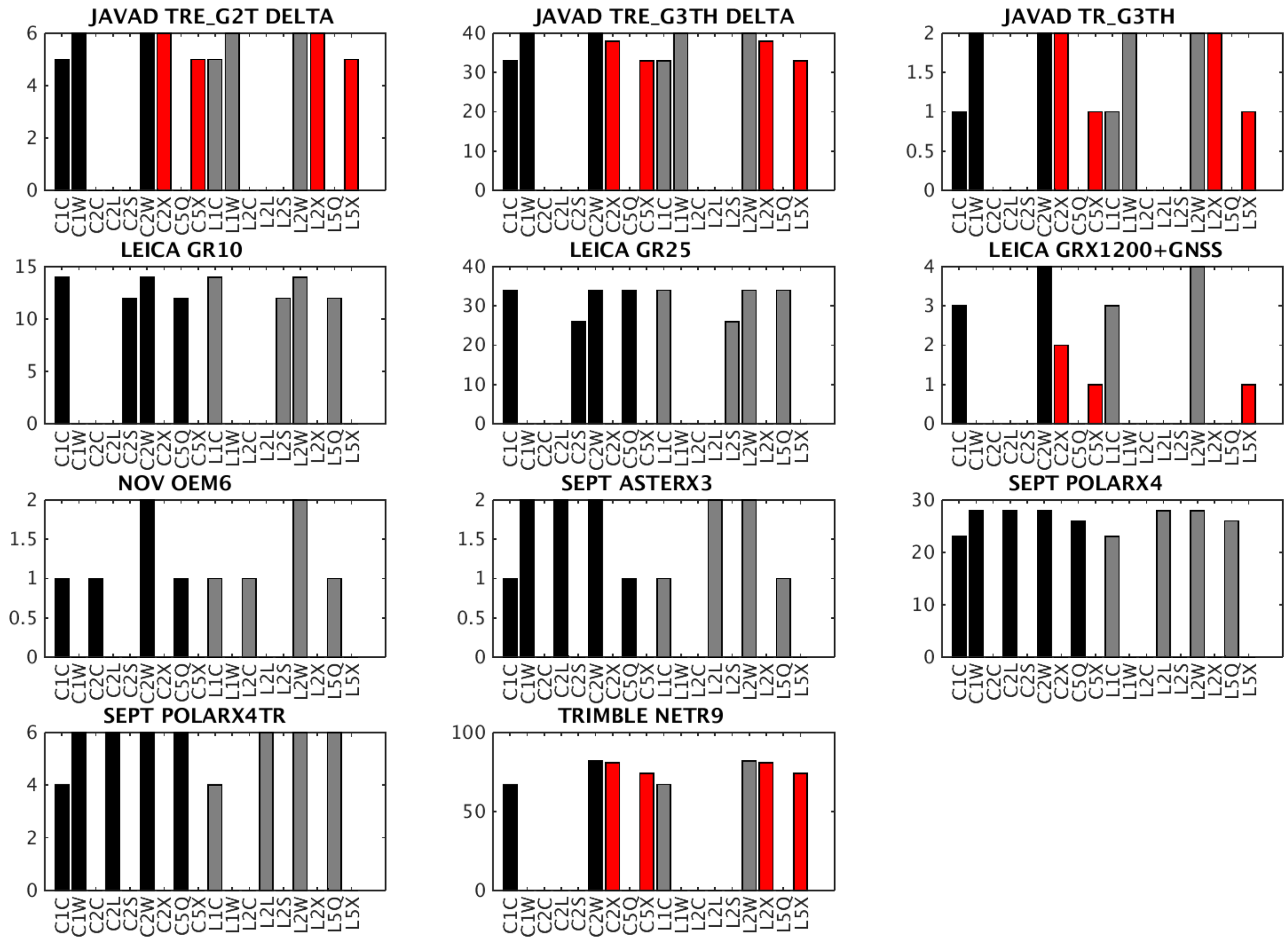
Improved attitude modelling



Advancing the bias handling in the Bernese GNSS Software

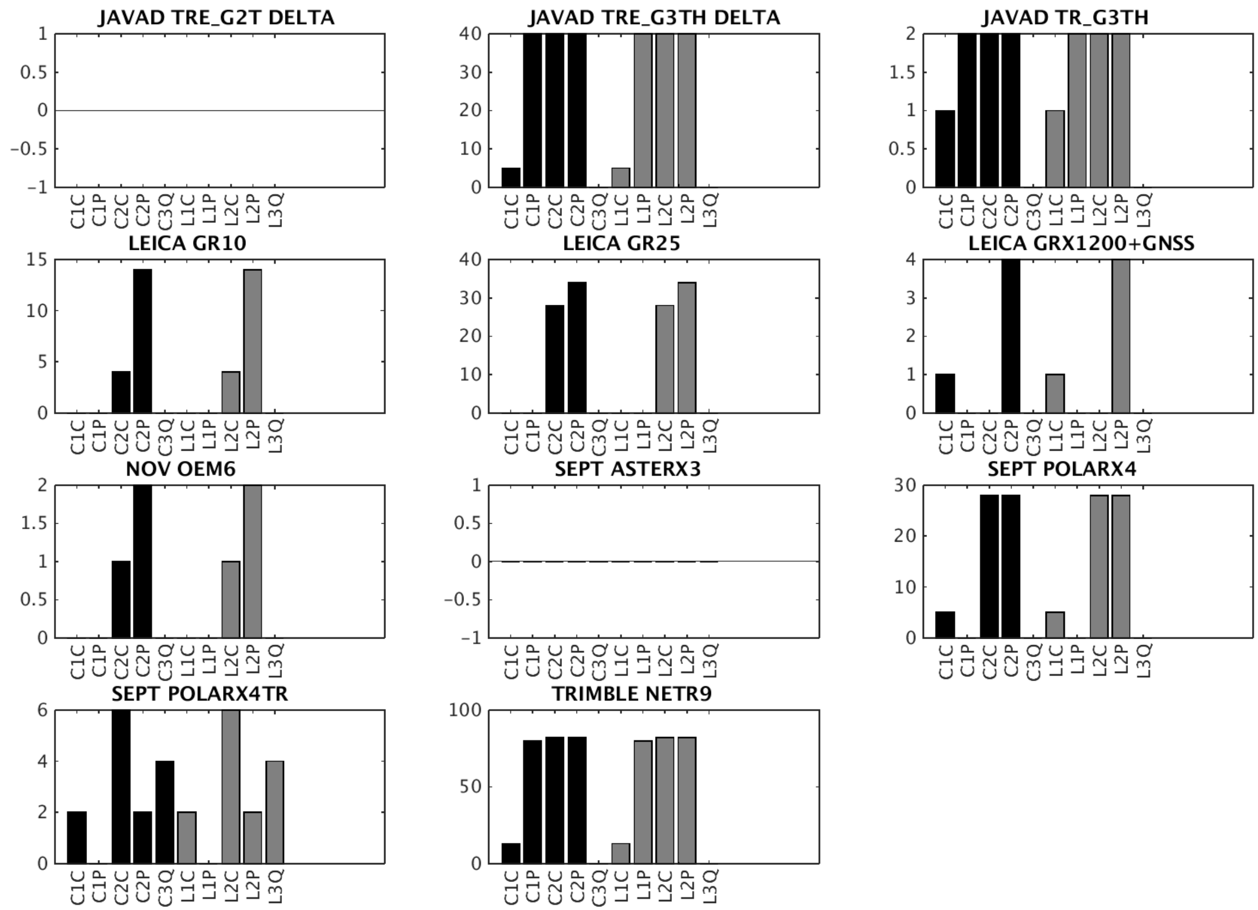
IGS RINEX3 Observation Types

GPS: Day 244 2015

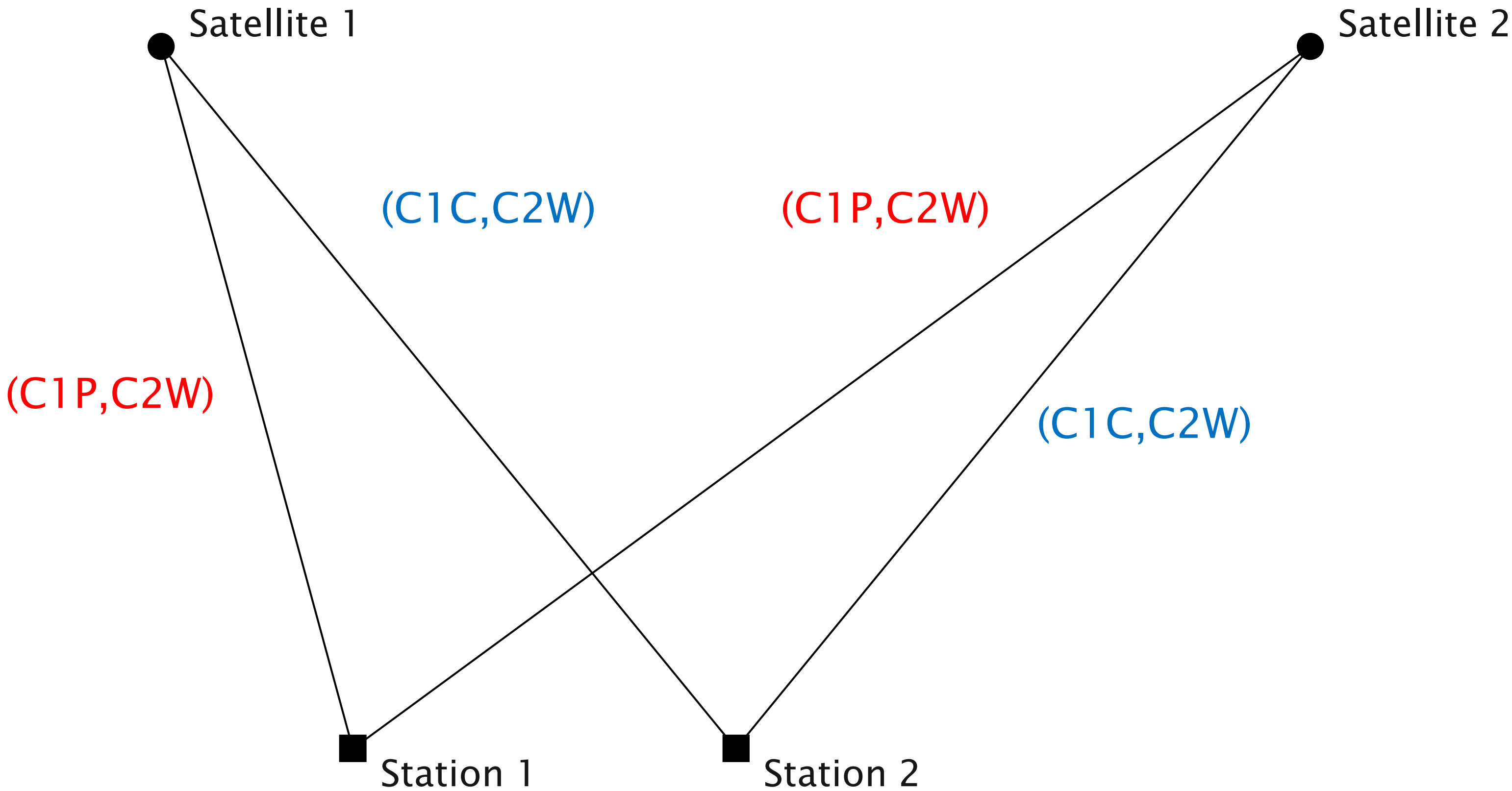


IGS RINEX3 Observation Types

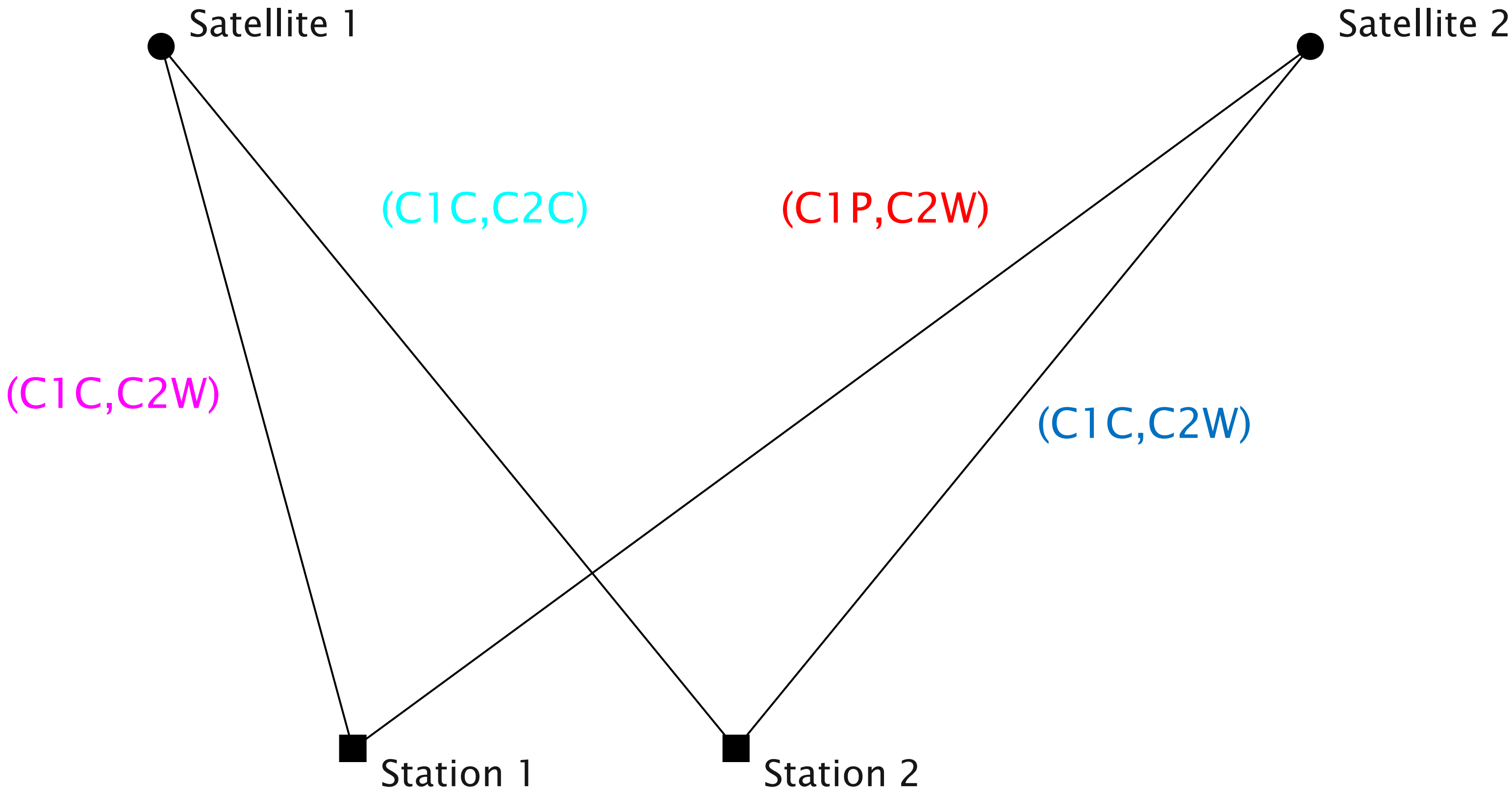
GLONASS: Day 244 2015



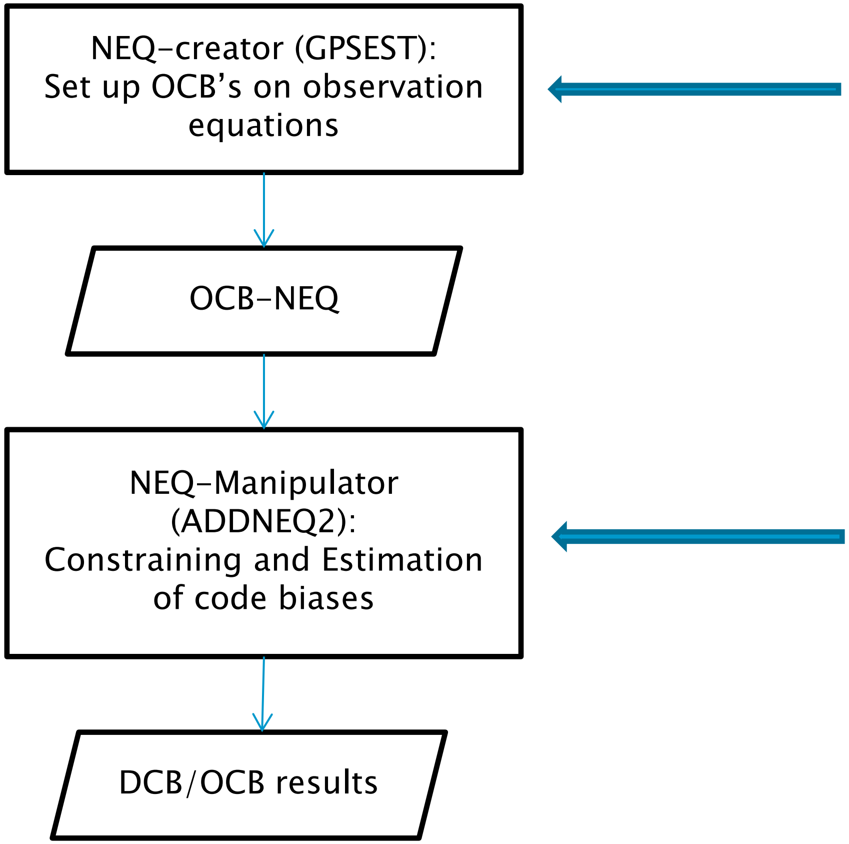
Mixture of different code observables (and biases!) is crucial for code-based widelane ambiguity resolution (1/2)



Mixture of different code observables (and biases!) is crucial for code-based widelane ambiguity resolution (2/2)



OCB Estimation Workflow based on NEQs



- Code biases setup as "Obervation Code Bias"
- Cross-correlation observations split into individual observables (for satellite only)

- Multiple NEQs
- Reference Observable Selection
- Observable Group consideration
- Datum Definition
- OCB's or DCB estimation feasible

Workshops recently hosted by AIUB

UNIVERSITÄT BERN

EUREF Analysis Centre Workshop

October 14–15, 2015

31 participants

Bernese GNSS Software Tutorial: Multi-GNSS Analysis

R. Dach
and the Bernese GNSS Software development team

Astronomical Institute, University of Bern, Switzerland
Sidlerstrasse 5, CH-3012 Bern

EUREF–Analysis Center Workshop
Bern, 15. October 2015

IGS Workshop on GNSS Biases

November 05-06, 2015

33 participants

IGS Workshop on GNSS Biases

- Follow up event to the 1st workshop in Jan. 2012
- Exchange between industry and academic experts
- Focus on multi-GNSS analysis and the related biases
- Discussion on an international exchange format:

SINEX_BIAS—Solution (Software/technique) INdependent EXchange Format for GNSS Biases Version 1.00

Stefan Schaer

stefan.schaer@aiub.unibe.ch

June 29, 2011 (Draft V0.01)
September 23, 2015 (Update to V1.00)

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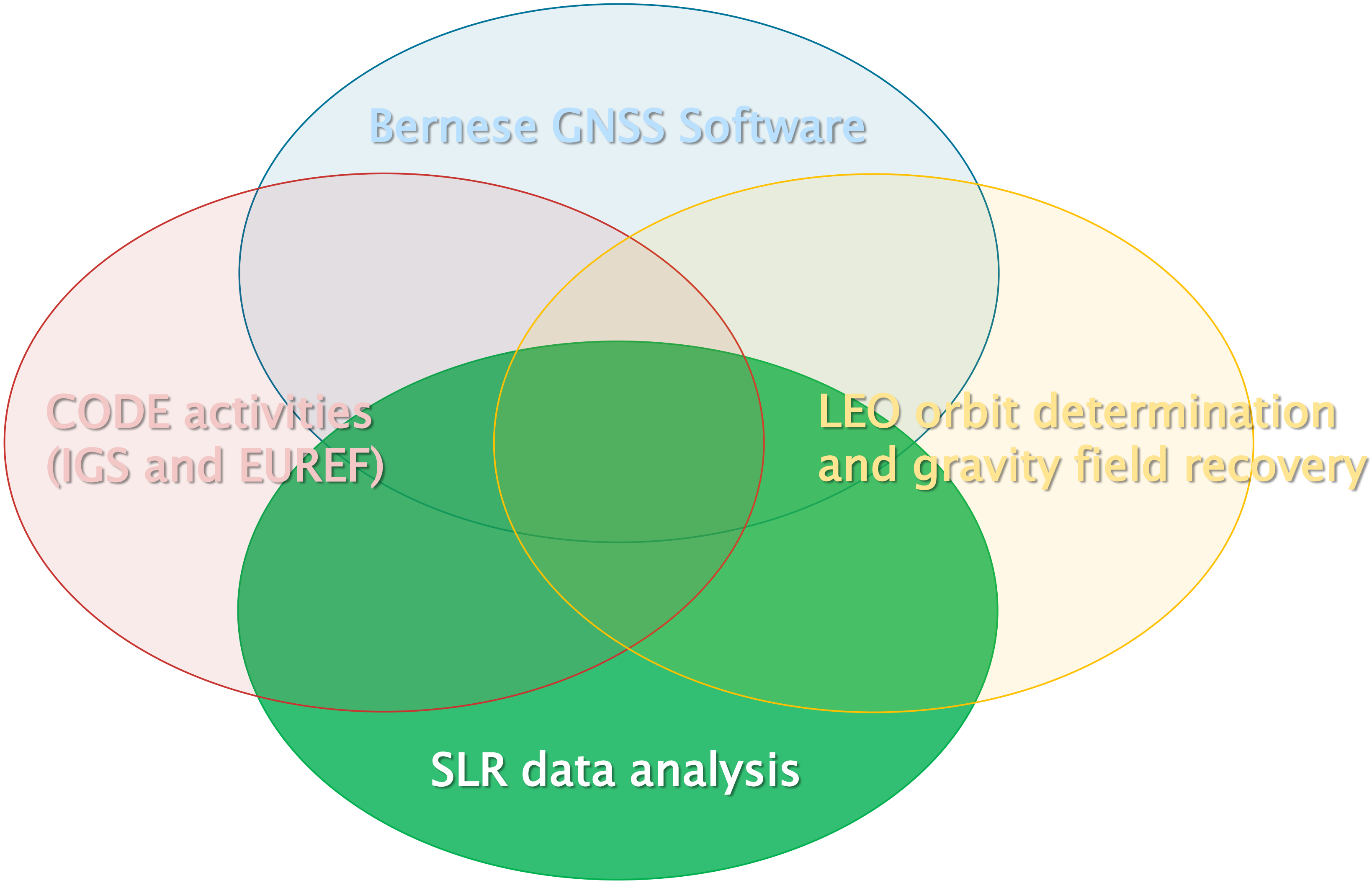
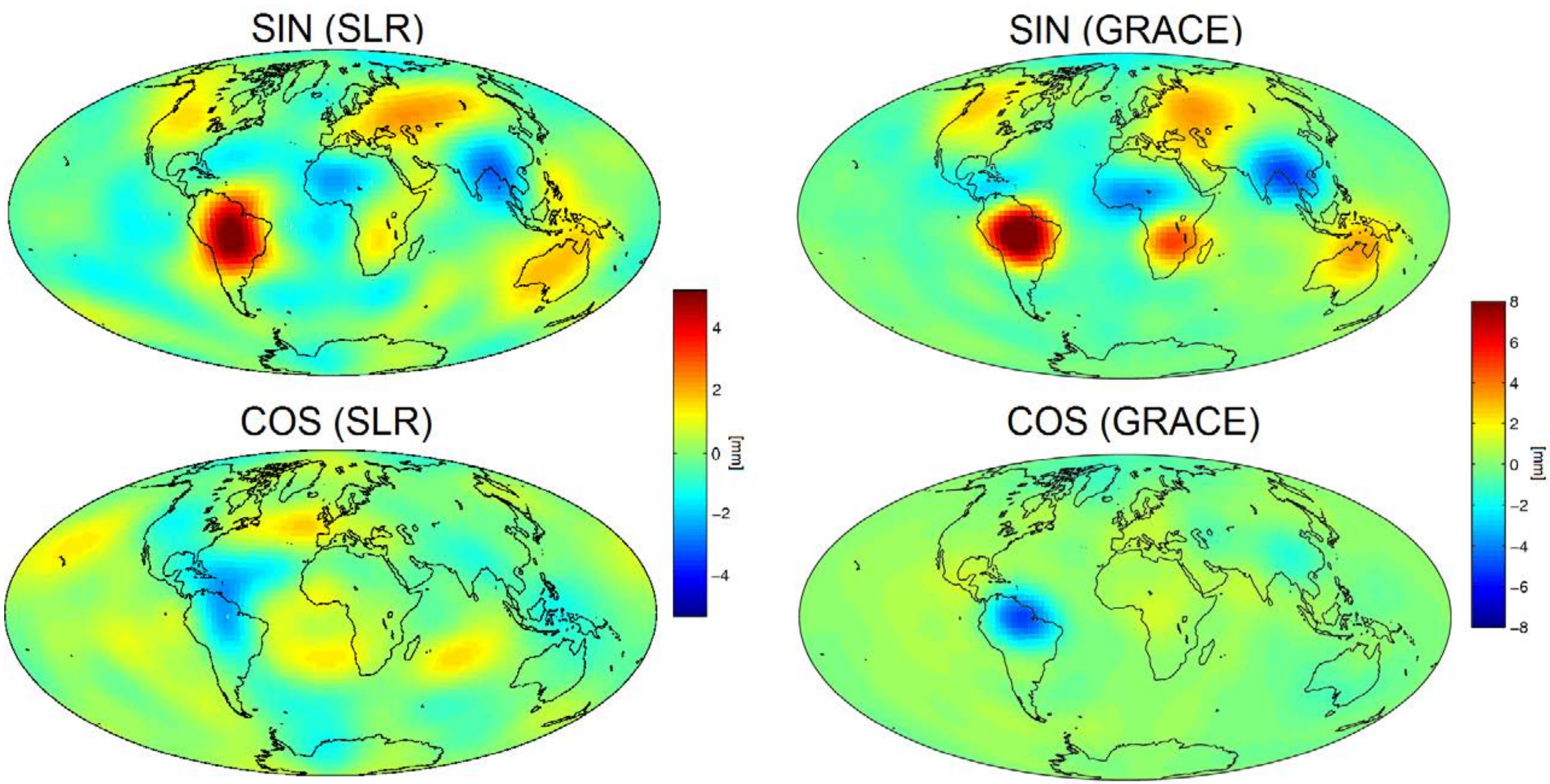


Satellite Laser Ranging (SLR) Solutions

Comparison w.r.t. GRACE K-Band

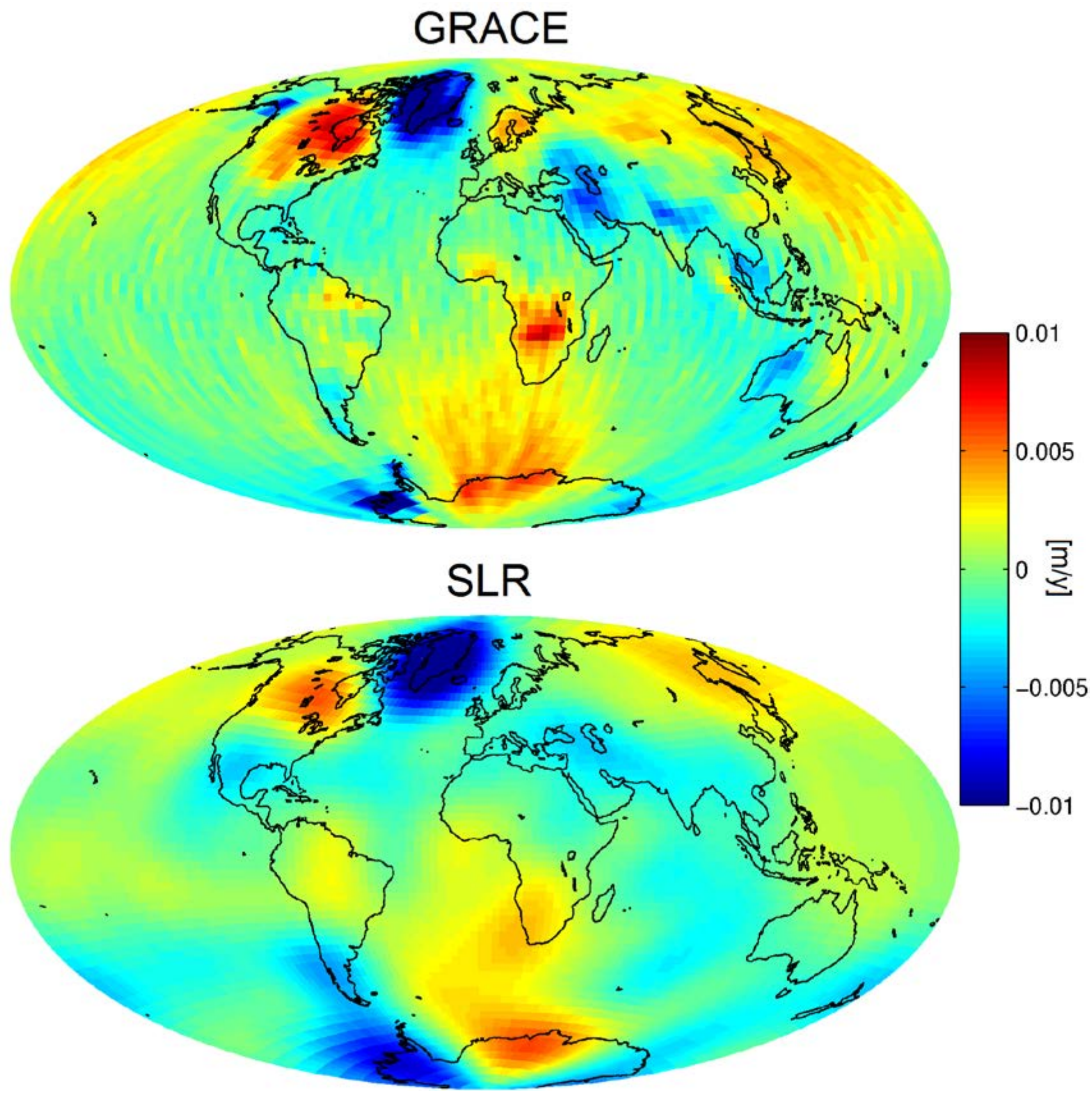


The annual variations of geoid height deformations can be well captured by SLR, however, the SLR-derived amplitudes of annual signal are typically smaller than the GRACE-derived values, because of the limited SLR sensitivity above degree 6.

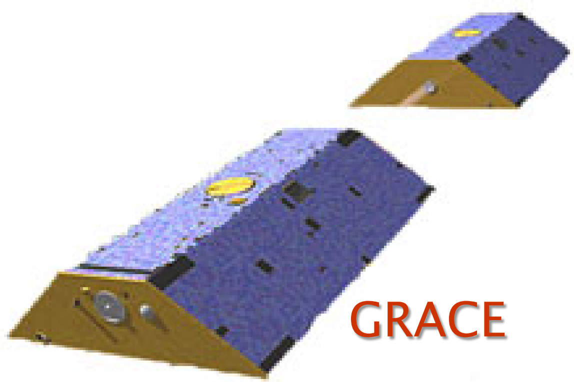
Comparison w.r.t. GRACE K-Band

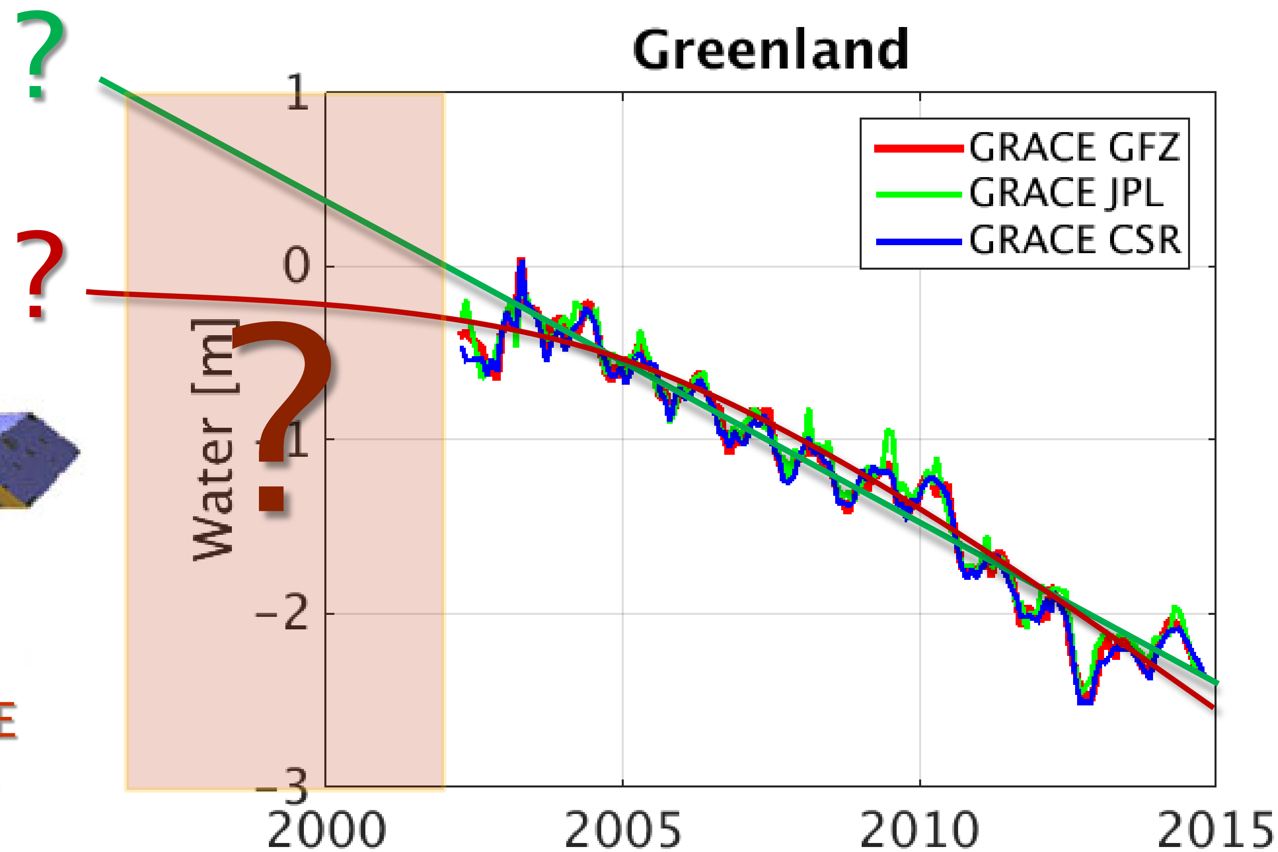
Secular changes of geoid deformations derived from SLR show a very high level of consistency with the GRACE-based results, however, with a lower spatial resolution.

The ice mass loss in Greenland, West Antarctica and Patagonia is well captured in the SLR solutions.



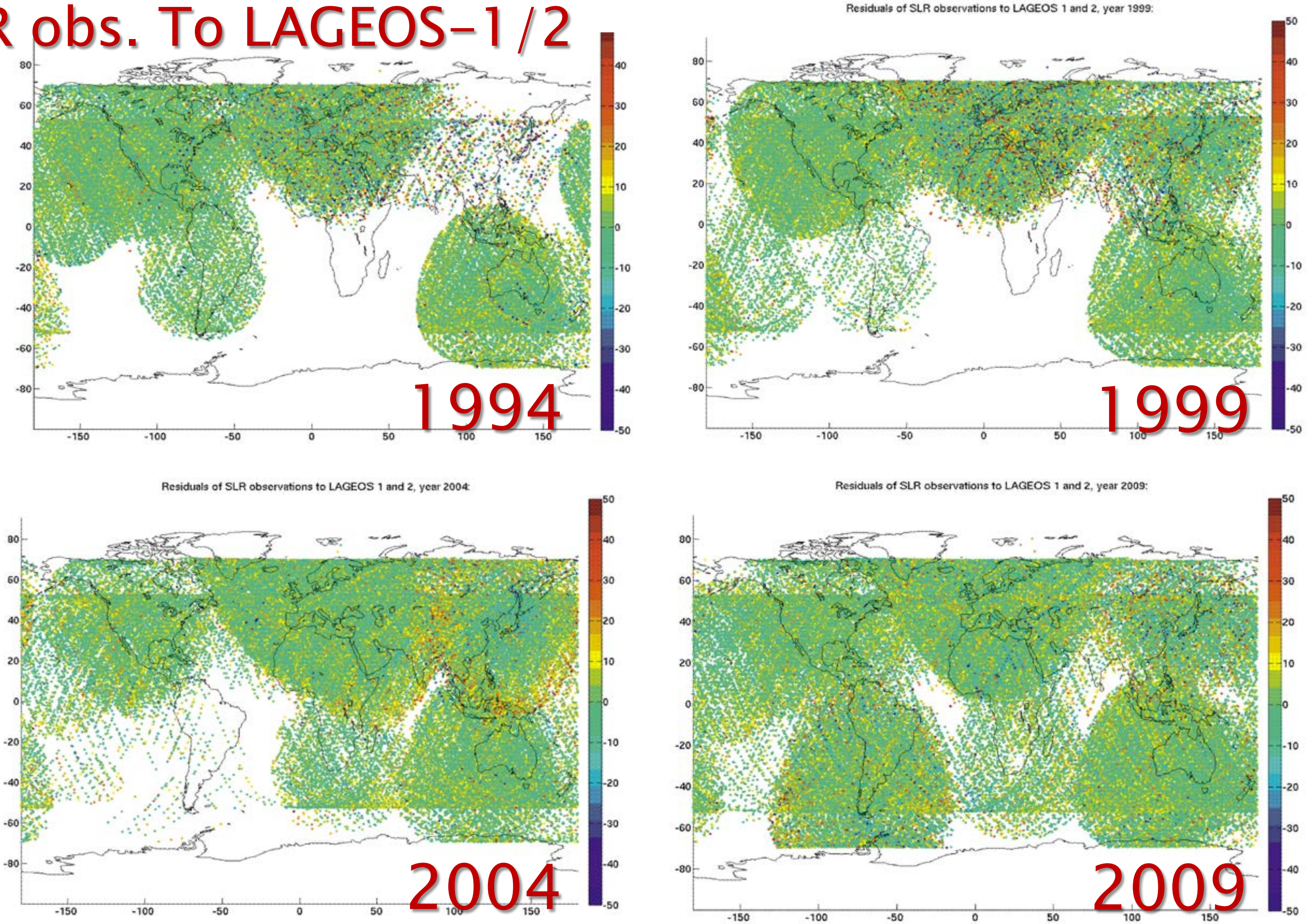
GRACE gravimetry



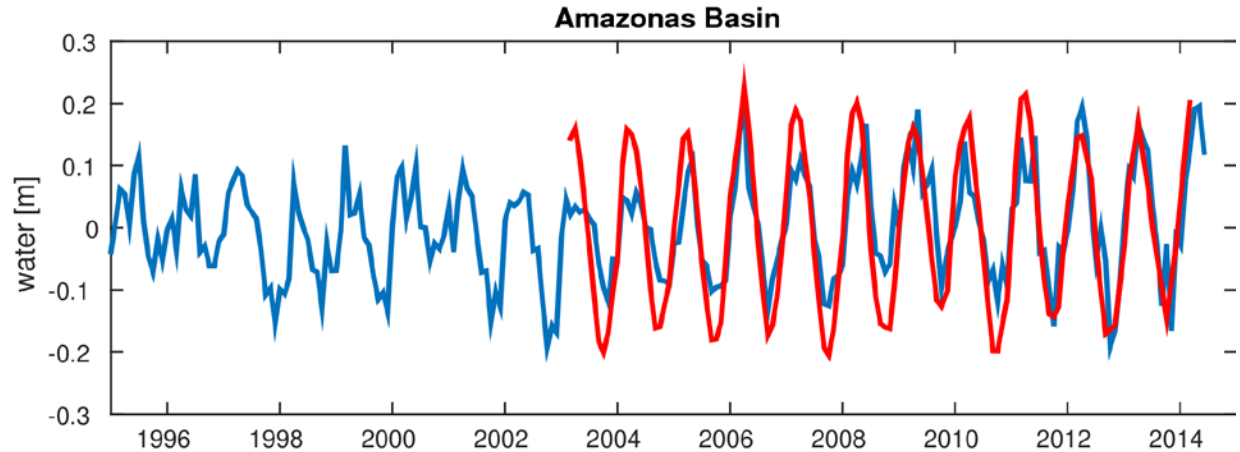


SLR solutions in '90s

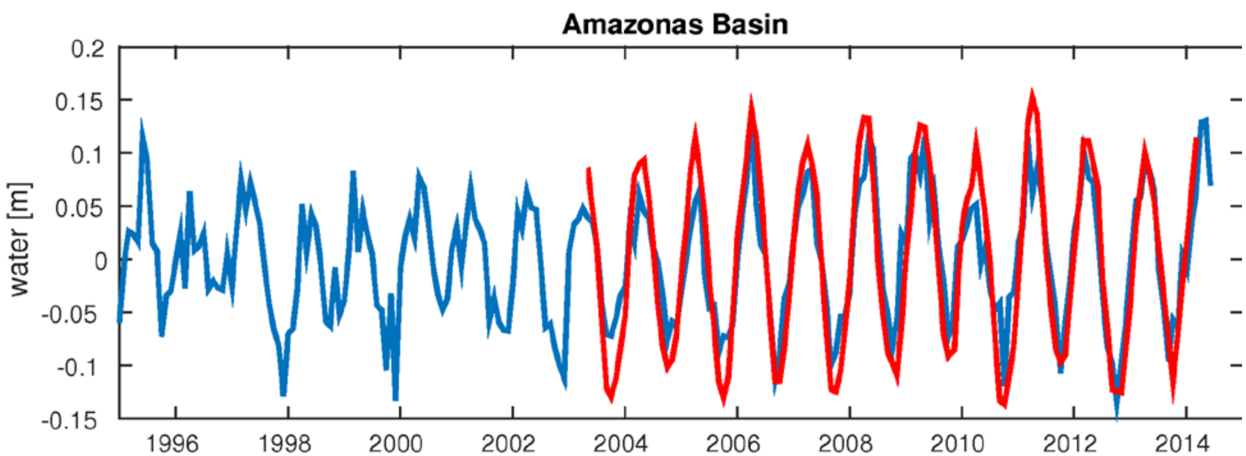
SLR obs. To LAGEOS-1/2



SLR solutions in ‘90s

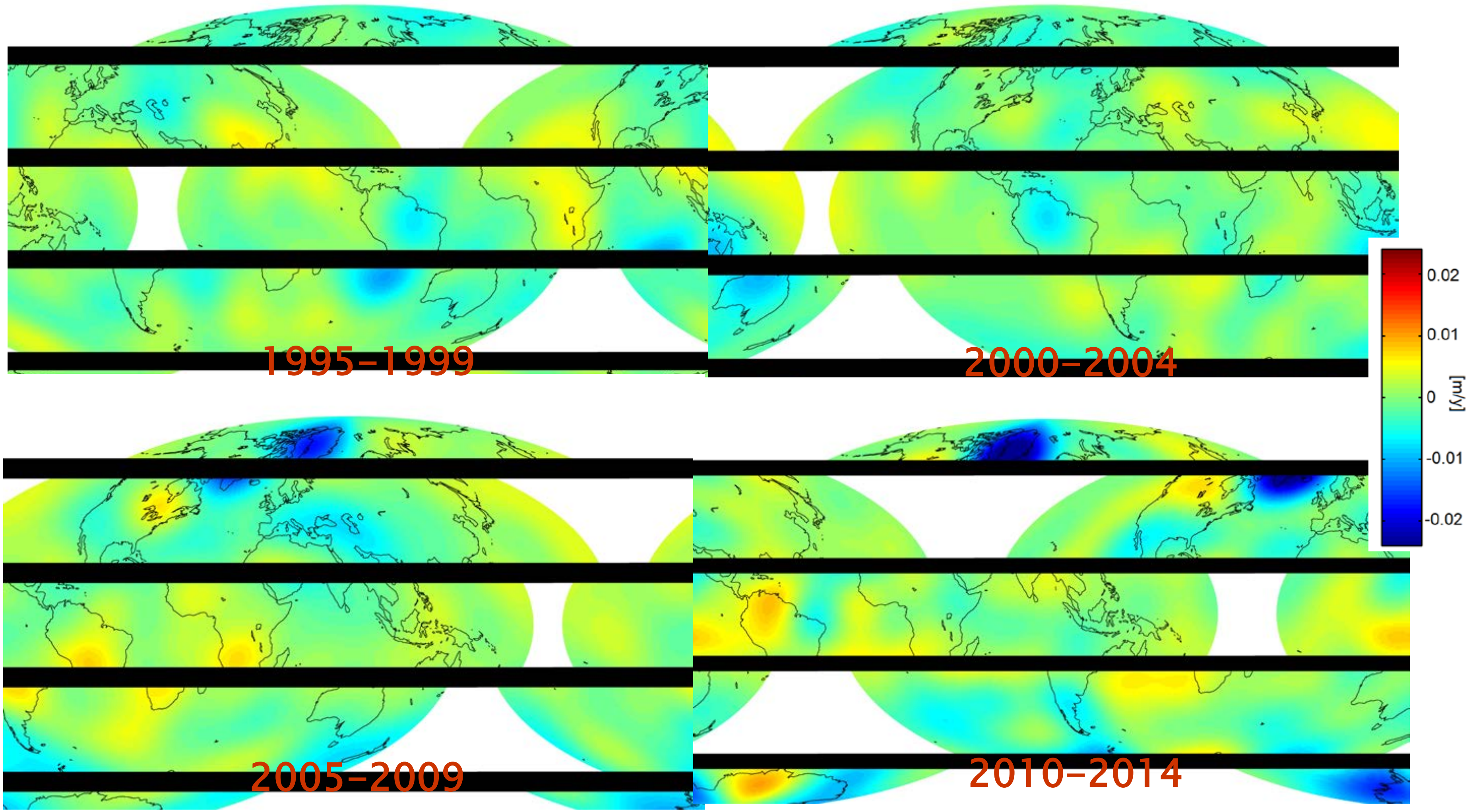


Up to d/o 10/10



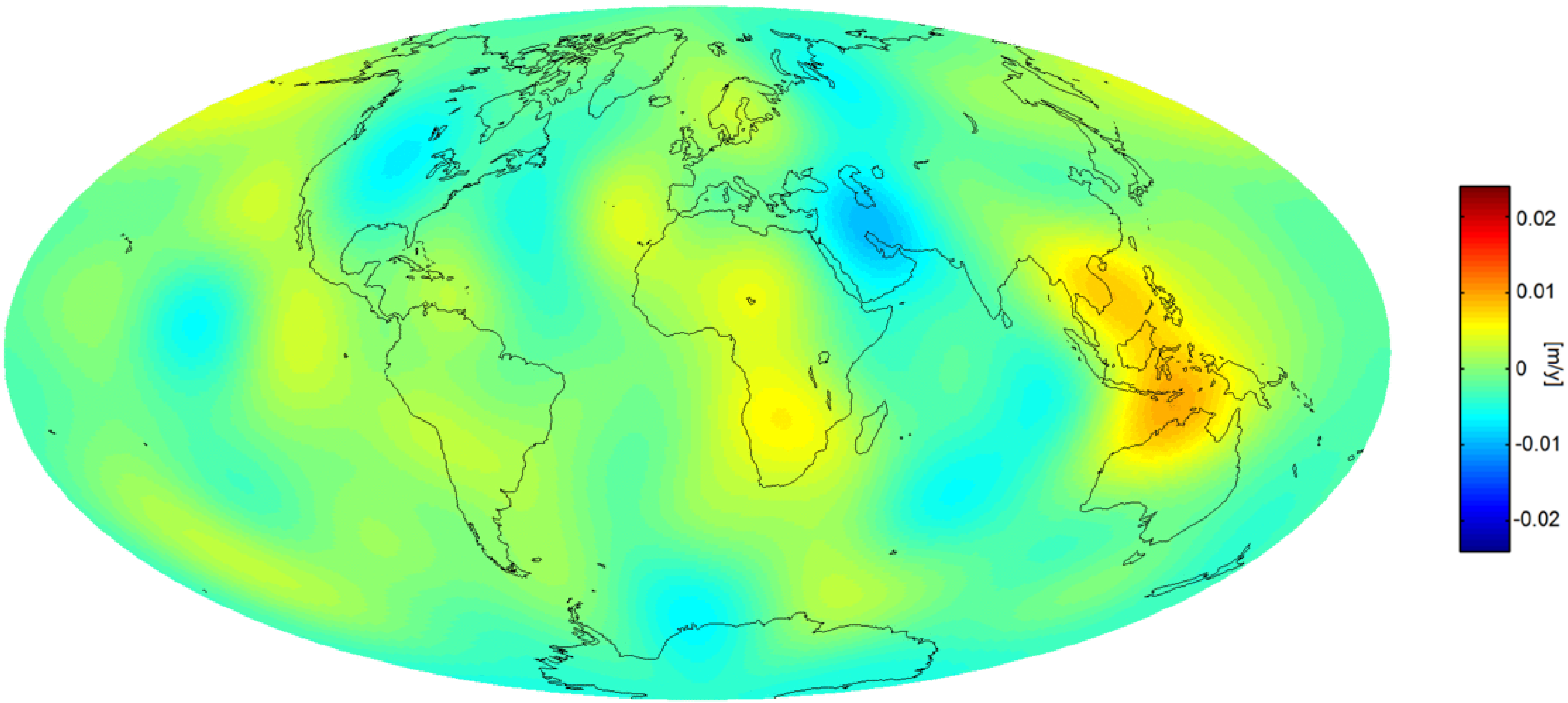
Up to d/o 6/6

Geoid height changes from SLR



Geoid height changes from SLR

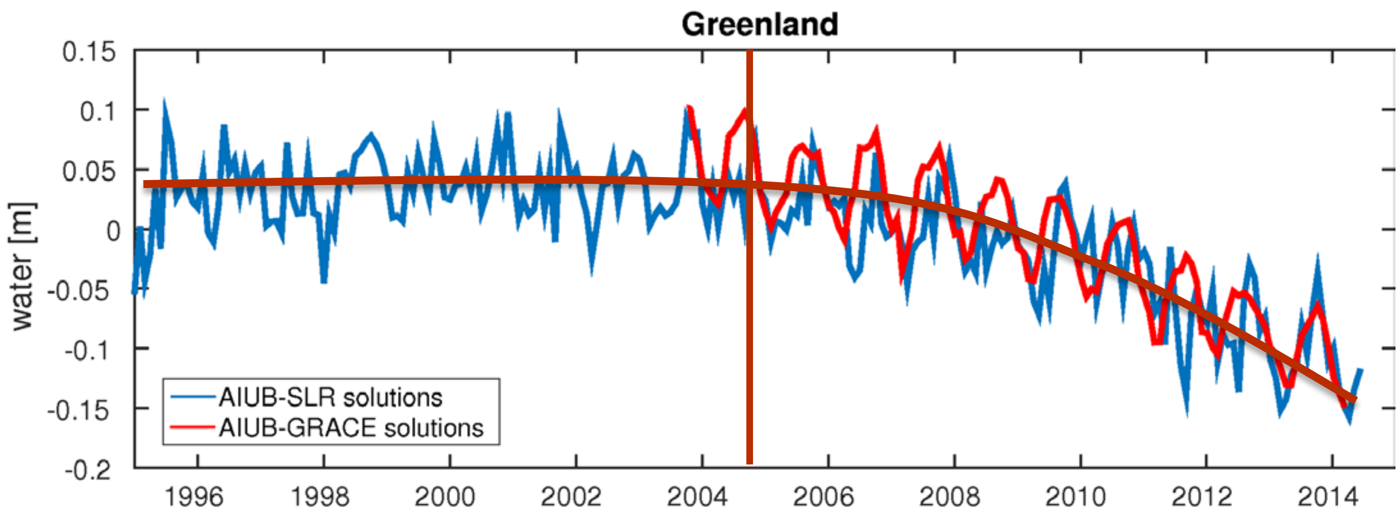
1998



Geoid height change

5-year sliding window

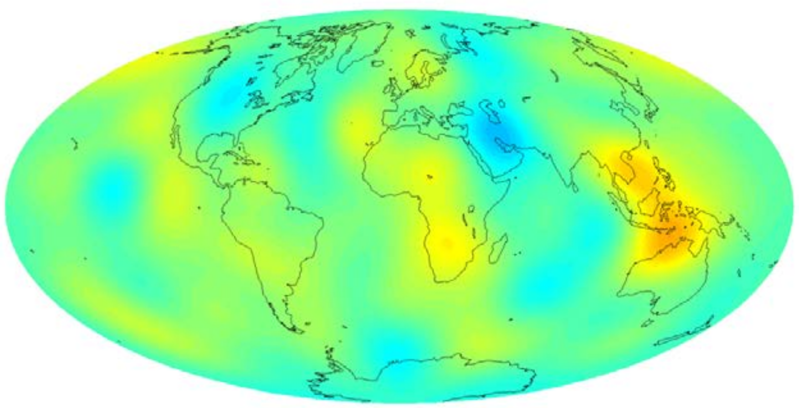
Geoid height changes from SLR



2005–2014: <u>accelerating</u> ice mass depletion

1995–2004
10 years without any changes

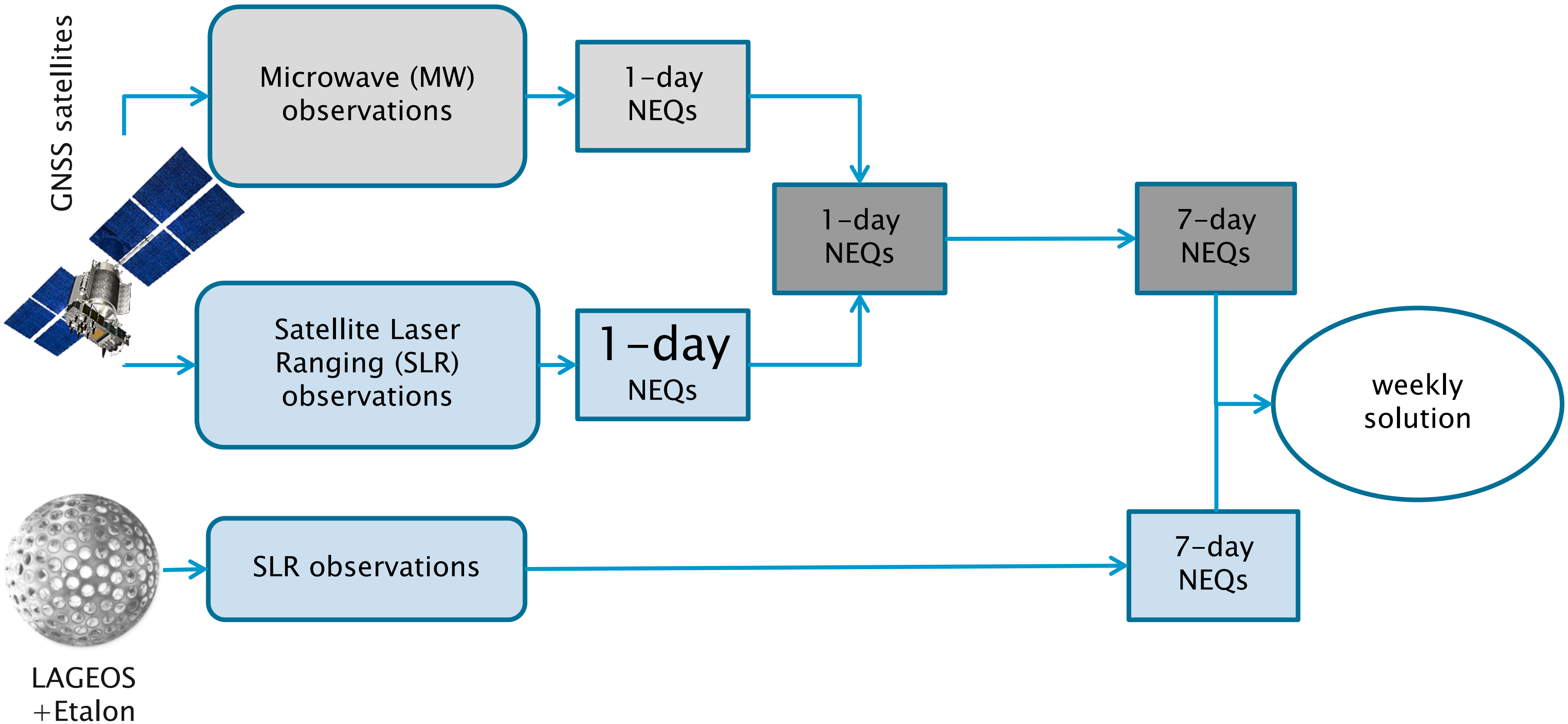
1998



SLR and GRACE solutions up to d/o 6/6

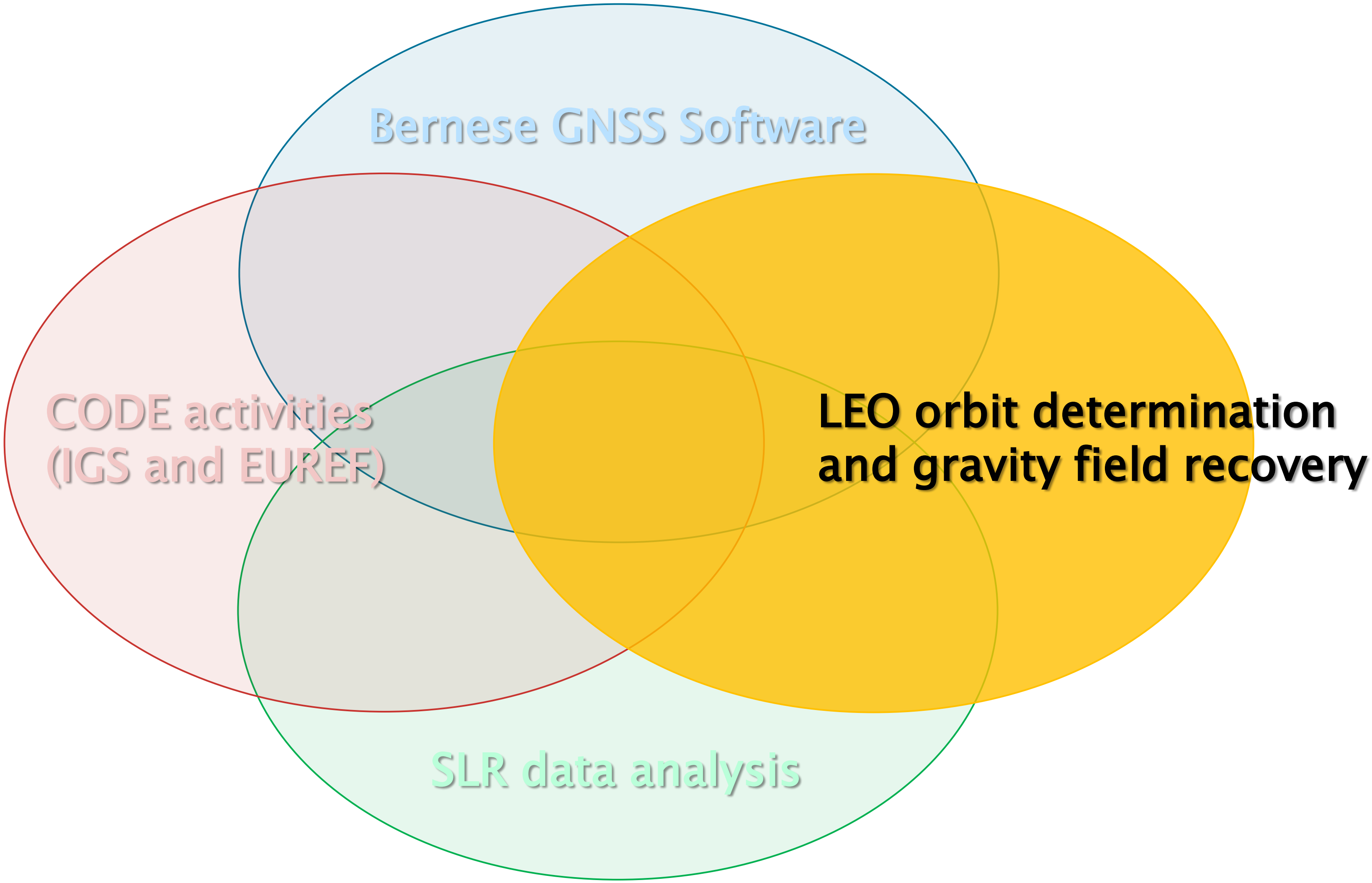
Establishment of a combined reference frame

- combination of GNSS and SLR data using satellite collocation:



→ station coordinates, Earth rotation parameters, geocenter

Satellite Geodesy Research Group



Sentinel:
Berechnung genauer Bahnen

Orbit Comparison for Sentinel–1

When excluding the mean differences, the following orbits from *different* software packages agree best (std. dev. for orbits of 1st SRM):

AIUB-ESOC	Bernese-Napeos	1.19 cm 1.54 cm 0.98 cm
AIUB-Delft	Bernese-GHOST	1.43 cm 2.89 cm 0.74 cm
ESOC-Delft	Napeos-GHOST	1.24 cm 2.78 cm 0.86 cm

Promising agreements between different S/W packages!

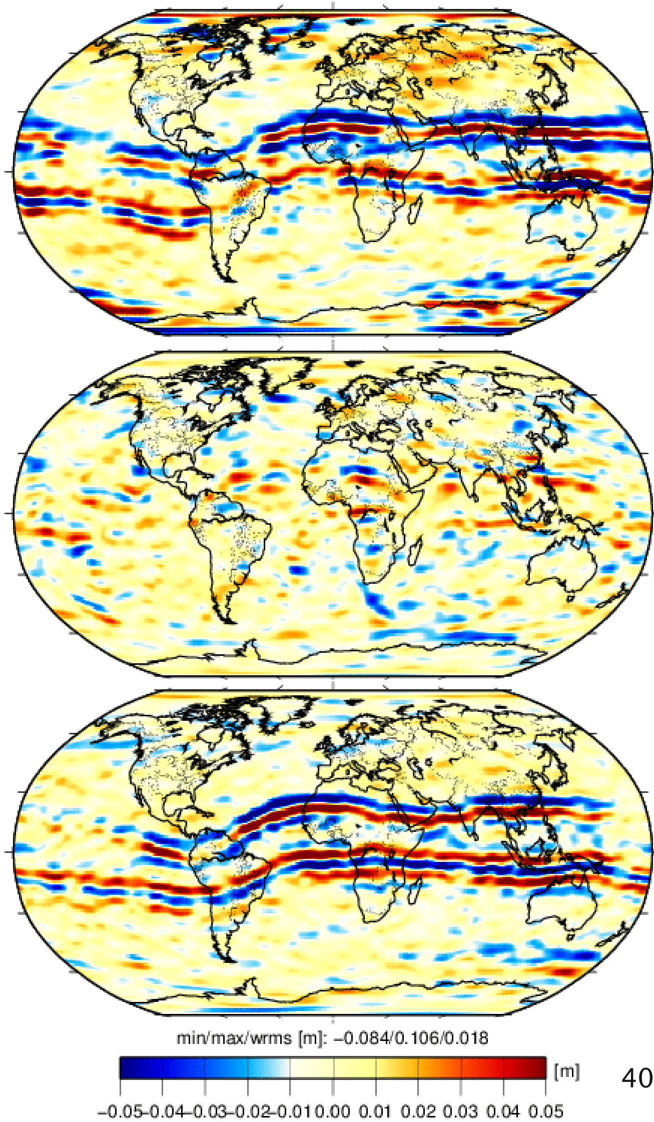
Difference between Sentinel PCVs

- AIUB PCV:
  - Is based on residuals of a reduced-dynamic orbit determination. The radial levelling of AIUB reduced-dynamic orbits is purely data-driven (kinematic-like) due to the estimation of a constant radial acceleration acting over the entire orbital arc.
  - Induces no radial offset when used in a kinematic POD
- PosiTim PCV:
  - Is based on residuals of a more dynamic orbit determination. The radial levelling of PosiTim reduced-dynamic orbits is given by the used dynamic models implemented in the Napeos software.
  - Induces a radial offset of about 3cm when used in kinematic POD
- GMV PCV:
  - Is based on residuals of a reduced-dynamic orbit determination. The used orbit parametrization is similar to PosiTim but solves for some more orbit parameters.
  - Induces a radial offset of about 1.5cm when used in kinematic POD

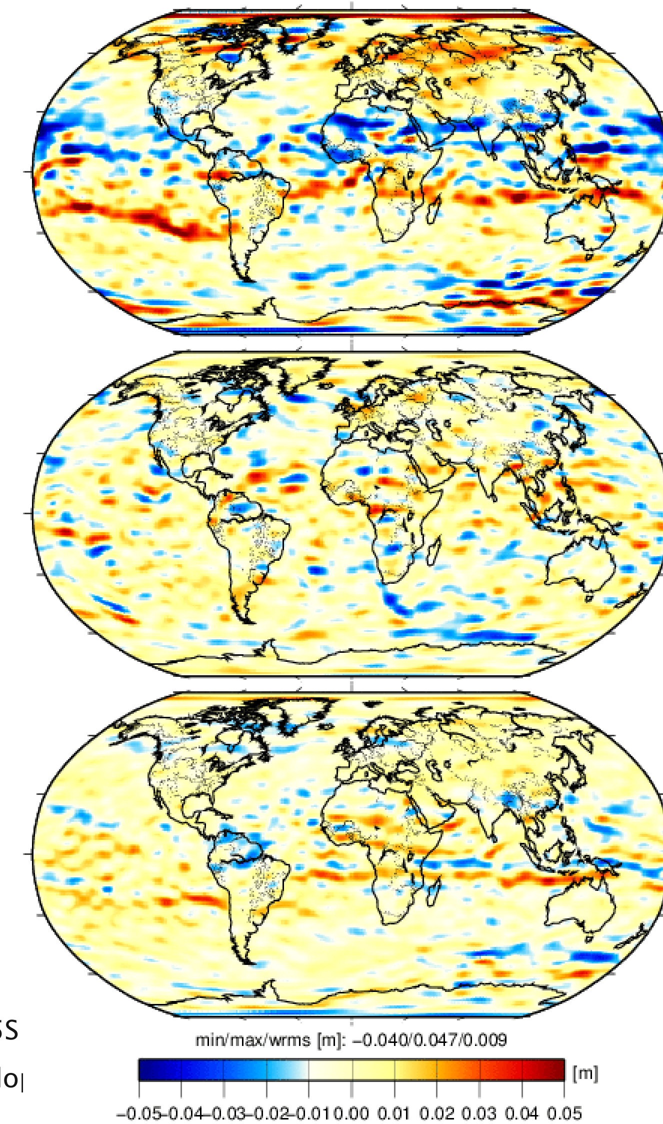
Swarm:
Bahn- und Gravitationsfeldbestimmung

Bi-Monthly Gravity Field Solutions up to d/o 90

Original GPS Data



Screened GPS Data



Mar/Apr 2014

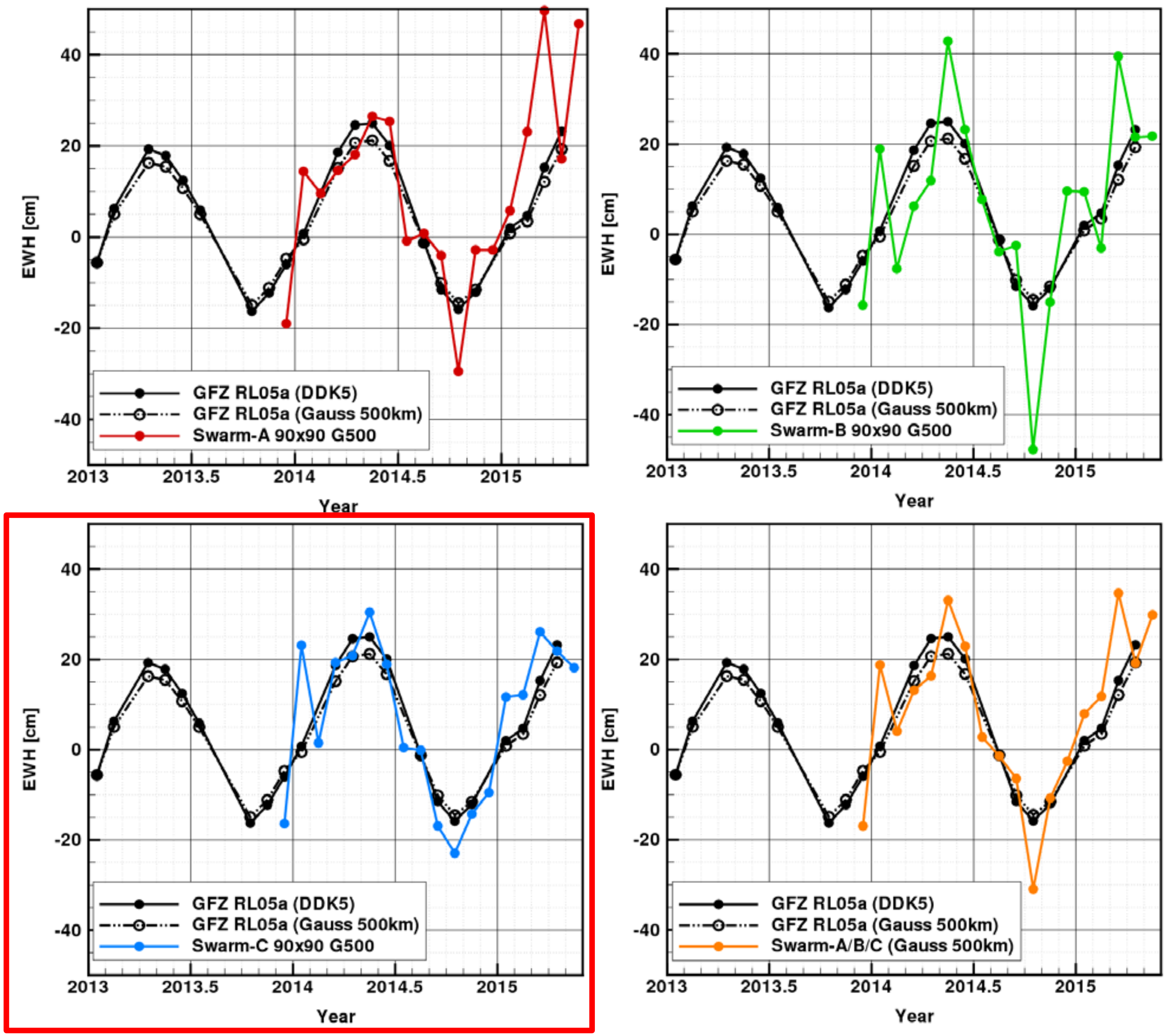
Jun/Jul 2014

Nov/Dec 2014

Differences wrt GOCO05S

400 km Gauss smoothing ado|

Time–Variable Gravity (Amazon)



“True” signal:

- GFZ–RL05a (DDK5–filtered)

“Comparison” signal:

- GFZ–RL05a (500km Gauss)

Swarm signal:

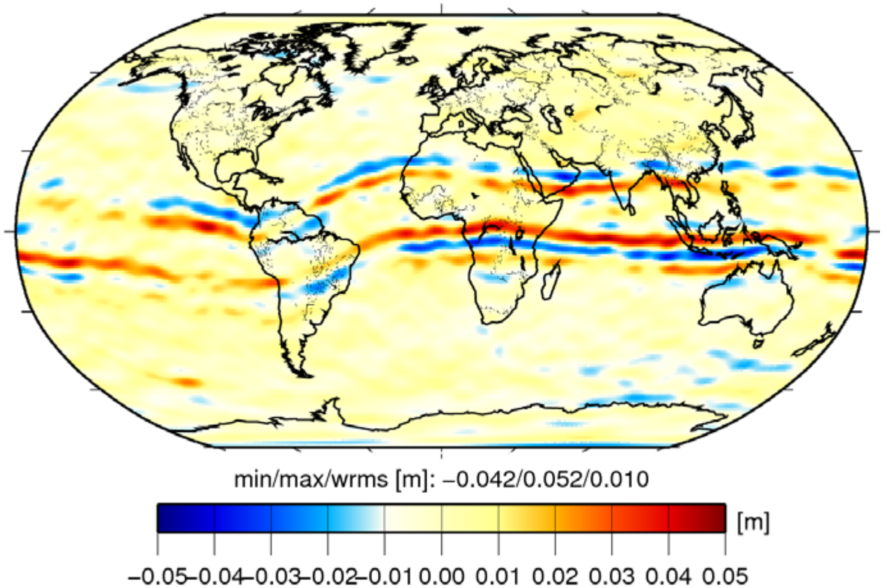
- 90x90 solutions (Gauss–filtered)

Result:

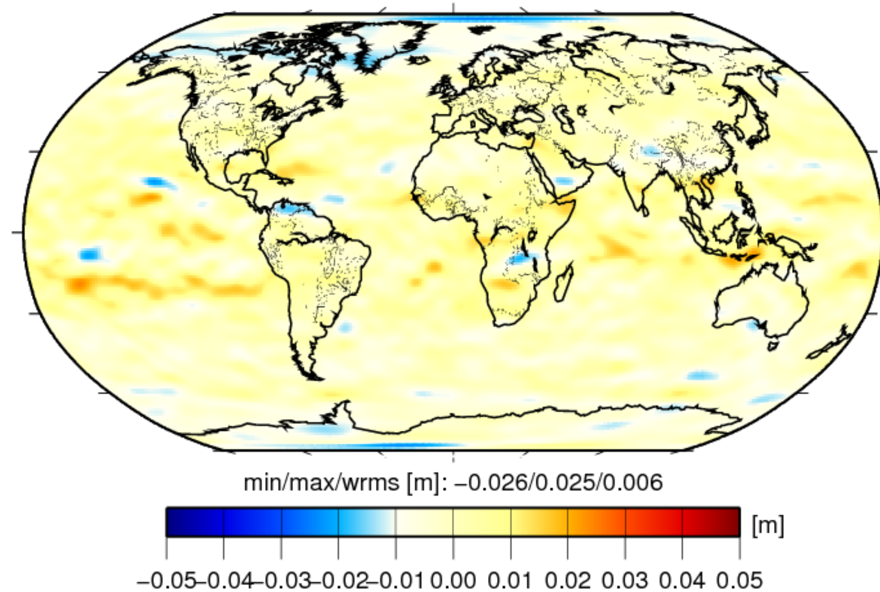
- Best agreement for Swarm–C
- Some outliers to be investigated

Comparison with GRACE hl-SST Solutions

Original GPS Data (Swarm)



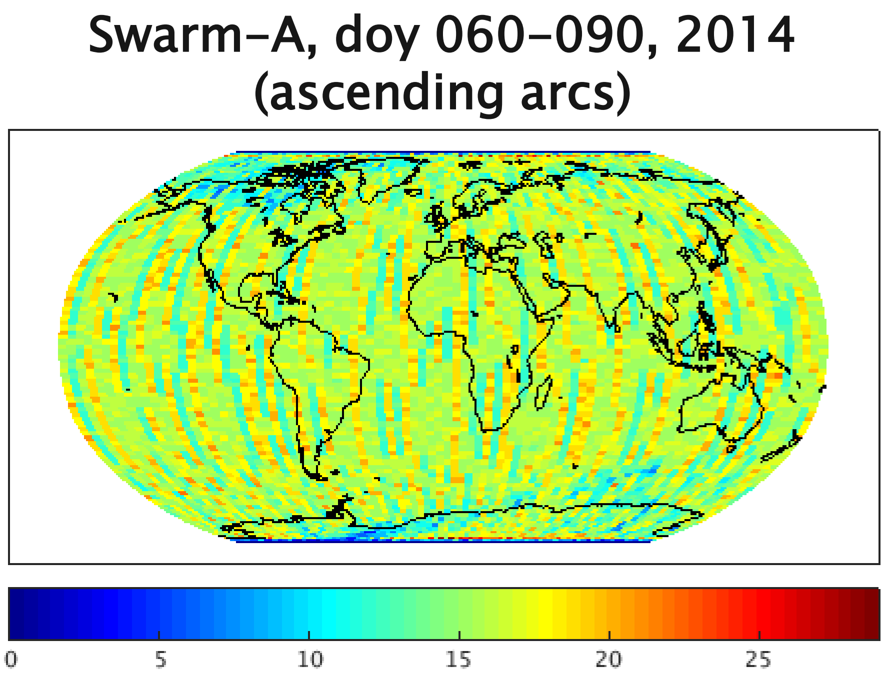
Original GPS Data (GRACE)

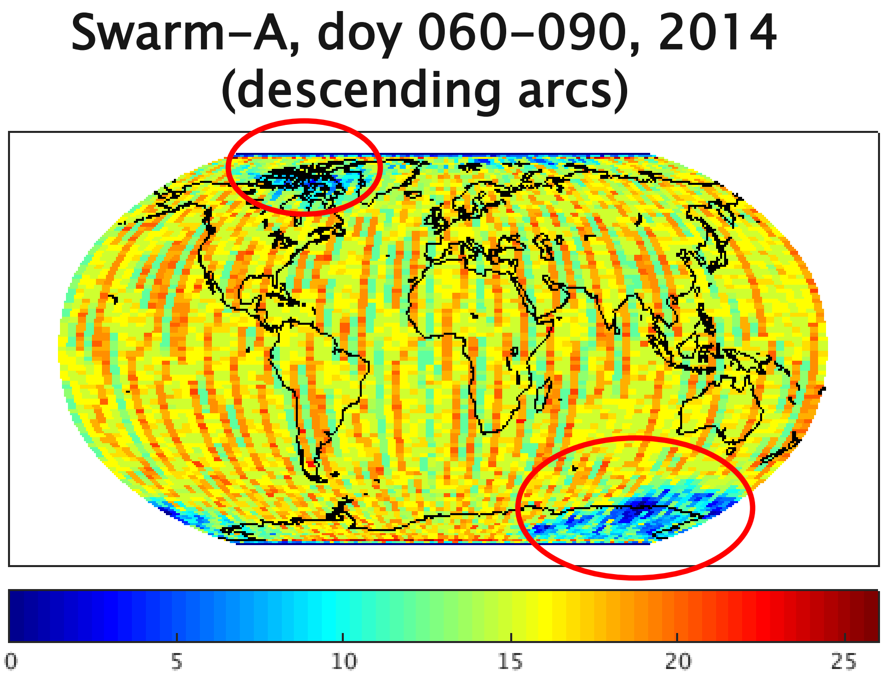


(Differences wrt GOCO05S, 400 km Gauss smoothing adopted)

Systematic signatures along the geomagnetic equator are not visible when using original L1B RINEX GPS data files from the GRACE mission.

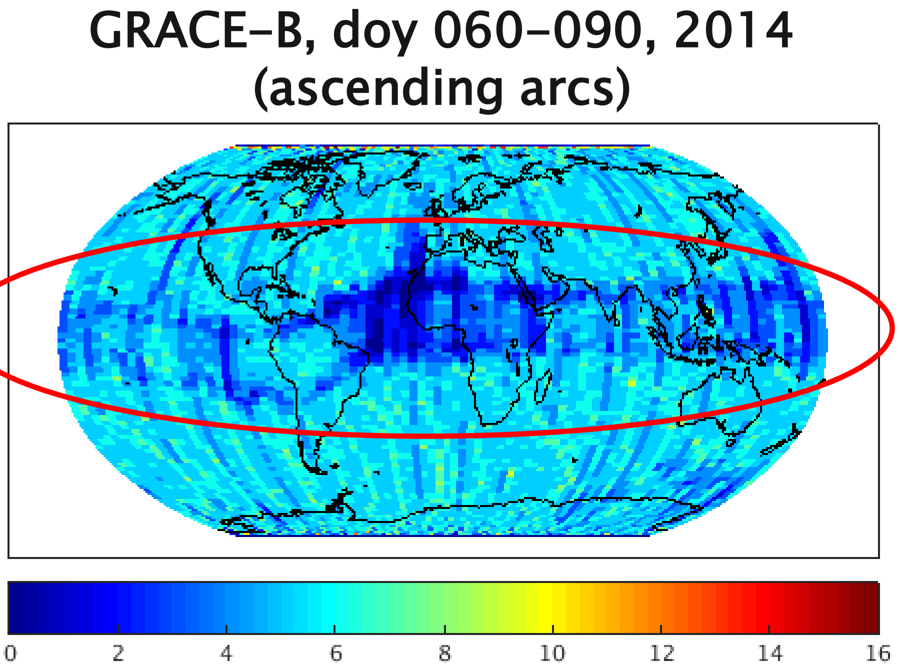
Number of available Kinematic Positions

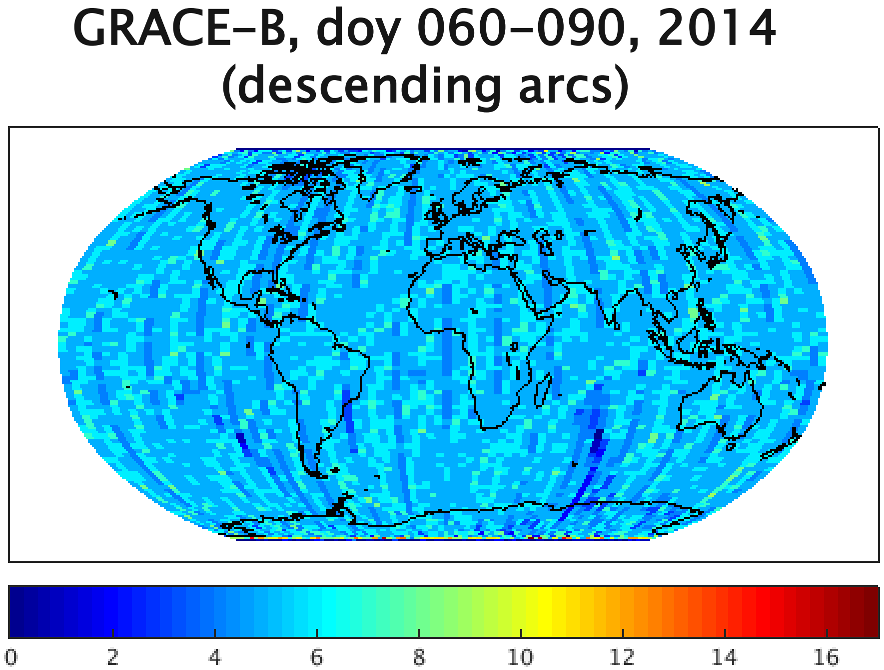




- For the selected period descending arcs are predominantly affected by ionosphere disturbances.
- Missing kinematic positions are found over the geomagnetic poles, but not along the geomagnetic equator.

Number of available Kinematic Positions

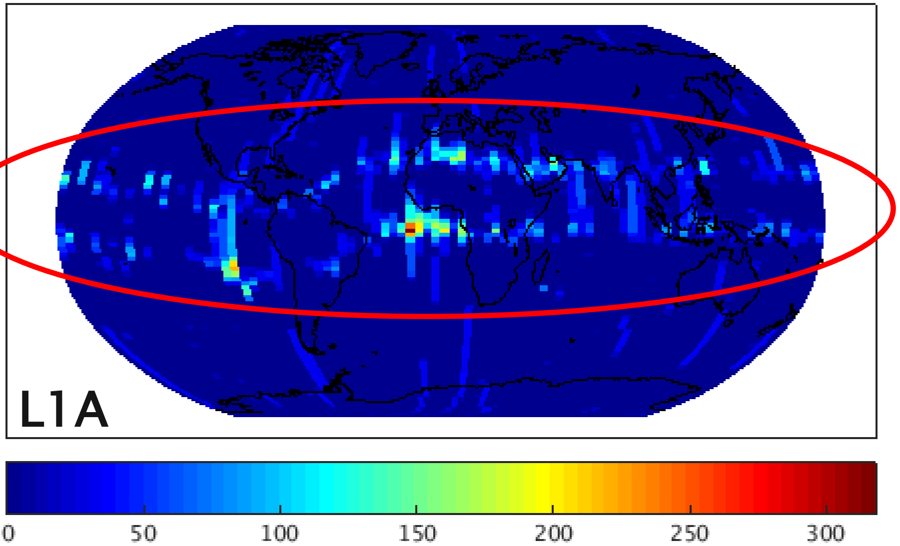




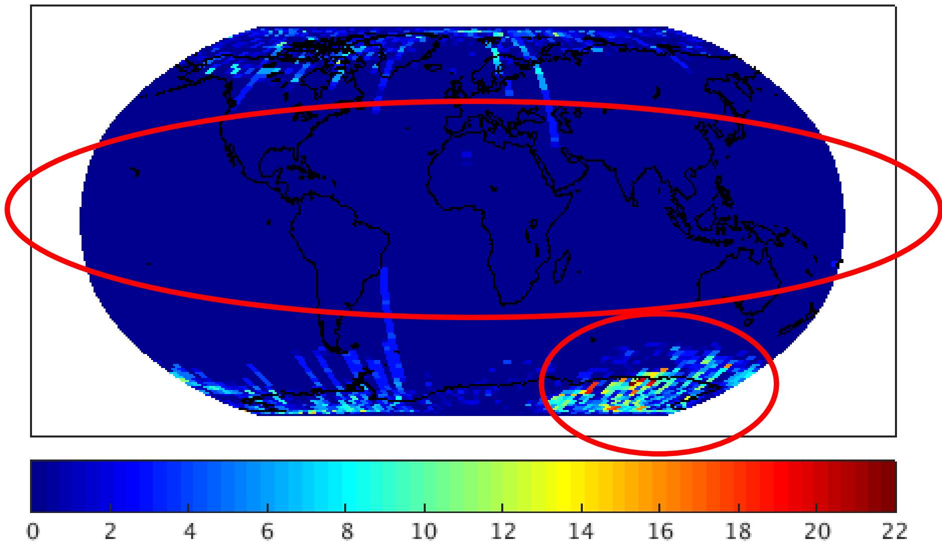
- For the selected period ascending arcs are predominantly affected by ionosphere disturbances (nodes happen to be separated by ~180°).
- Missing kinematic positions are found along the geomagnetic equator => problematic signatures cannot be present in the gravity field.

Number of missing Observations in RINEX files

GRACE-B, doy 060-090, 2014
(all arcs)



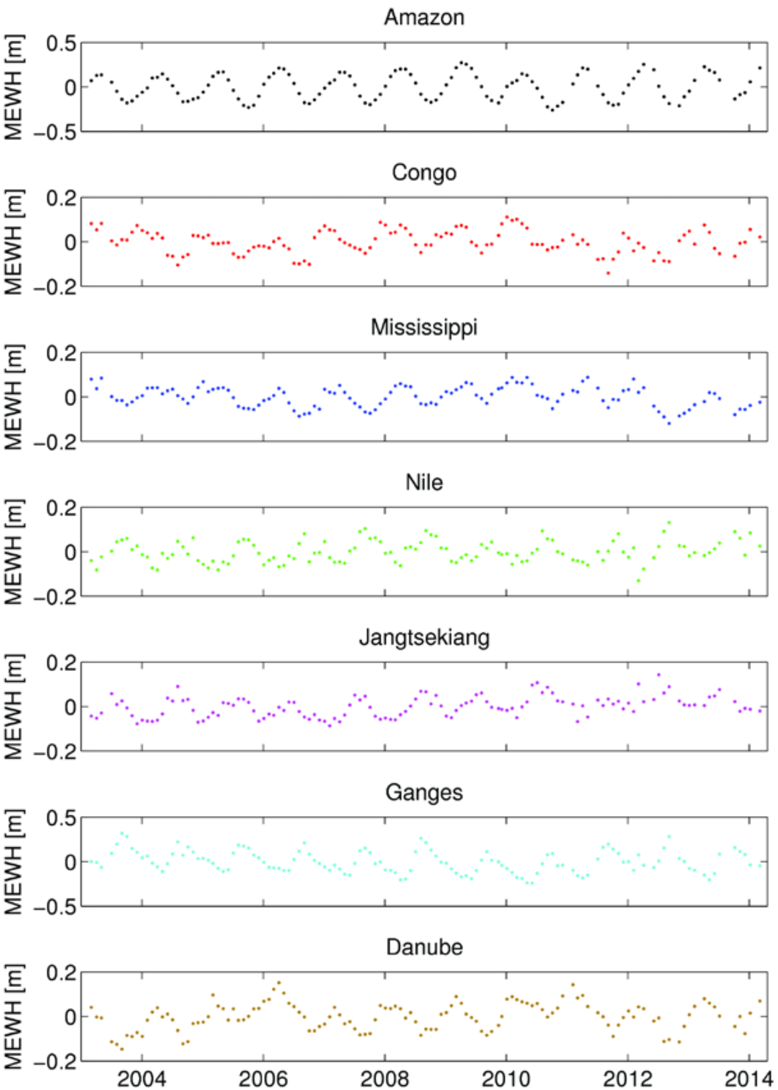
Swarm-A, doy 060-090, 2014
(all arcs)



- Significant amounts of data are missing in GRACE L1B RINEX files
  => problematic signatures cannot propagate into gravity field.
- Swarm RINEX files are more complete (gaps only over the poles)
  => problematic signatures do propagate into the gravity field.

Bestimmung des zeitvariablen Schwerefeldes mit GRACE

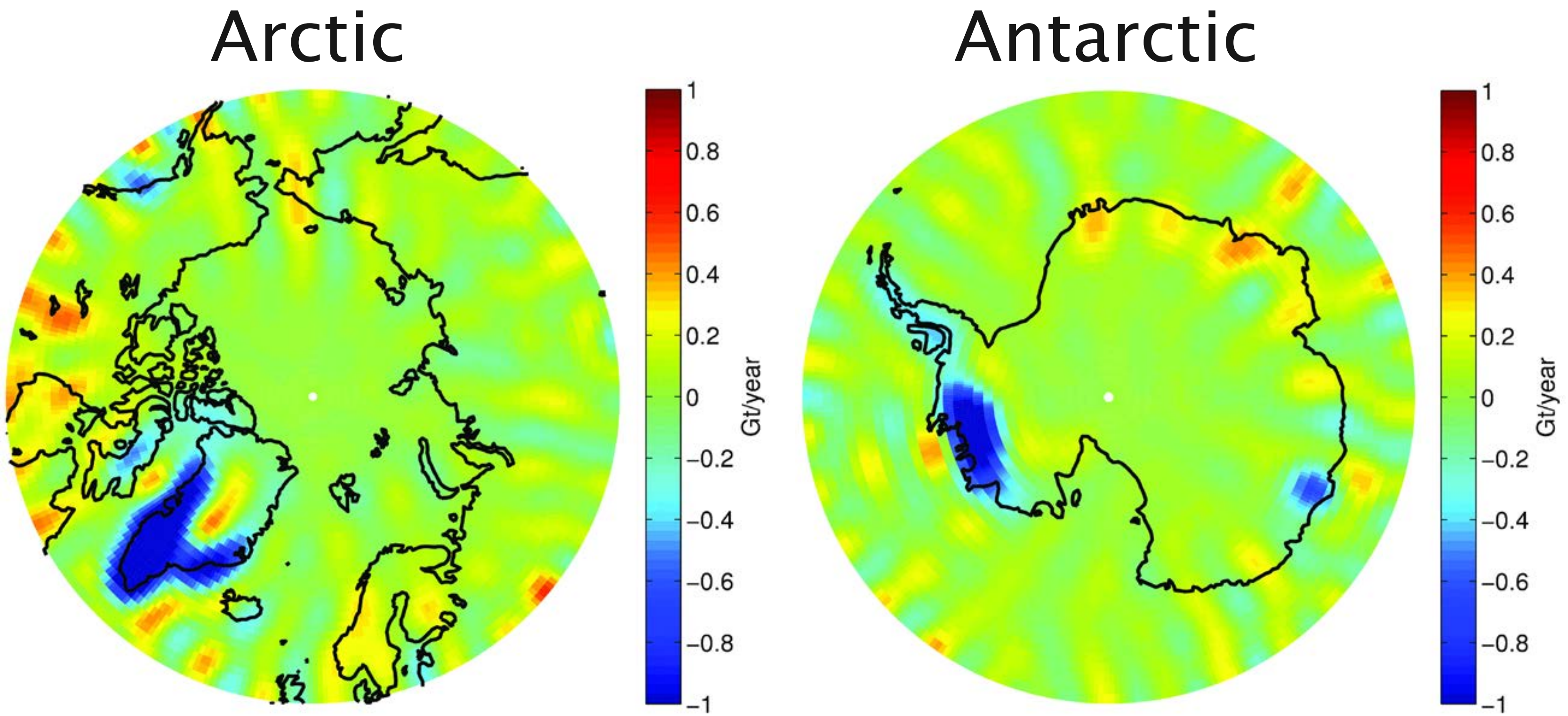
AIUB-RL02: river basins



Seasonal mass variations are mainly caused by the hydrological cycle. They are evaluated per river basin and are expressed in mean equivalent water height.

They may be approximated by a simple parametric model (bias+trend+annual variations) per basin. The fit of such models is increased by 25-35% from AIUB-RL01 to AIUB-RL02.

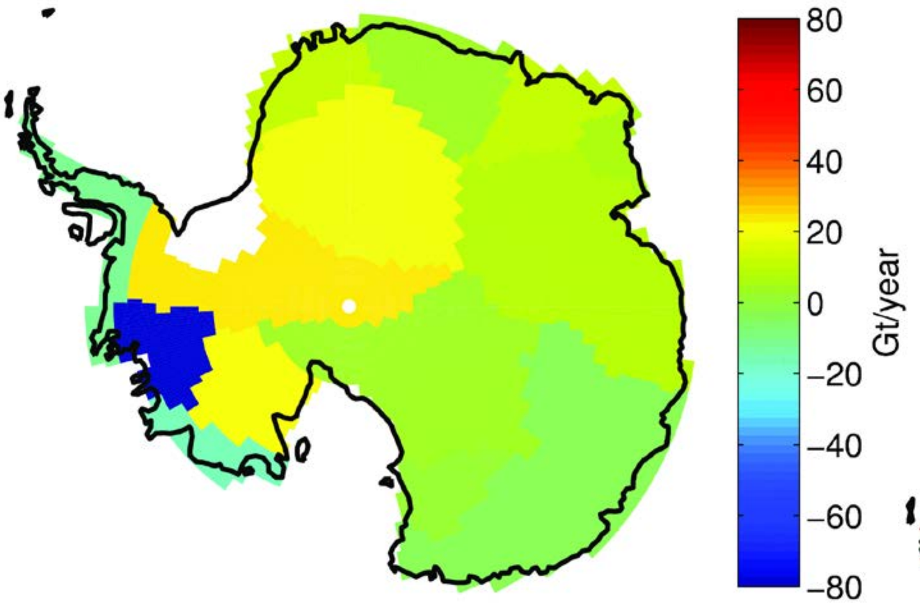
AIUB-RL02: Polar mass trends



Polar mass trends 2010–2014 per 1°-bin show mass loss at the coast of Greenland and West Antartica. To quantify these changes is a major application of GRACE monthly gravity models.

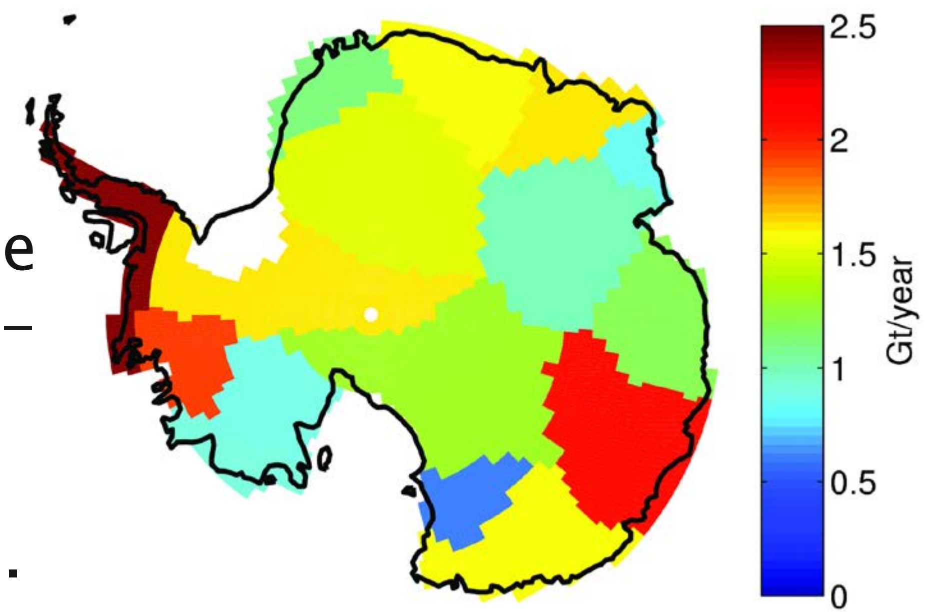
AIUB-RL02: Evaluation of Antarctic basins

Mass trends per basin



Mass trends are computed for glacial basins and reach −80 Gt/yr. Uncertainties from the linear fit are at the order of a few Gt/yr.

Uncertainties per basin



To separate ice mass change from glacial isostatic adjust-ment a GIA-model is used. The uncertainty of GIA reaches 40 GT/yr (Horwath).

Kombination von GRACE Schwerefeldlösungen

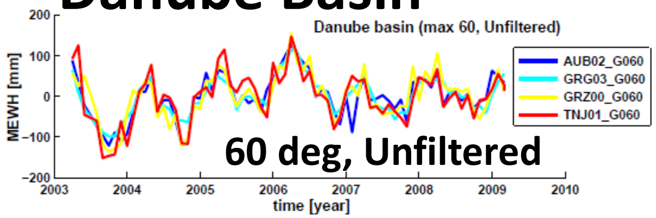
Comparison: Signal (MEWH)

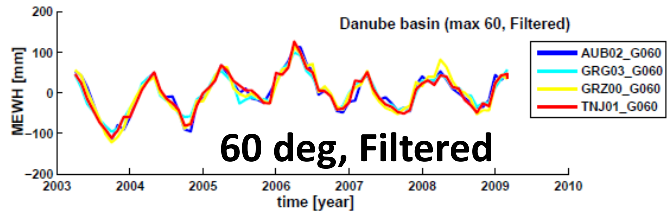
- Mean Equivalent Water Height

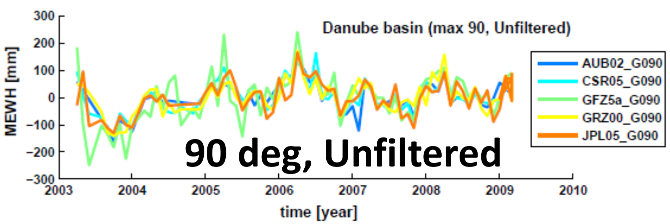
$$MEWH = \frac{\sum EWH * \sin\theta}{\sum \sin\theta}$$

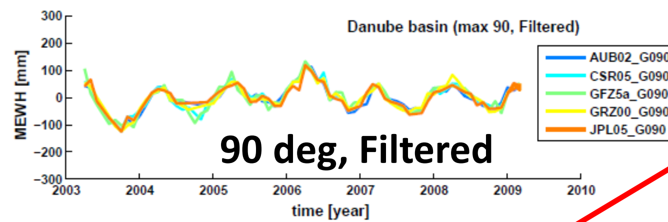
θ: colatitude

Danube Basin

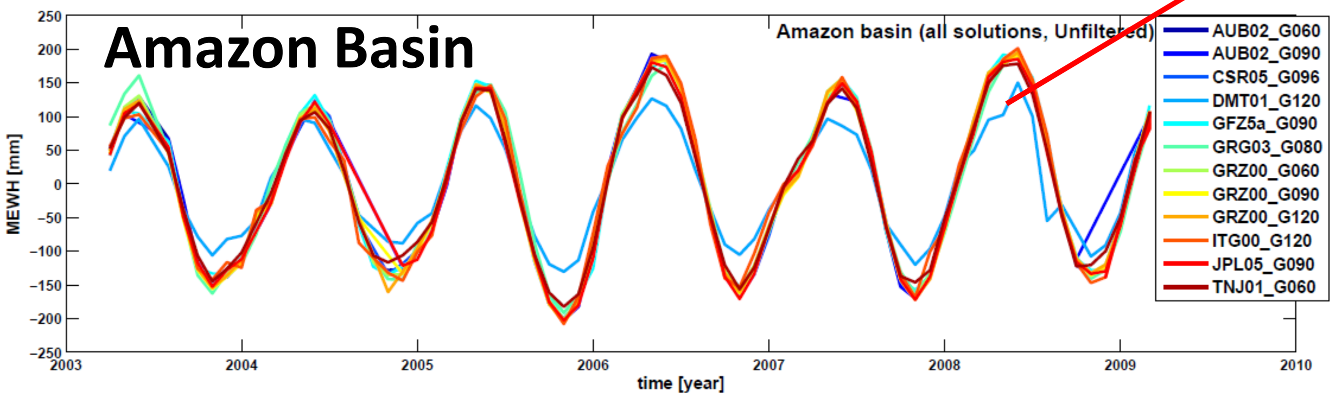






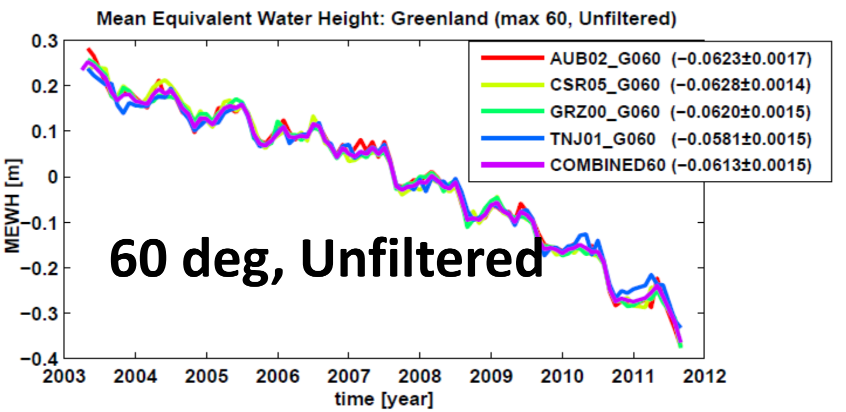


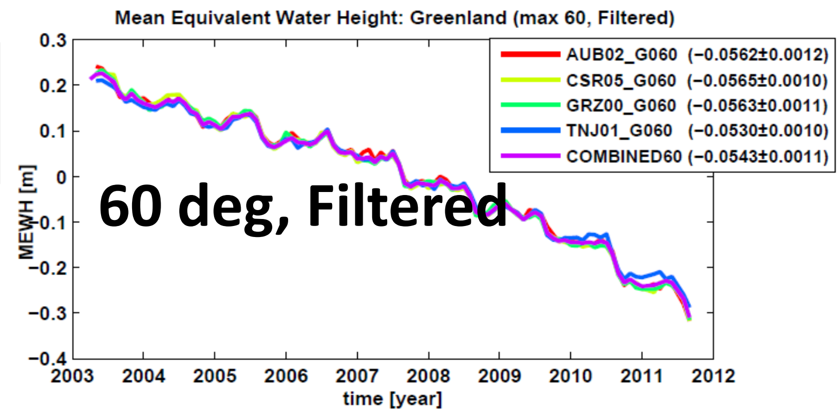
DMT solution:
Damped Signal
due to pre-filtering

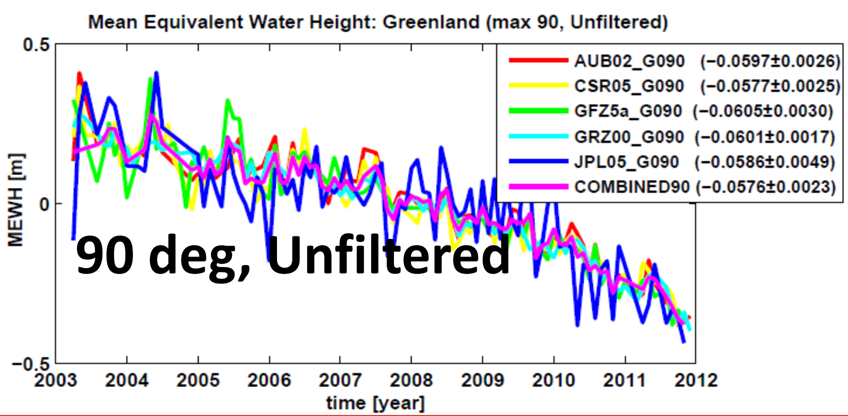


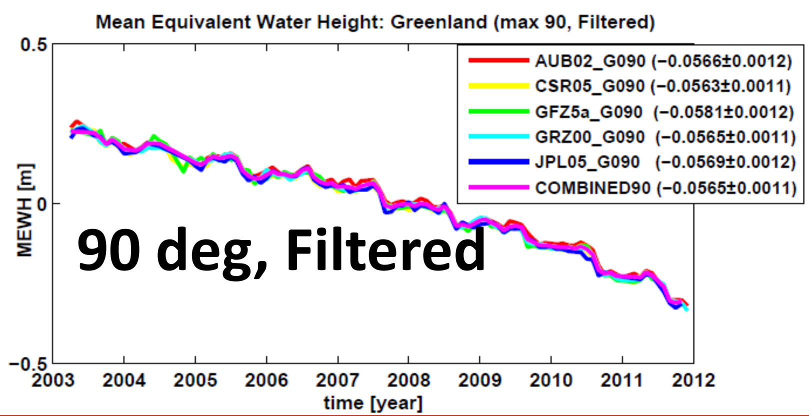
Combination

Combined Solution (Max. Deg.)	Involved Individual Solutions
Combined Solution (60)	AUB02, CSR05, GRZ00, TNJ01
Combined Solution (90)	AUB02, CSR05, GFZ5a, GRZ00, JPL05







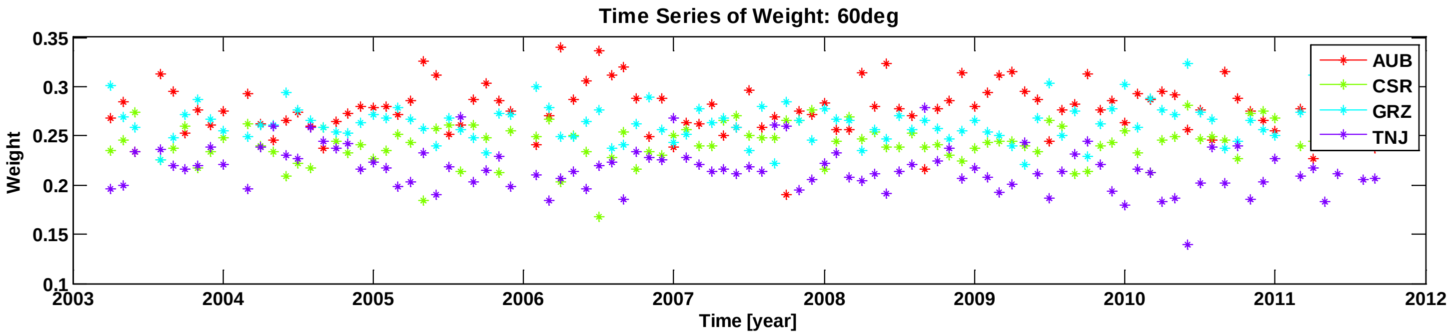


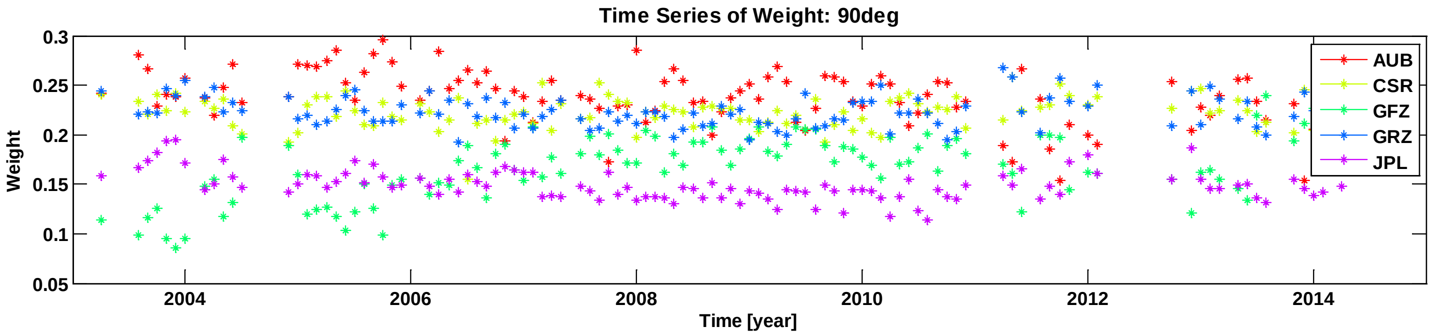
Combination: Weighting Schemes

Different Combined Solutions:

Weights are based on
(Individual Solution – Arithmetic Mean)$^{-2}$

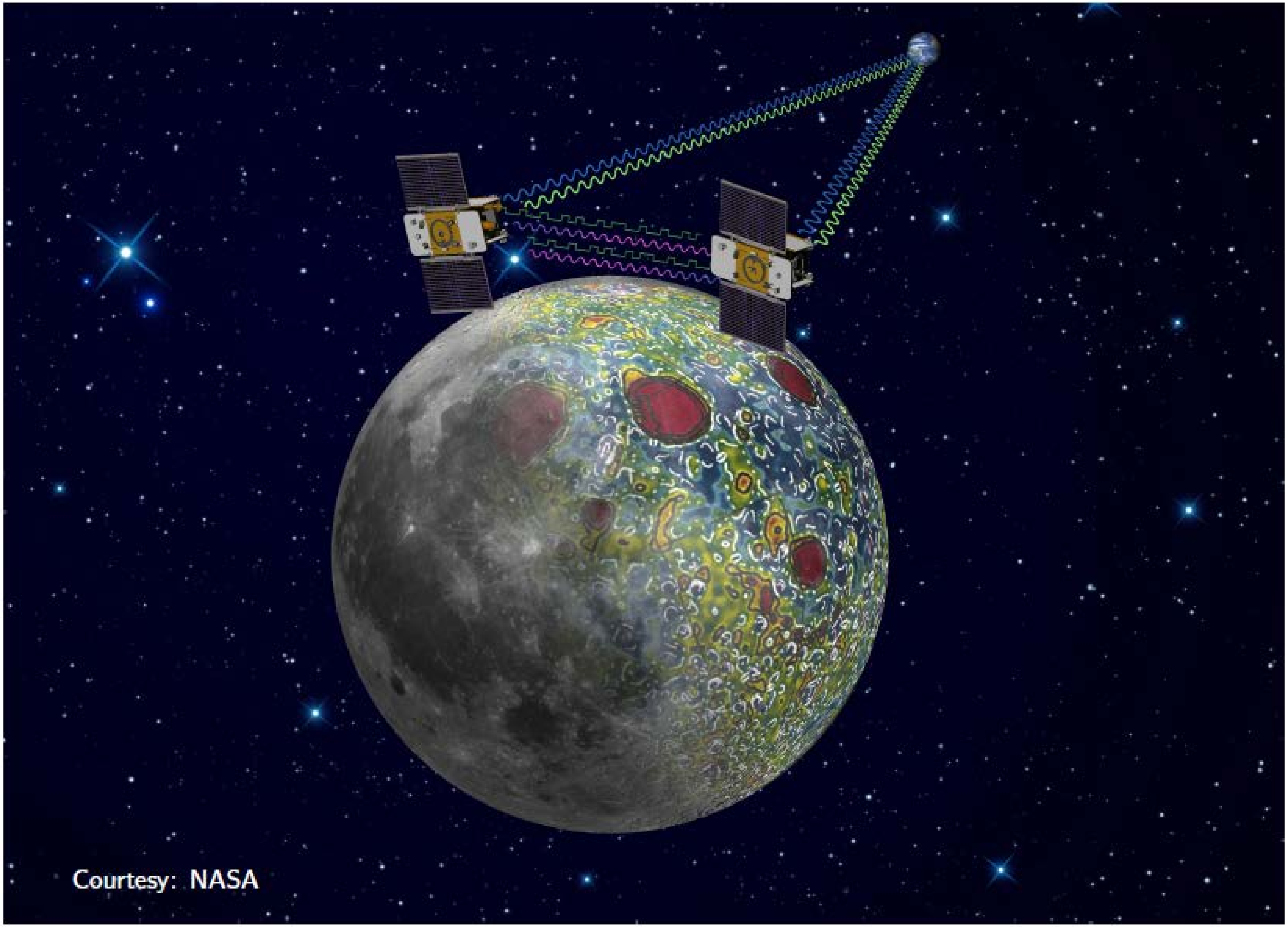
	Label	Type of Combined Solution	Weight
1	CMB00	**Simple Arithmetic Mean**	Identical weights
2	CMB02	Coefficient-wise **Weighted Mean**	Each **L** and each **M** in each **Month**
3	CMB03	Order-wise **Weighted Mean**	Each **M** in each **Month**
4	CMB05	Month-wise **Weighted Mean**	Each **Month**





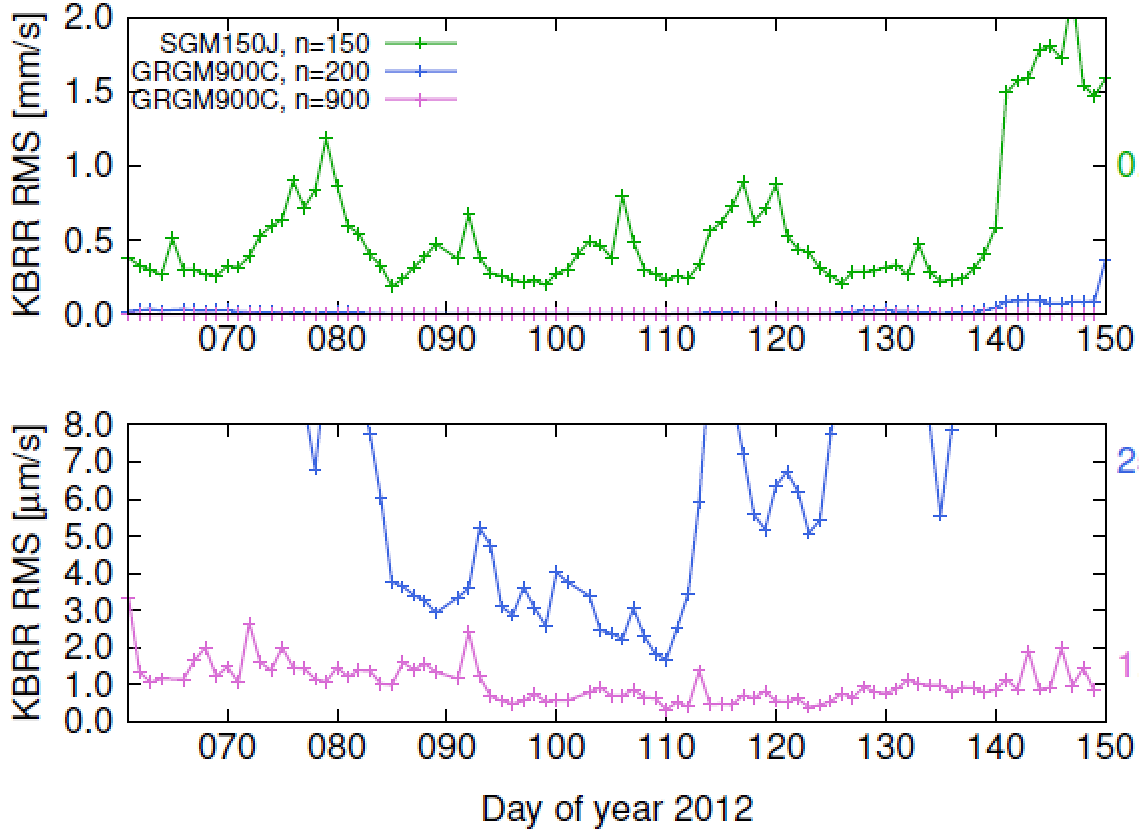
Bestimmung des Mondschwerefeldes aus Daten der Mission GRAIL

The GRAIL mission



Orbit determination: Position + KBRR data

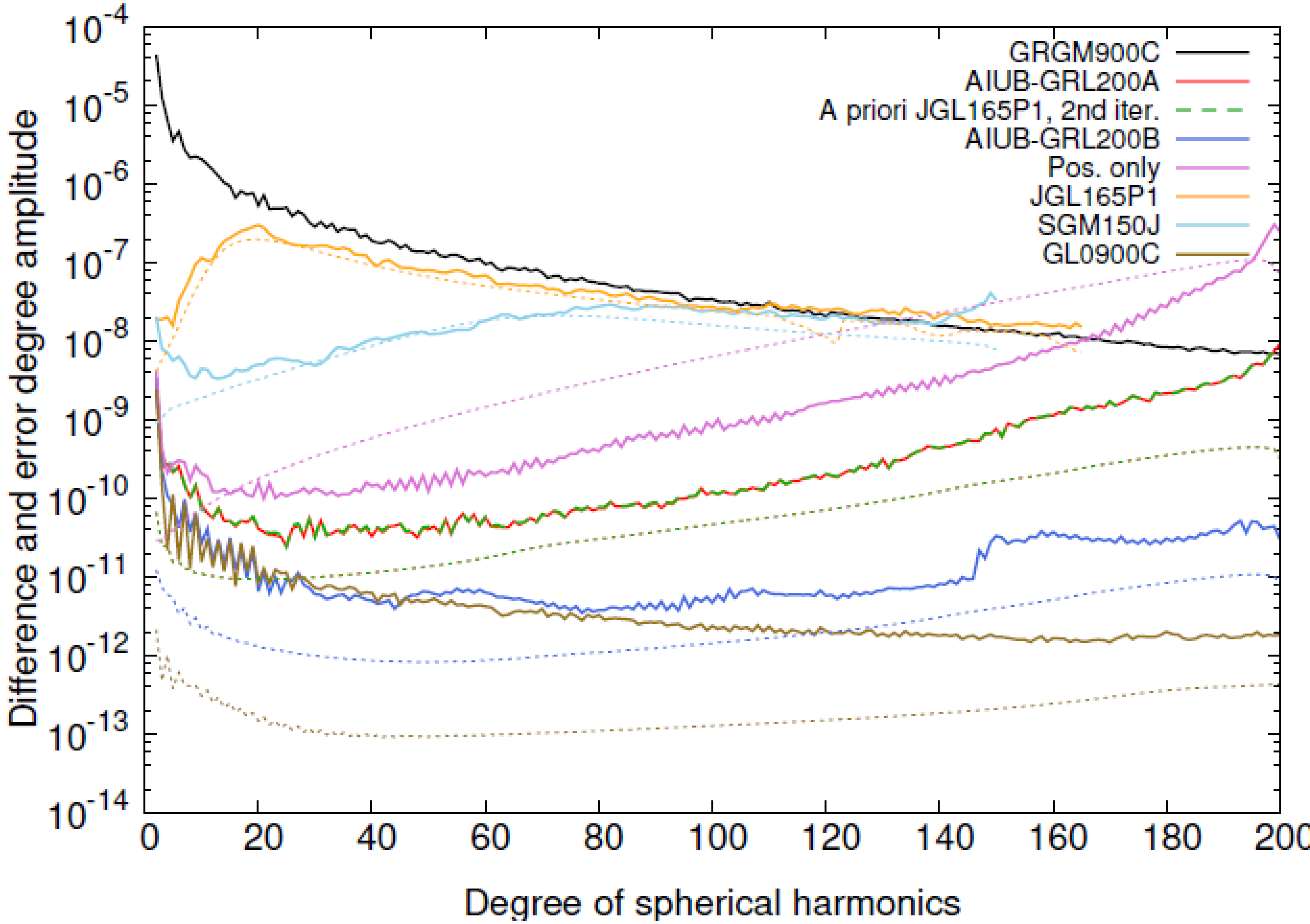
Use of the JPL provided positions as pseudo-observations : **back to GRACE-like scenario.**



Daily RMS values of KBRR residuals over the whole primary mission phase, using different gravity field models (**nominal:** $0.1 \mu m/s$).

Gravity field determination: GNI1B, $l_m = 200$

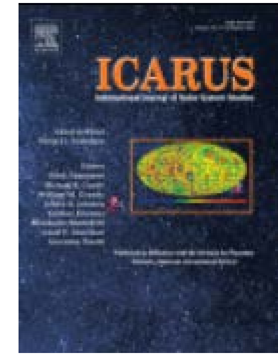
Difference degree amplitudes : $\Delta_l = \sqrt{\frac{1}{2l+1} \sum_{m=0}^{l} \left(\Delta \bar{C}_{lm}^2 + \Delta \bar{S}_{lm}^2\right)}$

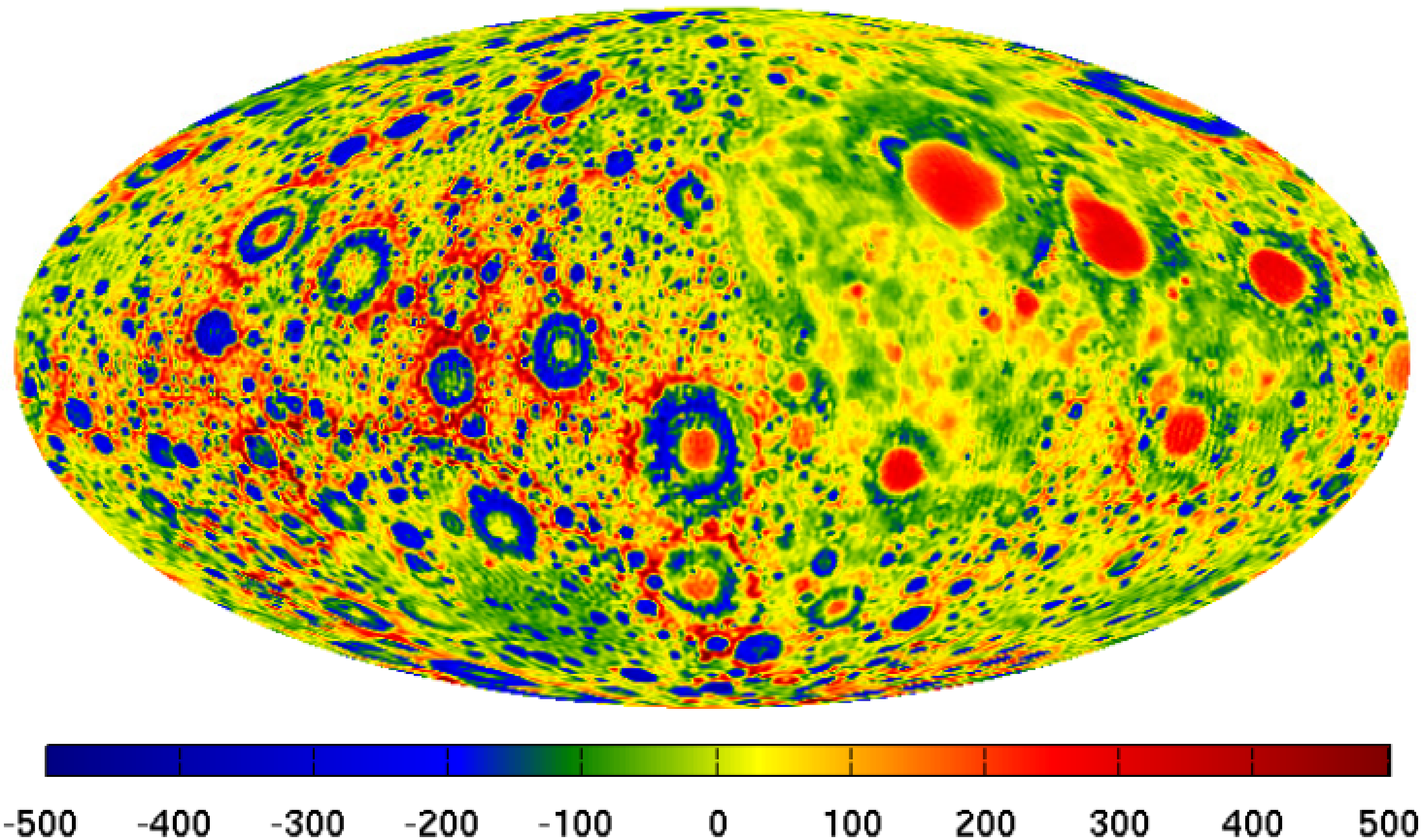


AIUB-GRL200A : a priori GRGM900C (d/o 200), post-fit KBRR = $19.7\ \mu m/s$

AIUB-GRL200B : a priori GRGM900C (d/o 600), post-fit KBRR = $0.7\ \mu m/s$

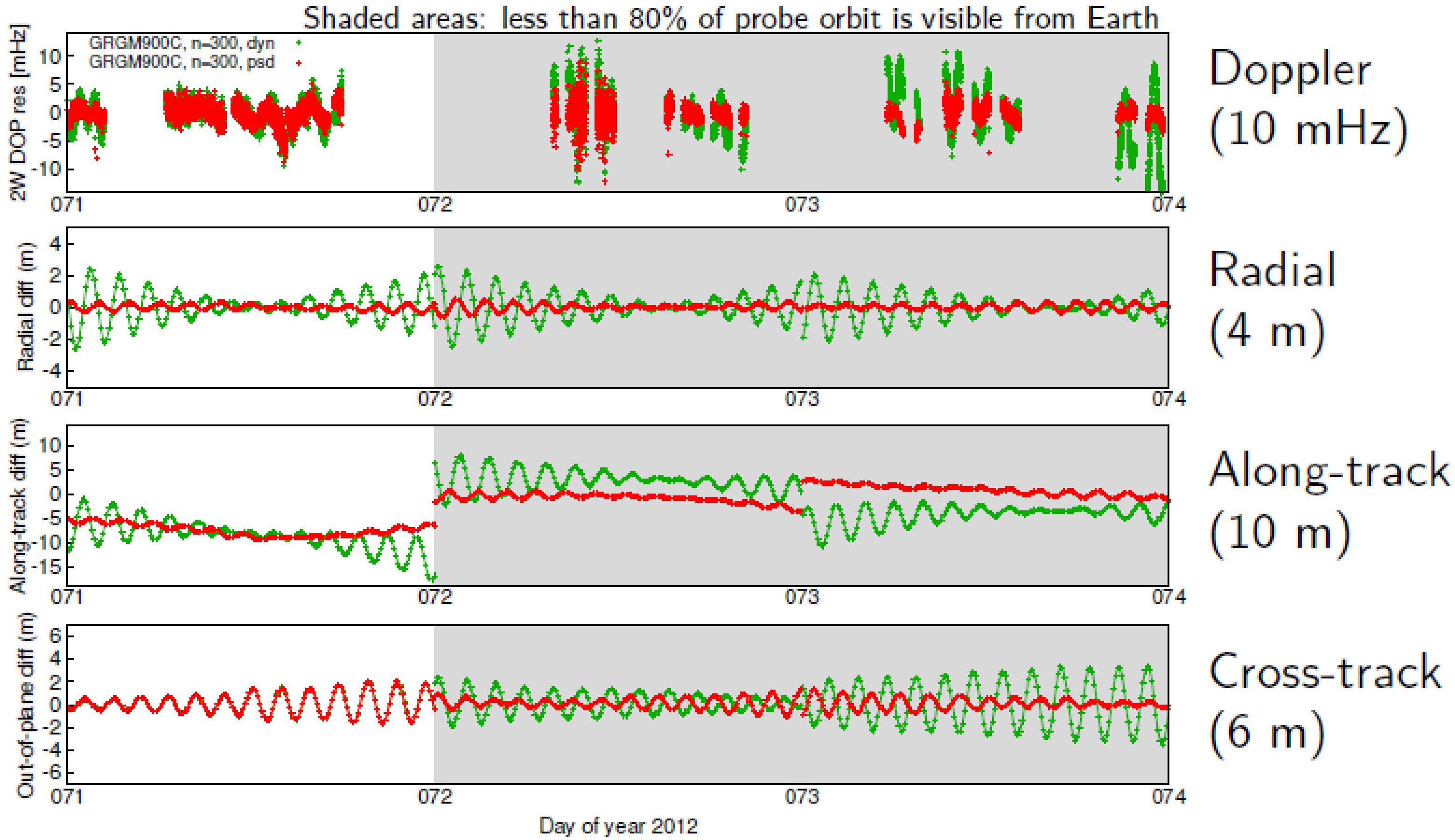
For details about our GNI1B + KBRR solution for orbit and gravity field, see: [Arnold, D., Bertone, S., Jäggi, A., Beutler, G. and Mervart, L. *GRAIL gravity field determination using the Celestial Mechanics Approach*, Icarus, 2015]





AIUB-GRL200A: Free-air gravity anomalies [mGal]

Orbit determination: Two-way DSN Doppler

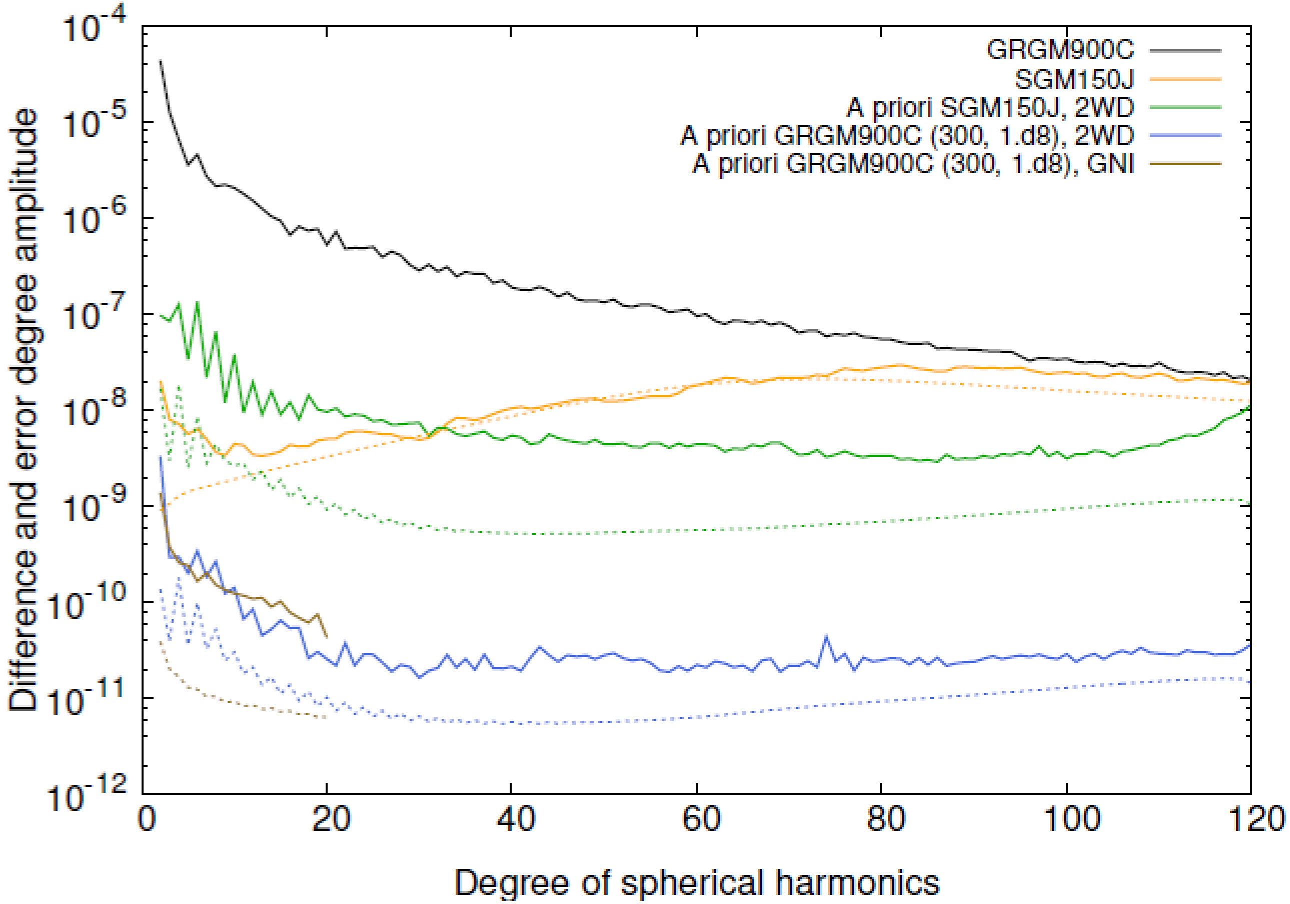


We consider 3 background models over the primary mission (PM):

- GRGM900C (up to d/o 300), dynamic modeling
- GRGM900C (up to d/o 300), acc: const A + opr R , pulses: 30' AO
- SGM150J (SELENE mission), dynamic modeling

Gravity field determination: 2WDOP, $l_\mathrm{m} = 120$

Difference degree amplitudes : $\Delta_l = \sqrt{\frac{1}{2l+1}\sum_{m=0}^{l}\left(\Delta\bar{C}_{lm}^2 + \Delta\bar{S}_{lm}^2\right)}$



a priori SGM150J: bad low degrees, more iterations needed

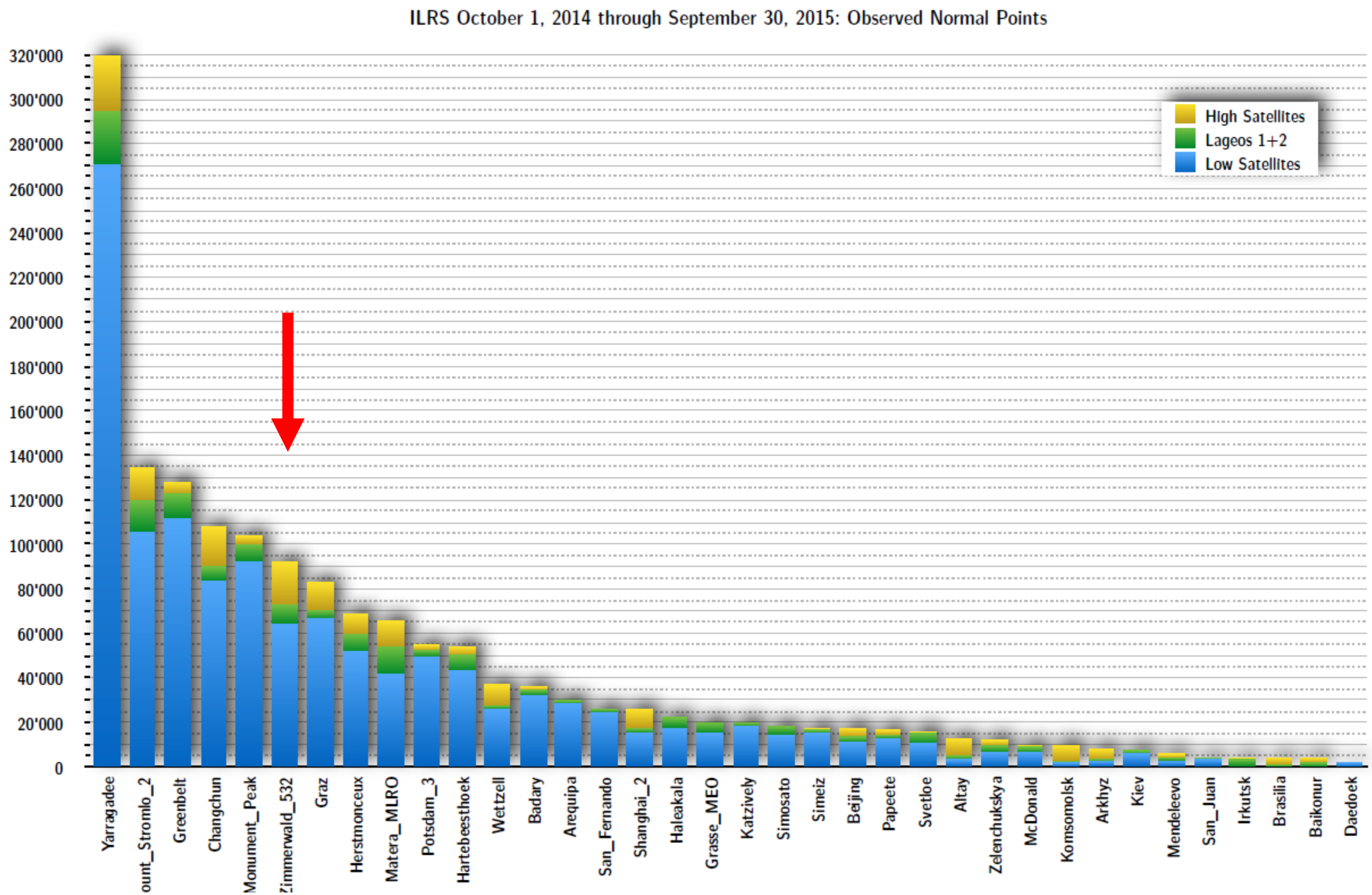
a priori GRGM900C (d/o 300): same level as GNI+KBRR solution

- First d/o 120 solution from original observations
- Need to iterate solutions starting from "poor" a priori gravity fields.

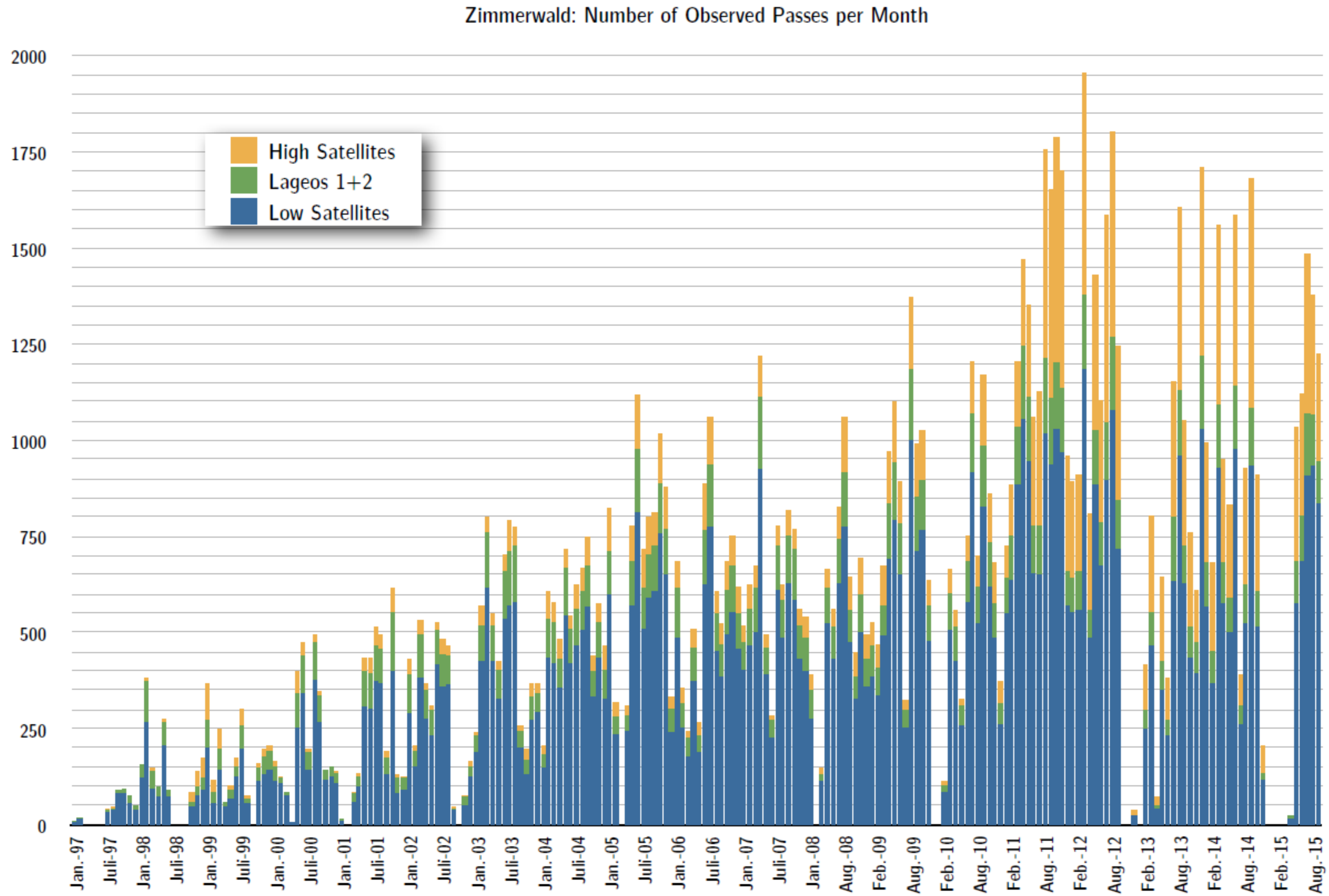
SLR Operations

- Laser down from November 2014 to April 2015!
  - Laser head had to be repaired by Thales (no replacement hardware available)
- Analysis/improvement of SLR mount model
  - Using pointing residuals of successful observations → 2-3 arcs rms
  - → Deformation during daytime due to thermal stress may most probably be modeled
  - → Improved return rate for GNSS satellites
- Laser Space Debris Observations (new study group in ILRS)
  - Envisat
  - Topex

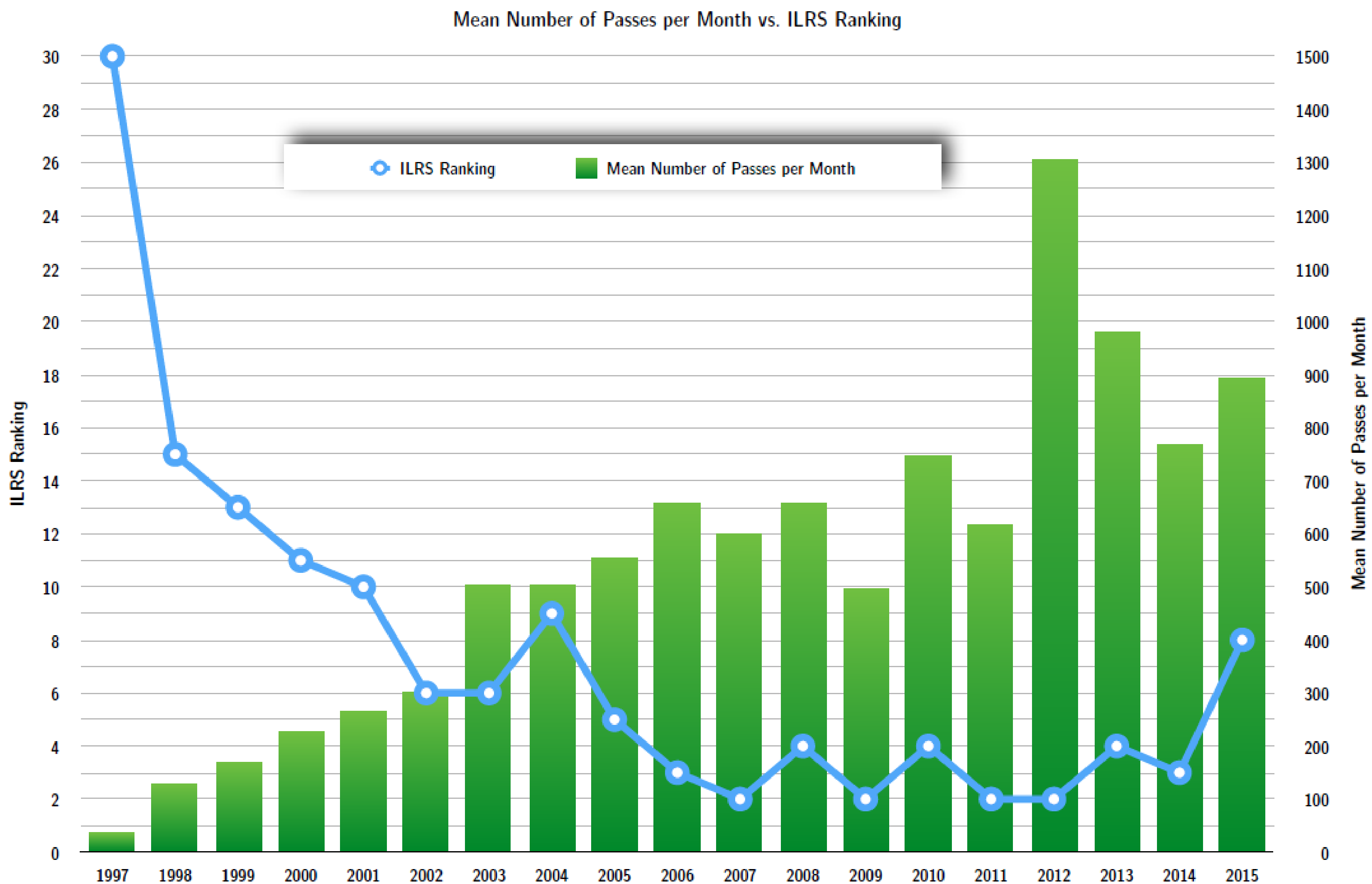
ILRS Station Performance



ZMD Station Performance

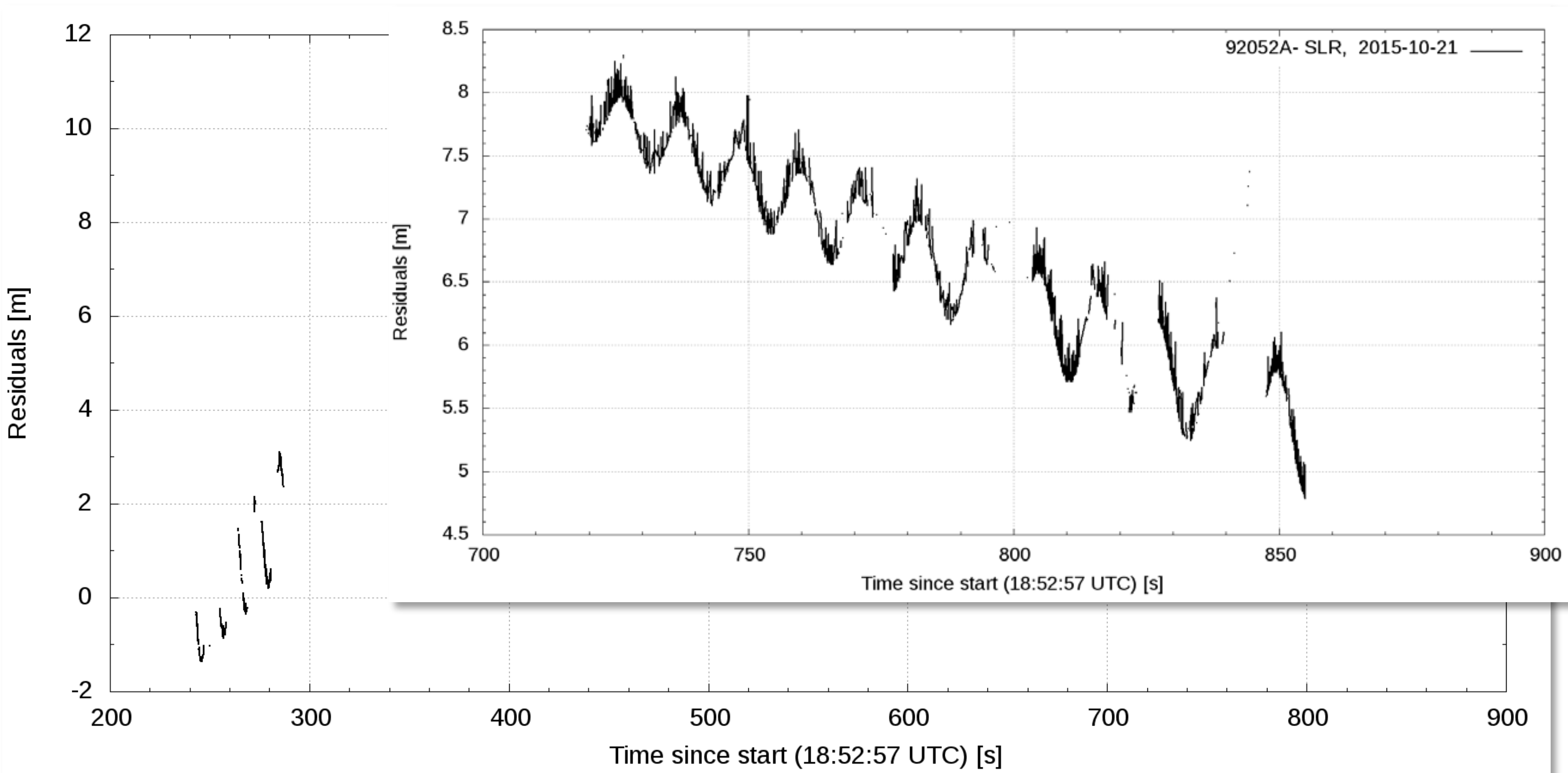


ZMD Station Performance

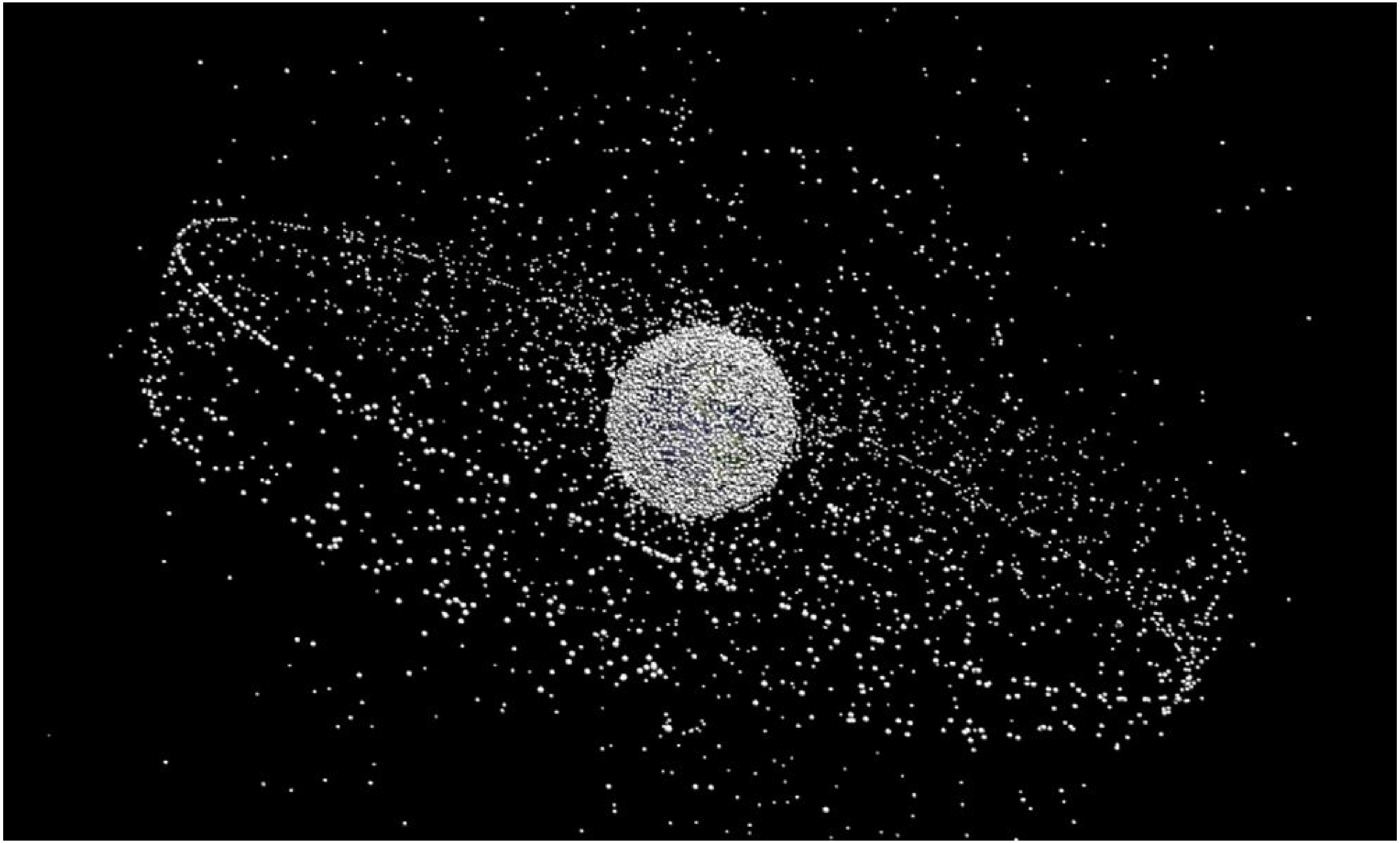


Topex

- Currently predictions from Graz/SDSG used
- for other targets own orbits – astrometry, ranges



Space Debris

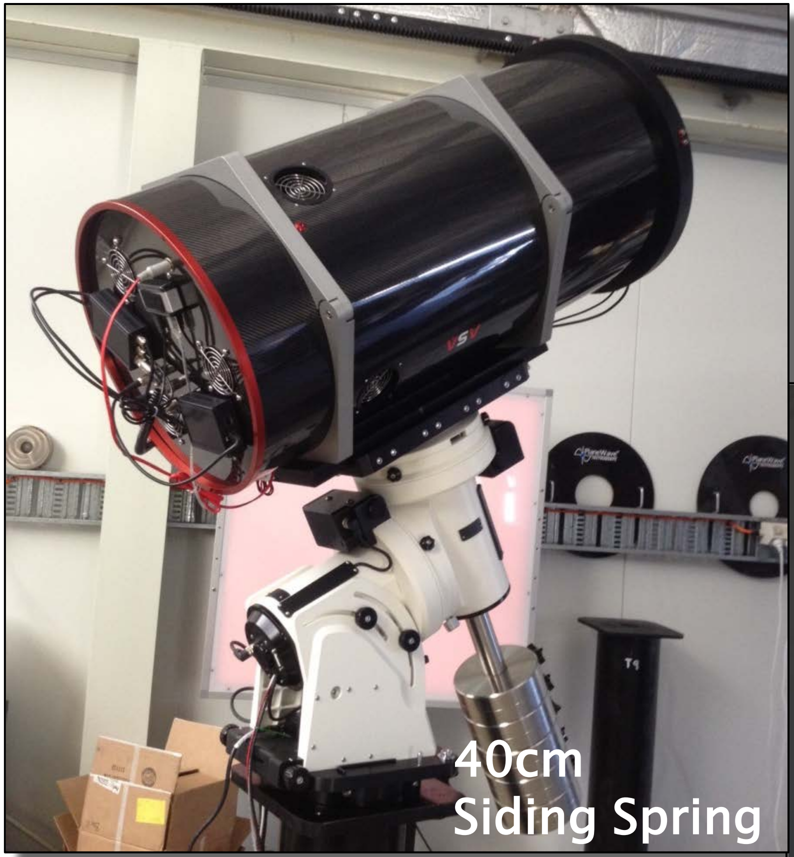


Space Debris Research

- Open Questions
  - Population
    - how many?
    - size distribution?
    - orbit regions?
    - nature of objects?
    - sources, sinks?
  - Physics/Mechanisms
    - creation
    - evolution of orbits
    - long-term evolution (chain reaction): → models
- Approach
  - Search for debris (surveillance)
  - Determine orbits (orbit catalogues)
  - Characterize (physical properties)

Optical Sensors

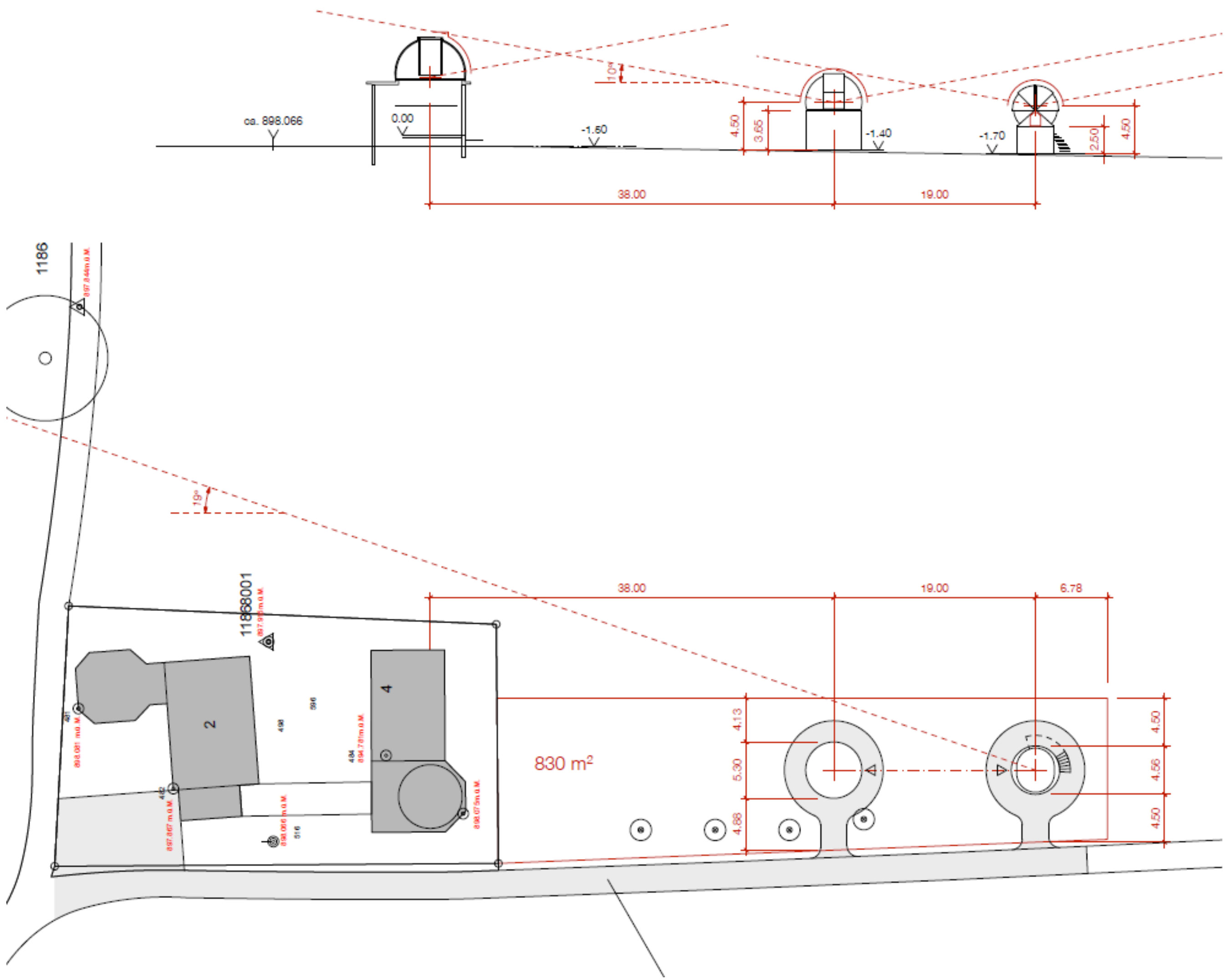
Optical Sensors



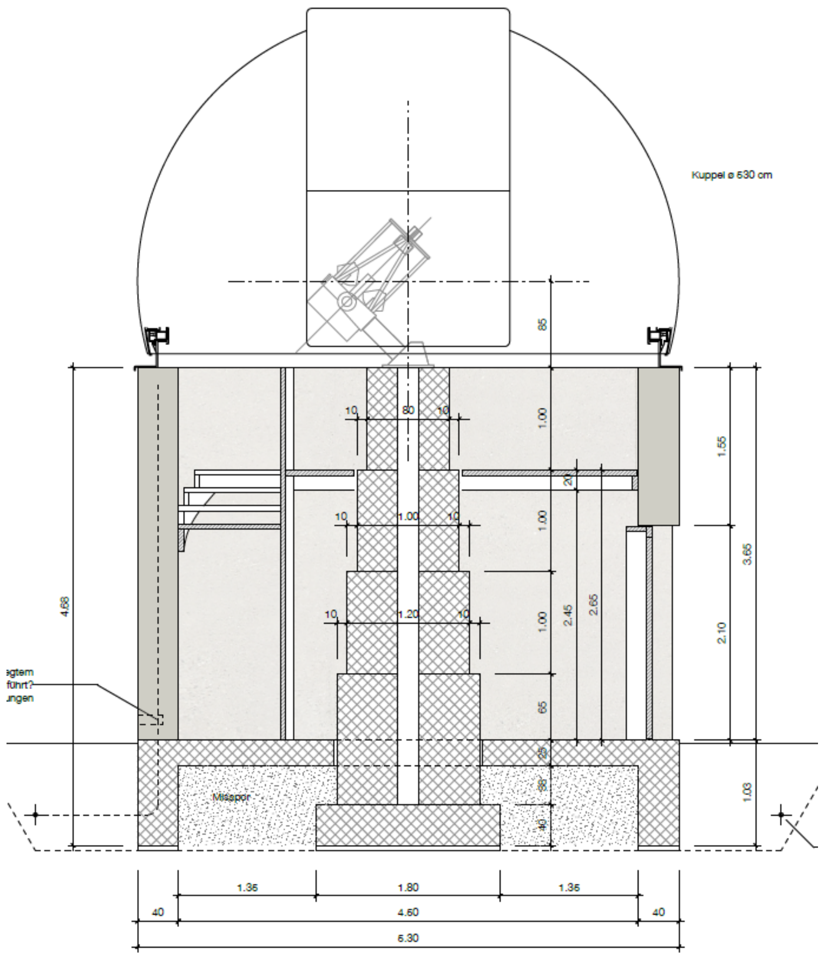
First Light 2016 ...

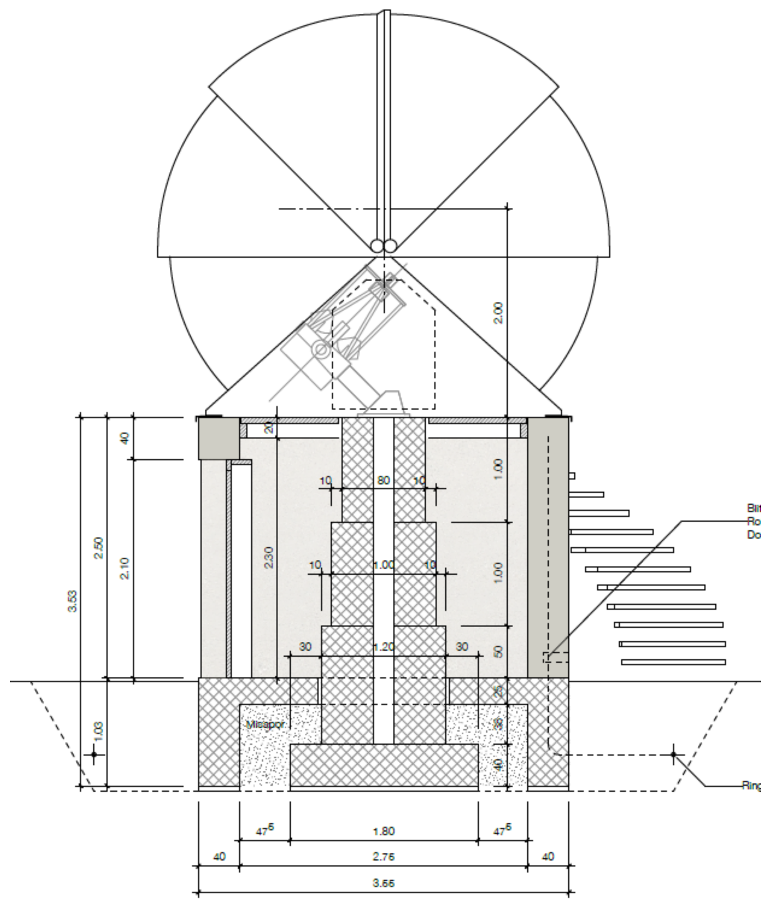
- 0.8/0.7m telescope
- Space debris research (AIUB)
- Optical communication demonstration with LEO s/c (Ruag Space)

New Domes (2016)



New Domes (2016)





Vielen Dank
für Ihre Aufmerksamkeit

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