Swiss Optical Ground Station and Geodynamics Observatory Zimmerwald

Schweizerische Eidgenossenschaft
Confédération suisse
Confederazione Svizzera
Confederaziun svizra

Bundesamt für Landestopografie
swisstopo

SLR Operations

- Laser down from November 2015 to 12. April 2016!
  - Laser head had to be repaired by Thales (no replacement hardware available)
  - April/May: energy ~4mJ (instead of 10mJ)
  - May–Nov: energy ~0.4mJ

  →Tracking of LEO up to LAGEOS o.k. high-altitude satellites difficult

  →new laser head ordered in July
- Laser down since 21.10.2016
  - high voltage power supply failure

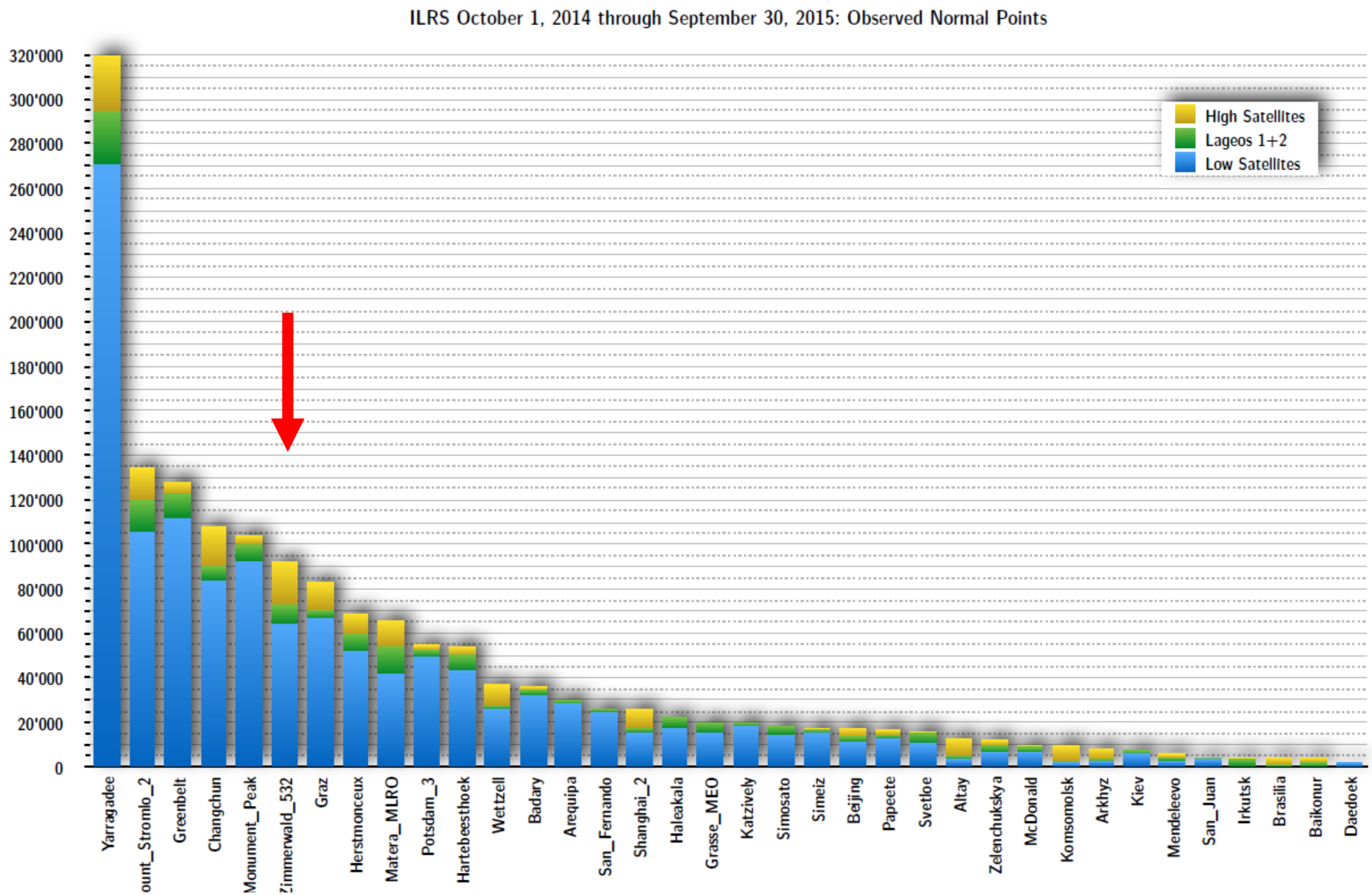
  →repair at manufacturer's premises

→new head expected in December 2016

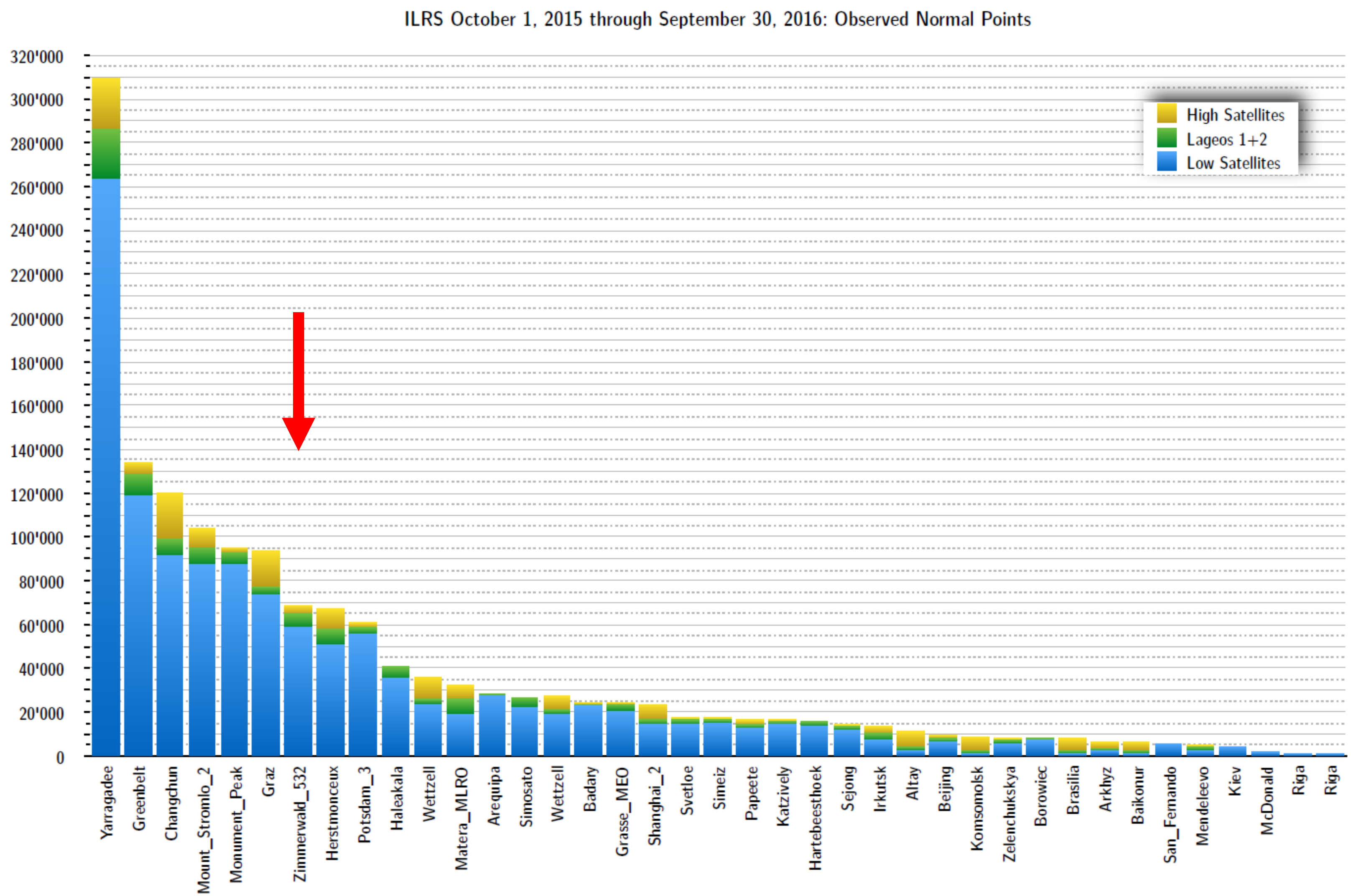
SLR Operations

- New SLR projects
  - New high-altitude satellite campaigns
  - European Laser Time Transfer project (ELT)(ACES experiment on ISS)
    - definition of hardware requirements
    - analysis of software requirements
  - Space Debris laser campaigns (new ILRS Space Debris Study Group)
- Definition/evaluation of new laser
  - 100Hz/kHz…?
  - discussions with and offers from several suppliers
  - possible “in-house” solution with Institute for Applied Physics (IAP)
- Main technical developments
  - EFOS-8 Maser is operational frequency standard for SLR since 9.8.2016
  - usability of sCMOS tracking camera improved
  - migration of telescope/electronics control software from DOS to Linux (in progress)

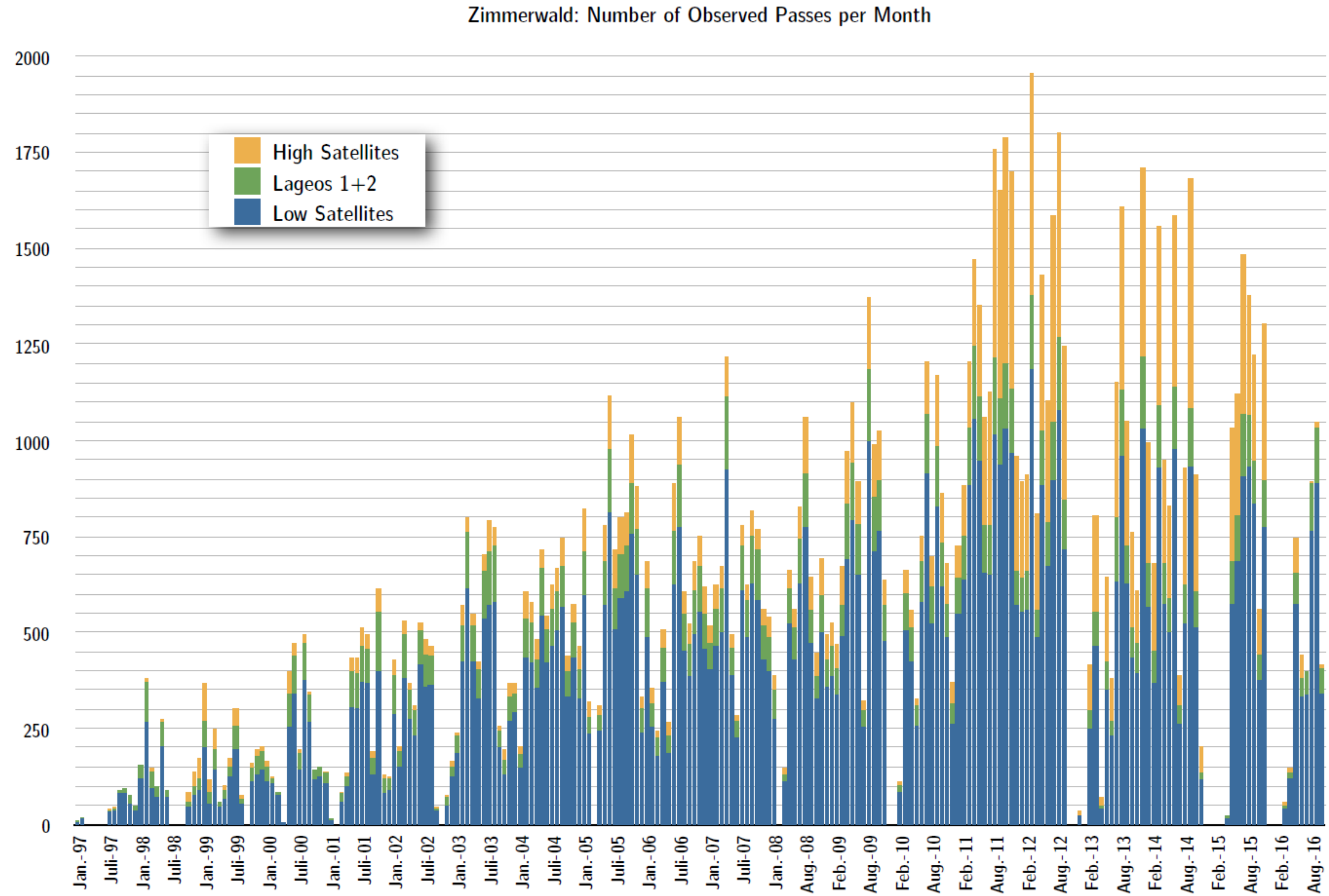
ILRS Station Performance 2014/2015



ILRS Station Performance 2015/2016



ZMD Station Performance 1997 – 2016

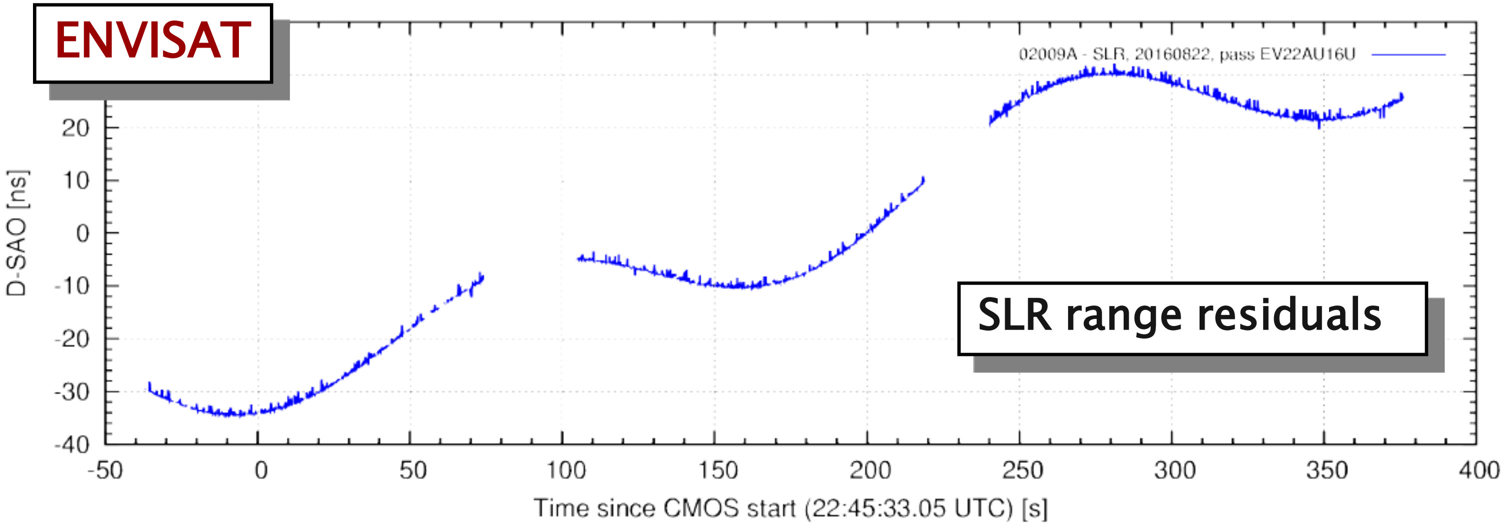


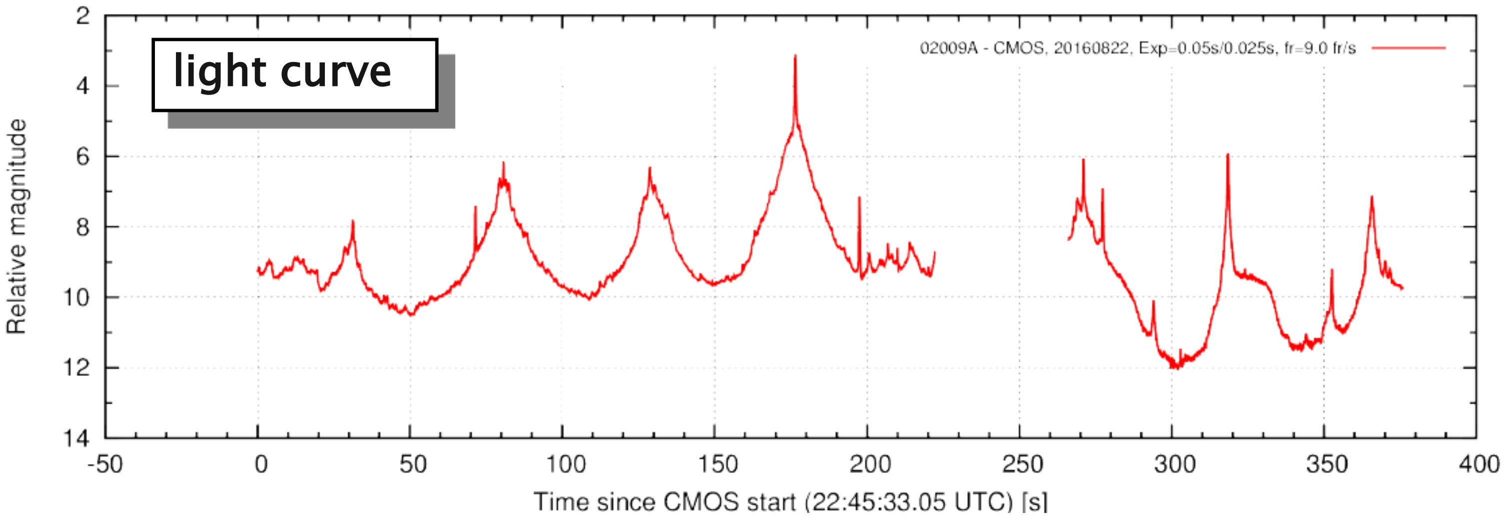
Optical Sensors in Zimmerwald

First Light 2017 ...

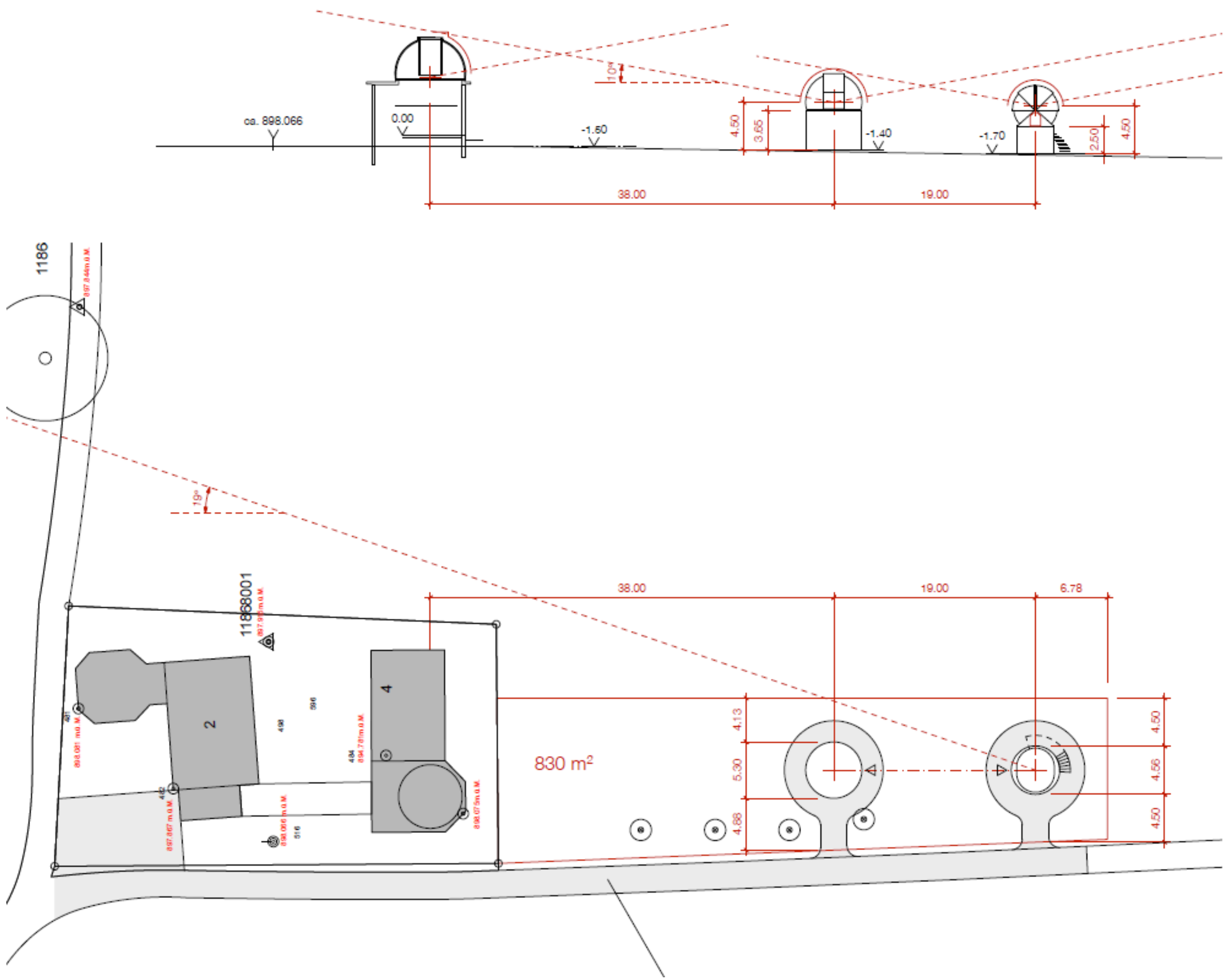
- 0.8m telescope
- Space debris research (AIUB)
- Offload ZIMLAT
- Optical communication demonstration with LEO s/c

Space Debris Attitude Determination

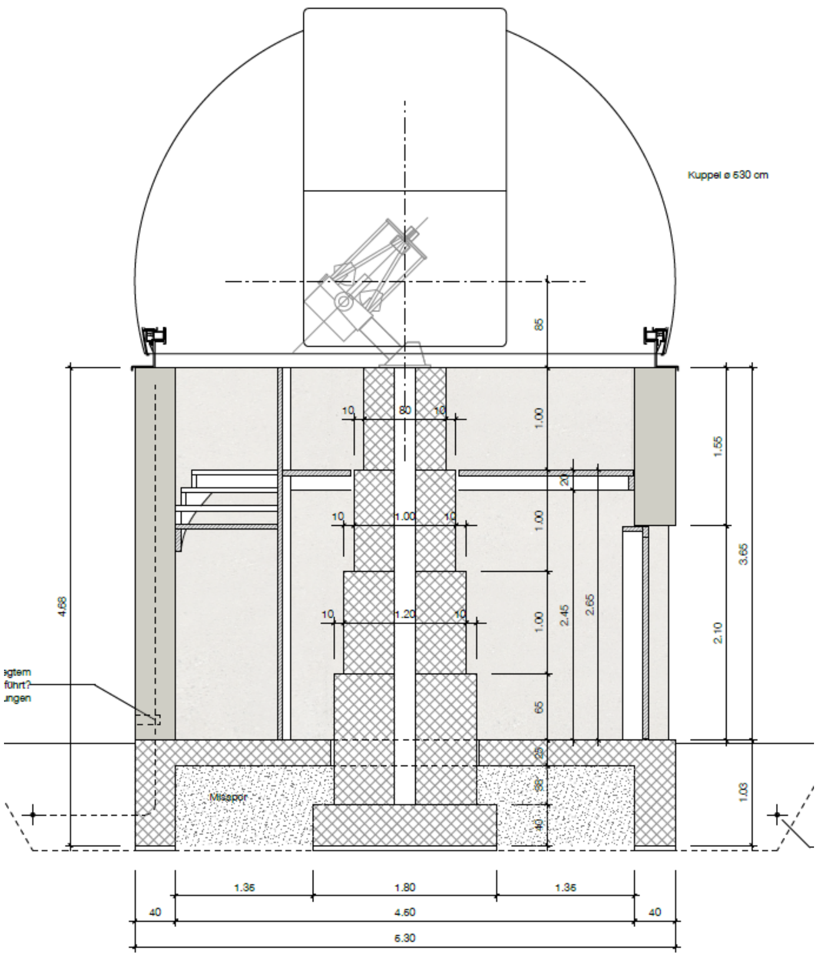


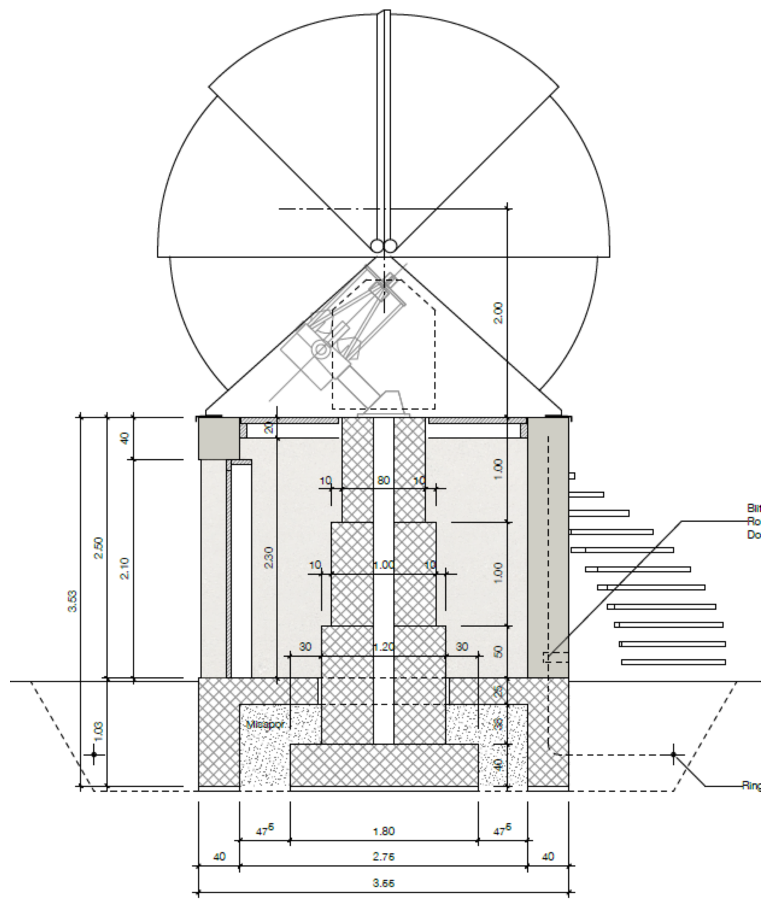


New Domes (2016)



New Domes (2016)





New Domes 2.9.2016

New Domes 10.2016

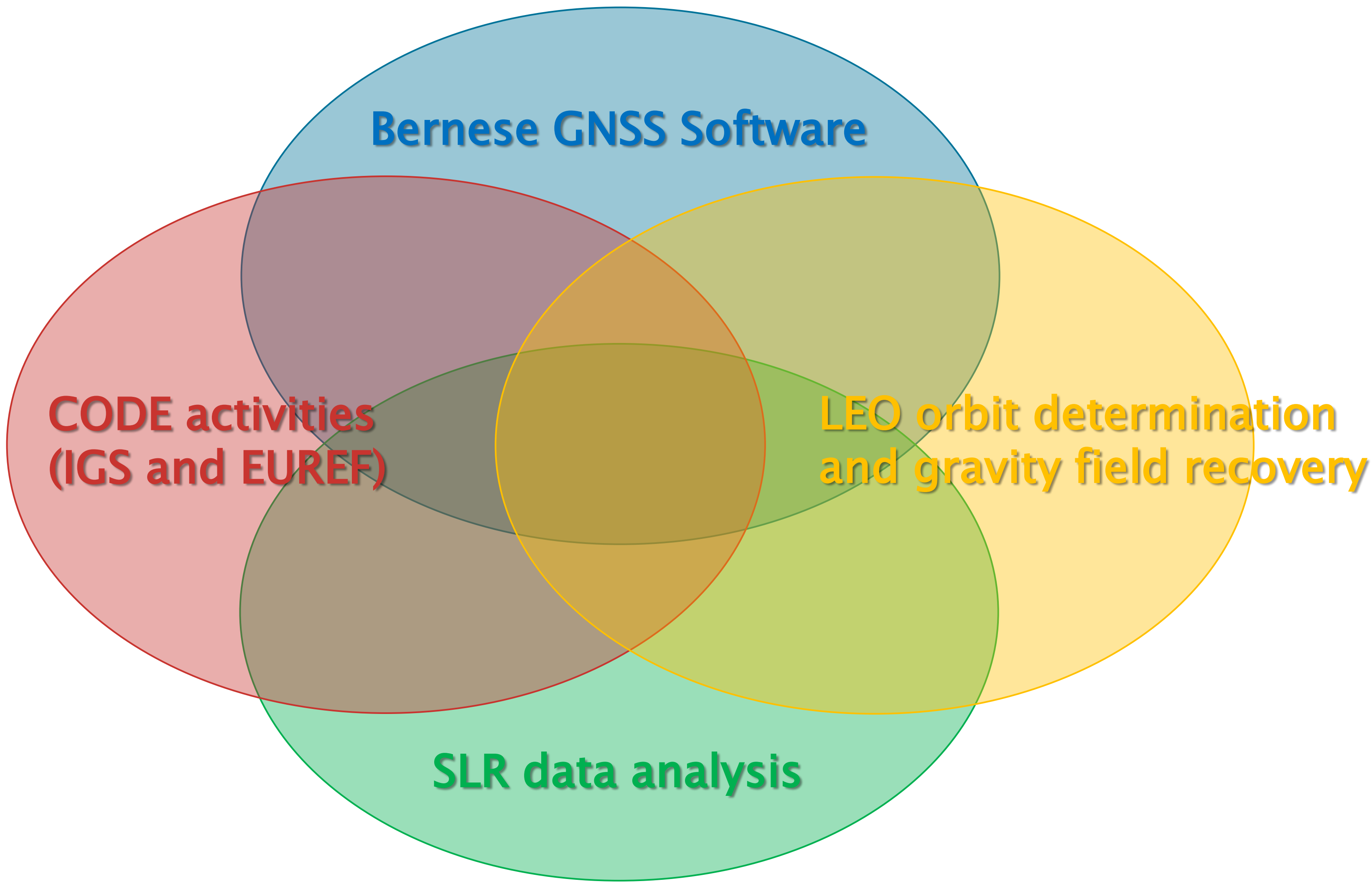
New Domes 10.2016

New Domes 10.11.2016

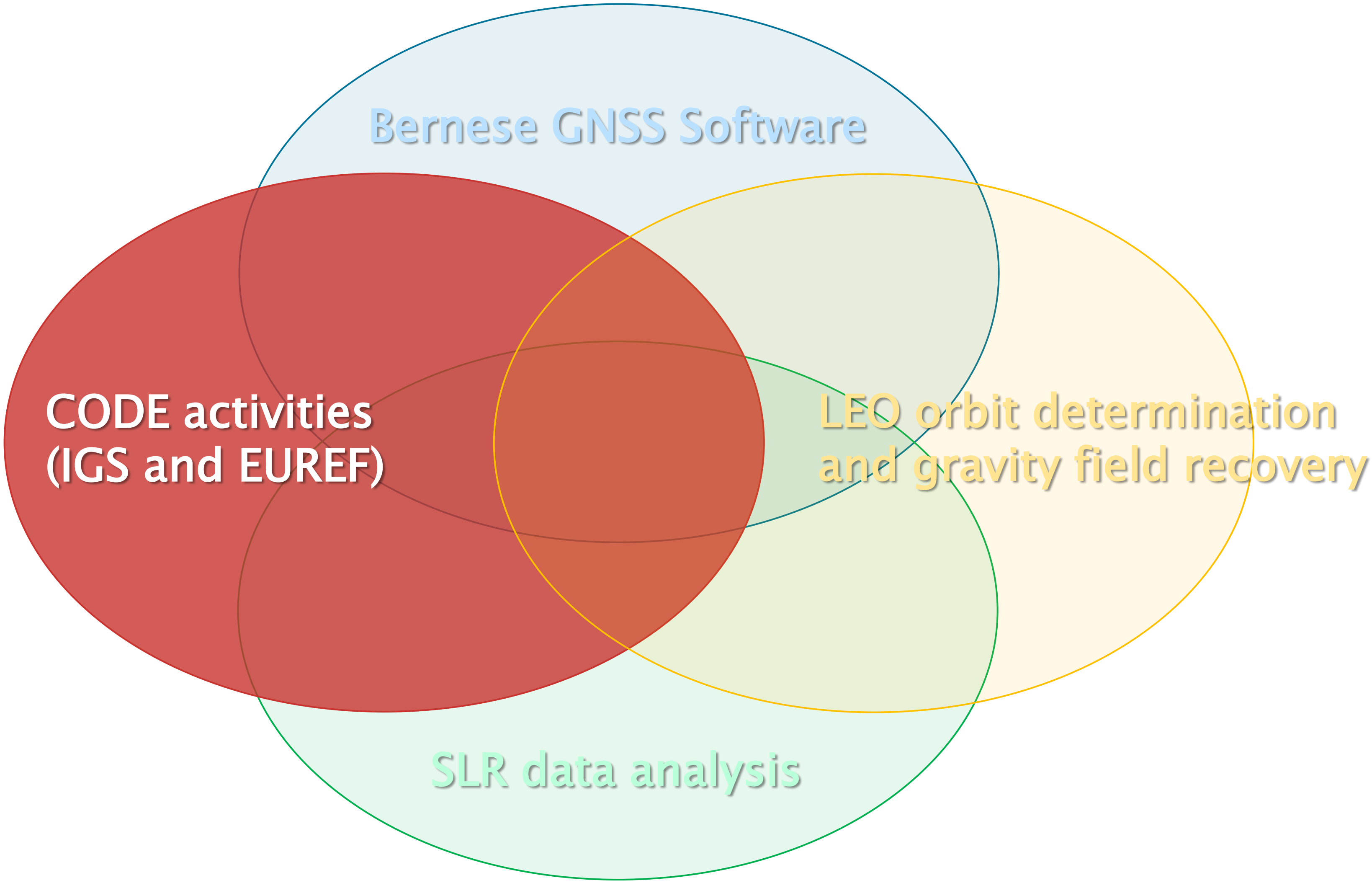
Aktivitäten der Forschungsgruppe Satellitengeodäsie am AIUB

R. Dach
F. Andritsch, D. Arnold, K. Bentel, S. Bertone,
P. Fridez, Y. Jean, A. Maier, U. Meyer,
~~E. Orliac,~~ L. Prange , S. Scaramuzza,
S. Schaer, D. Sidorov, P. Stebler,
A. Sušnik, A. Villiger, ~~P. Walser~~

Satellite Geodesy Research Group



Satellite Geodesy Research Group



Updates from the CODE analysis center

DOI for CODE products

Please acknowledge the usage of products from the CODE analysis center by the following references (see http://www.bernese.unibe.ch/publist/publist_code.php):

- Dach, Rolf; Schaer, Stefan; Arnold, Daniel; Orliac, Etienne; Prange, Lars; Sušnik, Andreja; Villiger, Arturo; Jäggi, Adrian (2016). CODE final product series for the IGS. Published by Astronomical Institute, University of Bern. URL: http://www.aiub.unibe.ch/download/CODE; DOI: 10.7892/boris.75876.

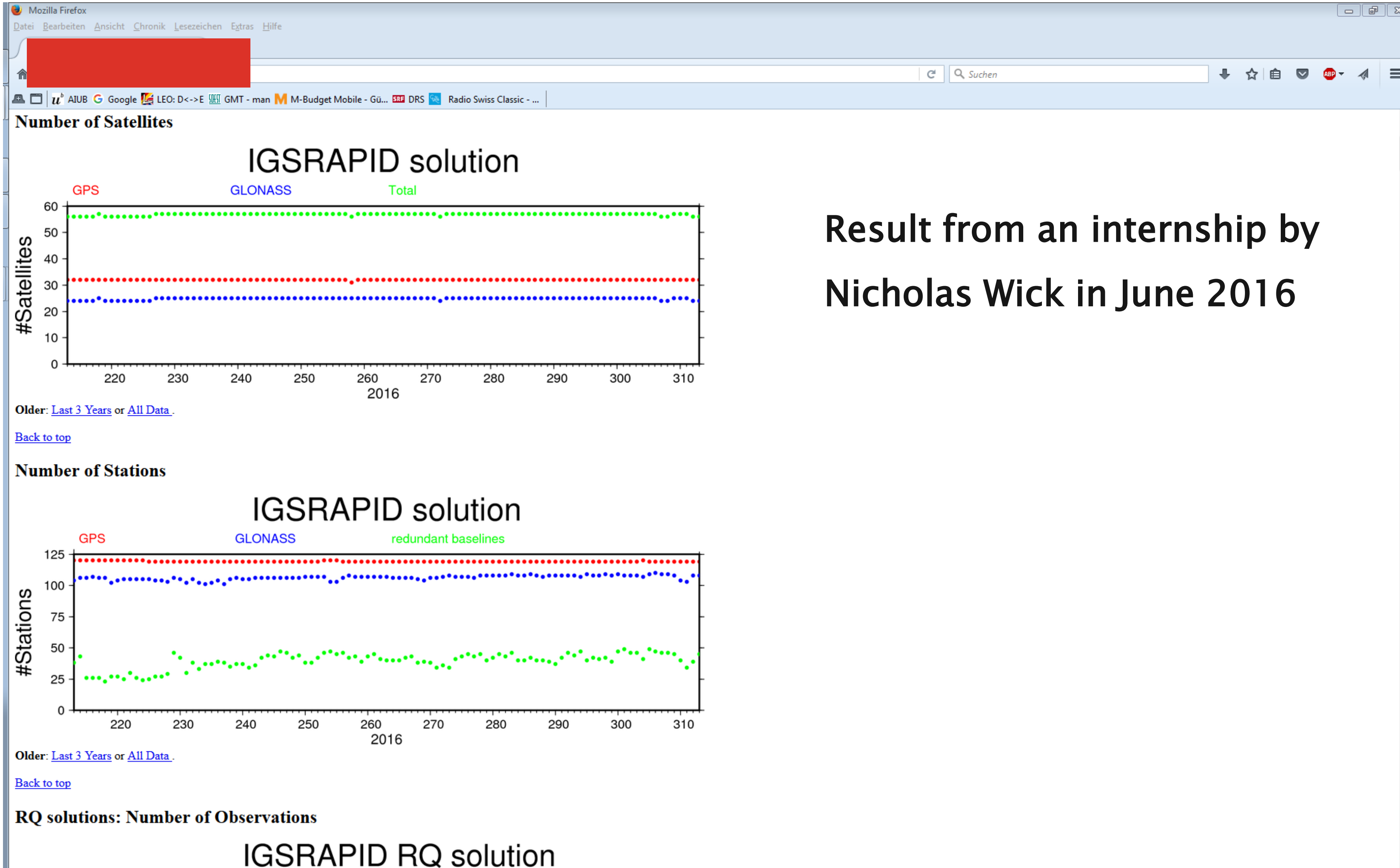
- Dach, Rolf; Schaer, Stefan; Arnold, Daniel; Orliac, Etienne; Prange, Lars; Sušnik, Andreja; Villiger, Arturo; Jäggi, Adrian (2016). CODE rapid product series for the IGS. Published by Astronomical Institute, University of Bern. URL: http://www.aiub.unibe.ch/download/CODE; DOI: 10.7892/boris.75854.

- Dach, Rolf; Schaer, Stefan; Arnold, Daniel; Orliac, Etienne; Prange, Lars; Sušnik, Andreja; Villiger, Arturo; Jäggi, Adrian (2016). CODE ultra-rapid product series for the IGS. Published by Astronomical Institute, University of Bern. URL: http://www.aiub.unibe.ch/download/CODE; DOI: 10.7892/boris.75676.

- Prange, Lars; Orliac, Etienne; Dach, Rolf; Schaer, Stefan; Arnold, Daniel; Jäggi, Adrian (2016). CODE product series for the IGS MGEX project. Published by Astronomical Institute, University of Bern. URL: http://www.aiub.unibe.ch/download/CODE_MGEX; DOI: 10.7892/boris.75882.

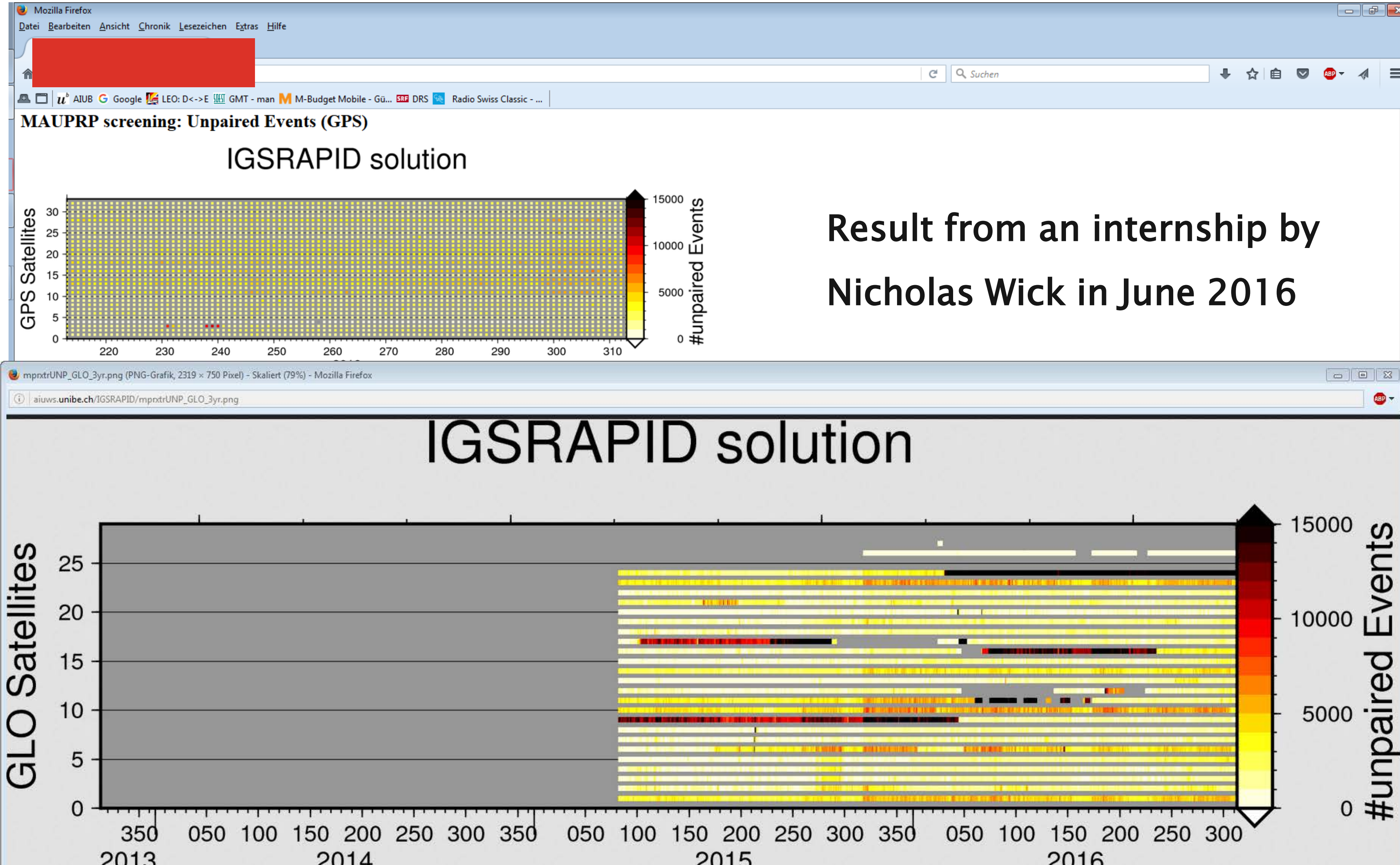
- Steigenberger, Peter; Lutz, Simon; Dach, Rolf; Schaer, Stefan; Jäggi, Adrian (2014). CODE repro2 product series for the IGS. Published by Astronomical Institute, University of Bern. URL: http://www.aiub.unibe.ch/download/REPRO_2013; DOI: 10.7892/boris.75680.

Key parameters from IGSRAPID as graphics



Result from an internship by Nicholas Wick in June 2016

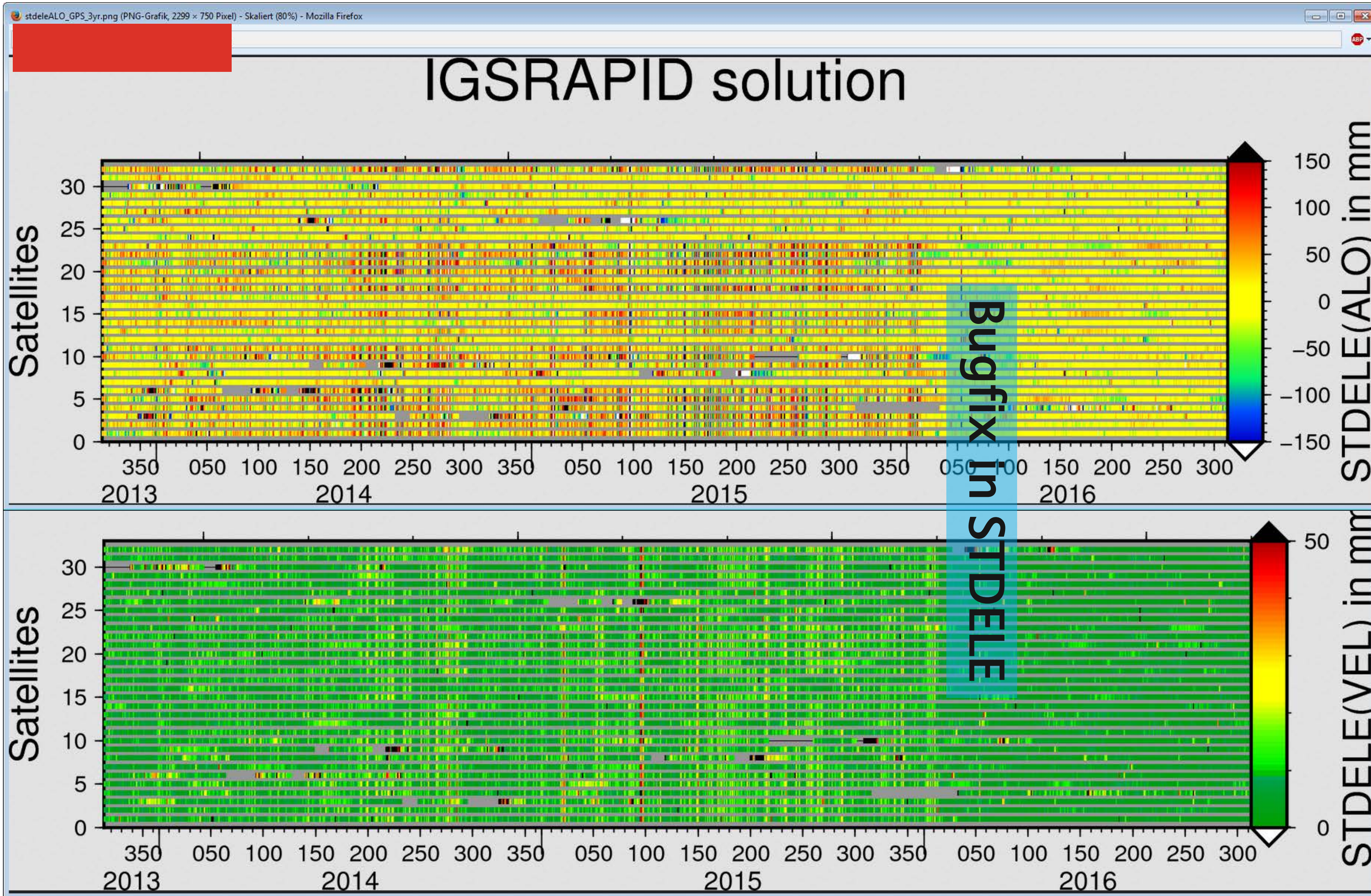
Key parameters from IGSRAPID as graphics



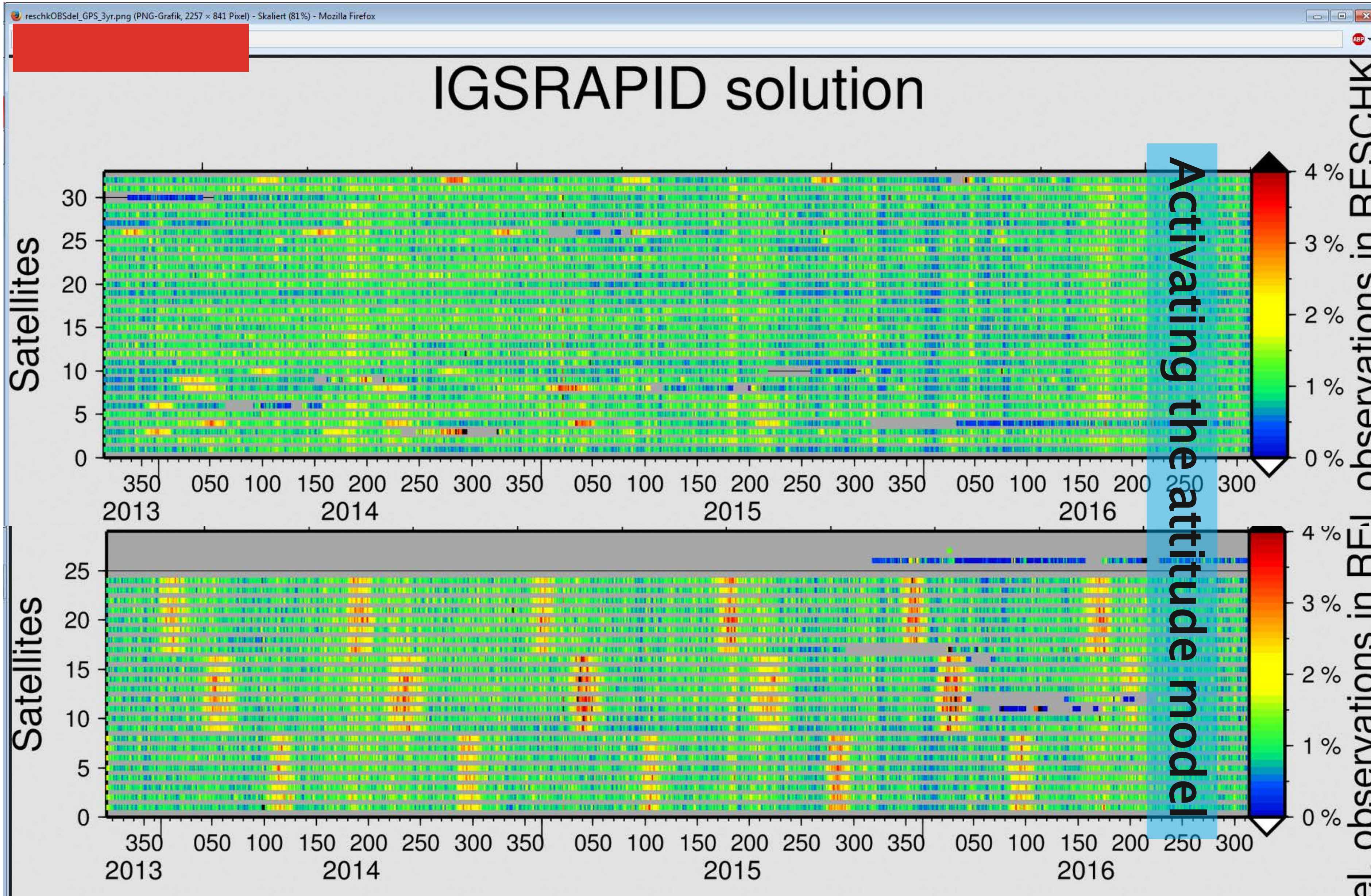
Result from an internship by

Nicholas Wick in June 2016

Key parameters from IGSRAPID as graphics

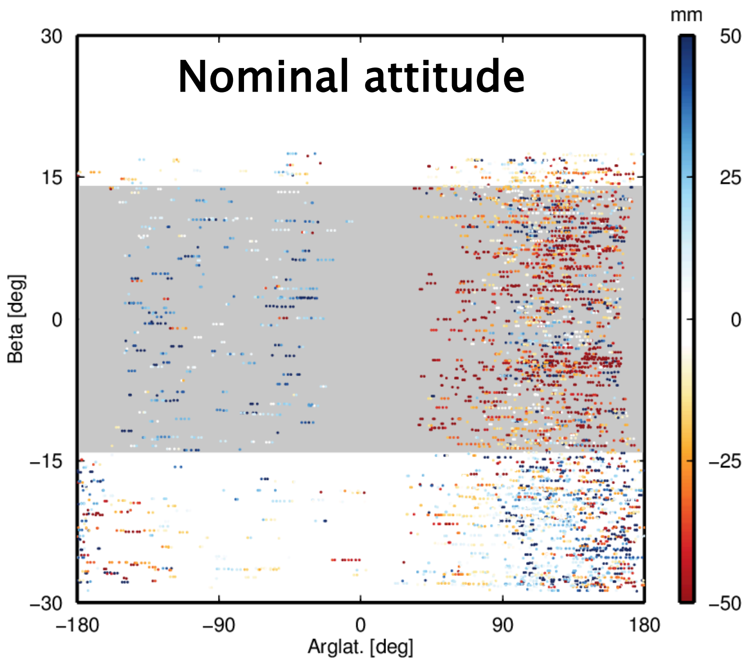


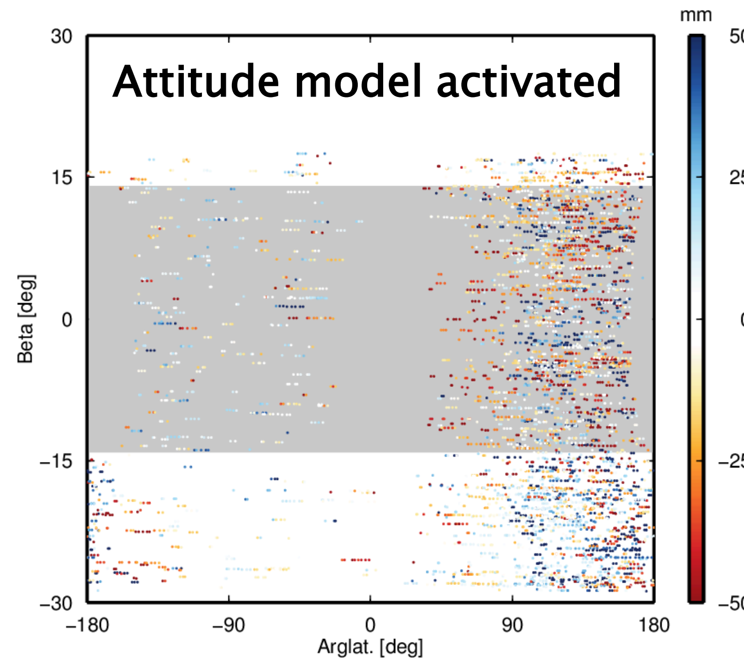
Key parameters from IGSRAPID as graphics



Attitude models activated at CODE

- GLONASS SLR residuals without/with attitude modelling
  - Eclipse condition: |β|< 14.1° (greyed area on the plots)

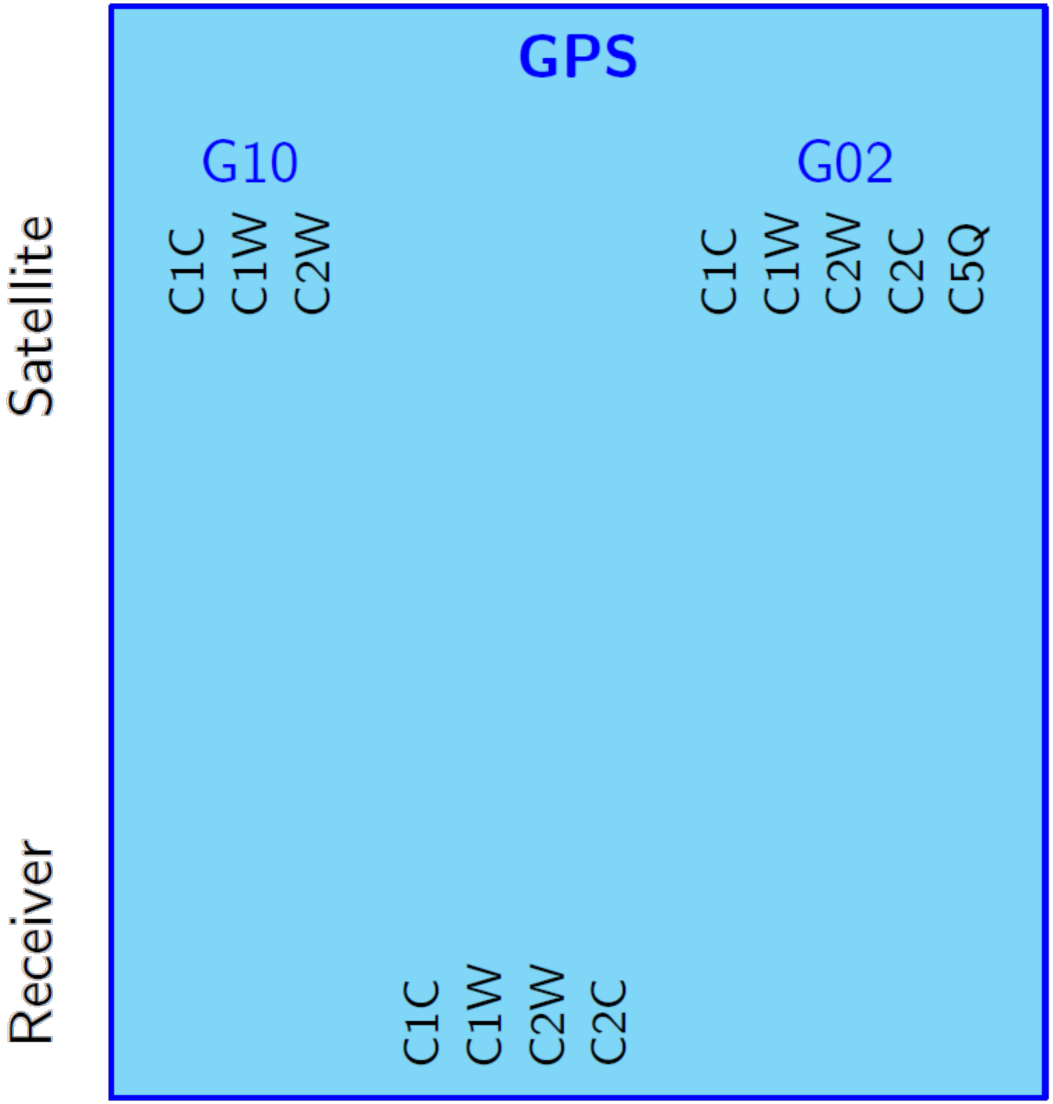




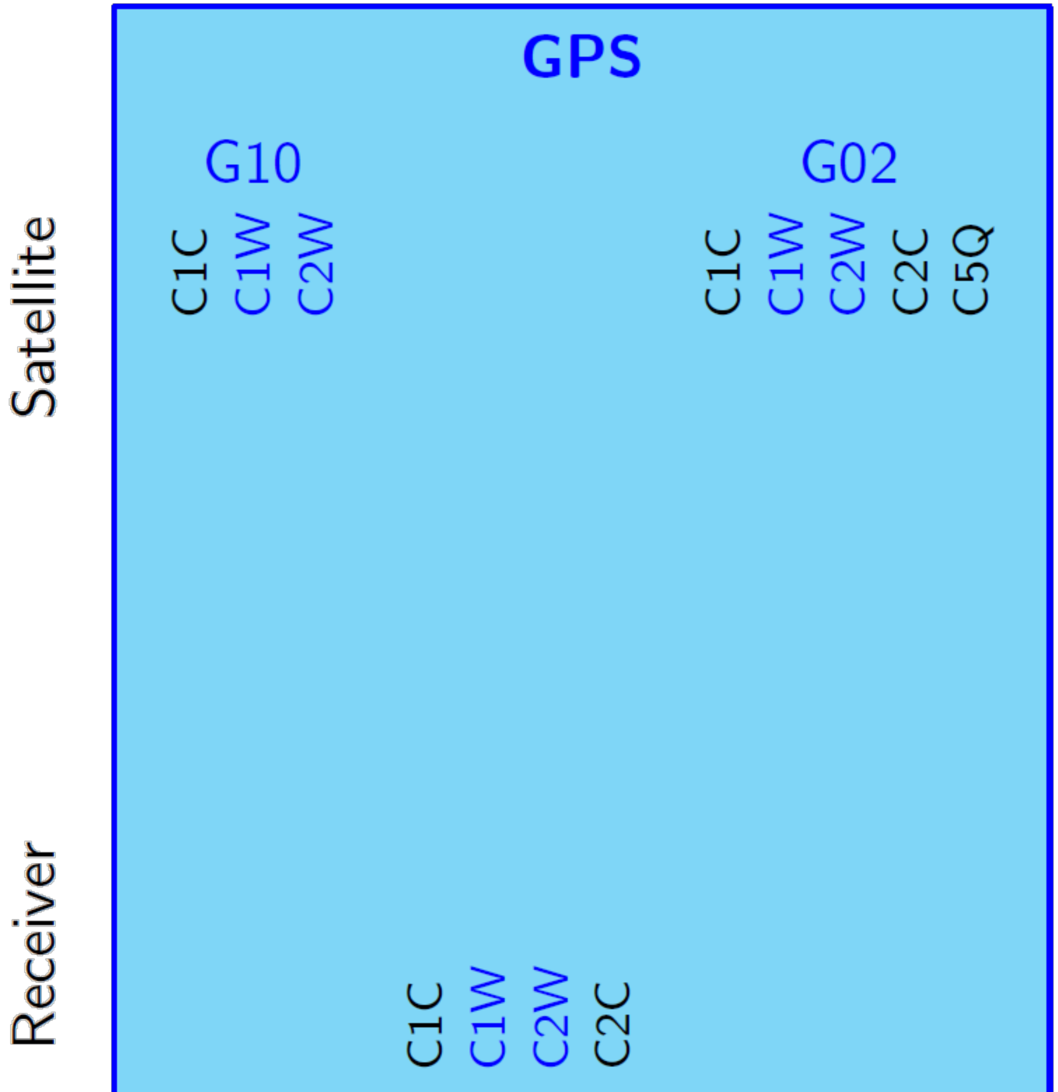
- SLR residuals as a function of the Sun elevation above the orbital plane (β) and argument of latitude of the satellite

Advancing the bias handling in the Bernese GNSS Software

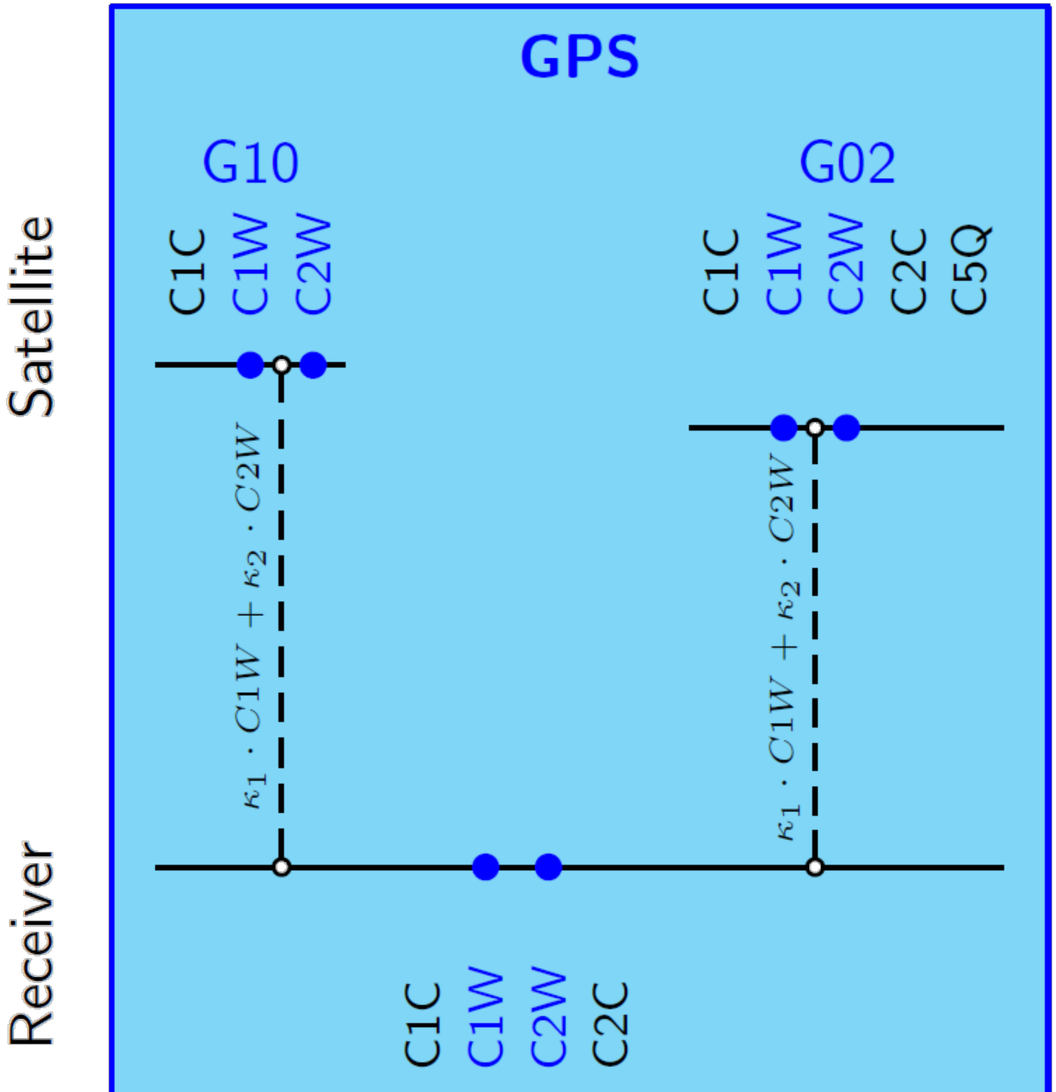
Pseudo–Absolute Code Biases: CLK



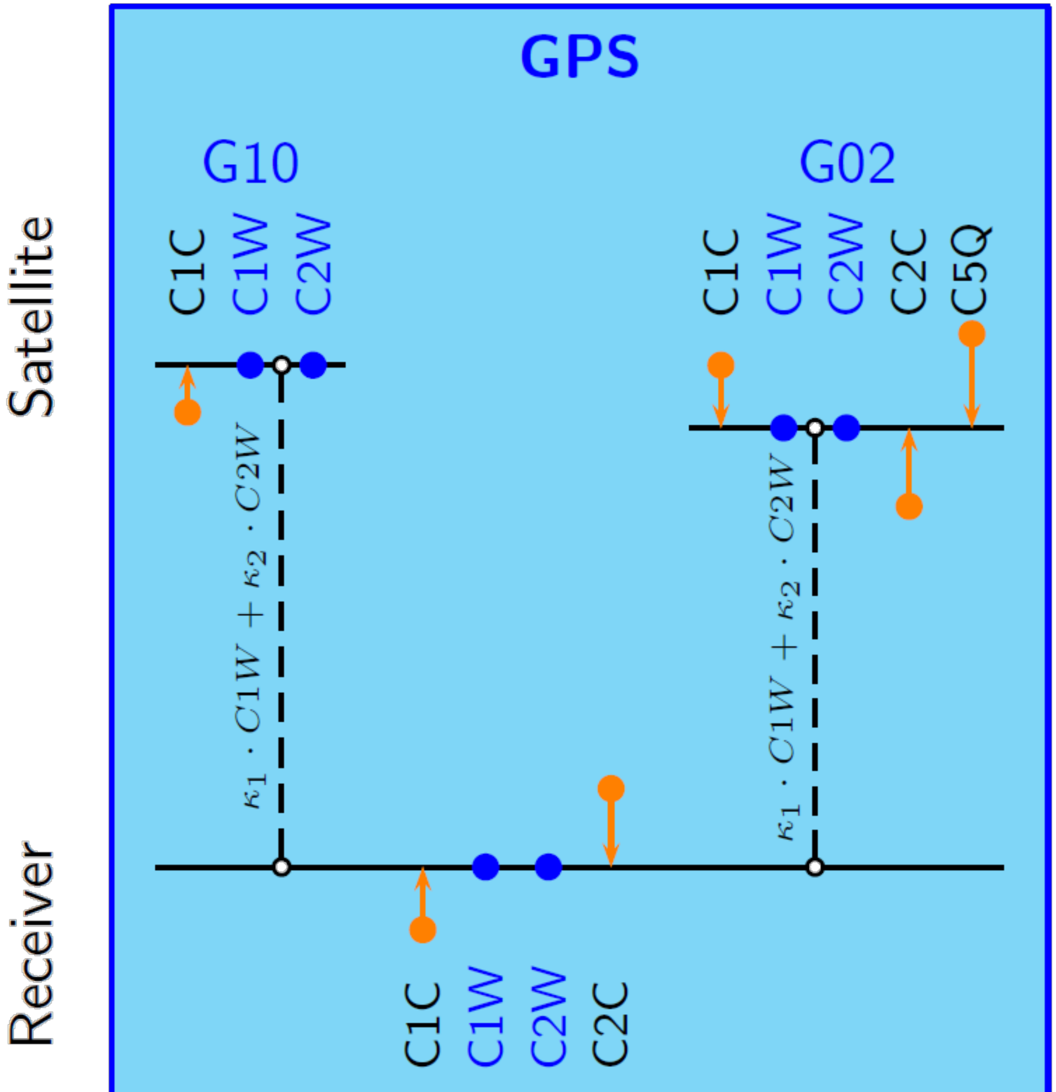
Pseudo-Absolute Code Biases: CLK



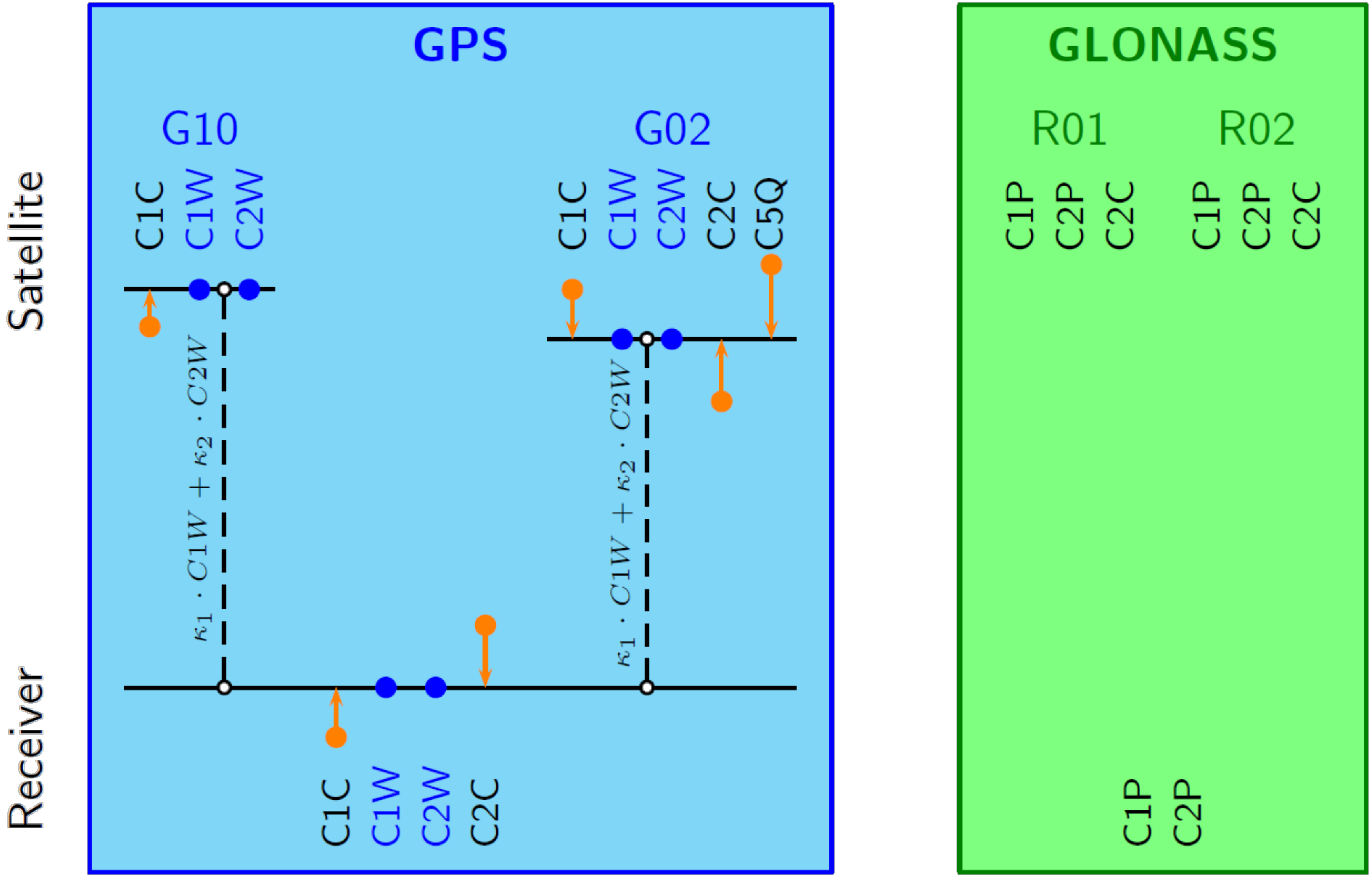
Pseudo–Absolute Code Biases: CLK



Pseudo–Absolute Code Biases: CLK

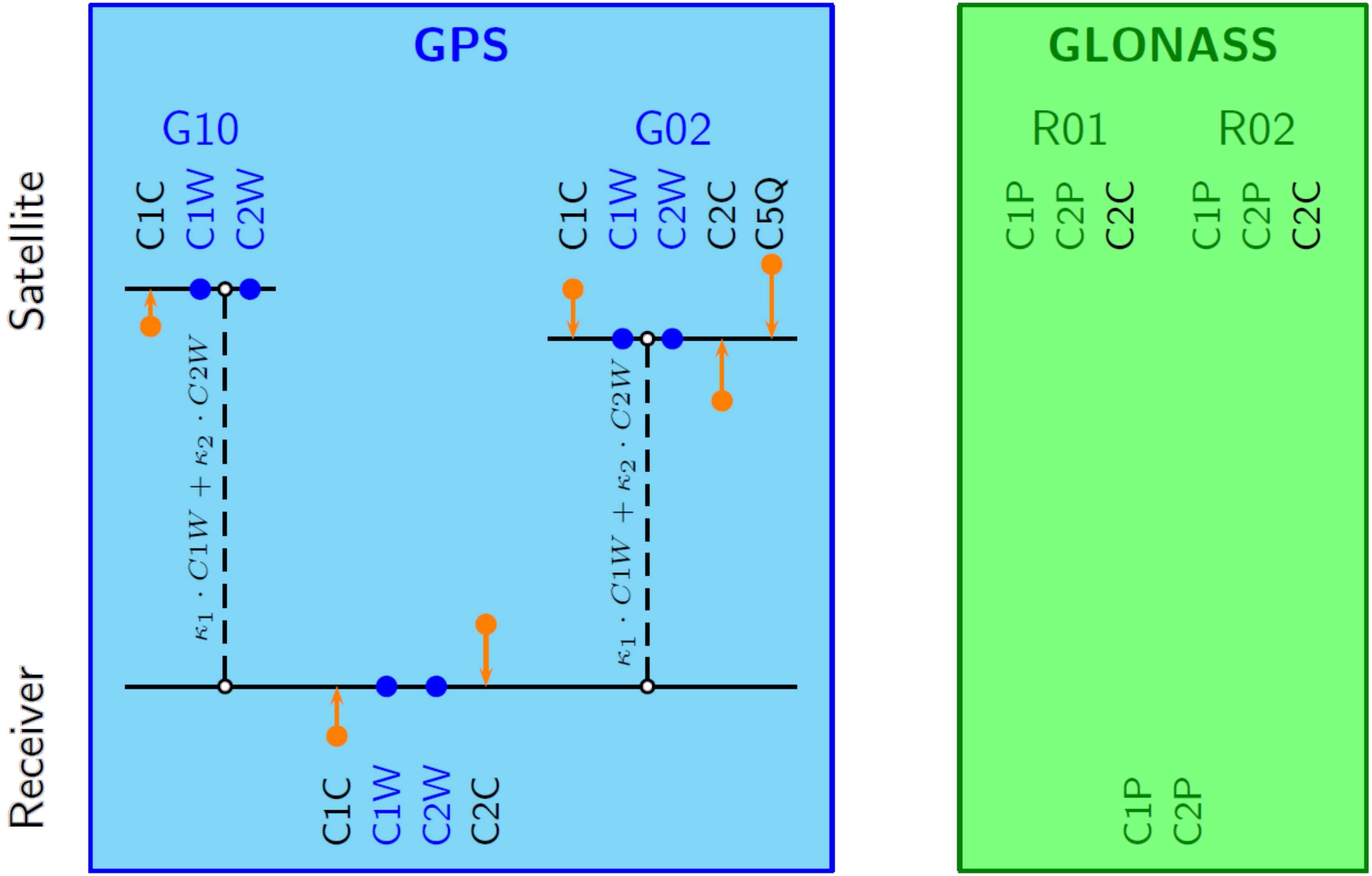


Pseudo-Absolute Code Biases: CLK

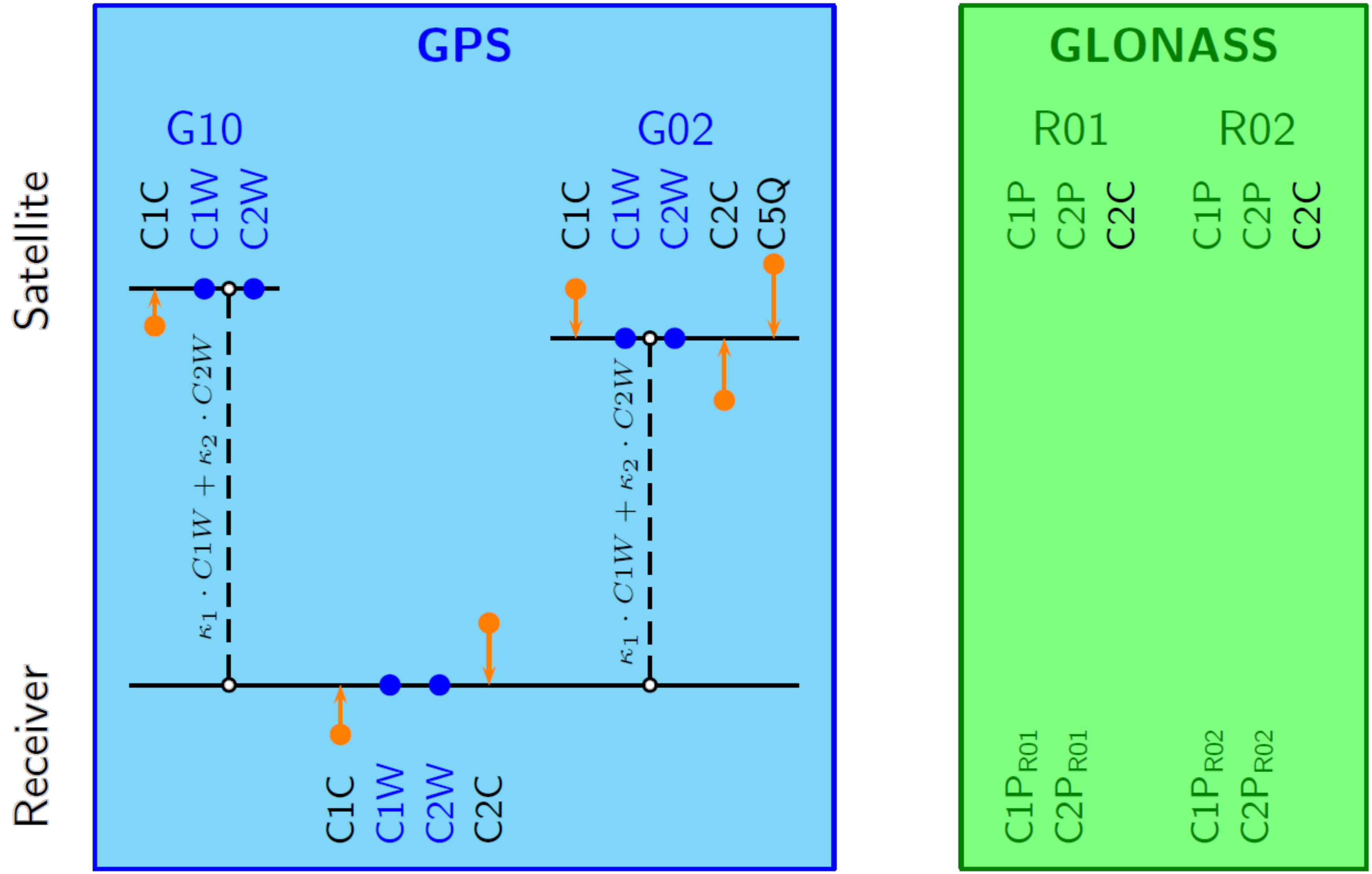


 Astronomical Institute University of Bern AIUB

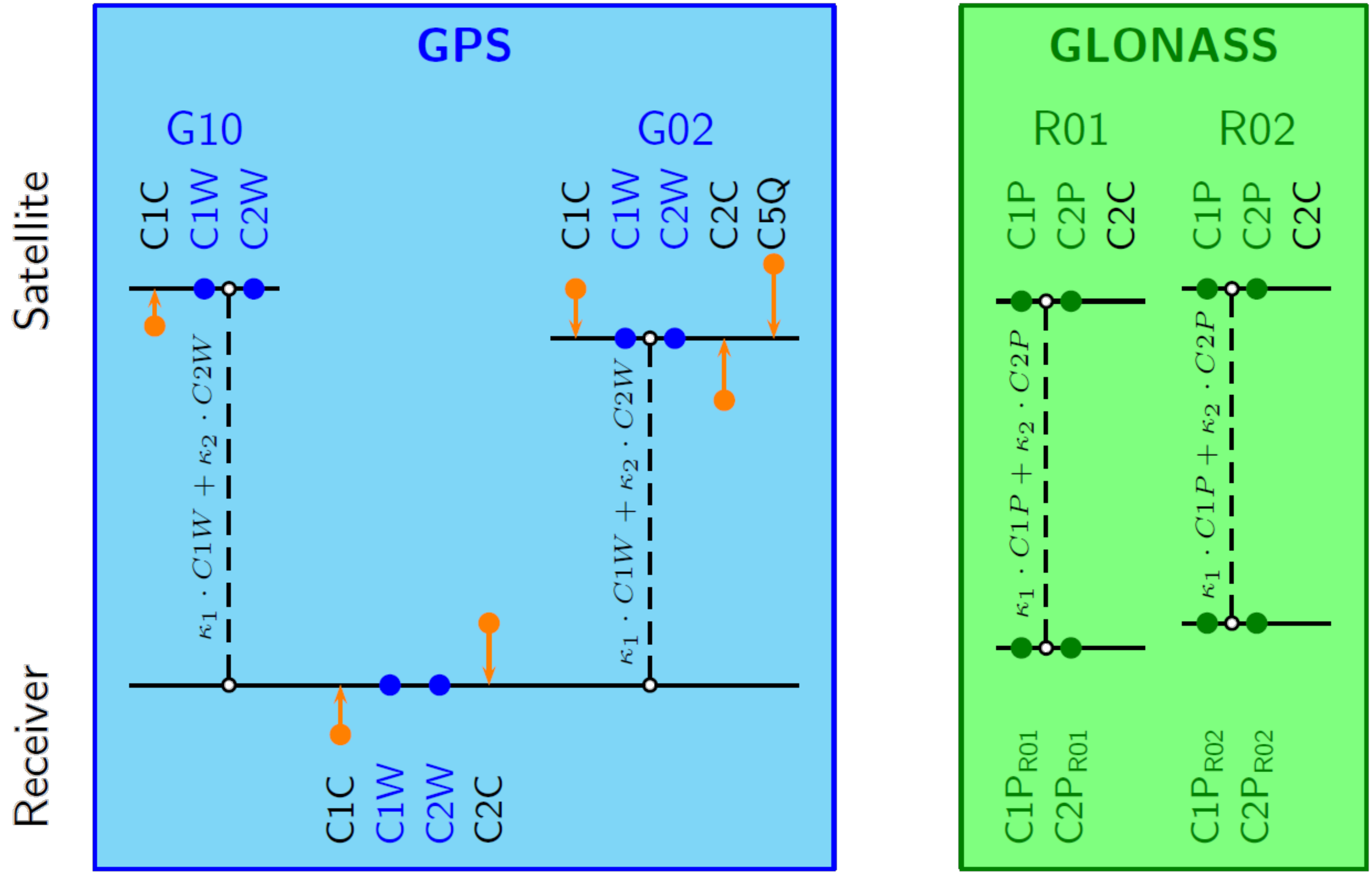
Pseudo–Absolute Code Biases: CLK



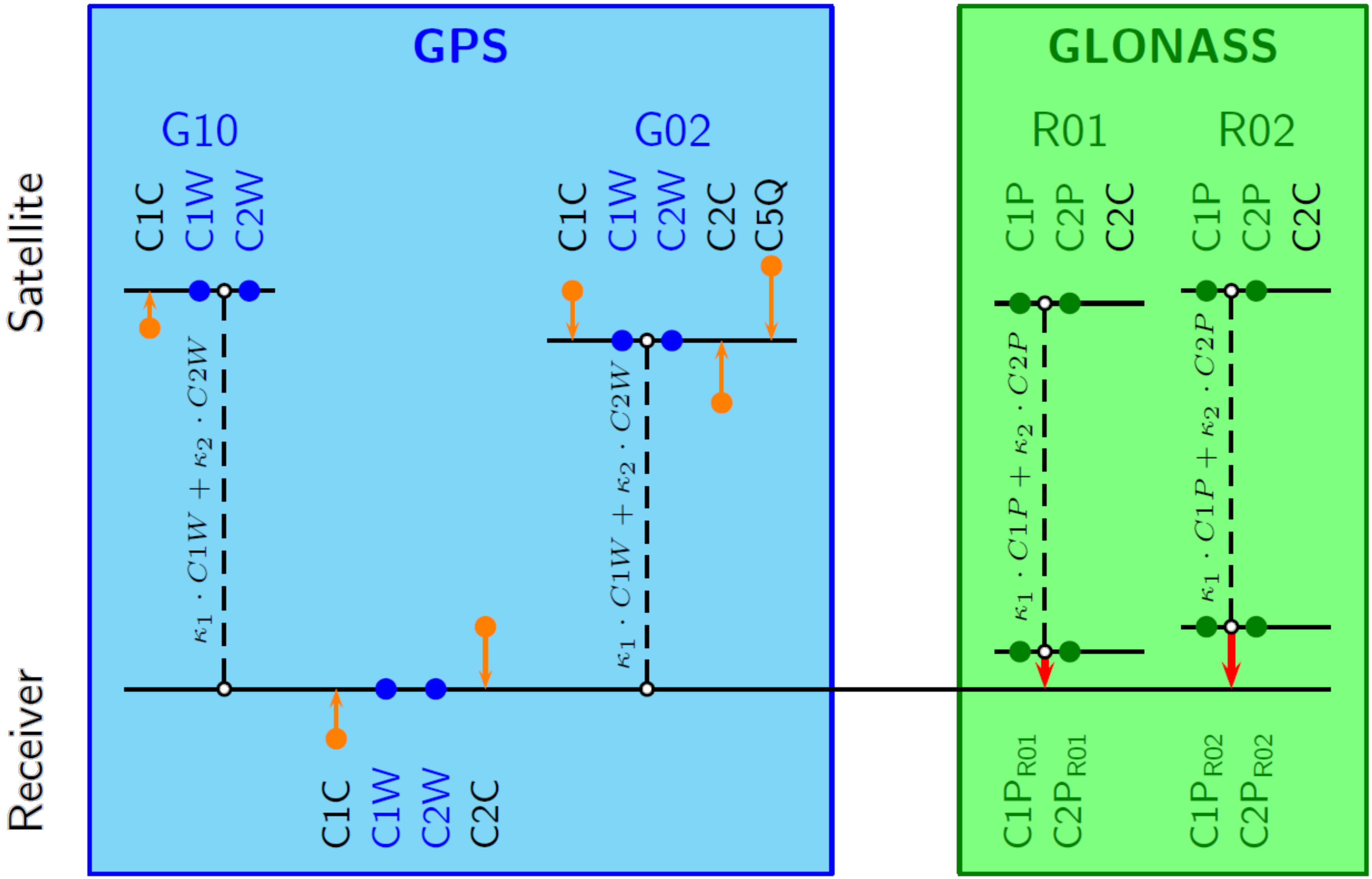
Pseudo-Absolute Code Biases: CLK



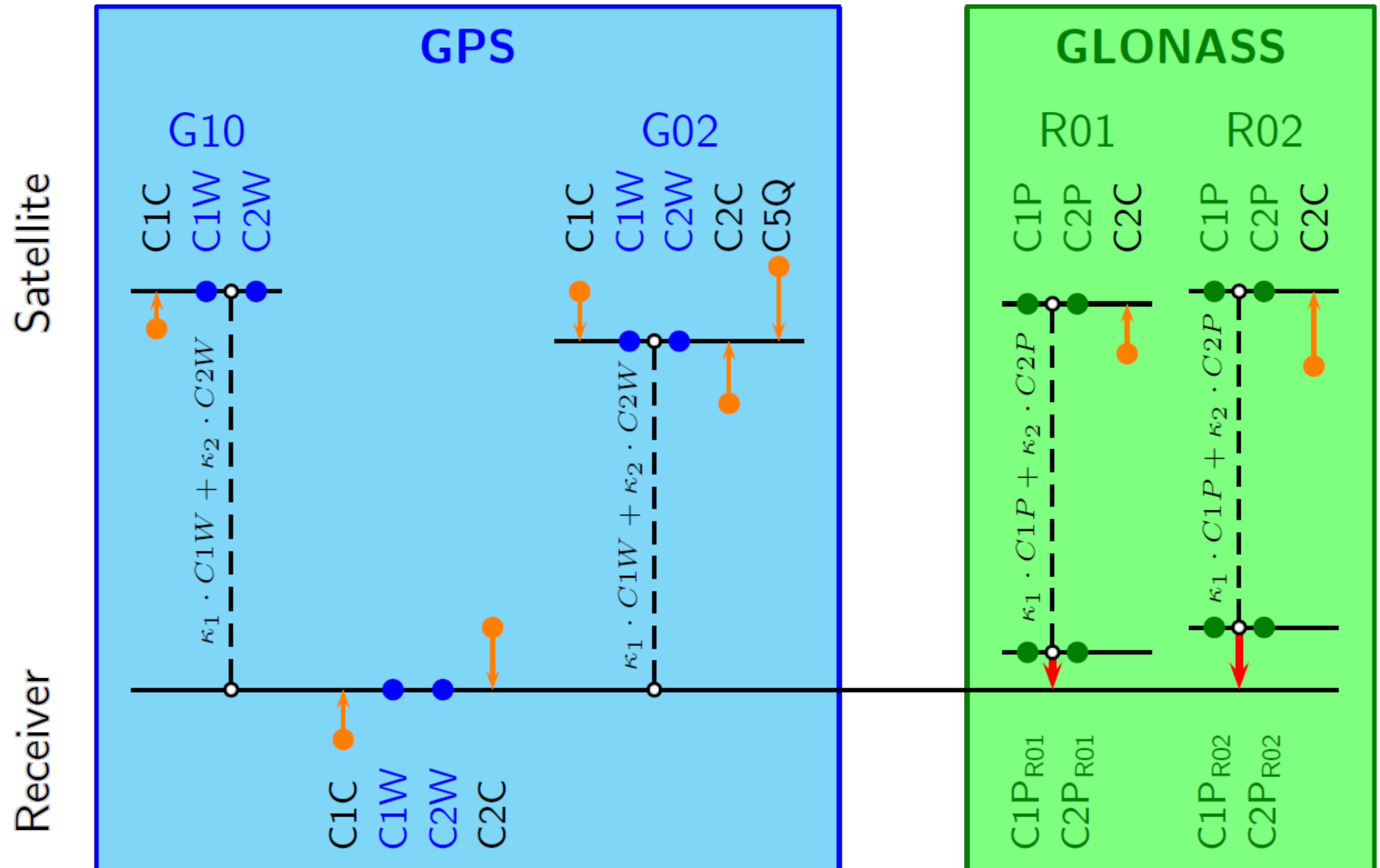
Pseudo-Absolute Code Biases: CLK



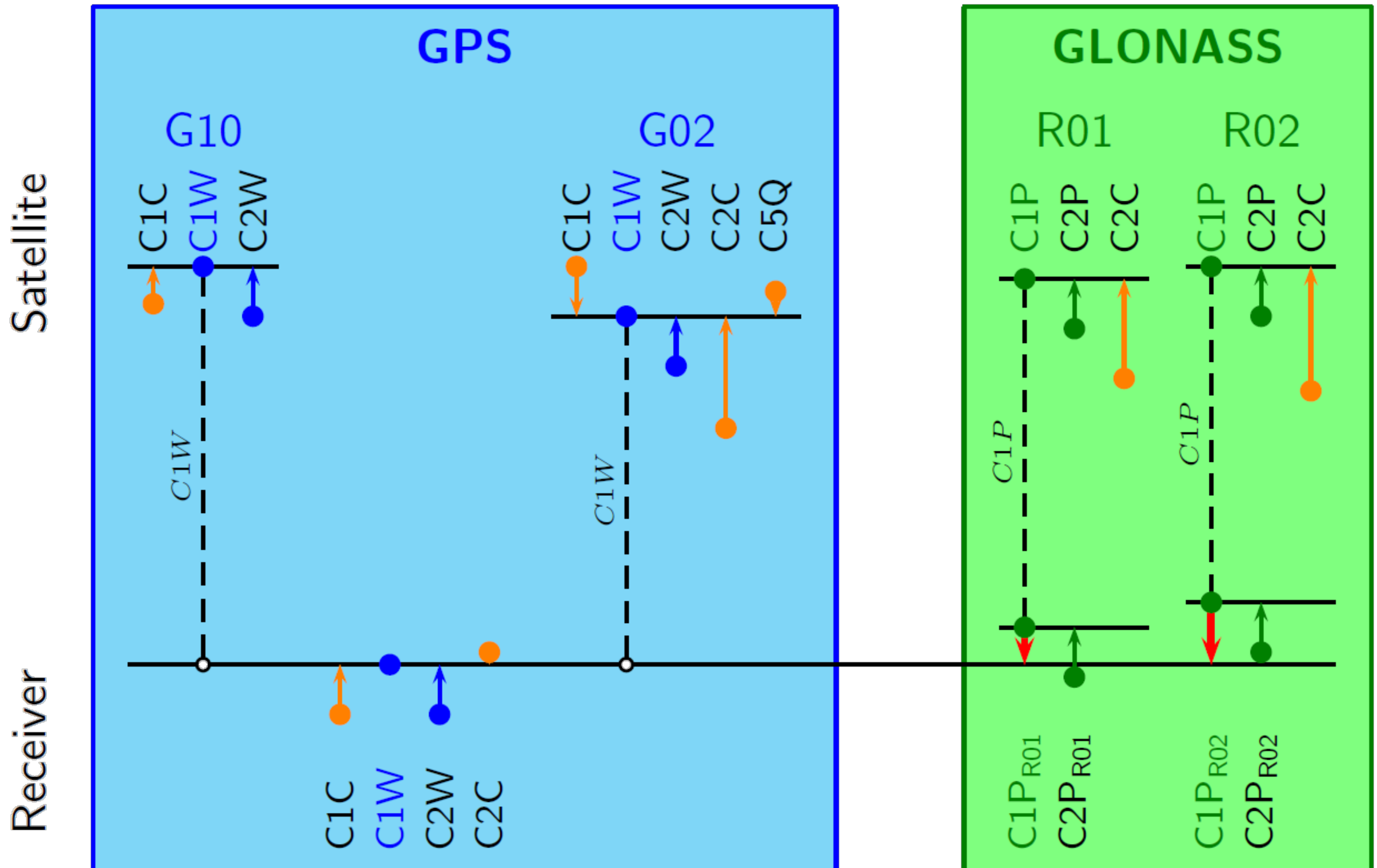
Pseudo-Absolute Code Biases: CLK



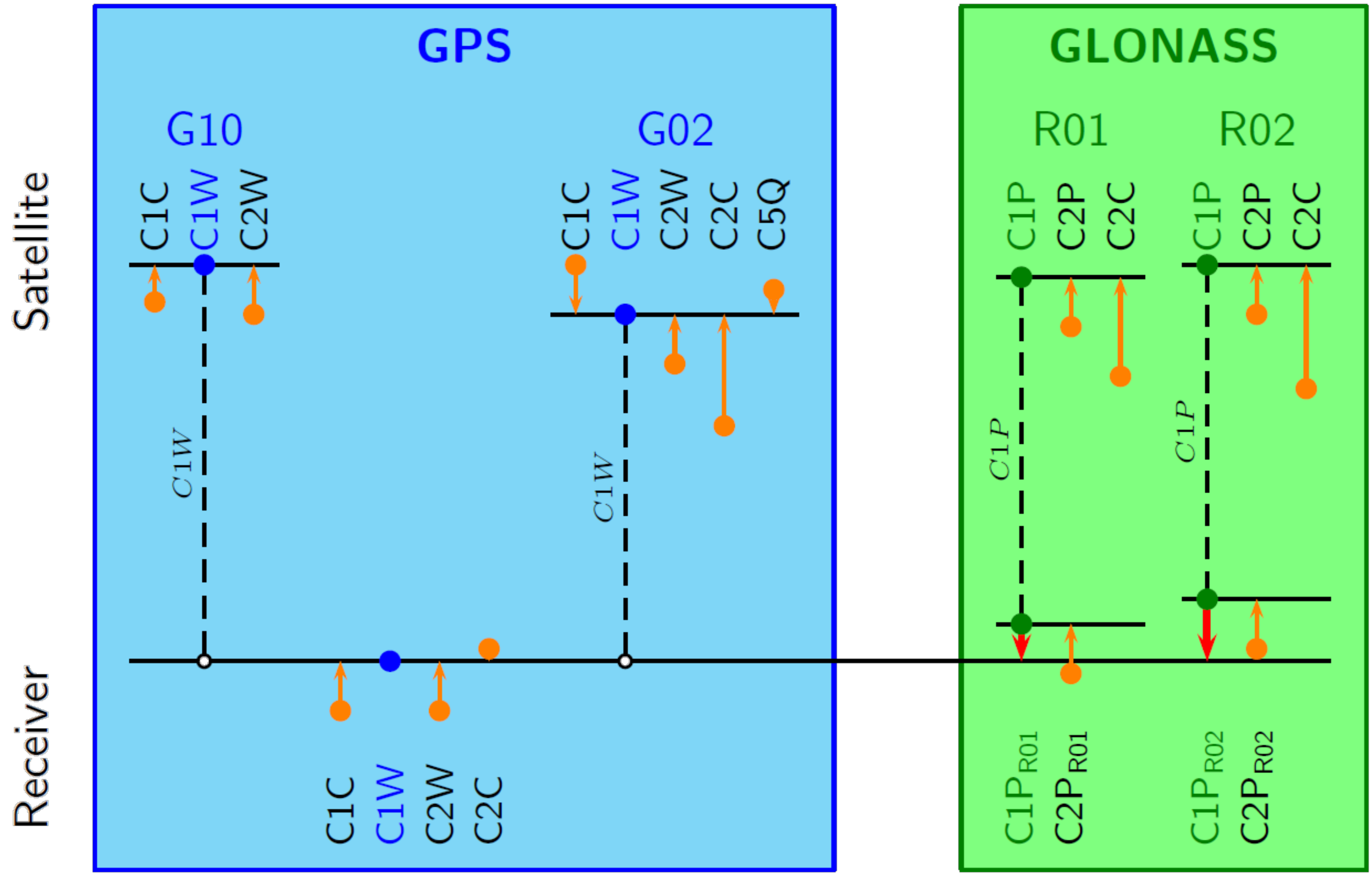
Pseudo-Absolute Code Biases: CLK



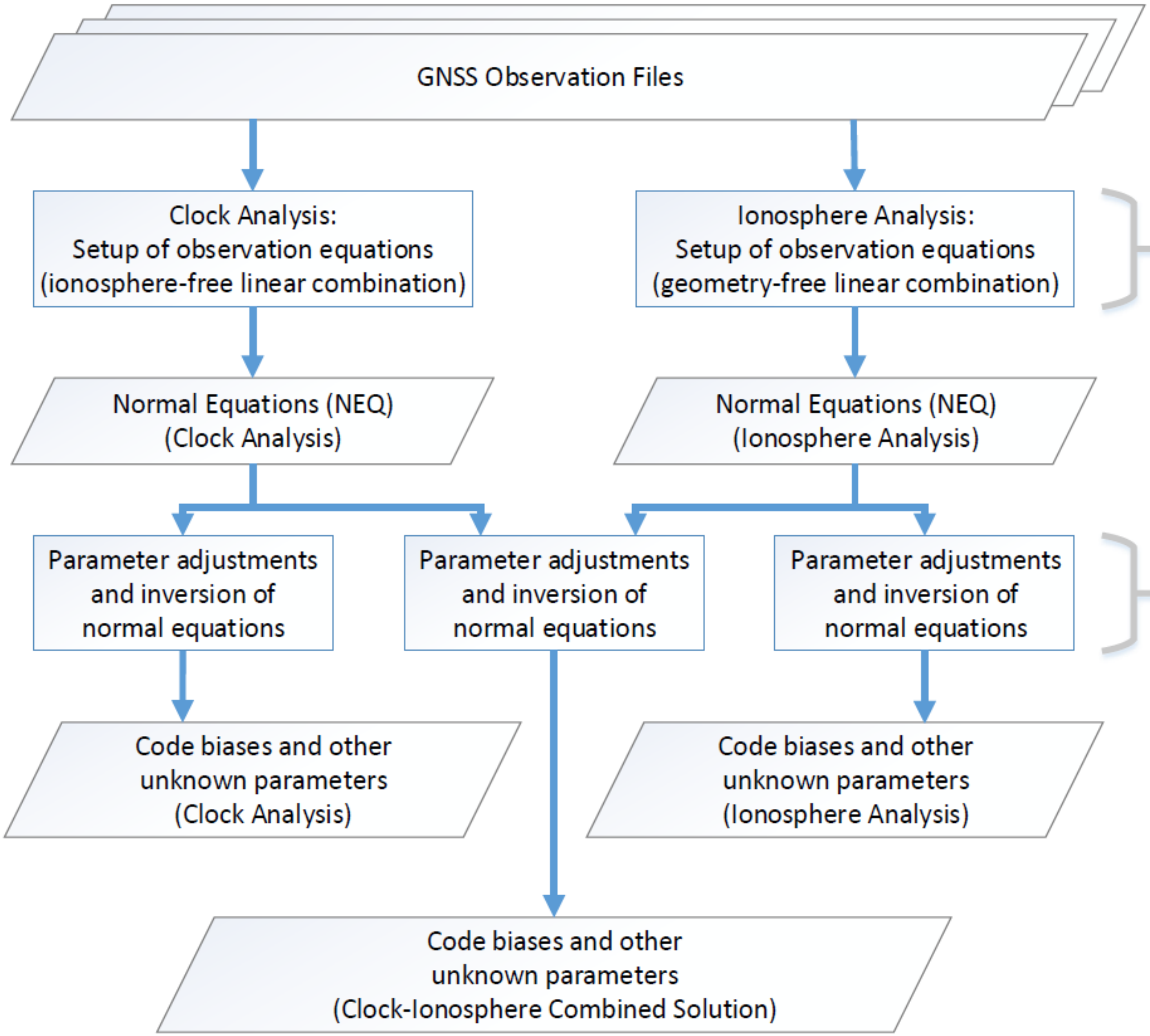
Pseudo–Absolute Code Biases: CLK+ION



Pseudo–Absolute Code Biases: CLK+ION



CODE's new Bias Estimation Workflow



- Code bias parameters specific to each observable
- Without code bias datum definition.

- Selection of reference observables for the current IGS clock convention.
- Bias datum definition imposed on (combined) NEQ-system.

Multi-GNSS Bias Estimation

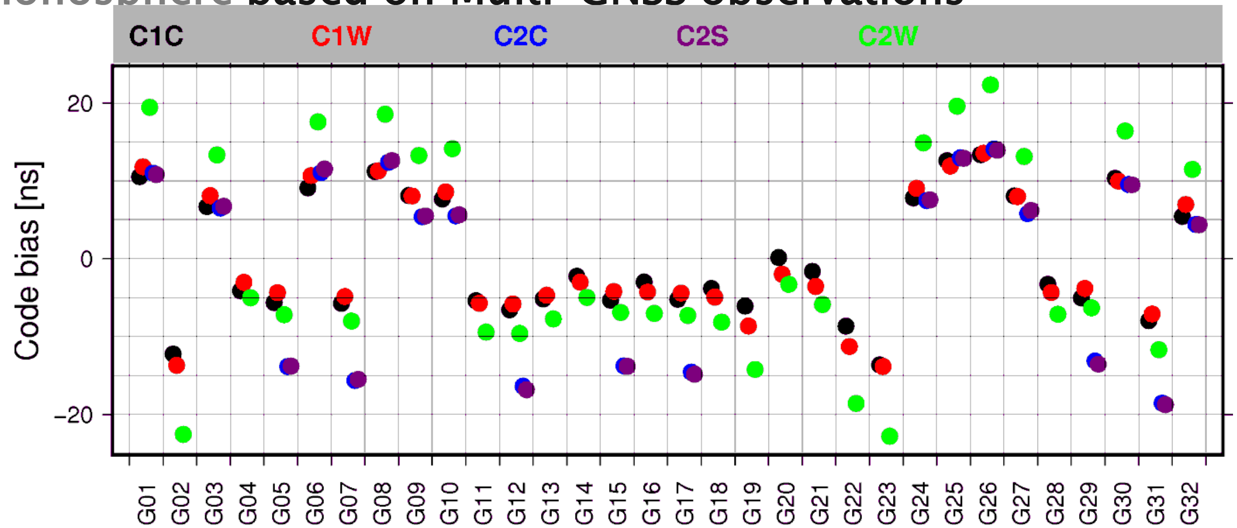
Input: – Orbits from CODE’s MGEX solution

– RINEX 3 and RINEX 2 observation files

Output: – Code Biases from ionosphere analysis, clock analysis and their combination (*Full set* of observable-specific code biases (OSB))

– Multiplier estimation (Receiver tracking mode)

– Ionosphere based on Multi-GNSS observations



GPS observable-specific code biases (OSB) (2016 176-186)

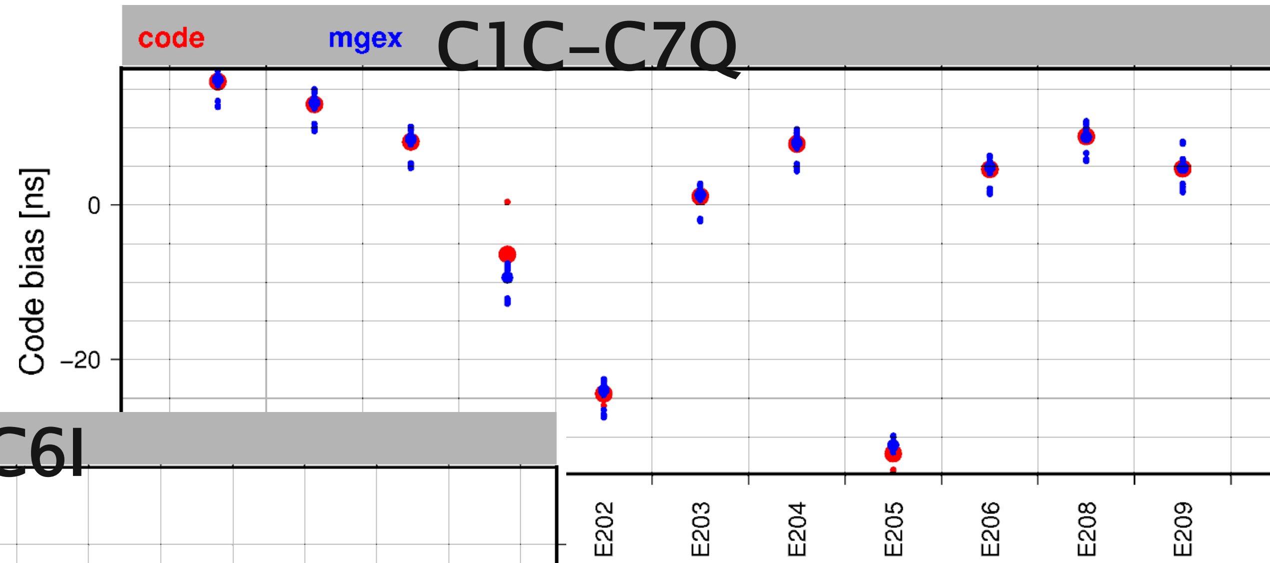
Comparison with MGEX Bias Solutions (DLR)

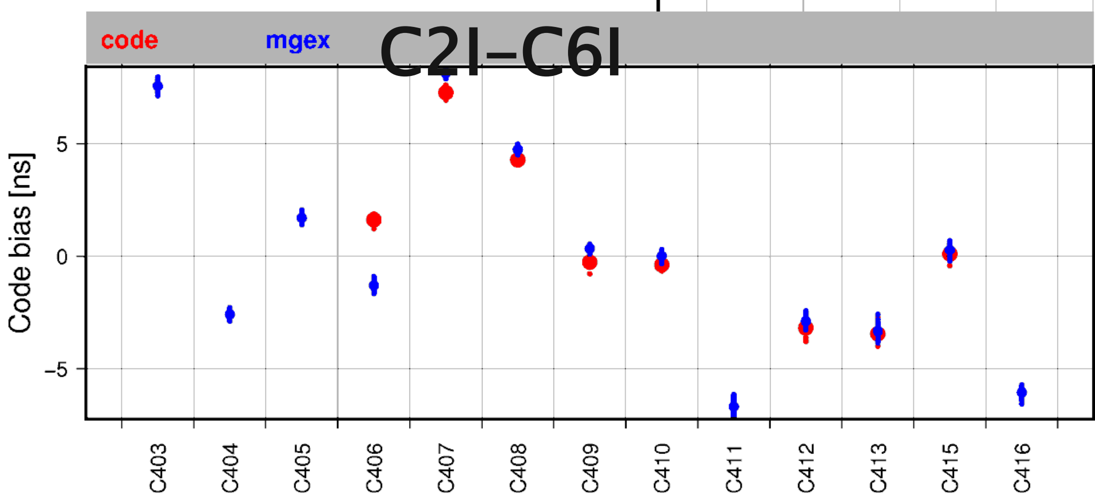
CODE: Observable-specific code biases transformed to DCB's (2016 176-186)

MGEX: Differential Code Biases (2016 001-092) (DLR - Solution)

Galileo Satellites:

C1C-C7Q





Beidou Satellites:

C1I-C7I

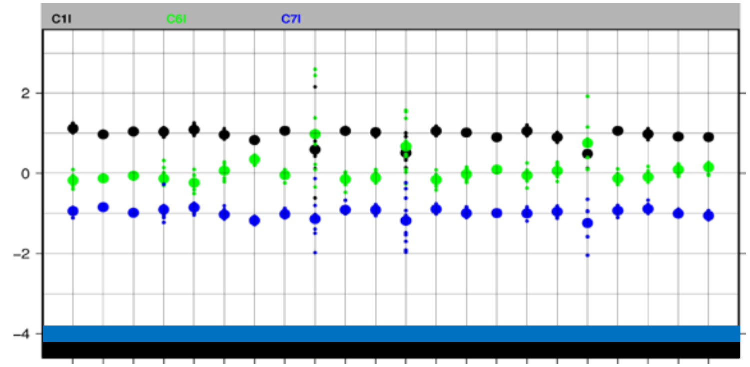
Verifying Receiver Tracking Modes

Verification of receiver tracking mode using

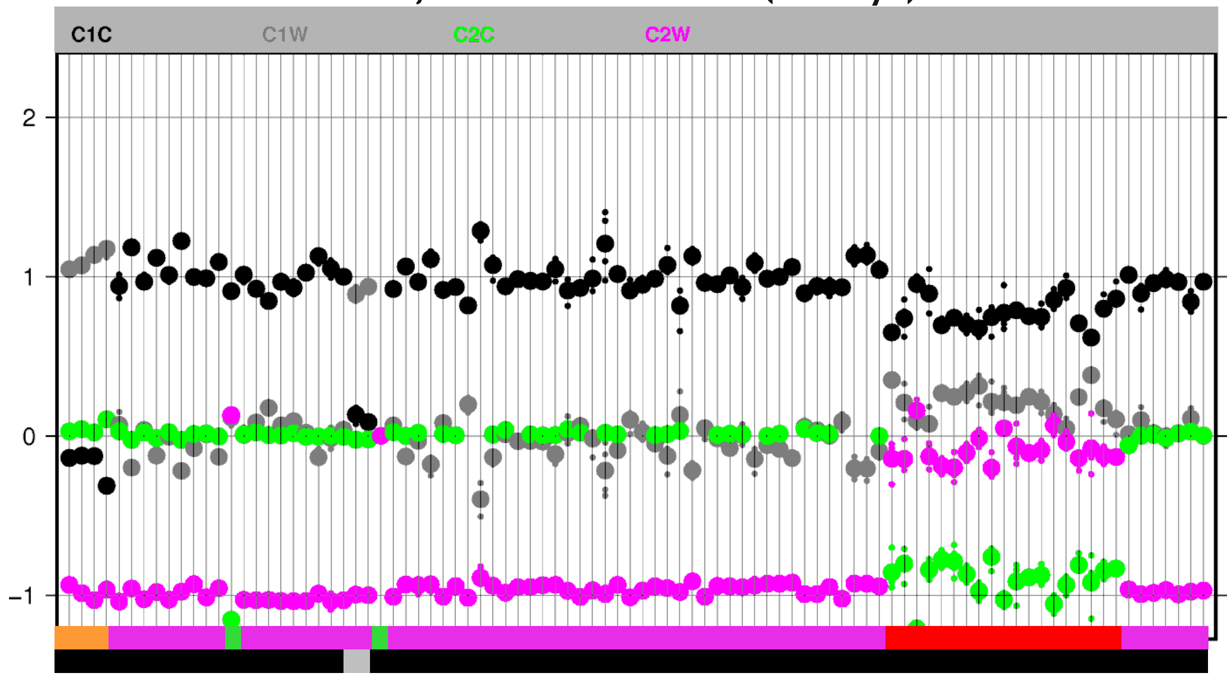
OSB multiplier estimation based on ionosphere analysis:

Estimation of a multiplier for each (known) satellite OSB per station and a regular receiver bias.

Beidou, TRIMBLE Receiver



GPS, TRIMBLE Receiver (4-Days)



Remark: C2C and C2S are very close together and have the same pattern for the satellite biases. They can not be separated by the multiplier approach.

Receiver Tracking Mode

C2D C2X

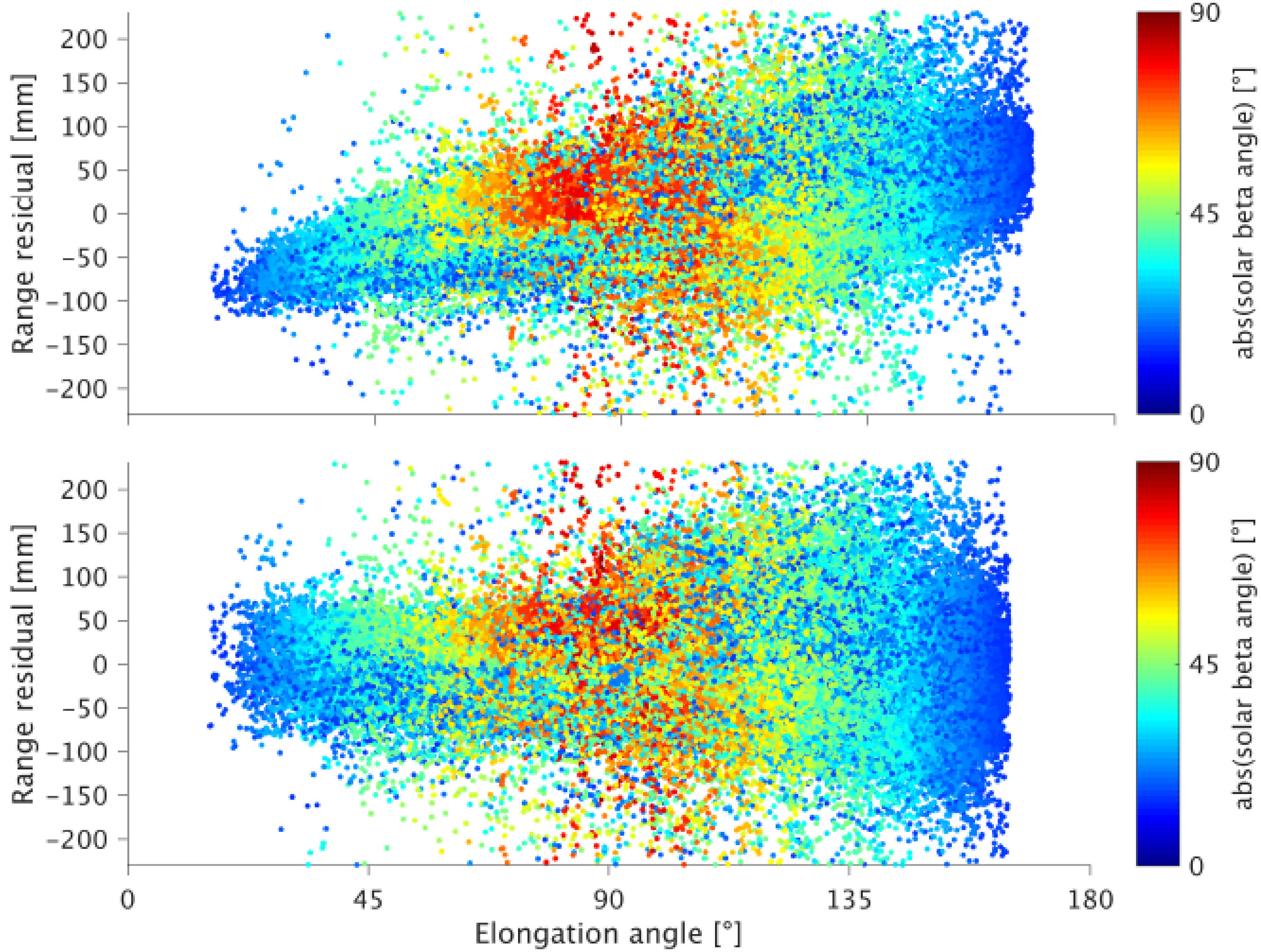
Reprocessing with the new Empirical CODE Orbit model

(in the frame of EGSIEM)

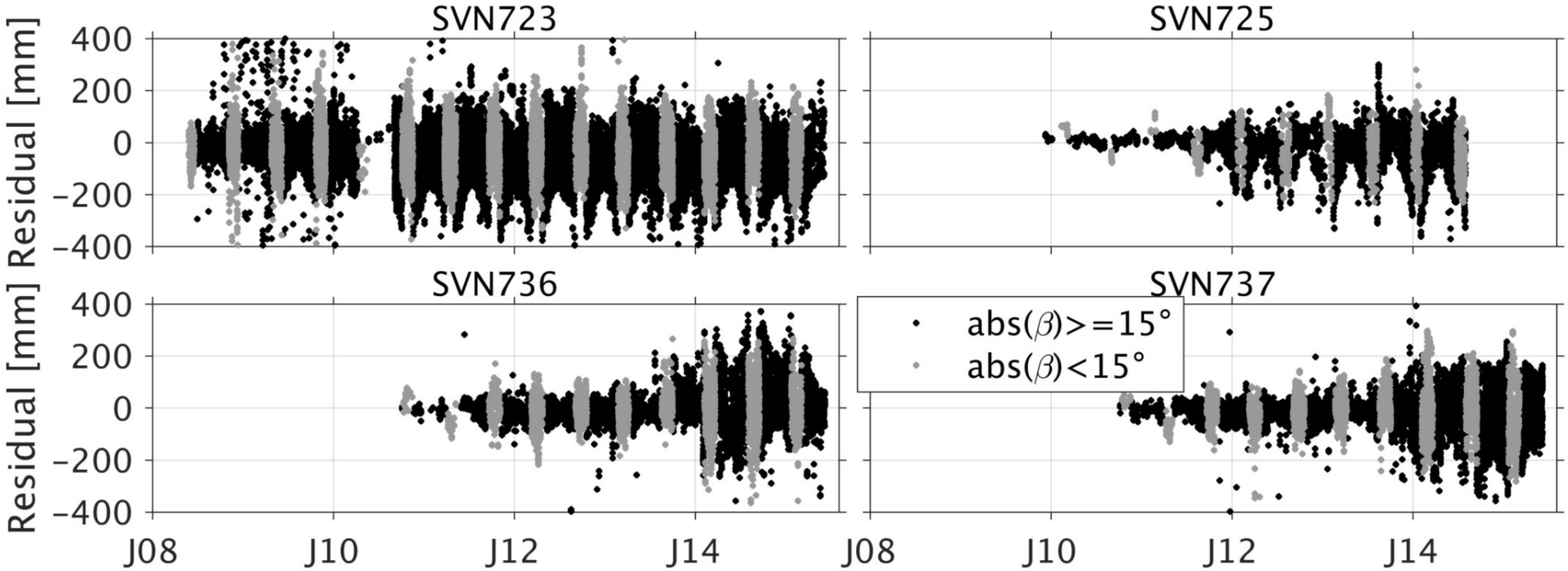
Orbit validation using SLR

repro02

current repro

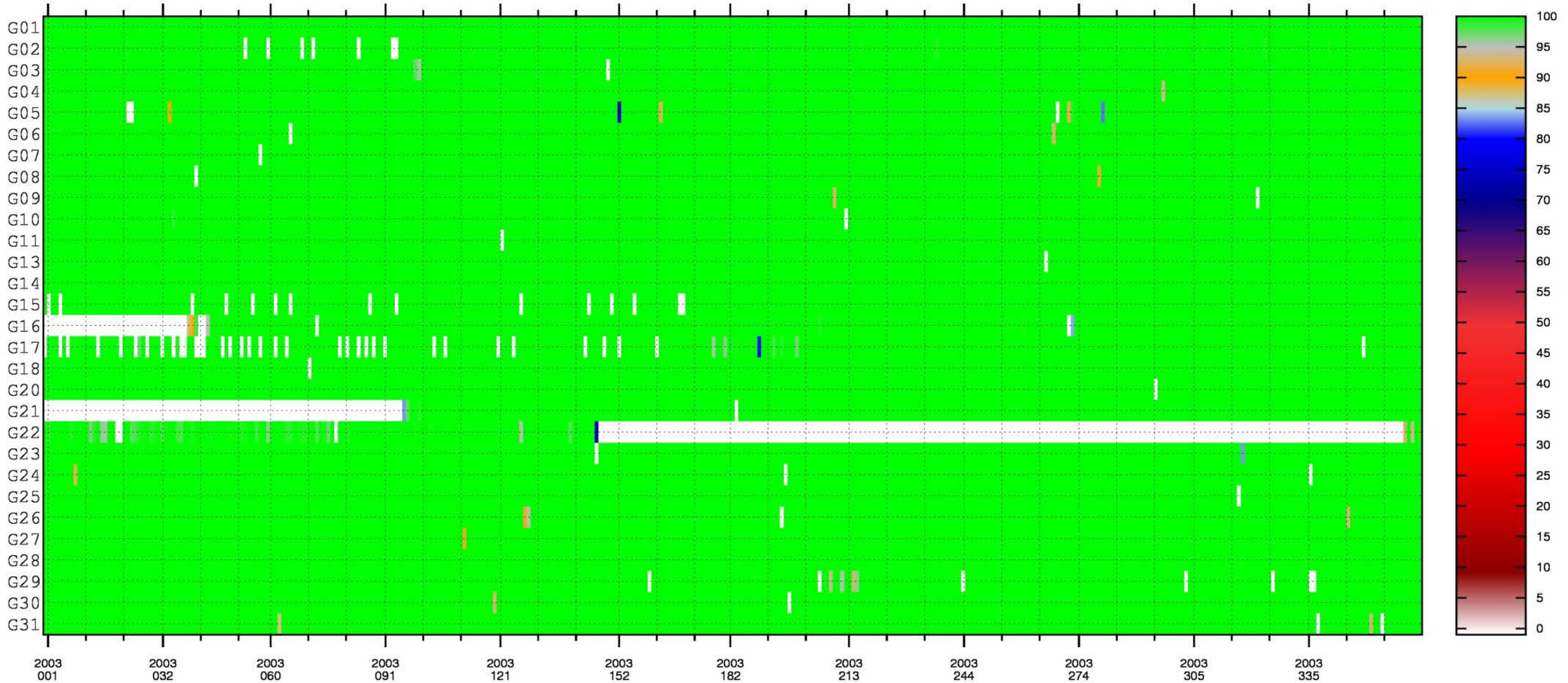


Orbit validation using SLR



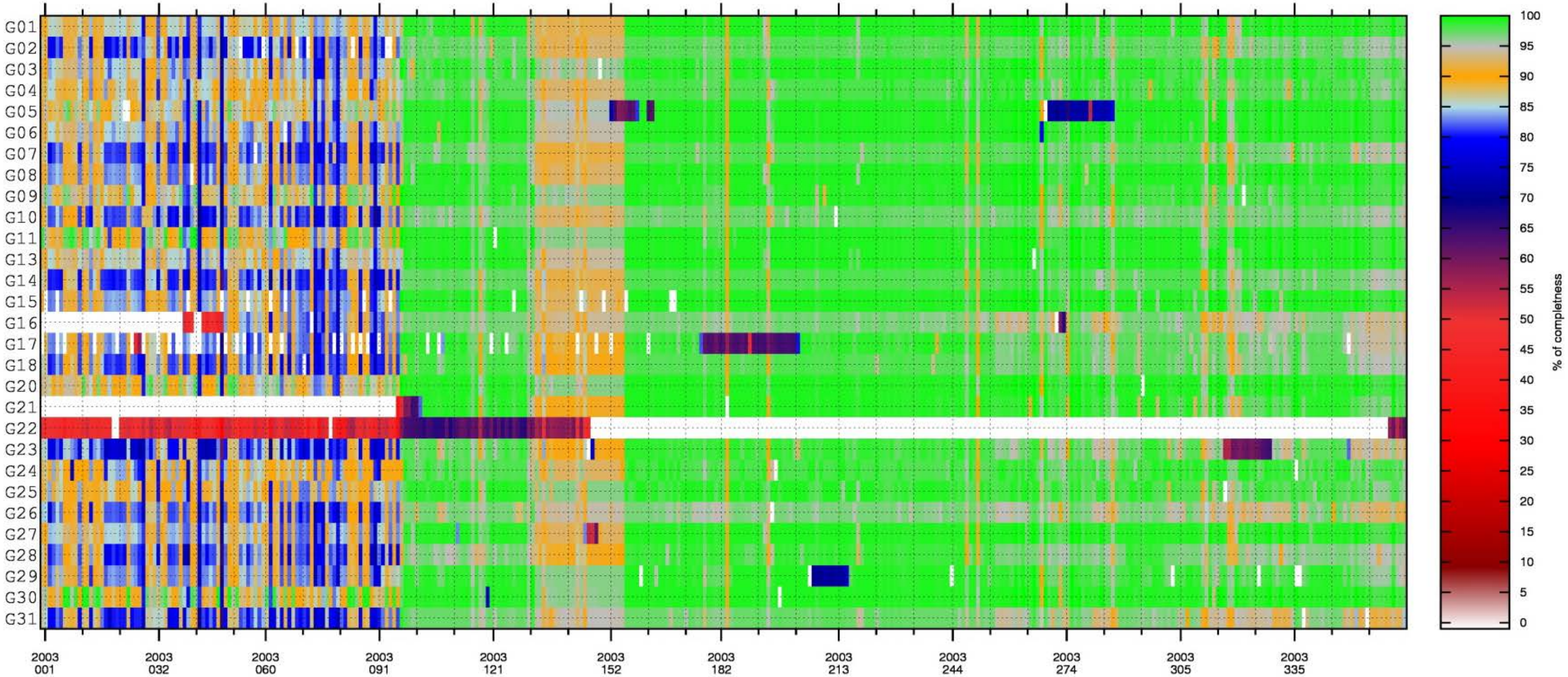
The SLR residuals to the GLONASS satellites increase after a few years of lifetime. The reason in still unkonwn!

Improving the completeness of the clocks



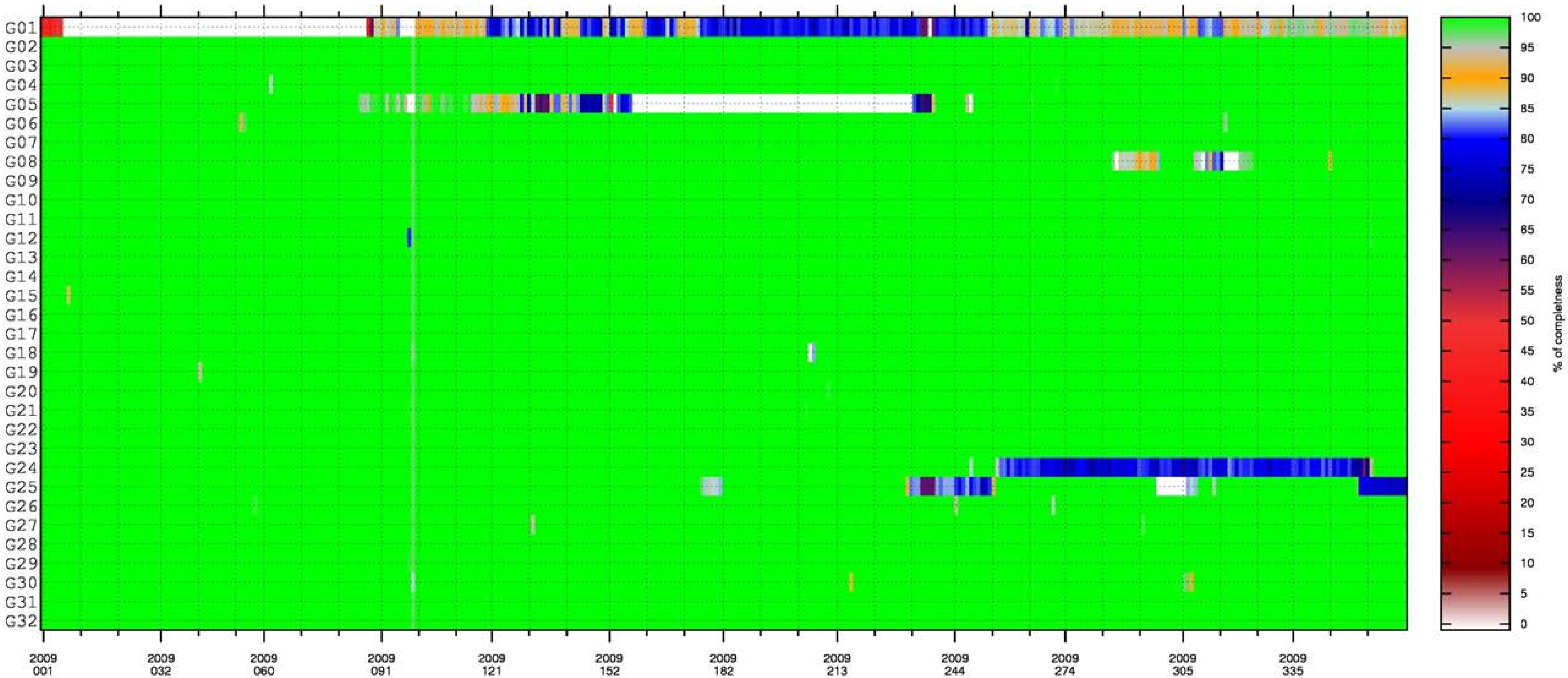
Completeness of 30 s GPS clock corrections for year 2003.

Improving the completeness of the clocks



Completeness of 5 s GPS clock corrections for year 2003.

Improving the completeness of the clocks



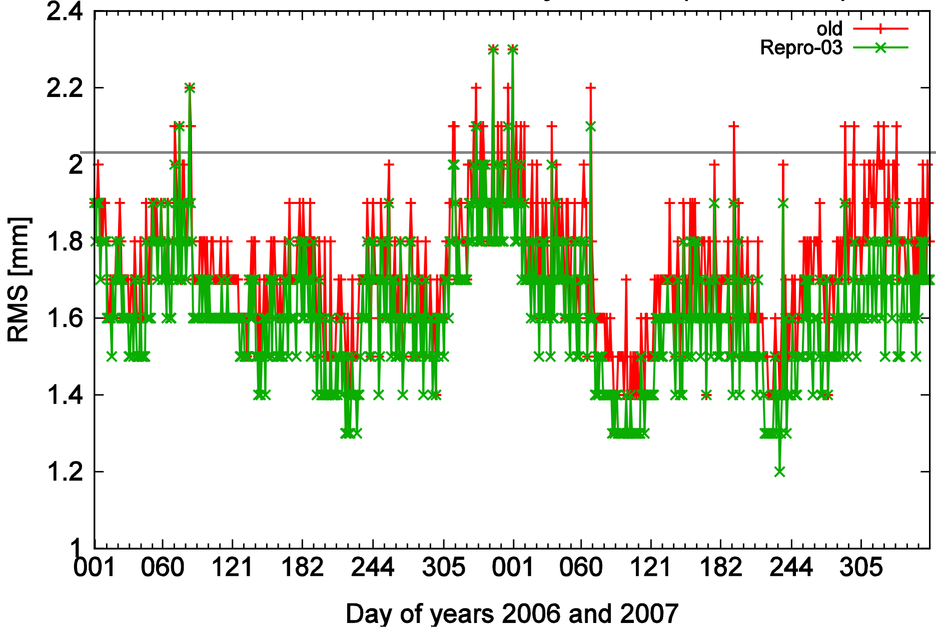
Completeness of 5 s GPS clock corrections for year 2009.

Targeting the following products

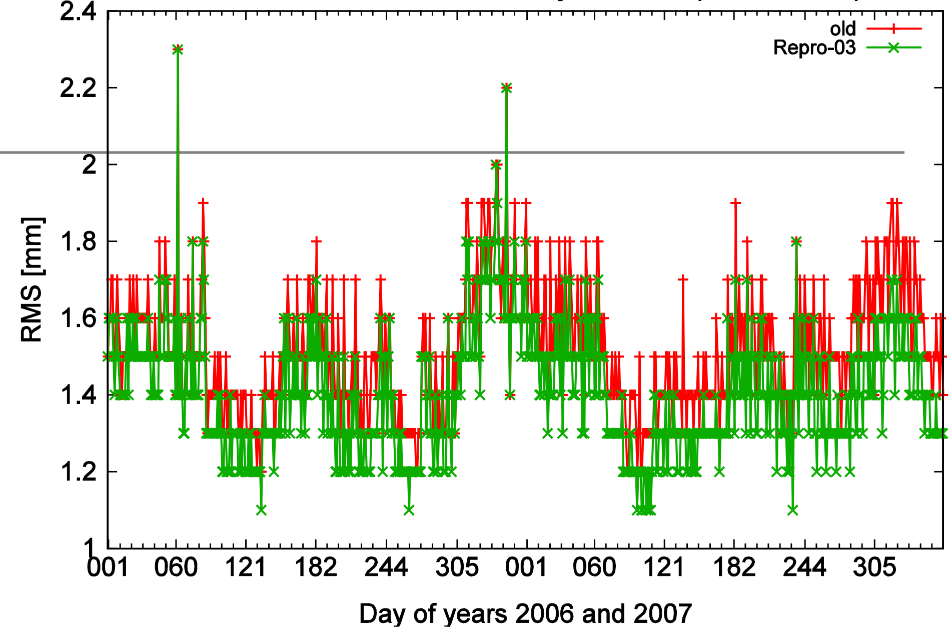
- GNSS-orbits:
  - GPS: 1994-now
  - GLONASS: 2002-now
- GNSS-satellite clocks:
  - GPS, 30 sec 1994-now
  - GPS, 05 sec 2003-now
  - GLONASS, 30 sec 2008-now
  - GLONASS, 05 sec 2010-now

  Limitations due to the global coverage with legacy and high-rate (IGS real-time) stations.

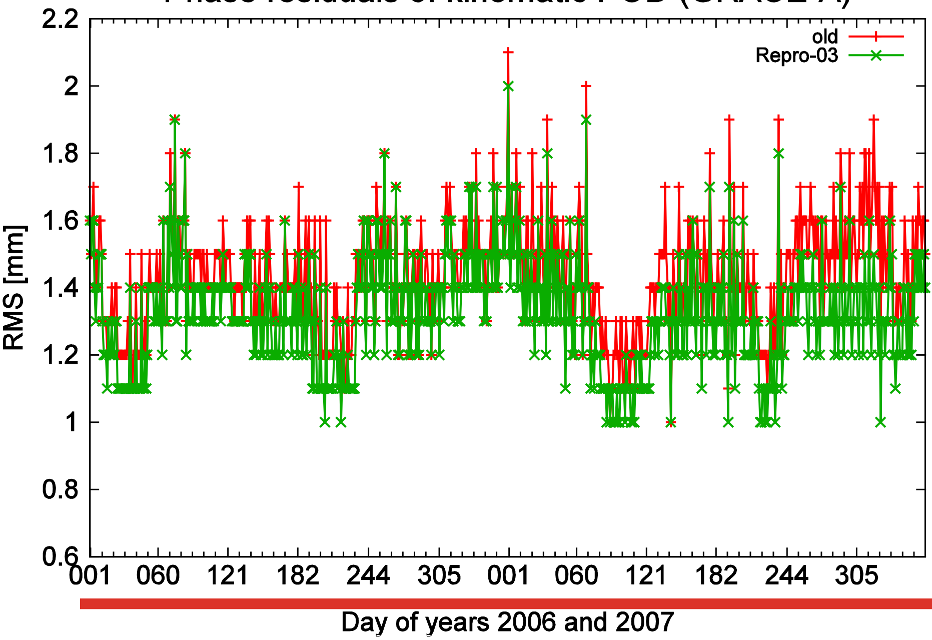
Phase residuals of red.-dyn. POD (GRACE-A)



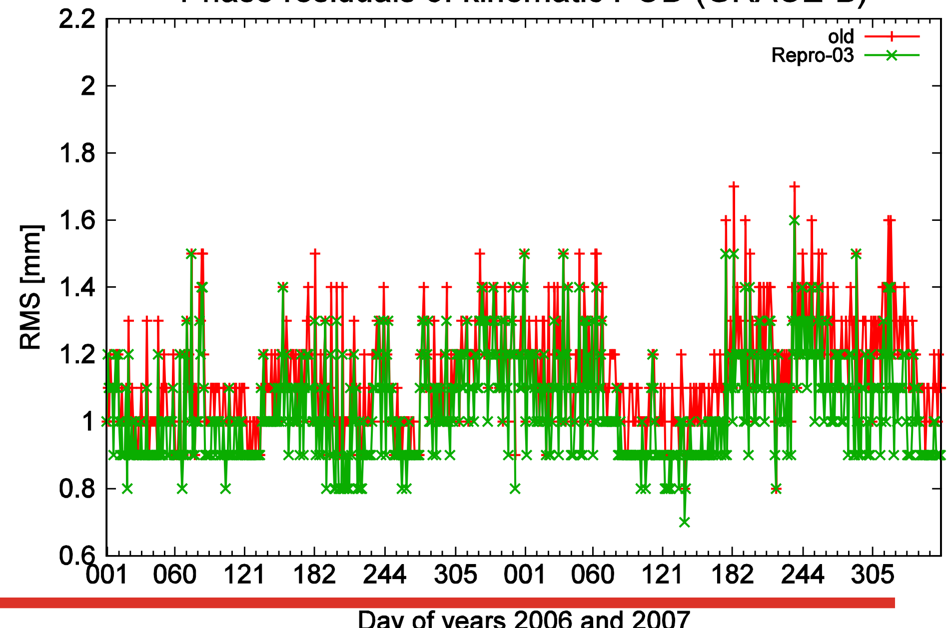
Phase residuals of red.-dyn. POD (GRACE-B)



Phase residuals of kinematic POD (GRACE-A)



Phase residuals of kinematic POD (GRACE-B)

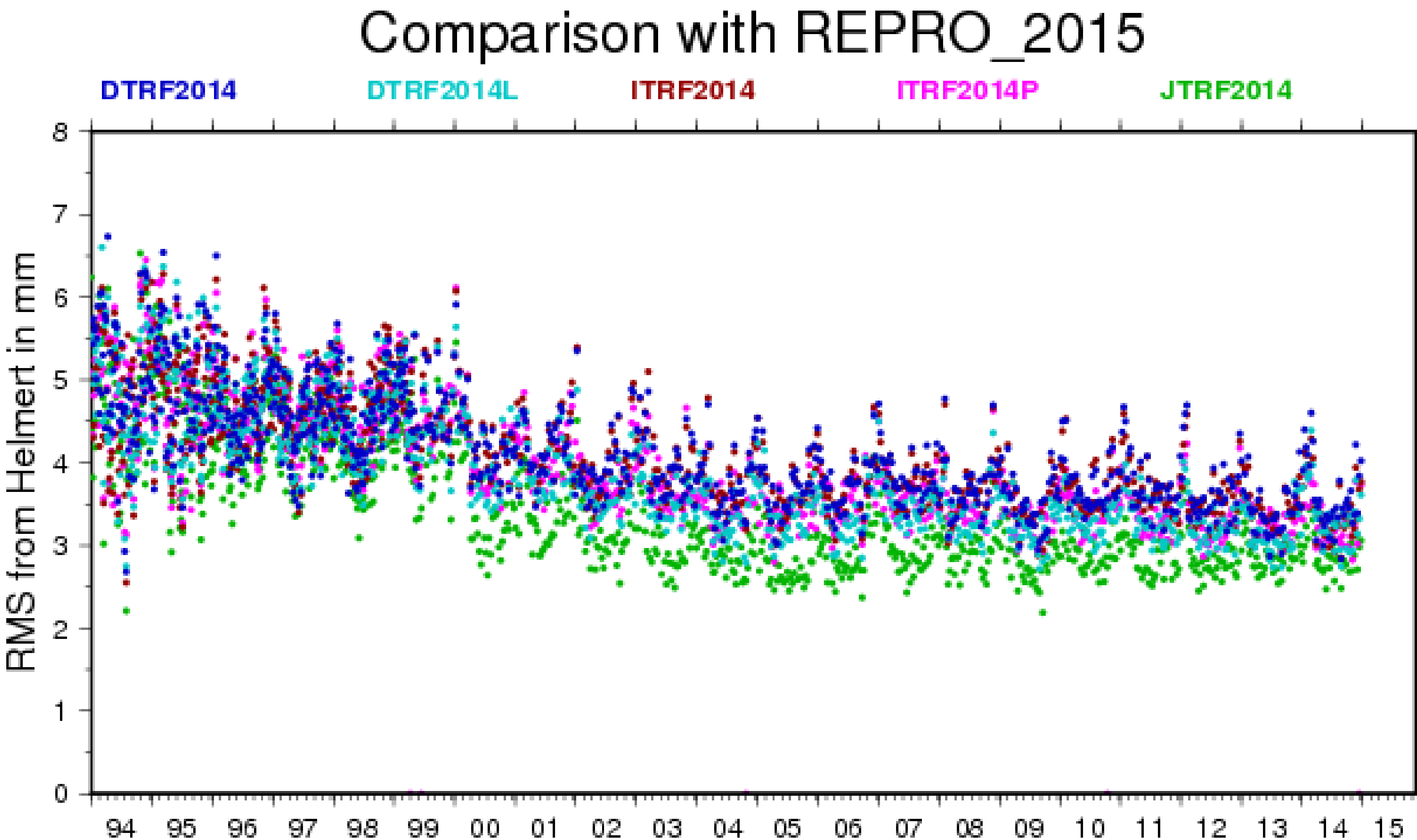


Introducing ITRF2014

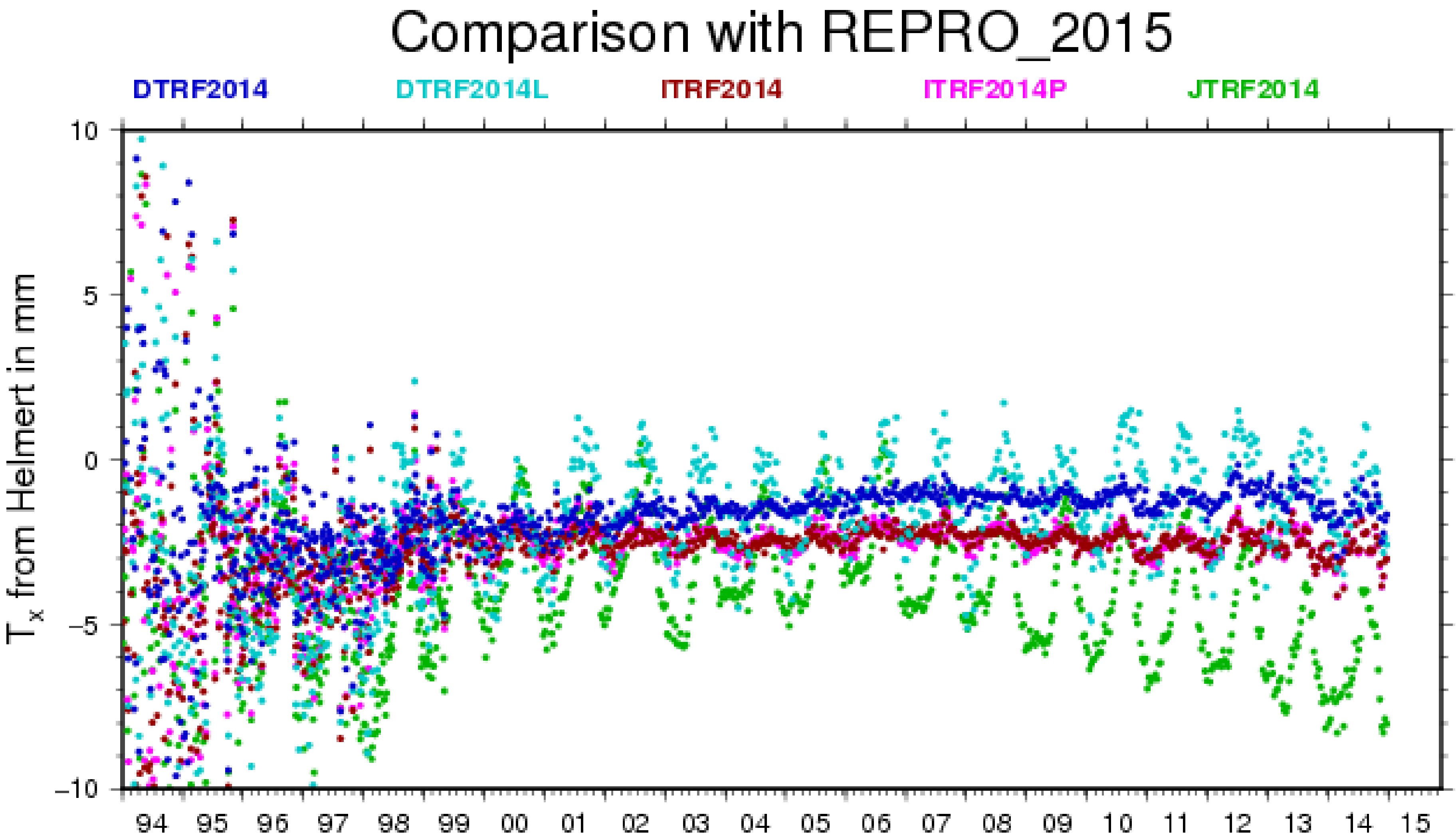
ITRF2014 solutions

- TUM-DGFI
  - DTRF2014: based on a classical coordinate+linear velocity solution
  - DTRF2014L: ATM+Hydro.-loading applied
- IGN
  - ITRF2014: based on coordinate+linear velocities+ empirical post-seismic deformation corrections (+annual/semi-annual periodic functions)
  - ITRF2014P: periodic functions recovered
- JPL
  - JTRF2014: **based on a filter approach**

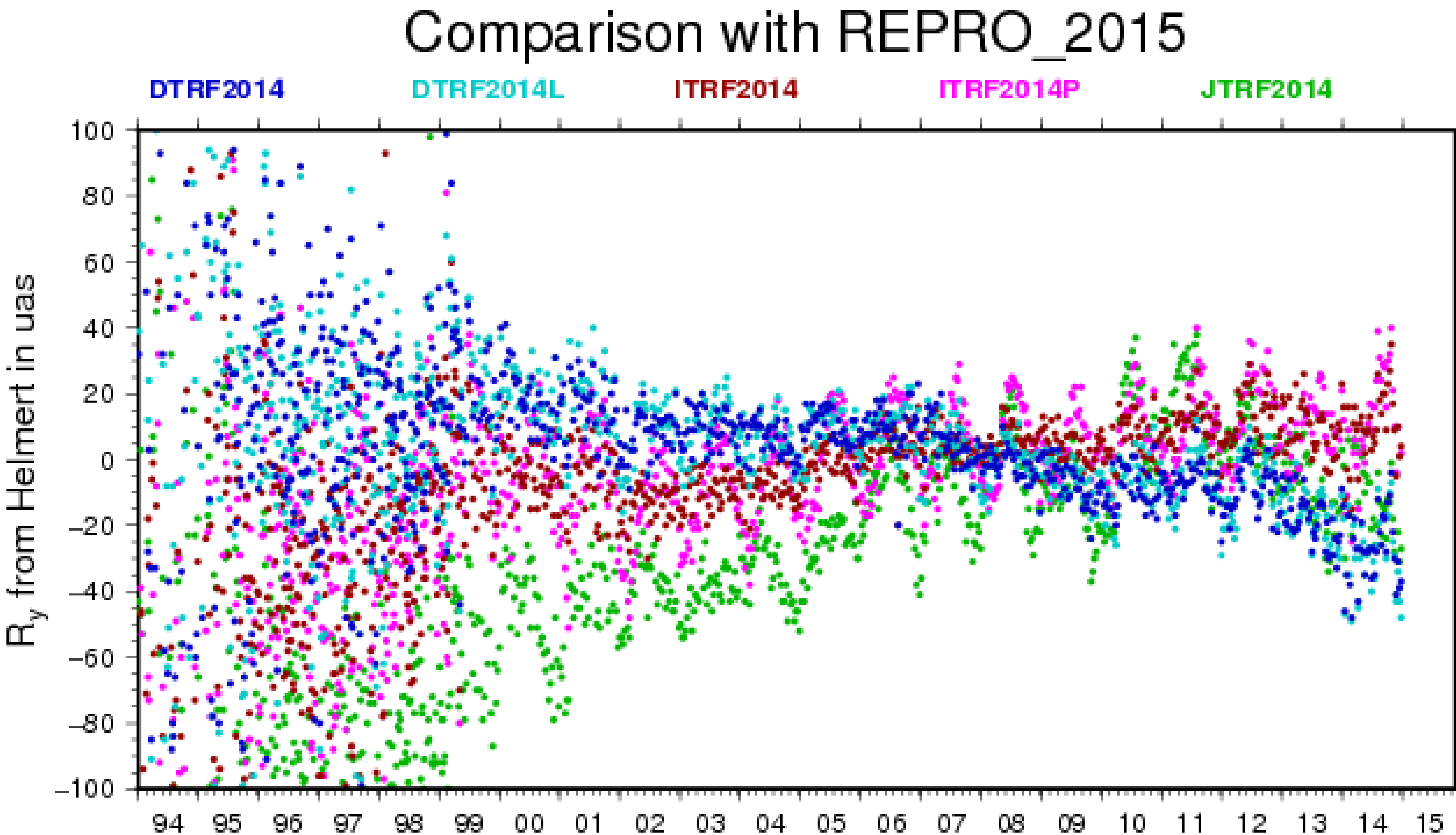
Comparison of the ITRF2014 solutions



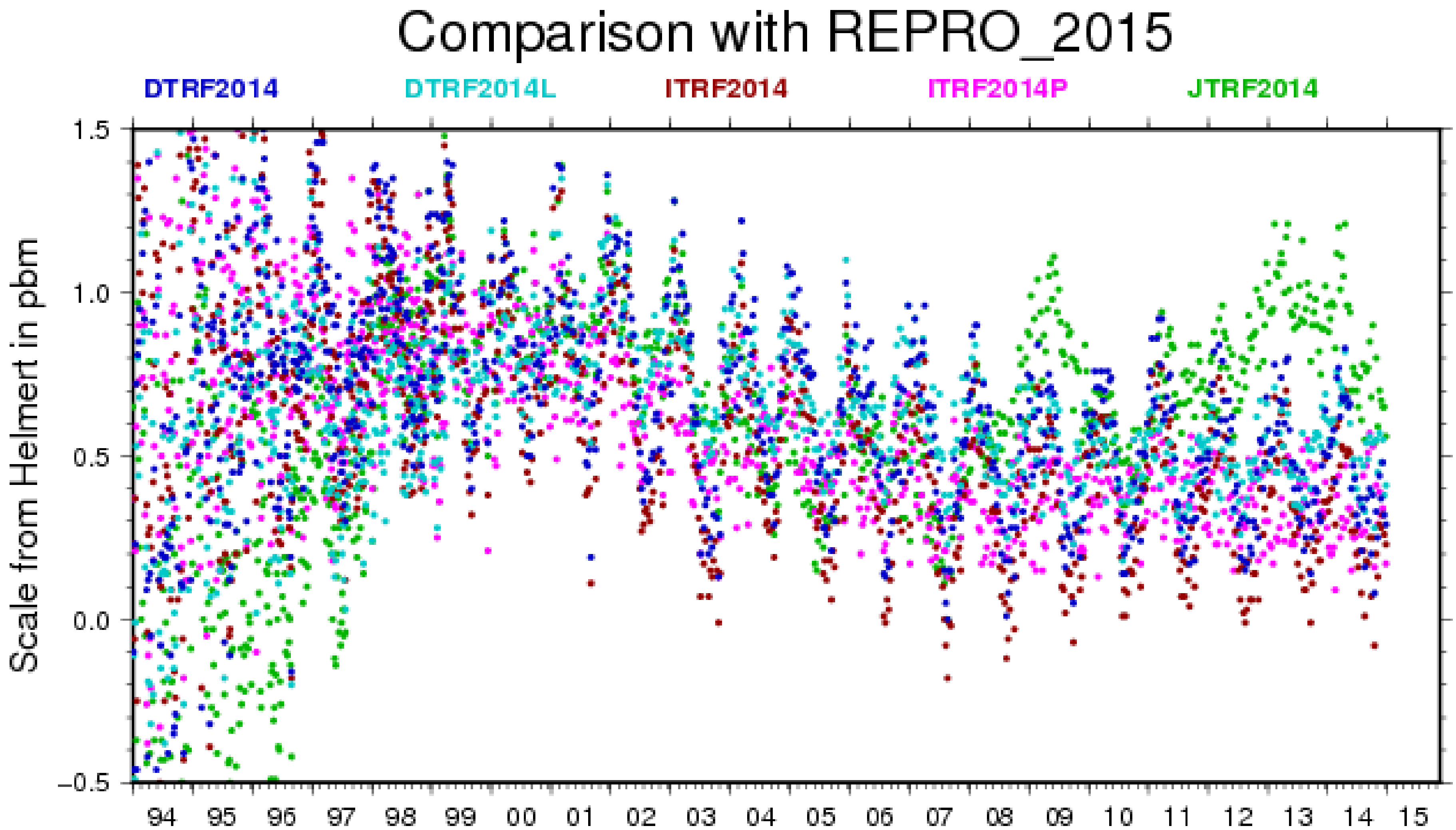
Comparison of the ITRF2014 solutions



Comparison of the ITRF2014 solutions



Comparison of the ITRF2014 solutions

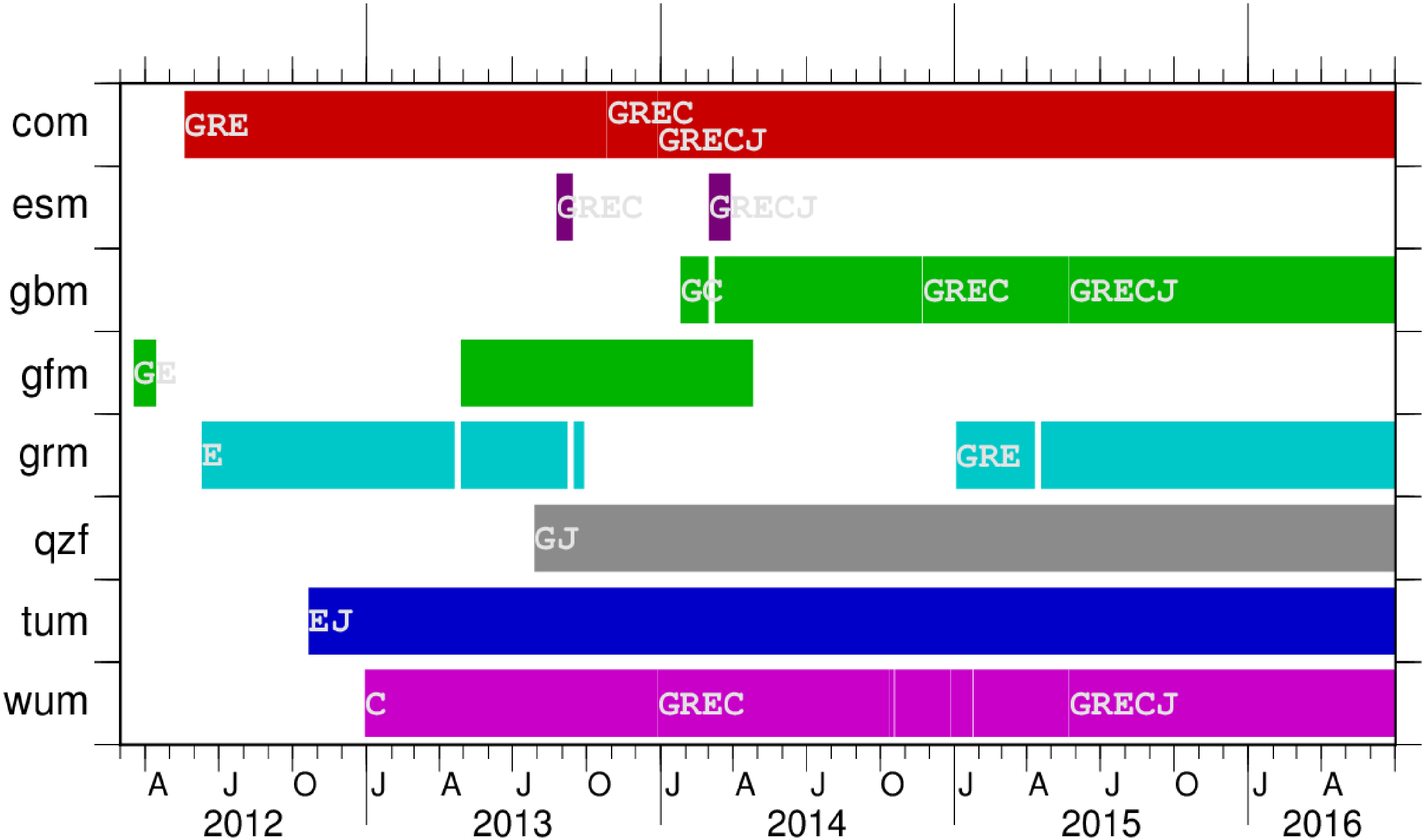


CODE contribution to IGS MGEX

CODE MGEX (COM) activities

- Allocation of COM products also via AIUB ftp server
- Adaptation to long RINEX file naming convention (consideration of additional download paths at data centers; file priorities)
- Downweighting of observations from satellites in orbit normal mode (QZS-1, all BDS)
- Change to standard multi-GNSS ANTEX provided by the IGS
- Improved data screening
- Experiments with orbit normal attitude mode and related SRP models
- Experiments with Galileo attitude
- Experiments with ground network geometry
- Long-term quality assessment and documentation (=> JoG paper)

MGEX products availability

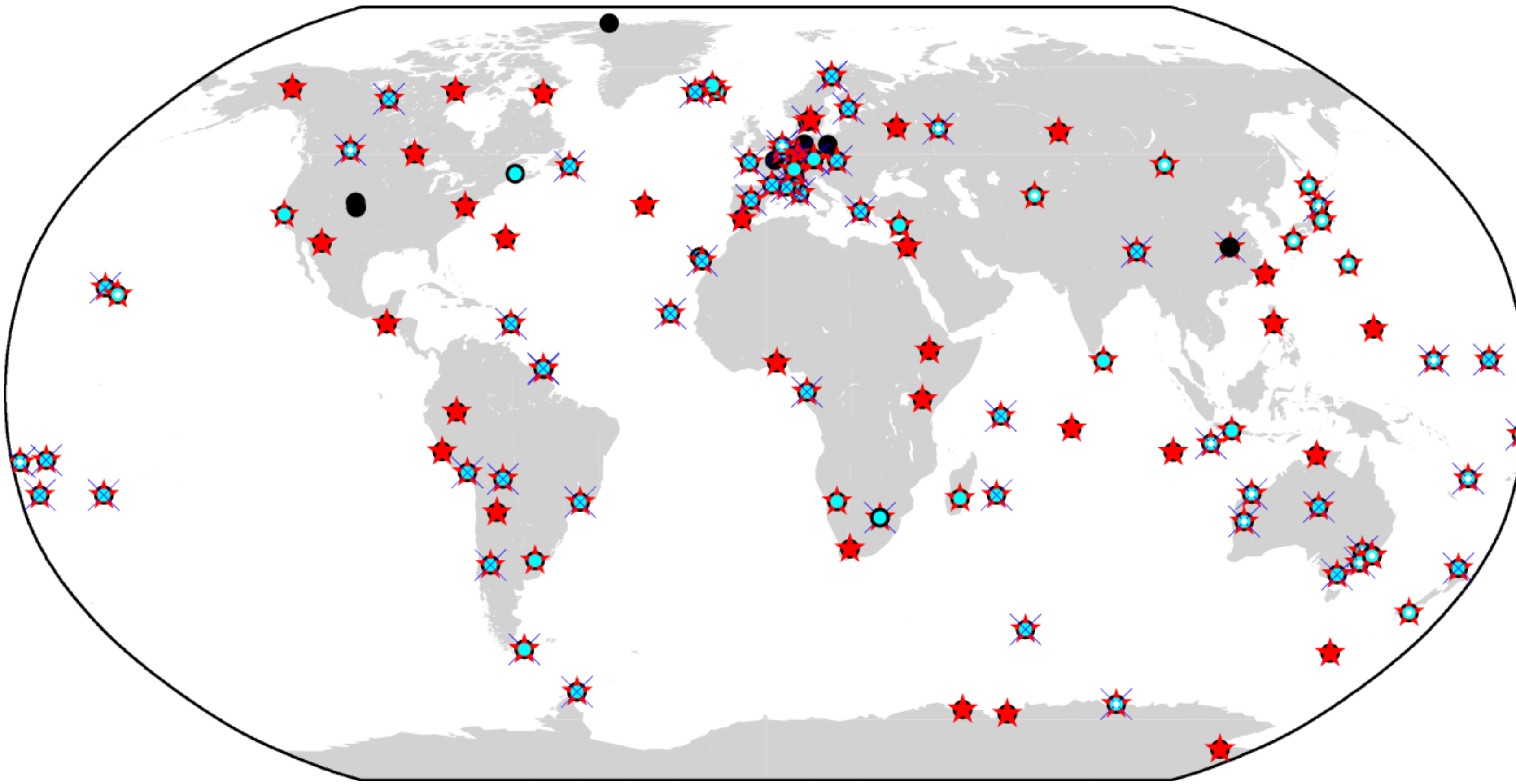


Status: 01-July-2016

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

MGEX station distribution

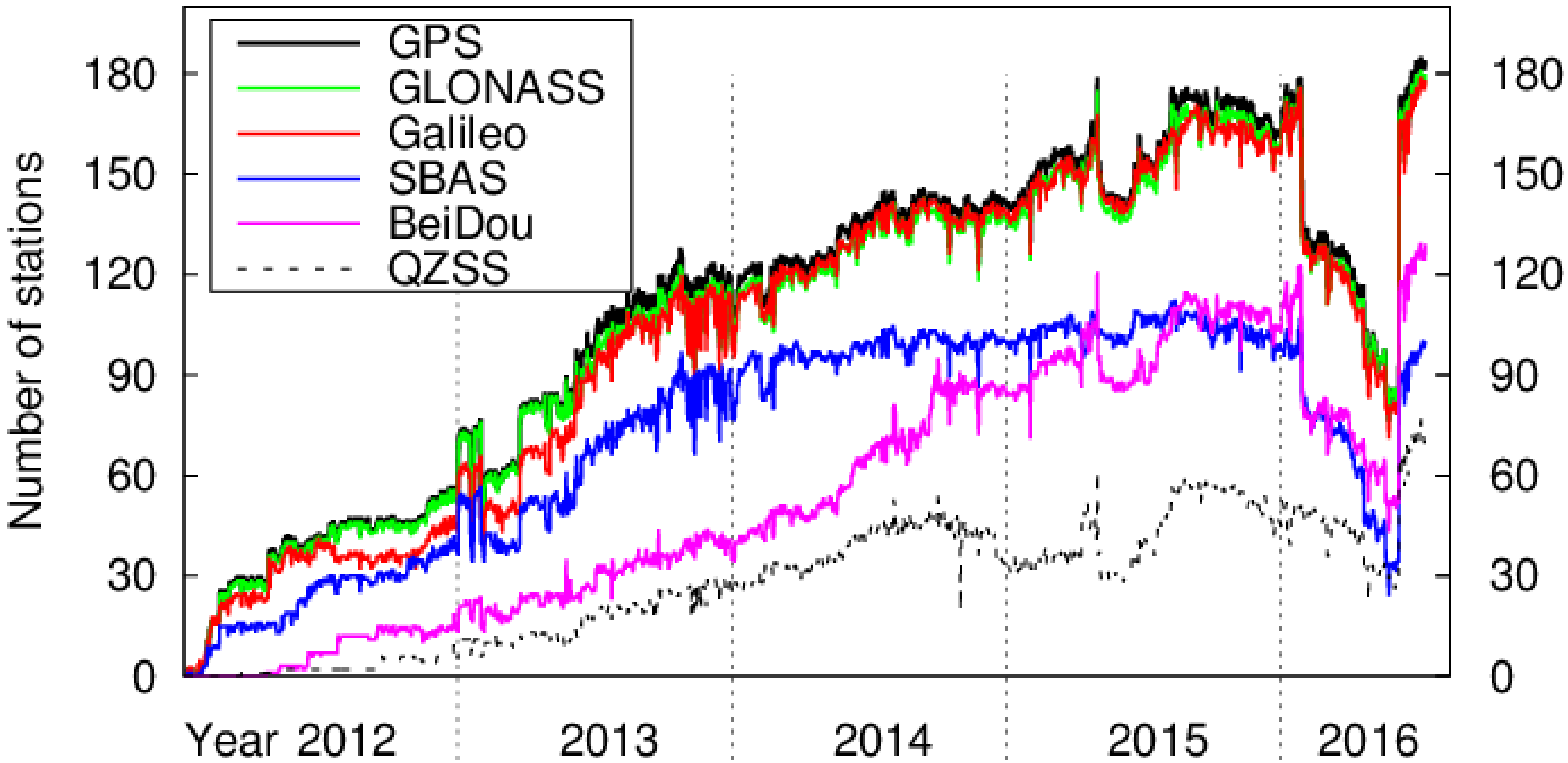
Station distribution for orbit solution (DOY 232/2016)



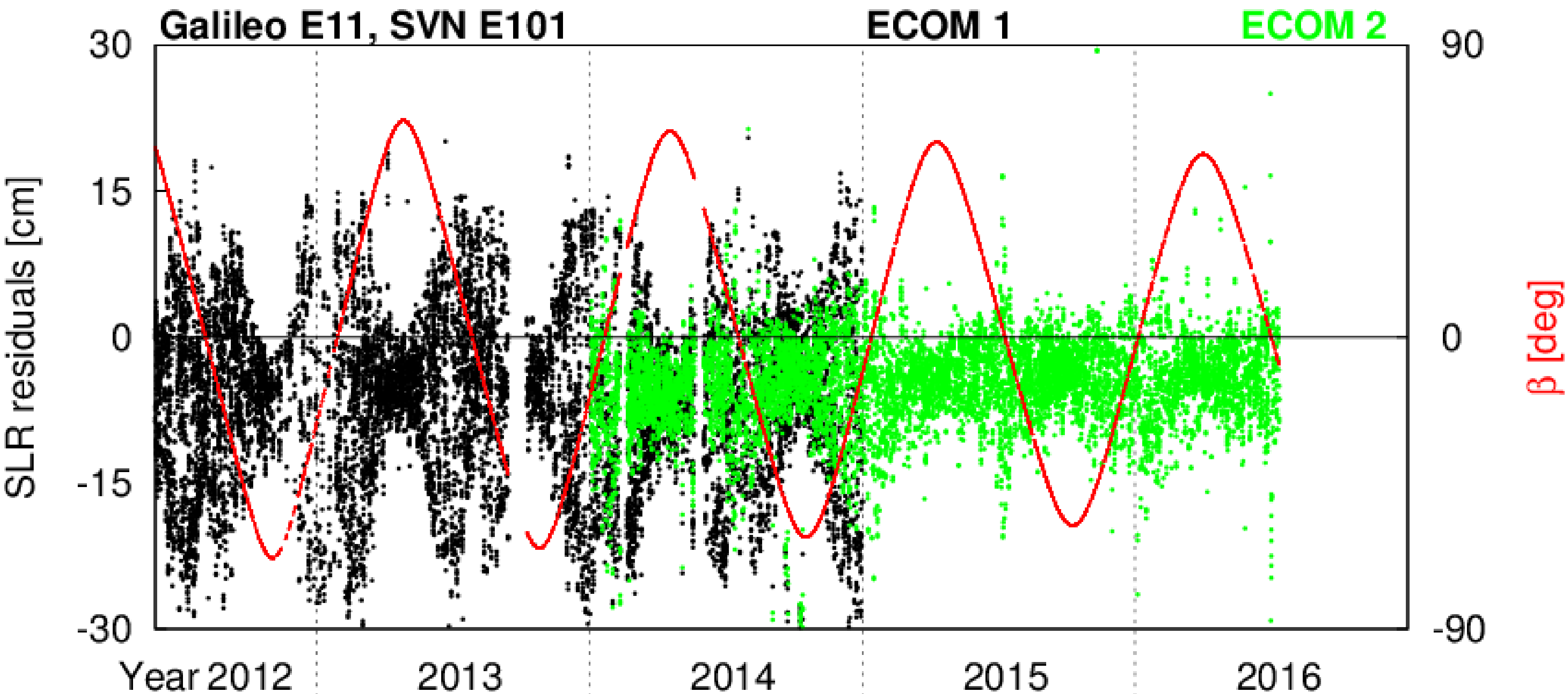
● GPS ★ GLONASS ● Galileo X BeiDou o QZSS

CODE MGEX data monitoring

Satellite systems being monitored (RINEX3 files):



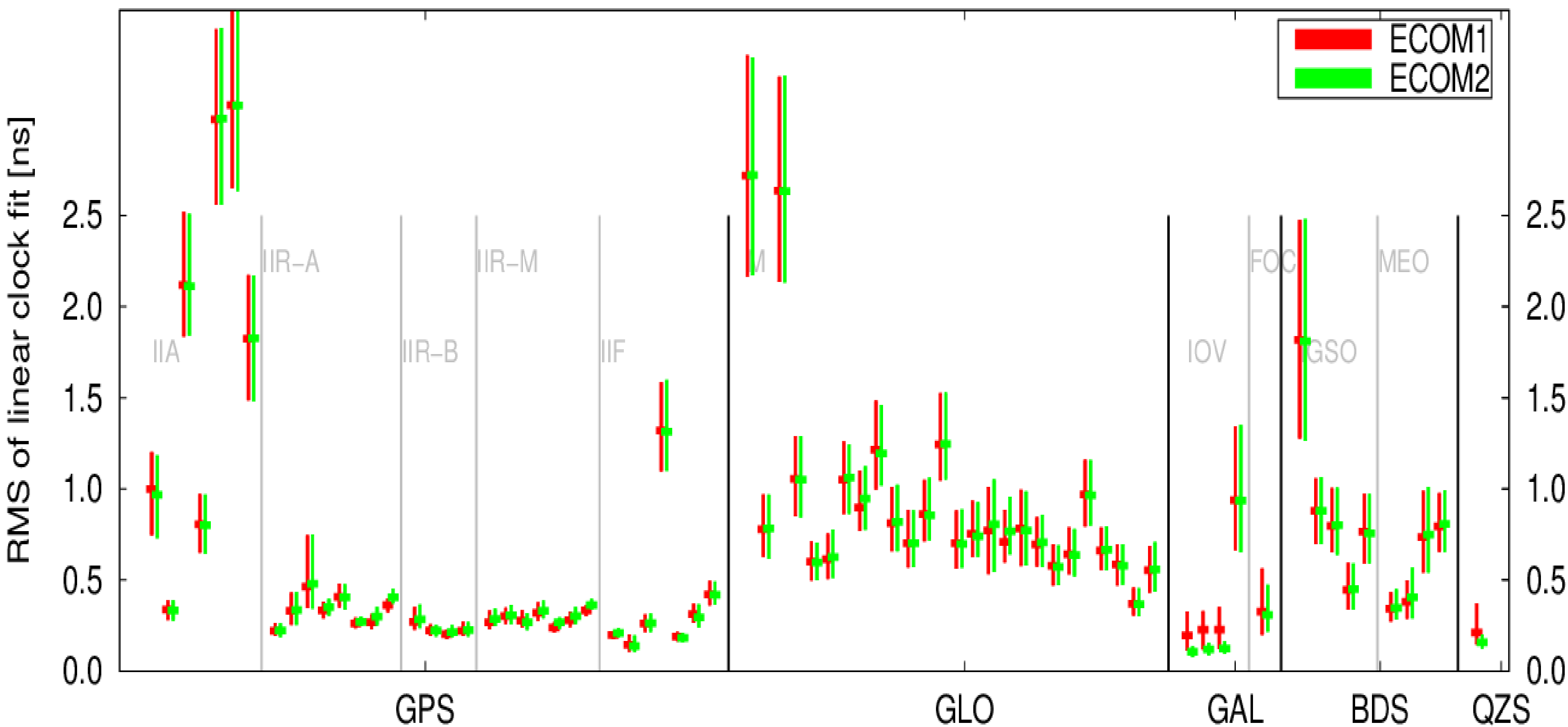
Galileo orbit validation



⇒ Significant reduction of dependency on beta-angle, when changing to the ECOM2

Clock validation 2014: median RMS of daily linear fit

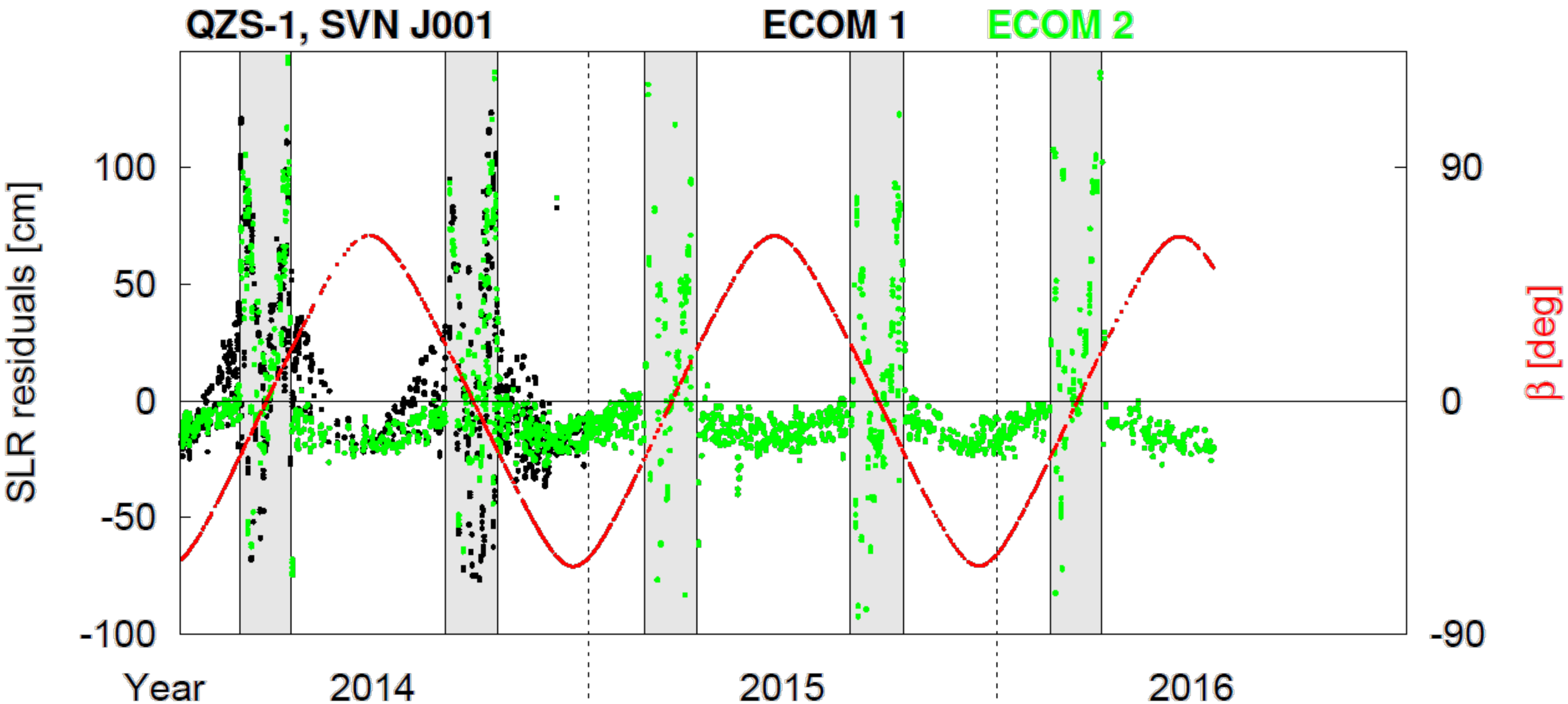
(Median and IQR; satellites in eclipse or normal mode are not considered)



⇒ Galileo PHM, QZS-1, most GPS IIR and IIF: excellent performance

⇒ Improvement with ECOM2 visible for Galileo PHM and QZS-1 clocks (=> these clocks are suitable for orbit validation)

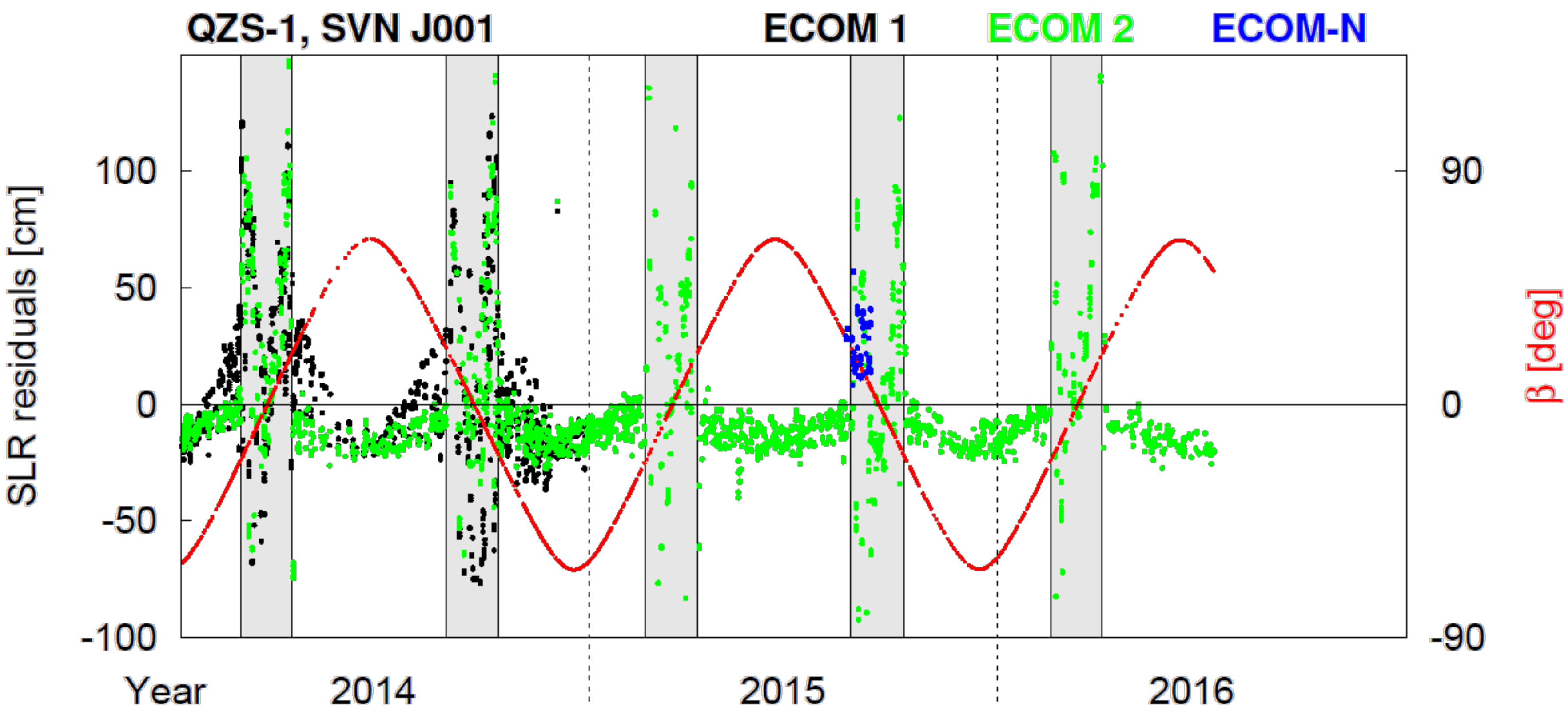
CODE MGEX solution (3d arc)



The ECOM2 decomposition is designed for the yaw-steering mode but not for the orbit normal mode.

SLR residuals

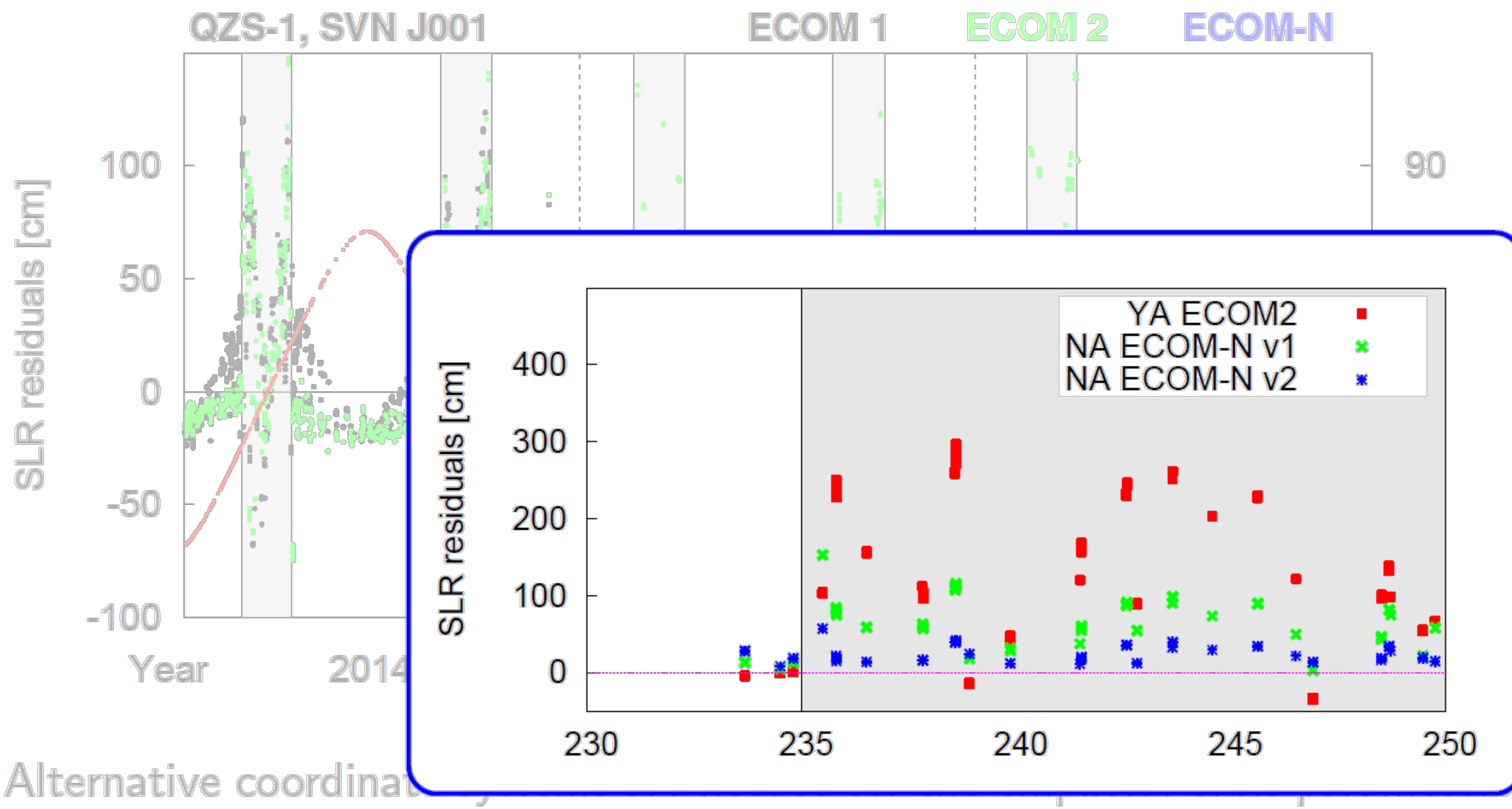
CODE MGEX solution (3d arc)



Alternative coordinate systems are needed for the empirical orbit parameters.

SLR residuals

CODE MGEX solution (3d arc)



SLR residuals

GNSS orbit validation activities at the Astronomical Institute in Bern

ILRSWS2016
International Laser Ranging Service
Workshop 2016
9 - 14 October, 2016
Potsdam, Germany

A. Grahsl[1], A. Sušnik[1], Lars Prange[1], D. Arnold, R. Dach[1], A. Jäggi[1]
[1]Astronomical Institute, University of Bern, Switzerland

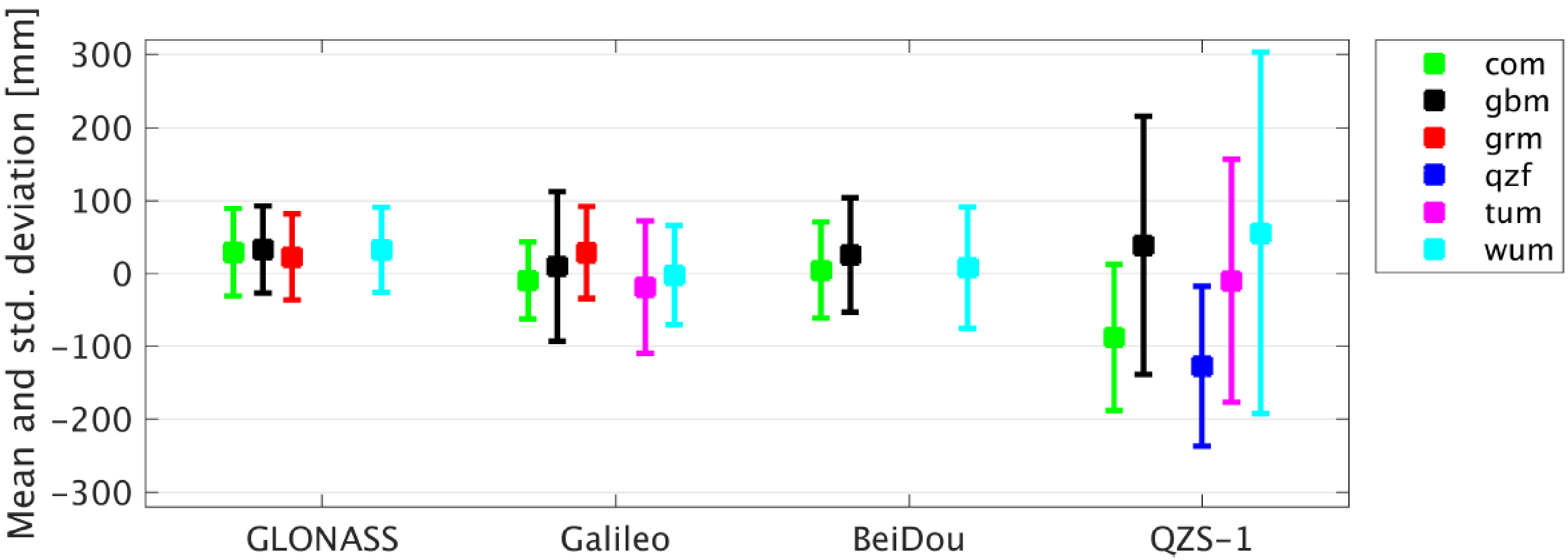
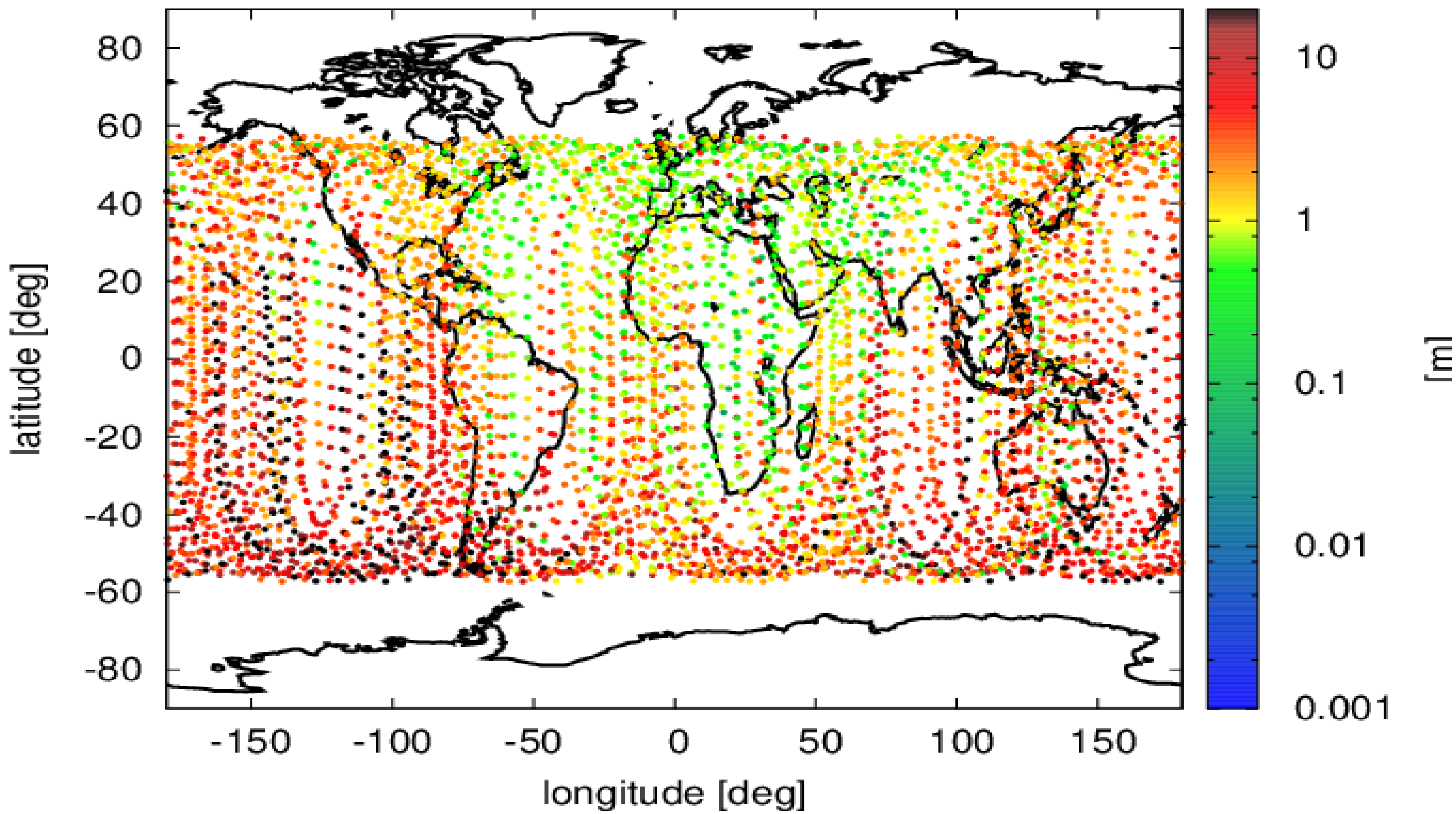


Figure 4: For each AC, mean value and standard deviation [mm] of SLR residuals with respect to GLONASS, Galileo, BeiDou, and QZS-1 satellites is shown. Note that all residuals larger than 300 mm (GLONASS), 500 mm (Galileo), 300 mm (BeiDou), and 1500 mm (QZS-1) were regarded as outliers. In addition, SLR observations during eclipses for GLONASS and during intervals with solar beta angle smaller than 20° for QZS-1 were not taken into account. For the description of acronyms see caption of Table 1.

European vs. global network: orbit differences

(Position differences of Galileo orbits with arclengths of 1 day)



Differences of 1-day Galileo orbits based on global and European station networks, respectively

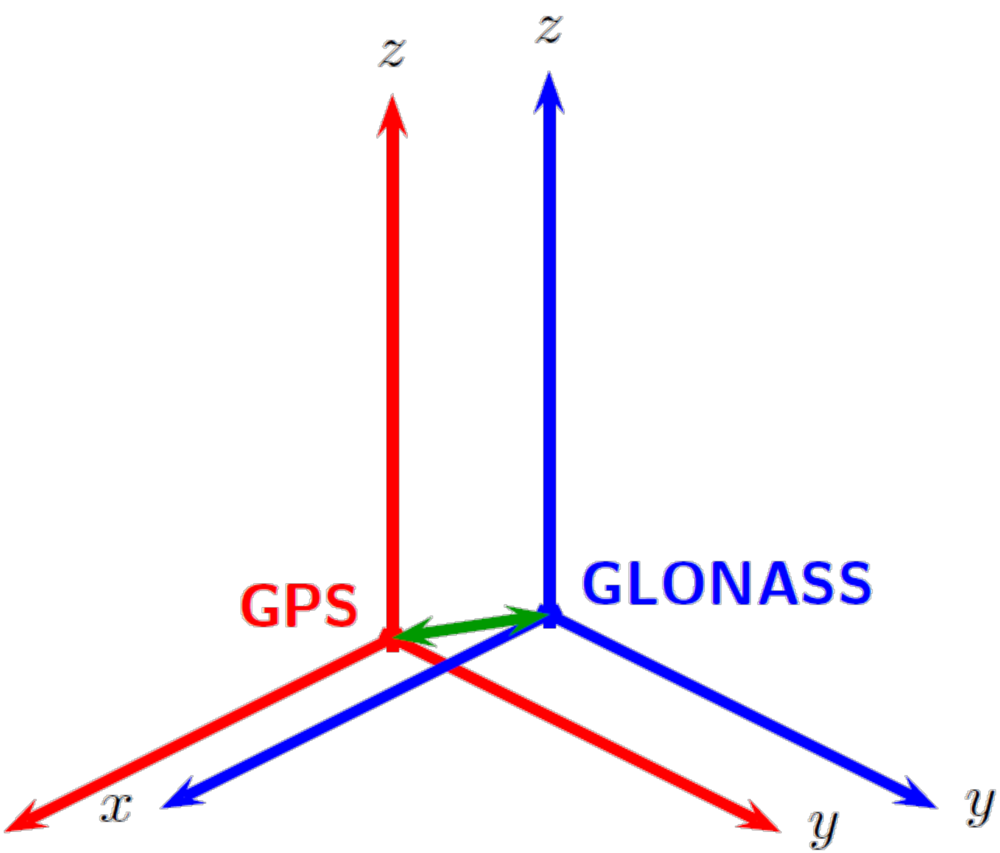
⇒ In unobserved regions the orbit differences might exceed 10 m

Compensating Deficiencies in the Receiver Antenna Calibration in an multi-GNSS environment

Receiver antenna biases

- A GNSS antenna should be individually calibrated for each GNSS.
- GEO++ (main source of IGS calibration) only provides receiver antenna calibrations for GPS and GLONASS (dual frequency).
- The coordinate/troposphere GLONASS-GPS translation bias has been implemented in order to compensate for a potential deficiency in the GNSS-specific calibration of the antenna phase center offset.

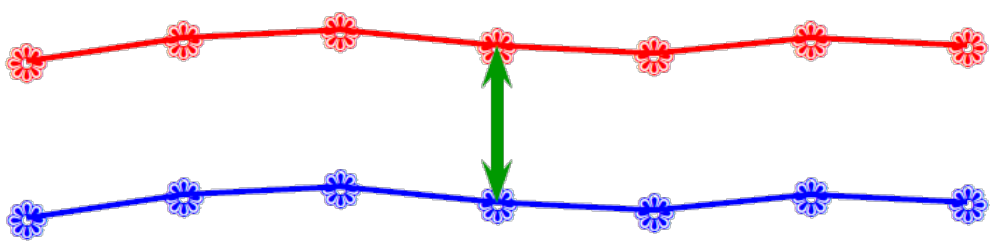
GPS–GLONASS antenna bias: Coordinates



- Station coordinate from GPS-only
- Station coordinate from GLONASS-only
- Vector between GPS– and GLONASS–coordinates
- two independent networks with independent datum definition
- zero–mean condition over all GPS–GLONASS–bias in xyz

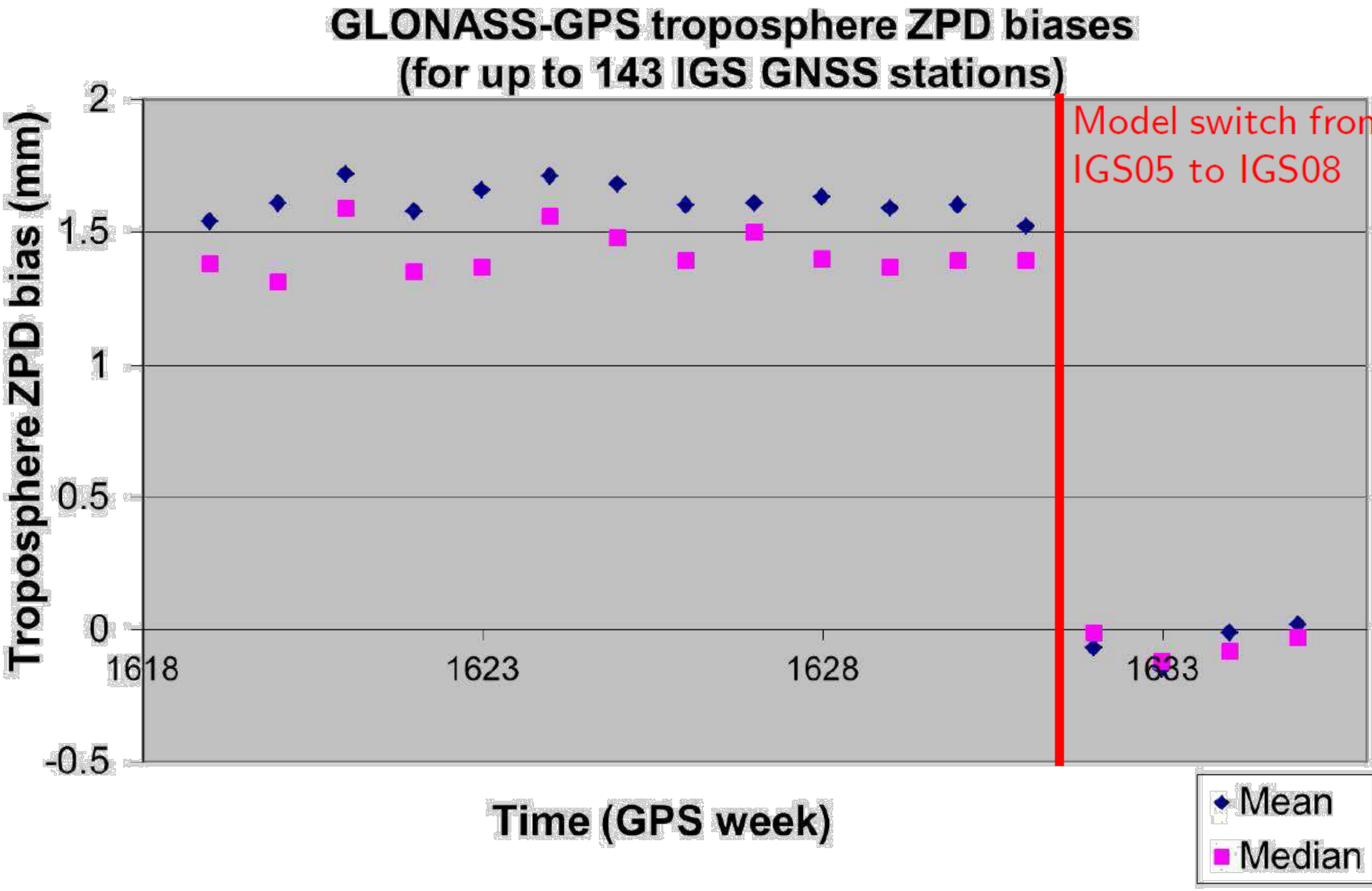
GPS–GLONASS antenna bias: Troposphere

The troposphere GLONASS-GPS translation bias shall compensate for a potential deficiency in the GNSS-specific calibration of the antenna phase center variation.



- Troposphere estimates from GPS-only
- Troposphere estimates from GLONASS-only
- Difference between GPS– and GLONASS–troposphere series

GPS–GLONASS antenna bias: Troposphere



Multi-GNSS receiver antenna bias

- The currently used IGS08.atx and IGS14.atx sets of corrections provide sufficient calibration for legacy GPS and GLONASS measurements.
- The missing receiver antenna calibration values are a significant problem in the current status of multi-GNSS processing.
- If this method is applied to multi-GNSS the influence of the deficiency on the results may be limited given that a sufficient amount of data are available.
  - Extending the parameters to all GNSS
  - Include also troposphere gradients

GNSS-specific characteristics in Earth rotation and geocenter parameter series

Method

GPS-only & GLONASS-only

GPS		GLO
recCLK		recCLK
CRD		CRD
TRP		TRP
GCC		GCC
ERP		ERP
ORB		ORB
satCLK		satCLK

Combined

GPS		GLO
recCLK	=	recCLK
CRD	=	CRD
TRP	=	TRP
GCC	=	GCC
ERP	=	ERP
ORB		ORB
satCLK		satCLK

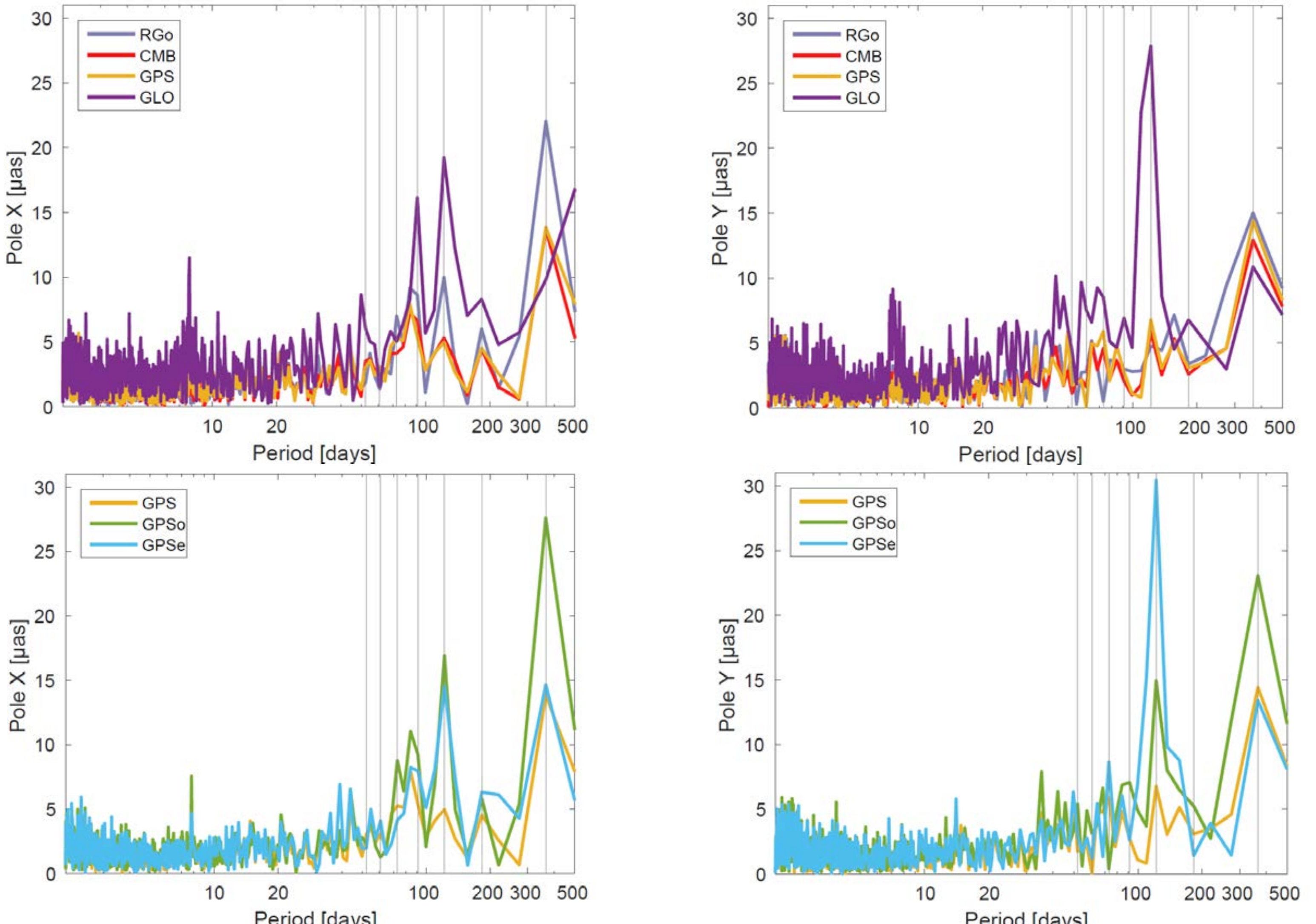
GNSS specific GCC/ERP

GPS		GLO
recCLK	=	recCLK
CRD	=	CRD
TRP	=	TRP
GCC		GCC
ERP		ERP
ORB		ORB
satCLK		satCLK

GNSS specific GCC/ERP of sub-systems

GPSo		GPSe		GLO
recCLK	=	recCLK	=	recCLK
CRD	=	CRD	=	CRD
TRP	=	TRP	=	TRP
GCC		GCC		GCC
ERP		ERP		ERP
ORB		ORB		ORB
satCLK		satCLK		satCLK

Results: Polar Motion



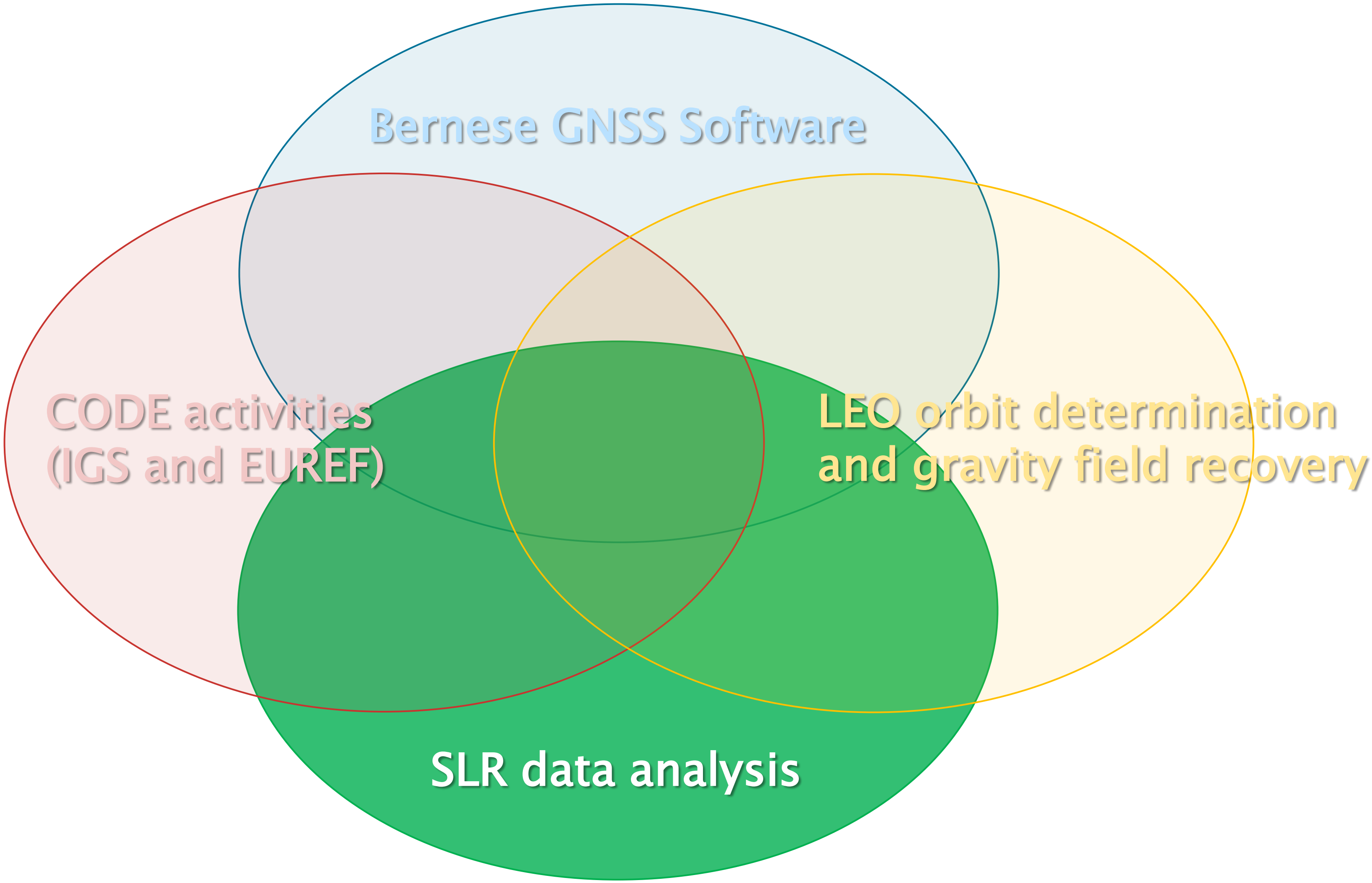
SNF project on GNSS orbit modelling

ESA project related to GNSS activities

Other projects:

- **TGVF/OVF: «Ground truth» for Galileo GMS**
  GSA-project with ESOC, BKG, GFZ, IGN
- **ORBIT /SRP Modelling for Long Term Prediction**
  ESA-project with Airbus (defense and space)
- **Improved GNSS-Based Precise Orbit Determination by using highly accurate clocks**
  ESA-project with ETH Zurich and TU Munich
- **Combination of inhomogeneous multi-GNSS products**
  ESA-NPI project with ESOC Darmstadt

Satellite Geodesy Research Group



Simulating SLR Data

Satellite Name	Satellite ID	SIC Code	NORAD Number	NP Indicator	Bin Size (Seconds)	Altitude (Km)	Inclination (deg)	First Tracked Date
Ajisai	8606101	1500	16908	5	30	1485	50	1986-Aug-13
Apollo11 Sea of Tranquility	0000100	N/A	N/A	2	variable	356,400	5	1969-Aug-20
Apollo14 Fra Mauro	0000102	N/A	N/A	2	variable	356,400	5	1971-Feb-07
Apollo15 Hadley Rille	0000103	N/A	N/A	2	variable	356,400	5	1971-Sep-01
Beacon-C	6503201	0317	1328	3	15	927	41	1976-Jan-02
COMPASS-G1	1000101	2002	36287	9	300	35,786	55.5	2012-Apr-28
COMPASS-I3	1101301	2003	37384	9	300	35,786	55.5	2012-Apr-27
COMPASS-I5	1107301	2005	37948	9	300	35,786	55.5	2012-Jul-06
COMPASS-IS1	1501901	2006	40549	9	300	35,786	55.5	2015-Sep-08
COMPASS-IS2	1505301	2010	40938	9	300	35,786	55.5	2015-Sep-29
COMPASS-M3	1201801	2004	38250	9	300	21,528	55.0	2012-Jul-11
COMPASS-MS1	1503702	2007	40749	9	300	21,528	55.0	2015-Jul-25
COMPASS-MS2	1503701	2008	40748	9	300	21,528	55.0	2015-Jul-25
Cryosat-2	1001301	8006	36508	3	15	720	92	2010-Apr-20
Etalon-1	8900103	0525	19751	9	300	19,105	65	1989-Jan-26
Etalon-2	8903903	4146	20026	9	300	19,135	65	1989-Jul-13
Galileo-101	1106001	7101	37846	9	300	23,220	56	2011-Nov-29
Galileo-102	1106002	7102	37847	9	300	23,220	56	2011-Nov-29
[illegible]	[illegible]	7103	[illegible]	9	[illegible]	23,220	[illegible]	2012-Nov-07
[illegible]	[illegible]	[illegible]	[illegible]	9	[illegible]	[illegible]	[illegible]	2012-Nov-07
Galileo-201	1405001	[illegible]	40128	9	300	17,000 - 26,210	~ 50	2014-Dec-05
Galileo-202	1405002	7202	40129	9	300	17,000 - 26,210	~ 50	2015-Mar-17
[illegible]	[illegible]	7203	40544	9	300	[illegible]	56 +/- 2 deg	2015-Mar-27
[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	2015-Mar-27
Galileo-205	1504501	7205	40889	9	300	23,220	56 +/- 2 deg	2015-Sep-11
Galileo-206	1504502	7206	40890	9	300	23,220	56 +/- 2 deg	2015-Sep-11
Galileo-208	1507902	7208	41175	9	300	23,220	56 +/- 2 deg	2015-Dec-17
Galileo-209	1507901	7209	41174	9	300	23,220	56 +/- 2 deg	2015-Dec-17

GLONASS-123	10(
GLONASS-125	11(
GLONASS-128	11(
GLONASS-129	11(
GLONASS-133	14(
GLONASS-134	14(
GRACE-A	02(
GRACE-B	02(
HY-2A	11(
IRNSS-1A	13(
IRNSS-1B	14(
IRNSS-1C	14(
IRNSS-1D	15(
IRNSS-1E	16(
[illegible]	16(
[illegible]	[illegible]
Jason-3	16(
KOMPSAT-5	13(
LAGEOS-1	76(
[illegible]	[illegible]
LARES	12(
Larets	03(
Luna17 Sea of Rains	00(
Luna21 Sea of Serenity	00(

Luna17 Sea of								
Luna21 Sea of								
PN-1A								
QZS-1								
Radio[illegible]								
SARAL								
Sentinel-3A								
Starlette								
SpinSat								
Stella								
STPSat-[illegible]								
STSAT-2C								
Swarm-A								
Swarm-B								
Swarm-C								
TanDEM-X	1003001	6202	36605	1	5	514	97.44	2010-Jun-21
TerraSAR-X	0702601	6201	31698	1	5	514	97.44	2007-Jun-16

Target: optimizing the observation scenarios at SLR tracking stations

Simulating SLR Data

Realistic SLR observation simulation:

- Considers differences between stations
- Operating times, day/night capabilities, strengths in high/low target tracking,...
- Noise resembles real bin RMS properties
- Possibility to factor in weather forecast/cloud coverage models
- Probabilistic availability of a given station at a given time

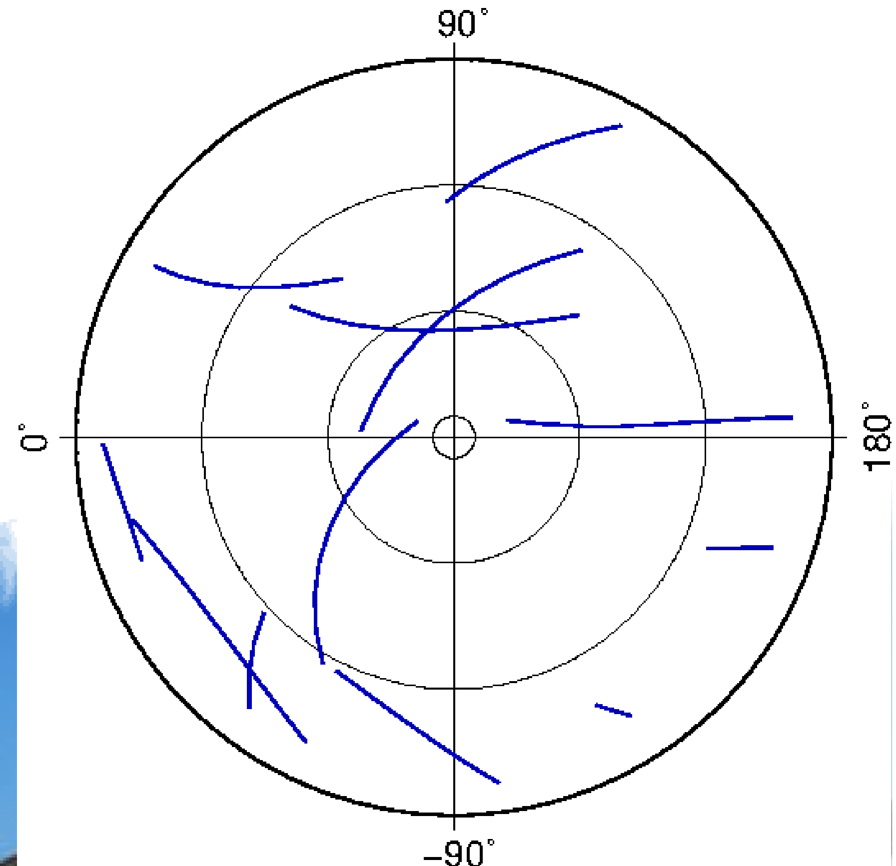
Resulting are synthetic observations upon which comparison and optimization can be done.

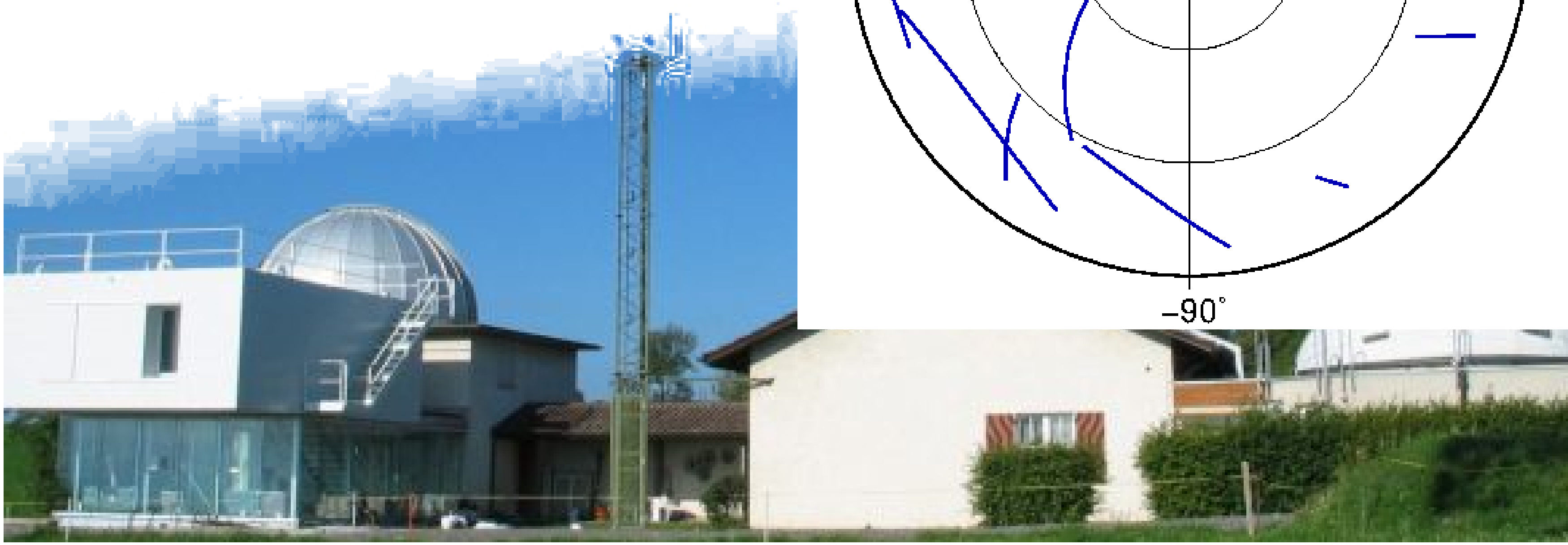
- Impact of number and distribution of observations on LAGEOS/ETALON
- SLR+GNSS combination

Simulating SLR Data

Starting from real observations,

alternative scenarios are developed.

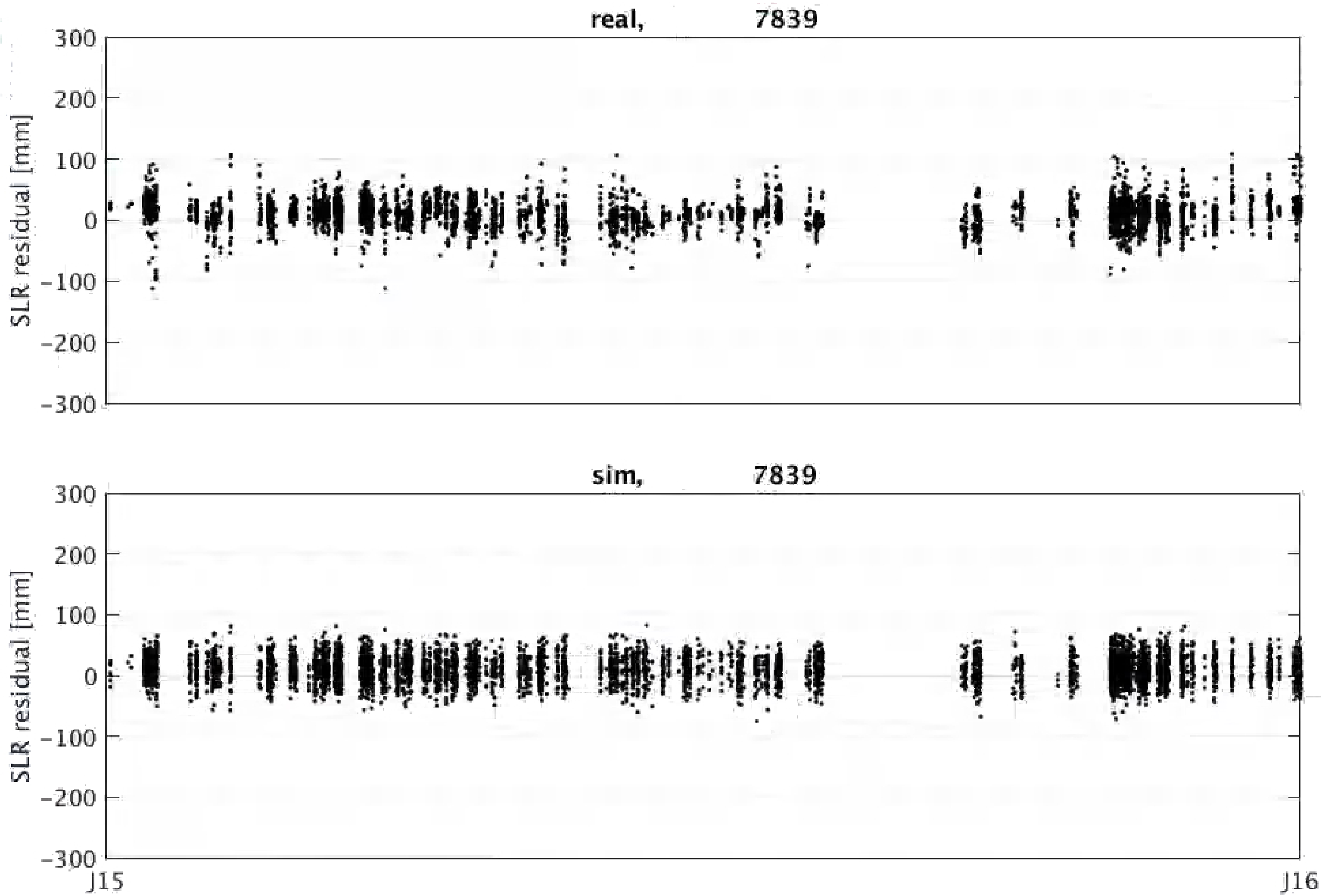




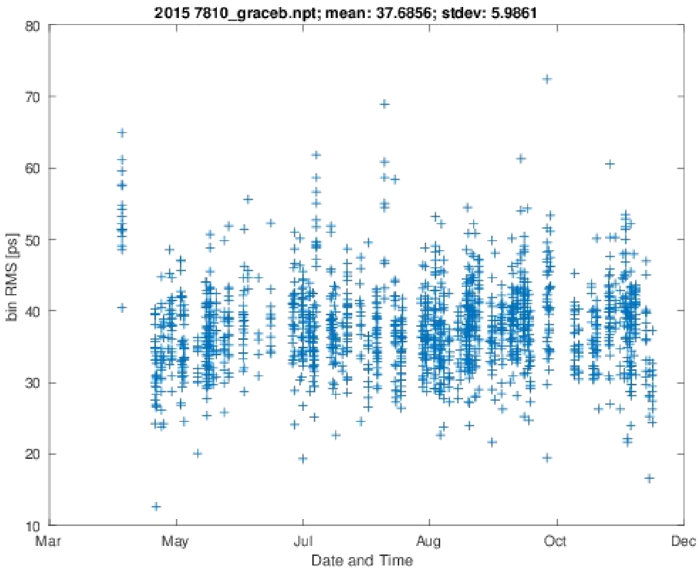
Simulating SLR Data

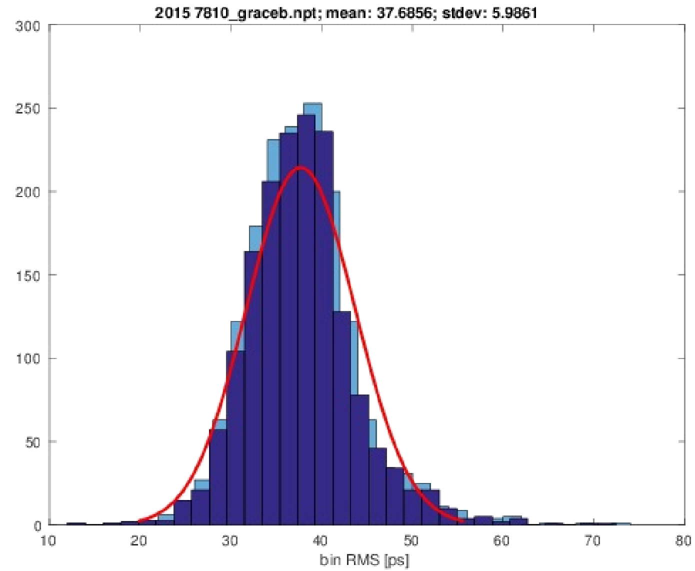
YYYY	MM	DD	STAT	TIME IN SECONDS	PRN	
****	**	**	****	******************	***	*
2015	05	06	7810	32046.185902247878	108	1
2015	05	06	7810	32126.060302248032	108	1
2015	05	06	7810	34742.648702320352	107	1
2015	05	06	7810	34862.552302311269	107	1
2015	05	06	7810	35154.578702318162	107	1
2015	05	06	7810	36243.455102316861	108	1
2015	05	06	7810	36376.229502318871	108	1
2015	05	06	7810	40050.113102219737	111	1
2015	05	06	7810	50219.056302341145	111	1
2015	05	06	7810	51928.352112342225	121	1
2015	05	06	7810	51932.583932335045	121	1
2015	05	06	7810	51936.500912335854	121	1
2015	05	06	7810	51942.945872333563	121	1
2015	05	06	7810	51946.872112332734	121	1
2015	05	06	7810	51951.641012342428	121	1
2015	05	06	7810	51958.623052340256	121	1
2015	05	06	7810	51962.188152332608	121	1
2015	05	06	7810	51967.808972341074	121	1
2015	05	06	7810	51972.374152341465	121	1
2015	05	06	7810	51977.856072334798	121	1
2015	05	06	7810	51982.106412339985	121	1
2015	05	06	7810	51987.792052336998	121	1
2015	05	06	7810	51992.042392342613	121	1
2015	05	06	7810	51997.524312334826	121	1
2015	05	06	7810	52001.691312335461	121	1
2015	05	06	7810	52007.451032332443	121	1
2015	05	06	7810	52018.155592334660	121	1
2015	05	06	7810	52022.054052340201	121	1
2015	05	06	7810	52027.526712332408	121	1
2015	05	06	7810	52031.951052338896	121	1
2015	05	06	7810	52037.587572334320	121	1
2015	05	06	7810	52042.560972338986	121	1
2015	05	06	7810	52047.119922336395	121	1
2015	05	06	7810	52052.738022335390	121	1
2015	05	06	7810	52056.818052335875	121	1
2015	05	06	7810	52061.561202337041	121	1
2015	05	06	7810	54224.806702237183	123	1
2015	05	06	7810	61700.233082270584	124	1
2015	05	06	7810	62868.262582268966	113	1
2015	05	06	7810	63549.433102269177	113	1
2015	05	06	7810	63843.317902267241	113	1
2015	05	06	7810	63903.531902260132	113	1
2015	05	06	7810	78878.631902225781	103	1
2015	05	06	7810	79022.709502223472	103	1
2015	05	06	7810	79281.893502318562	102	1
2015	05	06	7810	79286.484302322424	102	1

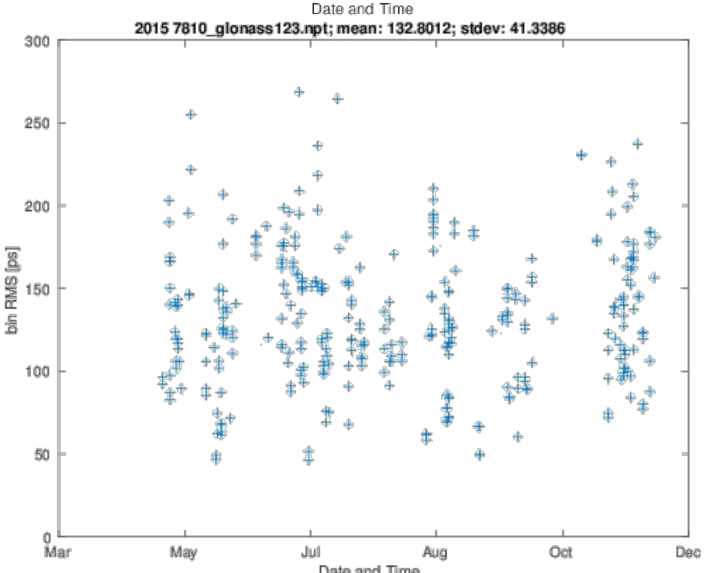
Simulating SLR Data

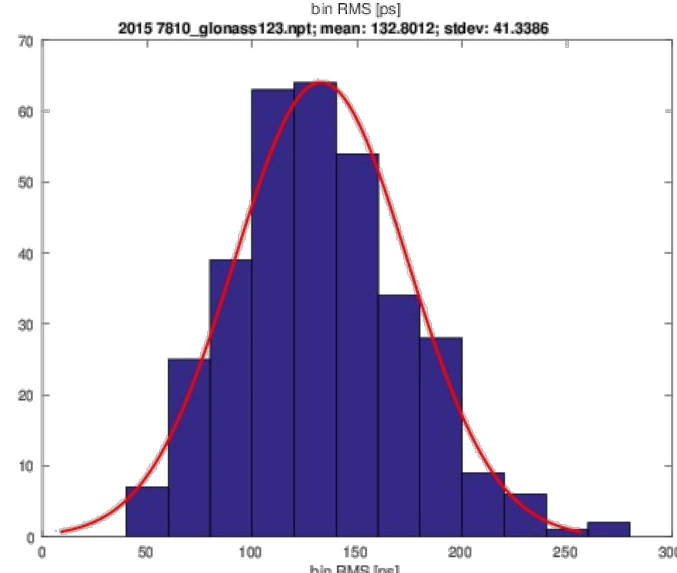


Simulating SLR Data

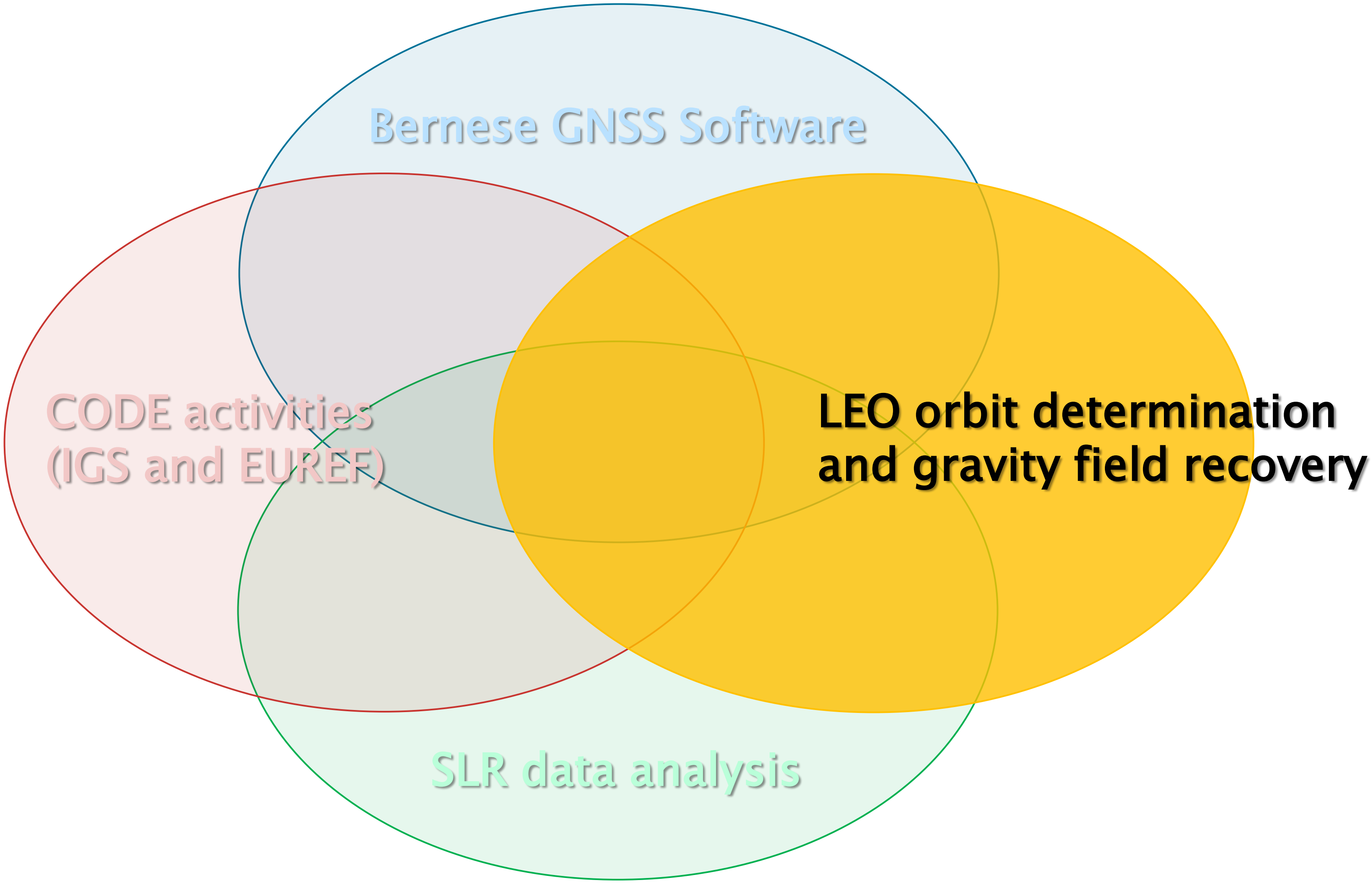








Satellite Geodesy Research Group

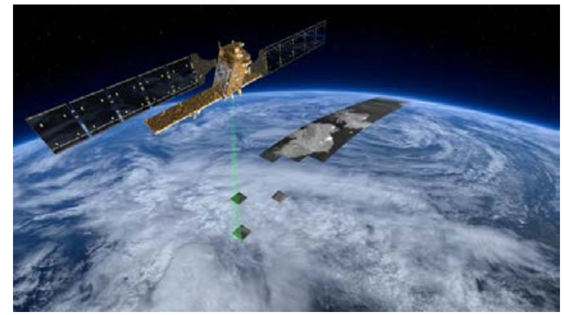


Copernicus POD Service

Copernicus satellite fleet

At AIUB precise orbits of all Sentinel satellites are computed

Sentinel-1A



Sentinel-1B

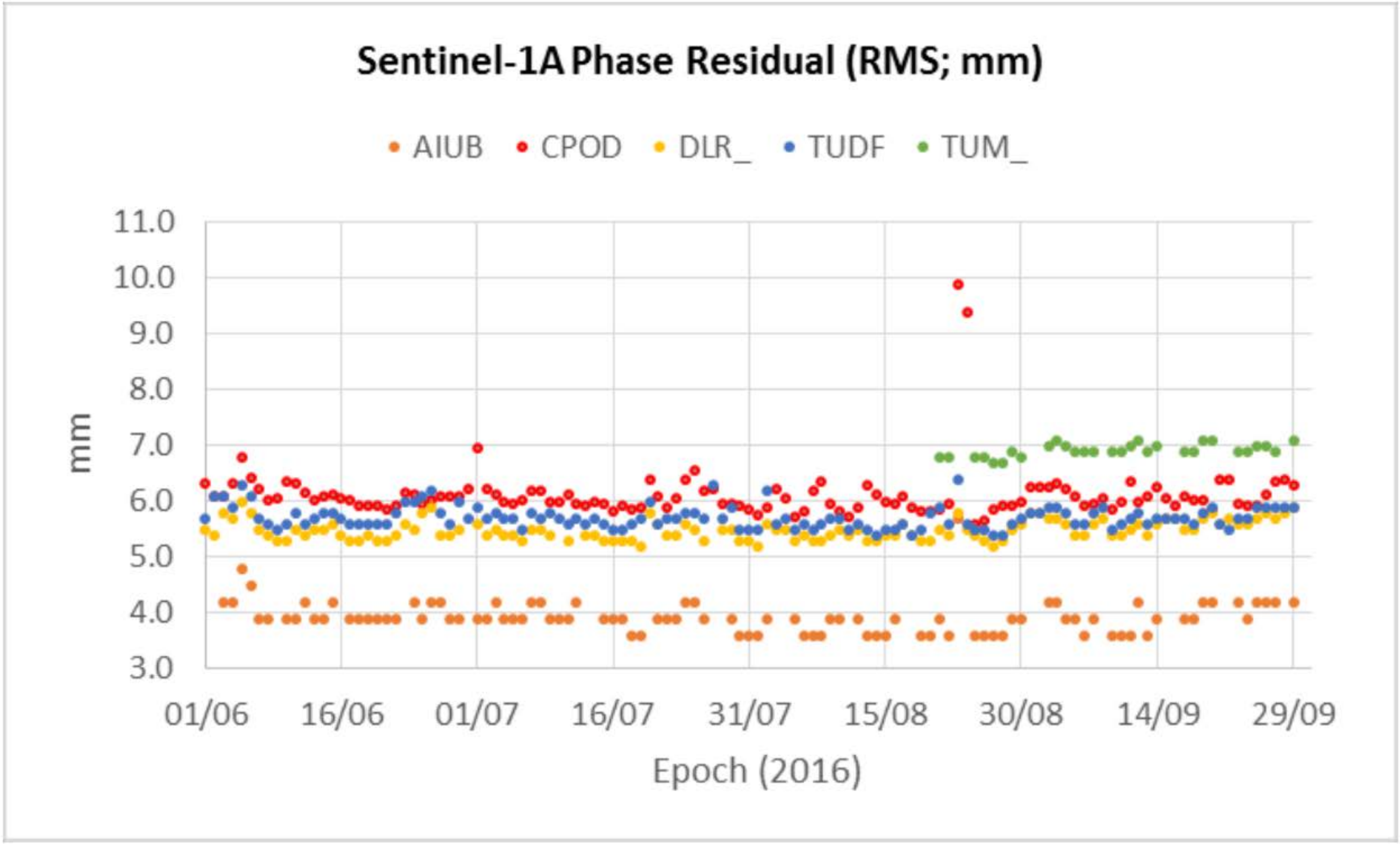
opernicus
Europe's eyes on Earth

Sentinel-2A

Sentinel-3A

Courtesy: ESA

RMS of GPS carrier phase residuals



3D-RMS of mutual orbit comparisons

S1A

	AIUB		COMB		CPOD		DLR		ESOC		TUDF		TUM	
COMB	0.91	0.12												
CPOD	2.44	0.28	1.84	0.33										
DLR	1.36	0.13	0.89	0.16	2.30	0.38								
ESOC	2.20	0.30	1.77	0.35	2.44	0.56	2.19	0.33						
TUDF	2.16	0.72	1.75	0.77	2.39	0.35	2.23	0.78	2.93	0.82				
TUM	1.48	0.13	1.10	0.10	2.16	0.24	1.62	0.18	2.25	0.27	1.45	0.11		
Avg.	1.51	0.24	1.18	0.26	1.94	0.31	1.51	0.28	1.97	0.38	1.84	0.51	1.44	0.15

S1B

	AIUB		COMB		CPOD		DLR		ESOC		TUDF		TUM	
COMB	3.09	0.40												
CPOD	3.87	0.73	1.59	0.29										
DLR	2.87	0.29	0.81	0.16	2.21	0.34								
ESOC	3.97	0.43	1.76	0.37	2.35	0.38	2.40	0.37						
TUDF	4.63	1.13	1.64	0.59	2.36	0.29	2.09	0.88	2.55	0.54				
TUM	11.35	3.63	11.44	3.56	11.39	3.55	11.53	3.53	11.83	3.47	11.67	3.47		
Avg.	4.25	0.95	2.90	0.77	3.40	0.80	3.13	0.80	3.55	0.79	3.56	0.99	9.89	3.03

3D-RMS of mutual orbit comparisons

S2A

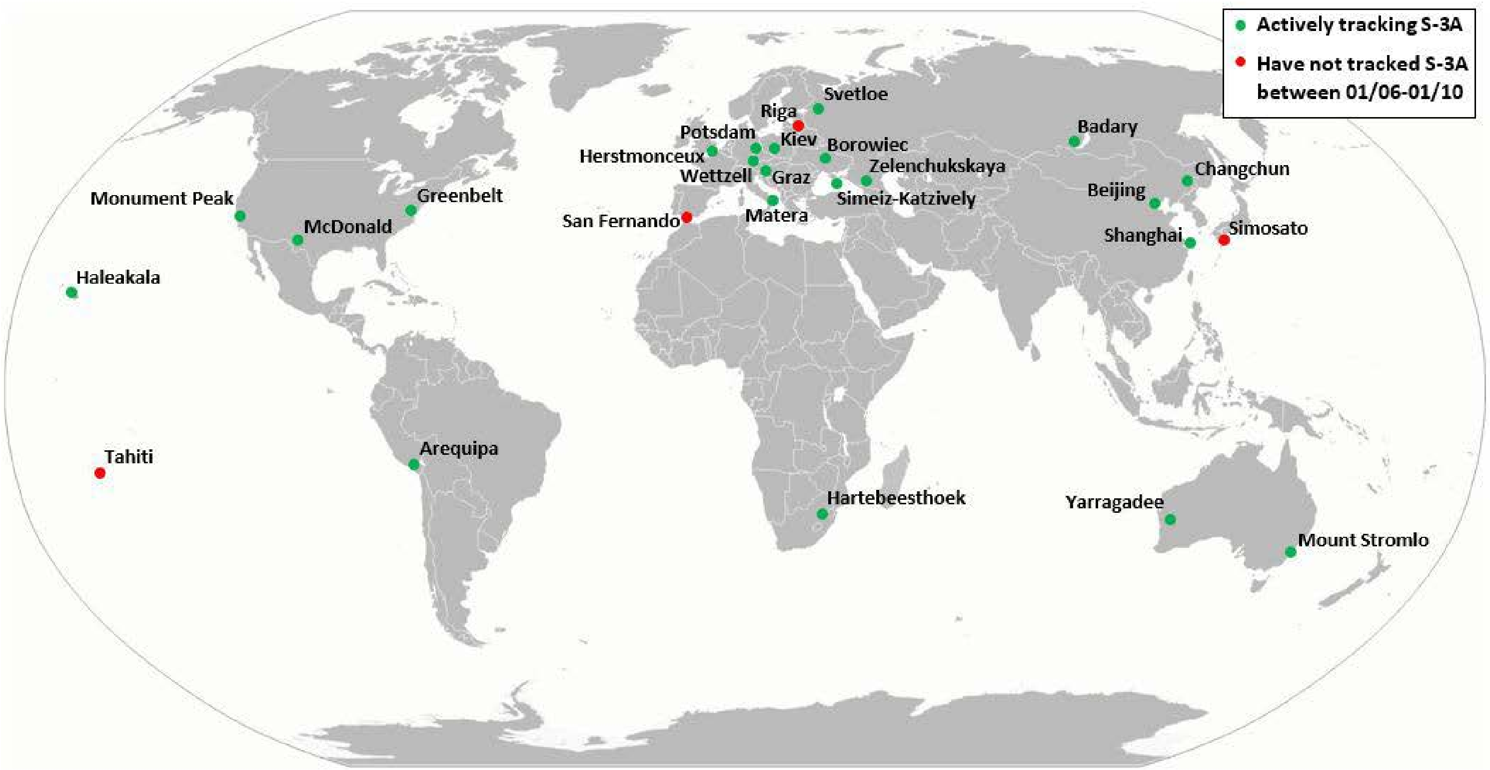
	AIUB		COMB		CPOD		DLR		ESOC		TUDF		TUM	
COMB	0.90	0.14												
CPOD	2.21	0.34	1.80	0.36										
DLR	1.26	0.23	0.73	0.15	2.14	0.39								
ESOC	2.10	0.32	1.69	0.33	2.08	0.36	2.14	0.38						
TUDF	1.22	0.24	0.66	0.17	2.06	0.38	1.03	0.16	1.99	0.36				
TUM	1.95	0.25	1.57	0.25	2.60	0.32	1.69	0.24	2.55	0.34	2.00	0.26		
Avg.	1.38	0.22	1.05	0.20	1.84	0.31	1.28	0.22	1.79	0.30	1.28	0.23	1.77	0.24

S3A

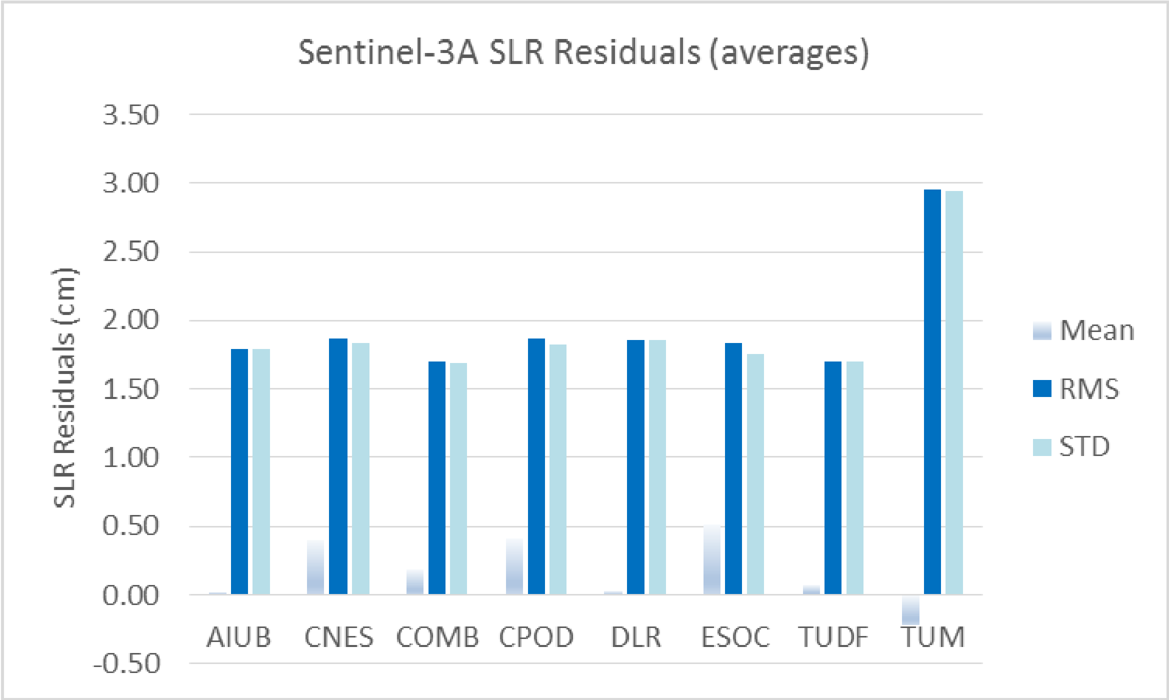
	AIUB		CNES		COMB		CPOD		DLR		ESOC		TUDF		TUM	
CNES	2.01	0.20														
COMB	1.08	0.16	1.48	0.23												
CPOD	2.25	0.24	1.84	0.24	1.72	0.26										
DLR	1.36	0.16	2.03	0.22	0.83	0.11	2.25	0.24								
ESOC	2.33	0.65	2.20	0.67	1.69	0.68	2.20	0.66	2.17	0.60						
TUDF	1.29	0.19	1.91	0.23	0.70	0.10	2.07	0.25	1.01	0.13	2.06	0.63				
TUM	3.94	0.48	3.91	0.48	3.43	0.47	4.20	0.46	3.21	0.45	3.90	0.59	3.63	0.50		
Avg.	1.78	0.26	1.92	0.28	1.37	0.25	2.07	0.29	1.61	0.24	2.07	0.56	1.58	0.25	3.28	0.43

SLR validation of Sentinel-3

ILRS Stations allowed to track Sentinel-3



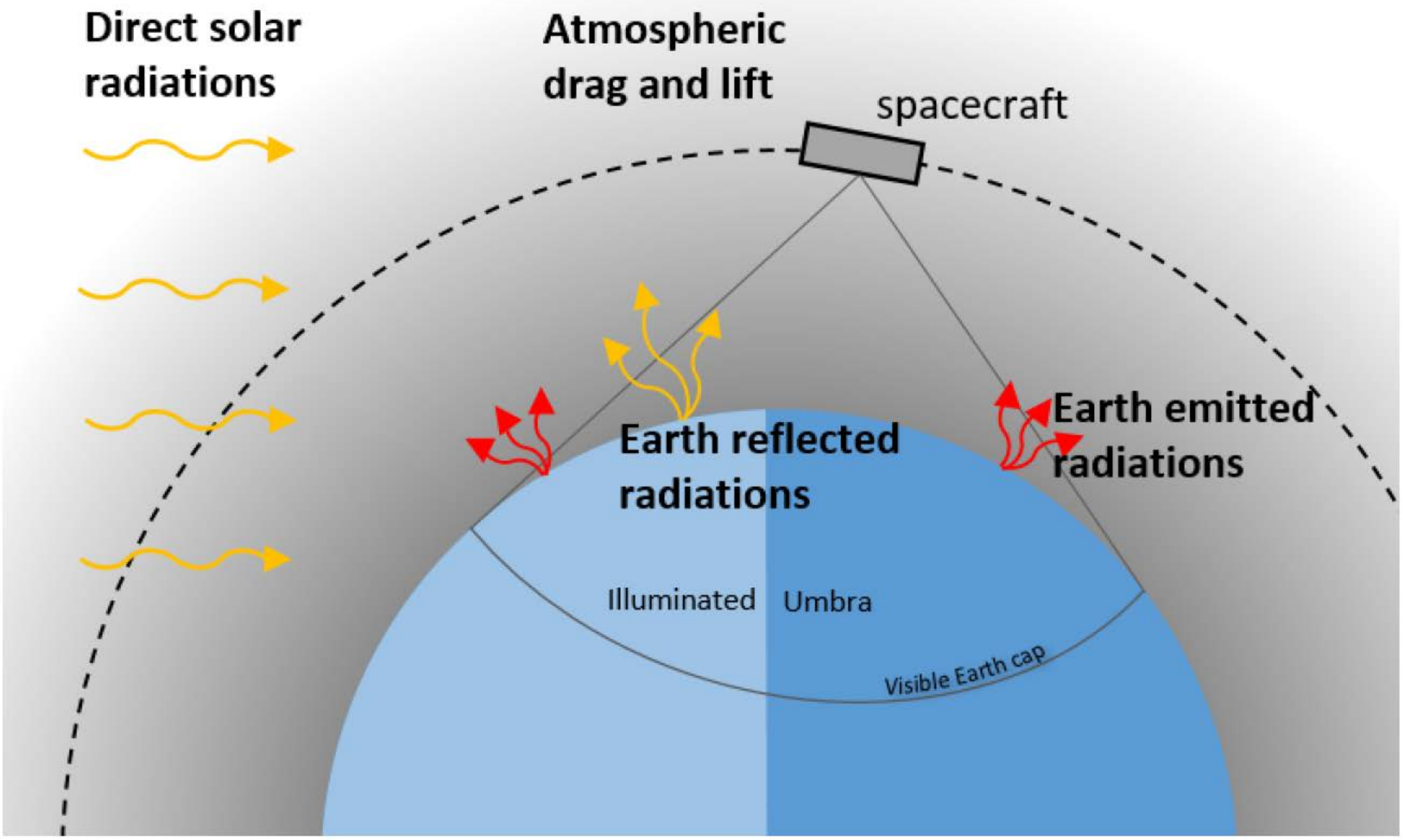
SLR validation of Sentinel-3



	AIUB	CNES	COMB	CPOD	DLR	ESOC	TUDF	TUM
Mean	0.02	0.40	0.19	0.41	0.03	0.51	0.07	-0.22
RMS	1.79	1.87	1.70	1.87	1.86	1.83	1.70	2.95
STD	1.79	1.83	1.69	1.82	1.86	1.76	1.70	2.94

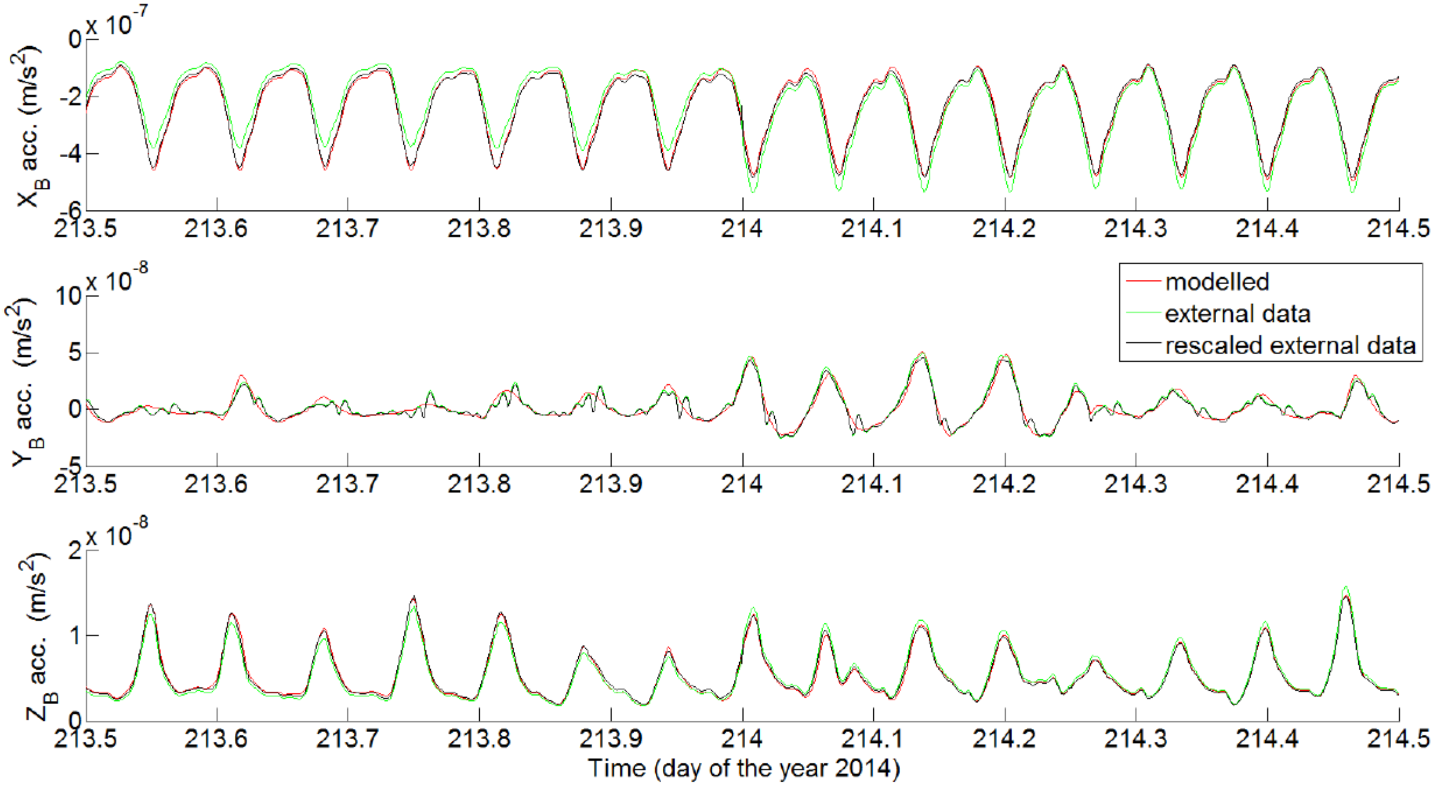
LEO non-gravitational force modeling

Force models considered



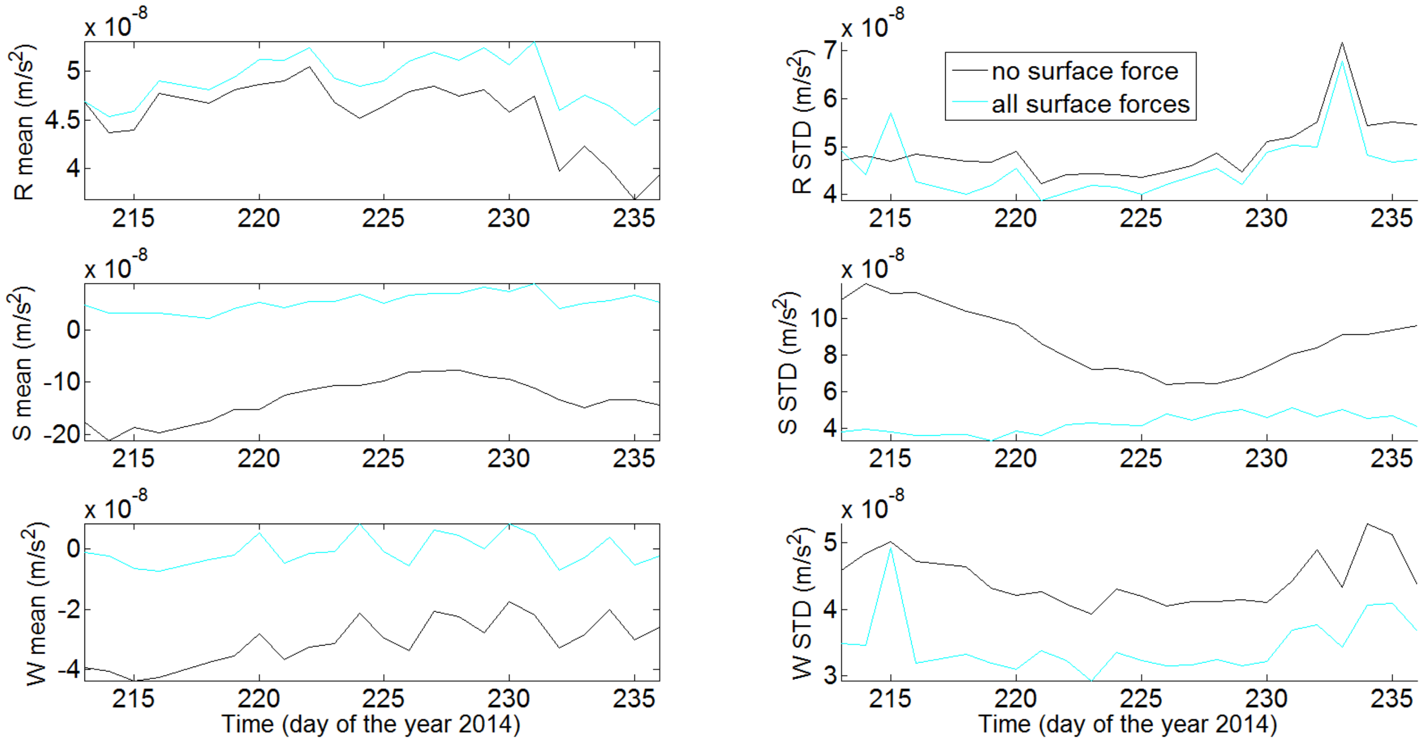
Comparison with other approaches

Aerodynamic acceleration acting on Swarm-C (satellite-fixed frame). Red: Bernese GNSS Software. Green: Acceleration computed by E. Doornbos from TU Delft. Black: Rescaled acceleration from TUD.



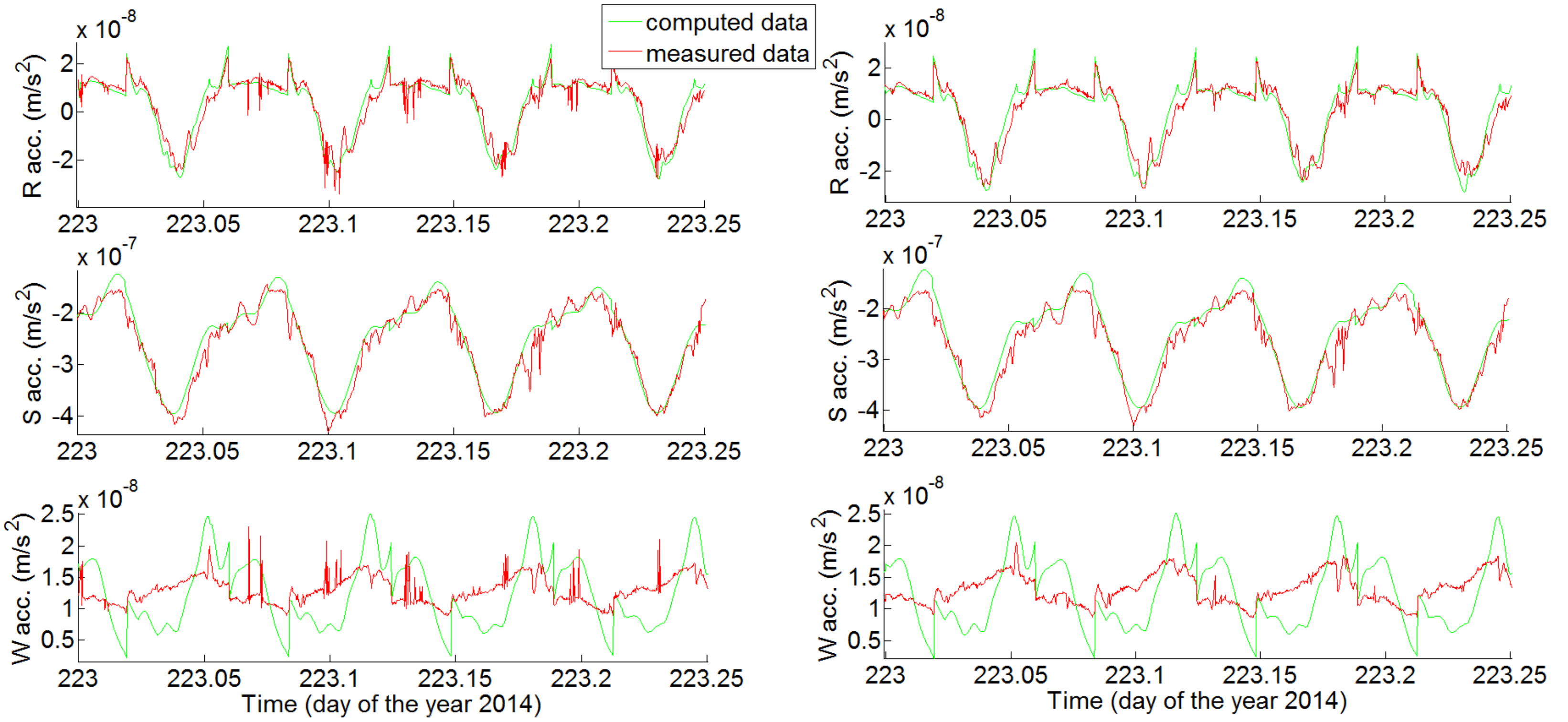
Reduction of empirical accelerations

Daily mean values (left) and standard deviations (right) of the piecewise-constant accelerations estimated for Swarm-C.



Comparison with accelerometer data

Computed and measured acceleration for GRACE-A



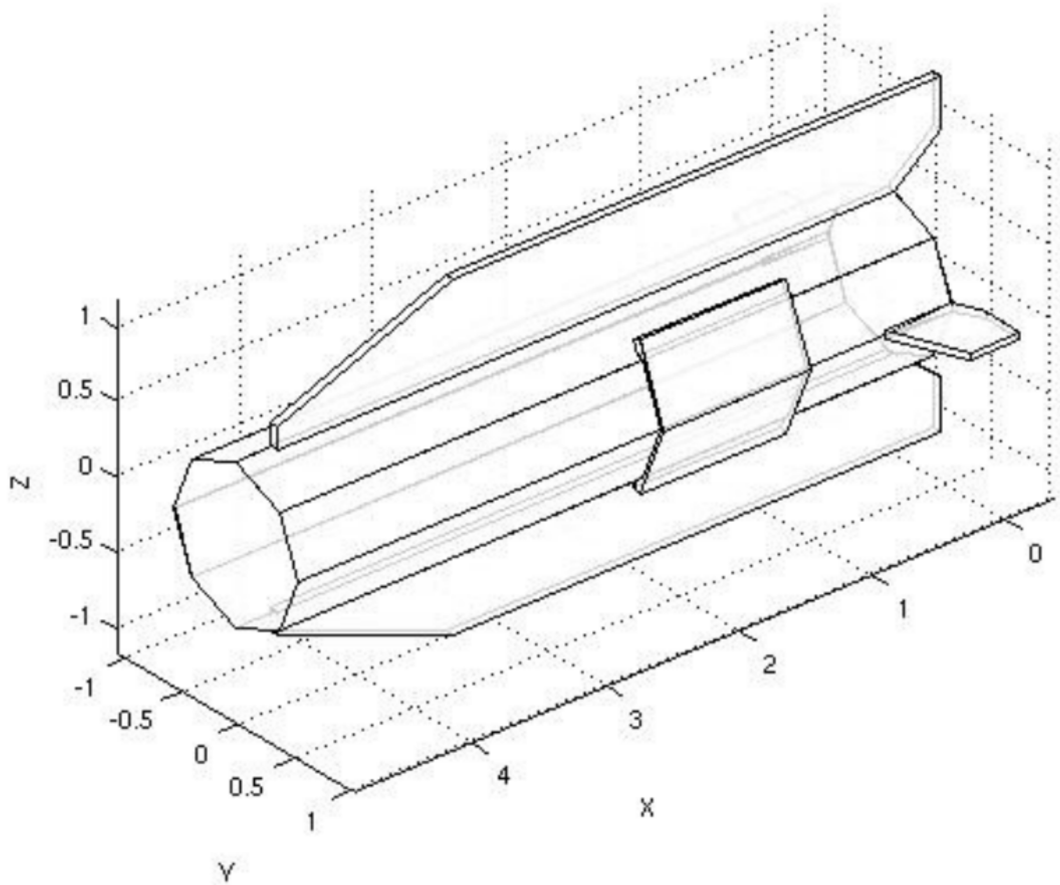
Precise orbit determination for the final stages of GOCE

Details of air-drag modeling

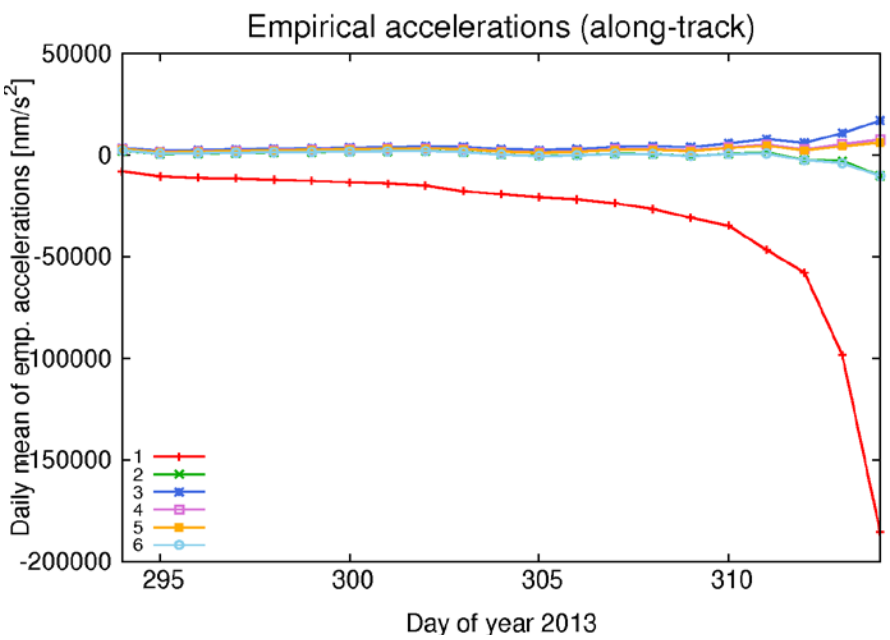
- **Implementation of air drag modelling**
  - **Air drag models have been implemented into Bernese GNSS software.**
  - **Two types of macro models:**
    - **6-plate box model of S. Bruinsma (2013) GOCE+ Theme 3: Air density and wind retrieval using GOCE data, Validation report. Surfaces: 0.70m2 (x), 10.77m2 (y), 5.90m2 (z).**
    - **44-plate model of GO-TN-AI-0179 (GOCE Stand-alone Aerodynamic Model of ThalesAlenia) resp. the 36-plate variant without radiator (self-shadowing?)**
  - **Computation of drag and lift coefficients for each plate according to Sentman's theory.**

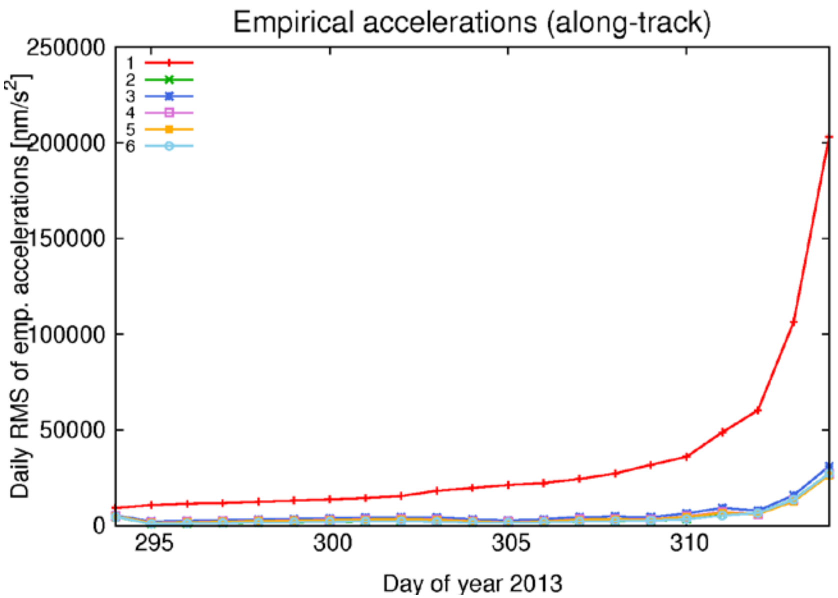
$$\boldsymbol{a}_D = -\frac{\rho A_{ref}}{2m} C_D v^2 \boldsymbol{e}_D, \qquad \boldsymbol{a}_L = -\frac{\rho A_{ref}}{2m} C_L v^2 \boldsymbol{e}_L, \qquad \boldsymbol{e}_D = -\frac{\boldsymbol{v}}{v}, \qquad \boldsymbol{e}_L = -\frac{(\boldsymbol{v} \times \boldsymbol{n}) \times \boldsymbol{v}}{|(\boldsymbol{v} \times \boldsymbol{n}) \times \boldsymbol{v}|}$$

GOCE macro model



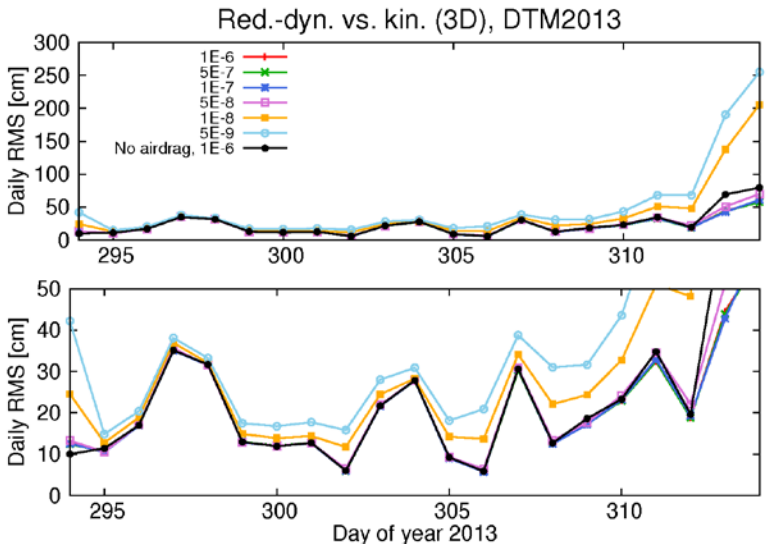
Reduction of empirical accelerations

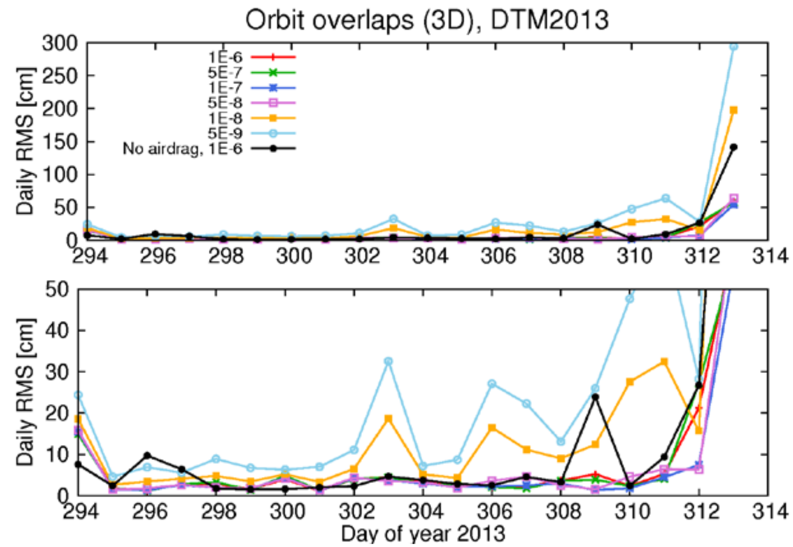




- **1: No air drag modelling**
- **2: DTM2013, no HWM, 6-plate macro model**
- **3: DTM2013, no HWM, 44-plate macro model**
- **4: DTM2013, no HWM, 36-plate macro model**
- **5: DTM2013, HWM14, 36-plate macro model**
- **6: DTM2013, HWM14, 36-plate macro model SESAM for energy accommodation coefficient**

Constraining of empirical accelerations



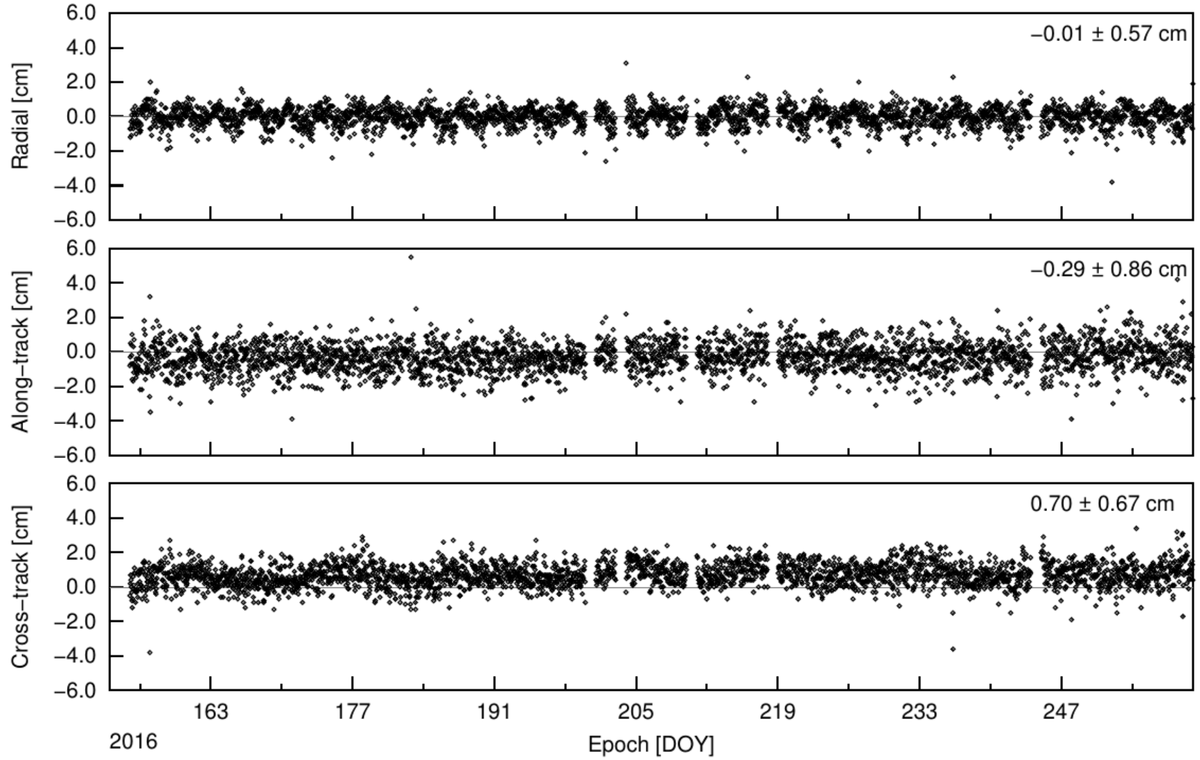


- **Differences to kinematic orbits and orbit overlaps show that a tightening of the constraints to ~ 5E-8 m/s^2 is possible without degrading the orbits (actually improving).**
- **Reached level: Roughly as without air drag modeling and very loose constraints (1E-6 m/s^2), except for single days (296, 307, 309) and the very last days (better).**

Application to Sentinel-3

Orbit differences to DLR orbits

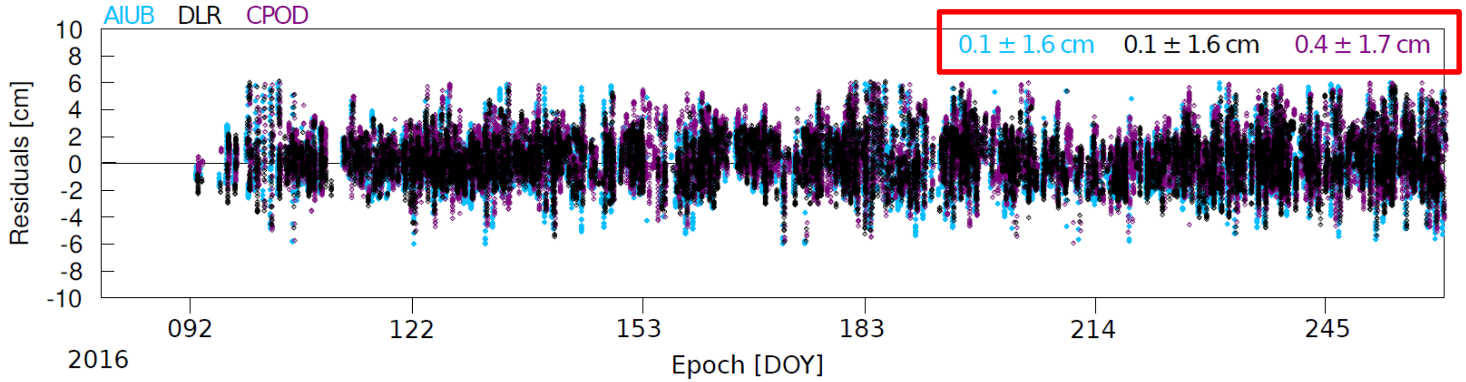
Sentinel-3A orbits have been computed with more dynamical stiffness (important for altimetry) and compared to DLR orbits.



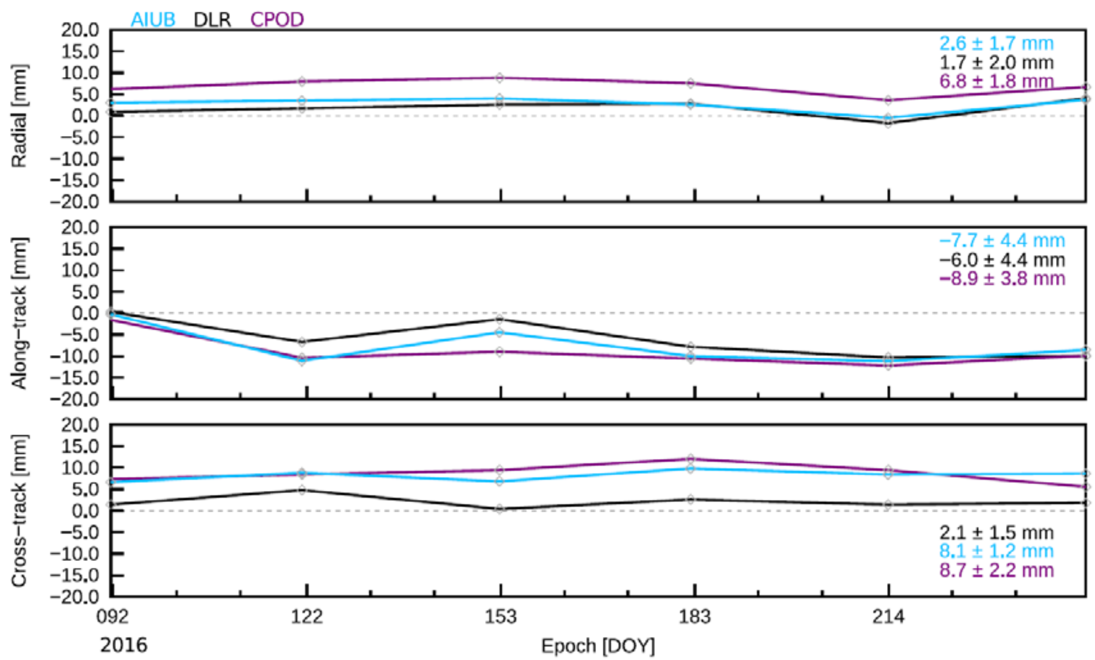
No radial offsets between the orbits from the two agencies.

SLR validation

SLR residuals



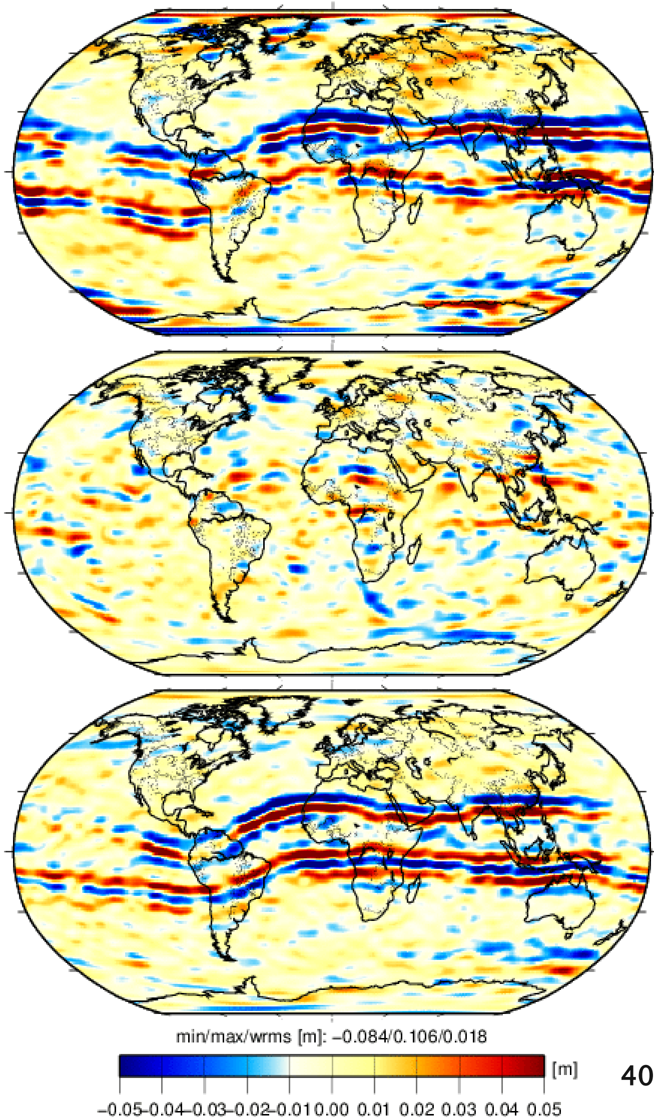
SLR offsets



Swarm GPS receiver issues

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

Original GPS Data | Screened GPS Data



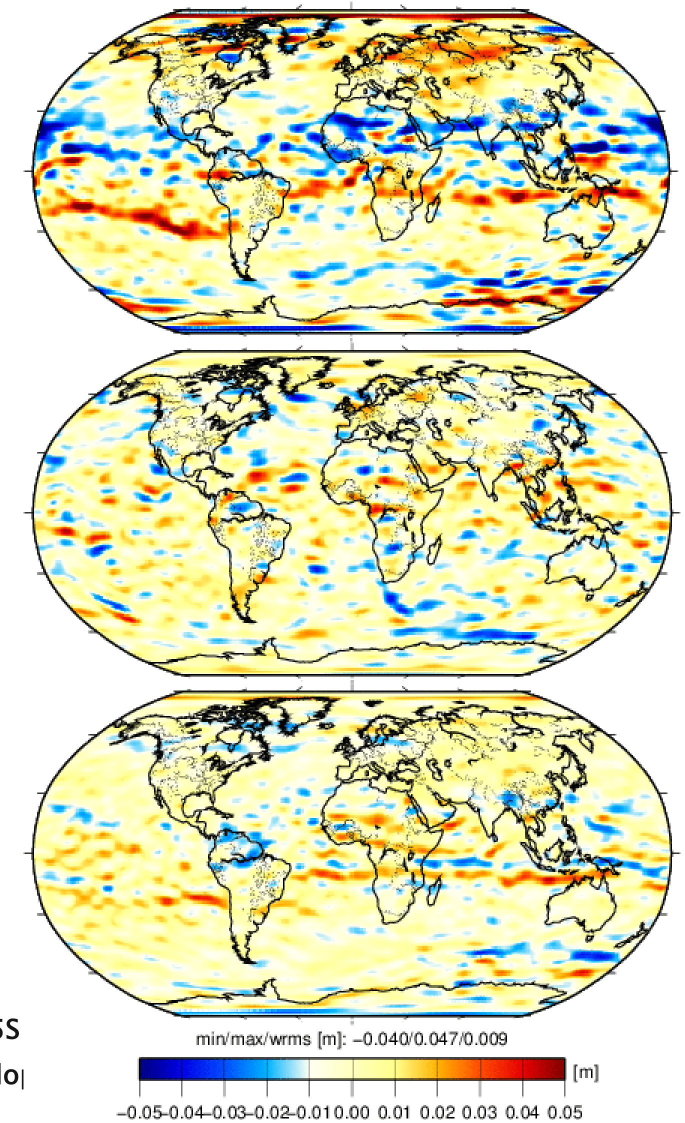
Mar/Apr 2014

Jun/Jul 2014

Nov/Dec 2014

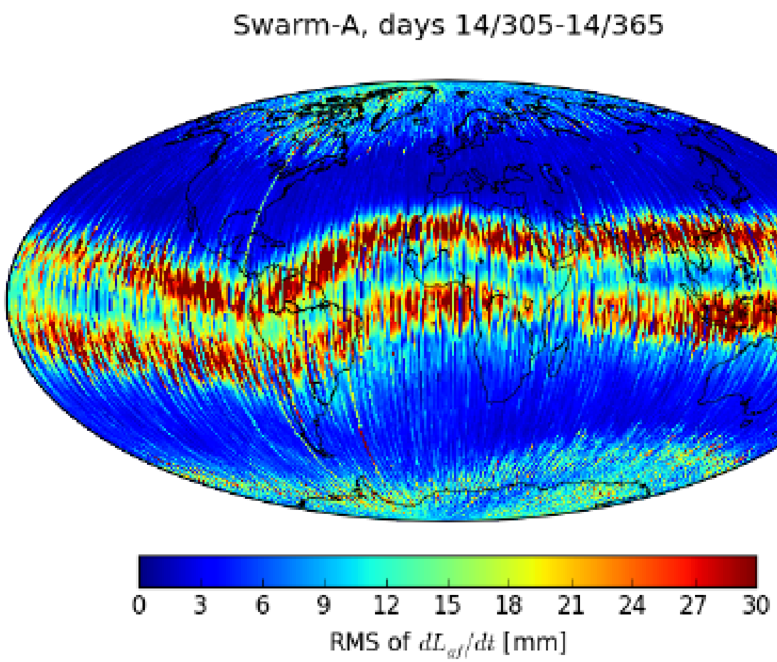
Differences wrt GOCO05S

400 km Gauss smoothing ado|

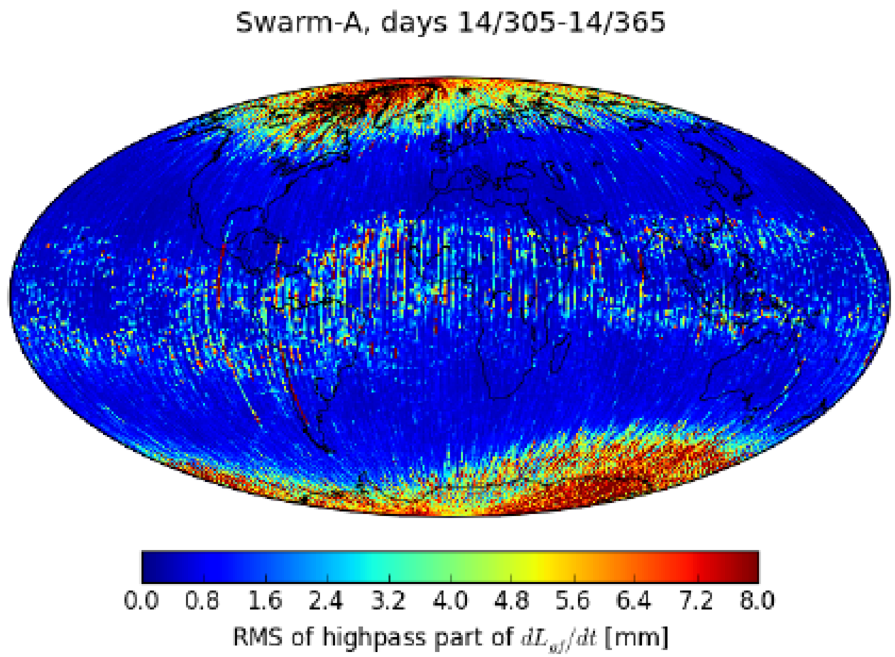


Global ionosphere behavior

RMS of ΔL_{gf} (full signal)



RMS of ΔL_{gf} (high-pass)



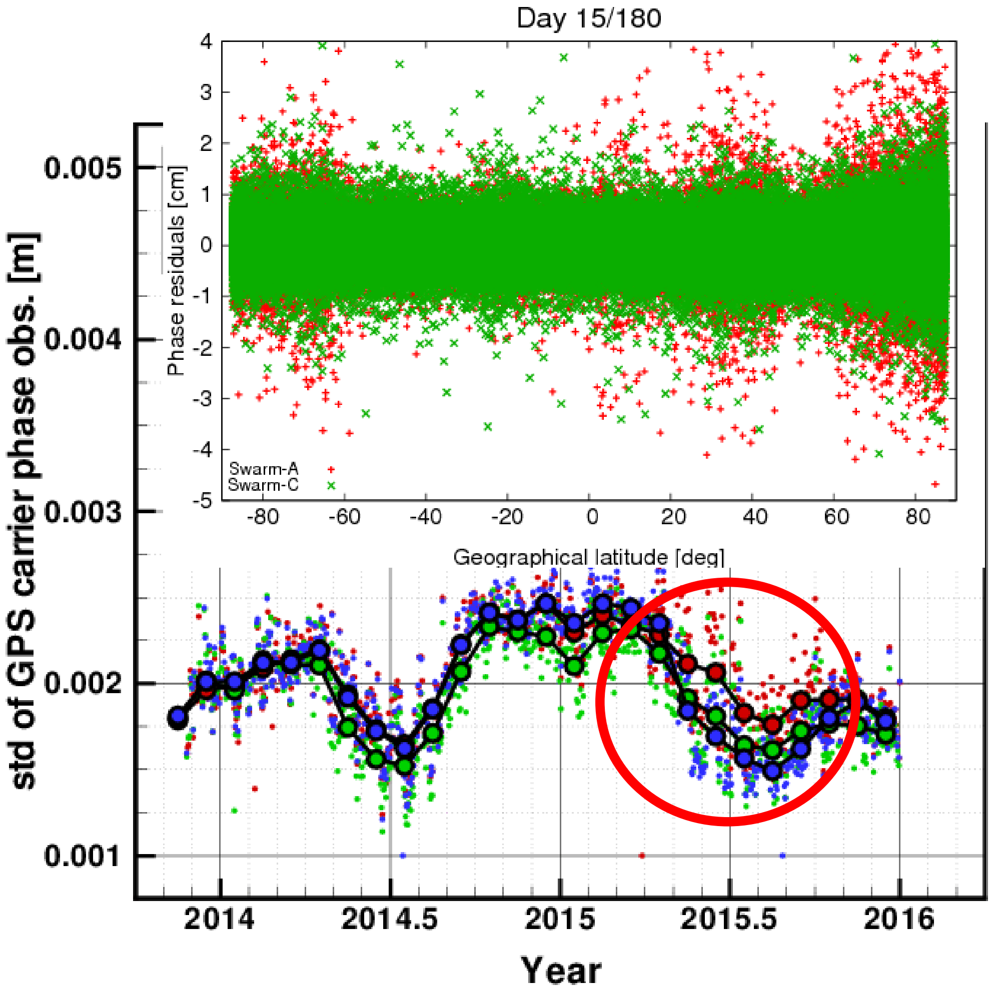
Equatorial regions are mainly governed by deterministic features

Polar regions are mainly governed by scintillation-like features

History of FOV and tracking loop changes

- Up to 20 Oct 2014: GPS antenna field-of-view (FOV) 80°, antenna correction applied in GPSx Level1b products
- 20 Oct 2014: Antenna FOV enlarged to 83°, antenna corrections switched off
- 01 Dec 2014: FOV enlarged to 86° for Swarm C
- 13 Jan 2015: FOV enlarged to 88° for Swarm C
- 06 May 2015: L1-carrier loop increased by 50% and L2-carrier and P(Y)-code loops increased by 100% for Swarm C. FOV enlarged to 88° for Swarm A and B.
- 08 Oct 2015: Swarm A: same tracking loop changes
- 10 Oct 2015: Swarm B: same tracking loop changes

RMS of kinematic POD

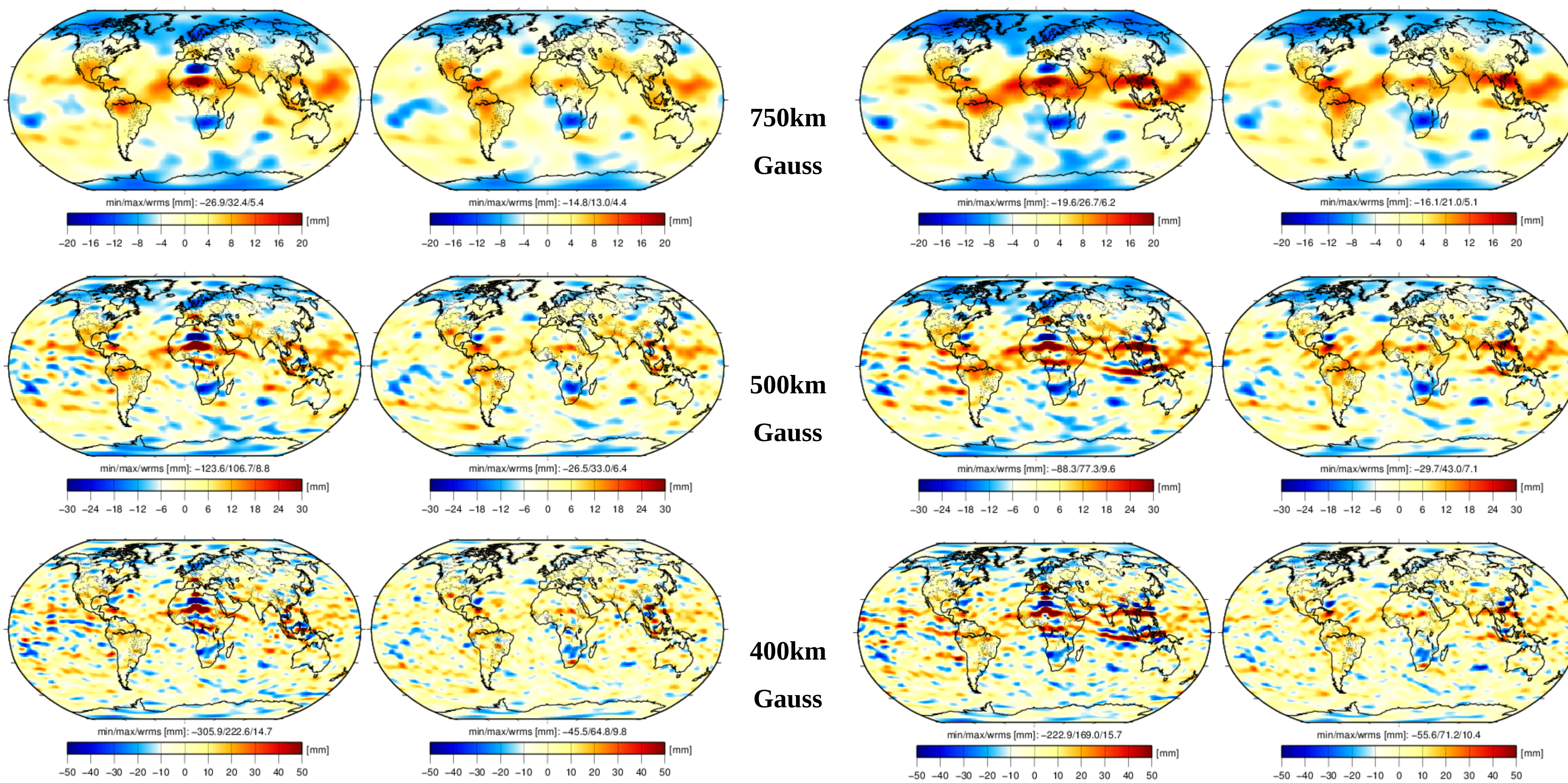


- Changed tracking loop settings lead to smaller carrier phase RMS (mainly due to reduction of large residuals over the polar regions)
- Differences between RMS of Swarm A and Swarm C only during period with different settings

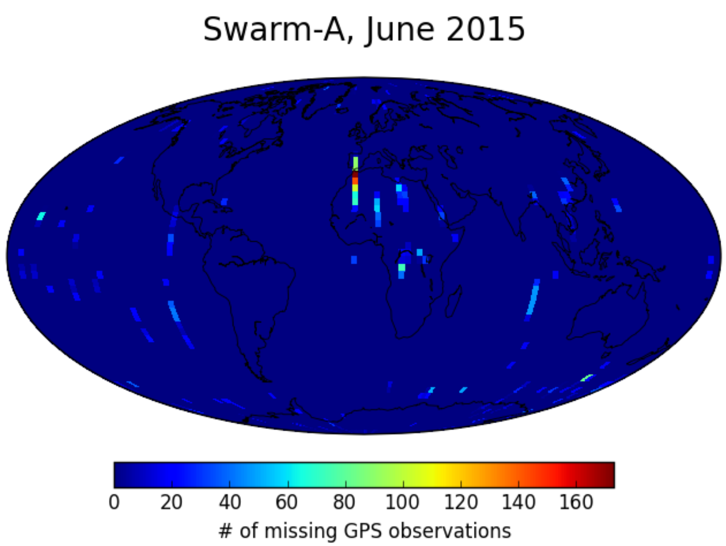
Gravity field solutions: June 2015

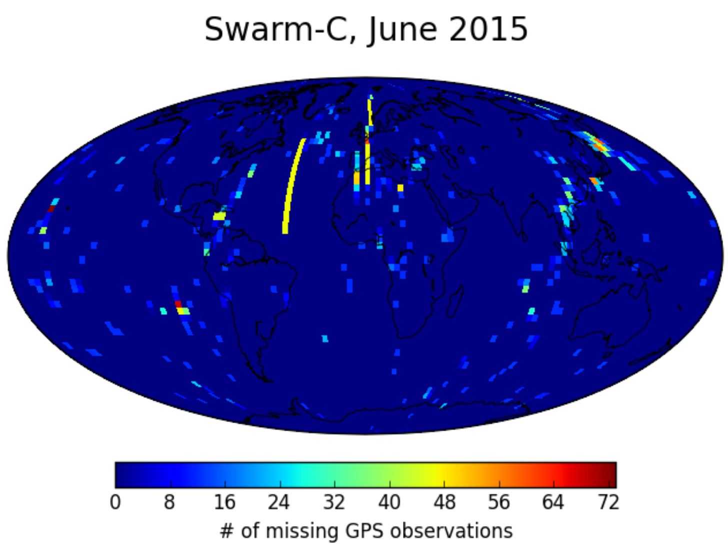
Screened GPS data (ΔL_{gf} > 2cm/s excl.) — **Swarm-A**, **Swarm-C**

Original GPS data — **Swarm-A**, **Swarm-C**



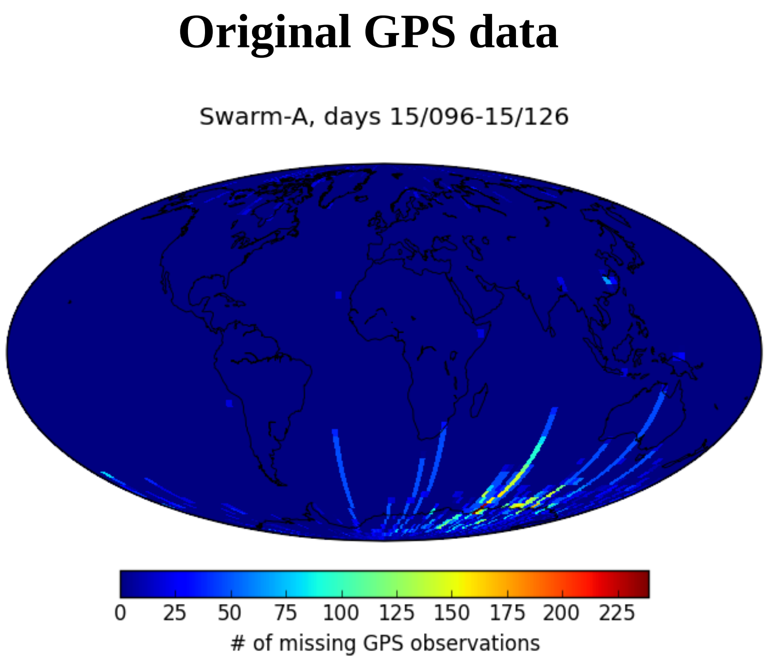
Missing observations in RINEX files (June 2015)

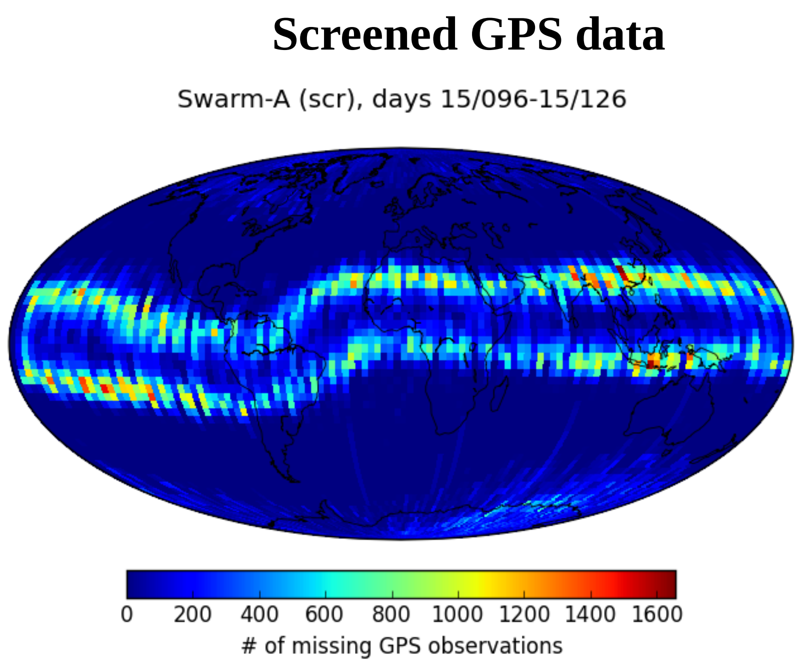




- No obvious gaps for Swarm−C along geomagnetic equator.
- Reduction of artefacts in gravity field solutions is therefore not due to skipped data.

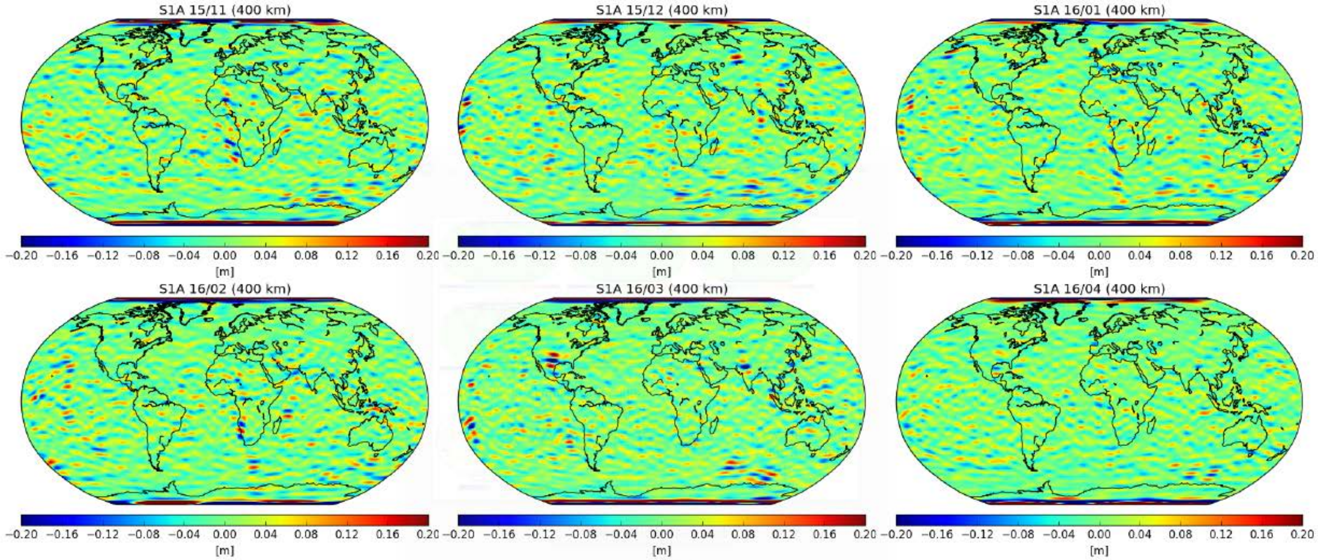
Summary



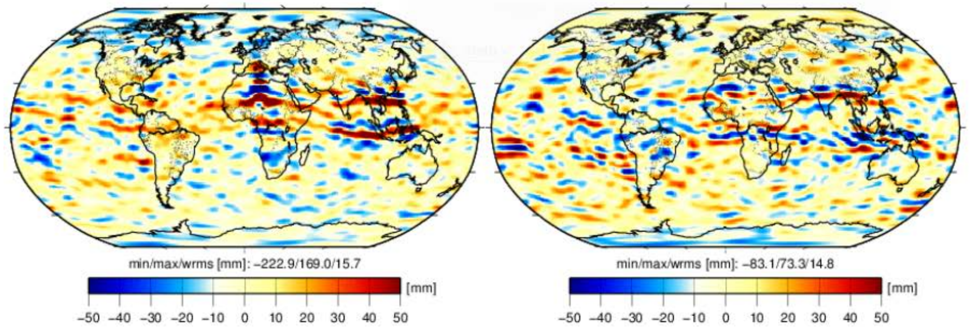


- RINEX screening is useful for gravity field recovery, but rejects a lot (too much) of GPS data
- Improved tracking loop settings are most promising to use the full amount of GPS data while significantly reducing the observed artefacts in the gravity field recovery.

Situation for Sentinel

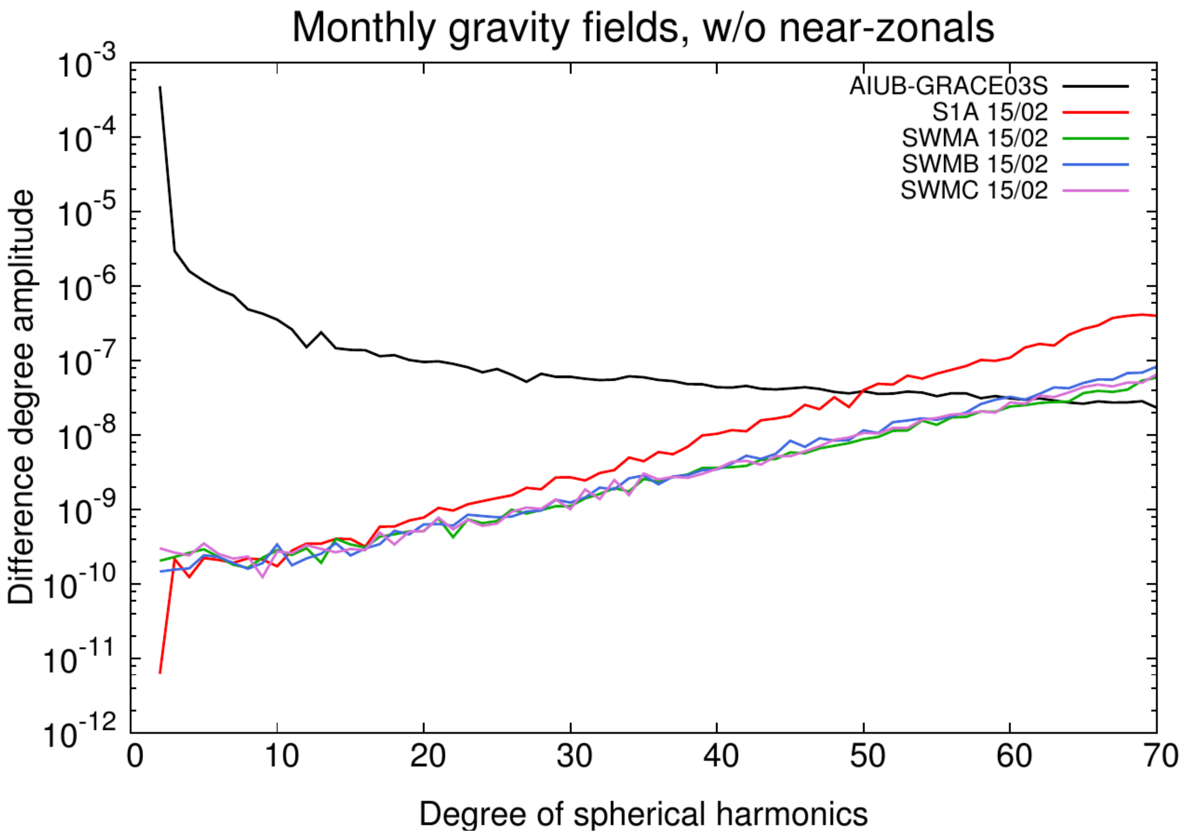


→ No trace of geomagnetic equator!



Swarm-A, June and September 2015

Contribution of Sentinel

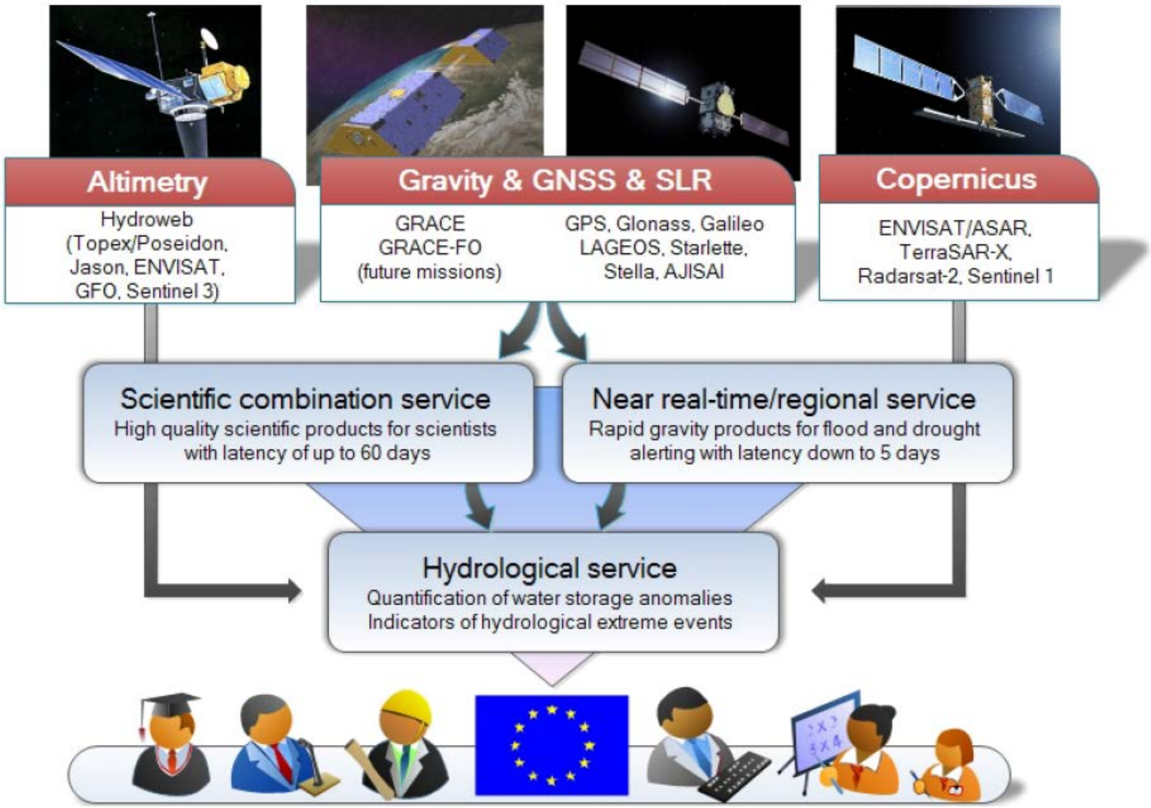


Leaving out near-zonal coefficients according to van Gelderen and Koop due to the polar gap of the Sentinel satellites.

Activities in the frame of EGSIEM

EGSIEM project

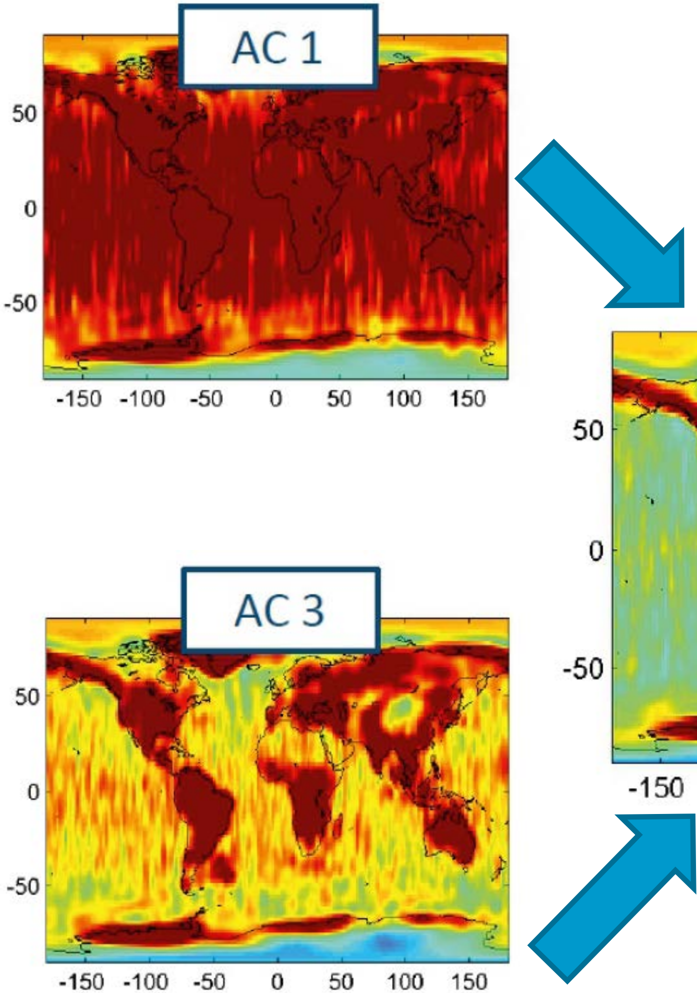
European Gravity Service for Improved Emergency Management

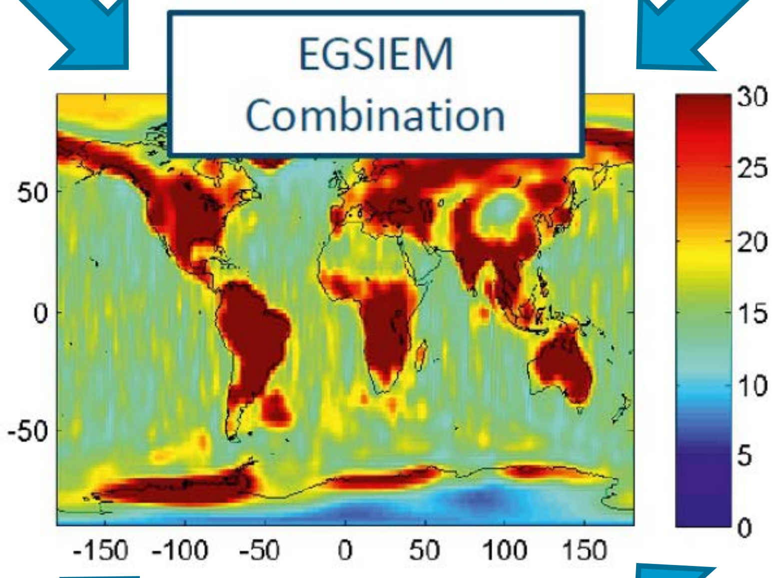


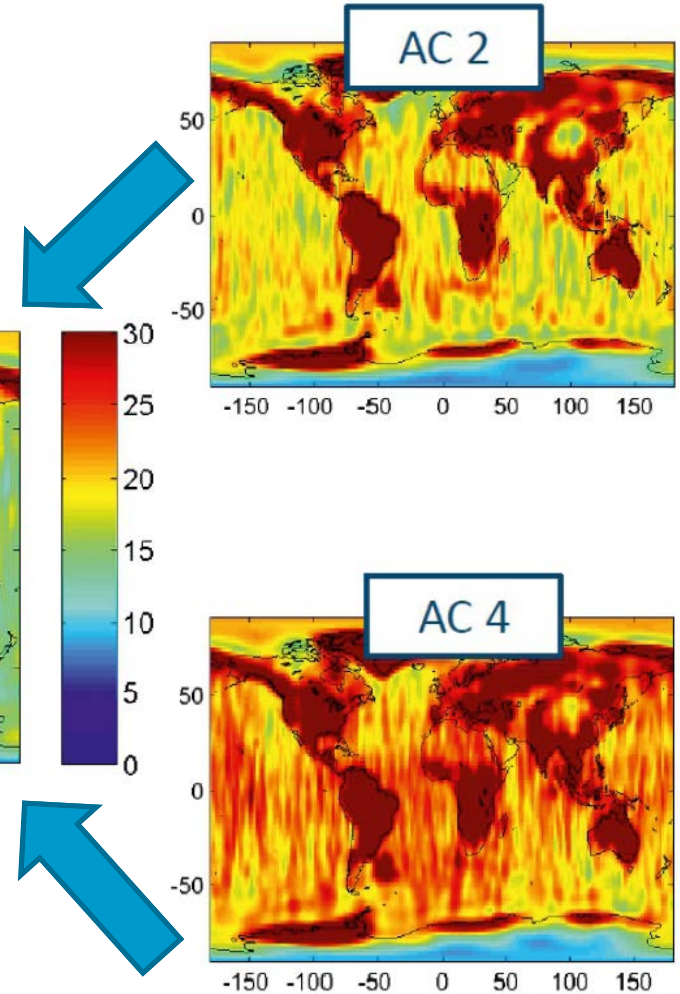
Services will be tailored to the needs of governments, scientists, decision makers, stakeholders and engineers. Special visualisation tools will be used to inform, update, and attract also the large public.

EGSIEM: Scientific Combination Service of monthly GRACE gravity fields

Scientific Combination Service

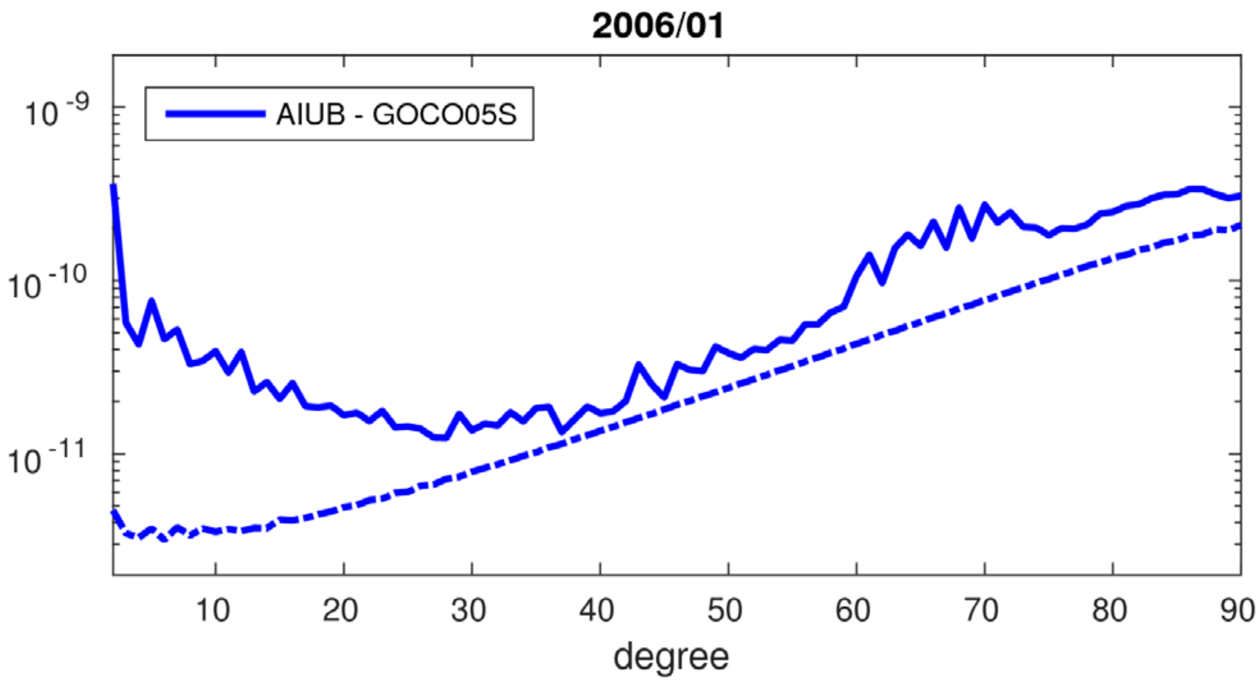






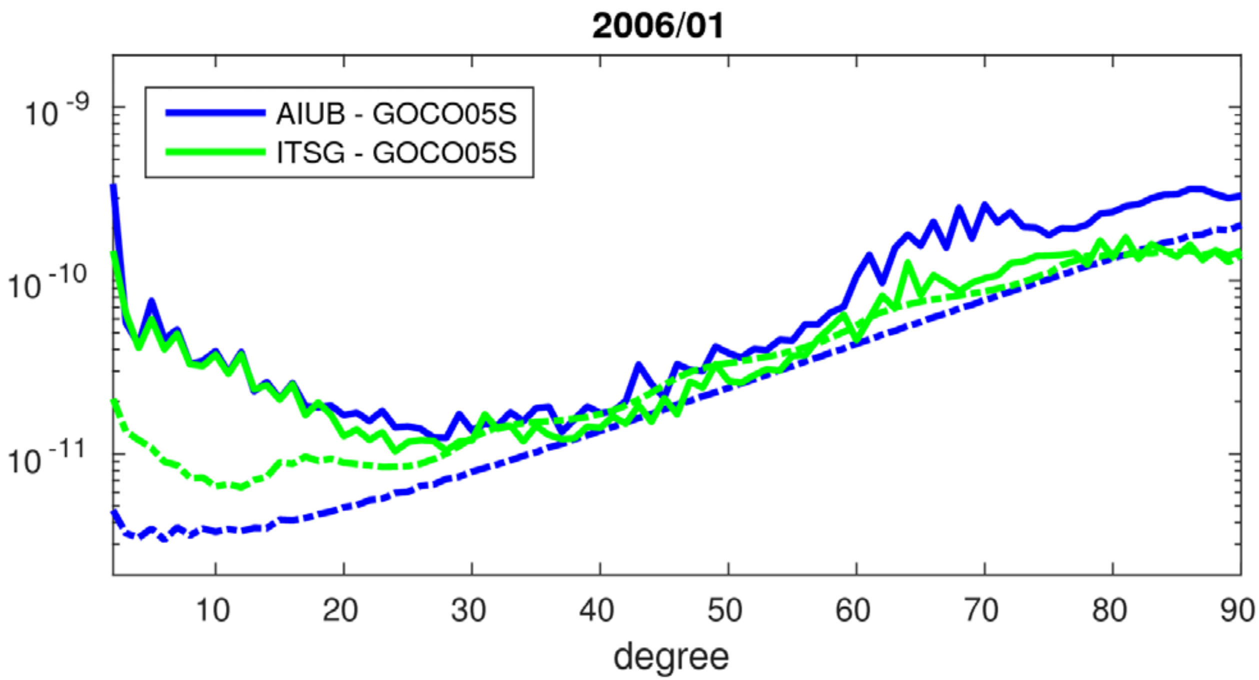
- **Only one product for the user**
- **Reduced noise**

Individual contributions: AIUB



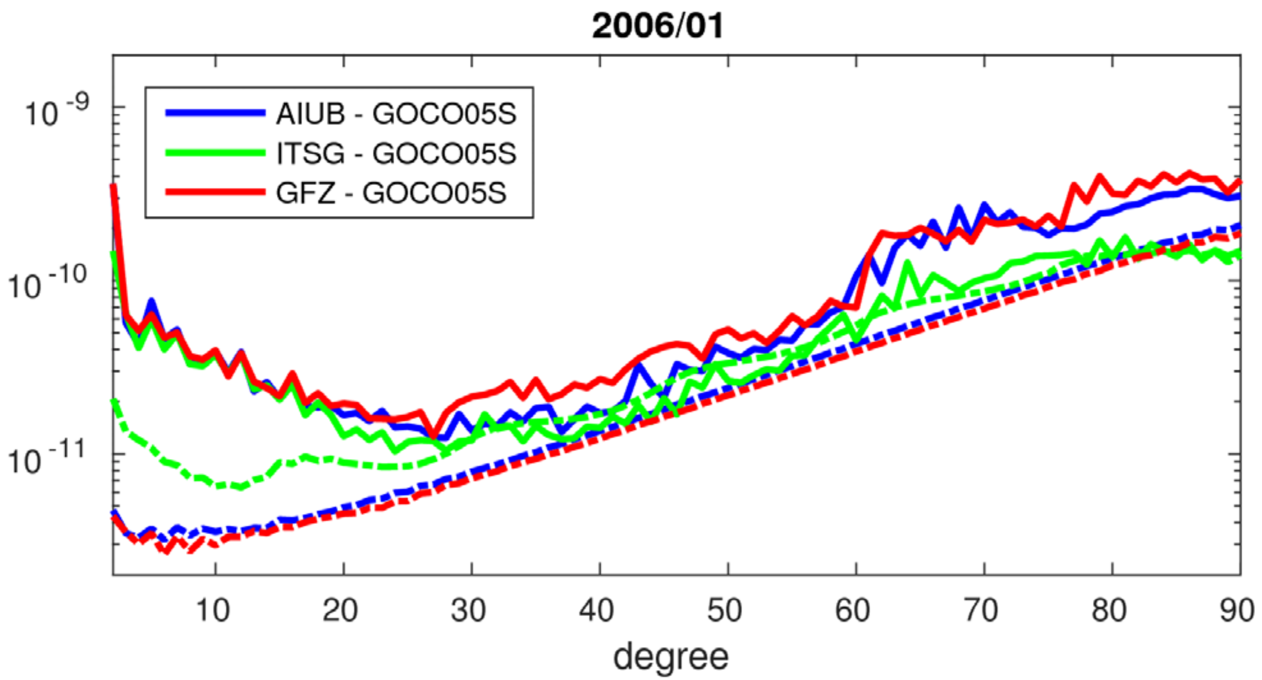
- AIUB: Celestial mechanics approach (dynamic approach relying on frequent pseudo-stochastic accelerations)
  - ~ 500‘000 KRR observations and
  - ~ 500‘000 kinematic positions (30s) / month

Individual contributions: ITSG



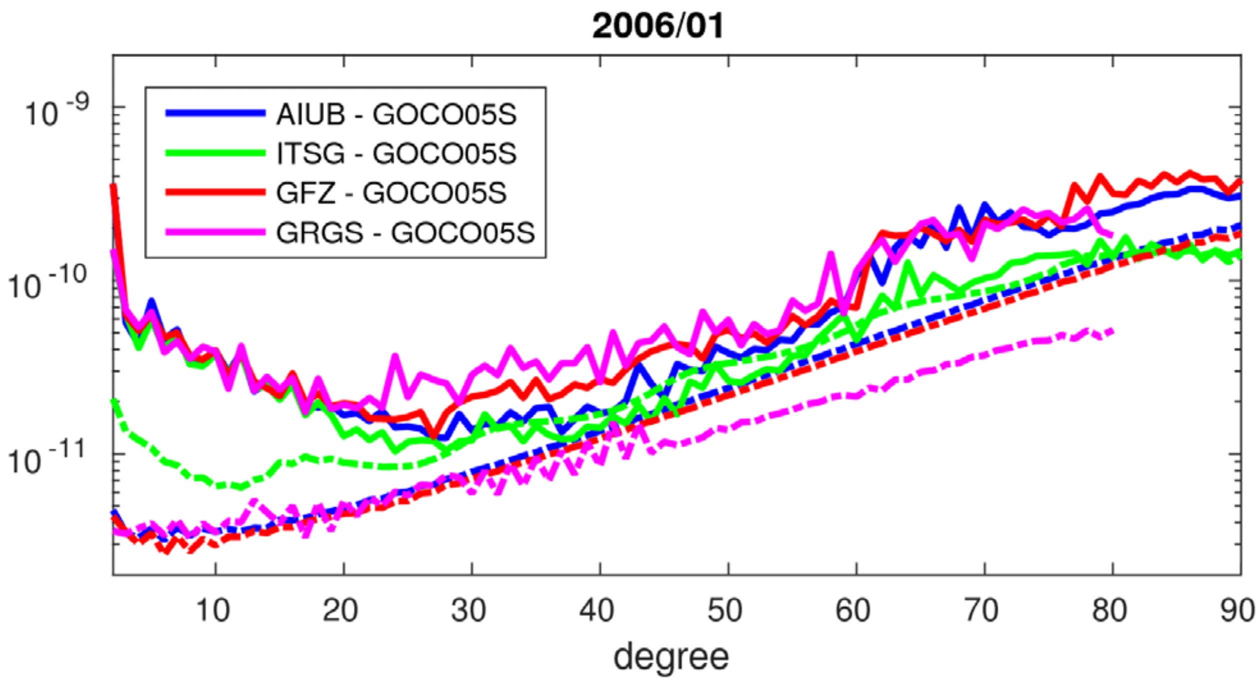
- ITSG: originally short arc approach, empirical noise model
  - ~ 500‘000 KRR observations and
  - ~ 50‘000 kinematic positions (300s) / month

Individual contributions: GFZ



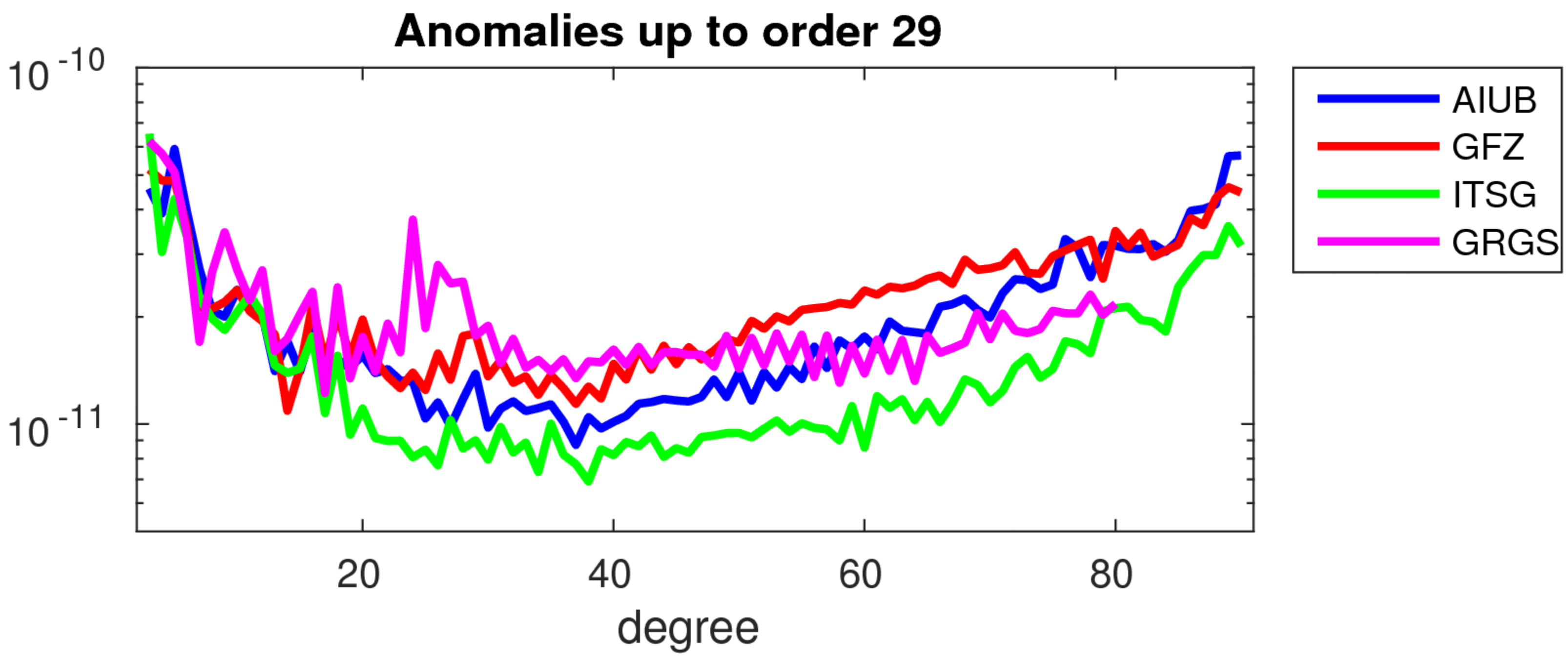
- GFZ: dynamic approach, dense accelerometer parametrization
  - ~ 500‘000 KRR observations and
  - > 2‘500‘000 GPS observations / month

Individual contributions: GRGS



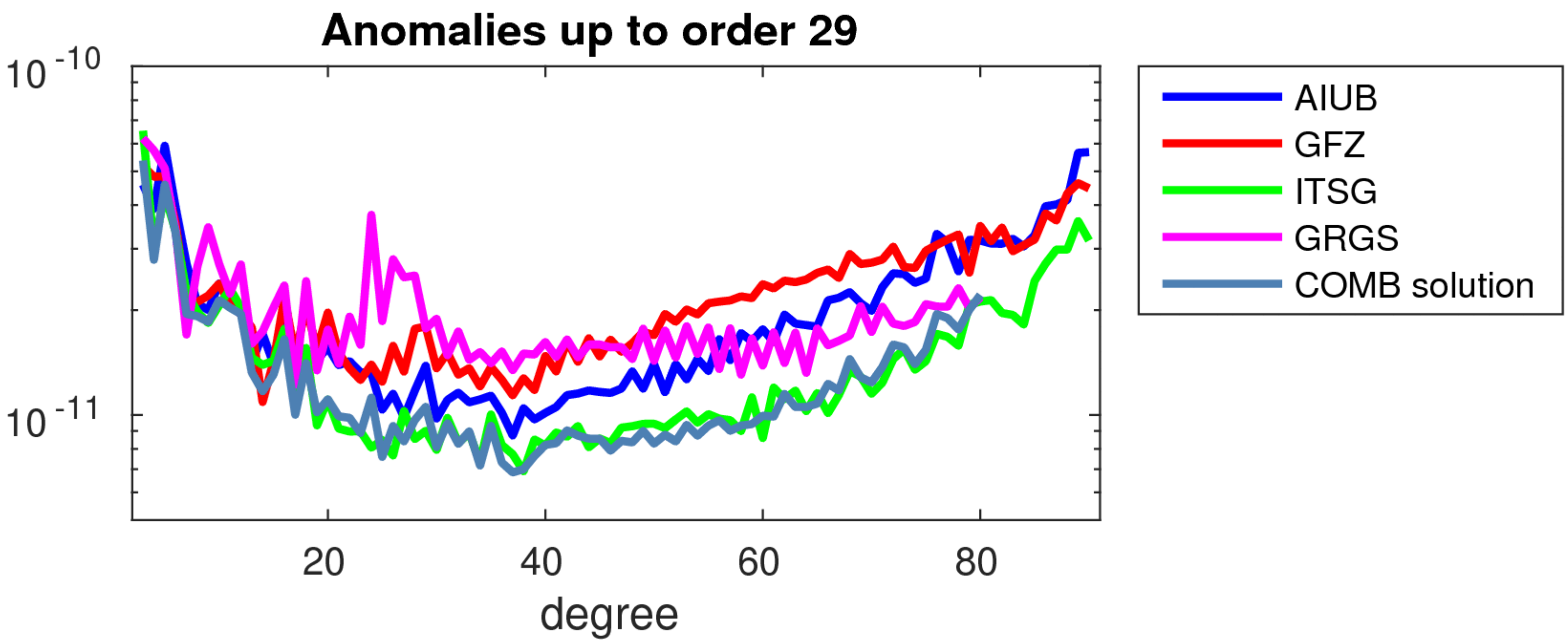
- GRGS: dynamic approach
  - approx. 500000 KRR observations and
  - 50000 kinematic positions (300s) / month

Monthly Combination



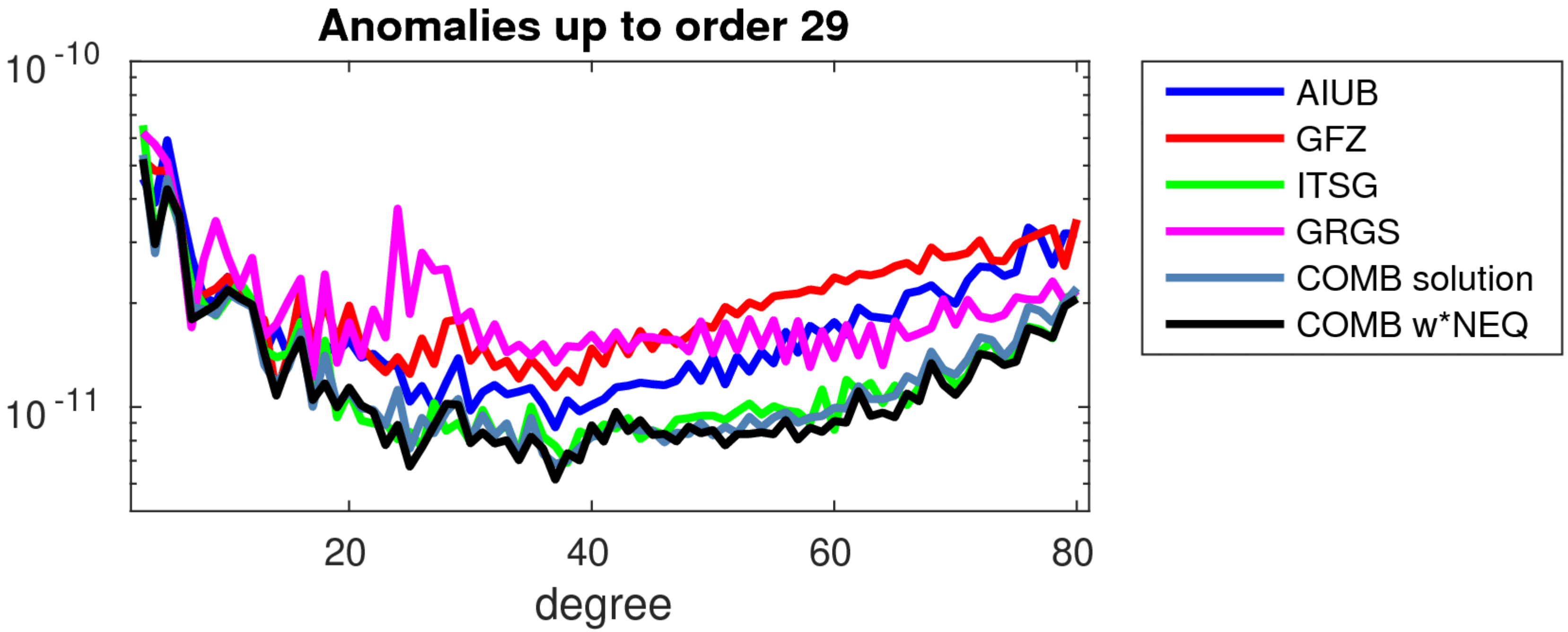
l_{max} = 80	AIUB	GFZ	ITSG	GRGS	COMB solution	COMB w * NEQ
weight	0.29	0.19	0.38	0.14		
wSTD	5.6 mm	6.6 mm	3.5 mm	6.4 mm		

Monthly Combination



l_{max} = 80	AIUB	GFZ	ITSG	GRGS	COMB solution	COMB w * NEQ
weight	0.29	0.19	0.38	0.14		
wSTD	5.6 mm	6.6 mm	3.5 mm	6.4 mm	3.9 mm	

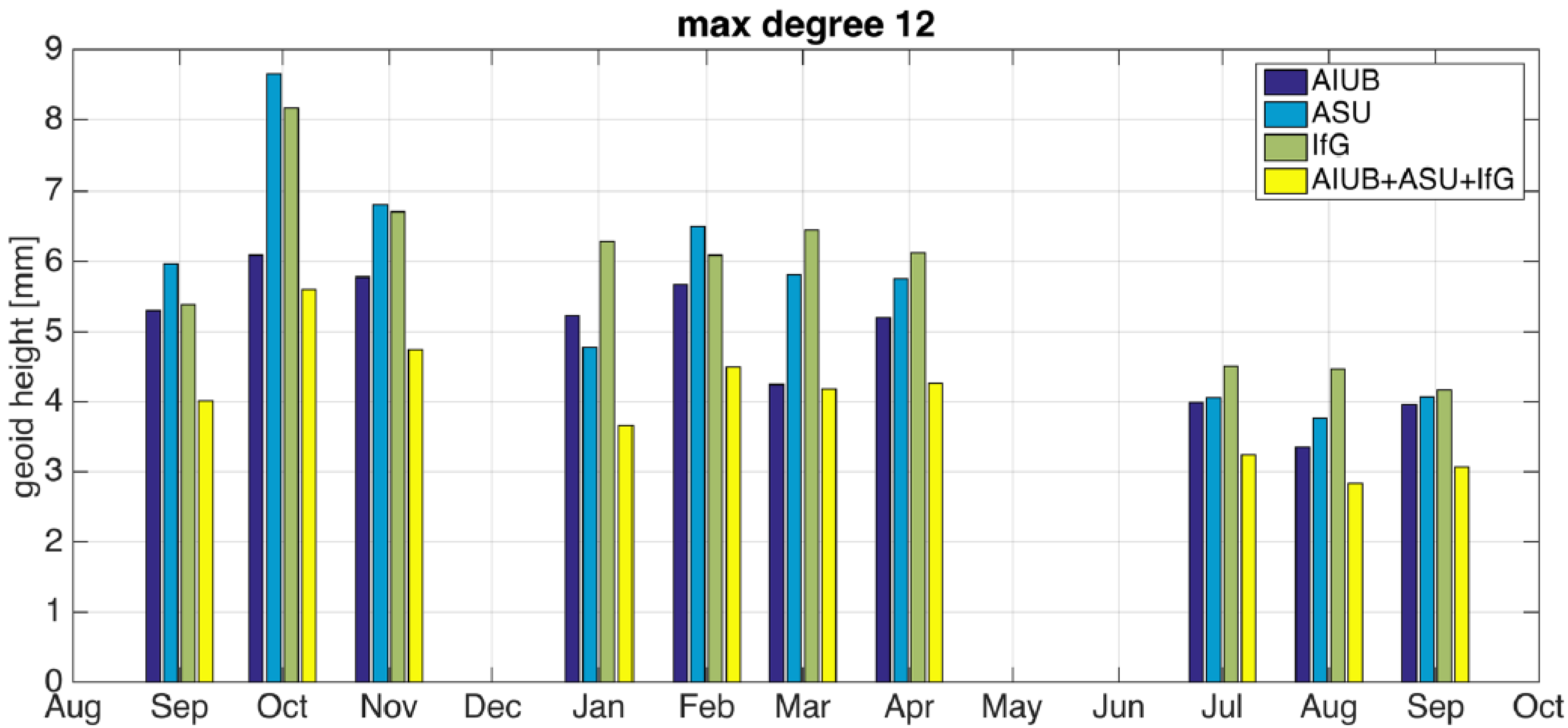
Monthly Combination



l_{max} = 80	AIUB	GFZ	ITSG	GRGS	COMB solution	COMB w * NEQ
weight	0.29	0.19	0.38	0.14		
wSTD	5.6 mm	6.6 mm	3.5 mm	6.4 mm	3.9 mm	3.9 mm

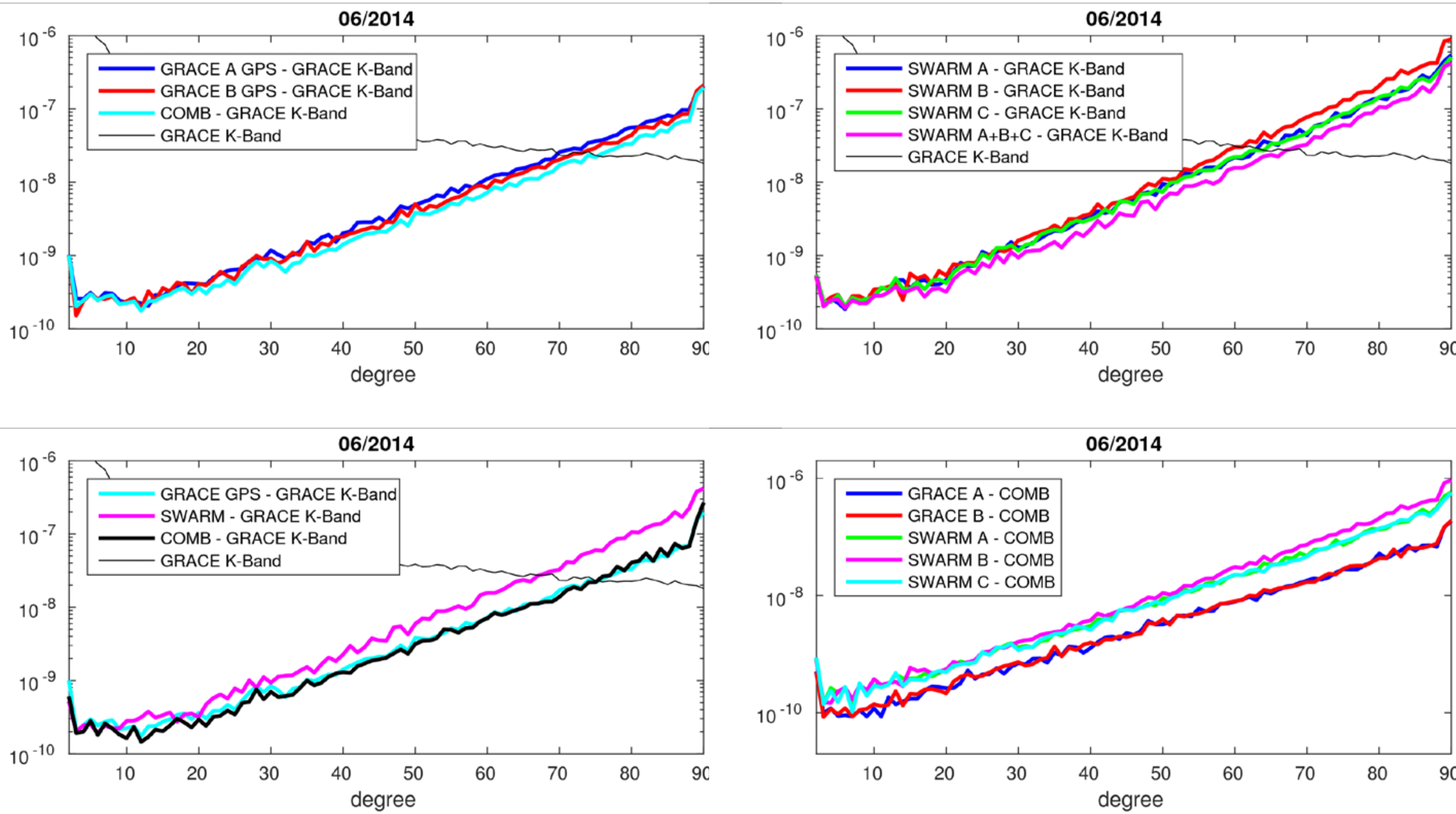
EGSIEM: Extension to GPS only gravity fields from GRACE and SWARM

Swarm combinations



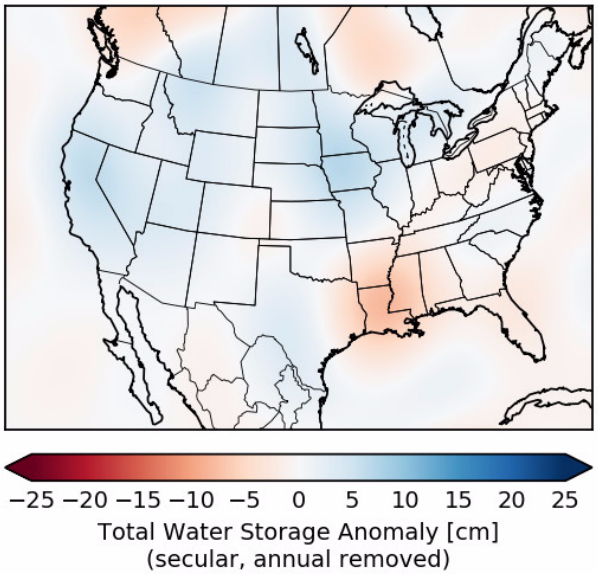
- Solutions based on AIUB orbits show a very good performance. This is probably mainly related to the quality of the underlying kinematic orbits.
- Combination of solutions from different groups (using different orbits and approaches for gravity field recovery) show further reduced noise.

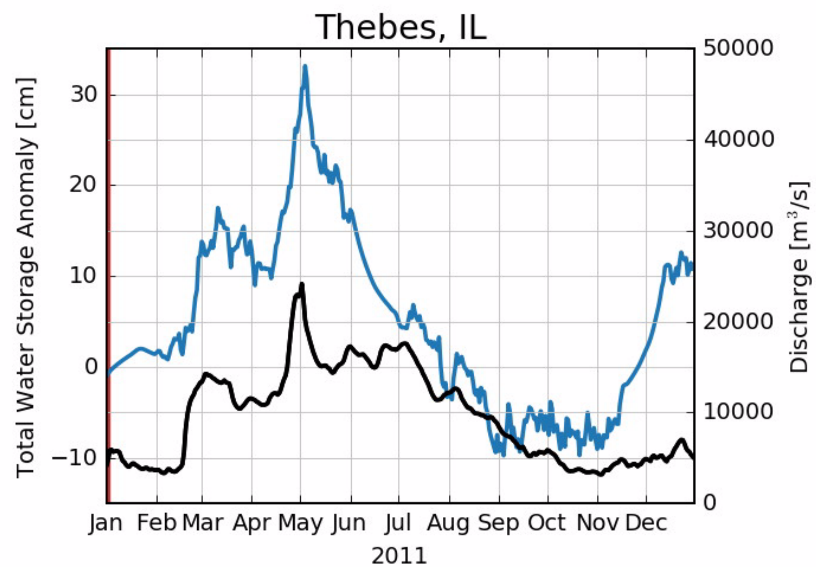
Validation against GRACE K-band



EGSIEM: Many other activities …

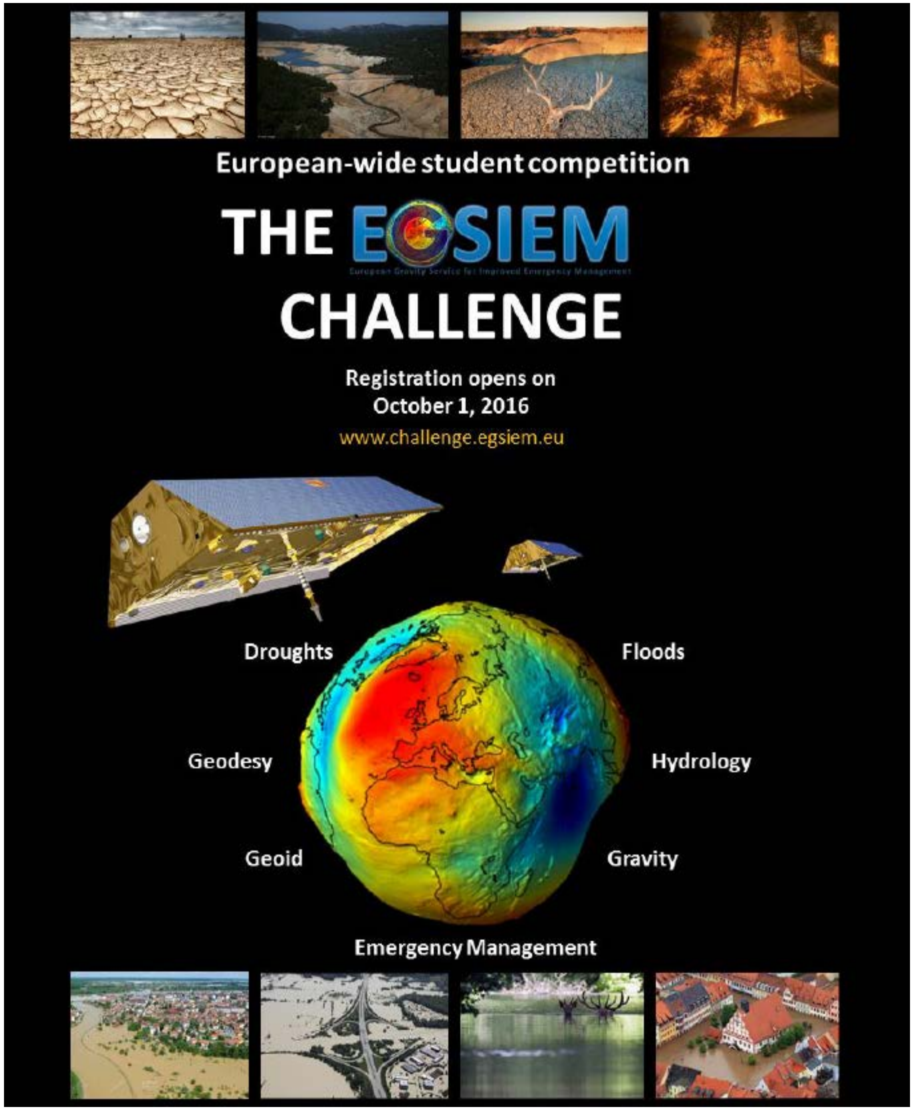
e.g. daily solutions from TU Graz





- Daily updated solution shall be generated in near real-time (max. 5 days delay) in the future

e.g. outreach activities from University of Hannover



News and updates will be regularly published on various media, e.g., by the quarterly EGSIEM Newsletter.

Issues can be accessed at

www.egsiem.eu

EGSIEM is also present on social media:

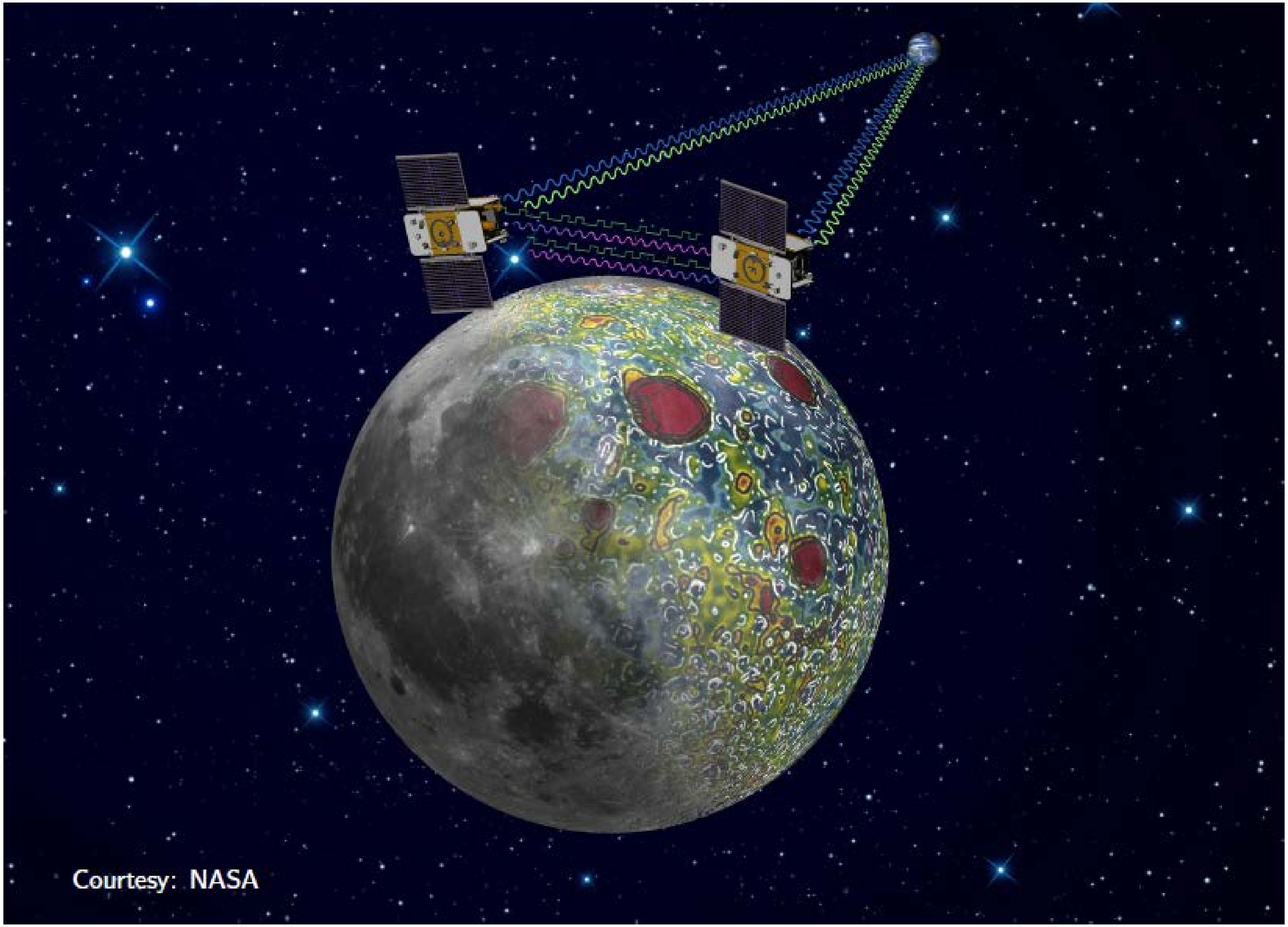
https://twitter.com/EGSIEM

www.facebook.com/egsiem

https://egsiem.wordpress.com

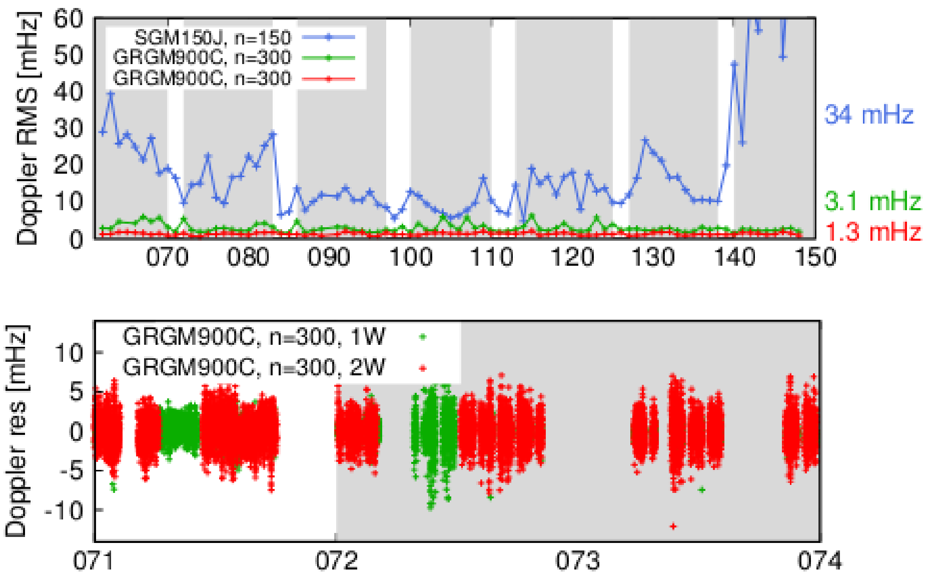
Planetary Geodesy

The GRAIL mission



Observation residuals

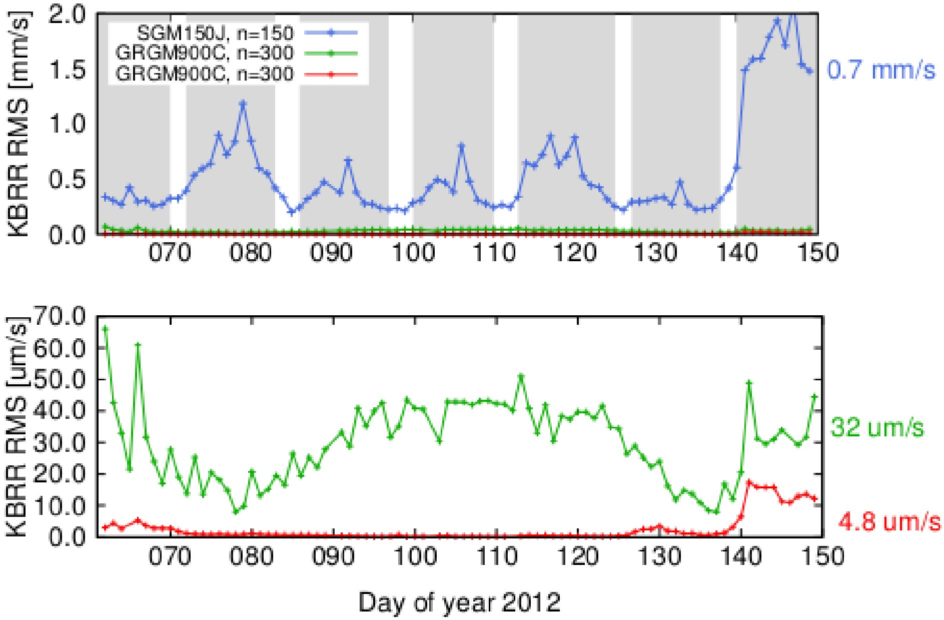
Doppler observations can be used for orbit and gravity field determination



Daily Doppler RMS values for GRAIL-A when using SGM150J and 2-way Doppler observations, as well as GRGM900C up to d/o 300 and 1-way and 2-way Doppler observations

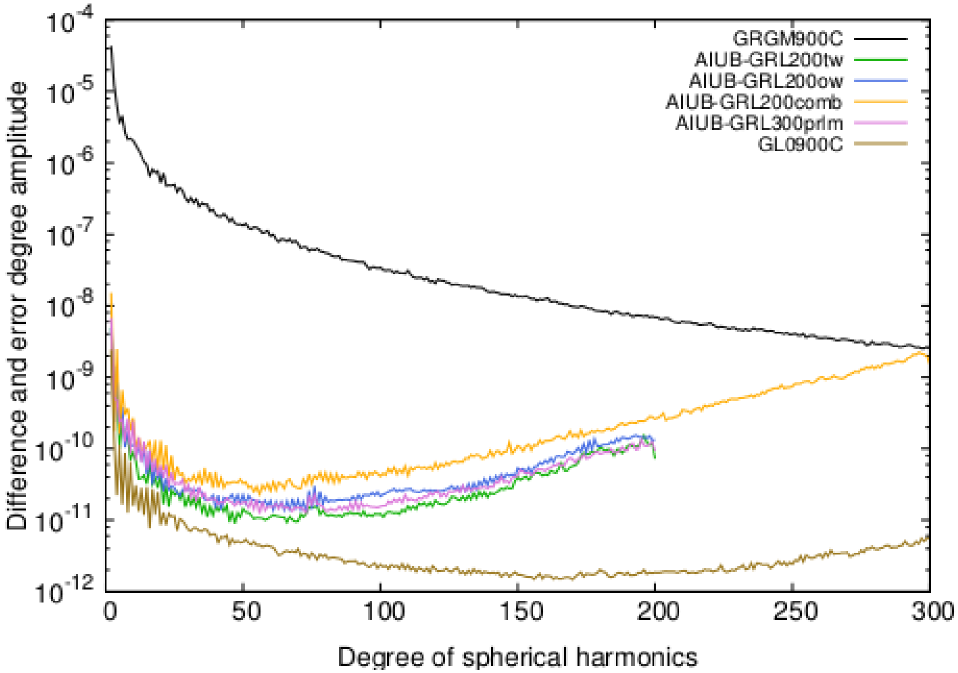
Observation residuals

Doppler observations can be used for orbit and gravity field determination



Daily KBRR RMS values when using SGM150J and 2-way Doppler observations, as well as GRGM900C up to d/o 300 and 1-way and 2-way Doppler observations

Gravity field solutions



Difference degree amplitudes (w.r.t. GRGM900C) of degree-200 AIUB solutions based on 2-way, 1-way, and combined 1- and 2-way Doppler and KBR observations, as well as a preliminary degree-300 solution based on 2-way Doppler and KBR observations. GRGM900C up to d/o 660 has been used as a priori field.

GRAIL orbits should be modeled more dynamically …