ASI AC&CC report

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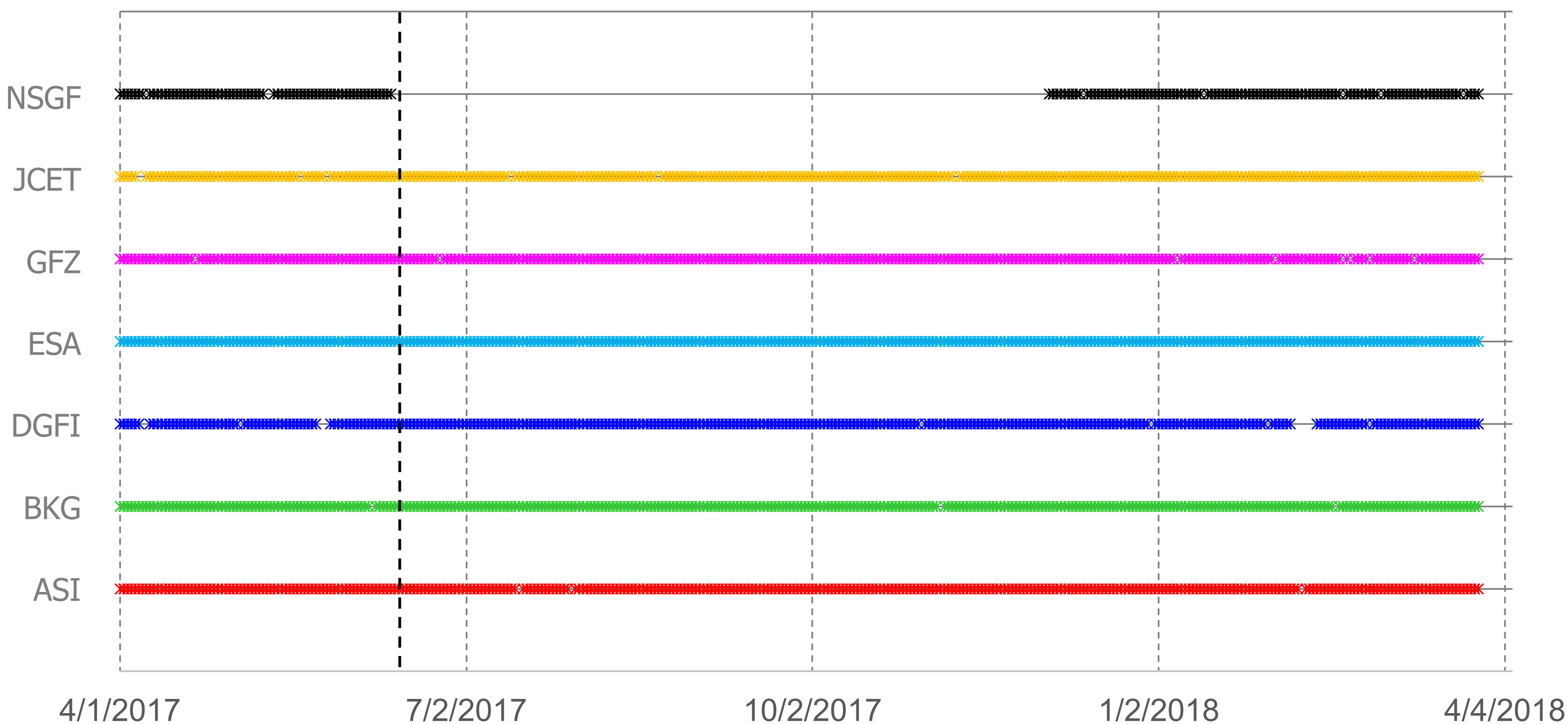
ILRS ASC Meeting, 12 April 2018, Vienna

Activities since last ASC meeting

- ACs performance check
  - Data submissions
  - 3D wrms of the residuals w.r.t. SLRF
  - Scale factor
  - Geocenter motion
  - LOD
  - Combination scale factor
  - Orbits: RMS of residuals w.r.t. combination
  - ILRS ACs orbit agreement
- Systematic Error Pilot Project
  - ACs time series v220
  - Preliminary analyses

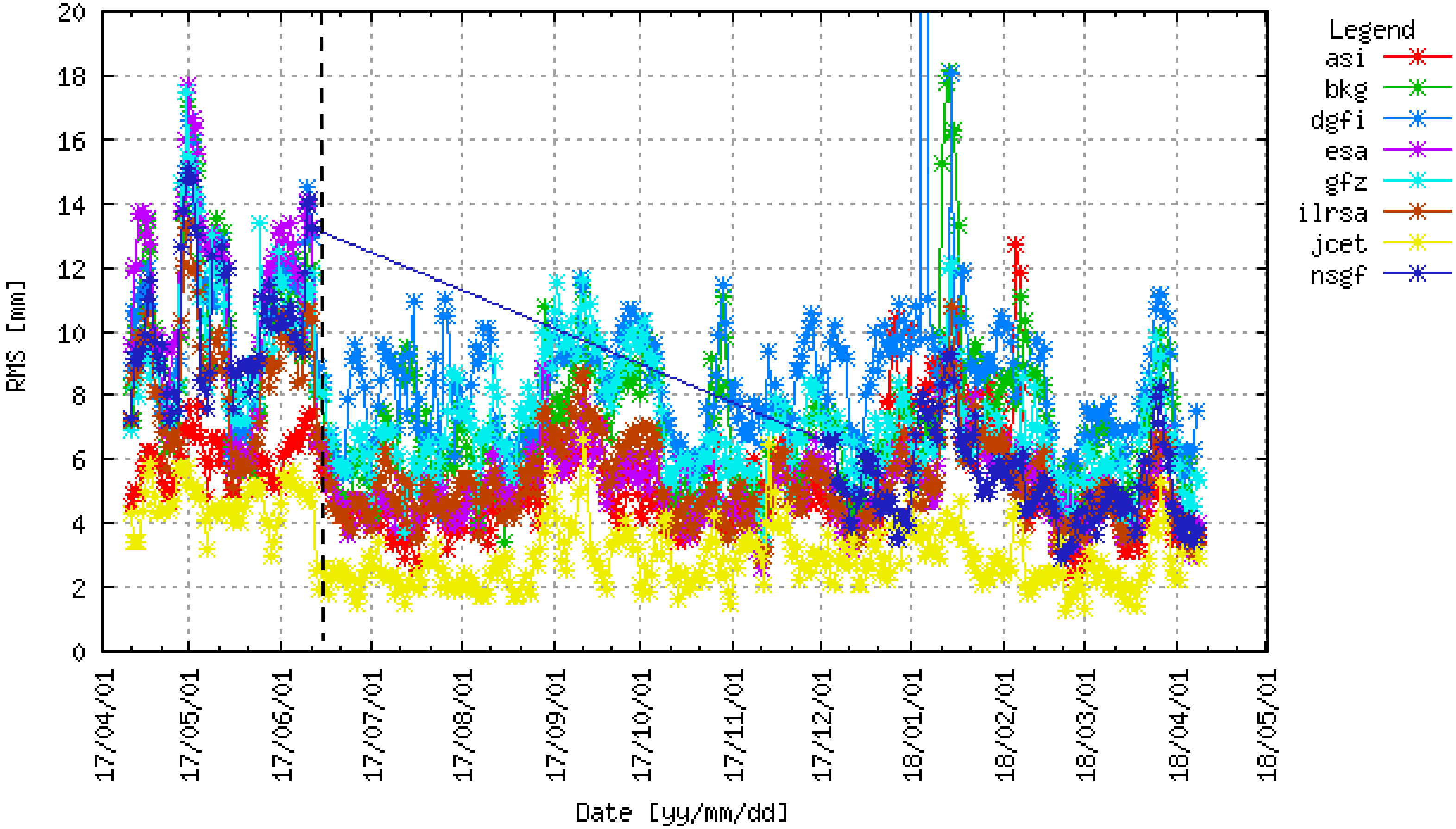
ACs submissions

ACs time series using SLRF2014 as *a priori* are the official products since 15 June 2017: daily (v170) and weekly (v70)



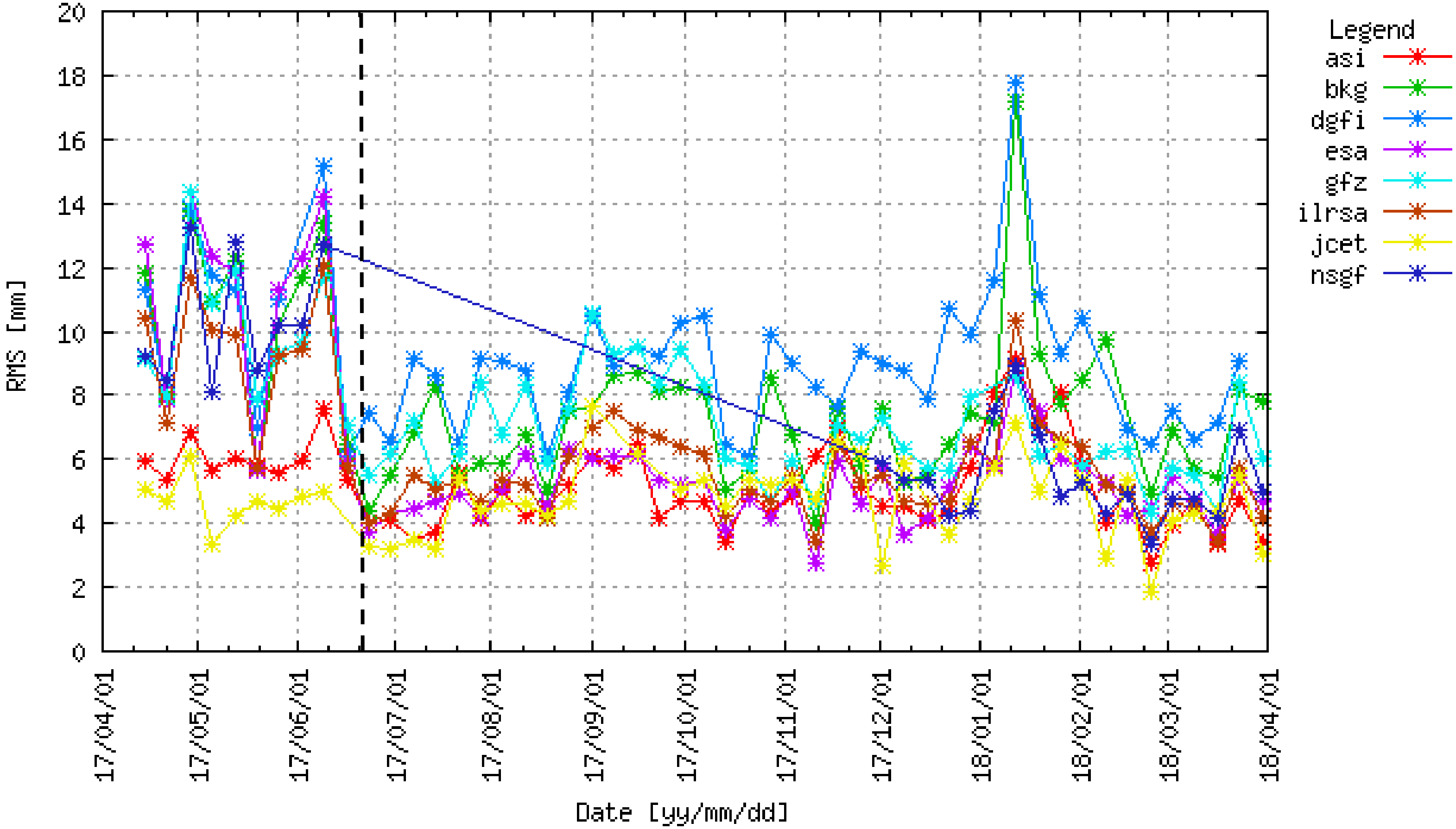
Daily solutions

3D wrms of the residual w.r.t. SLRF2008/SLRF2014
CORE SITES

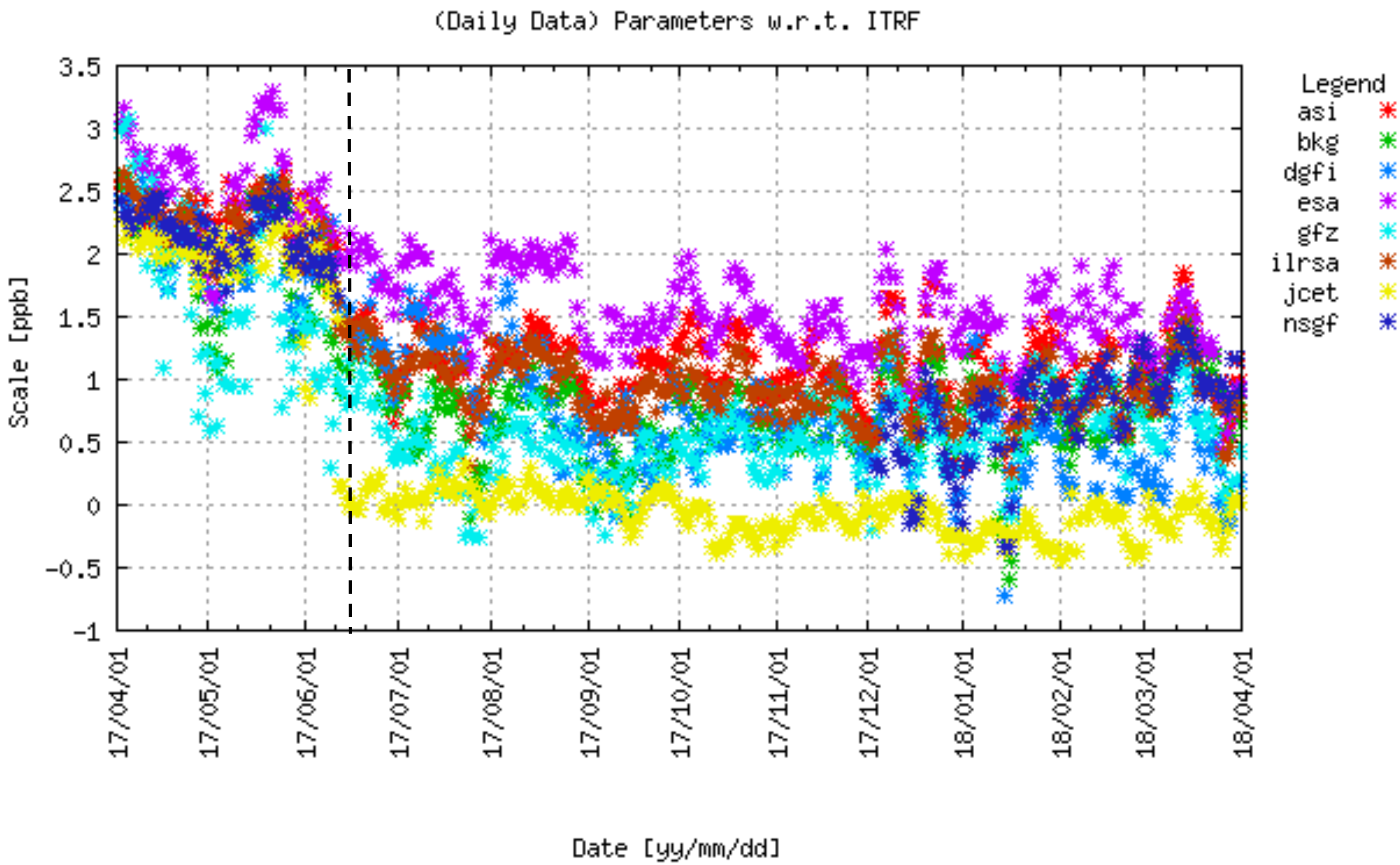


Weekly solutions

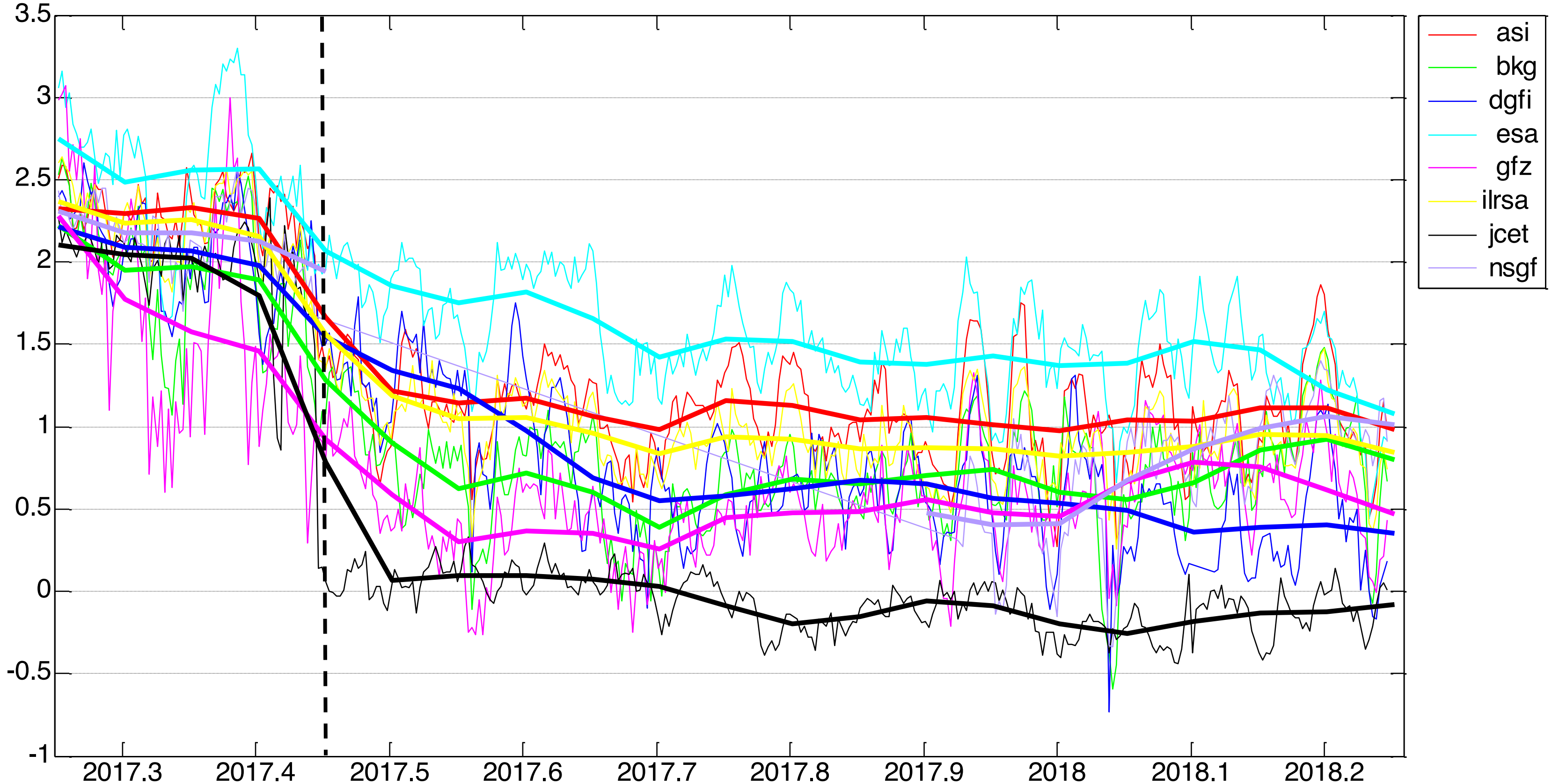
3D wrms of the residual w.r.t. SLRF2008/SLRF2014
CORE SITES



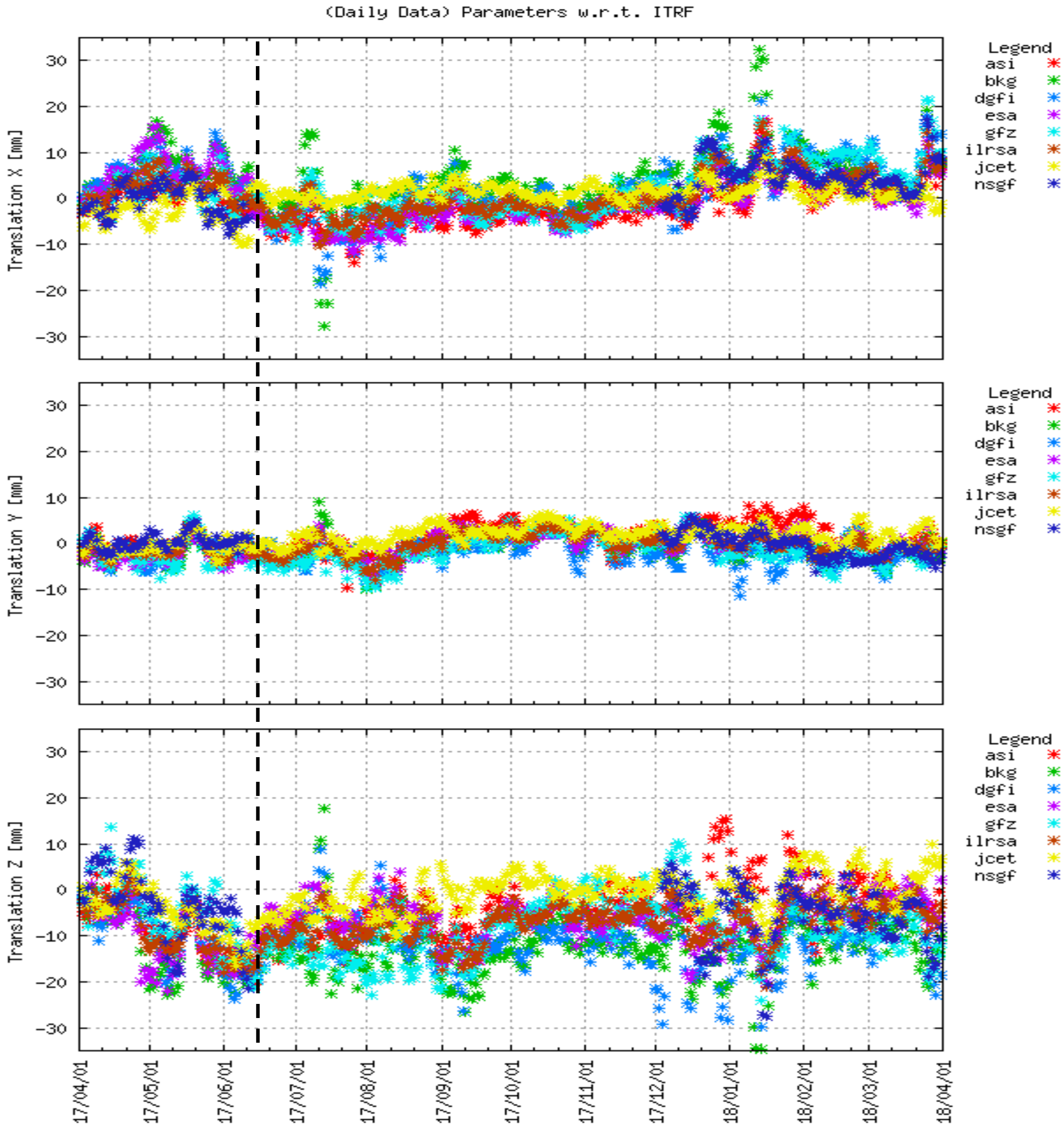
Scale from daily solutions



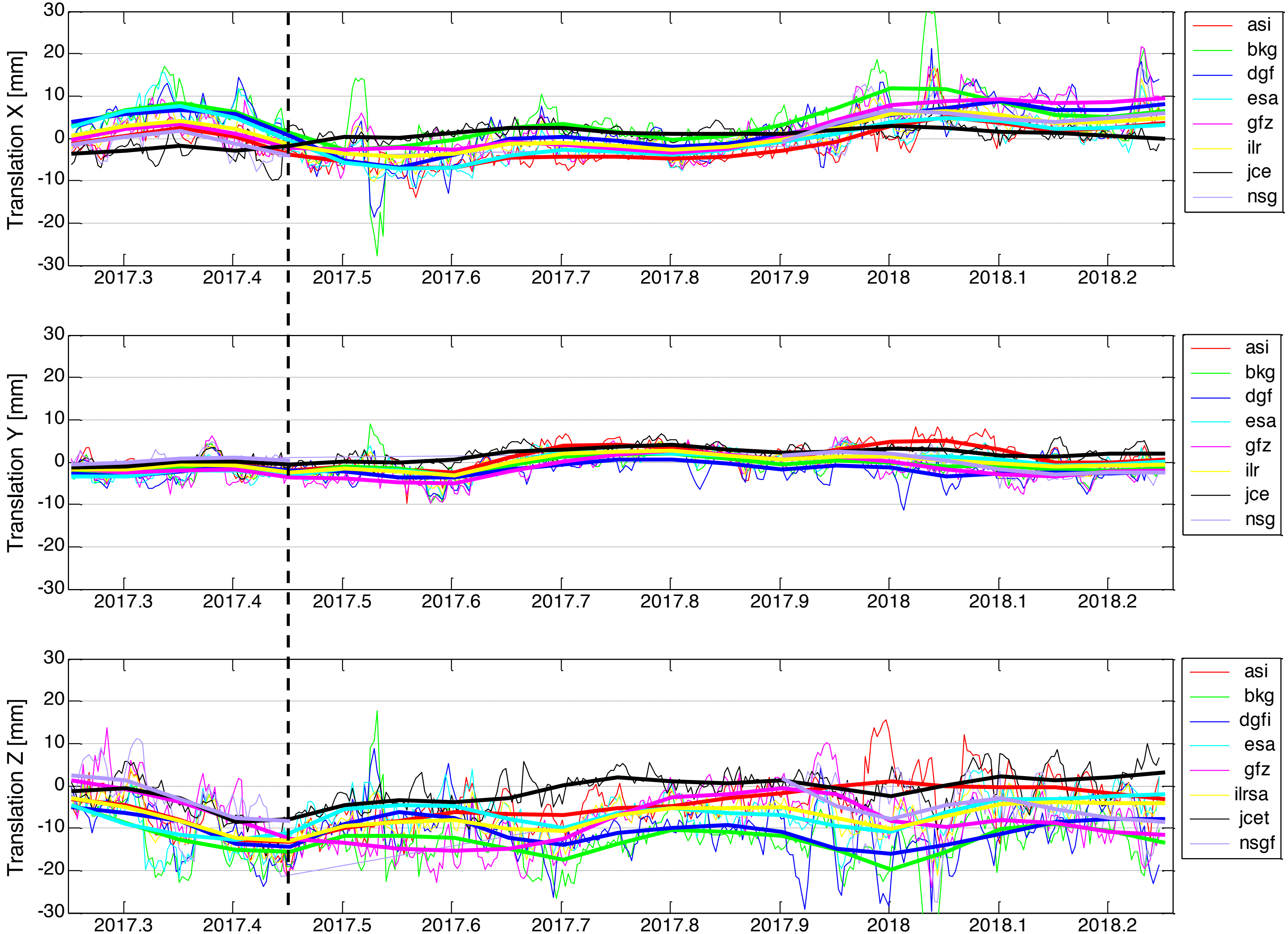
Scale from daily solutions



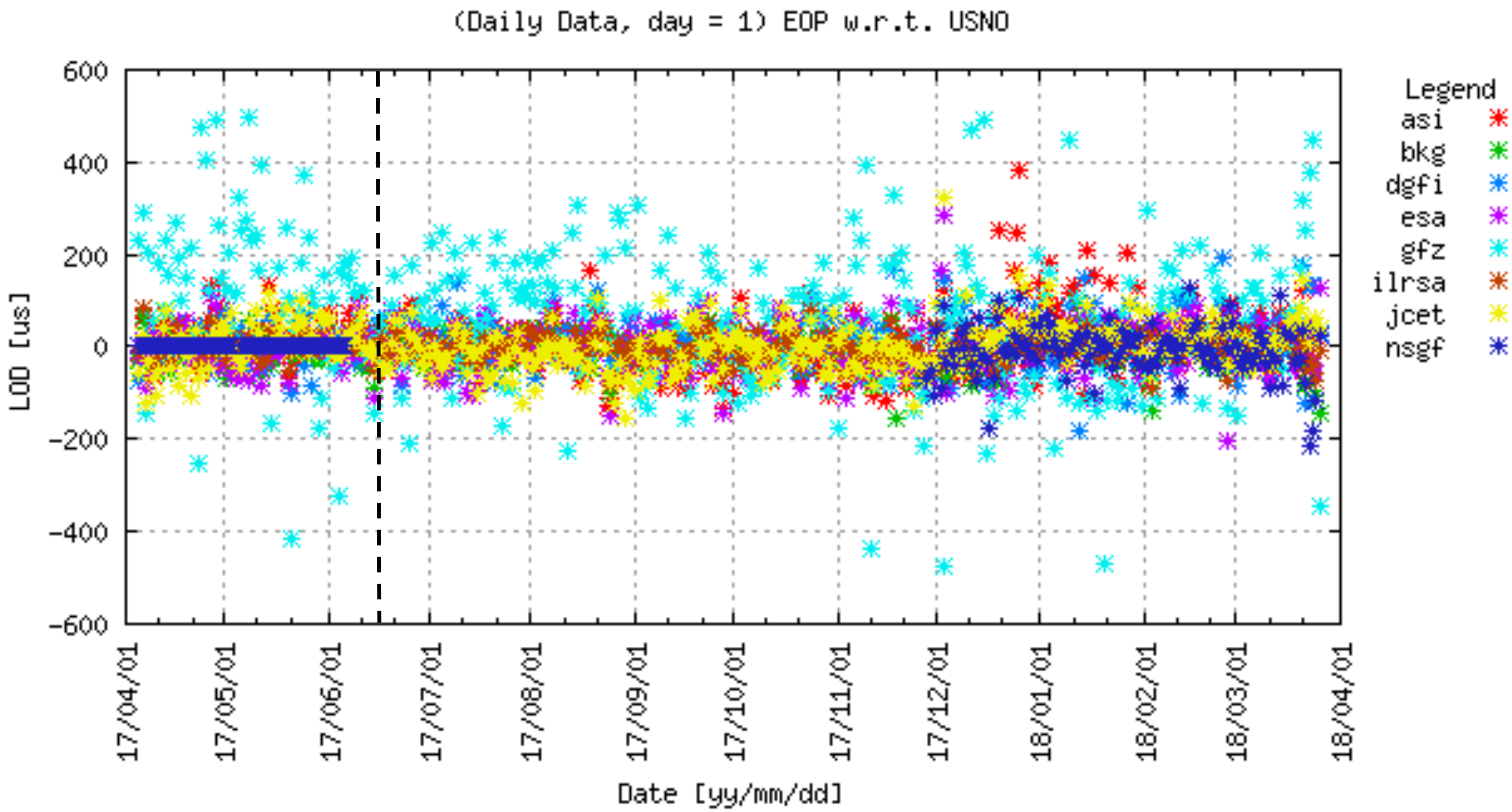
Geocenter motion from daily solutions



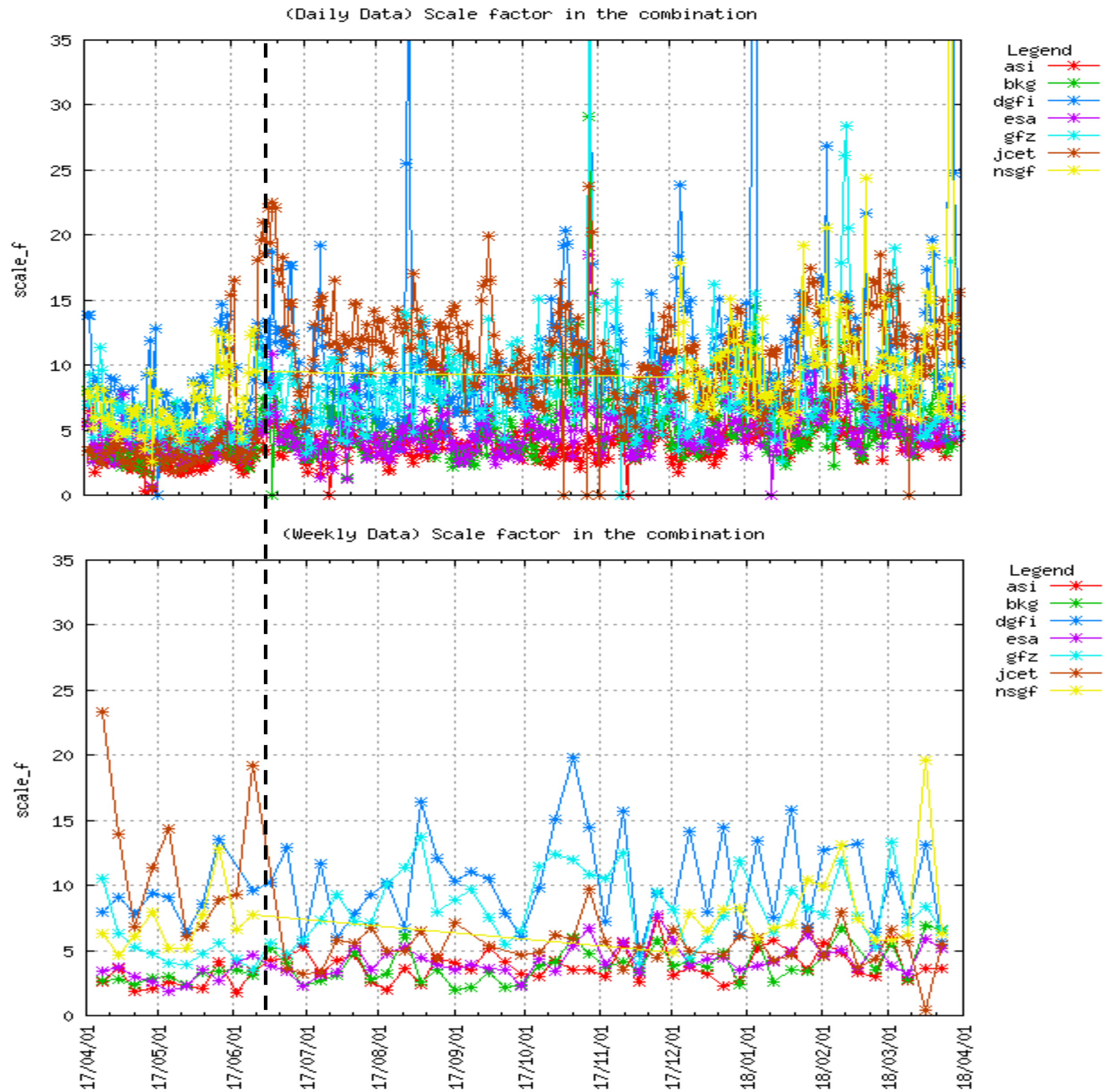
Geocenter motion from daily solutions



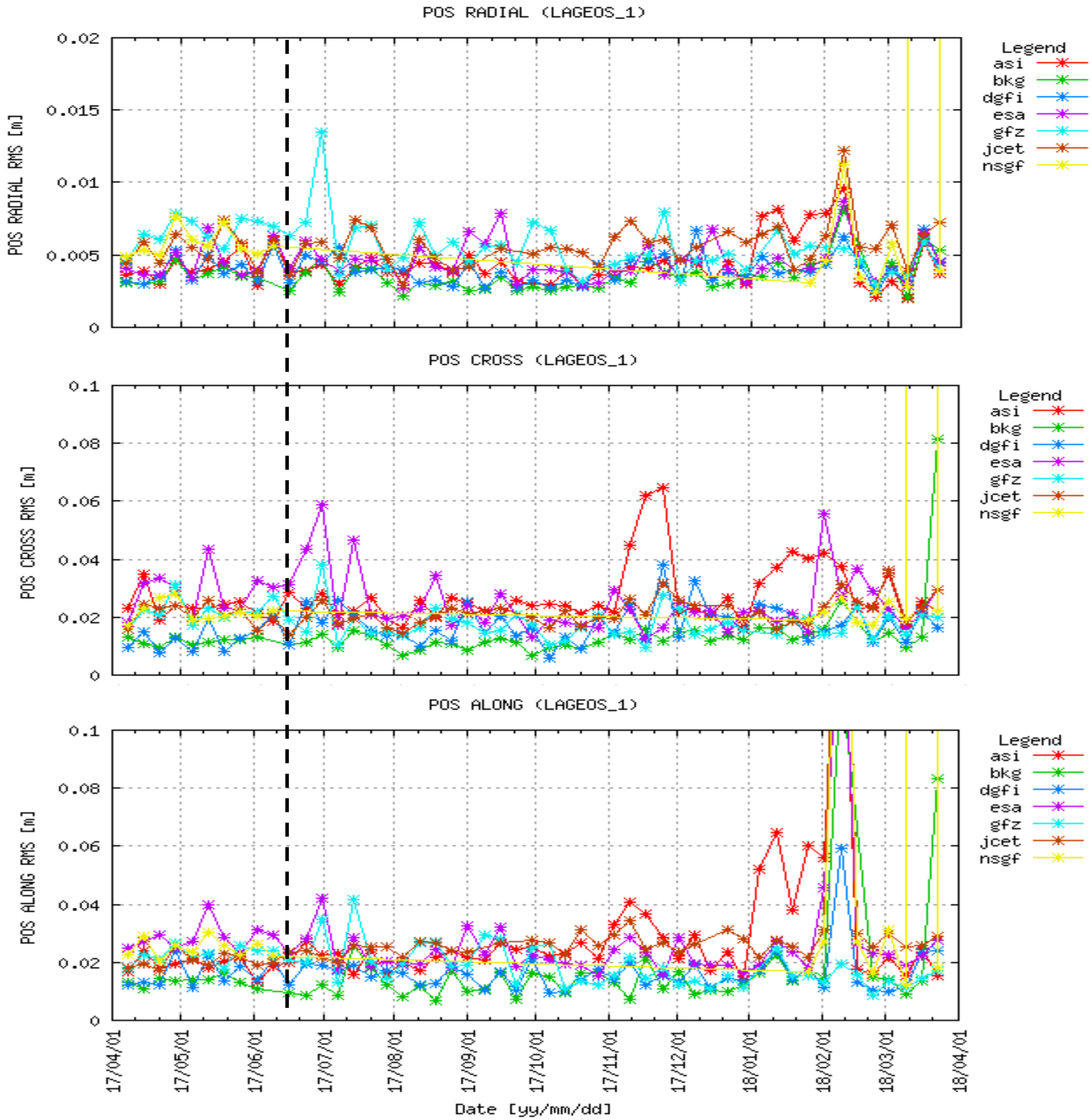
LOD from daily solutions



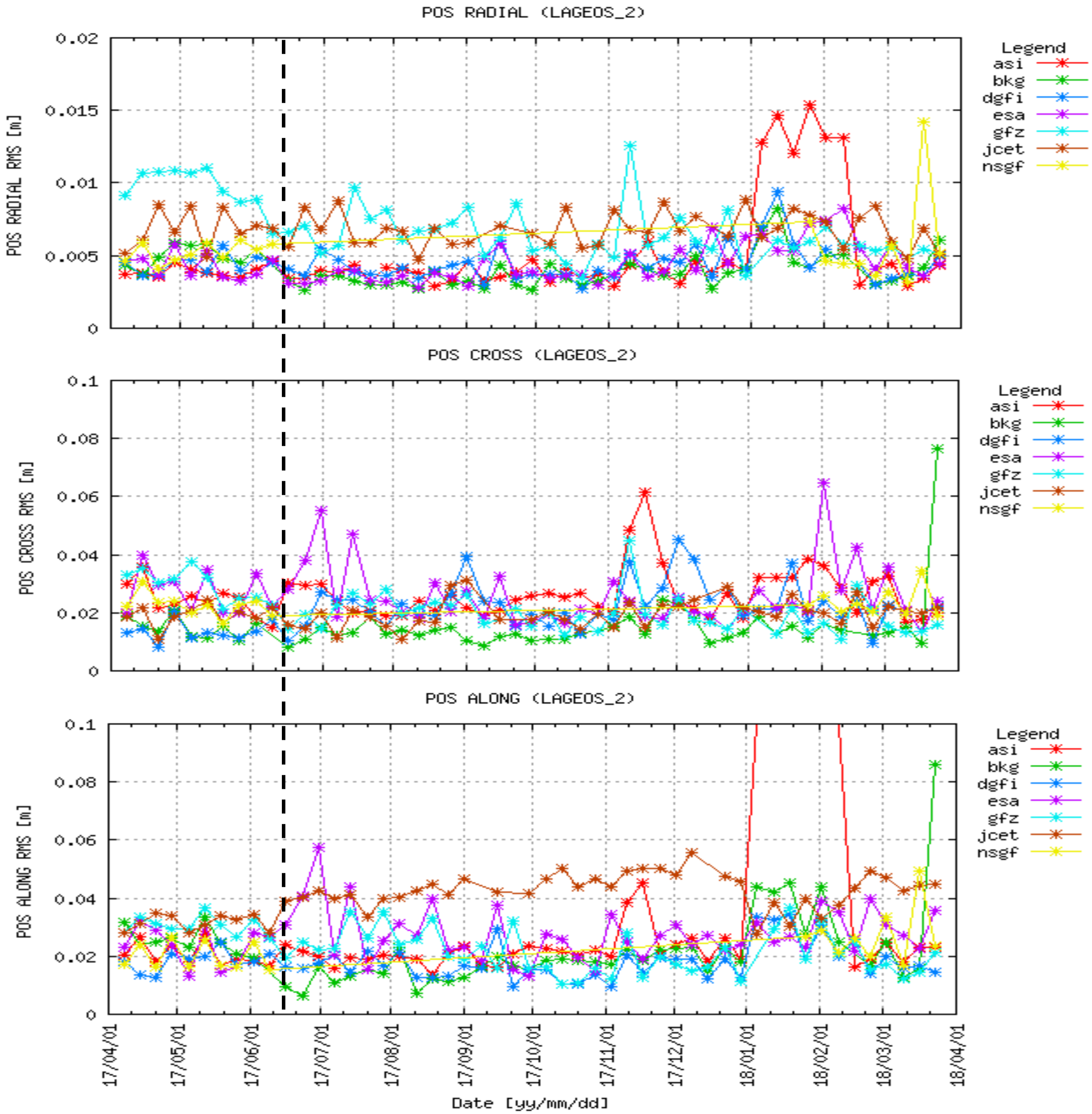
Combination scale factor



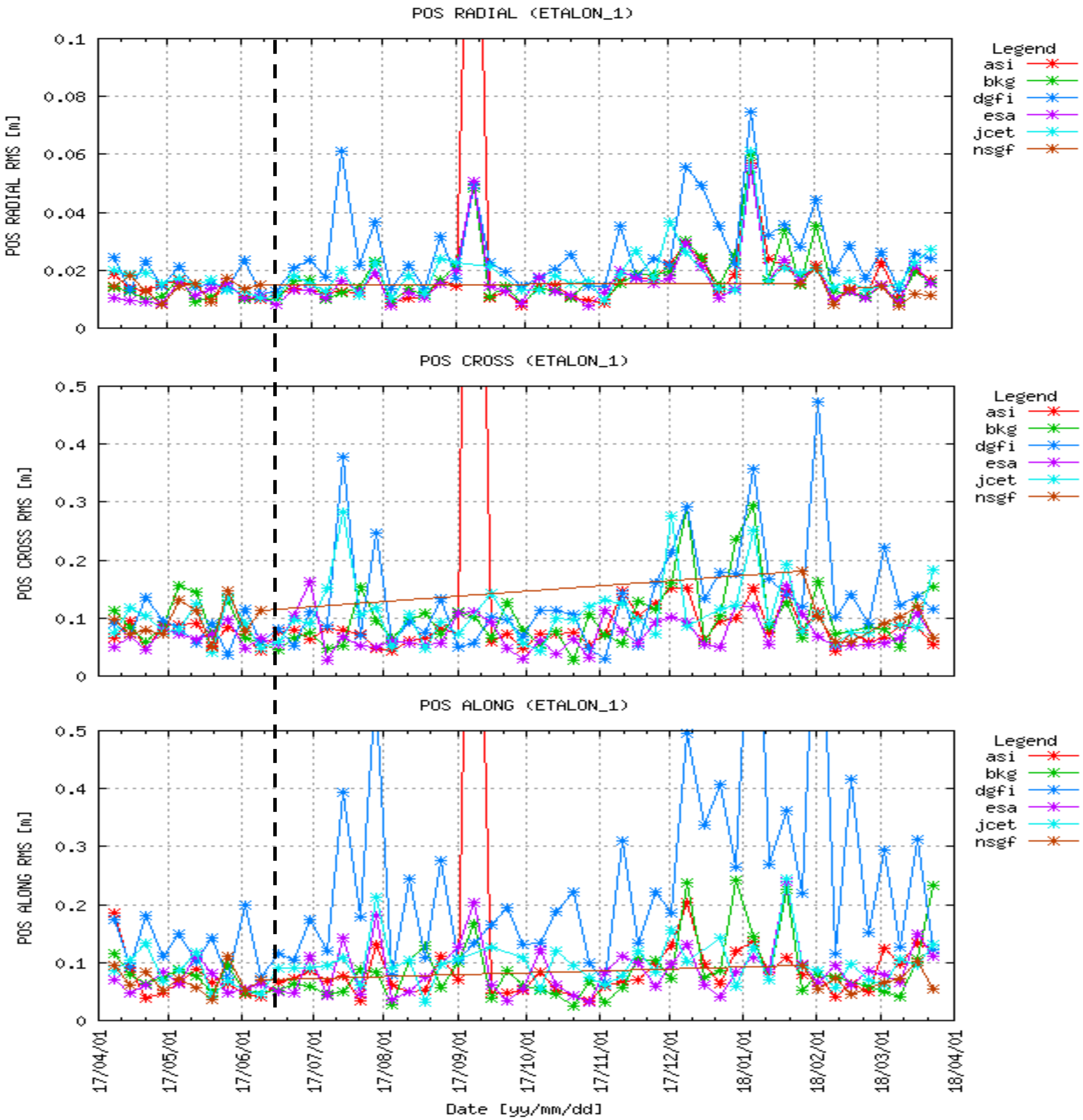
LAGEOS1 orbits – RMS of residuals w.r.t. combination



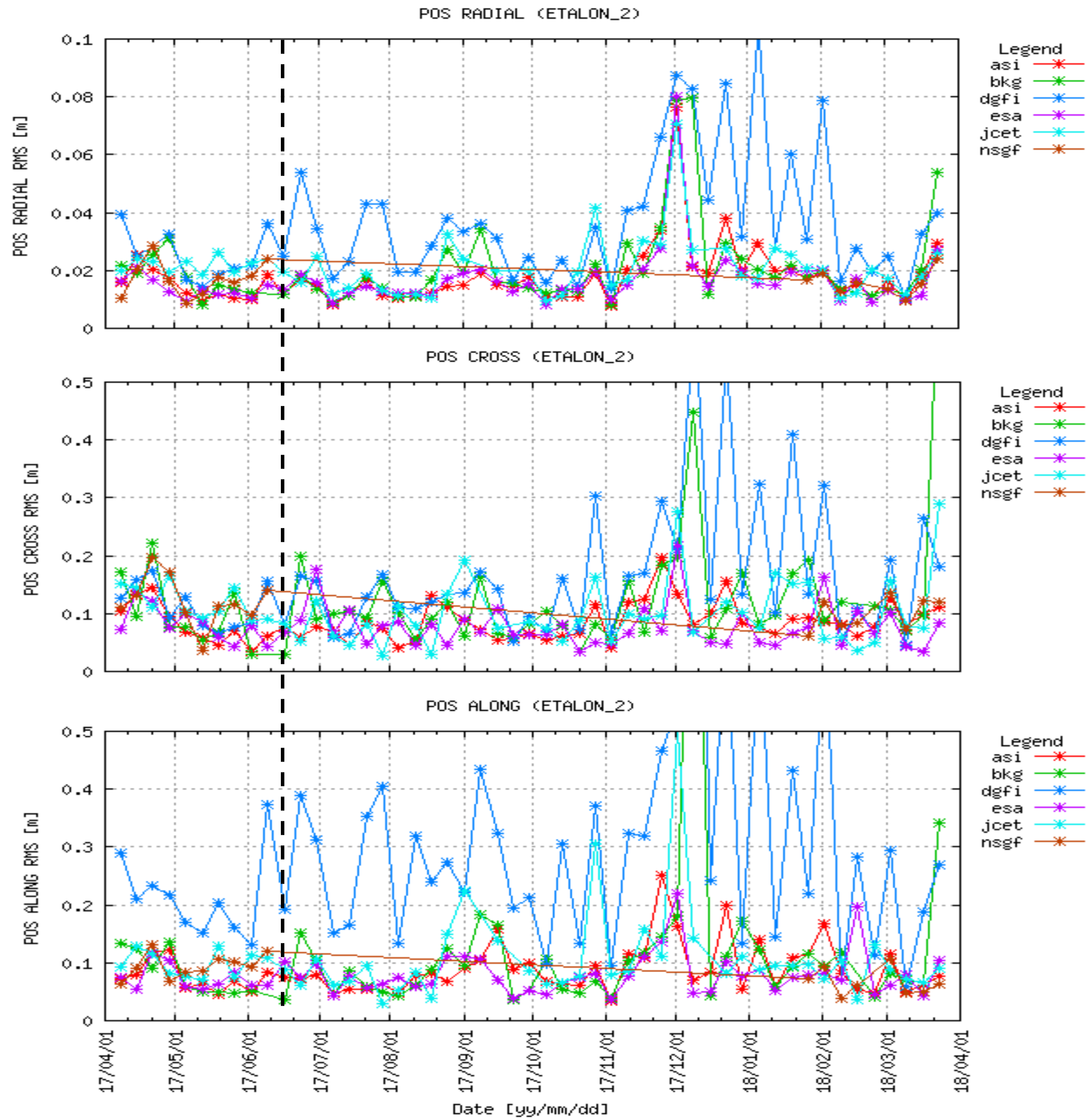
LAGEOS2 orbits – RMS of residuals w.r.t. combination



ETALON1 orbits – RMS of residuals w.r.t. combination



ETALON2 orbits – RMS of residuals w.r.t. combination



ILRS ACs orbit agreement

Satellite	Radial [mm]	Cross-track [mm]	Along-track [mm]
LAGEOS1	5	20	21
LAGEOS2	5	22	25
ETALON1	18 16*	95 91*	104 85*
ETALON2	20 18*	100 93*	113 87*

Mean RMS over the period 2017/04/01-2018/03/24

* DGFI not included

SYSTEMATIC ERROR PILOT PROJECT

ILRS Pilot Project on systematic errors

- Weekly estimation of coordinates, EOP and biases
- Time frame: 1993-2018
- Data: L1 and L2
- time series with separate biases
- New conventions for wavelength indication in the SINEX files

System	CDP ID#	SOLN Flag	Wavelength
Concepcion	7405	400	423
Concepcion	7405	800	846
Zimmerwald	7810	400	423
Zimmerwald	7810	500	532
Zimmerwald	7810	800	846
SOS Wettzell	7827	400	425
SOS Wettzell	7827	800	850
Matera	7941	300	355
Matera	7941	500	532

Use the hundreds of the wavelength instead of 1,2,3, etc.

ILRS Pilot Project on systematic errors

AC time series v220 uploaded at EDC

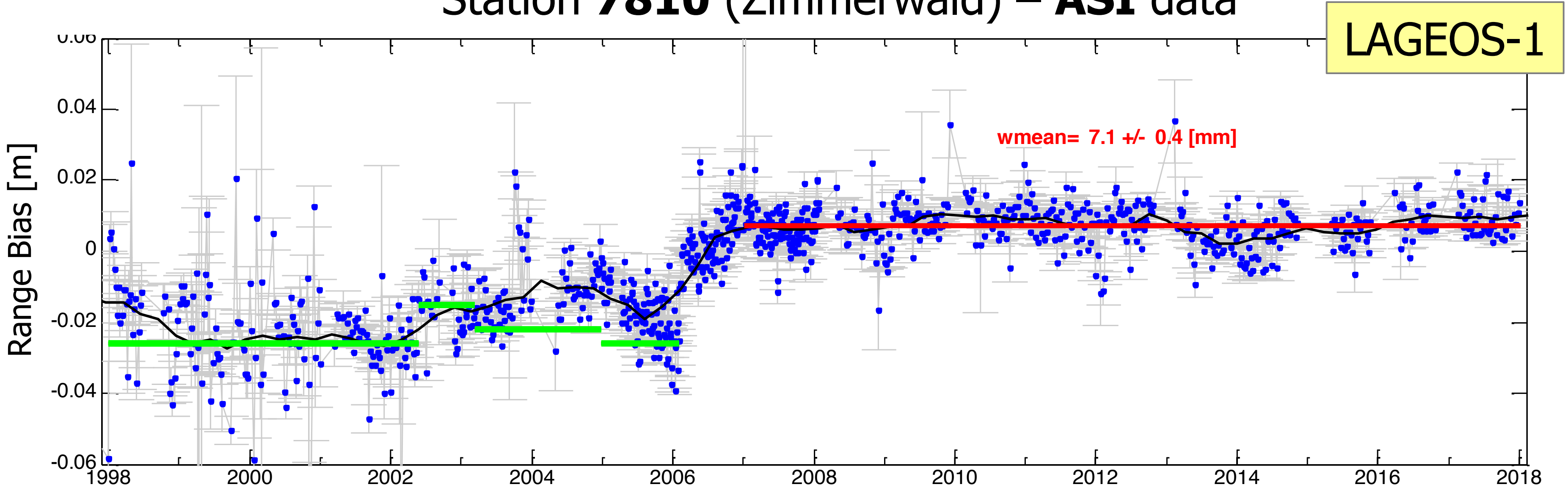
AC		Start	Stop		submission date	missing files [yymmdd]
ASI	--	1993.01.09	2018.01.06	>	14/03/2018	none
BKG	<	1993.01.09	2018.01.06	>	23-26/03/2018	none
DGFI	--	--	--	--	--	--
ESA	--	1993.01.09	2018.01.06	>	03/04/2018	none
GFZ	--	1993.01.09	2018.01.06	--	23/03/2018	none
JCET	--	1993.01.09	2018.01.06	>	27-29/03/2018	none
NSGF	--	1993.01.09	2018.01.06	>	13/03/2018	930710, 941231, 951230, 010929, 060107, 120707, 170107

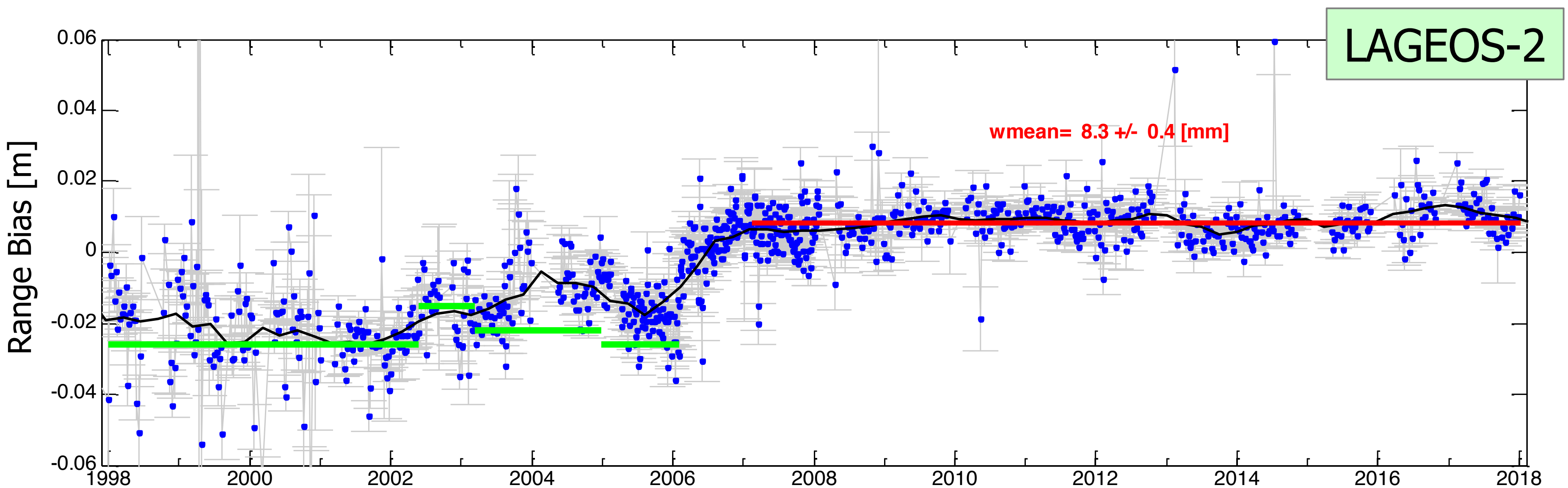
1305 files in the common time

(1298 files for NSGF)

ILRS Pilot Project on systematic errors

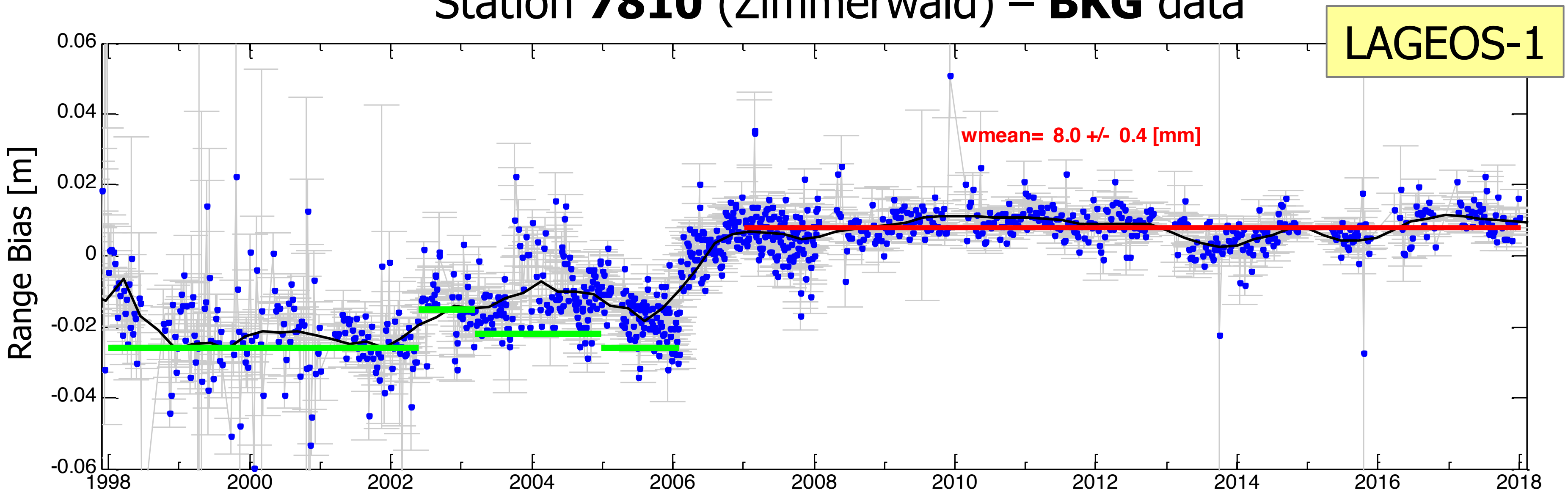
Station **7810** (Zimmerwald) – **ASI** data

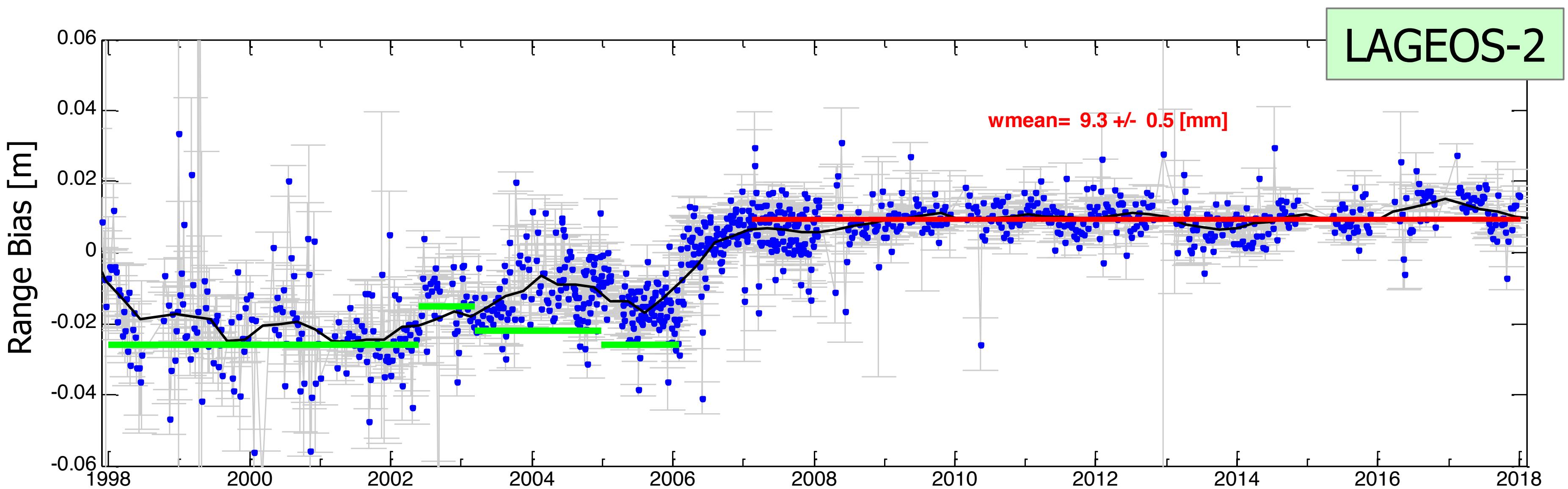




ILRS Pilot Project on systematic errors

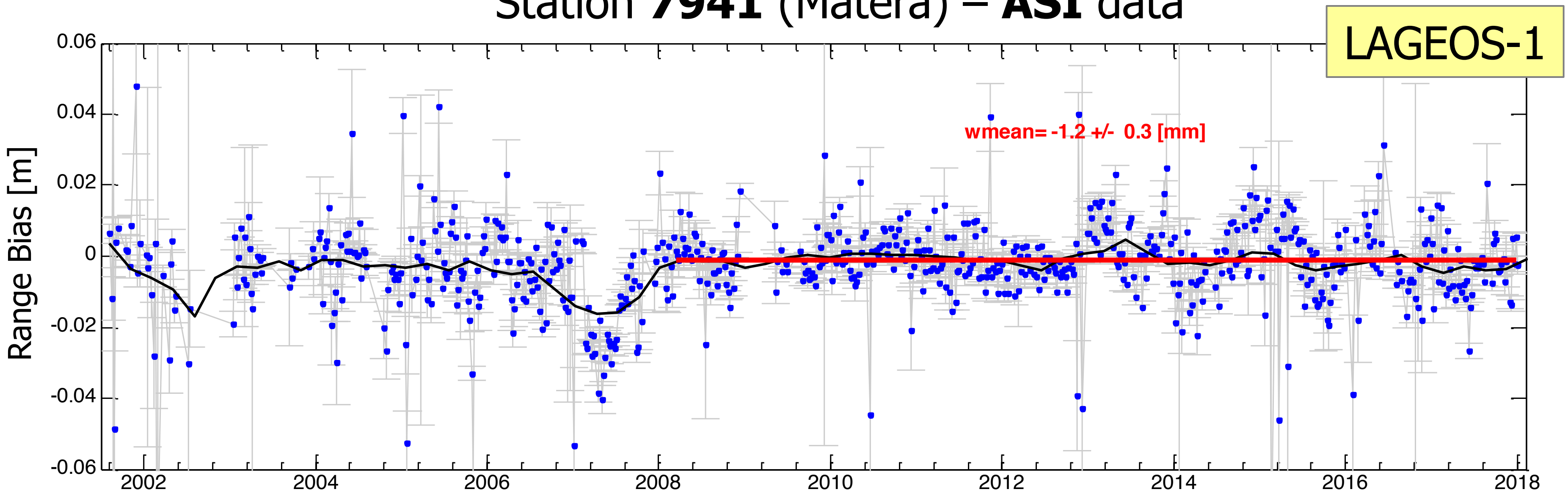
Station **7810** (Zimmerwald) – **BKG** data

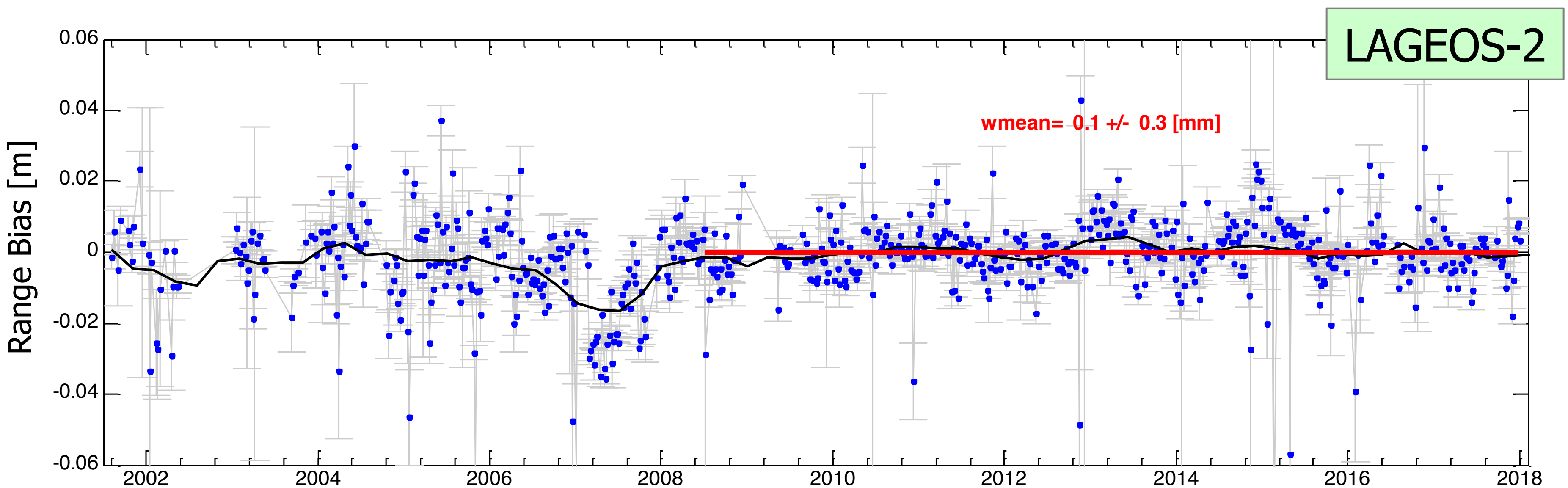




ILRS Pilot Project on systematic errors

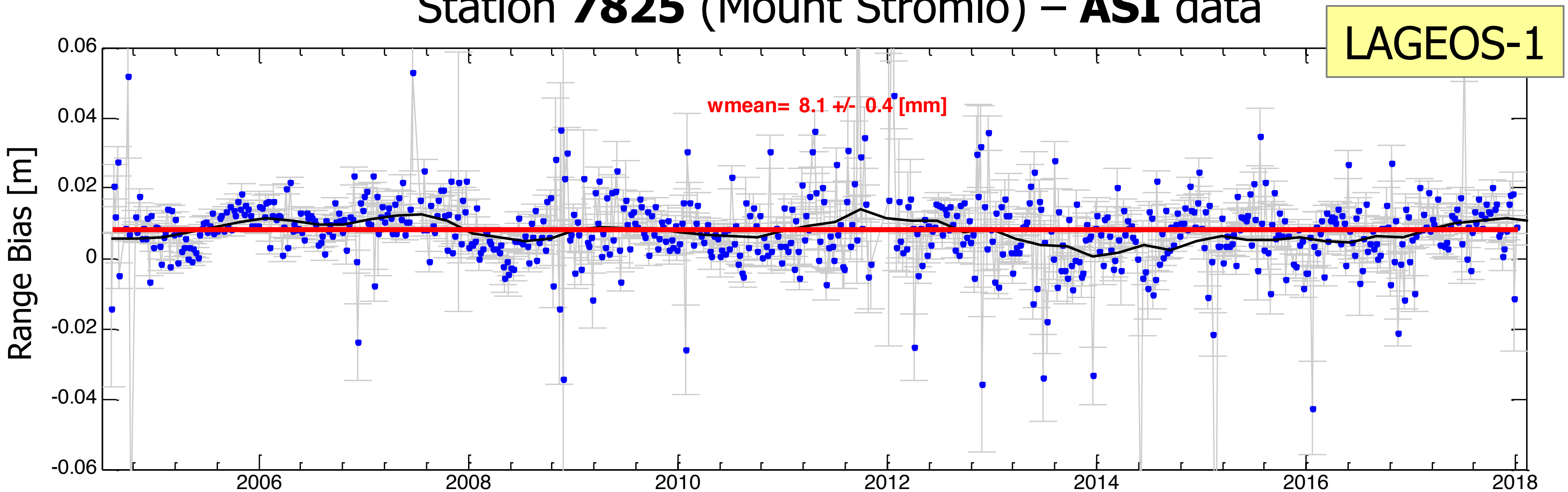
Station **7941** (Matera) – **ASI** data

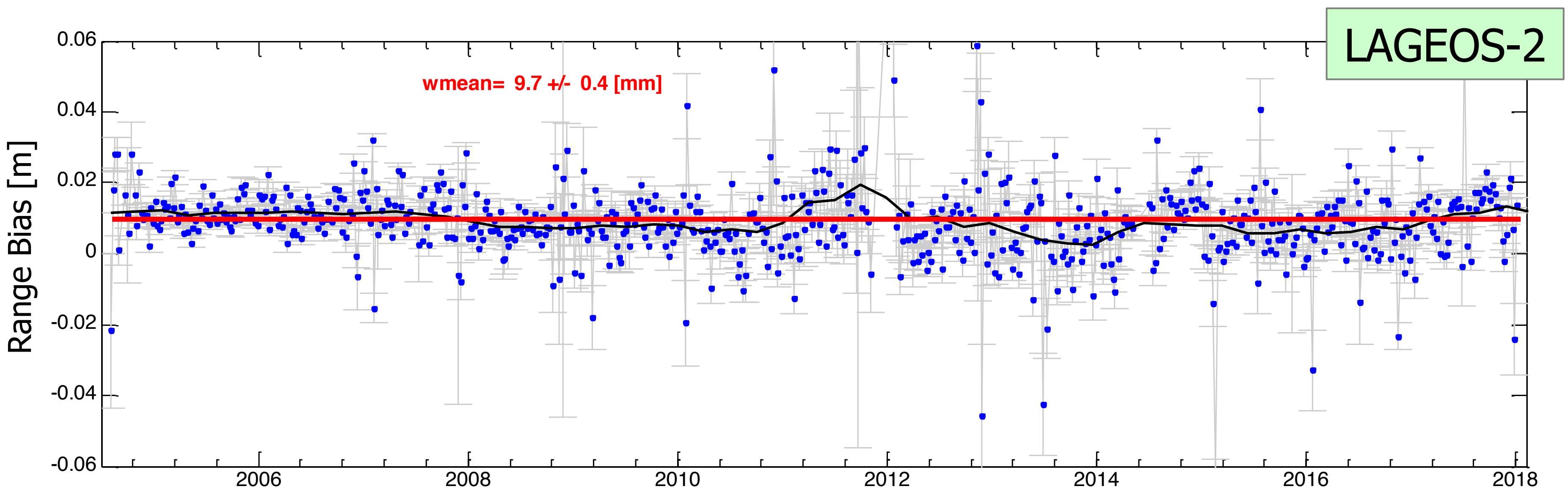




ILRS Pilot Project on systematic errors

Station **7825** (Mount Stromlo) – **ASI** data





ILRS Pilot Project on systematic errors

- Deep analysis of each single AC time series
- Combination
- Site by site investigation to detect discontinuities in the time series
- Compute biases and build the «bias table»
- Unique systematic error for both LAGEOS?

Federal Agency for
Cartography and Geodesy

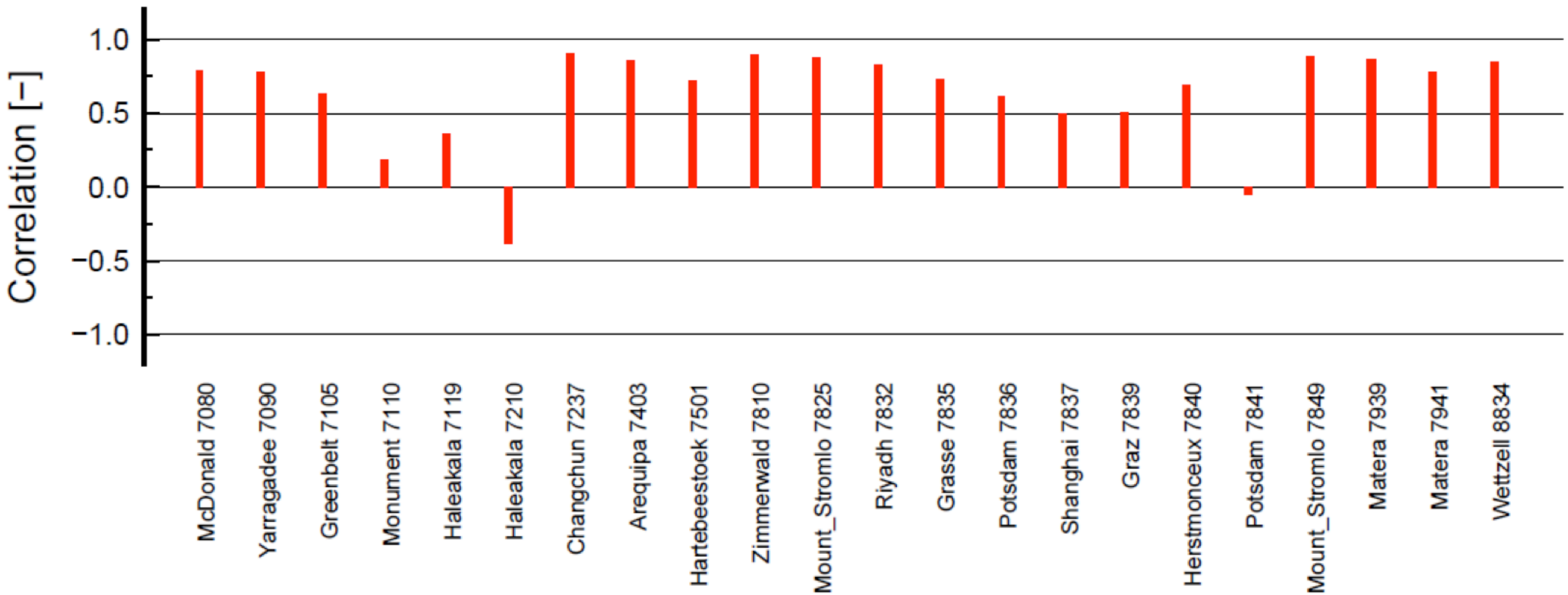
BKG Report

Daniel Koenig, Ulrich Meyer, Daniela Thaller

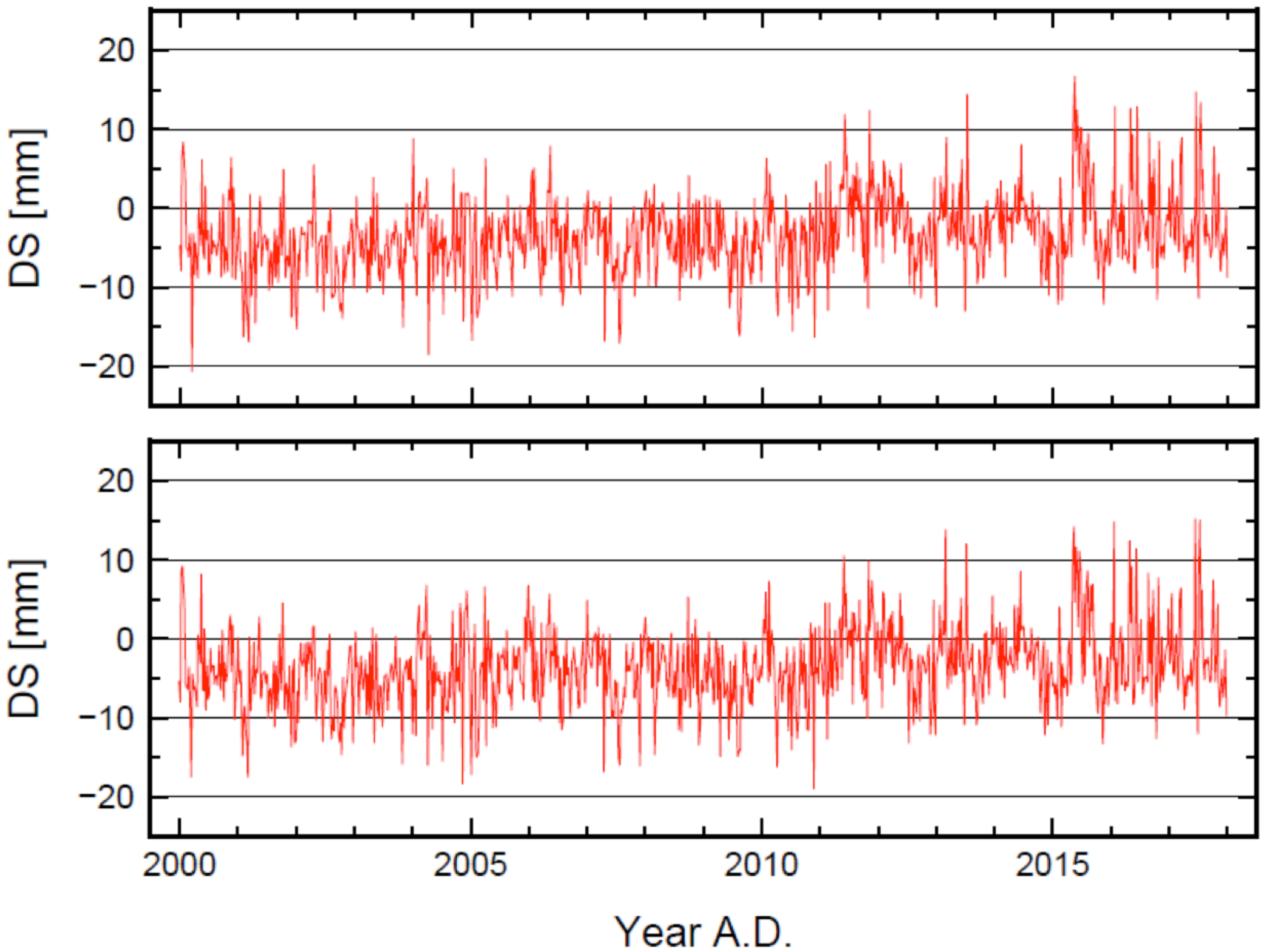
Activities since Riga WS

- Processing 1993/01-2018/02 for ILRS SSEM
  - new IERS mean pole needs to be implemented
  - time-variable gravity field implementation needs to be optimized to be more flexible
- Processing 2000/01-2017/12 for EGU2018
  - C04_14 used as a priori ERP
  - significant discrepancies with PM detected: issues w. C04_14?
  - solutions: (1) sep. L1/L2 RB
    (2) comb. LC RB
  - focus on RB time series, correlations
  - (1) revealing high correlations between L1 and L2 RB
    -> issues with Mon. Peak, Haleakala, Potsdam
  - (1) vs (2) without significant difference in global scale

Selected Results (1)



Selected Results (2)



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Status and future plans of the ILRS Analysis Center at DGFI-TUM

Mathis Bloßfeld

Deutsches Geodätisches Forschungsinstitut (DGFI-TUM)
Technische Universität München

ILRS ASC meeting, TU Vienna
Vienna, 2018-04-12

Current situation at DGFI-TUM (I)

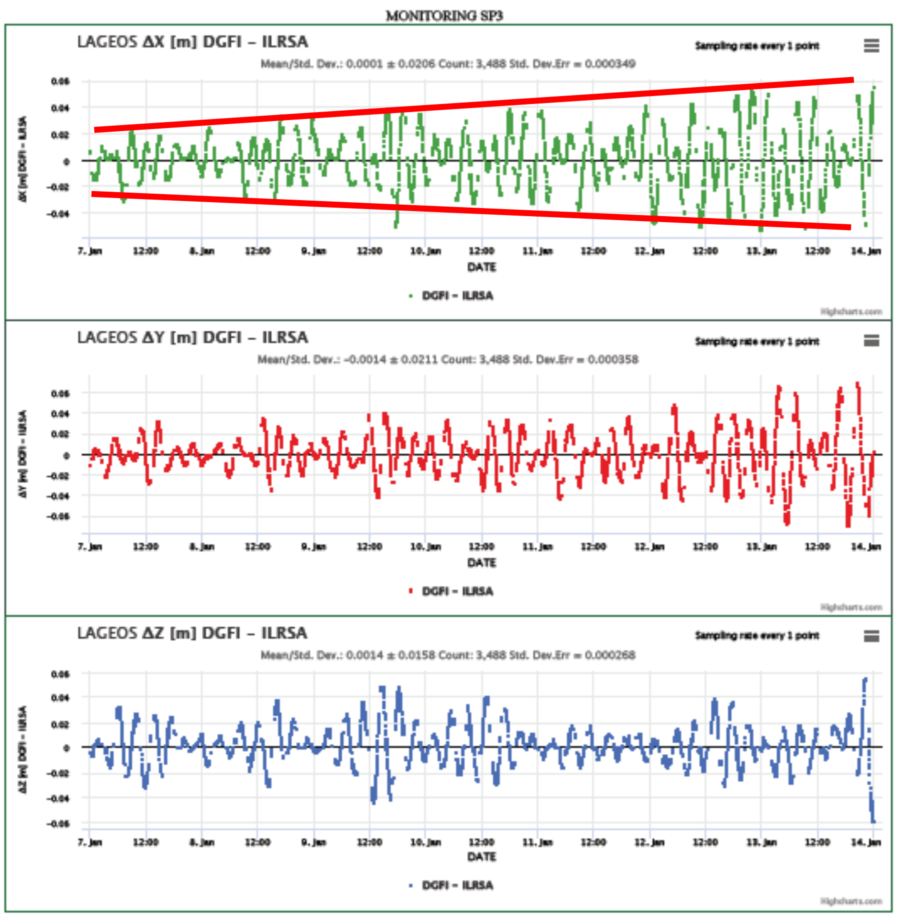
- Horst retired on April 1st (he is still available via email and telephone)
- since then, I am responsible for the ILRS AC at DGFI-TUM
- up to now, Horsts programs are still used for the operational service (daily, weekly submissions)

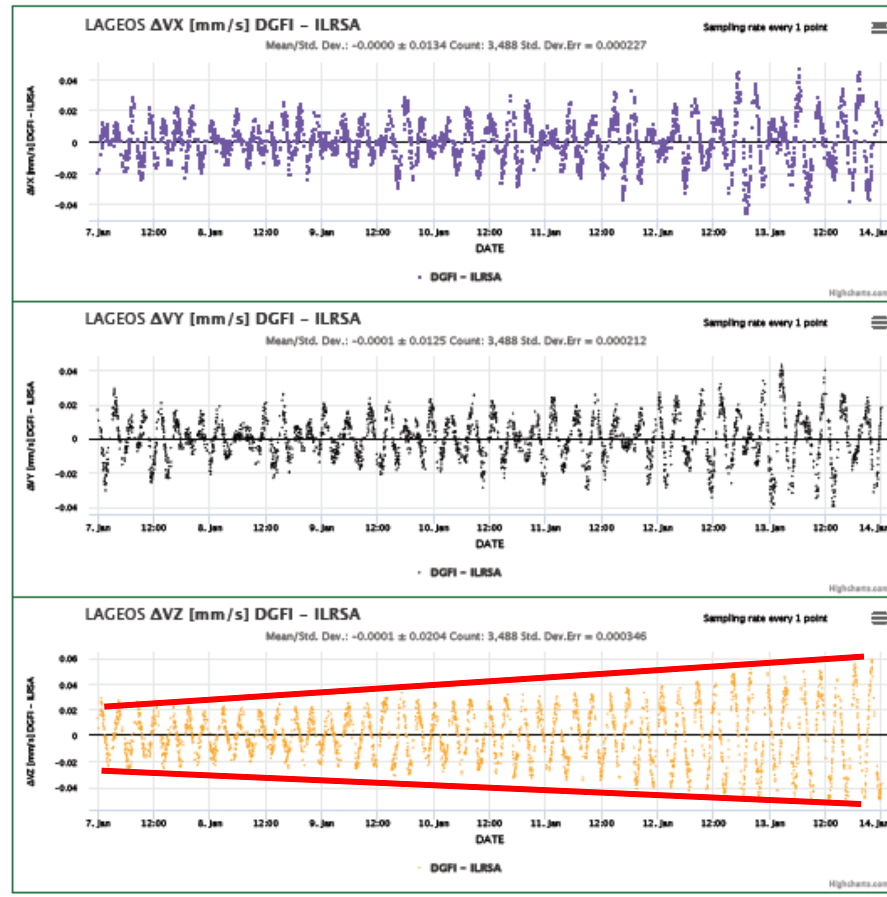
BUT:

- we are currently working on new versions of DOGS-OC and DOGS-CS
- DOGS-OC 5.1
  - able to process DORIS data; currently about 1.2mm/sec orbit RMS for Jason-2 (goal: 0.4 mm/sec); about 5cm orbit RMS for 7-day SLR arc
  - multiple changes in the program, implementation of HF EOP models, implementation of FORTRAN 2008 standards still ongoing
- DOGS-CS 5.1 (used for ILRS, IVS as well as for IERS ITRS CC)
  - refined treatment of parameter epochs

Current situation at DGFI-TUM (II)

- Increase of orbit RMS caused by solar radiation errors? → LA-1/2 7-day arc comparison (provided by JCET)





SLR constellation solutions at DGFI-TUM (I)

- Data used between 1978 and 2017
- Up to 11 spherical satellites
- Consistent estimation of TRF, EOP, and gravity field
- 11-sat. solution vs. 4-sat. solution:
  - Improvement of TRF: up to 20% less scatter in origin and scale time series
  - station repeatability improves up to 20% in hz and 8% in h
  - BUT: inclusion of Ajisai degrades solution due to “wrong/bad” CoM correction
  - about 15% improvement of pole, 10% for LOD
  - especially gravity field coefficients are improved significantly!!

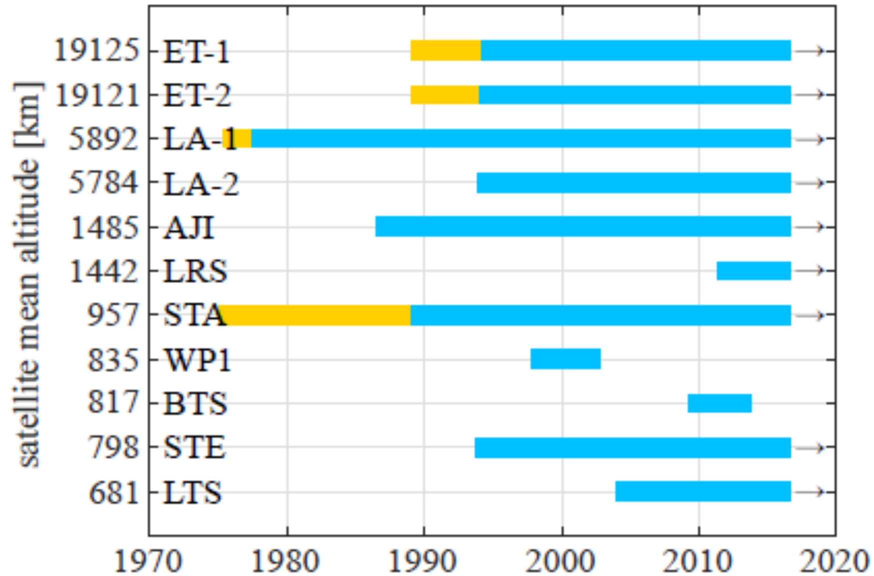


Fig. 1 Time intervals of used SLR observations (blue boxes) to different spherical satellites. The orange boxes indicate time intervals of unused observations with lower accuracy.

SLR constellation solutions at DGFI-TUM (II)

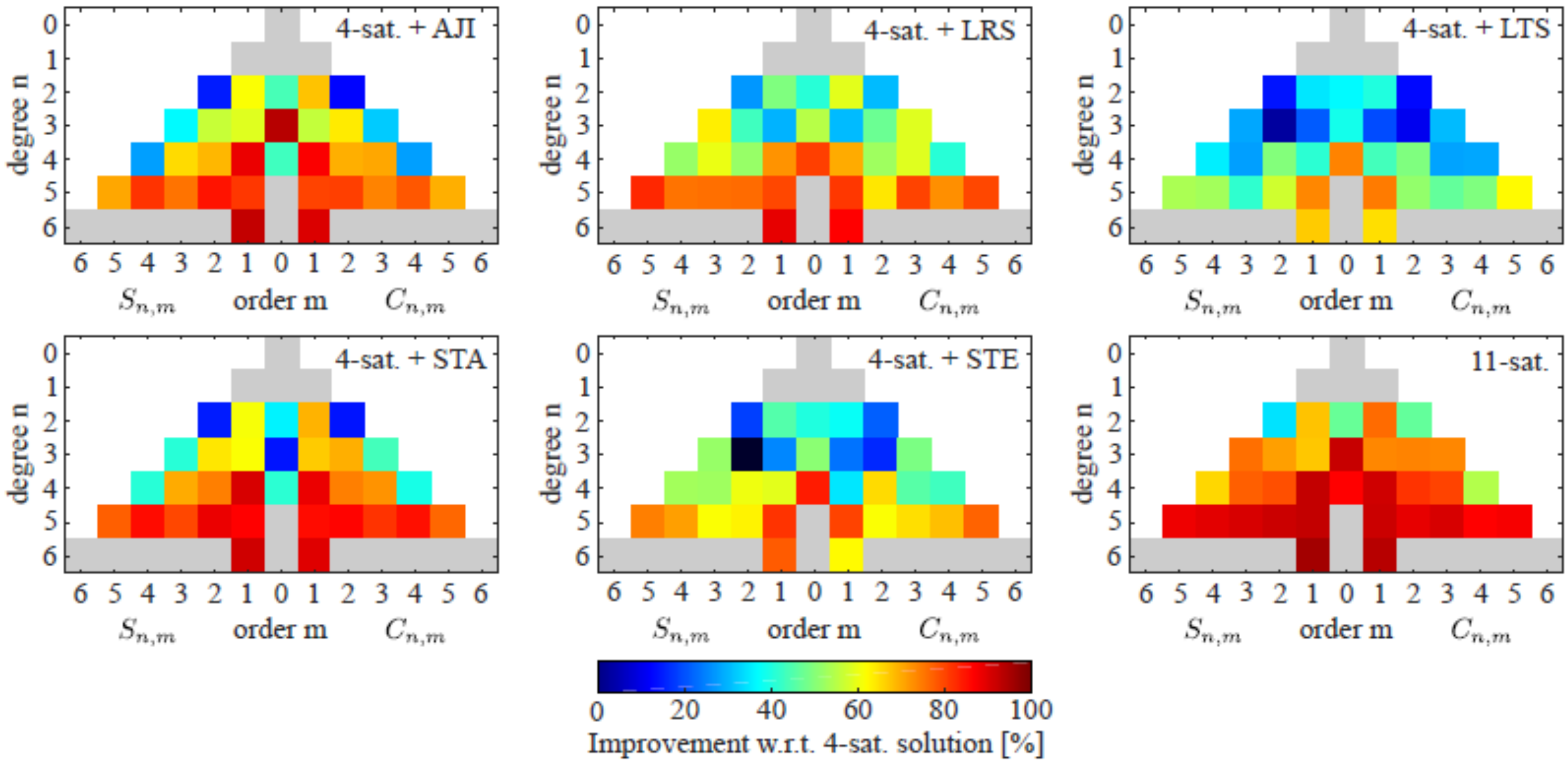


Fig. 15 Improvements of the WRMS over the weekly gravity field coefficient solutions w.r.t. the four-satellite solution. Coefficients marked in gray have not been estimated. Note: in the solution 4-sat. + STE, $S_{3,2}$ is degraded by 13 % (coefficient marked in black).

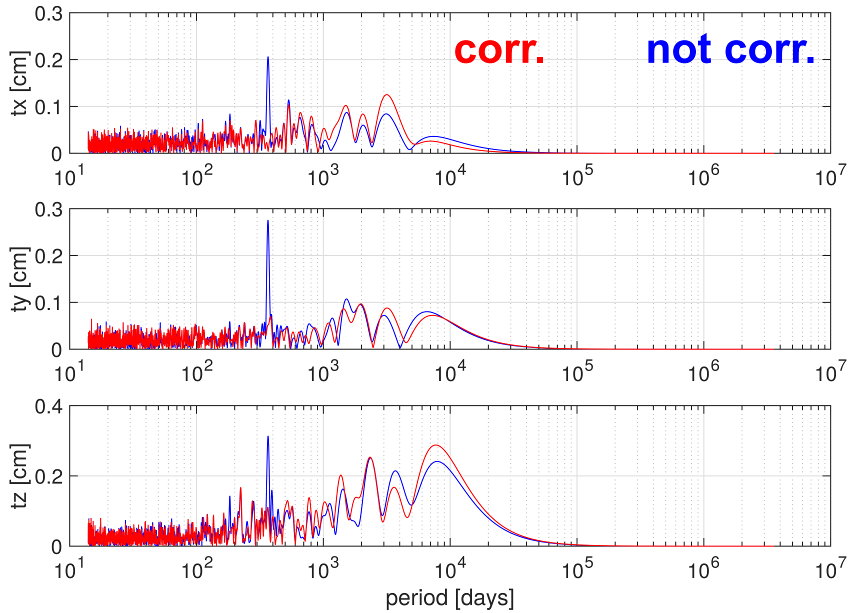
SLR constellation solutions at DGFI-TUM (III)

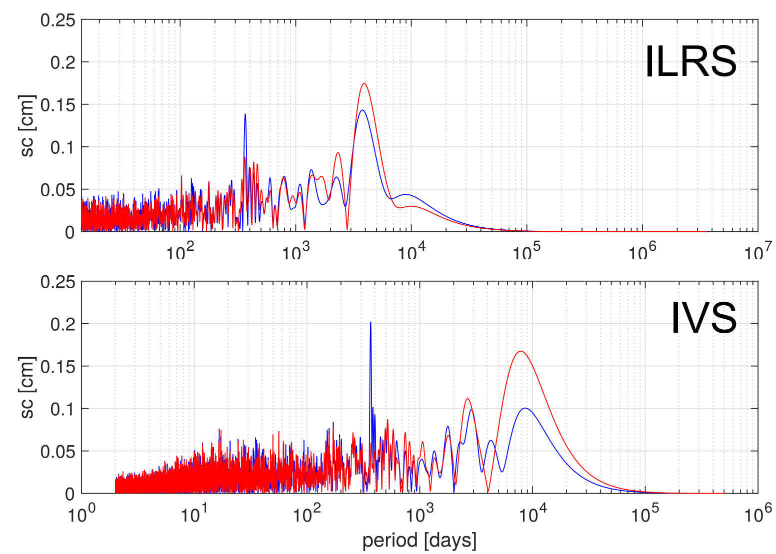
Table 6 Statistical quantities (WRMS, wmean) of specific fundamental geodetic parameters of selected SLR constellations. All values are computed for the time interval between **February 2012 and April 2017**, where in total 9 satellites were in orbit (frequently observed). 10-satellite solution means 11-satellite solution without Ajisai. For each solution, the first column gives the statistical quantity itself and the second column gives the improvement of its absolute value in percentage w.r.t. the standard ILRS solution setup (our 4-satellite solution). (*) marks the mean WRMS improvement over all Stokes coefficients $C_{(n,m)}$. Green color means improvement, red color means degradation, WR means WRMS, wm means wmean.

		4-sat. (ref.)	10-sat. value	[%]	11-sat. value	[%]	4-sat.+AJI value	[%]	4-sat.+STA value	[%]	4-sat.+STE value	[%]	4-sat.+LTS value	[%]	4-sat.+LRS value	[%]
TRF [mm]	WR (Tx)	6.2	4.7	24.2	4.7	24.2	6.0	3.2	5.4	12.9	5.3	14.5	5.5	11.3	5.3	14.5
	wme (Tx)	3.3	6.1	84.8	5.6	69.7	1.6	51.5	2.8	15.2	3.5	6.1	3.0	9.1	3.3	0.0
	WR (Ty)	6.3	5.0	20.6	5.4	14.3	6.3	0.0	5.7	9.5	5.6	11.1	5.7	9.5	5.5	12.7
	wm (Ty)	−4.6	−1.8	60.9	−2.3	50.0	−3.2	30.4	−3.3	28.3	−3.7	19.6	−4.6	0.0	−3.7	19.6
	WR (Tz)	9.8	8.6	12.2	6.2	36.7	7.5	23.5	9.5	3.1	8.1	17.3	9.5	3.1	9.0	8.2
	wm (Tz)	0.5	0.3	40.0	−1.1	120.0	−3.0	500.0	−1.2	140	−0.2	60.0	−0.3	40.0	0.0	100.0
	WR (Sc)	6.7	5.3	20.9	5.1	23.9	7.6	13.4	5.7	14.9	6.7	0.0	6.6	1.5	5.9	11.9
	wm (Sc)	4.7	2.9	38.3	8.8	87.2	16.0	240.4	5.0	6.4	4.5	4.3	5.2	10.6	4.3	8.5
	WR (north)	11.9	9.1	23.5	9.3	21.8	11.3	5.0	10.5	11.8	10.8	9.2	11.1	6.7	11.1	6.7
	WR (east)	10.8	8.5	21.3	8.7	19.4	10.0	7.4	10.1	6.5	9.9	8.3	10.6	1.9	10.6	1.9
	WR (height)	12.7	11.6	8.7	11.8	7.1	12.1	4.7	12.5	1.6	12.6	0.8	12.3	3.1	12.6	0.8
EOP [mas, ms/d]	WR (x-pole)	0.385	0.318	17.4	0.320	16.9	0.360	6.5	0.356	7.5	0.366	4.9	0.361	6.2	0.414	7.5
	wm (x-pole)	−0.107	−0.022	79.4	0.004	96.3	−0.053	50.5	−0.052	51.4	−0.079	26.2	−0.069	35.5	−0.102	4.7
	WR (y-pole)	0.387	0.295	23.8	0.305	21.2	0.355	8.3	0.352	9.0	0.353	8.8	0.355	8.3	0.384	0.8
	wm (y-pole)	0.165	0.065	60.6	0.027	83.6	0.035	78.8	0.099	40.0	0.118	28.5	0.134	18.8	0.193	17.0
	WR (ΔLOD)	0.047	0.042	10.6	0.043	8.5	0.040	14.9	0.039	17.0	0.036	23.4	0.035	25.5	0.038	19.1
	wm (ΔLOD)	−0.001	0.005	400.0	0.003	200.0	−0.006	500.0	0.009	800	0.002	100.0	0.004	300.0	0.001	0.0
GFC $\cdot 10^{-10}$ [-]	WR ($C_{(2,0)}$)	2.0172	1.1322	43.9	1.0554	47.7	1.1151	44.7	1.2835	36.4	1.1945	40.8	1.2655	37.3	1.1813	41.4
	WR ($C_{(3,0)}$)	17.224	6.7620	60.7	1.2346	92.8	0.9831	94.3	14.726	14.5	8.4124	51.2	10.414	39.5	7.7003	55.3
	WR ($C_{(4,0)}$)	6.9305	1.0032	85.5	0.8861	87.2	3.8998	43.7	4.0417	41.7	1.0756	84.5	1.7648	74.5	1.3144	81.0
	WR* ($C_{(n,m)}$)			77.5		79.3		64.4		66.1		52.3		41.9		61.7

ILRS pilot projects

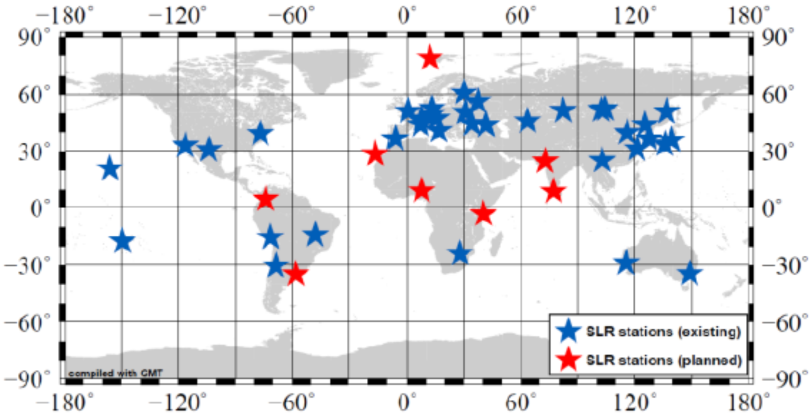
- With our DGFI-TUM SLR constellation solution, we can contribute to all ILRS pilot projects
  - Estimation of low-degree SH of the gravity field
  - Inclusion of LARES as a 5th satellite in our operational product development
  - Discussion of a plan for the expansion of the targets used in operational products
  - Revisit NT Atm. Loading & Gravity implementation as an internal PP
    - Ongoing research work motivated by DTRF2014 studies



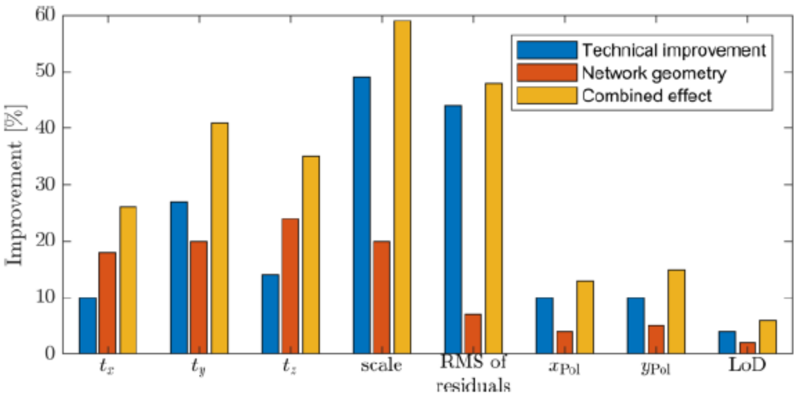


SLR simulation studies at DGFI-TUM

Simulated network:



Improvement of estimated parameters:



- Simulation of eight additional SLR stations in locations planned for the future
- Assumption of a realistic future scenario concerning performance (amount of data produced) and noise
- The studies have proven that **increased station performances** (to a minimum of 20 % of all passes) as well as an **improved network geometry** have to go hand in hand to achieve the future accuracy goals!

Recent SLR-related publications of DGFI-TUM

- Bloßfeld M. Rudenko S., Kehm A., Müller H., Angermann D., Seitz M.: Consistent estimation of geodetic parameters from SLR satellite constellation measurements. JoG, in review (minor revision)
- Bloßfeld M., Angermann D., Seitz M.: DGFI-TUM analysis and scale investigations of the latest terrestrial reference frame realizations. IAG Proceedings, in review (major revision)
- Kehm A., Bloßfeld M., Pavlis E. C., Seitz F.: Future global SLR network evolution and its impact on the terrestrial reference frame. JoG (2017), DOI: 10.1007/s00190-017-1083-1
- Kwak Y., Bloßfeld M., Schmid R., Angermann d., Gerstl M., Seitz M.: Consistent realization of celestial and terrestrial reference frames. JoG (2018), DOI: 10.1007/s00190-018-1130-6
- Männel B. Thaller D., Rothacher M., Böhm J., Müller J., Glaser S., Dach R., Biancale R., Bloßfeld M., Kehm A., Herrera Pinzon I., Hofmann F., Andritsch F., Coulot D., Pollet A.: Recent Activities of the GGOS Standing Committee on Performance Simulations and Architectural Trade-Offs (PLATO). IAG Proceedings (2018), DOI: 10.1007/1345_2018_30
- Panzetta F., Bloßfeld M., Erdogan E., Rudenko S., Schmidt M., Müller H.: Towards thermospheric density estimation from SLR observations of LEO satellites - A case study with ANDE-Pollux satellite. JoG, in review (minor revision)
- Pearlman M., Arnold D., Barlier F., Biancale R., Vasiliev V., Ciufolini I., Paolozzi A., Pavlis E., Sosnica K., Bloßfeld M.: Laser geodetic satellites: a high accuracy scientific tool. JoG (nearly submitted)
- Rudenko S., Bloßfeld M., Müller H., Dettmering D., Angermann D., Seitz M.: Evaluation of DTRF2014, ITRF2014 and JTRF2014 by Precise Orbit Determination of SLR Satellites. IEEE Transactions on Geoscience and Remote Sensing (2018), DOI: 10.1109/TGRS.2018.2793358
- Xiong C., Lühr H., Schmidt M., Bloßfeld M., Rudenko S.: An empirical model (CH-Therm-2018) of the thermospheric mass density derived from CHAMP. Annales Geophysicae - Special Issue: Dynamics and interaction of processes in the Earth and its space environment: the perspective from low Earth orbiting satellites and beyond (submitted)

Future plans

- Further debugging of DOGS-OC 5.1
- Reset of ILRS/IVS server at DGFI-TUM
  - Re-writing of Horsts routines necessary and already ongoing… to be finished end of May
  - a lot of technical changes have to be made in the programs (i.e. IN/OUT, etc.)
- other tasks of Horst (QCB, bias reports, …): decision still pending if DGFI can further provide input
- inclusion of DORIS-tracked satellites into an SLR/DORIS-constellation solution

Status and future plans of the ILRS Analysis Center at DGFI-TUM

Mathis Bloßfeld

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Technische Universität München

ILRS ASC meeting, TU Vienna
Vienna, 2018-04-12

ESA/ESOC Status

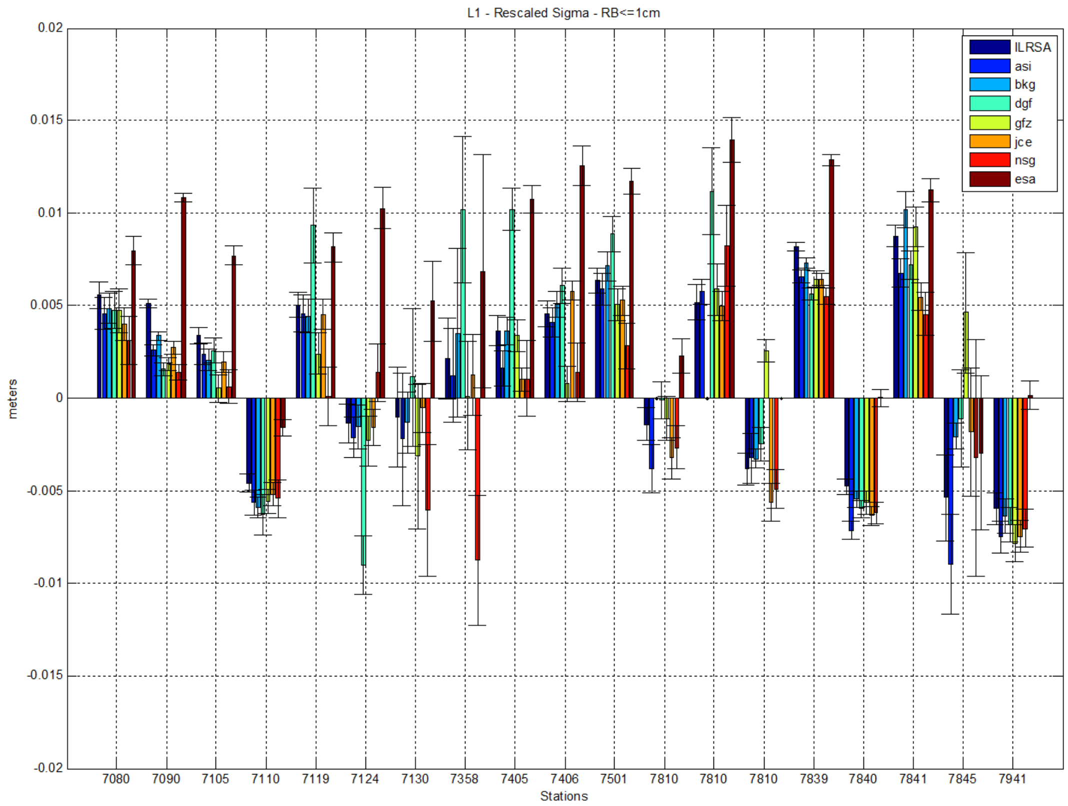
T. Springer, E. Schoenmann, W. Enderle

ESA/ESOC Navigation Support Office

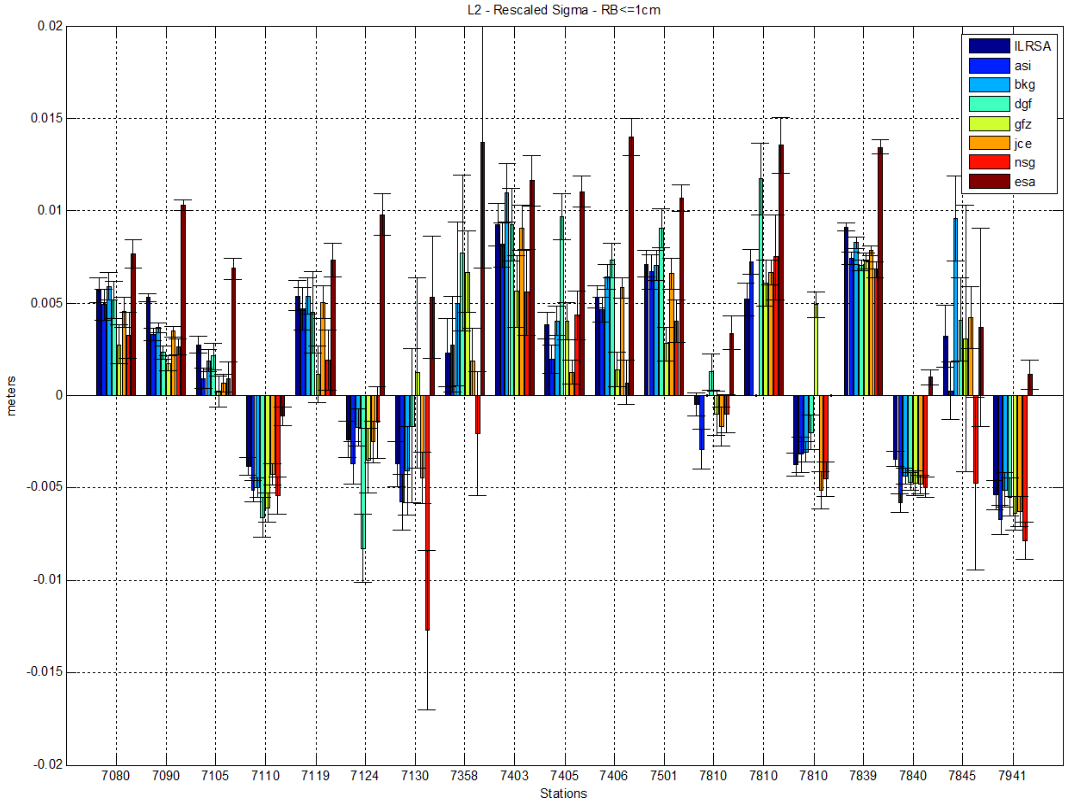
Content

- Issues in BIAS PP
- Status regarding future ILRS plans
- Other ILRS/SLR related activities and plans
    - LARGE working group!?

BIAS PP ISSUE (plots courtesy of Cinzia and Paolo)



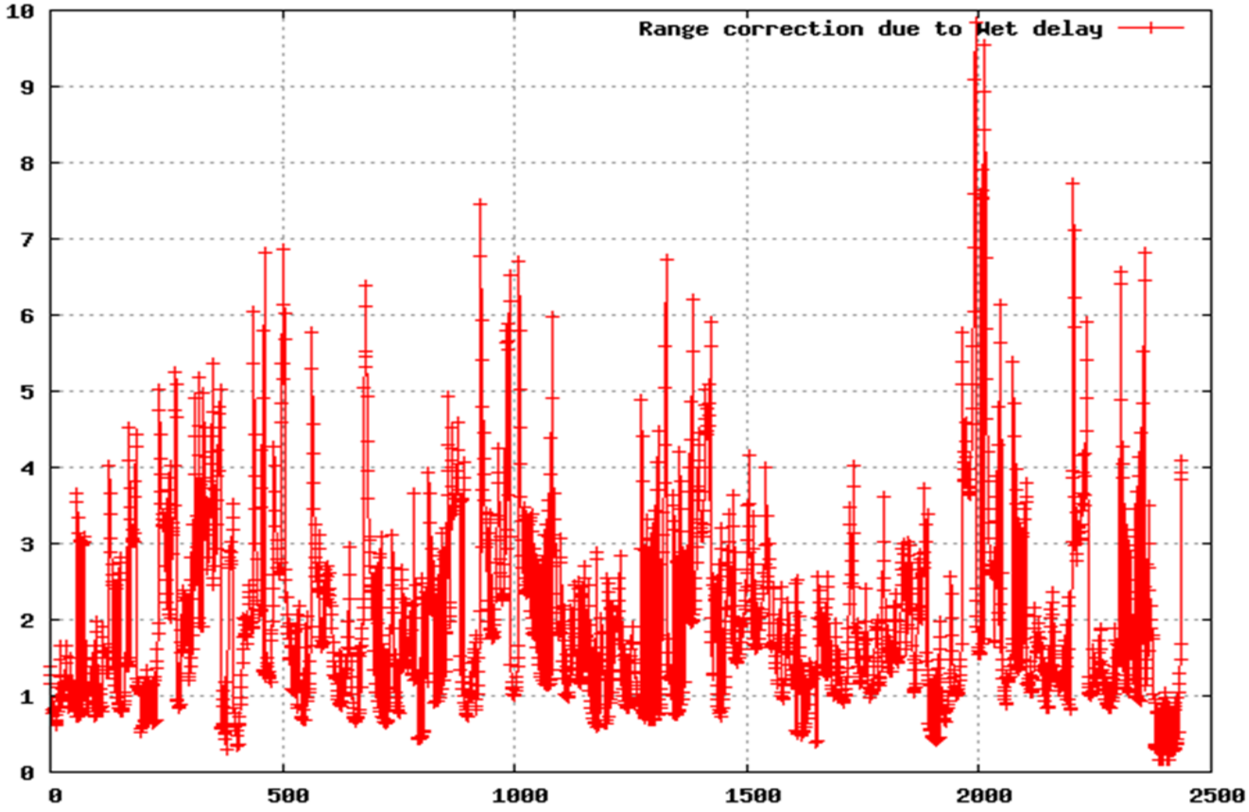
BIAS PP ISSUE (plots courtesy of Cinzia and Paolo)



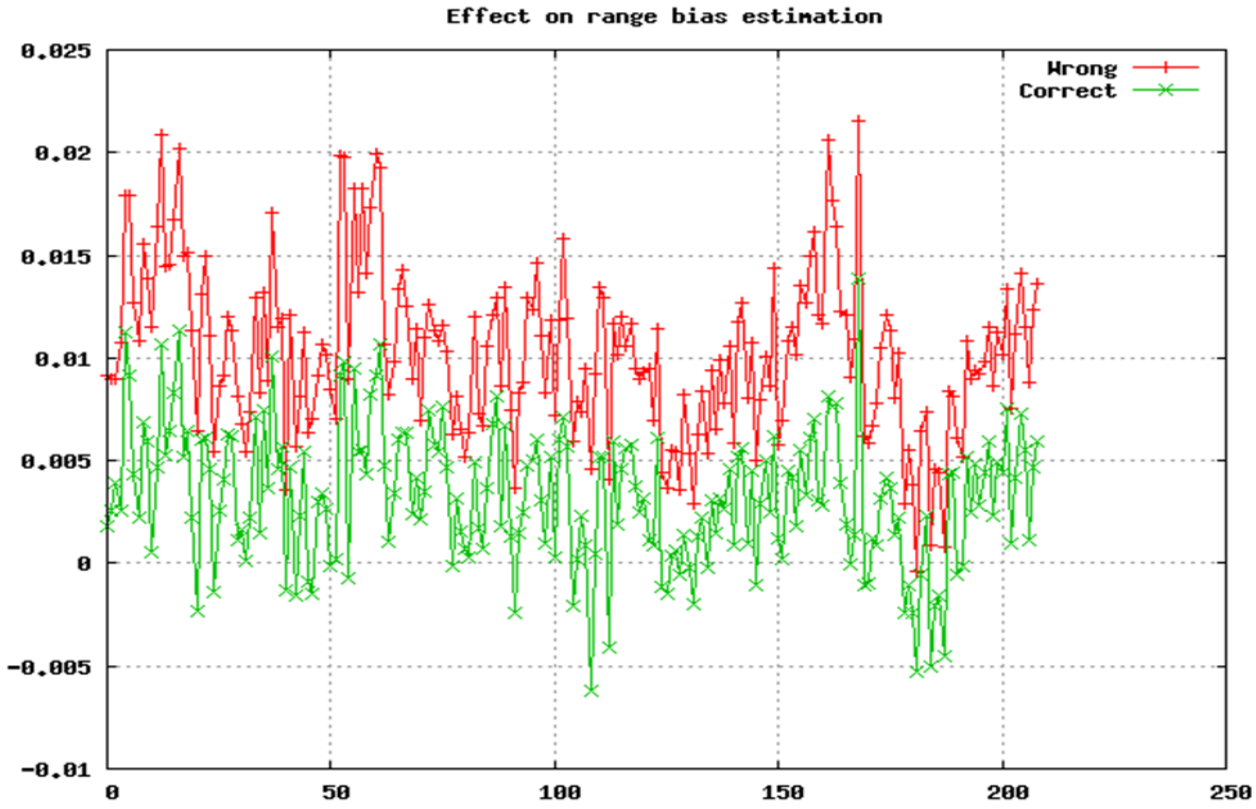
BIAS PP Issue

- A clear bias was observed in the ESA solutions for all stations
  - In particular also for good stations which should have hardly have a bias
- At ESA many tests were done to investigate the issue
  - Only test which showed a similar performance was switching the troposphere from the new Mendez-Pavlis model to the old Marini-Murray model, indicating that something in the troposphere model was most likely causing the issue.
  - In the end the effect was found “deep down” in the software being caused by an option which should only be used for Altimetry processing but was incorrectly also active for GNSS and ILRS under certain circumstances.
  - Was causing the “wet” troposphere effect to be set to zero.

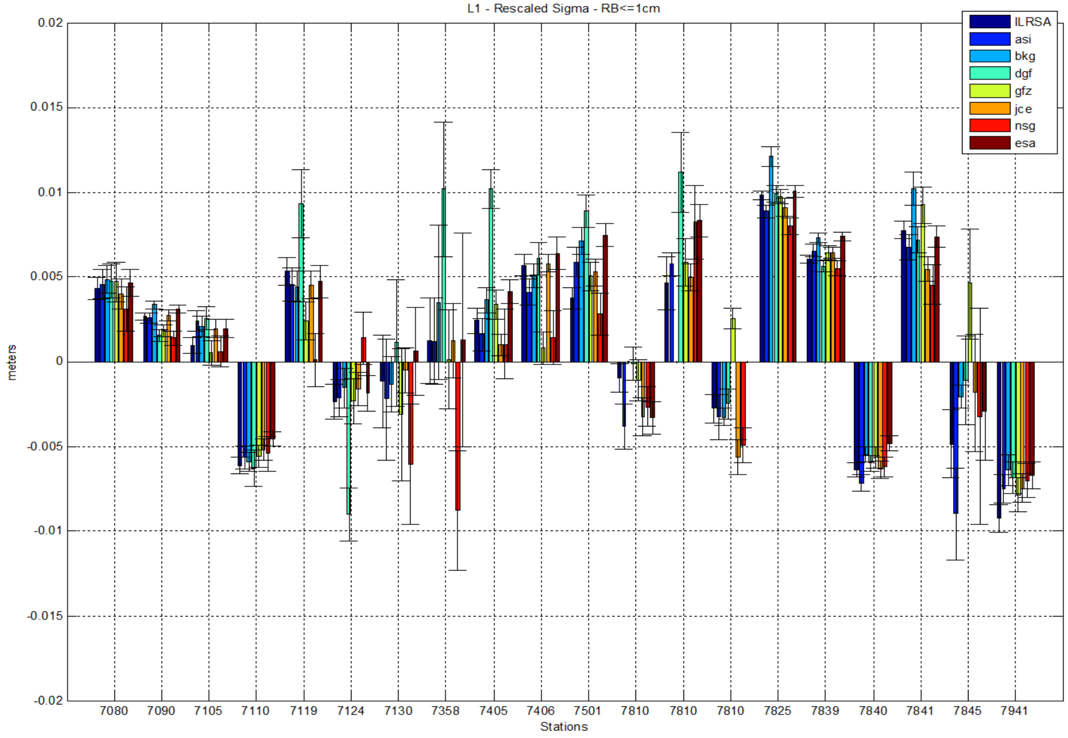
Range correction due to Wet delay



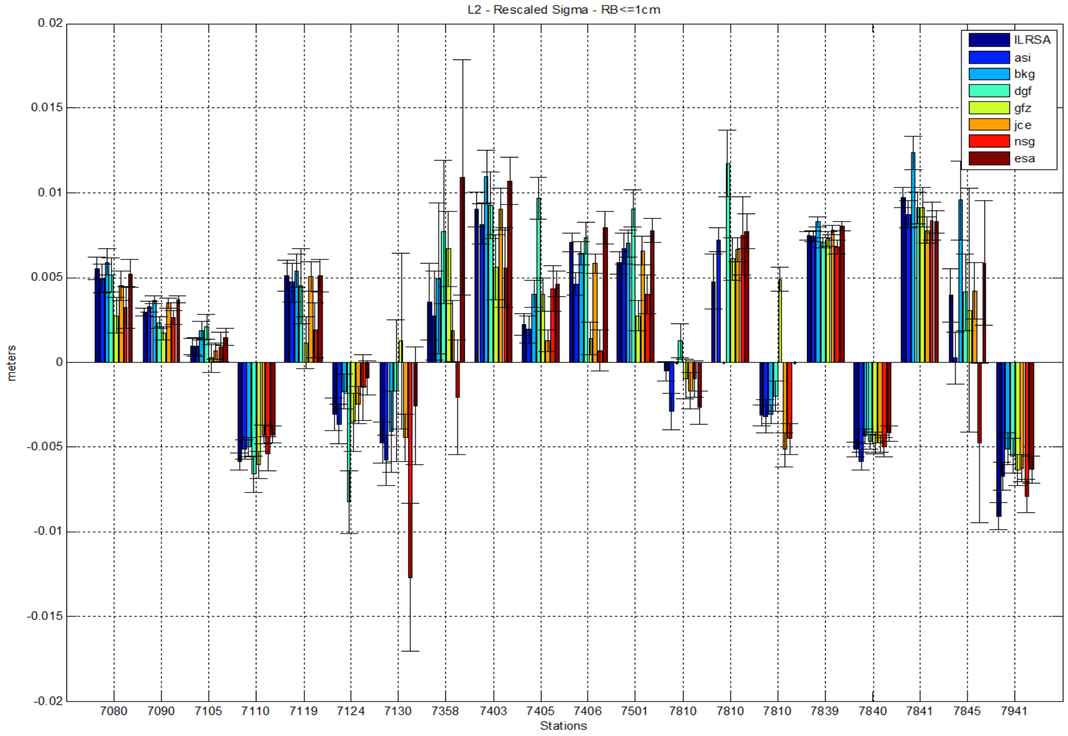
Effect on Range Bias estimation (station 7090)



ISSUE Resolved (plots courtesy of Cinzia and Paolo)



ISSUE Resolved (plots courtesy of Cinzia and Paolo)



Status of ESA/ESOC ILRS AC

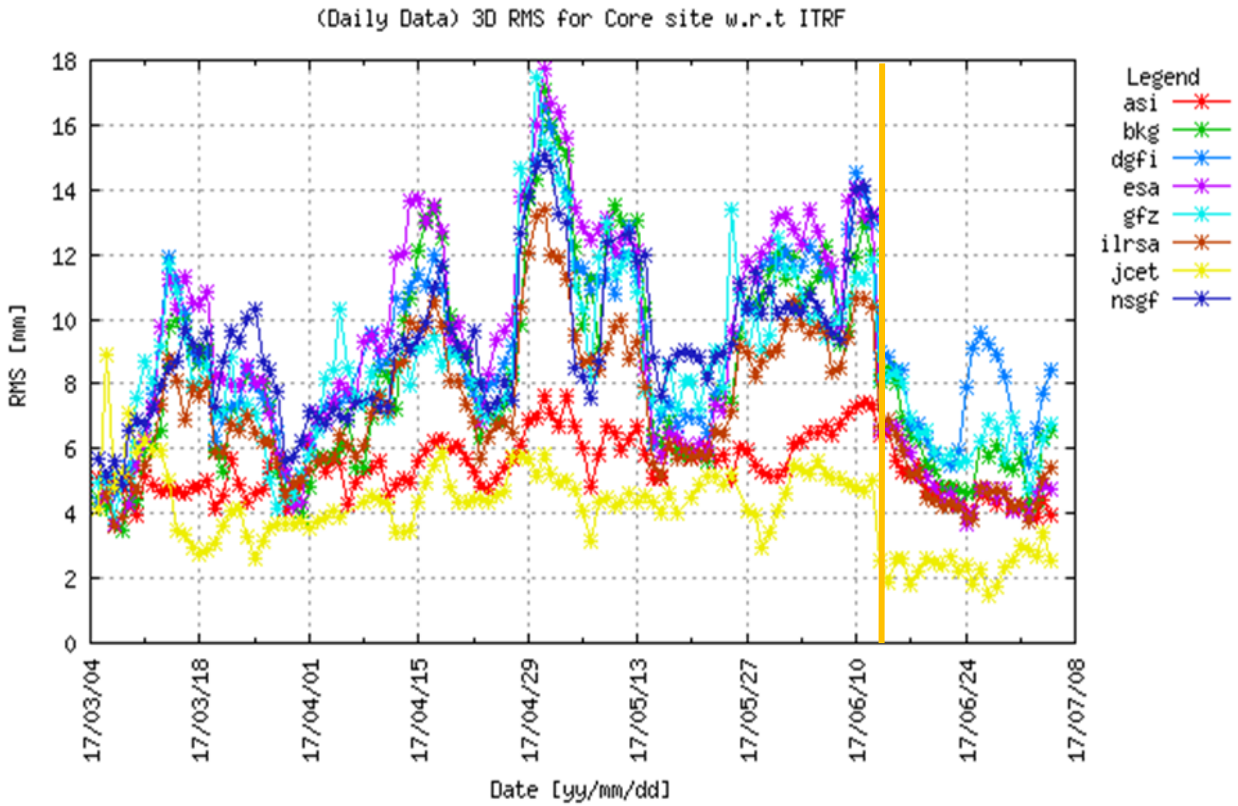
ESA/ESOC AC Status

- Reprocessing for ITRF2104 was used to improve our processing scheme
    - Discovered that estimation constant cross track force was sub-optimal
    - Most significant change was station data weighting
    - We now use 4 groups: CORE, Good, OK, and rest

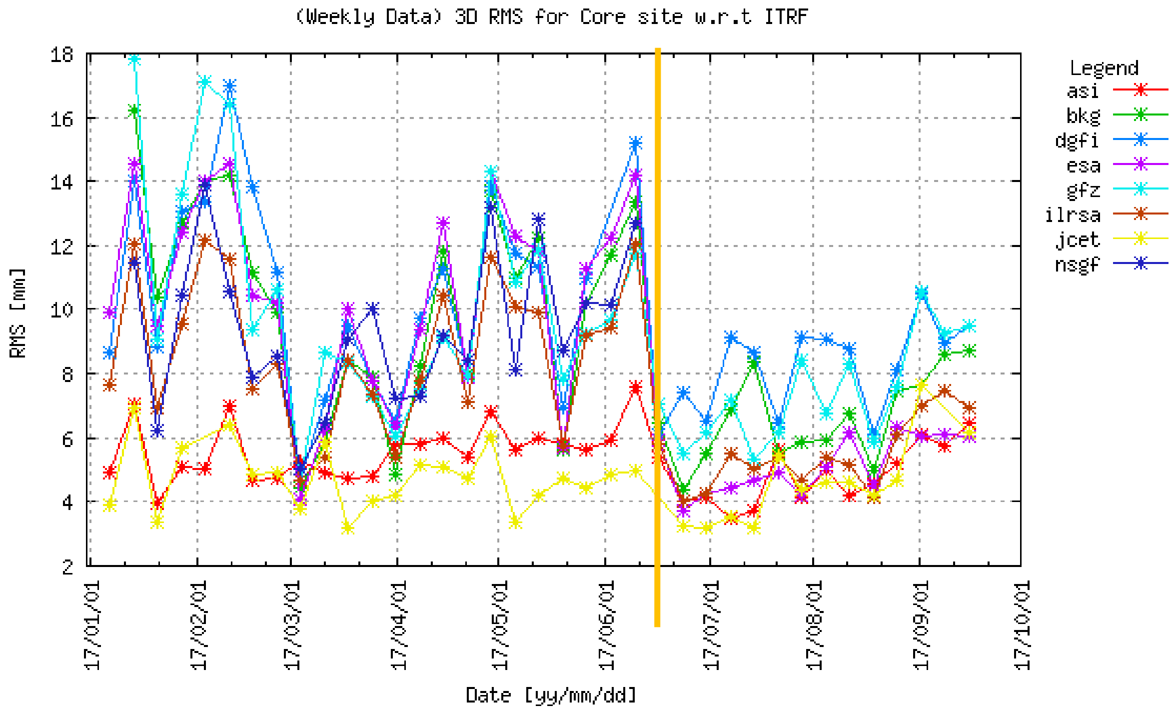
- Switch to using our processing strategy developed for the ILRS reprocessing
    - At same time as the switch to ITRF2014

- All our solution were affected in scale by the tropo bias
    - Must be a visible "jump" in our scale since our recent bug fix

Improvement in 3D RMS for ESA after switch

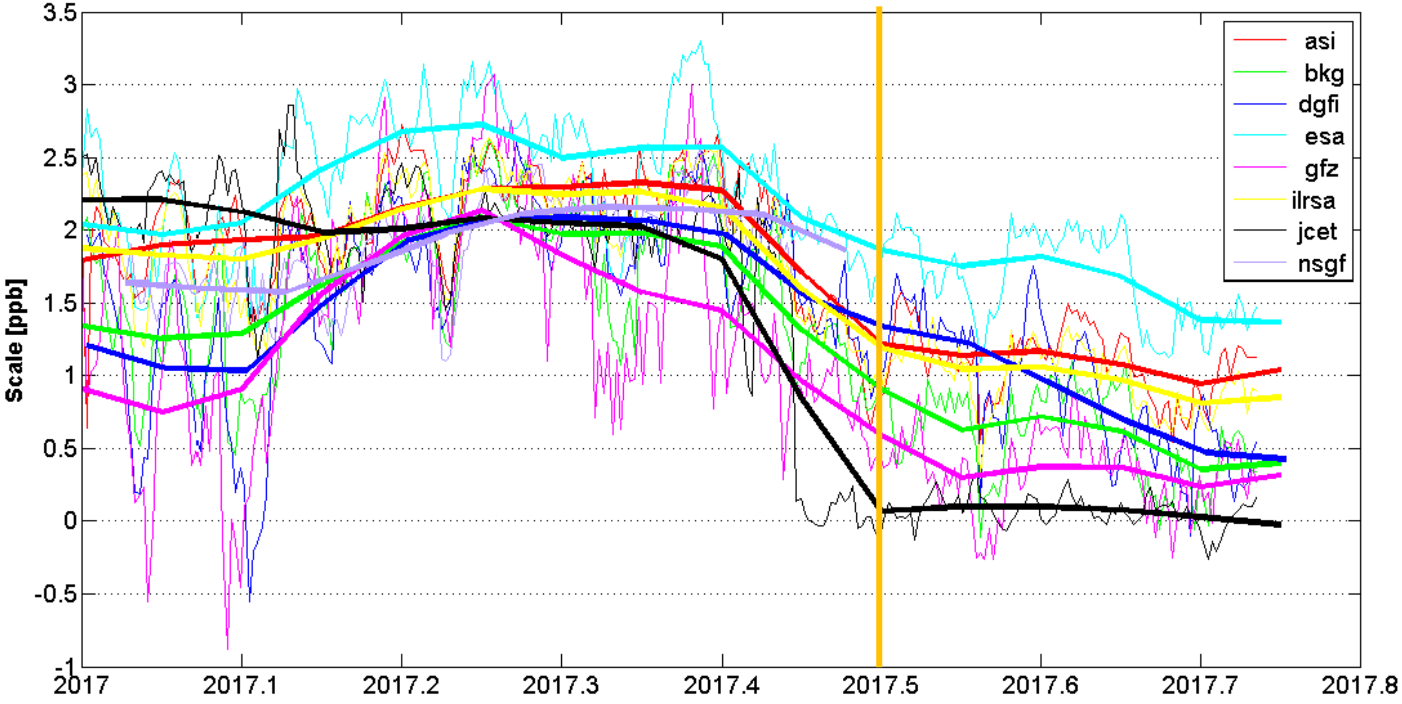


Improvement in 3D RMS for ESA after switch



ESA Scale issue. Should have improved now!

But still on the high side.



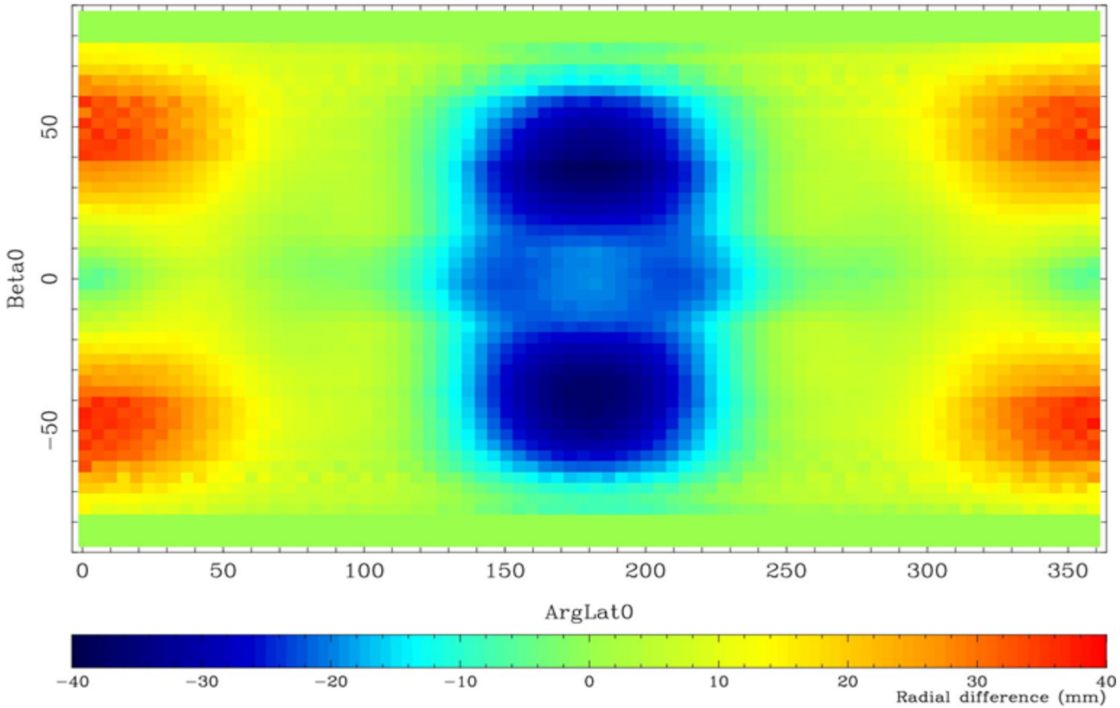
Open Issues

- Bias per station per wavelength
  - Only works for one wavelength
  - Some work needed to handle stations with multiple wavelengths
- SINEX with gravity field coefficients
  - Not 100% sure that the partials are correct
  - Otherwise fully ready for LARES (SRP coefficient?)
- Time biases to be tested/reviewed
  - 1-way versus 2-way issue in our software
  - Simple enough so no issue expected
- Detailed tests of sub-daily ERP planned
  - So far did not notice much in the ILRS solutions
  - Gipson model tested, Sibois model to be tested
- Several different mean pole motions available in the software, no issue there.

Other ILRS/SLR Activities at ESA/ESOC

GPS Radial Orbit Differences

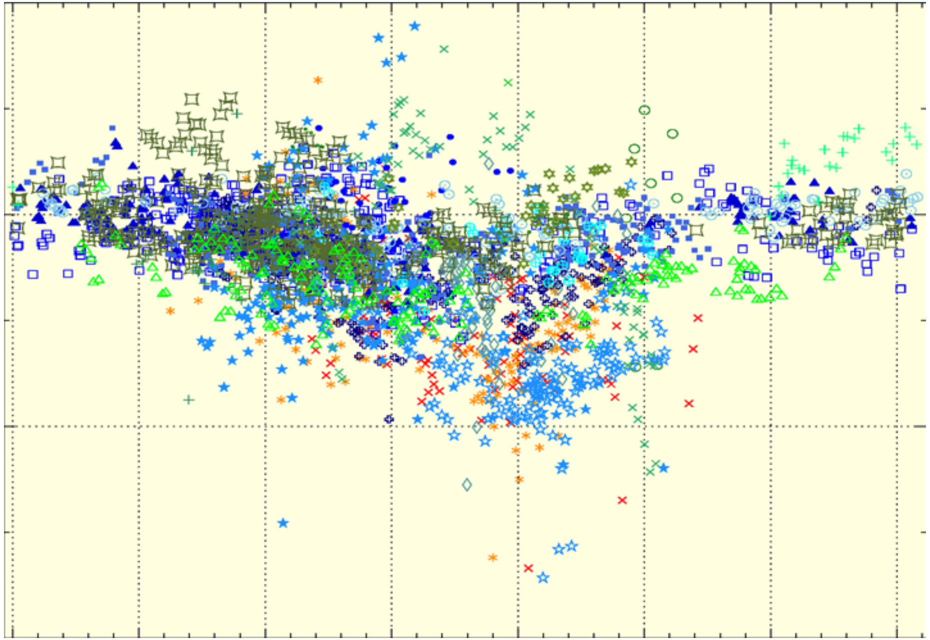
GPS-IIA no-model vs box-wing model



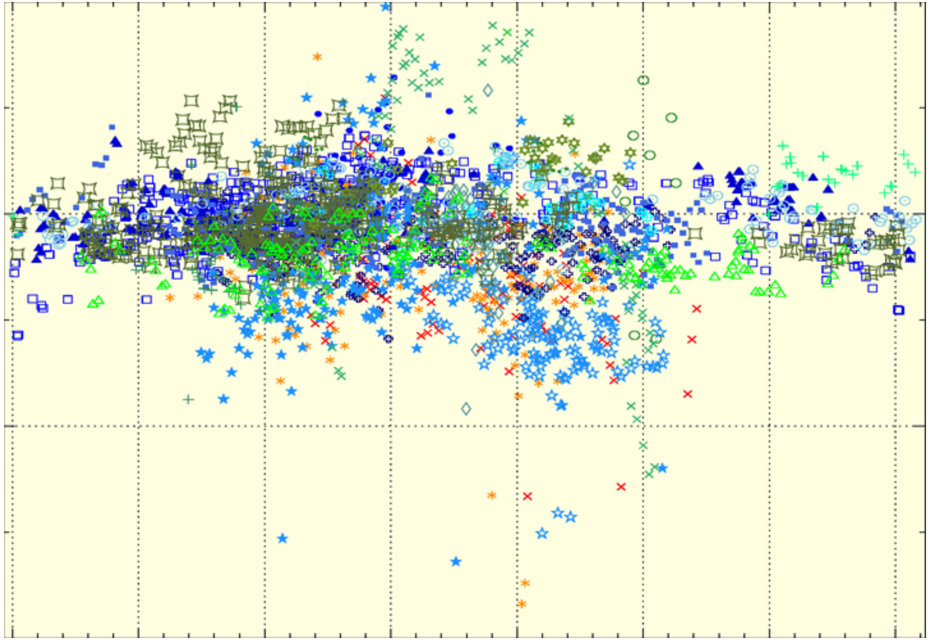
GPS SLR Orbit Validation

SLR residuals (2-way) GPS-IIA

without box-wing

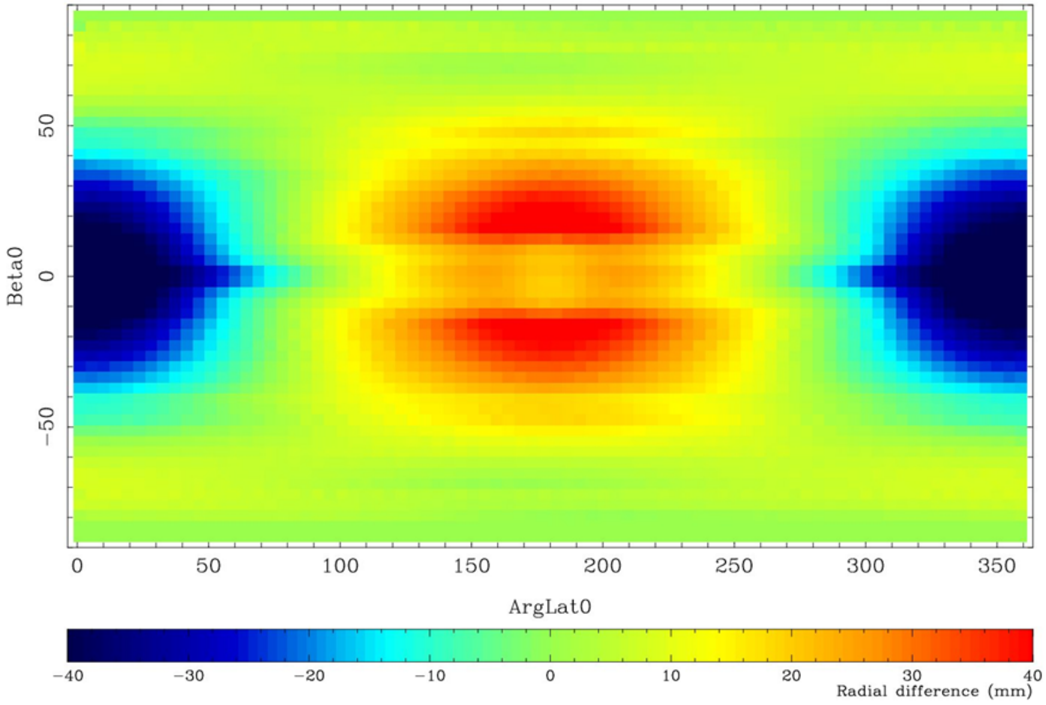


with box-wing



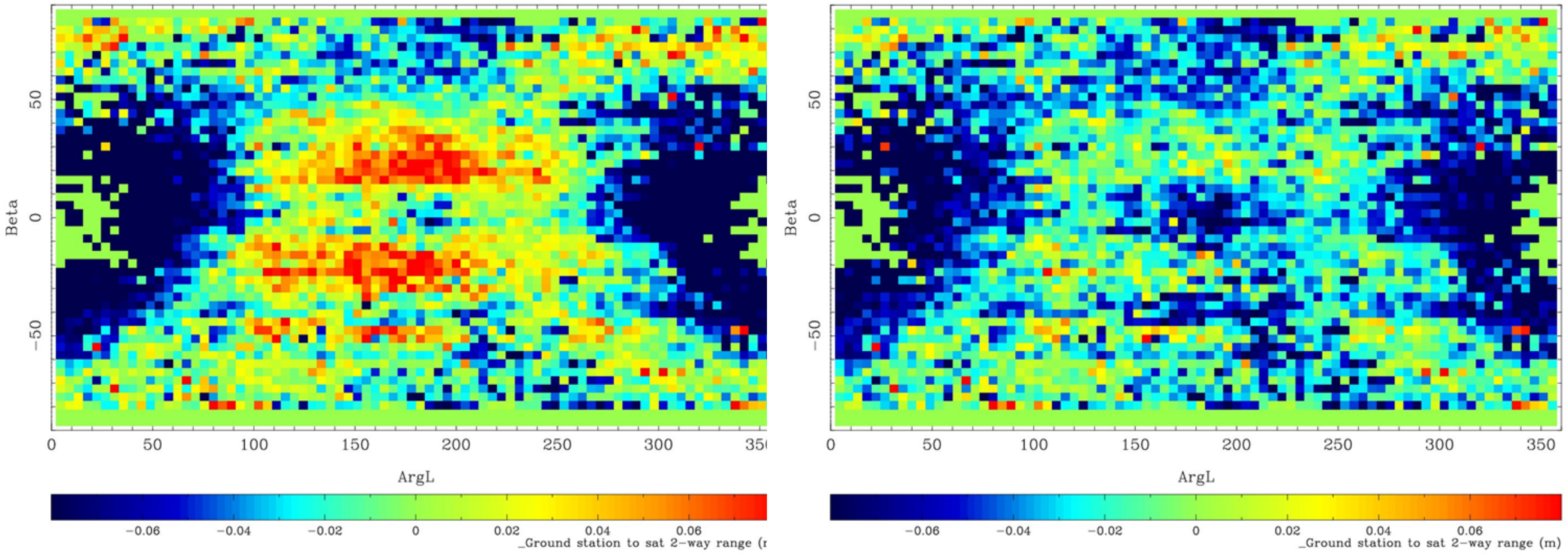
GLONASS Radial Orbit Differences

GLONASS no-model vs box-wing model



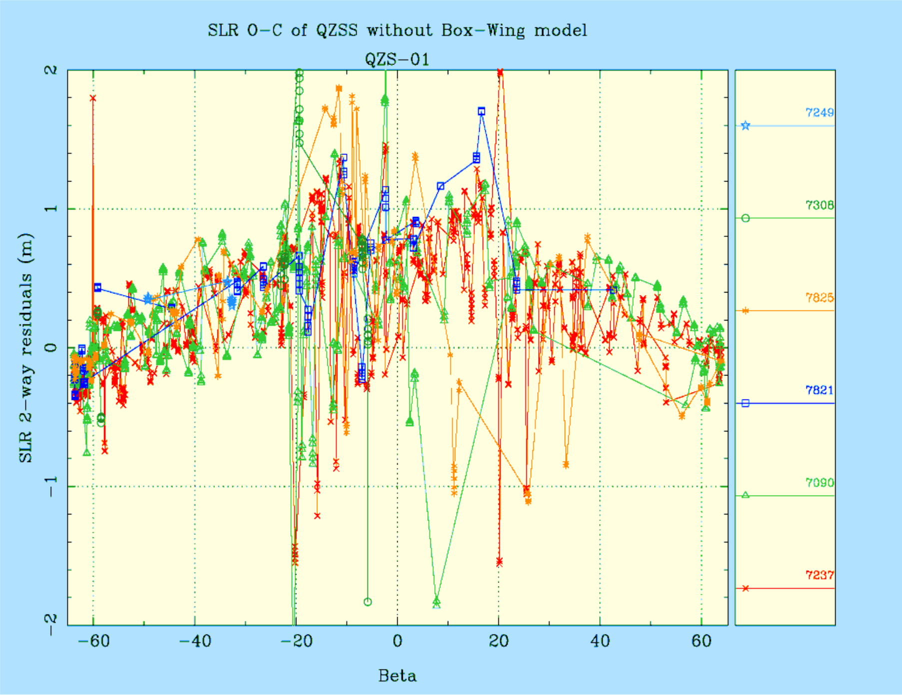
GLONASS SLR Orbit Validation

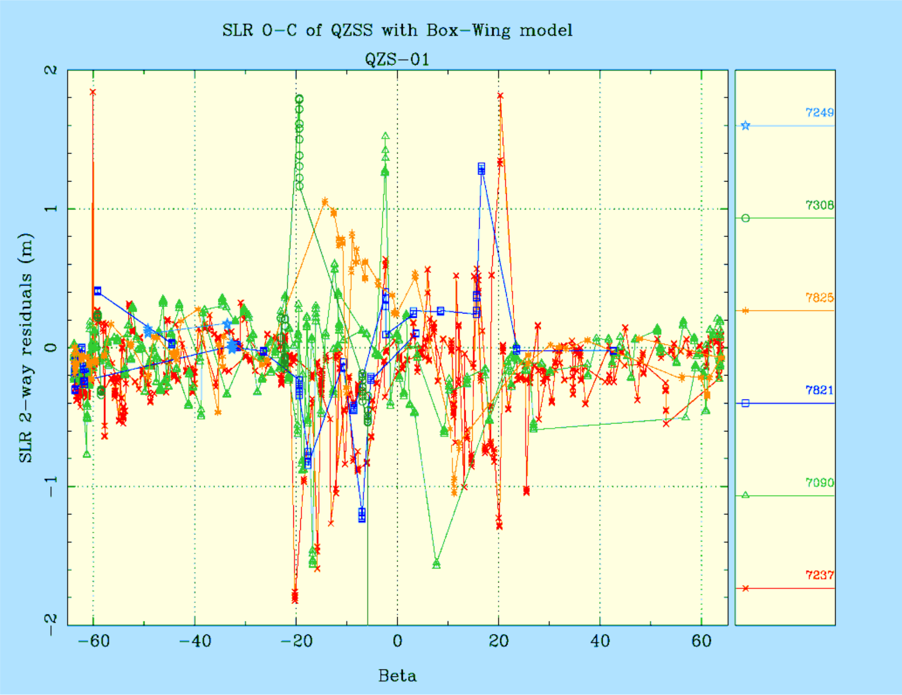
no-model vs box-wing model



QZSS SLR Orbit Validation

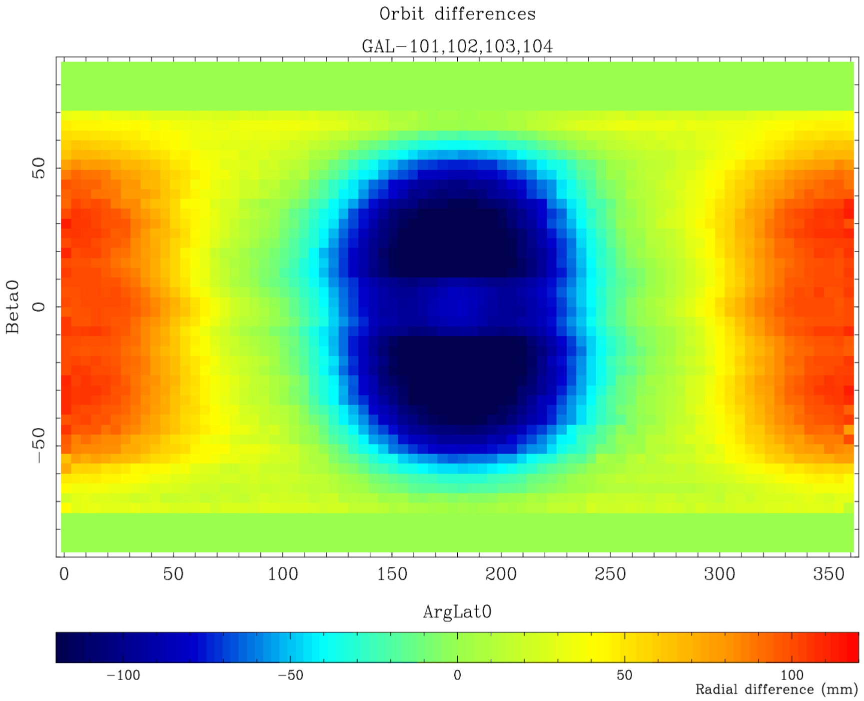
no-model vs box-wing model

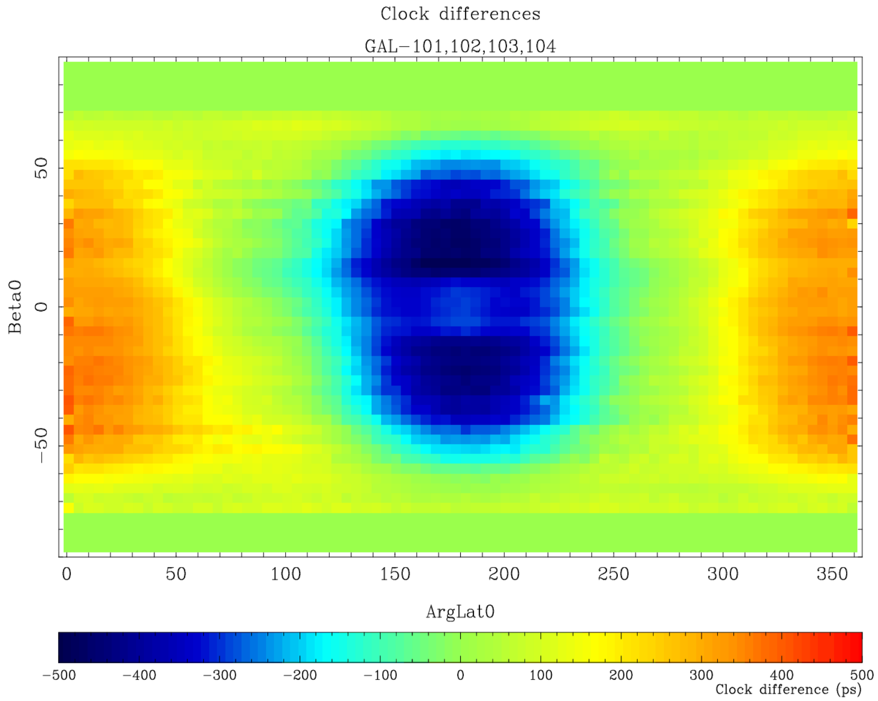




GALILEO Radial Orbit Differences

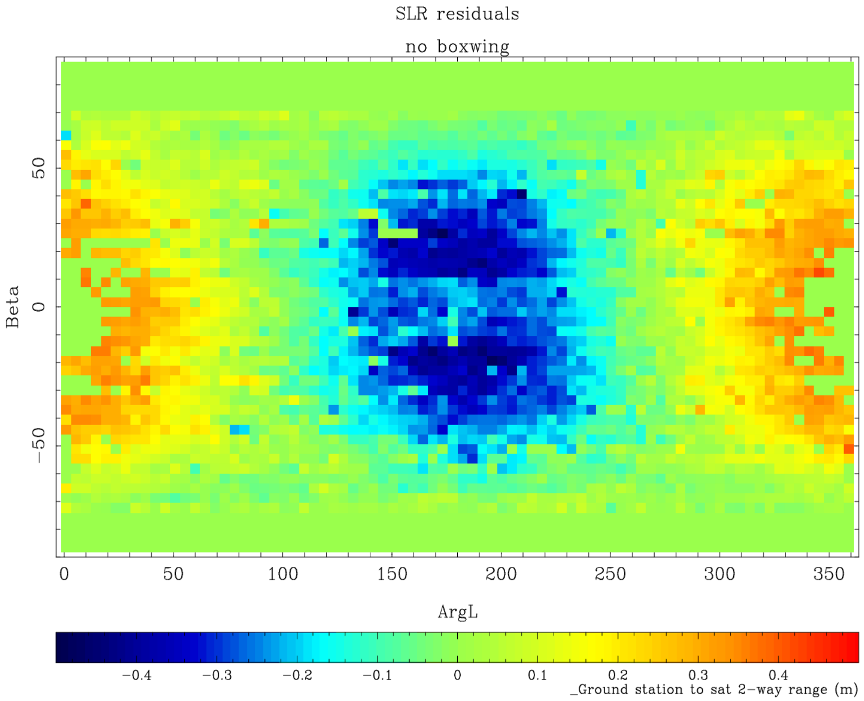
GALILEO no-model vs box-wing model

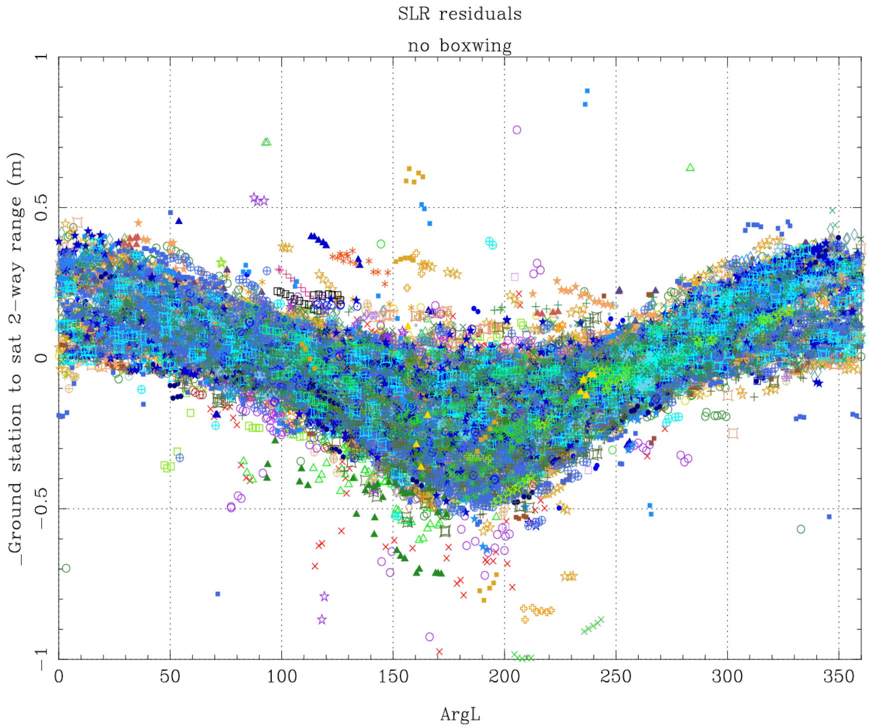




GALILEO SLR Residuals without Box-Wing model

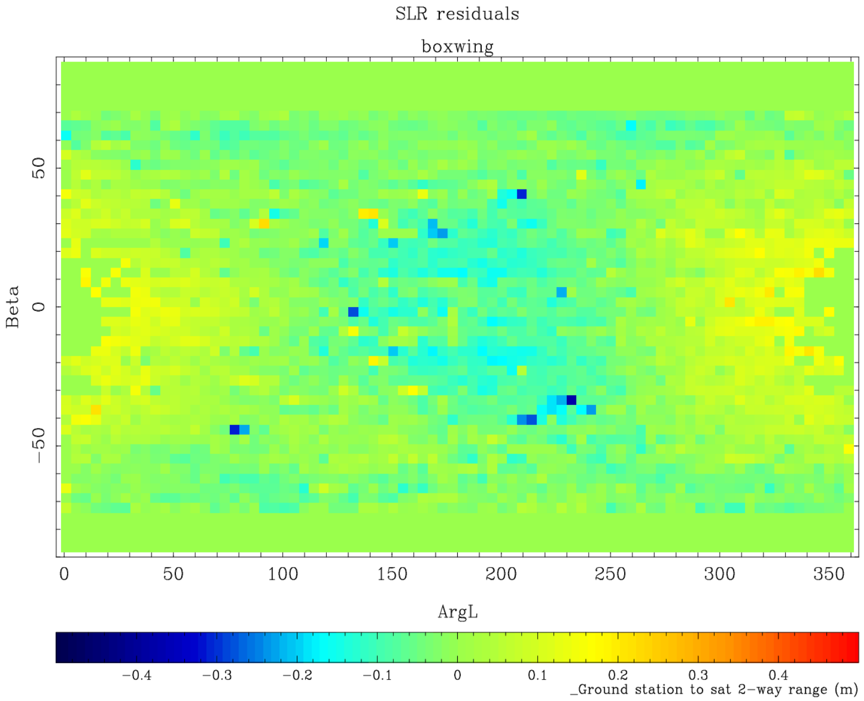
GALILEO no-model vs box-wing model

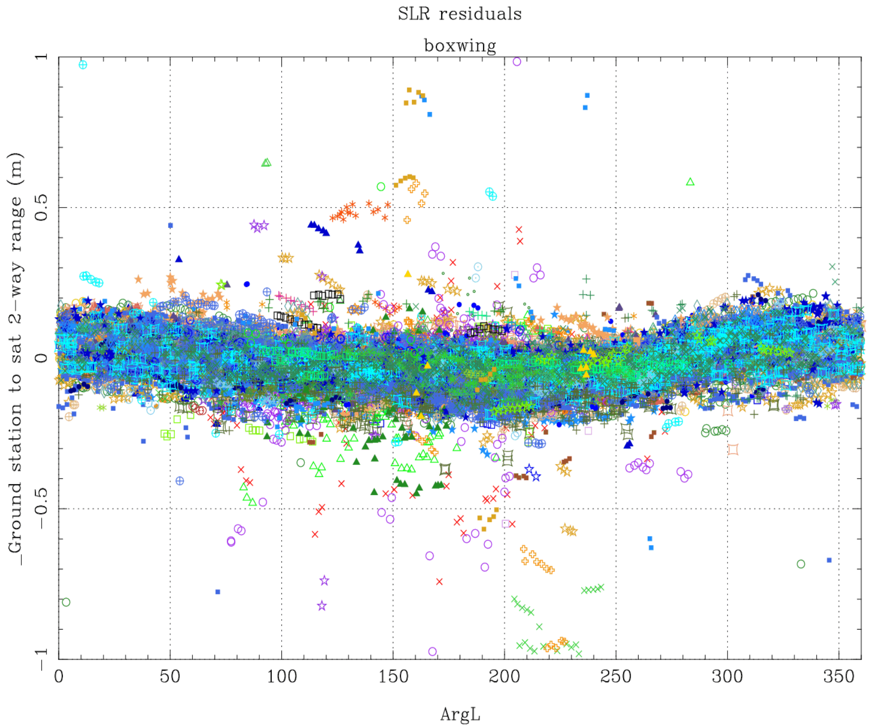




GALILEO SLR Residuals with Box-Wing model

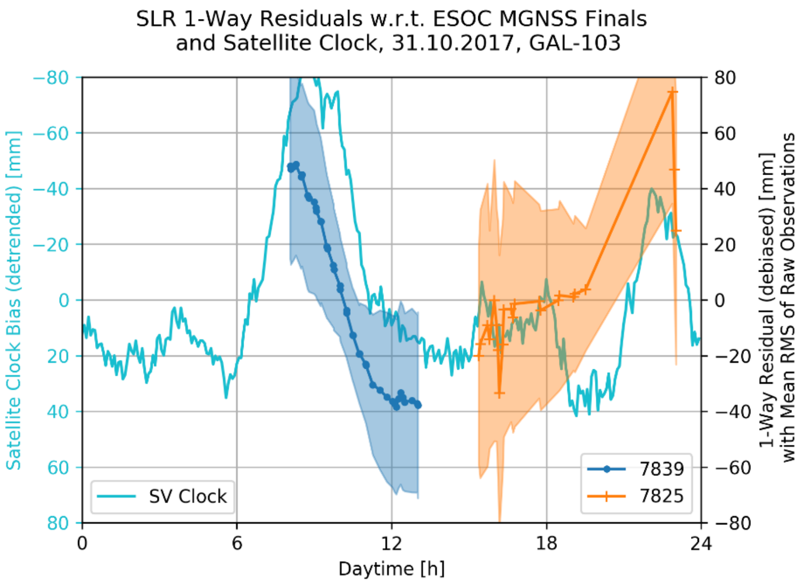
GALILEO no-model vs box-wing model

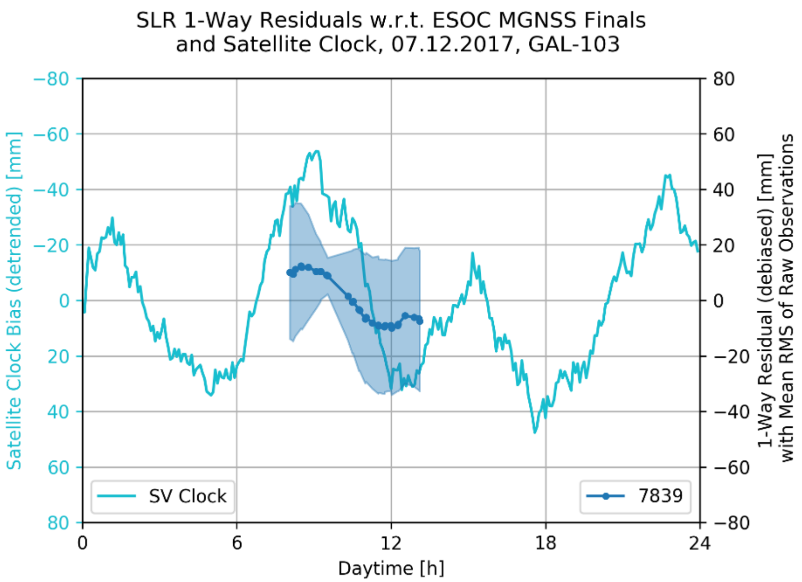




Example analysis

Comparison of Orbit Residuals and Clock Bias



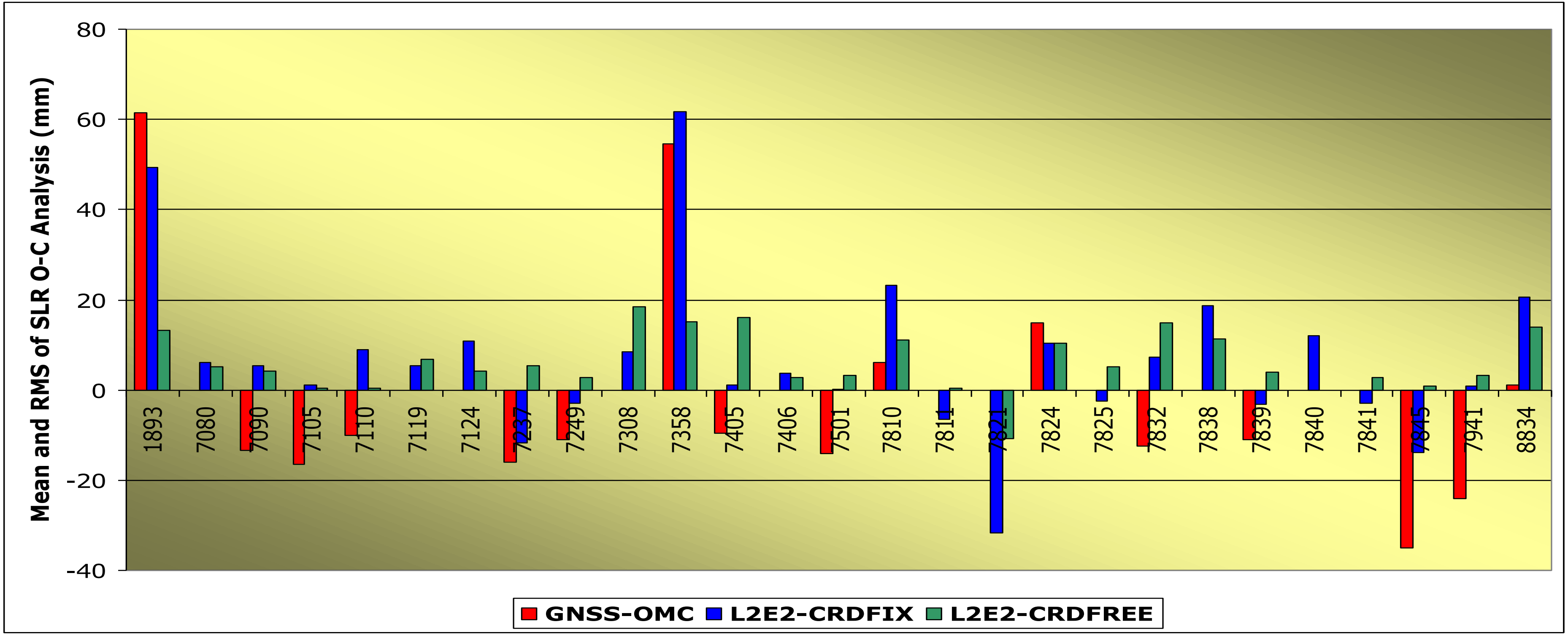


SLR residuals confirm orbit effects on clock estimate.

Significant differences in NP accuracy/systematics between stations.

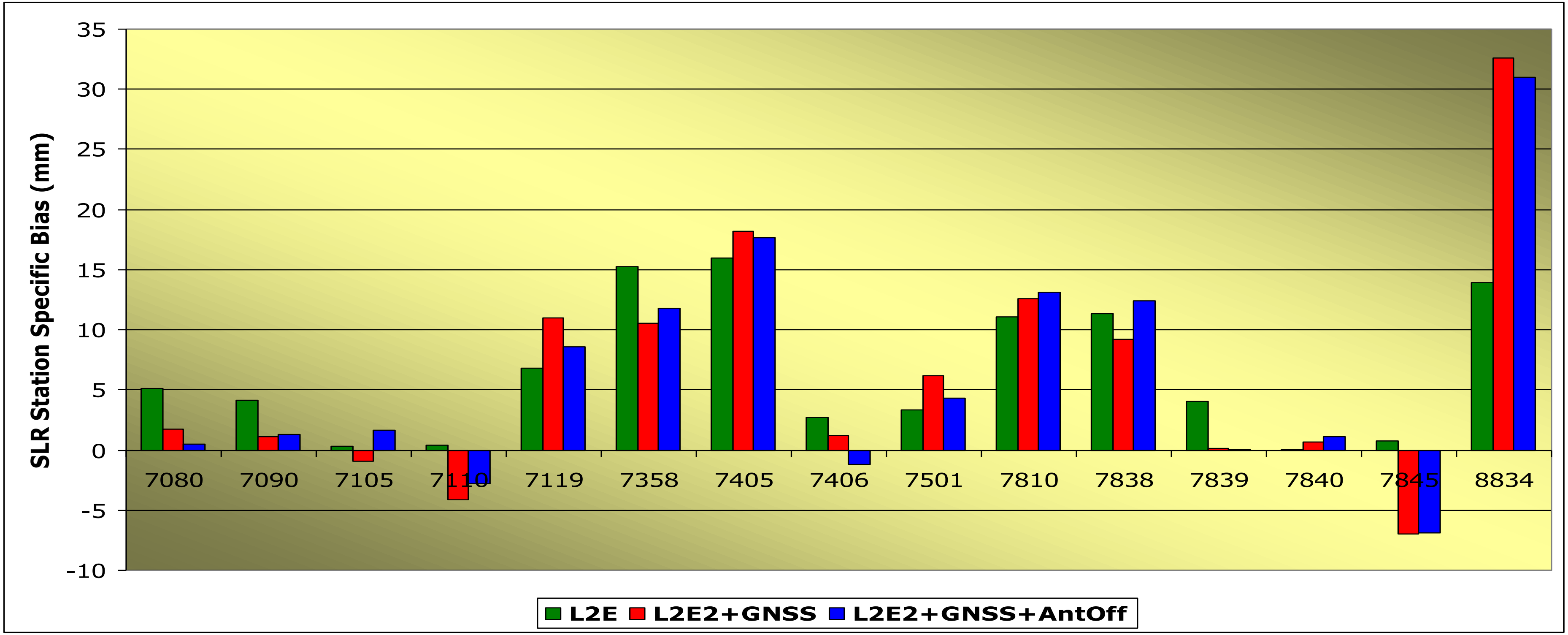
Combined ILRS + IGS Analysis + SLR observations of the GNSS targets

SLR Station Specific Mean of Residuals
GNSS OMC and SLR(L2E2) (from 2009) (2-way)



Good agreement for large biases (coordinate issues?)!
SLR(L2E2) biases mostly positive, GNSS OMC biases negative

SLR Station Specific Range Biases (2-way)
GNSS + SLR(GNSS) + SLR(L2E2) (from 2009)



Combination of GNSS and SLR works.
Biases in good agreement. Some significant GNSS influence visible

Discussion / Outlook

- Combination on the obervation Level (CooL) of SLR and GNSS is very strong!
  - Issue with 8834 (Wetzel) showed up very clear in the 2009 combined analysis
  - When it was later (2010 or even 2013?) detected this made us realize how strong this combo is!
- But in 2010 we gave up on this CooL combo because
  - No more GPS with SLR reflectors
  - SLR tracking of GLONASS more noisy
  - GLONASS orbits worse then GPS
- Now (2018) SLR+GNSS CooL becomes interesting again
  - Much more and better tracking of GNSS targets
  - Galileo orbits quality equal to that of GPS, and in some aspects even better
  - All Galileo satellites have SLR reflectors
  - GLONASS orbits meanwhile also significantly better then in 2010
- What kind of tracking of the GNSS makes most sense for CooL
  - Make LARGE GREAT again!?

GFZ AC Report

Rolf Koenig

Status Report

- Timely availability of daily pos+eop in 2017: 97.5 % (2016: 95.4 %)
- Timely availability of weekly pos+eop in 2017: 96.0 % (2016: 100 %)
- Weekly pos+eop v70 is running since June 2017
  - Gravity field GGM05S plus time variable parts: C(2,0), C(2,1), S(2,1) per arc as provided by ECP and secular C(3,0) to C(6,0)
  - SLRF2014 including Post Seismic Deformations (PSD)
- Daily pos+eop v170 is running since June 2017
  - As v70
- PP systematic biases
  - Solutions v220 from 1993 to 2017 covering 1305 SINEX files delivered

Status Report

- Status for re-analysis:
  - Secular pole: no problem
  - T2L2 time biases
    - expected to come with data handling file: some days for adopting and testing needed
  - CoM offsets
    - Expected to come with NSGF file. No problem
  - Inclusion of LARES
    - Not yet decided wether on observation level or on normal equation level
  - High frequency EOP
    - No tests done so far. Needs some programming and testing: few weeks time needed
- Other plans:
  - DTRF2014, JTRF2014 tests not started yet

Lunar Laser Ranging Analysis at the Institute of Applied Astronomy RAS

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ILRS Analysis Standing Committee Meeting
TU Wien, Vienna, 12 April 2018

LLR Analysis at IAA RAS: Past and Present

Milestones

- 1987: IAA RAS founded in Leningrad, USSR (now St. Petersburg, Russia)
- 1998: IAA RAS united with the Institute of Theoretical Astronomy (ITA RAS). Ephemerides of Planets and the Moon (EPM) development continues at IAA
- 2013: release of EPM2011 with lunar physical libration
- 2016: release of EPM2015 with JPL DE430 lunar model (Folkner et al, 2014)
- 2017: release of EPM2017 (most recent version)

Present Activities

- Building high-precision numerical ephemeris of planets and the Moon
- Improving the model of orbital and rotational motion of the Moon
- Improving models used in reductions of LLR observations
- Determining the accuracy of the lunar ephemeris
- Building lunar reference frame for navigation and selenodesy – by 2020
- Developing ephemeris support and normal point computation for the Russian LLR Station (AOLC, near Zmeinogorsk, Altai Krai) – expected to start by 2020

Observations

McDonald	1969-1985	3604 NPs (MINI). Source: POLAC (polac.obspm.fr/llrdatae.html)
Crimea	1982-1984	177 historical NPs (Mulholland's format). Source: CrAO **(recently found).** Available at iaaras.ru/en/dept/ephemeris/observations/
MLRS1	1983-1988	587 NPs (MINI). Source: POLAC
MLRS2	1988-2015	3670 NPs (MINI). Source: POLAC. **No data found after 2015 (discontinued?)**
Haleakala	1984-1990	770 NPs (MINI). Source: POLAC. Discontinued.
OCA	1984-2005	Ruby laser: 1188 NPs, YAG laser: 8324 NPs (MINI). Source: POLAC.
OCA	2009-2017	MeO laser: 1836 NPs (MINI). Source: ASTROGÉO (geoazur.fr/astrogeo/?href=observations/donnees/luneRG/brutes)
OCA	2015-2017	IR laser: 2840 NPs (MINI). Source: ASTROGÉO. **Very high quality.**
APO	2006-2016	2648 NPs (MINI). Source: Tom Murphy's webpage (tmurphy.physics.ucsd.edu/apollo/norm_pts.html). **Expecting 2017 data soon.**
Matera	2003-2015	118 NPs (MINI). Source: POLAC. **No data found for 2016.**
Matera	2017	33 NPs (CRD). Source: CDDIS (ftp://cddis.gsfc.nasa.gov/pub/slr/data/npt_crd).

Model of the Orbital Motion of the Moon

- E-I-H relativistic equations for point masses (Sun, Moon, planets, 5 asteroids)
- Acceleration from solar oblateness
- Earth gravity field: EGM2008 up to degree 6 with conventional IERS corrections (Moon, Sun, Venus, Mars, Jupiter)
- Moon gravity field: GRAIL solution GL660b up to degree 6 (Earth, Sun, Venus, Mars, Jupiter)
- Acceleration from Earth solid and ocean tides
  - IERS2010 model
  - DE430 model (Williams, Boggs, 2016): simpler, but with two determined parameters
- Acceleration from solar pressure (Vokrouhlický, 1997)
- **Should try figure-figure acceleration** (Hofmann et al, 2018)

Model of the Lunar Physical Libration

- ➢ Torque from point masses in lunar gravitational field: Earth, Sun, Venus, Mercury, Mars, Jupiter
- ➢ Figure-figure torque between Earth's J2 and Moon **(should try higher harmonics?)**
- ➢ Dynamic tensor of inertia: delayed dissipation from rotation and Earth tides
- ➢ C20, C22, C21, S21, S22 respond accordingly
- ➢ Inertia and torque from inner rotating liquid core (Williams et al, 2001)
- ➢ Torque from friction on the core-mantle boundary (ibid)

Compromises made for now

- ➢ Mean C21, S21, S22 are fixed to zero (model is built on principal axes) despite GRAIL's nonzero values (**S21 is strongly nonzero even from LLR itself**)
- ➢ C32, C33, S32 are fit to observations despite GRAIL's values.
- ➢ Additional kinematic longitude libration terms (few mas)

Work in progress on nonzero S21.

Reductions of Observations

- Relativistic delay (Kopeikin, 1990) from Sun, Earth, Moon, Saturn, Jupiter
- Tropospheric delay (Mendes, Pavlis, 2004). **Tried Leonid Petrov's numerical model based on global weather model, no positive change for now.**
- UTC ➛ TDB transformation with numerically integrated TT−TDB
- ITRF ➛ ICRF transformation
  - IAU2000/2006 model
  - IERS C04 EOP series **(JPL KEOF used for old McDonald observations)**
  - IERS-recommended libration and ocean variations
- Tidal displacement due to solid Earth (Matthews et al, 1997), ocean (FES2012) and pole tides
- Relativistic transformation of coordinates to BCRS
- Solid Moon tides from Earth and Sun (H2, L2)
- Determined biases (4 for APO, 7 for OCA, 7 for Haleakala, 5 for McDonald)

Statistics of Residuals

Station	Timespan	NPs	Used	Rejected	One-way wrms, cm
McDonald	1970-1985	3604	3553	51	20.0
Crimea	1982-1984	177	177	0	58.9
MLRS1	1983-1988	631	588	43	11.2
MLRS2	1988-2015	3670	3216	454	3.4
Haleakala	1984-1990	770	747	23	5.5
OCA (Ruby)	1984-1986	1188	1109	79	17.1
OCA (YAG)	1987-2005	8324	8207	117	2.0
OCA (MeO)	2009-2017	1836	1814	22	1.41
OCA (IR)	2015-2017	2840	2797	43	1.25
APO	2006-2016	2648	2610	38	1.36
Matera	2003-2017	151	143	8	3.0

Present Results

- ➢ Lunar ephemeris (meter ➛ decimeter accuracy for years in the future)
- ➢ Location of LLR stations (few millimeters accuracy for OCA and APO) and drift for OCA and McDonald/MLRS1/MLRS2 (accuracy about 1 mm/yr)
- ➢ Lunar reference frame based on five retroreflector points (meter ➛ decimeter)
- ➢ Determination of parameters of the lunar inner structure
- ➢ Determination of celestial pole (wrt ecliptic) with 3σ ≈ 0.2 mas. ICRF X rotation trend is detected: −0.037 ± 0.013 mas/yr. Secular aberration?
- ➢ Proof-of-concept determination of ~~daily~~ nightly UT0 (σ ≈ 0.2 ms), VOL (σ ≈ 5 mas), two out of three lunar orientation angles (σ ≈ 4 mas)
- ➢ With NPs accuracy in millimeters, the main suspects of O−C nightly scatter are: tropospheric delay model, temperature deformations, sub-diurnal EOP
- ➢ Crimea observations were valid (including three Lunokhod 1 ranges in 1974)

Some references

Pavlov et al. 2016

Pavlov, Yagudina, 2017 (in Russian)

Tryapitsyn et al: historical abstract on CrAO LLR submitted to ILRS Workshop 2018

ILRS AC Hot Topics and Future Work

ILRS AC hot topics

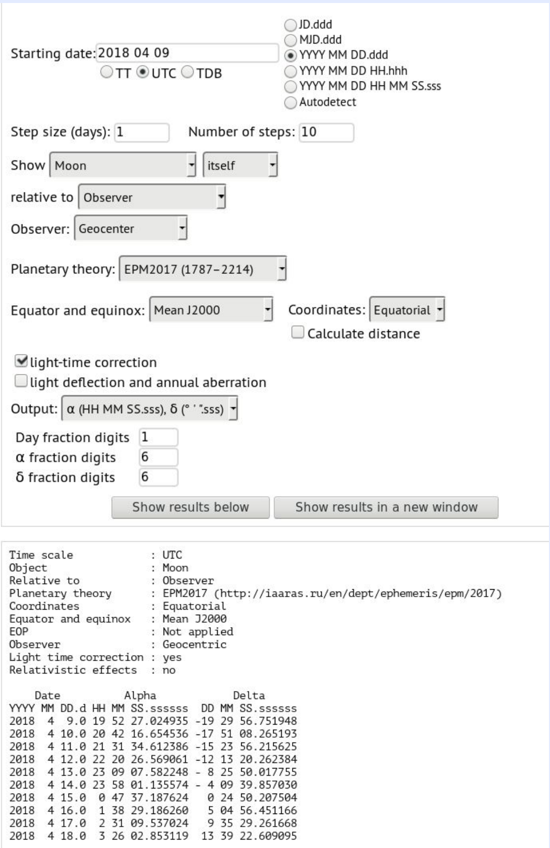
- **Time transfer by laser link** seemingly not possible with LLR?
- **ITRF2014 reanalysis, secular polar motion:** hardly possible because stations' locations and their drift (for OCA and McDonald) are determined from LLR itself. Other stations' drift is taken from GNSS solutions.
- **High frequency EOP** models certainly can be checked with LLR. IAA RAS is ready to join the IERS pilot project and test various models proposed. Benefit of LLR in testing HF EOP: large timespan, very stable orbit.

Other future work

- Improve ties between LLR frame, lunar gravitational field frame (GRAIL), and lunar topology (LRO)
- Gradually improve lunar model; determine the cause of nonzero S21
- Deal with tropospheric delay? Ask stations to combine LLR with SLR/GNSS?
- General relativity tests

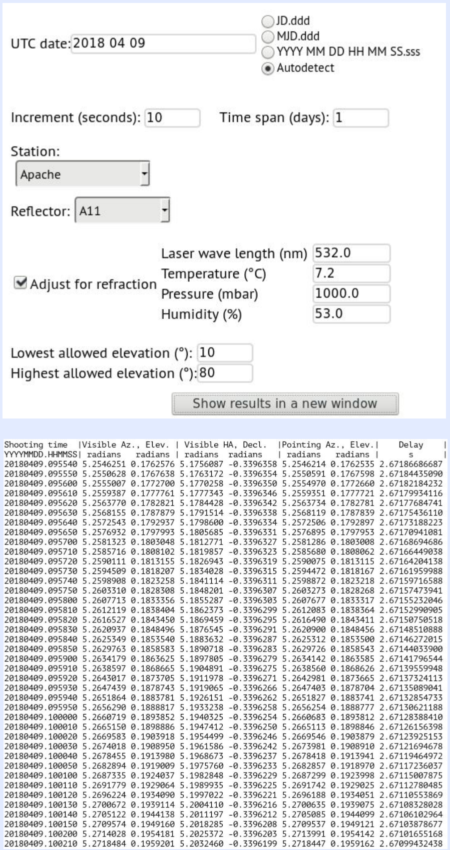
Our Web Applications

Ephemeris calculation



iaaras.ru/en/dept/ephemeris/online

LLR pointing



iaaras.ru/en/dept/ephemeris/llr-pointing

LLR O−C calculation

iaaras.ru/en/dept/ephemeris/llr-oc

Happy Cosmonautics Day!

IERS Directing Board, 9 April 2018

- ISO standard on ITRS are written in a complete document submitted to ISO WG for comment and approval. Available on request
- IERS Technical note on ITRF2014 completed and distributed.
- IERS Technical note on the comparisons of ITRF2014, DTRF2014 and JTRF2014 under preparation
- Still discussion on the scale discrepancy between VLBI and SLR apparently seen only in ITRF2014. Further analyses made at JPL confirm the existence of the discrepancy
- Next ITRF roadmap
  - Based on the results coming from the questionnaire prepared by IGN, the next ITRF will be ITRF2020
  - Call for participation by the end of 2018
  - Specific solution for testing purposes may be requested to the Technique Services, e.g. solution with SLR range biases estimated

IERS Directing Board, 9 April 2018

- IERS conventions
  - Chapter 6 and 7 updated on February to be consistent with the new conventional "mean pole"
  - Major revision foreseen in 2021-2022. Call for participation to experts helping in the next revision.
  - Discussion on convention versioning for IERS2010

- EOP products
  - Importance of IVS UT1 intensive session. High residuals in the LAGEOS orbits disappeared using the EOPC04 14 that contains the intensive UT1. Starting from January EOPC04 includes the intensive from IAA and BKG (more ACs will be considered). Very soon the full EOPC04 14 series will have the updated UT1.
  - The rule to have final values after 30 days is too strict and not allow to correct past errors in the EOPC04 series. Proposal to change this rule in order to have updated series whenever necessary with proper management of the versioning

ILRS Prediction and Data Formats Update

R. Ricklefs
University of Texas / CSR
For the ILRS Format Change Study Group
ILRS Data Formats and Procedures SC
ILRS CB

Need for Changes

- New missions with new requirements
- Expanded configuration information
- Correct oversights in original formats
- Accommodate debris and other non-SLR/LLR tracking to avoid multiple format branches
- Update manuals

Fortunately, these formats were designed to be flexible and expandable

Consolidated Prediction Format (CPF)

- ELT mission:
  - Transponder Clock Reference Time added (in H4 record)
  - Two-digit ephemeris Sequence number rather than one-digit (in filename and H1 record) for more than 10 updates/day
- Break Target Type (H2) into 2 fields, target class and target location
- Make headers (H1-Hn) free format like the rest of the record types.
- Manual was rewritten to free it from TIV heritage

Consolidated Range Data Format (CRD) 1

- Header records (“H”) now free format like the other record types
- Target type was split into 2 fields (same as CPF) (“H3” record)
- Added a prediction header (“H5”) to track down prediction issues (includes format, source, date, and sequence number)
- Added more configuration information
  - C5: Software – New
  - C6: Meteorological Instrumentation – New
  - C0: Updated to allow C5 and C6

Consolidated Range Data Format (CRD) 2

- Added transmit amplitude (already had receive amplitude) (“10” record)
- Return rate (SLR) and signal:noise (LLR) split into 2 separate fields (“11” record)
- Added sky temperature and renamed precipitation type to weather conditions, allowing use of met sensor SYSOP/WMO codes (“21” record)
- Manual includes an appendix with acceptable values for all fields

CRD – Changes mainly to support non-SLR/LLR tracking

- Add network name to “H2” record and to non-SLR/LLR data filename
- On the filename, the network name will prevent debris data from being mistaken for SLR/LLR data at the OCs and DCs (these files should not be submitted to the OCs, but in case a few get through...)
- Make station and target wording in the manual more general (“H2” and “H3” records)
- Add az, el, and range rates (“12” and “30” records)

Changes discussed but not included

- Seconds of day – leaving maximum value at 86400: problem dictating SOD > 86400 no longer exists
- Lunar data: Detailed APOLLO processing info to remain in comment lines (“00”)

Implementation Notes 1

- OCs, DCs, and ACs will need to be able to accept data in format versions 1 and 2 permanently.
- V1 and v2 data can be mixed in the same file.
- Revised CRD and CPF sample code will be made available on the ILRS web site in the next month.
- A set of CRD v1 files will be converted to v2 and either mailed or put onto the ILRS web site for analysts' testing of their software. The pad id will be somewhere between 9990 and 9999, depending on the original pad ID.
  - How many test passes and sites do you all need to ensure your software is working?

2 sites, passes for one day, all targets

Implementation Notes 2

- The ASC will be vetting stations' conversion to v2
  - Parallel v1 and v2 versions of the CRD files will come from the stations.
  - How many passes from what satellites are needed to vet a station's conversion?

To be on the safe side, we would ask for ONE WEEK of passes from ALL possible targets.

CRD Implementation Working Schedule 1

- April 2018: Post Manuals on ILRS web site
- April 2018: Complete and distribute sample code (beta version)
- May 1, 2018: **Last date for accepting additional suggested changes**
- May 15, 2018: Test v2 CRD files available via private correspondence
- July 1, 2018: Test v2 CRD files available on ILRS web site
- July 2018: OCs, DCs able to handle CPFs

CRD Implementation Working Schedule 2

- Sept 1, 2018: some analysts able to process v2 CRD files
- Oct 1, 2018: One or two stations able to produce v2 CRDs. ASC vetting of station implementation begins.
- Jan 1, 2019: All analysts are able to handle and process v2 CRDs.
- June 1, 2020: almost all stations able to produce v2 CRDs

Schedule will change as needed

The JCET AC/CC Report to the ILRS ASC

E. C. Pavlis and M. Kuzmicz-Cieslak

Vienna, Austria,

April 12, 2018

Outline

- Operational Products Status
- Station Systematic Error Monitoring Project
- LAGEOS/LARES Data distribution in elevation and pass duration
- Journal of Geodesy ILRS Special Issue Status Report

Operational Products Status

- Daily and Weekly series delivered routinely and consistently by six of the eight ACs
- We have not received contributions from GRGS for over a year
  - Latest news from Florent indicate that a restart is imminent (AGAIN)
- With the routinely contributing ACs down to six-seven, it is important that all ACs make an effort to deliver their contributions regularly, to maintain the quality of our products!
- ACs that do not participate in test PPs and demonstrate their ability to deliver quality products, delay us from wrapping up PPs and moving to the next phase or PP. We need to establish a process to move such cases to the ACC group and move on, until they can recover and come back.

Currently Quarantined Sites

Quarantine Stations

Station	Code	Site	DC	SOD	DOMES	First Data	Last Data	
1888	SVEL	Svetloe, Russia	EDC	18889801	12350S002	2012-02-03	2018-04-09	2 day(s)
7358	GMSL	Tanegashima, Japan	NASA	73588901	21749S001	2004-09-01	2018-04-04	7 day(s)
7395	GEOL	Geochang, Republic of Korea	EDC	73956501	23910S001	0000-00-00	0000-00-00	None day(s)
7503	HRTL	Hartebeesthoek, South Africa	EDC	75036401	30301S010	2017-03-24	2018-04-08	3 day(s)
7816	UROL	Stuttgart, Germany	EDC	78165201	10916S001	0000-00-00	0000-00-00	None day(s)
7824	SFEL	San Fernando, Spain	EDC	78244502	13402S007	1999-04-08	2017-07-01	284 day(s)
8834	WETL	Wettzell, Germany (WLRS)	EDC	88341001	14201S018	1991-01-08	2018-04-10	1 day(s)

- Four sites (**above in RED**) are actively undergoing validation of their data;
- Two “engineering” sites (**above in PURPLE**) that have yet to submit any data (no need for official validation, but may request it if they want to see the quality of their data assessed);
- San Fernando is reaching ”end of operations” phase, so no need to proceed.

Station Systematic Error Monitoring-SSEM Project -1

- Six ACs (so far) have contributed series following the new "labeling" of the biases according to the used wavelength for the re-analysis period 1993 to present:
  - ASI, BKG, ESA, GFZ, JCET and NSGF
  - These results are now available online:
    - **http://geodesy.jcet.umbc.edu/ILRS_AWG_MONITORING/**
  - The combination results will be added online when available
- We need to receive ASAP the DGFI contribution so that the final combination can be formed;
- A commitment from all the ACs that they will support a weekly product, now that the PP is completed, so we can launch the operational phase;

Station Systematic Error Monitoring-SSEM Project -1

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ACs Supporting the SSEM Project

- AC-contributed series that we received so far:

Analysis Center	Status of Submission
ASI	Submitted
BKG	Submitted
DGFI	???
ESA	Submitted
GFZ	Submitted
JCET	Submitted
NSGF	Submitted

Site Selection for the SSEM Project

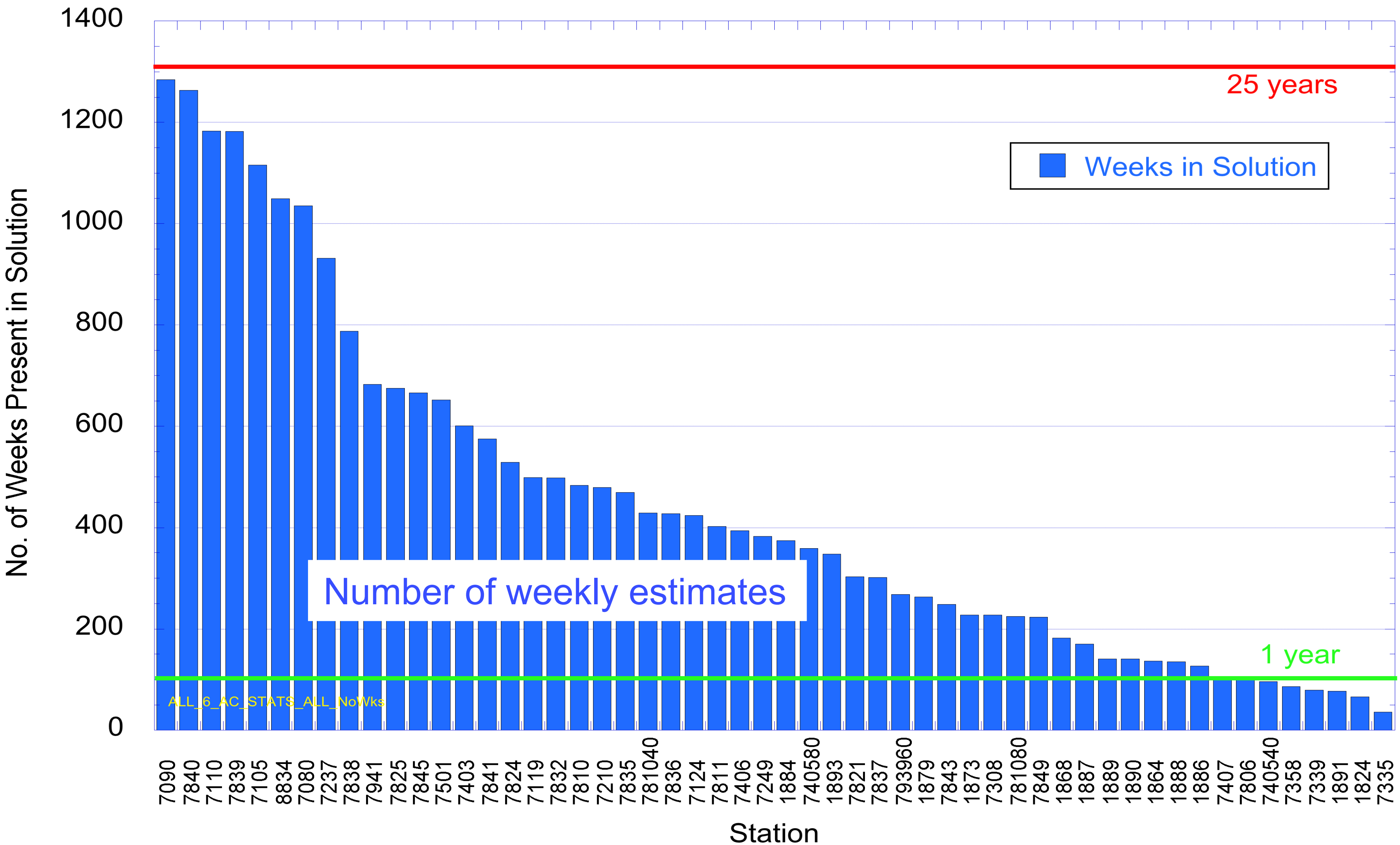
1824 Golosiiv
~~1831 Lviv~~
~~1863 Maidanak 2~~
1864 Maidanak 1 2003.0->
1868 Komsomolsk-na-Amure 2008.0 ->
1873 Simeiz 2001.0 ->
1879 Altay
1884 Riga
~~1885 Riga~~
1886 Arkhyz
1887 Baikonur
1888 Svetloe
1889 Zelenchukskya
1890 Badary
1891 Irkutsk
1893 Katzively
~~1953 Santiago~~
7080 McDonald Obs.
7090 Yarragadee
~~7097 Easter I~~
7105 Greenbelt
7110 Monument Peak
7119 Haleakala
7122 Mazatlan

7124 Easter I
7124 Tahiti
~~7125 Greenbelt~~
~~7130 Greenbelt~~
7210 Haleakala
~~7231 Wuhan~~
7236 Wuhan
7237 Changchun
7249 Beijing
~~7295 Richmond~~
7308 Koganei
~~7328 Koganei~~
7335 Kashima 99/04-00/05
~~7337 Miura~~
7339 Tateyama
~~7355 Urumqi~~
~~7356 Lhasa~~
~~7357 Beijing-A~~
7358 Tanegashima
~~7359 Daedeok~~
~~7394 Sejong~~
7403 Arequipa
~~7404 Santiago~~
7405 Conc@423
7405 Conc@847

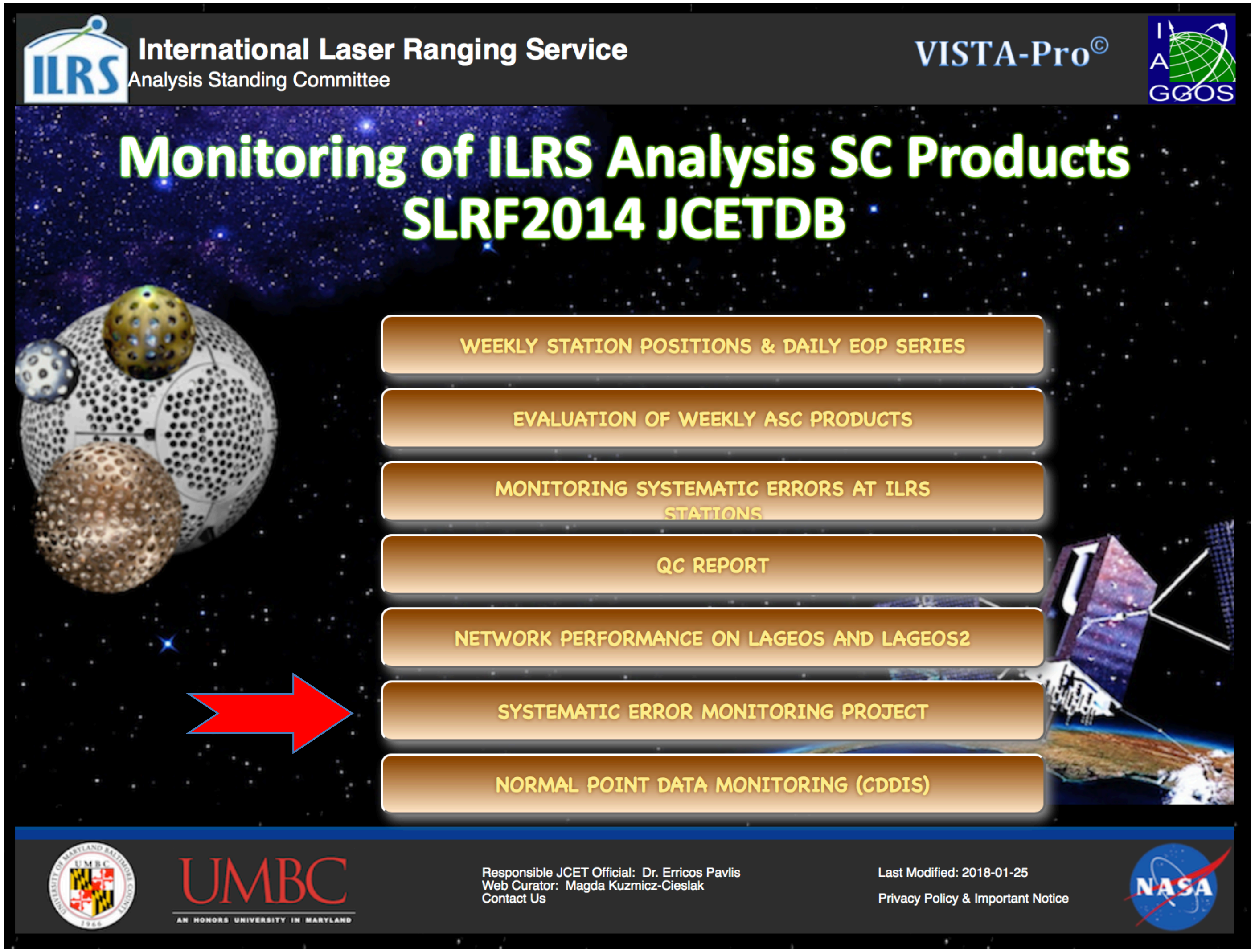
7406 San Juan → 2013.0
7407 Brasilia
~~7410 Algonqui~~
~~7411 La Grand~~
7501 Hartebeesthoek
~~7502 Sutherla~~
~~7525 Xrisokel~~
~~7530 Bar Giyy~~
~~7545 Punta Sa~~
~~7548 Cagliari~~
~~7597 Wettzell~~
7806 Metsahovi 99/09->
7810 Zimm@423
7810 Zimm@532
7810 Zimm@846
7811 Borowiec
7819 Kunming
~~7820 Kunming~~
7821 Shanghai
~~7822 Tahiti~~
~~7823 San Fernando~~
7824 San Fernando
7825 Mt Stromlo
~~7830 Chania~~
~~7831 Helwan~~

7832 Riyadh
7835 Grasse
7836 Potsdam
7837 Shanghai
7838 Simosato
7839 Graz
7840 Herstmonceux
7841 Potsdam
7843 Orroral
7845 Grasse
~~7848 Ajaccio~~
7849 Mt Stromlo
~~7850 Mcdonald~~
~~7882 Cabo San~~
~~7883 Ensenada~~
~~7884 Albuquer~~
~~7918 Greenbelt~~
7939 Matera
7941 Matera
~~8833 Kootwijk~~
8834 Wettzell

Site Participation in the SSEM Project



JCET Portal UPDATE



http://geodesy.jcet.umbc.edu/ILRS_AWG_MONITORING/

Station Systematic Error Monitoring

Station Systematic Errors Estimated from LAGEOS and LAGEOS-2 SLR DATA

Reanalysis Project Results since 1993

INDIVIDUAL ESTIMATE L1	INDIVIDUAL ESTIMATE L2
☐ **ASI v220**	☐ **ASI v220**
☐ **BKG v220**	☐ **BKG v220**
☐ **DGFI v220**	☐ **DGFI v220**
☐ **ESA v220**	☐ **ESA v220**
☐ **GFZ v220**	☐ **GFZ v220**
☐ **JCET v220**	☐ **JCET v220**
☐ **NSGF v220**	☐ **NSGF v220**
☐ **ILRSA v220**	☐ **ILRSA v220**
☐ **ILRSB v220**	☐ **ILRSB v220**

Start (MM-DD-YYYY):

End Date (MM-DD-YYYY)

Station: Station

Plot Size: Minimum Maximum

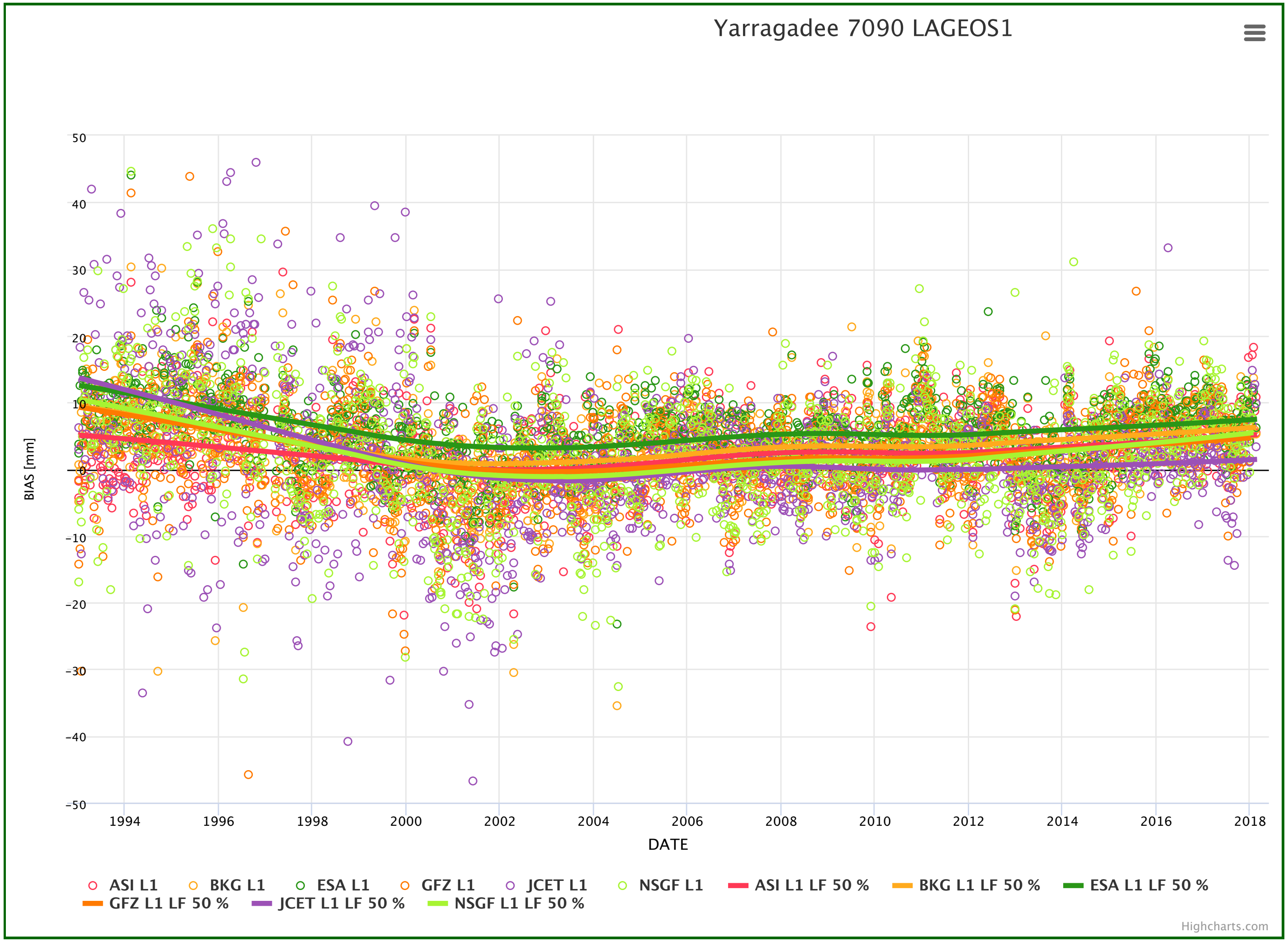
Y axis

LOESS regression: 15 %

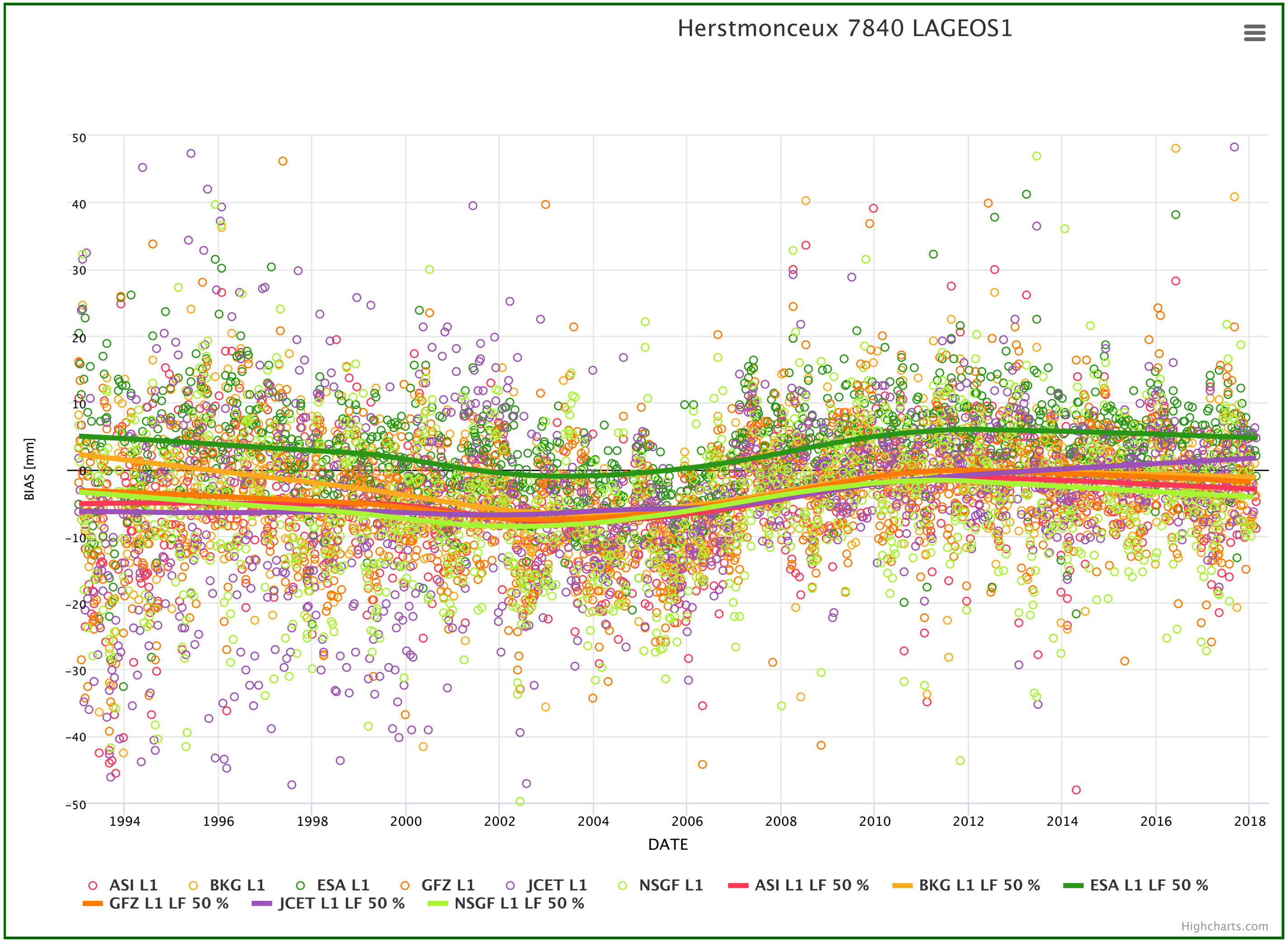
Submit

Reset form

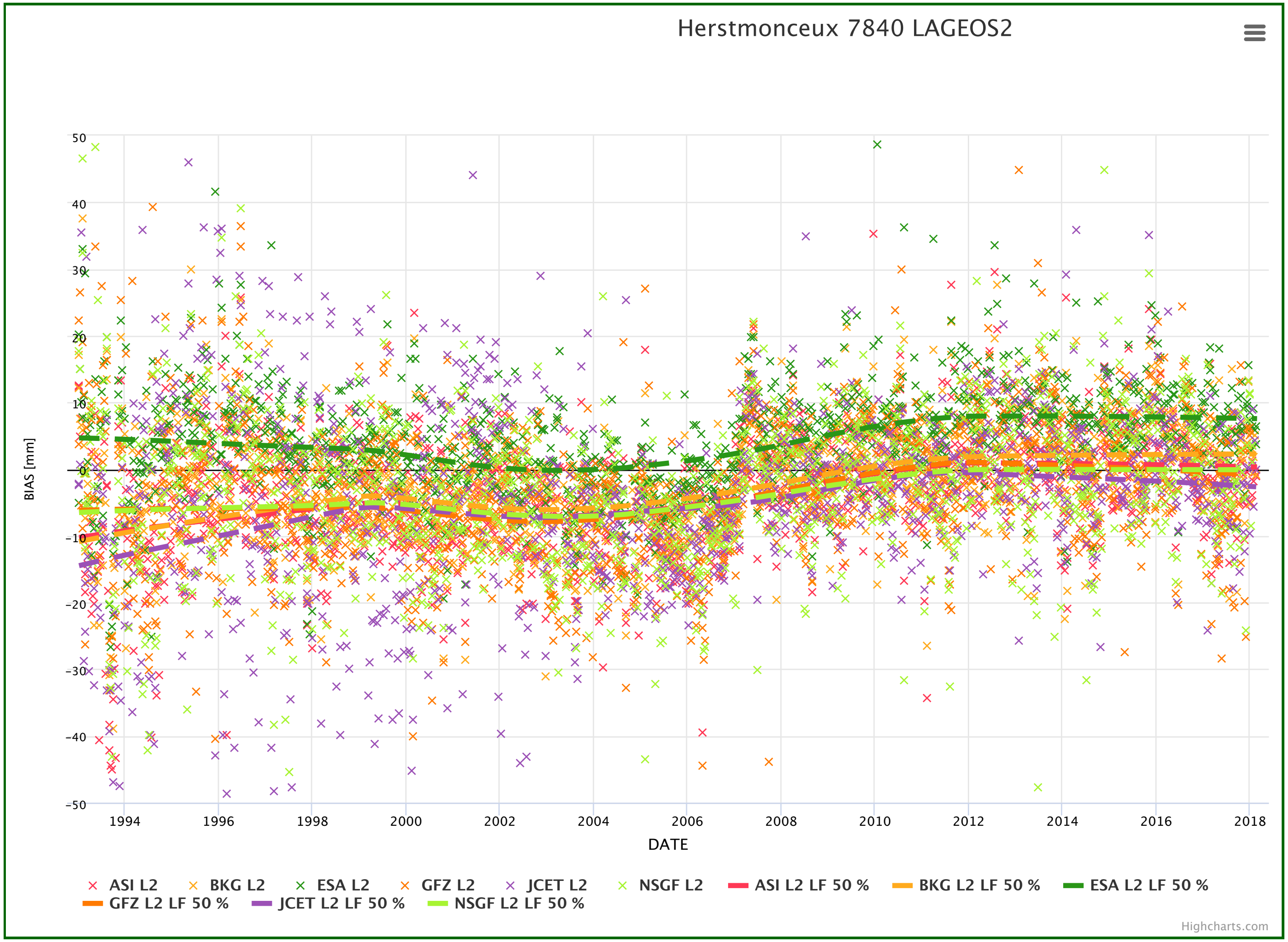
Station Systematic Error Project Results 1



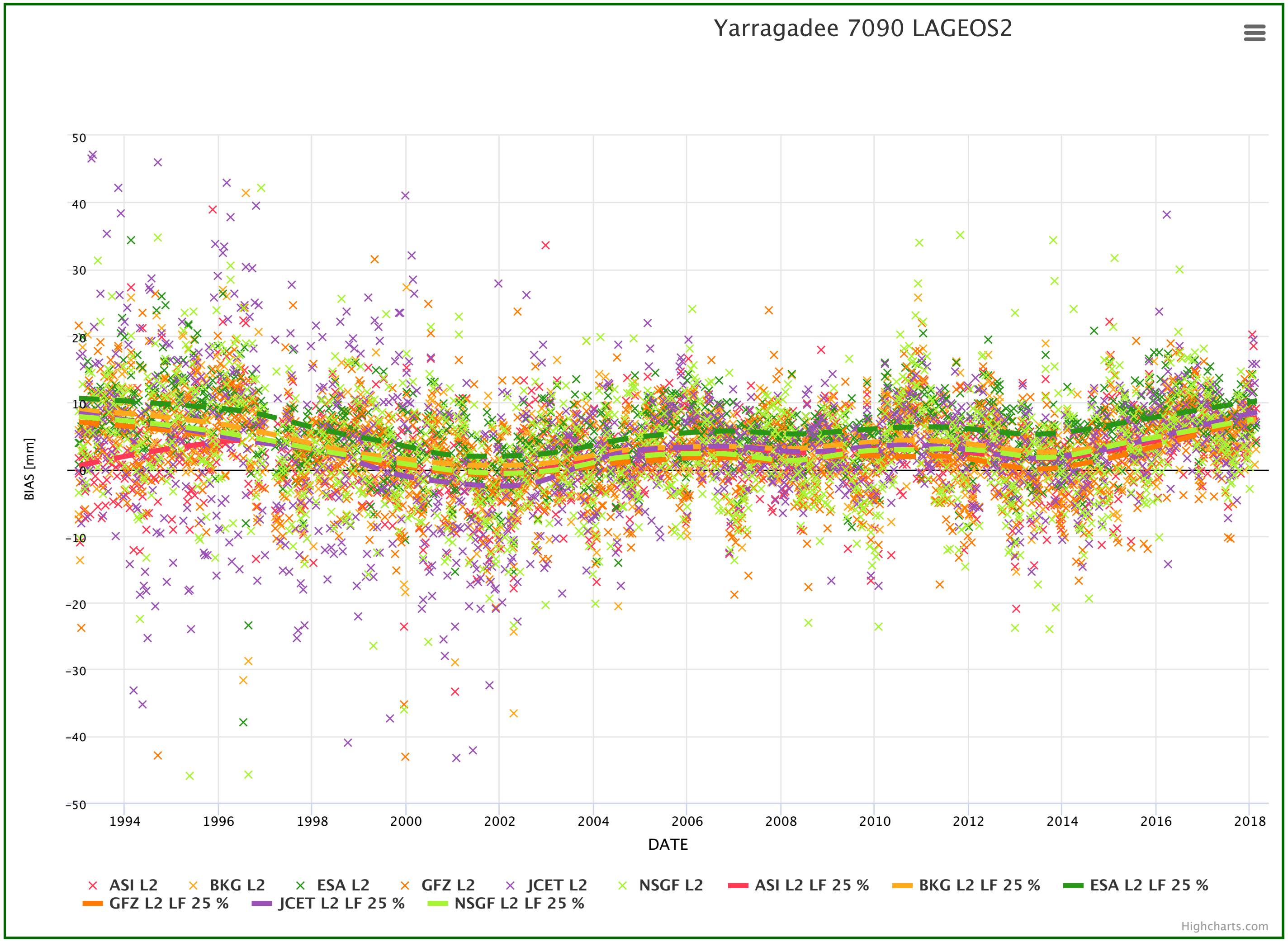
Station Systematic Error Project Results 2



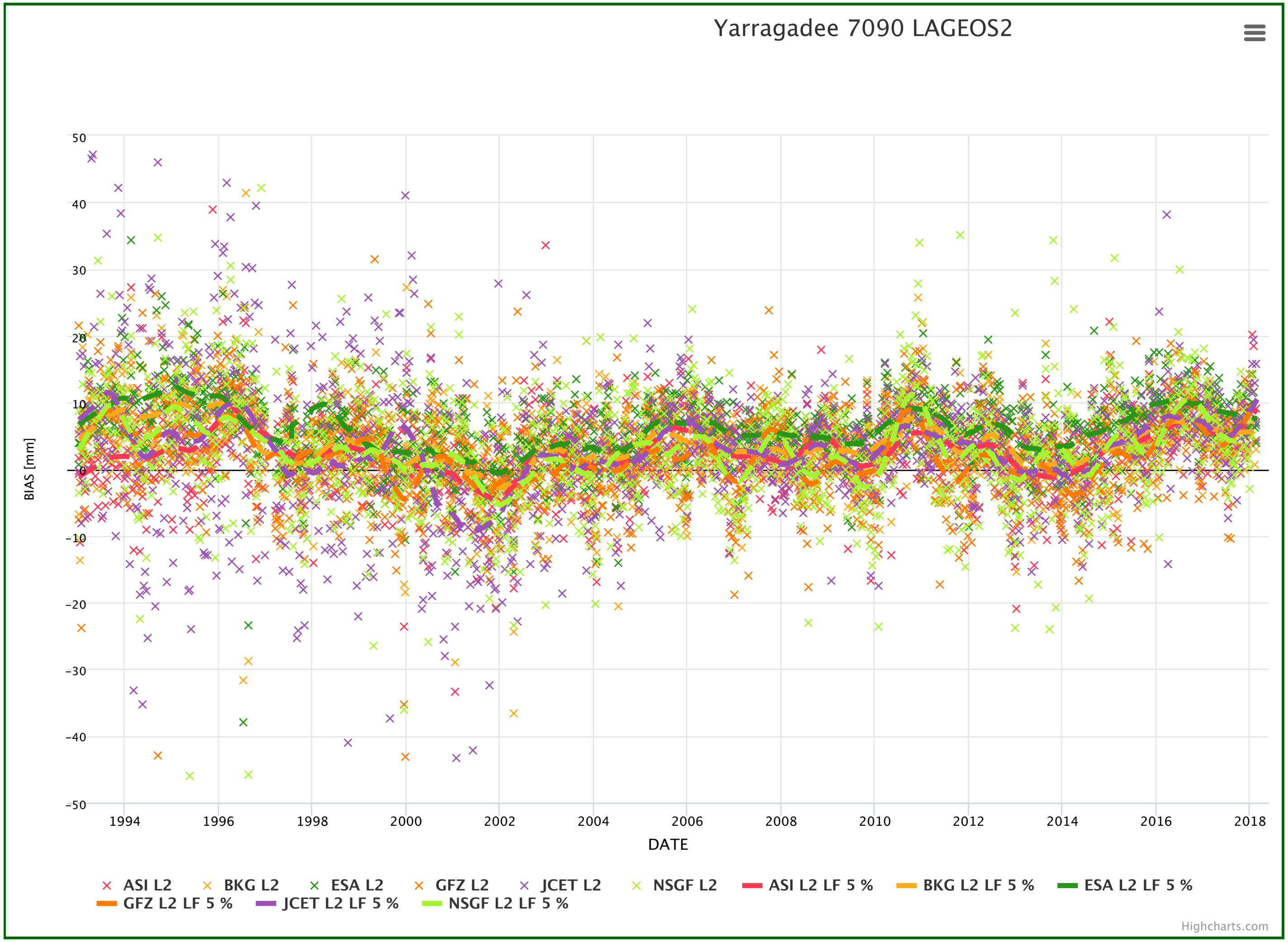
Station Systematic Error Project Results 3



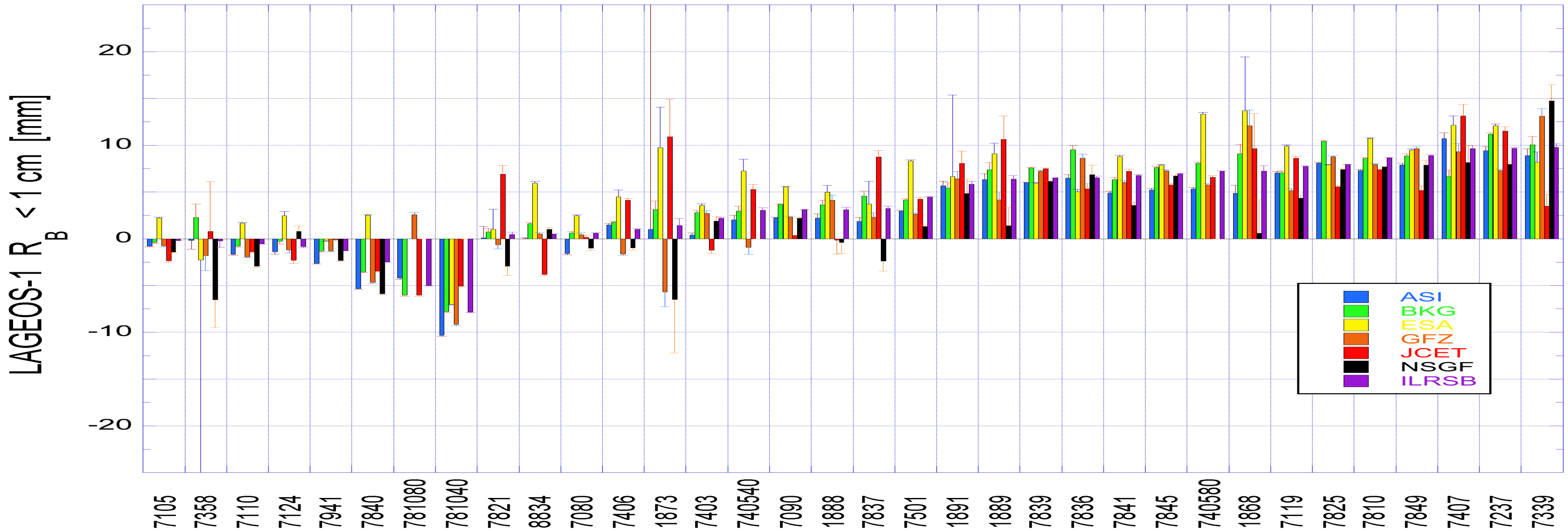
Station Systematic Error Project Results 4

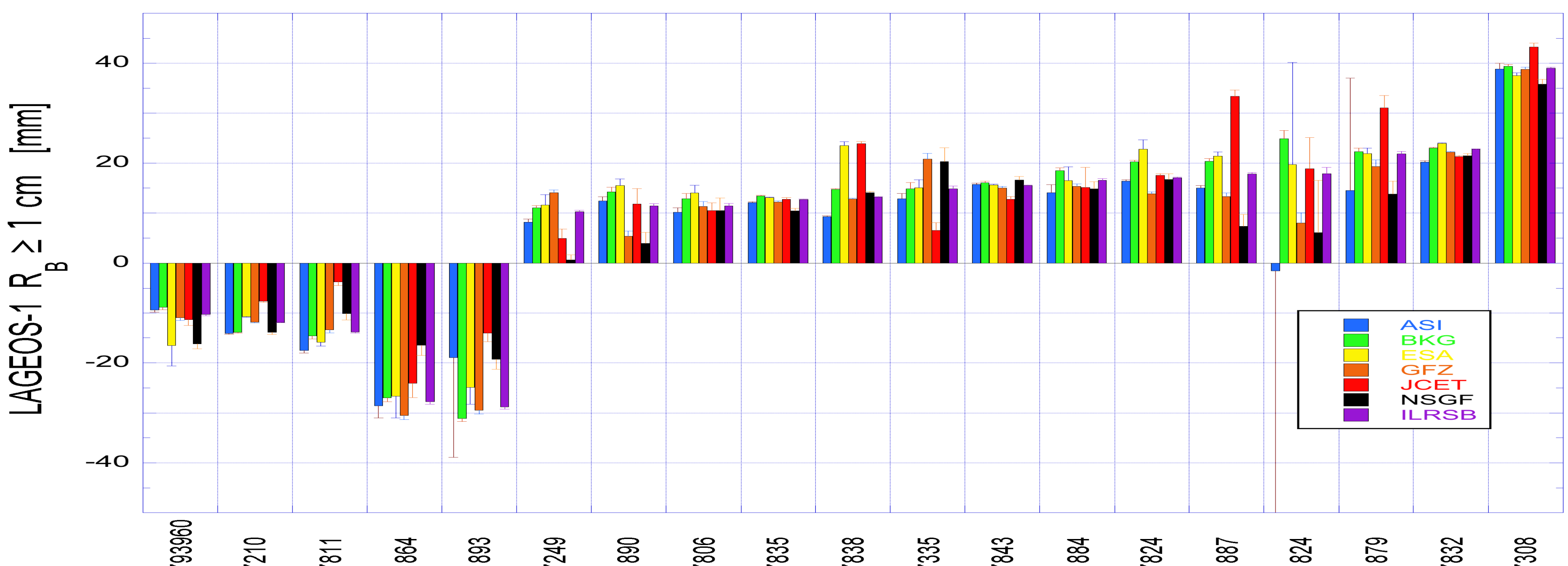


Station Systematic Error Project Results 5

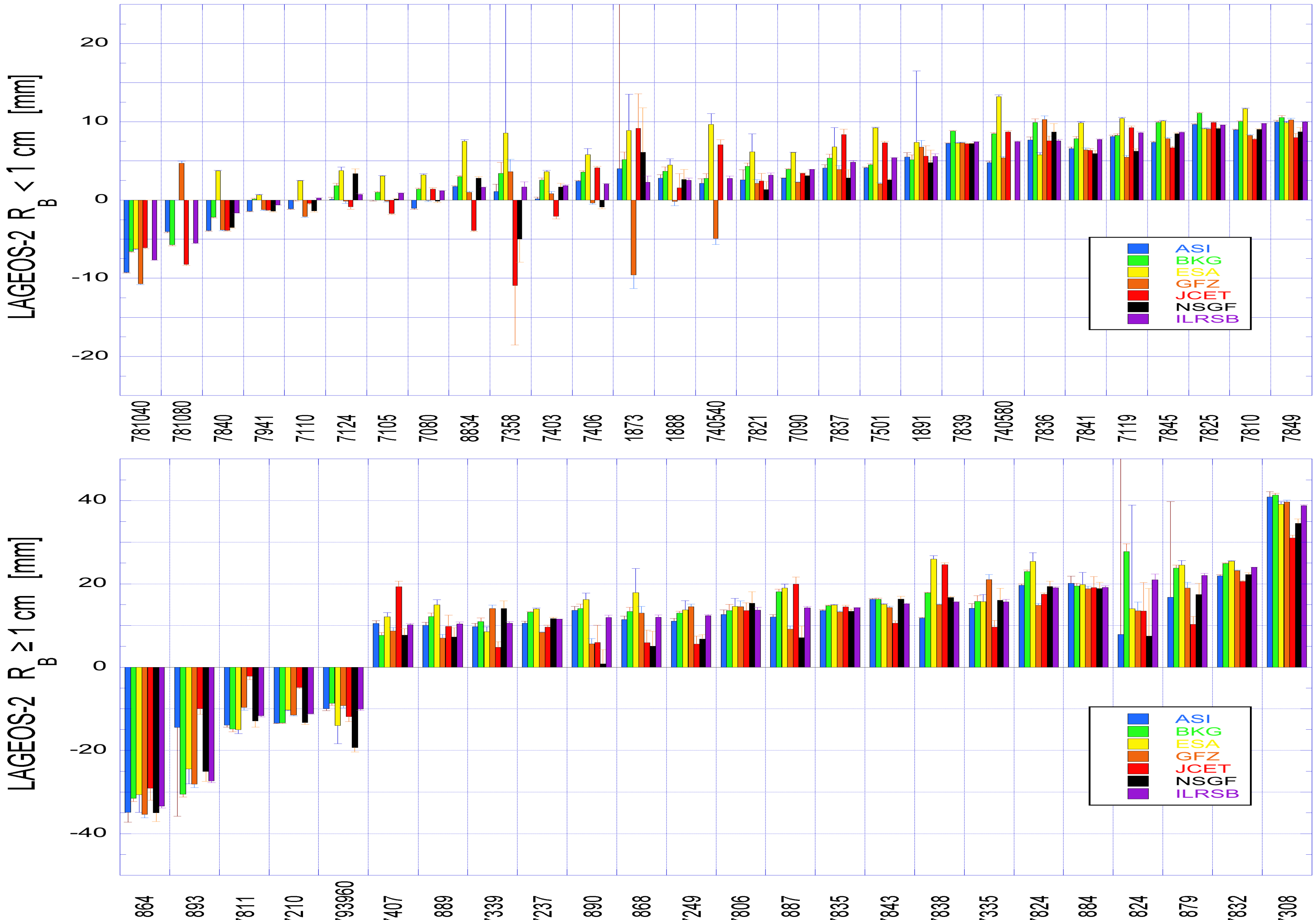


Long-term Systematic Errors LAGEOS

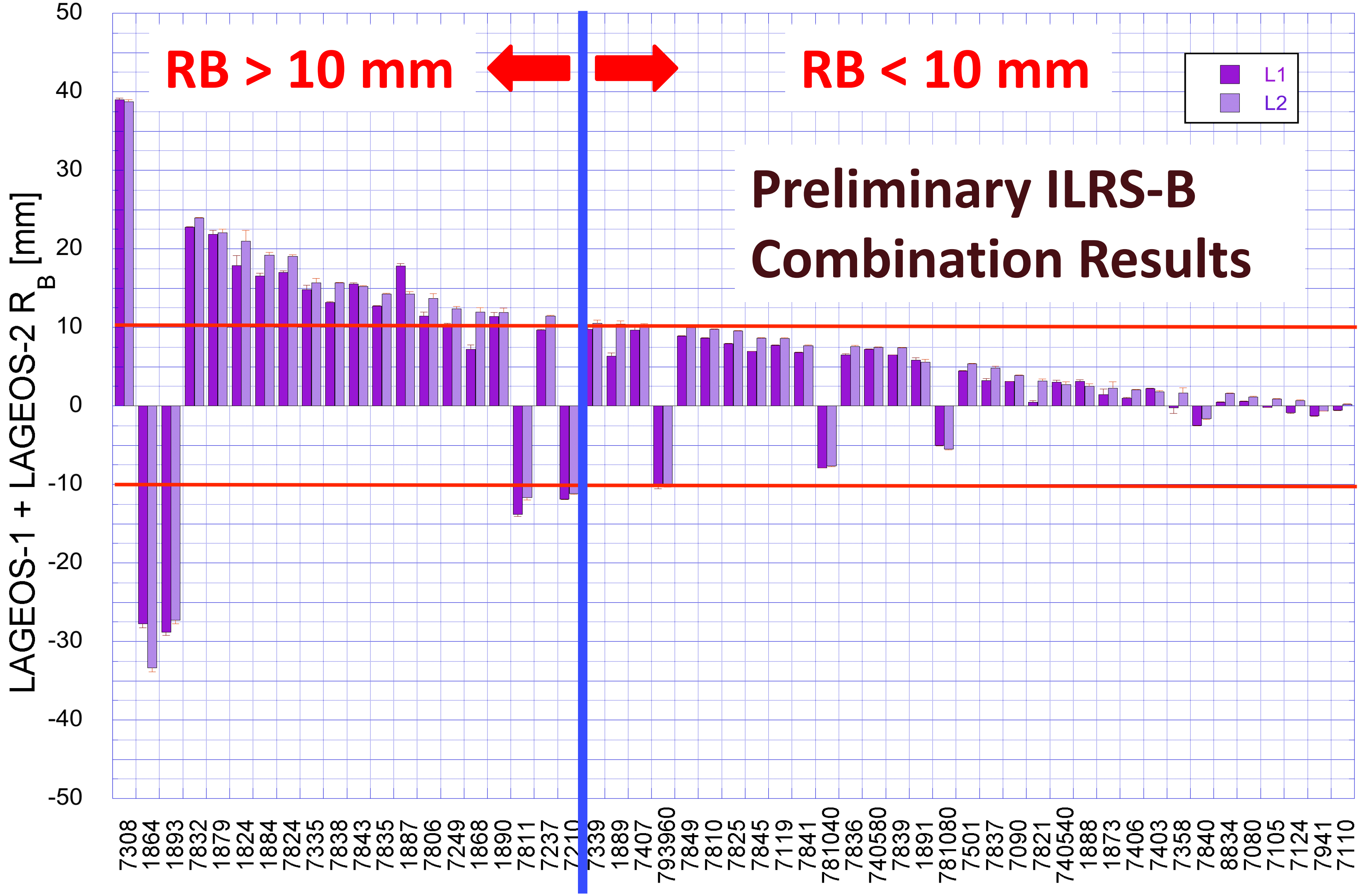




Long-term Systematic Errors LAGEOS-2



Long-term Systematic Errors LAGEOS1/2



Station Systematic Error Monitoring-SSEM Project -2

- We need to evaluate the results from each AC and subsequently review the combined result for each LAGEOS;
- The combined time series will be reviewed for each system at each site and the goal here is to identify the "breaks" due to logged activities at the site (from their HST logs);
- At a next step we will need to discuss* with the stations any additional "events" identified in their time series, to rationalize the adoption of additional corrections;
- The adopted long-term mean biases will be applied a priori;
- We will need to do a "dry run" for 1-2 months, then move to an operational phase by June 1st 2018 or soon thereafter.

* We already have had discussions up to ~2014, so we have most of the answers by now

ILRS ASC – ITRFXX Plans - 1

All Techniques were asked to:

- **Implement linear mean pole model** -- YES, agreed
- **Develop and implement diurnal-subdiurnal tidal EOP models**

  -- We plan to adopt one of the models currently under test (HFEOP PP) by various ACs from all techniques
- **Adopt post EGM2008 static gravity field based on ~all GRACE & GOCE data**

  – We will adopt a model of that class after a test through an ASC-administered PP
- **Highest-fidelity time-variable gravity (TVG) model (degrees >1) using GRACE + SLR + geophysical fluid models for full space geodetic era, consistent with GRACE + GOCE standards**

  -- We have been using state-of-the-art gravity models and we can easily pick one that is even of newer vintage than GGM05S that we now use, hopefully the one that will come out from the final reanalysis of the GRACE data set (RL06), due to be available immediately after the launch of GRACE-FO sometime this spring. These models have associated TVG models that are equally of high quality and they are available for adoption.

ILRS ASC – ITRFXX Plans - 2

- **If a loading model is applied [but preferably not],**

(1) ensure consistency with TVG model;

(2) ensure the same loading model is used by all techniques and all ACs;

(3) provide contribution of loading corrections to the right-hand side of the normal equation in SINEX.

– We will not include a loading model in the reanalysis product for the next ITRF, because in that case we would have to provide enough information for you to be able to rigorously remove it, a capability that we do not currently have, which means developing a capability that would delay our reanalysis with very little to gain for us.

ILRS ASC – ITRFXX Plans - 3

- **Derive and implement models for instrument/monument thermal 3D effects for all techniques; validate present VLBI model**

- **Collect metadata needed to implement instrument-monument thermal effect models**

-- We do not think that this is a task for the analysts and we do not see how we could do this in time for the next reanalysis. We have neither the expertise nor the resources to create such models. Although VLBI has been doing this for several years now, they are dealing with very similar antennae at their sites. In this case, each SLR system is a unique environment and we would have to have the local groups involved to provide the data and measurements for such a model. These deformations are not of appreciable magnitude to warrant the development of such a model. We can consult with the Network & Engineering SC to look deeper into this question, however, I doubt that there is anything that we can do in less than a year, which is the kind of timeline that we are shooting for here.

ILRS ASC – ITRFXX Plans - 4

- **IERS Conventions updates to document all the above**
  – We agree!
- **<u>SLR SPECIFIC:</u>**

◆ **Add estimation/handling of station Range Biases**
  – This is already agreed and implemented

◆ **Use updated CoM offsets (target signature corrections)**
  – A preliminary model will be available by EGU2018, the complete model by this coming summer

◆ **Add estimation/handling of Time Biases**
  –Time biases are now modeled based on T2L2 results

◆ **Include applied R_B & T_B in SINEX file for next contribution to ITRF with their constraint information**
  – The SINEX will contain the R_B & T_B values applied to each station

Planning for the Development of ITRF20XX

- We need to wait until the end of next summer(?) to start our reanalysis, if we are to use the latest and best CoM estimates for the targets we will use in ITRF development: LAGEOS 1 & 2, LARES and ETALON 1 & 2;

- We will start our re-analysis with the use of the adopted long-term biases and constrained adjustment of the remaining bias (NOT free at the ~1 m level anymore!), which should be completed by early/mid-2020, when the CCs will have a stable set of contributions to start the combination process;

- The CCs estimate they need 6-8 months to complete this process based on the ITRF2014 experience (and the prior models);

- This implies that we should be able to include most if not all of 2020 in the initial step of the combination, work out any issues with the individual contributions, and by the time all these are cleared, we can include the remainder of 2020, assuming that by that time all the ACs have corrected their issues and the processing of the remainder of 2020 becomes a trivial process;

- If ITRS can wait until early 2021, then we can certainly have all of 2020 included in the analysis. This plan assumes that all of the LARES data will also be part of this analysis this time around.

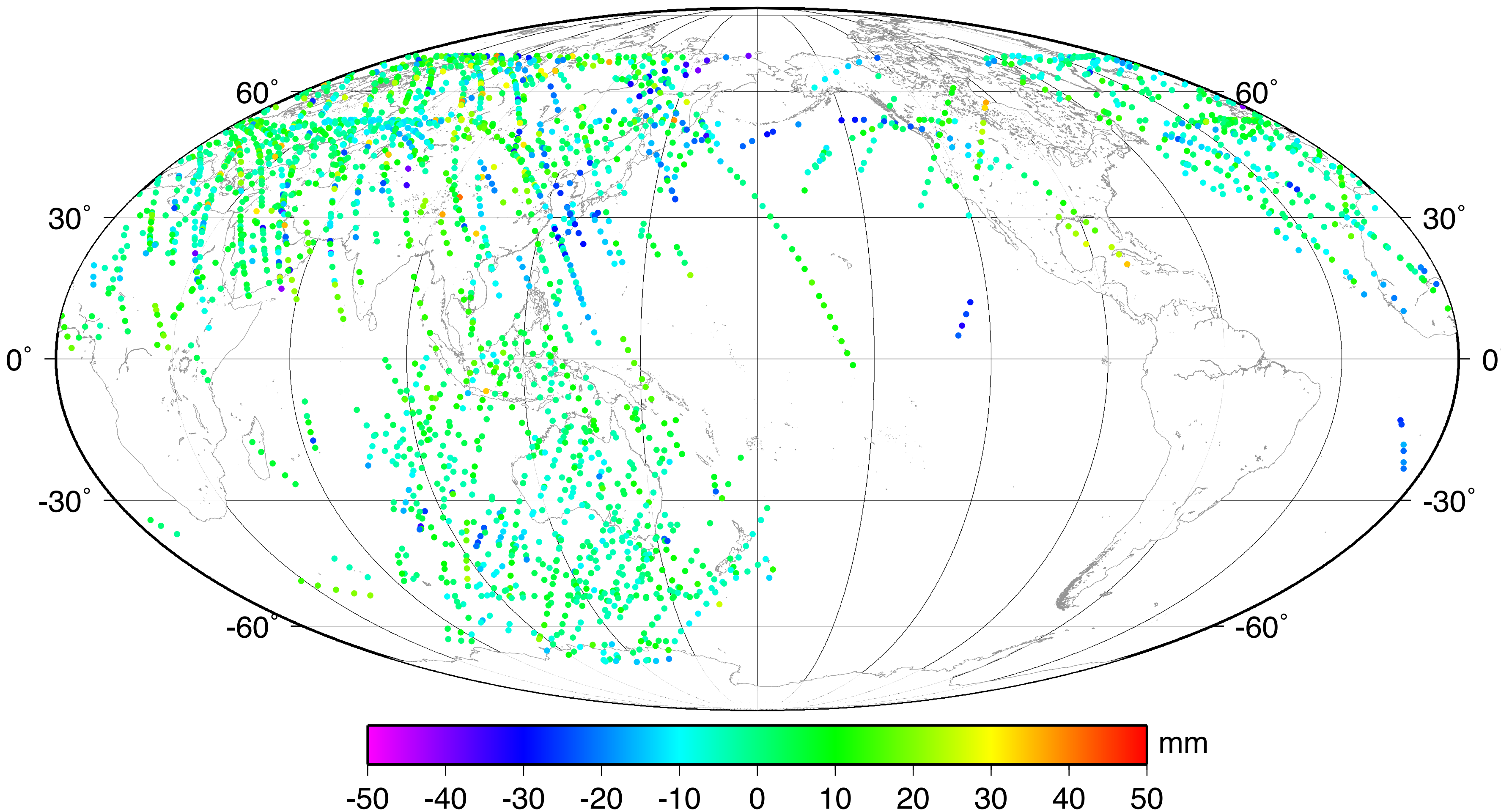
Expand the of List of Targets for Operational Products

- The intent is to produce higher quality EOP in a shorter timeframe (e.g. the day after the data were collected);

- The benefits of such an expansion were demonstrated already with a simulation of tracking 24 GPS s/c that was presented at the 2013 IAG meeting in Potsdam;

- Last March, in discussions with Mathis Blossfeld while at Goddard, we agreed to propose the generation of a new ASC product, to be tested first in a short PP, where we focus on tracking the expanded list of targets for an improved EOP product (initially), and using these series to test the viability of generating additional products of interest.

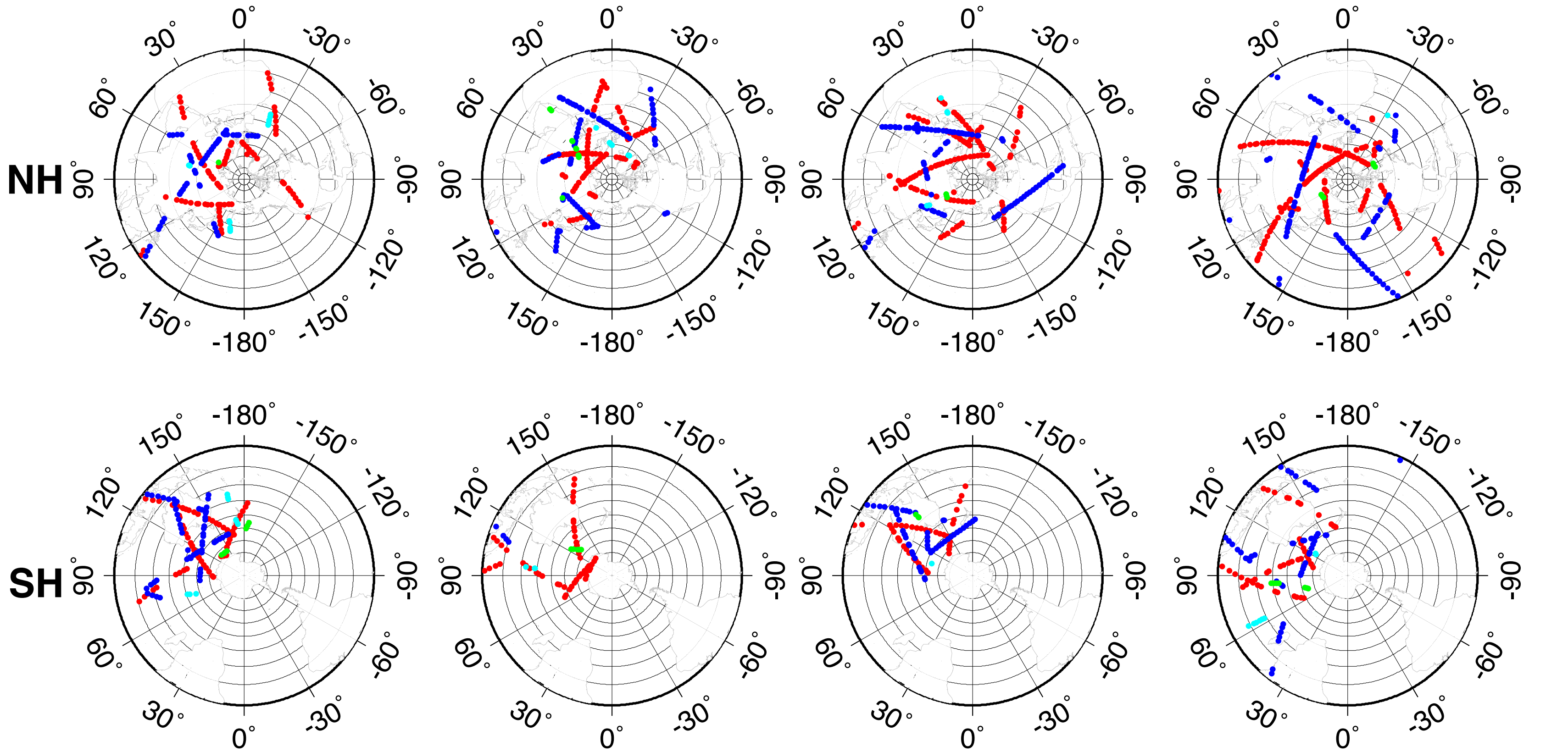
ILRS Weekly Product Example – Data Used



SLR Range Residuals

ILRS Weekly Product Example – Coverage (1)

DAY 1 | DAY 2 | DAY 3 | DAY 4

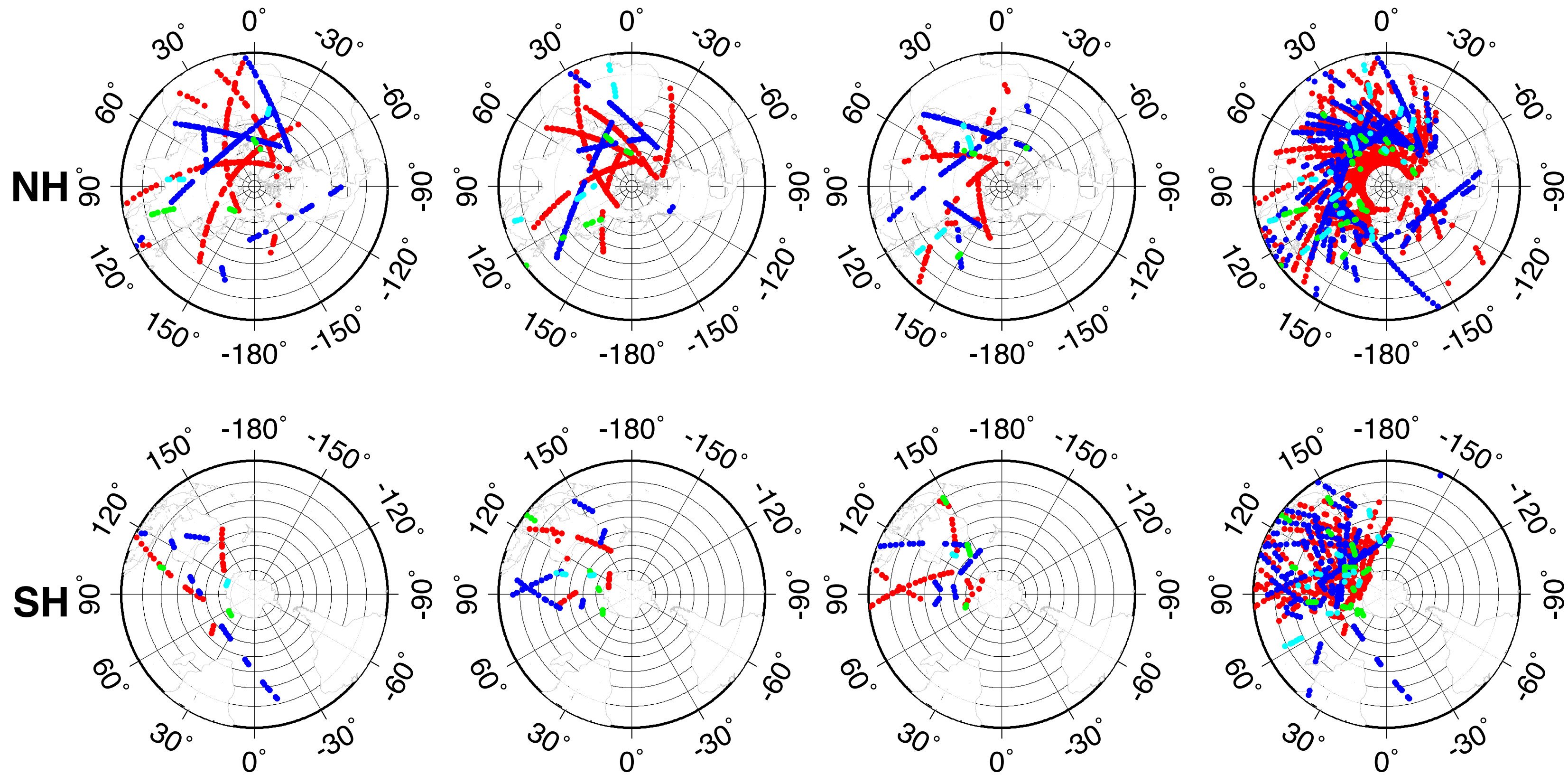


04/02/2018 **04/03/2018** **04/04/2018** **04/05/2018**

red = L1 **blue = L2** **green = ETA1** **cyan = ETA2**

ILRS Weekly Product Example – Coverage (2)

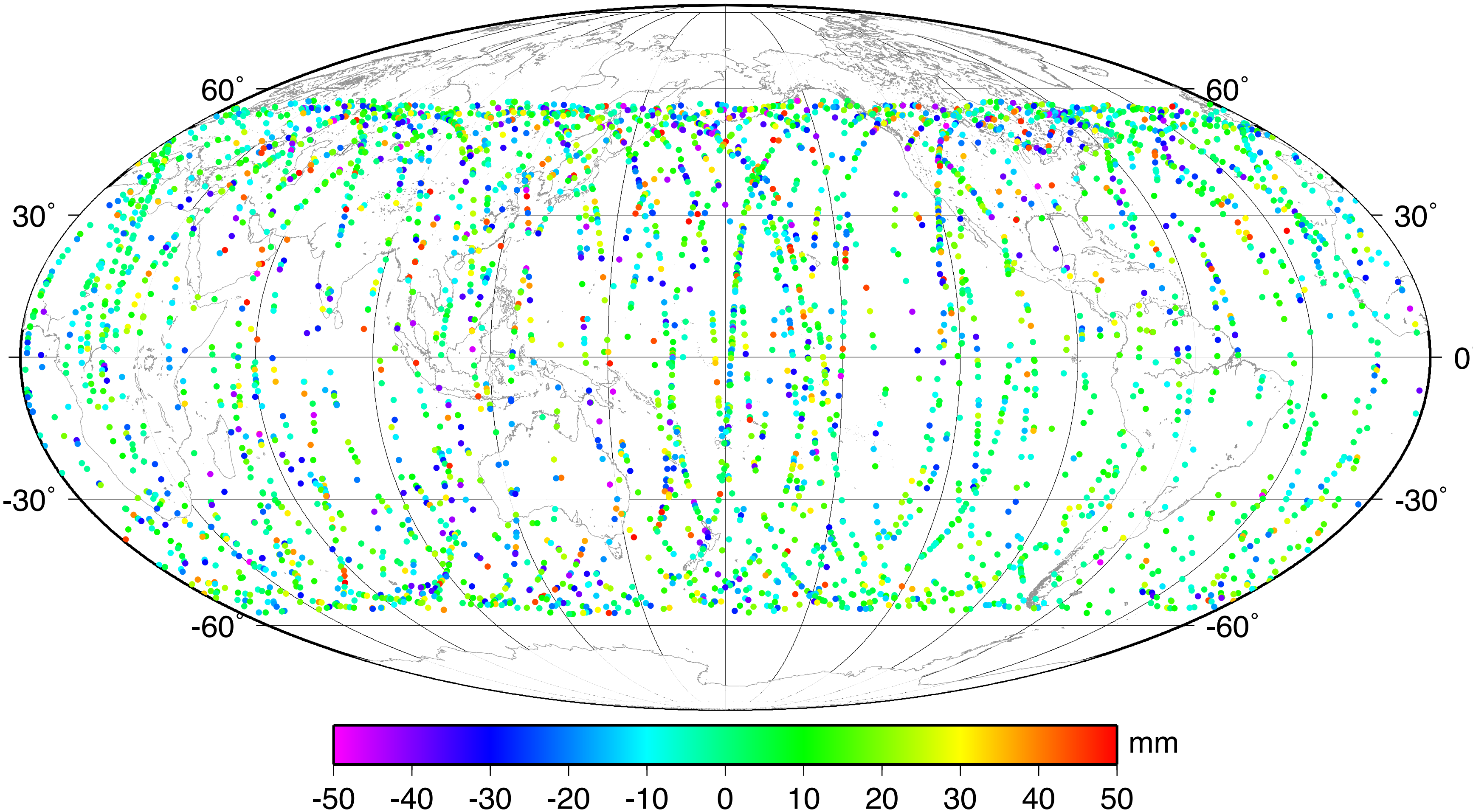
DAY 5 | DAY 6 | DAY 7 | ENTIRE WEEK



04/06/2018 | **04/07/2018** | **04/08/2018** | **04/02/2018 - 04/08/2018**

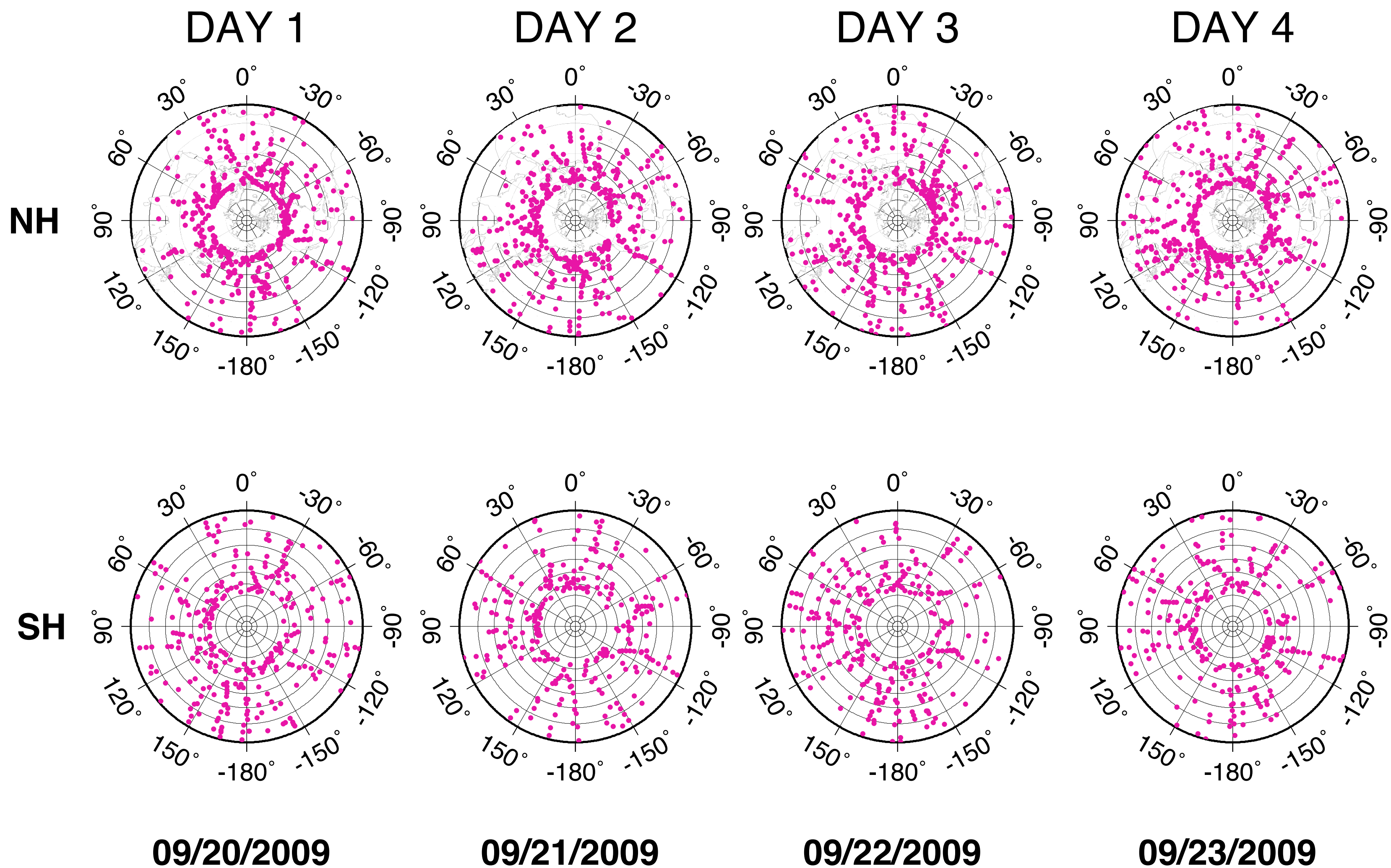
red = L1 **blue = L2** **green = ETA1** **cyan = ETA2**

Simulated ILRS Weekly Tracking of 24 GPS s/c

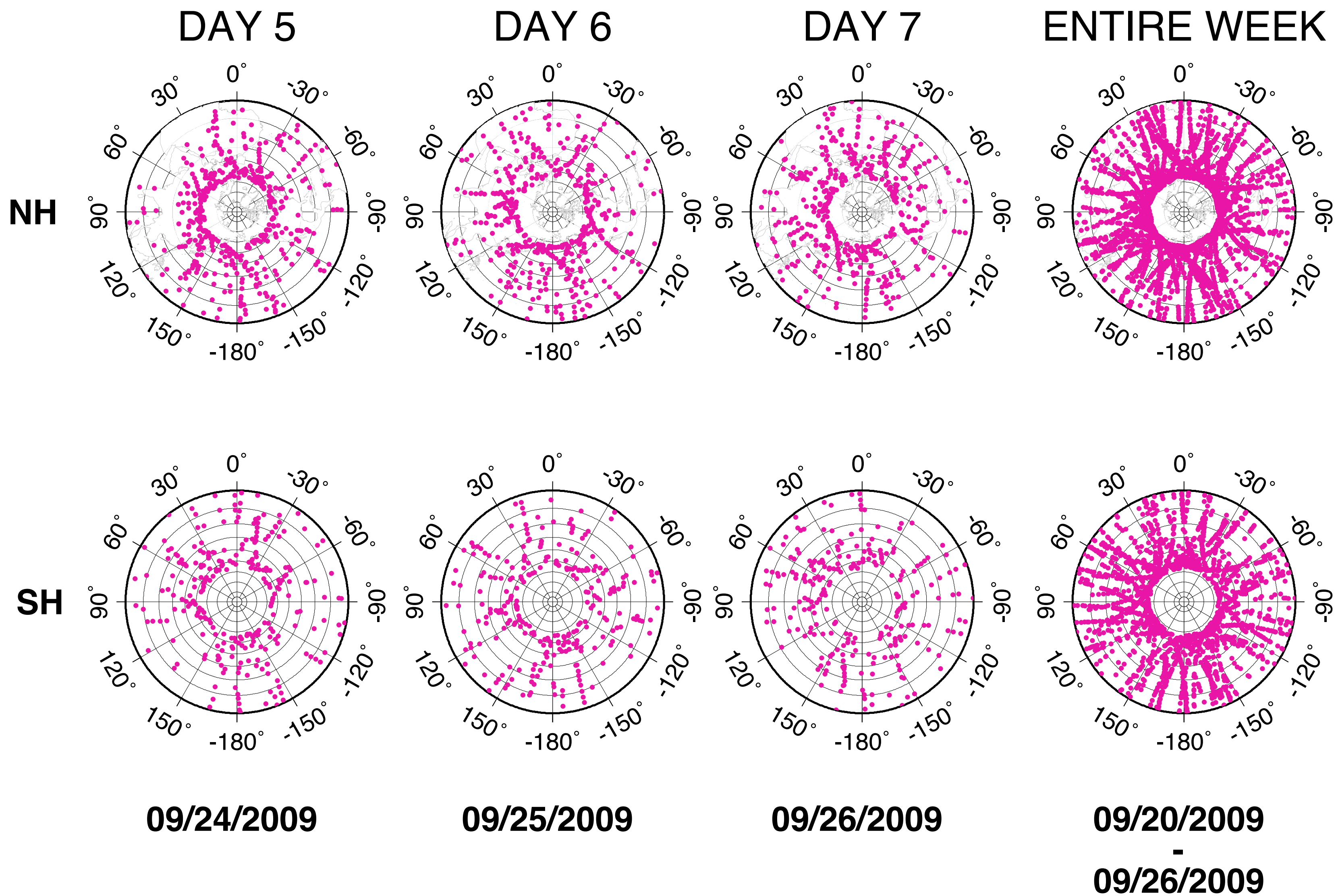


SLR Range Residuals

ILRS Tracking of 24 GPS s/c -- One Week's Coverage (1)

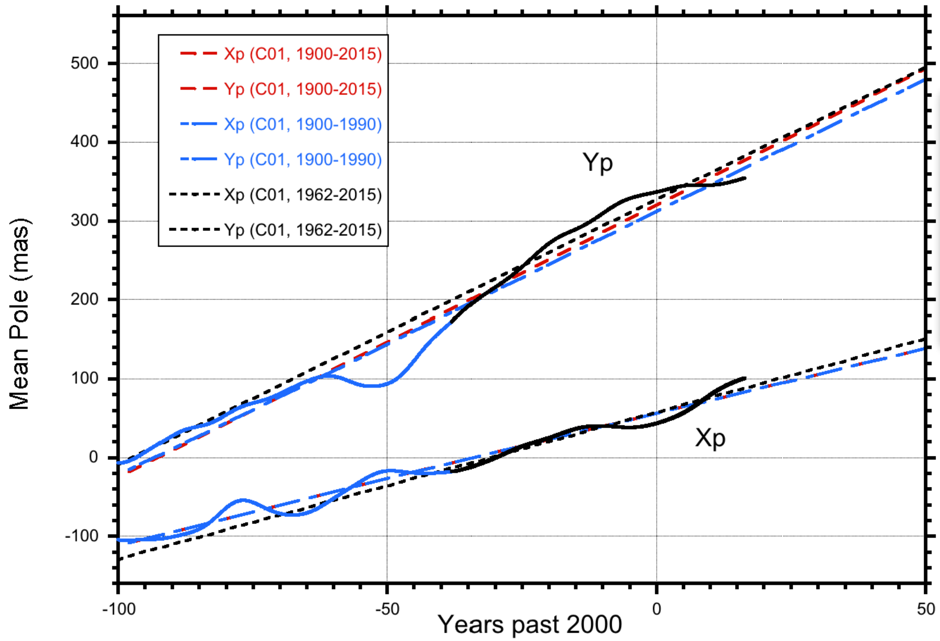


ILRS Tracking of 24 GPS s/c -- One Week's Coverage (2)



IERS Secular Pole Definition

Determining an appropriate linear mean pole (2)



In milliarcsec:

Xp = 55.0 + t*1.677

Yp = 320.5 + t*3.460

t is years past 2000

Any of these fits to C01 seem reasonable and internally consistent, though the span of 1900-2015 provides the longest baseline for a linear (presumably GIA-dominated) mean pole

More important, even if we cannot be sure this represents the true effect on the mean pole due to GIA, it is likely to best represent the future linear trend of the IERS polar motion, and that variations about this are the variations we wish to preserve in the pole tide model

Journal of Geodesy Special Issue (JOGSI) on Laser Ranging

- We have received ONLY 11 manuscripts so far (and one abstract was withdrawn);
- We have extended the submission deadline to end of May, with NO further extension for the submission process;
- Reviews start as soon as papers are submitted;
- We had one manuscript accepted already;
- PLEASE get your manuscripts submitted ASAP!
- Those of you who are reviewing manuscripts, please do not delay the process!

NSGF AC report

Graham Appleby, José Rodríguez

Vienna, 12nd April 2018

Stuff

NSGF is submitting daily and weekly routine solutions again since December 2017

3-digit wavelength coding in SINEX output

25 years of LAGEOS data reprocessed for the pilot project on systematic errors

CoM modelling progress

CoM modelling

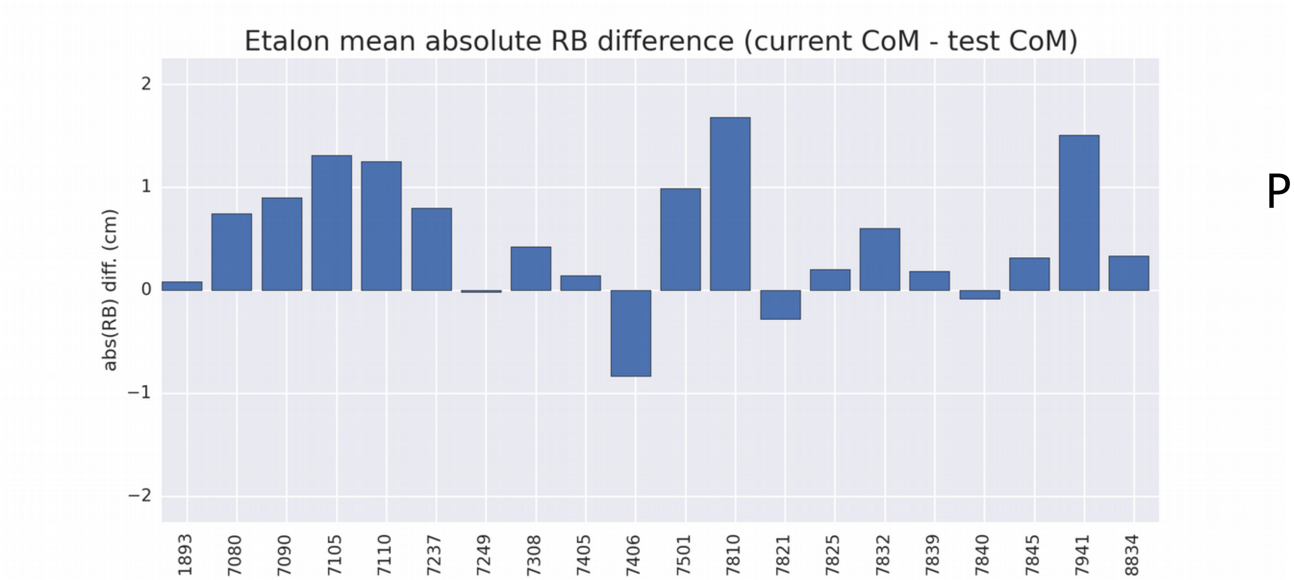
Redone everything from scratch, incorporating effects previously approximated

New modelling strategy for multi-photon stations (Monte-Carlo simulation)

Preliminary results for Etalon and LAGEOS:

- encouraging for Etalon, with biases of ~1 cm removed from many stations
- not so clear scenario for LAGEOS. But at least three important sites benefit from the new values unequivocally (Potsdam, Mount Stromlo and Zimmerwald)

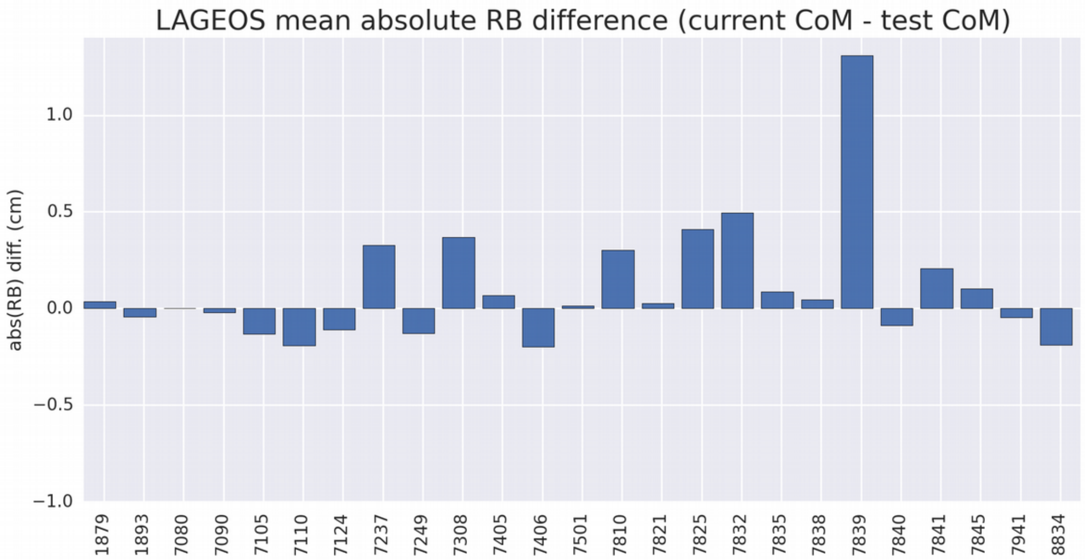
No silver bullets to eliminate LAGEOS biases found



Positive better: reduced RB

For Etalon, test CoM values remove about 1 cm biases from several stations

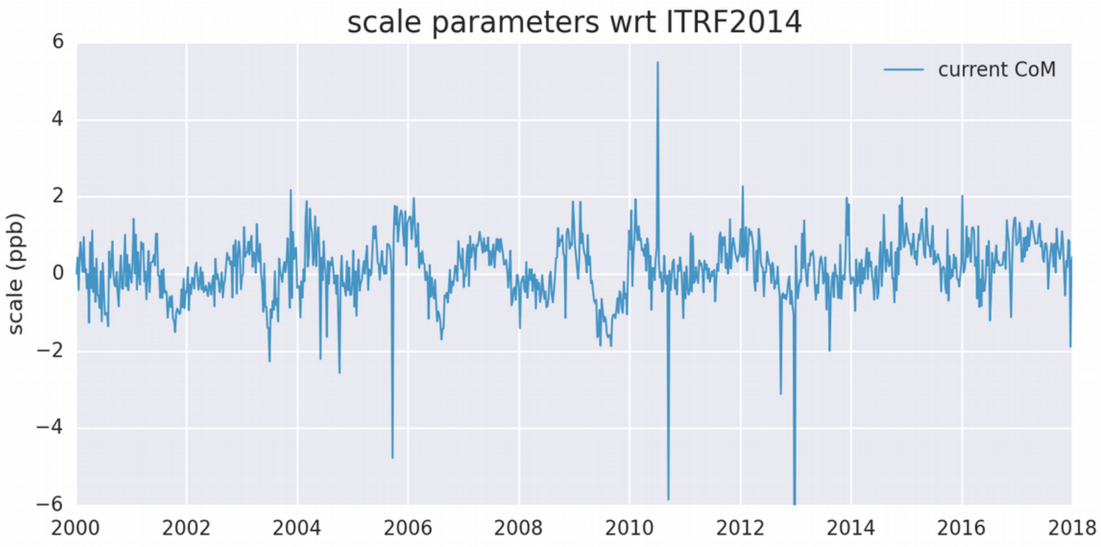
Very few stations see an increase in RB

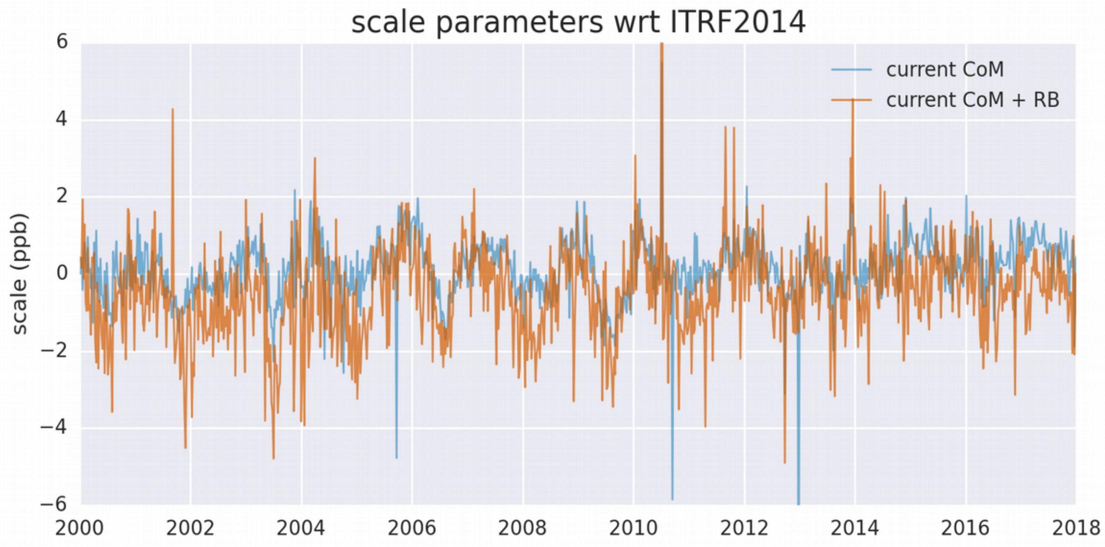


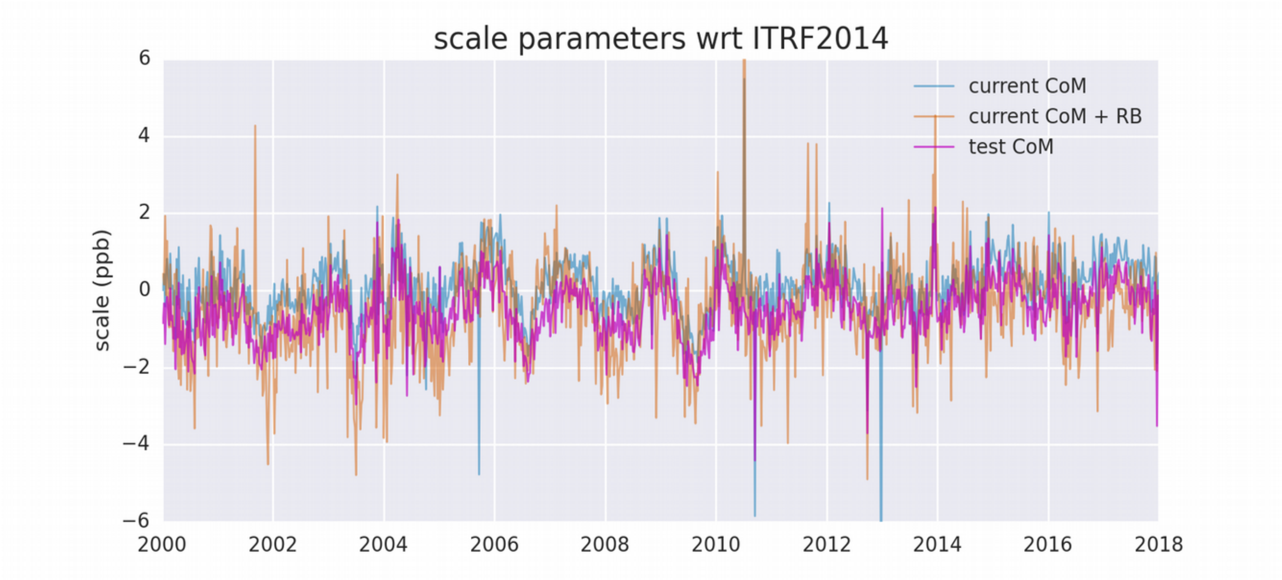
Positive better: reduced RB

More mixed picture for LAGEOS, although “gains” probably outweight “losses”

This does not inform us about the sign of the changes...


scale parameters wrt ITRF2014
current CoM
scale (ppb)
6
4
2
0
−2
−4
−6
2000
2002
2004
2006
2008
2010
2012
2014
2016
2018

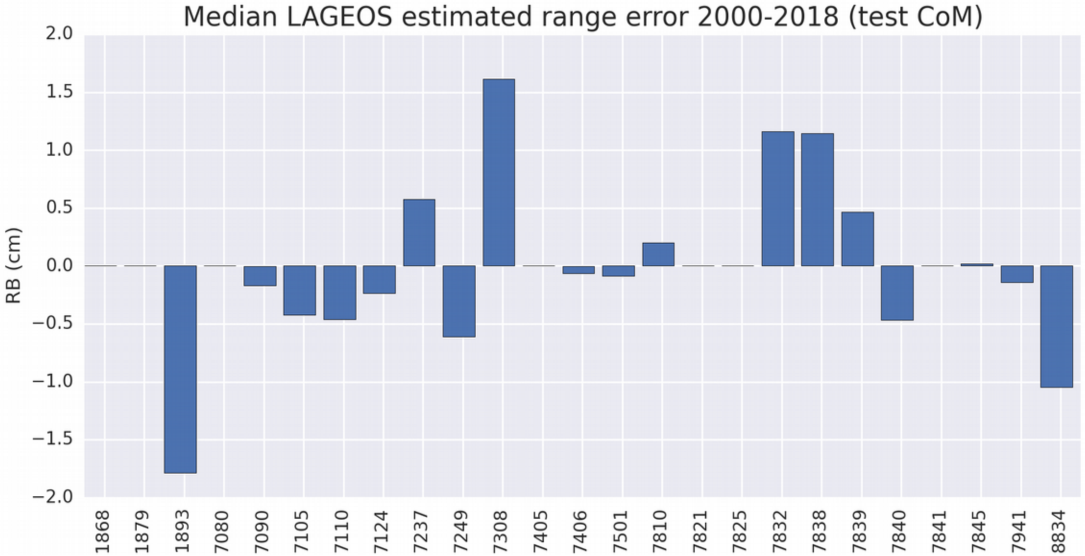

scale parameters wrt ITRF2014
current CoM
current CoM + RB
scale (ppb)
6
4
2
0
−2
−4
−6
2000
2002
2004
2006
2008
2010
2012
2014
2016
2018



Similar average scale change when estimating RB and when using test CoM values: ~0.6 ppb

Or in other words: both solution types have **increased** station heights

...but this is not the end of the story



Landing in the "right" place, on average, does not mean absence of problems

Everything indicates that the scale change is, at least partly, for the wrong reasons. As the new CoM values are for the most part lower, the average estimated RB becomes negative for some stations

Caveats:

- not final values
- some model assumptions to be checked
- sensitivity analysis not done
- realistically, accuracy no better than ~2-3 mm for LAGEOS and ~6 mm for Etalon
- a few other issues currently under investigation

LARES to be done shortly (Ajisai and Starlette next with lower priority)

New CoM offsets to be released when job is completed (LAGEOS, Etalon and LARES), together with table of systems details used as input for the computation

Handling of estimated errors must of course be done using the same CoM model in all solutions

Site log and CRD

No field for supplying information about amplifiers (model, bandwidth)

Ranging policy should be specified for three different cases: LEO, LAGEOS, GNSS/Etalon

Detection rate in NP should be a more meaningful value than returns/NP duration (e.g. median return rate in NP)

Request for typical calilbration detection rate (or perhaps “adjusted to match satellite” if that is the case)

System identifier in CRD header means, to the best of my knowledge, nothing at all. It would be very useful if it referred to specific system configurations in the site log:

- enable the implementation of multiple CoM entries per station in a clean, elegant way
- bring some desperately needed order to the detector section of the logs

Thank you

ILRS ASC meeting

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Outline

1、 Motivation

2、 SLR Quick Processing

3、 SLR Post Processing

4、 EOP

5、 Combination Of SINEX

6、 Conclusions and Future plans

1、Motivation

- As AAC of ILRS we would like to improve our models for better SLR data processing and provide normal products for users. So some models are checked and changed.
- We would like to become AC of ILRS. So we do some study and find some problems. We hope somebody could help us to solve it or give us some suggestions.

2、SLR Quick Processing

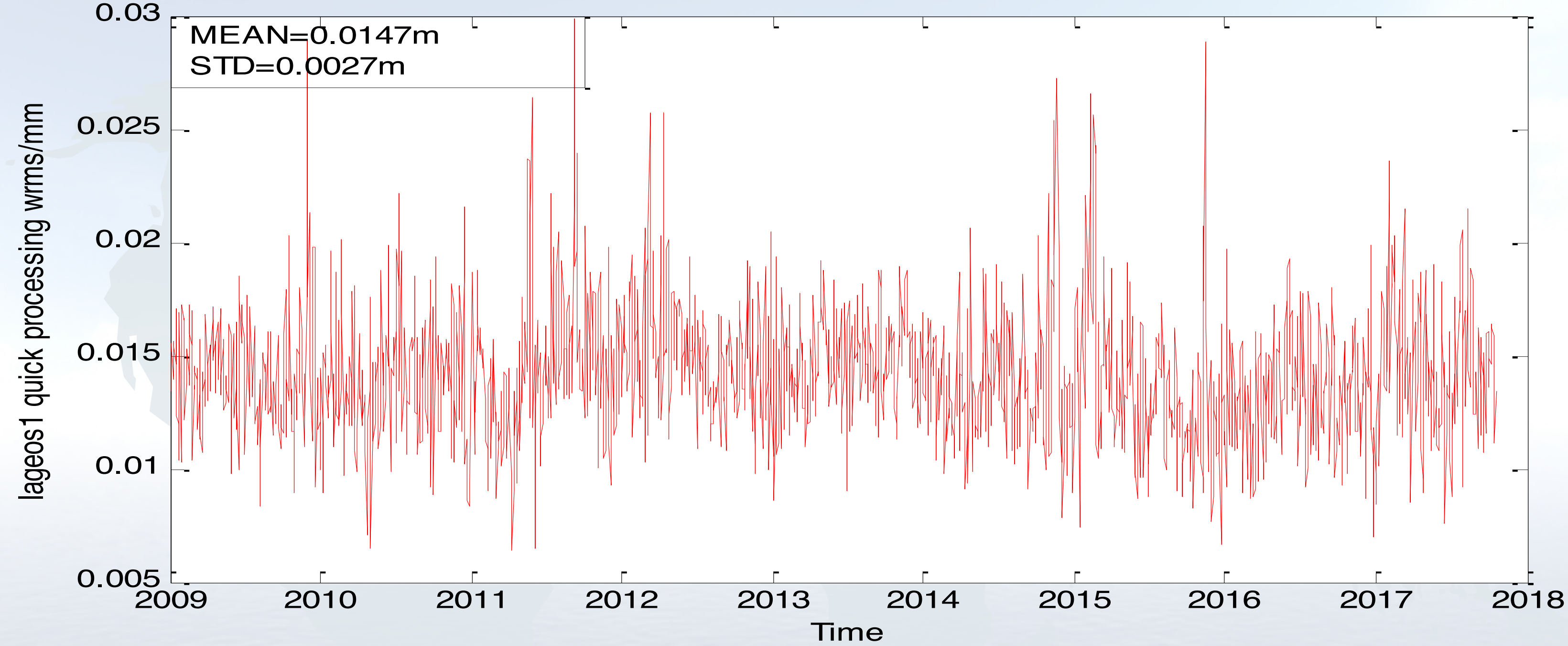


Figure1 Lageos1 quick processing RMS

2、SLR Quick Processing

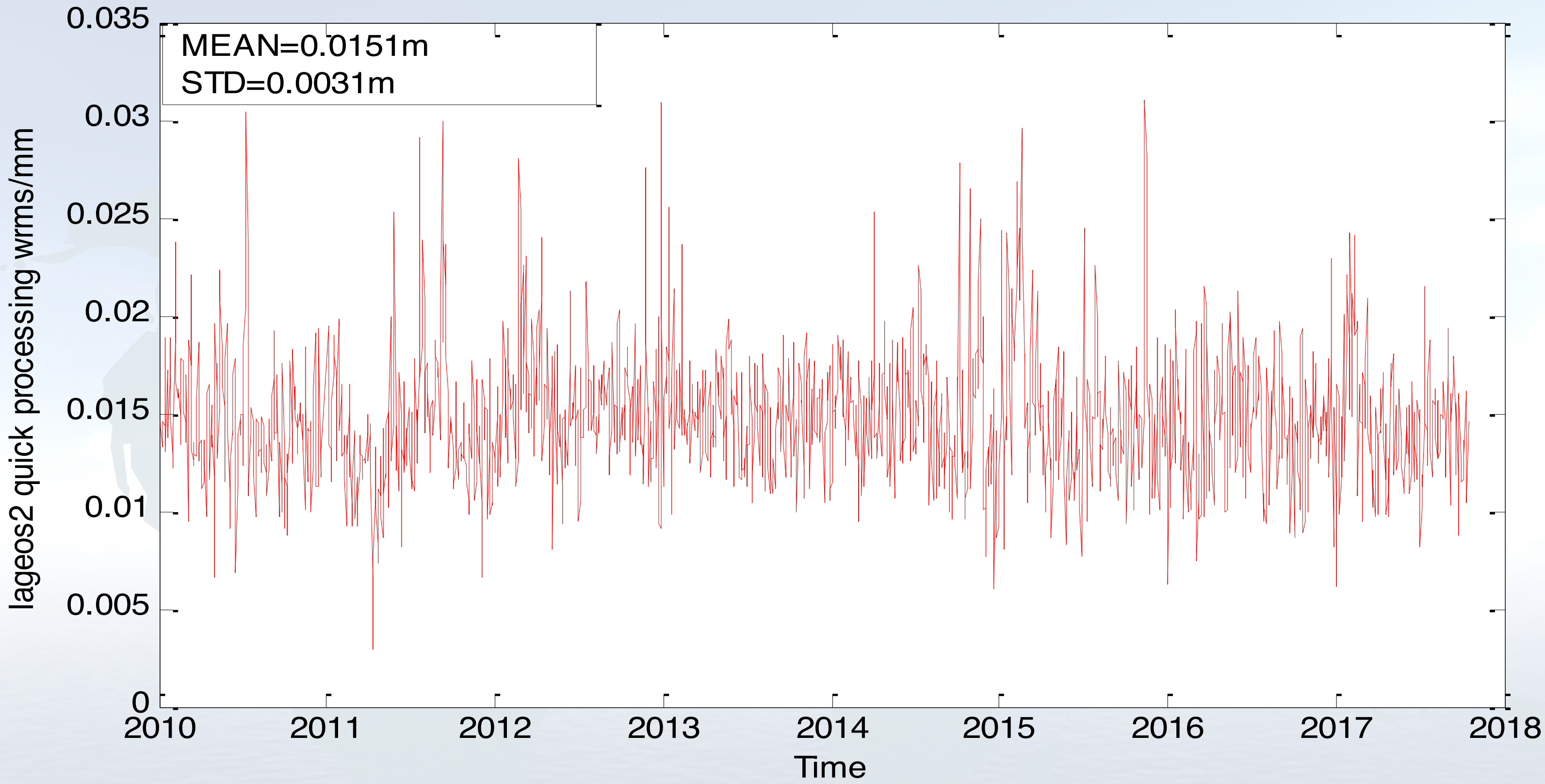


Figure2 Lageos2 quick processing RMS

2、SLR Quick Processing

Table1 SLR data Processing strategy

Measurement models	
Troposphere	Mendes mapping function and Mendes-Pavlis zenith delay model
Satellite center of mass	station dependent in accordance with the official ILRS CoM data
Orbit Models	
Geopotential	EGM2008，100×100degree
Solid earth tides	IERS 2010 Conventions model
Ocean tides	FES2004
Ephemeris	JPL DE421
Terrestrial Reference Frames	SLRF2014 (a priori station coordinates and station velocities)

2、SLR Quick Processing

Tidal corrections	IERS 2010 Conventions
Ocean loading	FES2004
Earth Orientation Parameters	IERS 14 C04 a priori
Estimated Parameters	
Stations	definition: SLR monument (eccentricities subtracted) at mean epoch of each arc a priori values: SLRF2014 a priori standard deviation: 1 m
EOP	definition: x-pole, y-pole, UT1-UTC and LOD epoch: at noon of each day frequency: daily a priori values: IERS 14 C04 a priori standard deviation: 20 masec, 2 msec
Range biases	for some (non-core) stations a priori value: 0 m a priori standard deviation: 1m

Comparison of tropospheric parameters obtained by different techniq

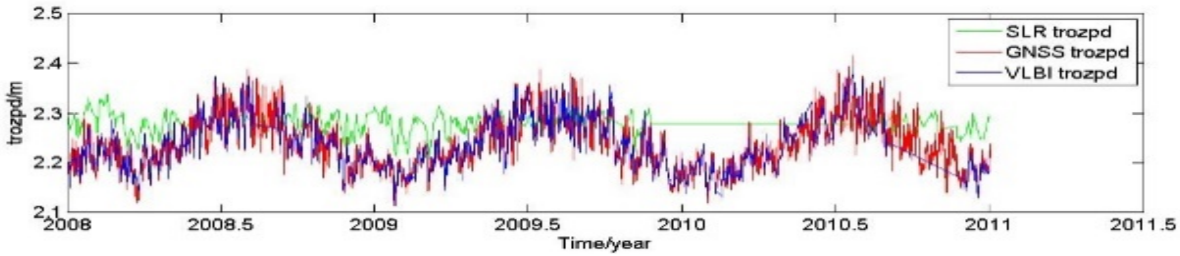


Figure 3 VLBI, SLR, GNSS zenith delay at colocation site WETZ

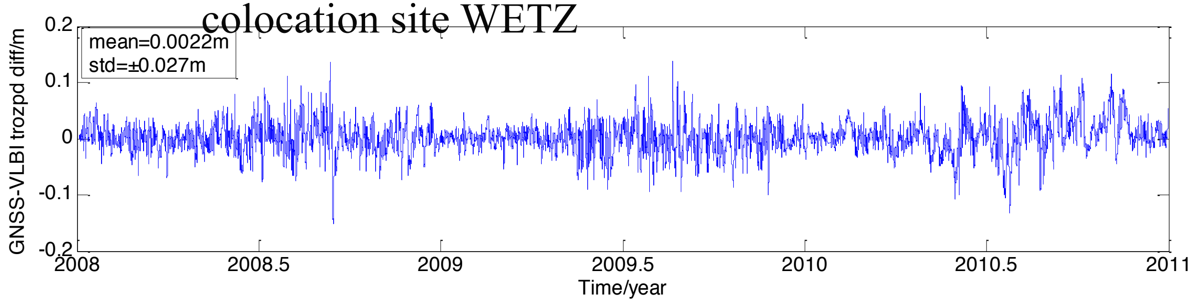


Figure 4 the zenith delay difference between VLBI and GNSS and spectrum analysis (WETZ)

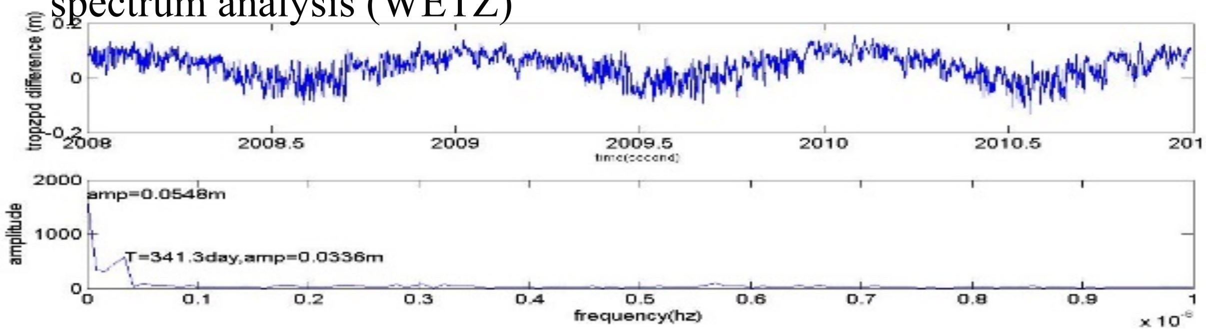


Figure 5 the zenith delay difference between SLR and GNSS and spectrum analysis (WETZ)

VLBI tropospheric zenith delay is approximately consistent with GNSS

There exits a constant term and a long period (about 1 year) term in the tropospheric zenith delay difference between SLR and GNSS.

2、SLR Quick Processing

Comparison of tropospheric parameters obtained by different techniq

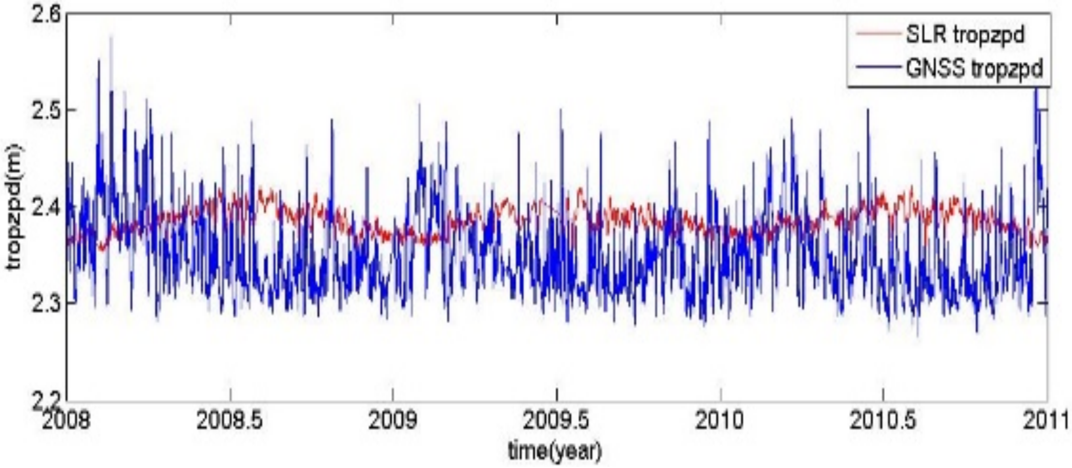


Figure 6 The SLR, GNSS zenith delay at collocation site YARA

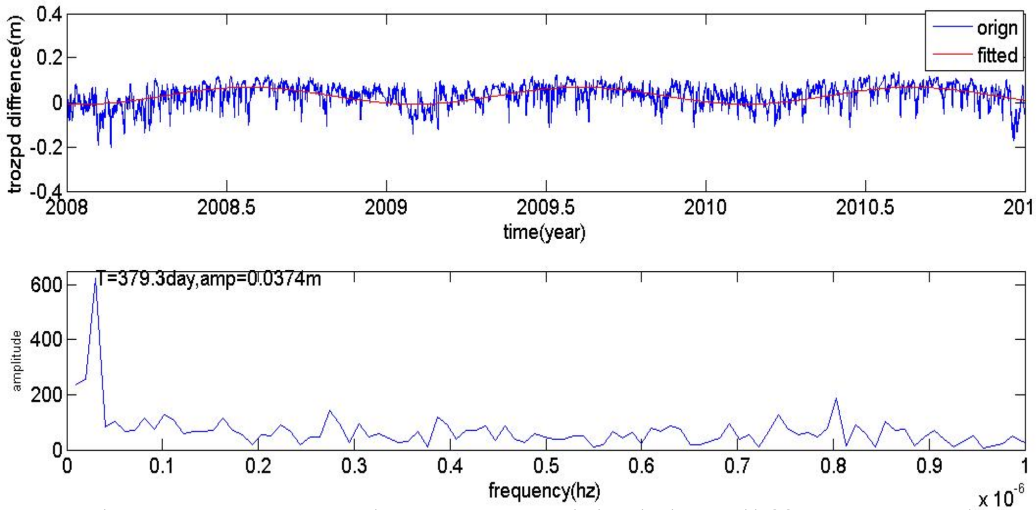


Figure 7 SLR and GNSS zenith delay difference and spectrum analysis (YARA)

There exits a constant term and a long period (about 1 year) term in the tropospheric zenith delay difference between SLR and GNSS.

2、SLR Quick Processing

Comparison of mapping function used in SLR and GNSS

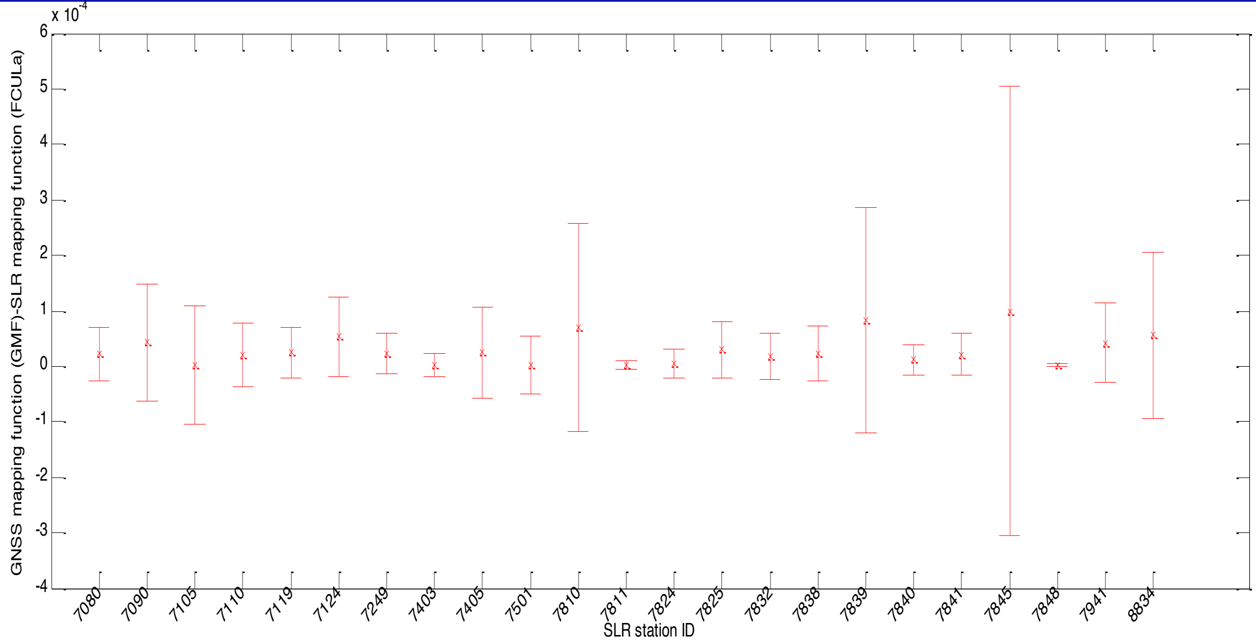


Figure 8. The difference of the mapping function between GNSS (GMF) and SLR (MP)

The red * represents the mean value of the difference, the length represents the standard deviation.

2、SLR Quick Processing

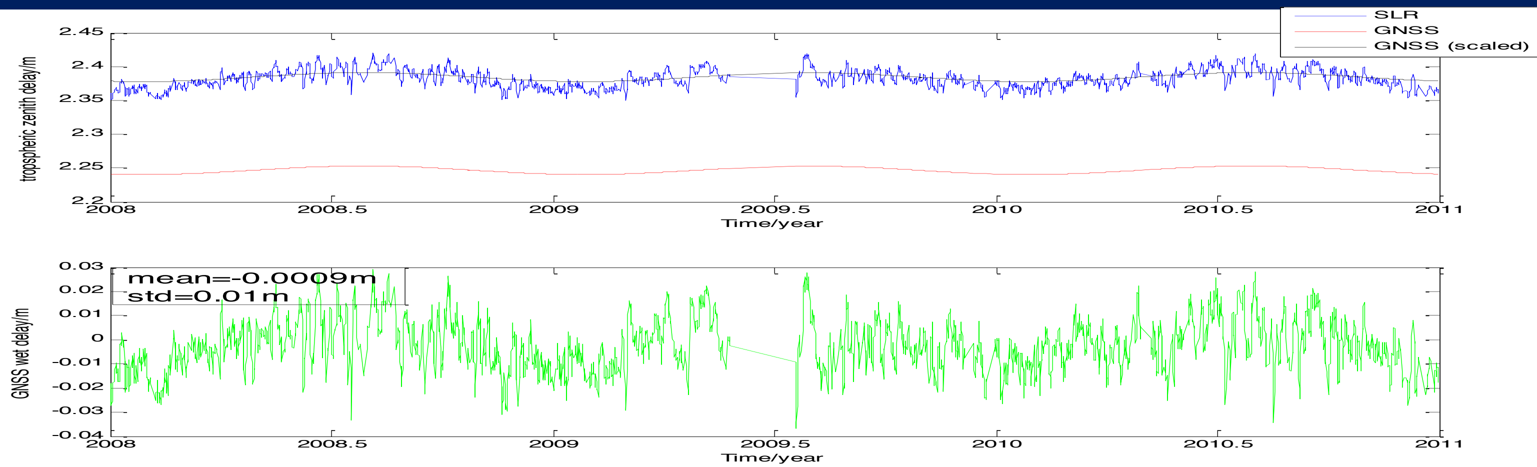


Figure 9. The zenith hydrostatic delay difference between SLR and GNSS at site YARA (factor= 1.061392746364195)

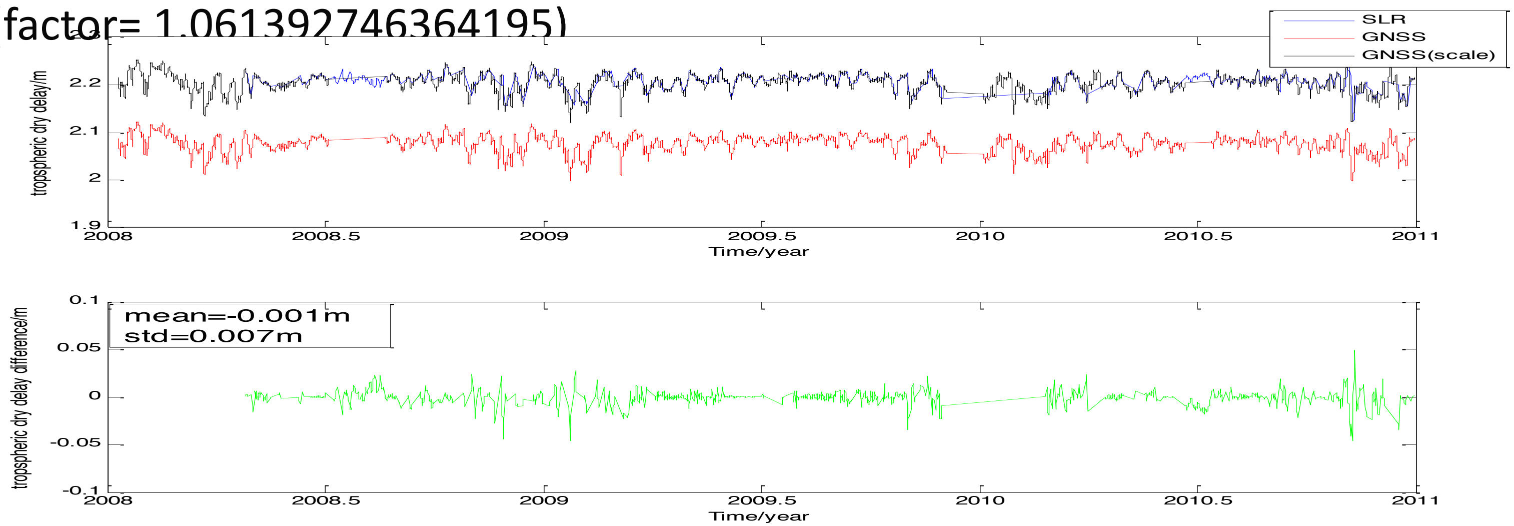
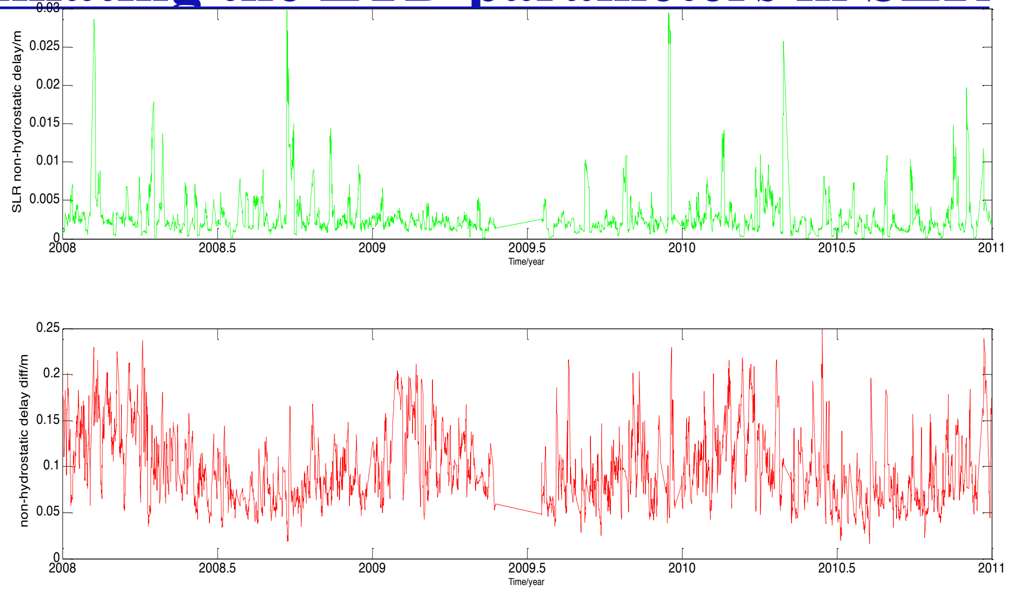


Figure 10. The zenith hydrostatic delay difference between SLR and GNSS at site ZIMM (factor= 1.061392746364195)

2、SLR Quick Processing

Estimating the ZTD parameters in SLR



$$D_L = m_h(e)D_{hz} + m$$
$$m_g(e)[G_N \cos(\alpha) +$$

Figure 11. The estimated SLR and GNSS tropospheric wet delay at site YARA

Compared with the strategy used in GNSS, our SLR orbit determination didn't consider estimating the ZTD parameters. Then we add the ZTD parameters in our estimation. The results shows that there is still a big offset exiting in SLR and GNSS zenith wet delay, since radio wavelength technique is more sensitive to water vapor in troposphere than optical wavelength technique. Next step, we decide to consider the effect of the horizontal gradients of atmosphere on tropospheric delay in SLR, which is described by G. C. Hulley (2007). We will adopt the parameterization (1) used in GNSS to our SLR data processing, then estimate the horizontal gradient parameters G_N and G_E, finally compare them with GNSS .

2、SLR Quick Processing

Improvement of POD solution

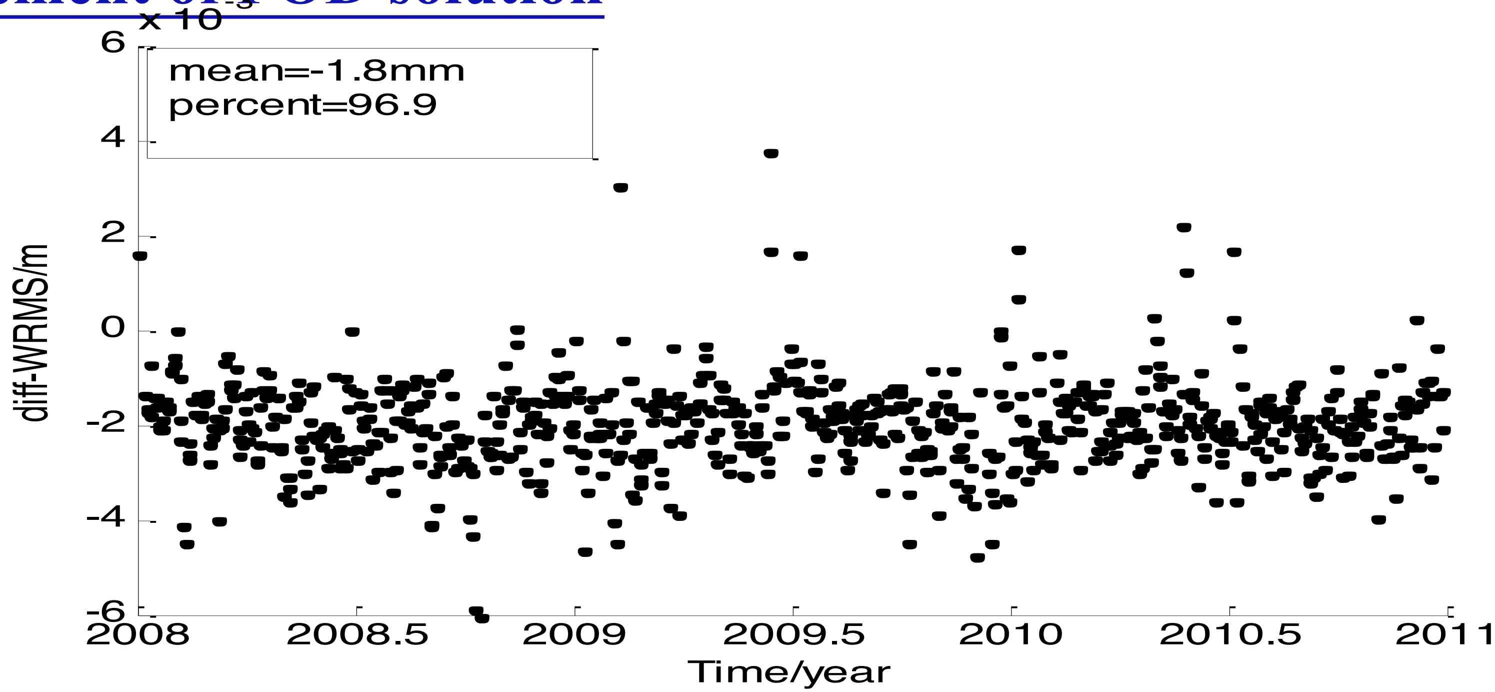


Figure 12. The observation WRMS after estimating the tropospheric parameters

We adopt the parameterization (1) used in GNSS to our SLR data processing. The result shows improvement in the WRMS of the global POD solution. As shown in figure 8, the negative points represents an improvement, and the improvement rate reach 96.9 percent, the average improvement is about 1.8mm.

2、SLR Quick Processing

Estimating the Horizontal gradient parameters in SLR

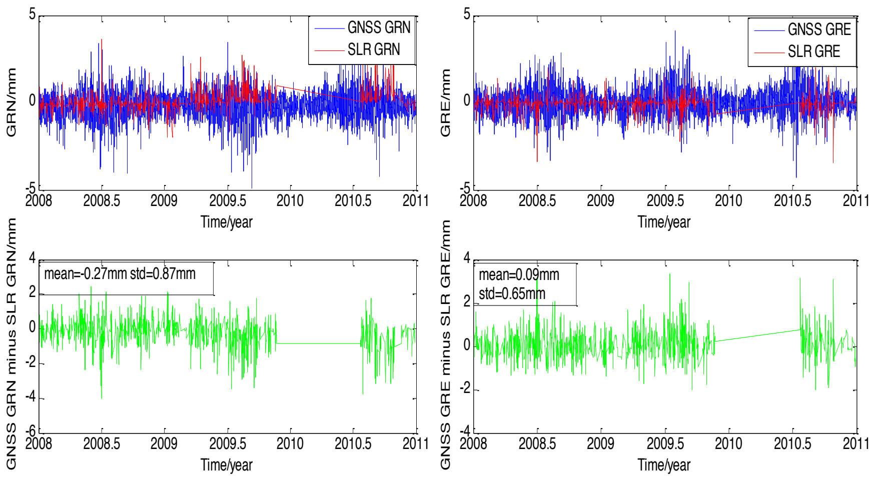


Figure 13 The GRN and GRE difference between SLR and GNSS at site WETZ

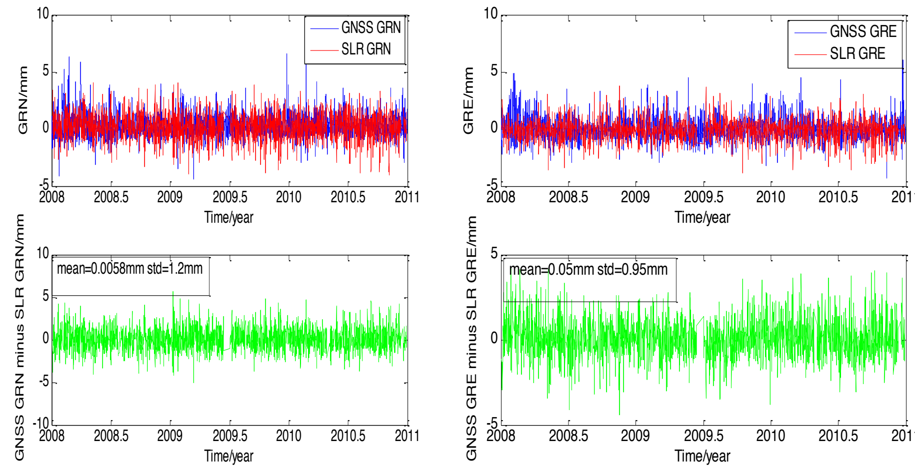


Figure 14 The GRN and GRE difference between SLR and GNSS at site YARA

We compare the horizontal gradient parameters G_N and G_E with GNSS hor parameters at SLR collocation sites WETZ and YARA. The result shows t significant difference between SLR GRN, GRE with GNSS. The mean value o reached 0.27mm in north component and 0. 09mm in east component at site WE the mean value is small, but it has a big standard deviation. It may insufficient observational geometry since SLR system just can observe one time.

2、SLR Quick Processing

Modified Fuzzy C-Means algorithm :

A fuzzy partition of X in C clusters is represented by a matrix, $U = \{u_{xk}\}$, where

$$u_{xk} = [0,1], \qquad \sum_{k=1}^{c} u_{xk} = 1, \qquad \sum_{x \in X} u_{xk} > 0, \qquad k = 1, \ldots, c.$$

Step 1: Define c and ε, a small positive constant. Initialize

$$u_{xk}^{(0)} = \{0,1\}, \qquad k = 1, \ldots, c.$$

Step2: Calculate the initial cluster center

$$v_k^{(0)} = \frac{\sum_{x \in X} (u_{xk}^{(0)})^2 x}{\sum_{x \in X} (u_{xk}^{(0)})^2}$$

Step3: Calculate $g_{v_k}^{(0)}$

$$\wedge_k = \frac{\sum_{x \in X} \left(u_{xk}^{(0)}\right)^2 (x - v_k^{(0)})(x - v_k^{(0)})^T}{\sum_{x \in X}^{n} (u_{xk}^{(0)})^2}, \qquad \forall k = 1, \ldots, c,$$

$$g_{v_k}^{(0)} = |g_{v_k}^{(0)}|^{-1}$$

Step4: $t = t + 1$, start the iteration

$$d_{xv_k} = \sqrt{(x - v_k) \wedge_k^{-1} (x - v_k)^T}, \qquad \mu_{v_k}^{(t)} = \frac{1}{1 + d_{xv_k}^2}$$

$$u_{xk}^{(t)} = \frac{(\mu_{v_k}^{(t)})^{3/2} \sqrt{g_{v_k}^{(t-1)}}}{\sum_{j=1}^{c} \mu_{v_j}^{3/2} \sqrt{g_{v_j}^{(t-1)}}}, \qquad v_k^{(t)} = \frac{\sum_{x \in X} (u_{xk}^{(t)})^2 x}{\sum_{x \in X} (u_{xk}^{(t)})^2}$$

Step5: if $\left| v_k^{(t)} - v_k^{(t-1)} \right| < \varepsilon$ $\forall k$ Stop. Else go to Step 4.

2、SLR Quick Processing

Table2 SLR Global Performance Report Card (2016.05)

Site number	LAG EOS NP total	LAG RMS(mm)	LAG NP RMS(mm)	Short term(mm)	Long term(mm)	% good LAG .NP
1873	1331	10.4	17.0	27.4	12.4	92.0
1879	1399	29.5	1.7	20.9	17.9	93.8
1887	2302	31.2	6.7	20.8	6.5	95.4
1888	4523	30.7	6.0	24.7	5.9	95.2
1889	2421	29.1	4.9	16.2	9.6	97.7
1893	1256	14.1	12.4	22.8	7.2	91.1
7080	2522	11.6	2.3	14.3	6.2	96.2
7501	8425	18.9	2.8	19.8	6.1	90.5
7810	7849	11.4	1.7	13.3		95.3
7941	11488	4.1	1.2	16.1	2.6	96.1

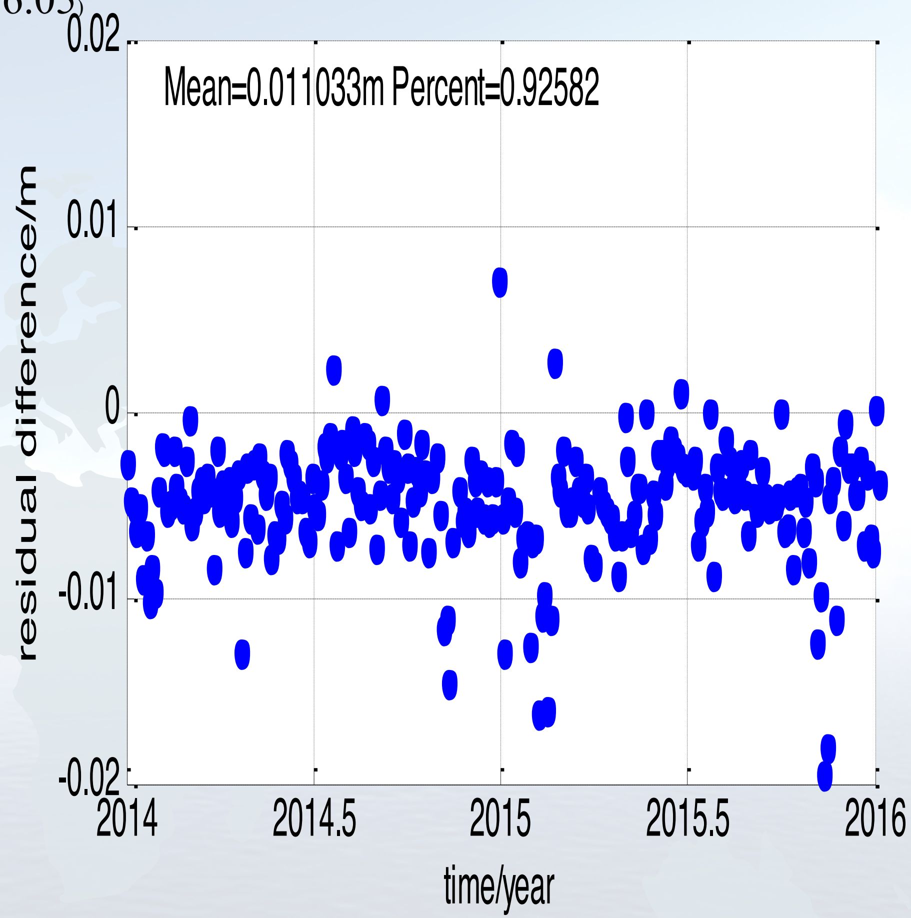


Figure 15. Observational residuals RMS difference after applying FCM reweighting station (solution 2)

3、SLR Post Processing

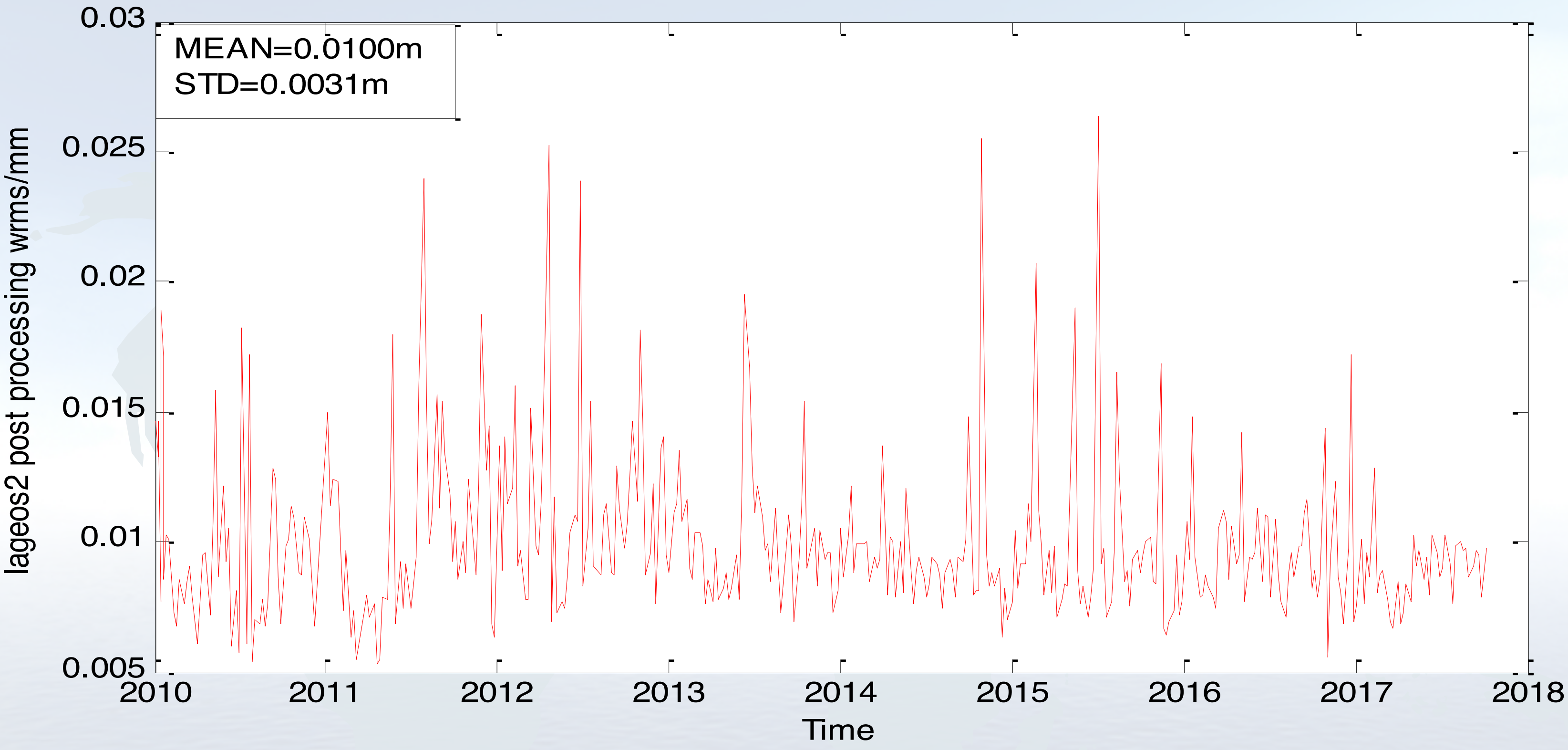


Figure 16. Lageos2 Post processing RMS

3、SLR Post Processing

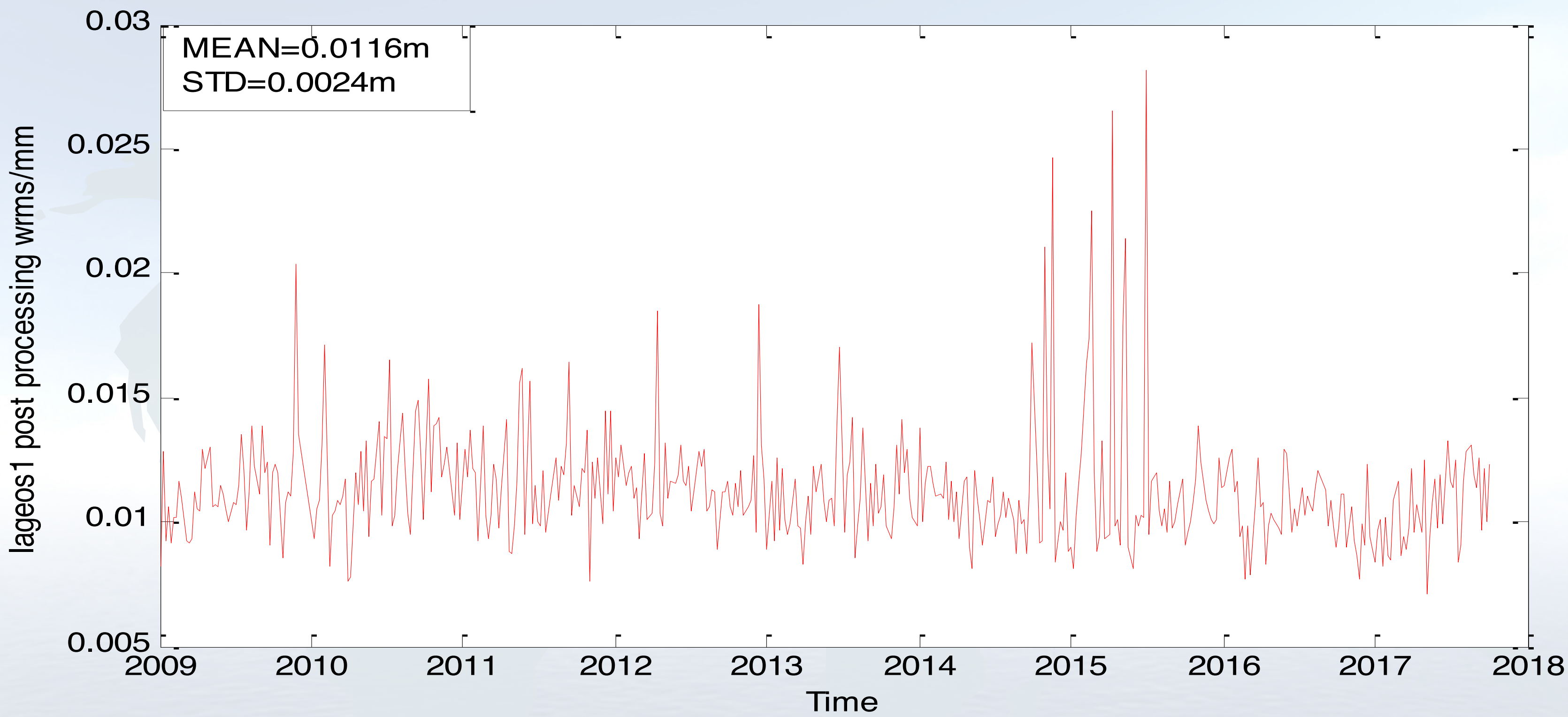


Figure 17 Lageos1 Post processing RMS

3、SLR Post Processing

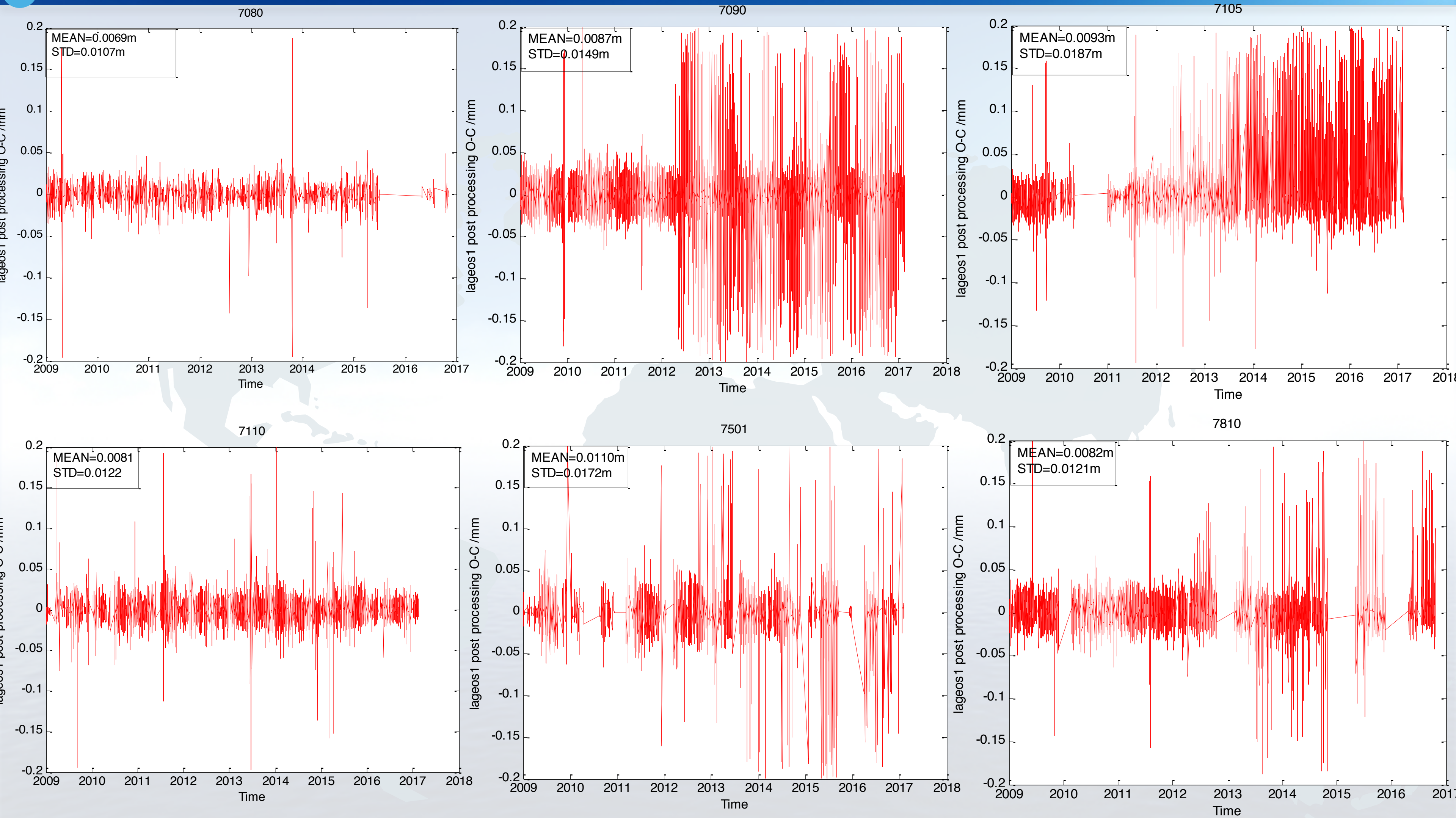


Figure 18. The residual time series of some core station

3、SLR Post Processing

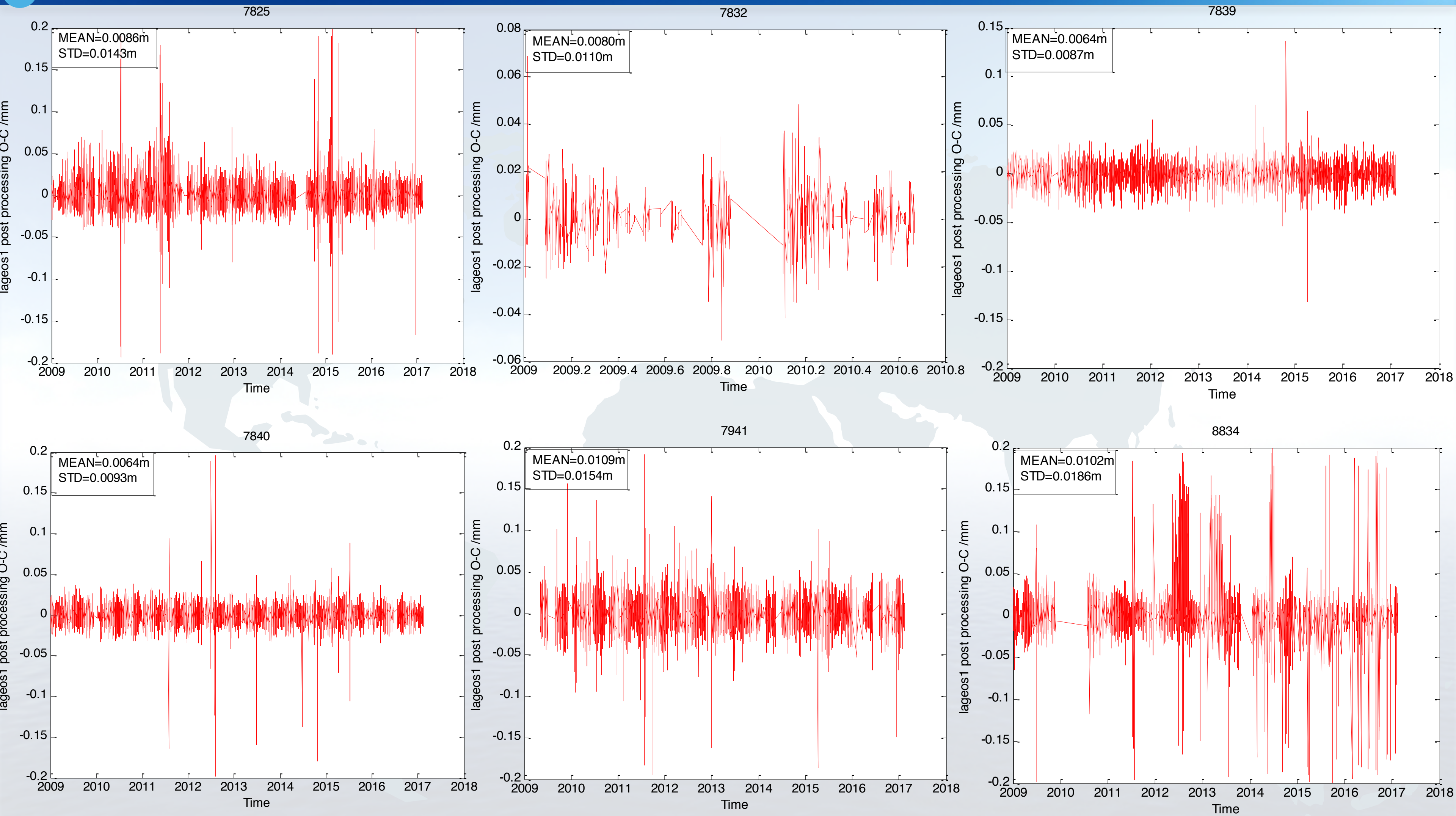


Figure 19. The residual time series of some core station

4、EOP

Table2 Statistics of EOP

Series	Year	Px(mas)	Py(mas)	LOD(ms)
SHAO	2008-2017	0.25	0.35	1.2

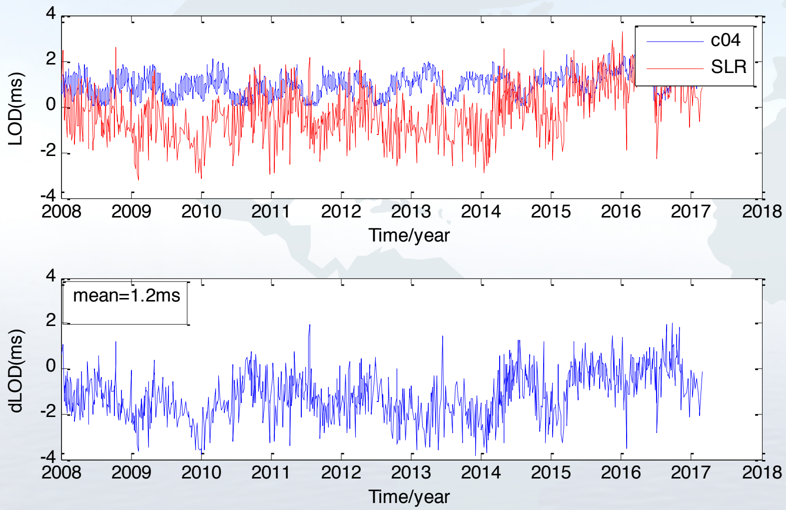


Figure 20. The comparison of LOD with respect to IERS EOP C04

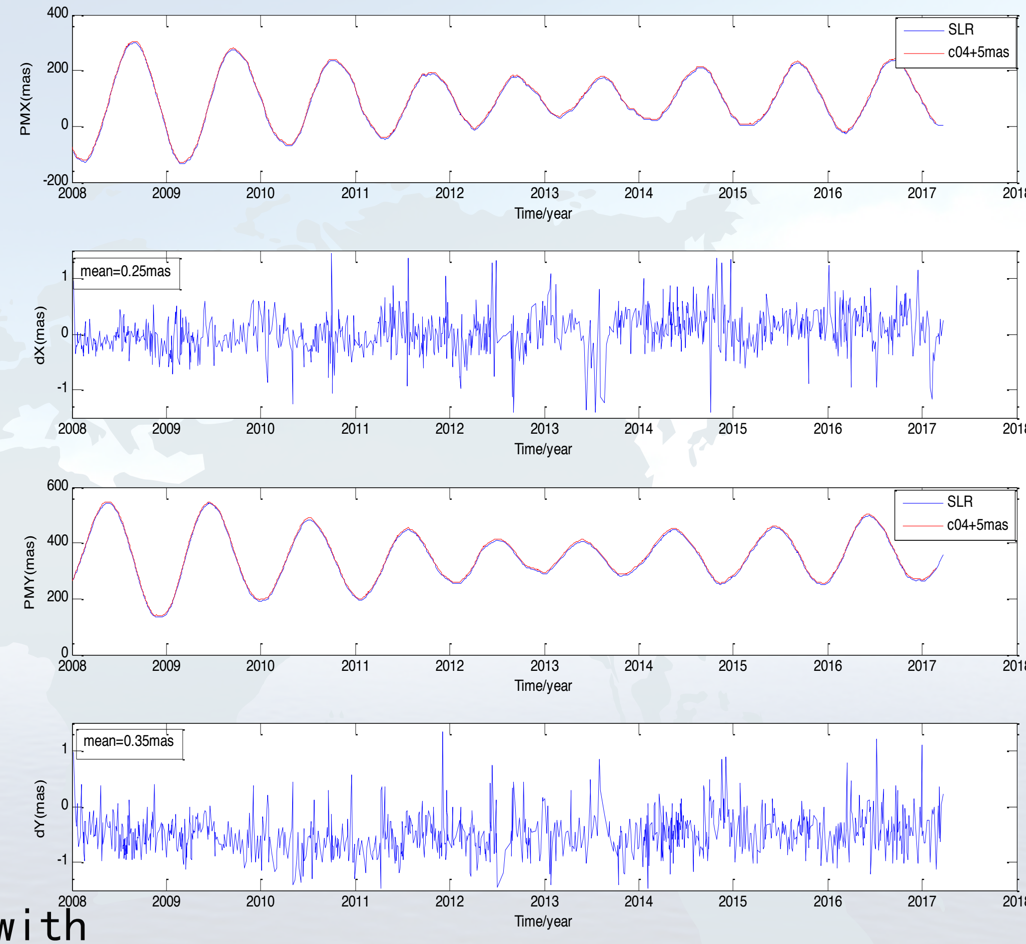


Figure 21. The comparison of of pole motion with respect to IERS EOP C04

5、Combination of SINEX

Step1: read SINEX file of each satellite

Step2: removing a priori constraints

Step3: eliminate the unconcerned parameters

Step4: accumulation of the normal equation

Step5: introduce a new datum

Step6: solve and use Robust Variance Component Estimation to fix the weight for each analysis center

5、Combination of SINEX

Problems:

◆If we do not removing a priori constraints, the combined results could be affected? If yes how much it is?

◆If we want to combined the weekly solution of each AC, we should transfer the SINEX file to a unique datum (eg SLRF2014)?

◆Since the covariance of EOP are very small, when we begin the combination, the weight of EOP are very big. Once it exists a big difference between AC solutions, the EOP error will be shifted to the station solution. How to solve it ?

6. Conclusions and Future plans

- Some SLR models should be improved. It is better for <u>**SLR tropospheric parameters estimated**</u> and <u>**SLR horizontal gradient parameters considered. More reasonable weighting such as FCM reweighting methods should be applied**</u>.
- The LODs of SLR has a bigger difference from IERS C04 LOD. <u>**It needs to continue to look for the reasons.**</u>
- <u>**The combination of different AC solutions need to be continued**</u> and <u>**our SINEX solutions need to be evaluated.**</u>

Acknowledgments

ILRS

National Natural Science Foundation of China (NSFC) No. 11173048

Ministry of Science and Technology of China No.2015FY310200

Thank you for your attention！