SLR in the framework of the EGSIEM project

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A. Maier[1], A. Sušnik[1], U. Meyer[1], D. Arnold[1], R. Dach[1], A Jäggi[1], K. Sośnica[2], D. Thaller[3]

[1]Astronomical Institute, University of Bern, Switzerland,
[2]Institute of Geodesy and Geoinformatics, Wroclaw University of Environmental and Life Sciences, Poland
[3]Federal Agency for Cartography and Geodesy, Frankfurt/Main, Germany;

Introduction

This contribution describes the roles of Satellite Laser Ranging (SLR) within the European Gravity Service for Improved Emergency Management (EGSIEM). One of the purposes of this Horizon 2020 project is to combine monthly gravity field solutions from the Gravity Recovery and Climate Experiment (GRACE) mission that are derived by different institutions. The combined gravity field product will provide complementary information to traditional products for flood and drought monitoring and forecasting. SLR data (Pearlman et al., 2002) to geodetic satellites are used

- to validate the microwave-based GNSS orbits,
- to estimate low-degree terrestrial gravity field coefficients, and
- to establish a reference frame from both GNSS and SLR data.

The poster gives a status report on the current work of the first two out of the three bullets above.

Validation of GNSS orbits using SLR

A reprocessing campaign (Repro15, Sušnik et al. 2016) was initiated at the Astronomical Institute of the University of Bern (AIUB) covering more than 250 globally distributed tracking stations of the International GNSS Service (IGS, Dow et al. 2009). The purpose of this reprocessing is to establish a homogenous and state-of-the-art basis for the GNSS-based orbit determination of GRACE. As an example, the extended Empirical CODE Orbit Model (ECOM, Arnold et al. 2015) was used for this reprocessing campaign. The reprocessing products include GNSS orbits (GPS since 1994; GLONASS starts in 2002) and ultra high-rate satellite clock corrections with a sampling of up to 5 seconds (GPS since 2003; GLONASS 30 seconds between 2008 and 2011, later 5 seconds).

The principle of validating GNSS orbits using SLR is as follows: the SLR observations ('observed') are directly compared against the geometry based on the coordinates of the SLR stations in the SLRF 2008 reference frame and the microwave-based orbit ('computed') without estimating any parameter. The residuals ('observed minus computed') indicate how well the orbits agree with the SLR observations.

Fig. 1 demonstrates the benefit of the extended ECOM over the classical one. Thanks to the twice-per-revolution empirical parameters in the satellite-Sun direction, which are estimated in case of the extended ECOM, the elongation-dependent systematic pattern has been significantly reduced.

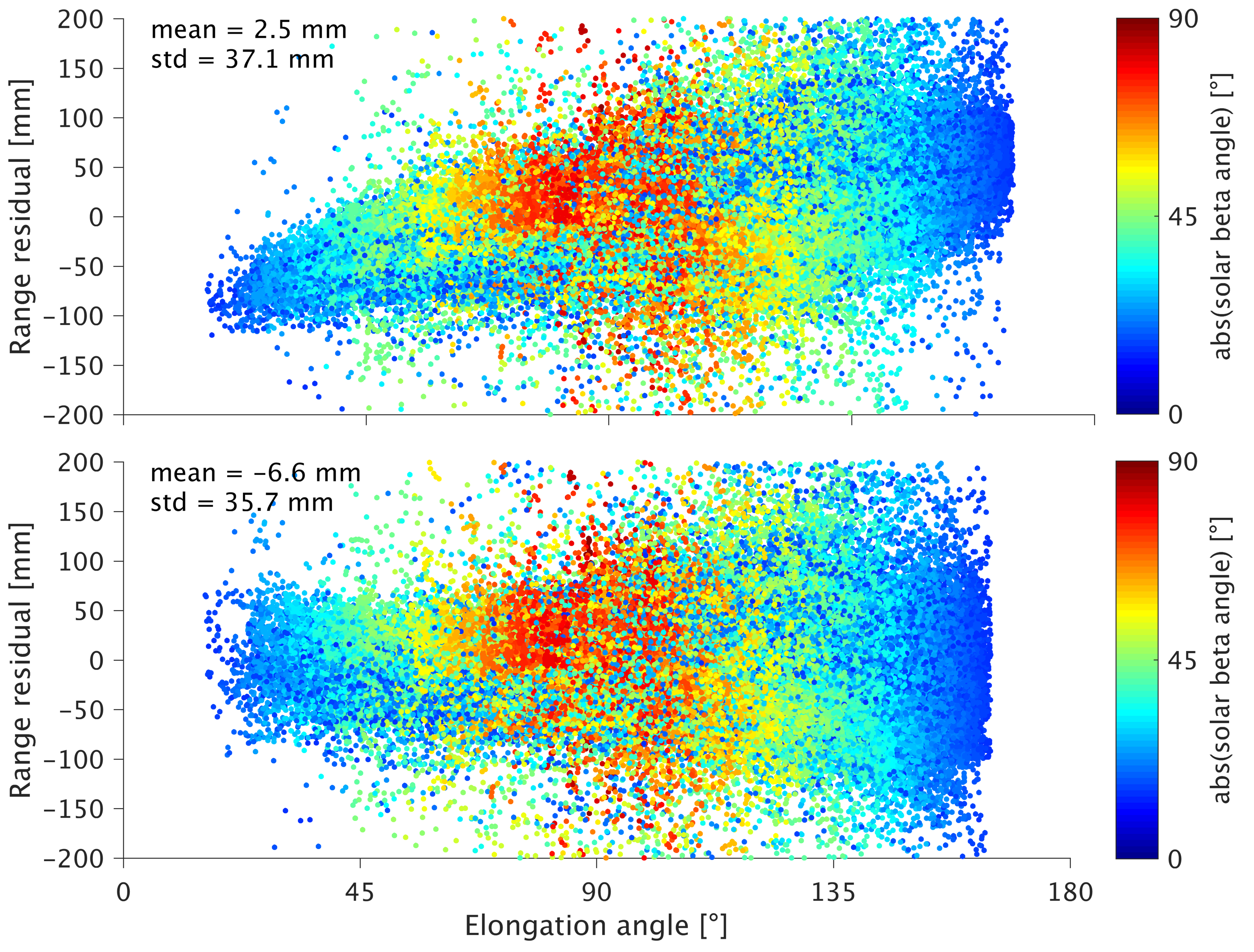

Figure 1: SLR residuals w.r.t. 3-day GLONASS-M orbits between January 2000 and December 2013 using the classical ECOM (top) and the extended ECOM (bottom). The residuals are shown as a function of the elongation angle (i.e., the angle between Sun and satellite as seen from the geocenter) and of the solar beta angle (i.e., the elevation of the Sun above the orbital plane). Mean value (mean) and standard deviation (std) are computed w.r.t. all residuals whose absolute value is smaller than 150 mm. Furthermore, all residuals having an absolute beta angle smaller than 15° have not been taken into account due to uncontrolled attitude during eclipses. The SLR residuals to SVN 723, 725, 736, and 737 have been excluded due to anomalous behavior.

The SLR residuals to the orbits of certain GLONASS satellites (SVN 723, 725, 736, and 737, for instance) increase with the life time of the satellite as shown in Fig. 2. The four mentioned satellites belong to the same orbital plane. The effect of the increasing residuals, however, is not a modeling issue since other satellites in the same orbital plane (e.g, SVN 716, 724, 729) do not show this effect.

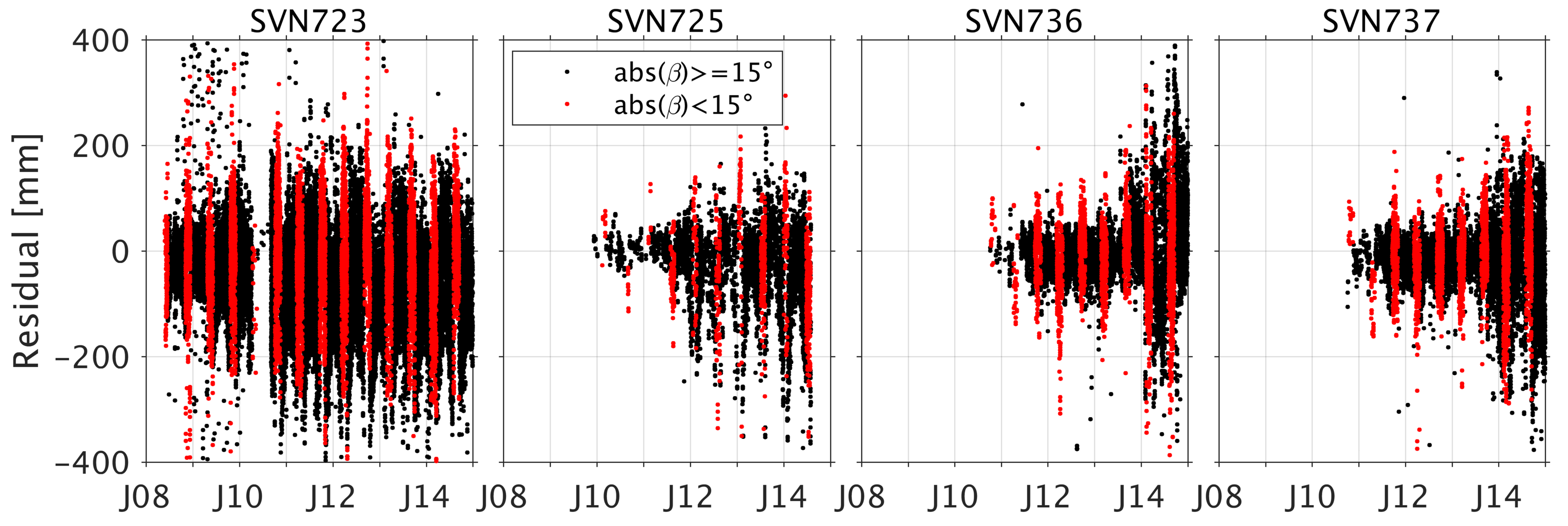

Figure 2: SLR residuals w.r.t. 1-day GLONASS orbits between January 2008 and December 2014 using the extended ECOM. Observations during satellite eclipses (solar beta angle smaller than 15°) are colored red. The residuals of SVN 723 are generally larger compared to other satellites. The residuals of all four satellites seem to increase the longer the satellites are in orbit.

Using the classical ECOM the daytime residuals are slightly shifted towards negative values. They are, however, more evenly distributed when the extended ECOM is used (cf. Fig. 3).

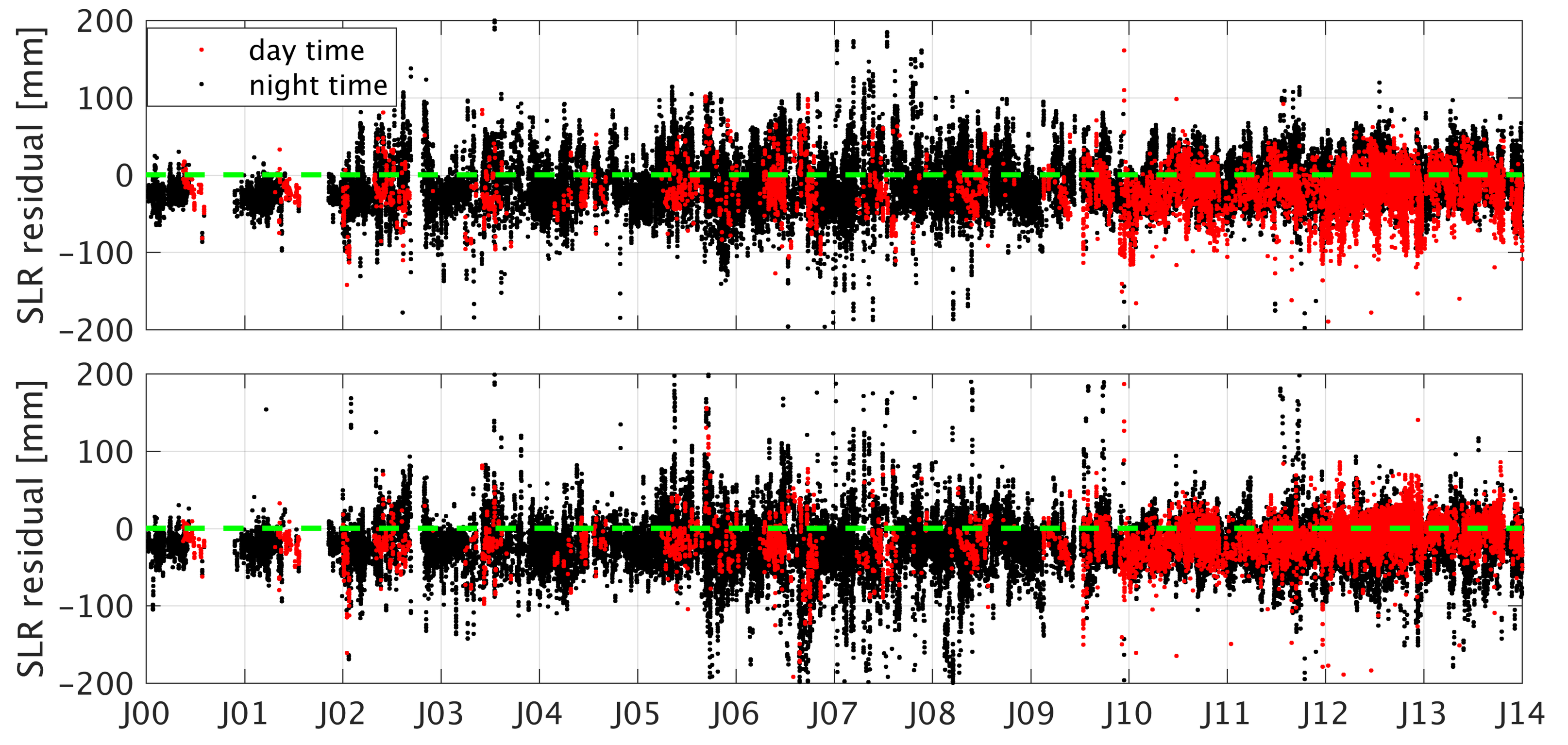

Figure 3: SLR residuals from the tracking station in Yarragadee, Australia, w.r.t. 3-day GLONASS orbits between January 2000 and December 2014 using the classical ECOM (top) and the extended ECOM (bottom). The residuals are subdivided into daytime (07:00 to 19:00 local time) and nighttime observations (19:00 to 07:00 local time). The mean value of the daytime residuals amounts to -22 mm and -16 mm for the classical and the extended ECOM, respectively. Residuals to SVN 723, 725, 736, and 737 as well as residuals during eclipses have been excluded

Low-degree gravity field estimation using SLR

Satellite laser ranging to geodetic satellites is the best technique to derive the Earth's dynamical oblateness (i.e., the C_{20} gravity field coefficient). Typically, GRACE-based estimates of C_{20} do not reflect the seasonal signals as well as SLR-based ones due to aliasing on the 161-day frequency. This is why the monthly gravity field normal equations (NEQs) resulting from GRACE data analysis

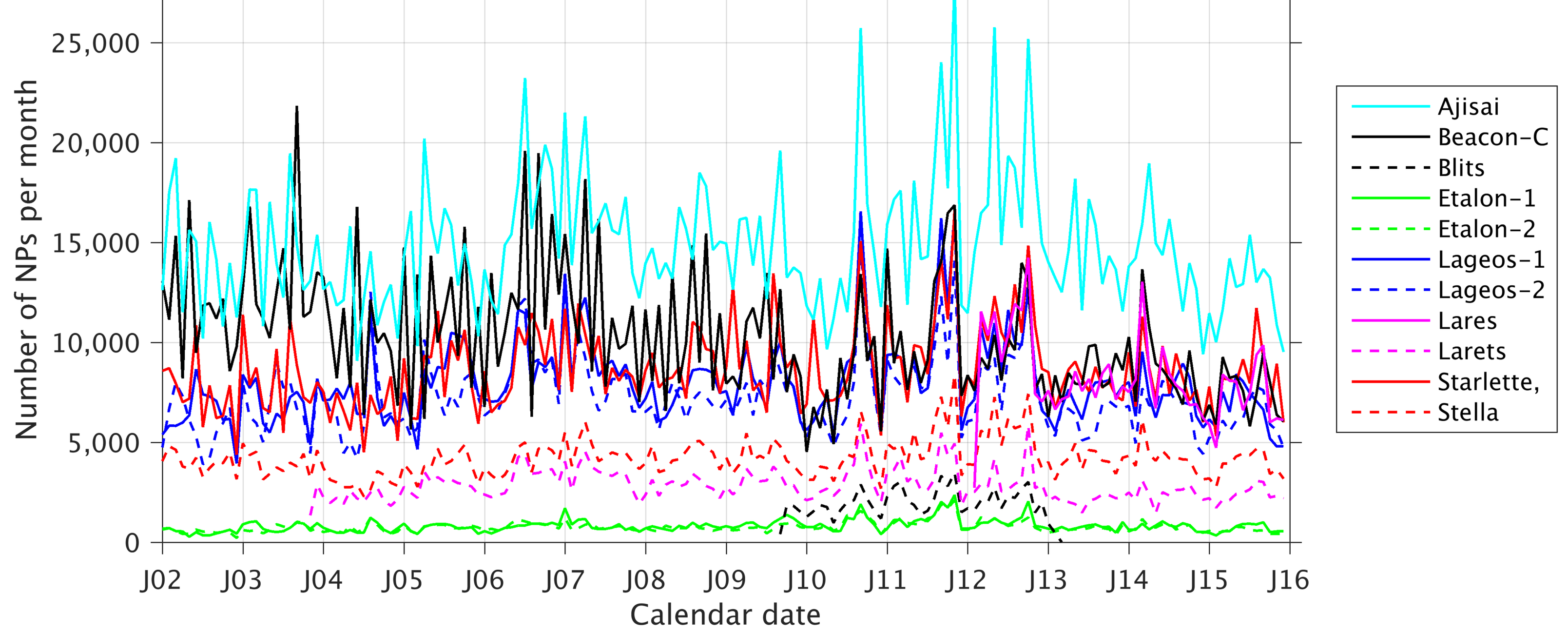

Figure 4: Number of normal points (NPs) per month to geodetic satellites and Beacon-C between January 2002 and December 2015.

will be combined with SLR normal equations. Up to this date, monthly gravity field coefficients up to spherical harmonic degree and order (d/o) 3 have been estimated between January 2003 and December 2015. Observations to LAGEOS-1 and -2, Ajisai, Stella, and Starlette were analyzed. Fig. 4 depicts the number of normal points (NPs) to all geodetic satellites and Beacon-C. To strengthen our solution, we intend to include data to Lares, Larets and Beacon-C. For the time being, however, each 30-day gravity field set is composed by 3 10-day LAGEOS NEQs and 30 1-day NEQs to the lower orbiting satellites Ajisai, Stella, and Starlette (see Table 1 and Sośnica et al. 2015 for more information about orbit modeling and estimated parameters).

Table 1: Estimated arc-specific and common parameters from SLR data.

	LAGEOS-1/2	Stella, Starlette, Ajisai
Arc-specific parameters:		
Osculating elements	1 set per 10 days	1 set per day
Dynamical parameters	constant and 1/rev in along track (1 set per 10 days)	constant and 1/rev in along track, 1/rev in cross track (daily)
Pseudo-stochastic pulses	none	1/rev in along track
Common parameters:		
Earth rotation parameters	X_P, Y_P, UT1-UTC (piecewise linear, 1 set per day)	
Geocenter coordinates	1 set per 30 days	
Gravity field coefficients	up to d/o 3 (1 set per 30 days)	
Station coordinates	1 set per 30 days	
Range biases	for selected stations (1 set per 30 days)	for all stations (1 set per 30 days)

Fig. 5 (left) depicts our estimated C_{20} coefficients. It is interesting to notice that the long-term trend of our solution fits the trend of the GRACE solution significantly better than the SLR solution from CSR does. The offset between our solution and the external SLR-based solution is under investigation. The afore mentioned 161-frequency is easy to detect in the amplitude spectrum of the GRACE series (Fig. 5, right). Annual and semiannual signal are well distinguishable in the two SLR series.

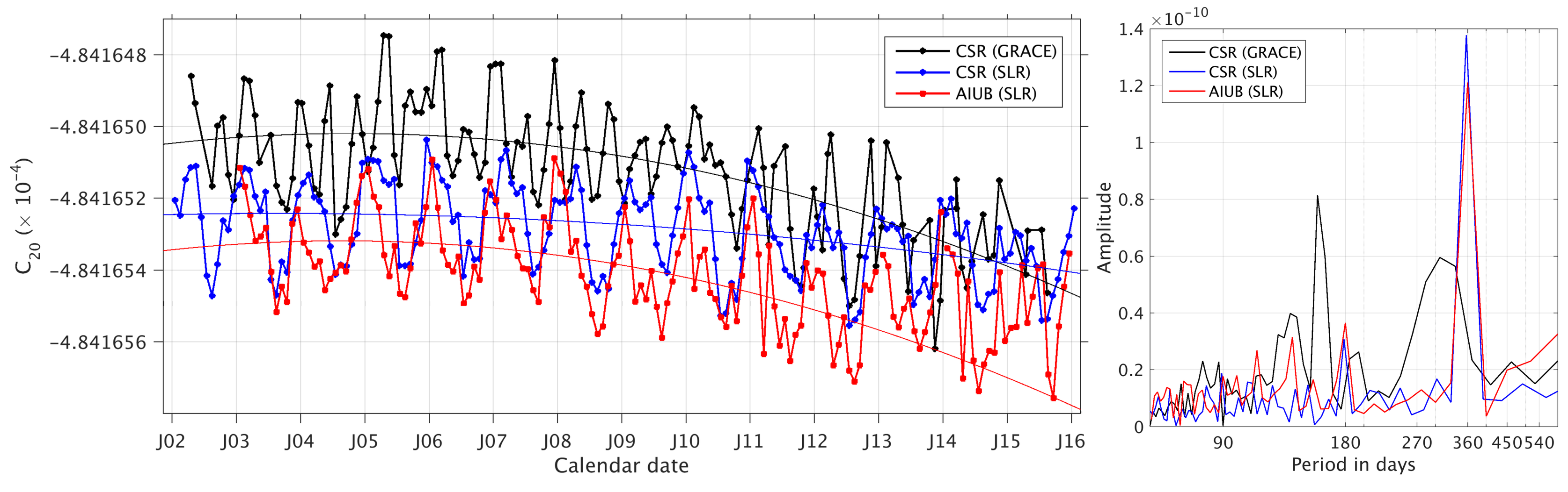

Figure 5: (Left) Monthly C_{20} coefficients. Our solution (January 2003 to December 2015, red squares) is compared to an SLR-based solution (blue circles) and a GRACE-based solution (black circles) stemming both from the Center for Space Research (CSR) at Austin, Texas. All three solutions were fit by a polynomial of second degree. (Right) Spectral analysis of the three C_{20} series.

Summary

The validation of the reprocessed GNSS orbits using the extended ECOM showed that the elongation-dependency of the SLR residuals could be significantly diminished. Apart from a small bias, the monthly C_{20} coefficients derived from SLR data agree well with the solution from CSR. The bias between the two SLR series is under investigation.

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Contact address

Andrea Maier
Astronomical Institute, University of Bern
Sidlerstrasse 5
3012 Bern (Switzerland)
andrea.maier@aiub.unibe.ch

Poster compiled by A. Maier, April 2016
Astronomical Institute, University of Bern, Bern
andrea.maier@oeaw.ac.at