Earth Rotation and Gravity Field Parameters from Satellite Laser Ranging

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Remembering the Past and Planning for the Future›
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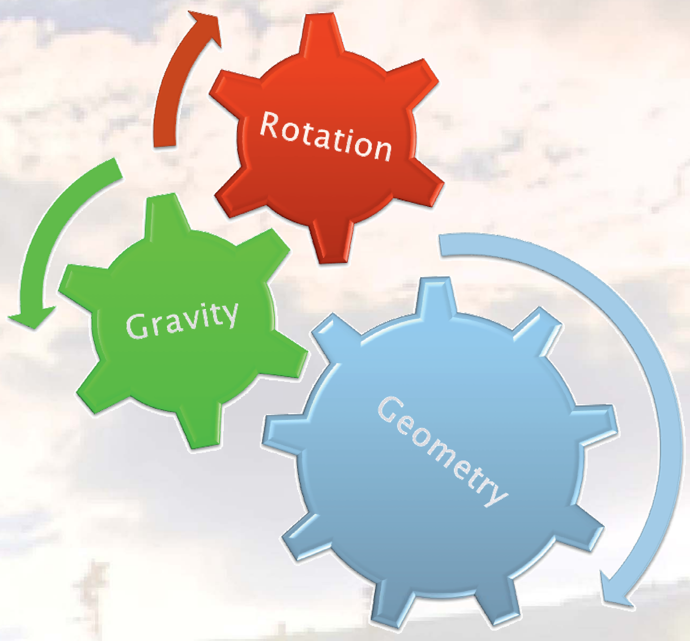

Introduction

The main 'three pillars' of satellite geodesy can be summarized as:

- precise determination of geometrical three-dimensional positions and velocities (geometry),
- modeling and observing of geodynamical phenomena including the Earth rotation parameters (ERP, rotation),
- determination of the Earth's gravity field and its temporal variations (gravity).

Although all three pillars describe geodetic and geodynamic phenomena within the system Earth, the gravity has typically been treated separately from the geometry and rotation. Many SLR solutions comprise the estimation of SLR station coordinates, pole coordinates and the Length-of-Day (LoD) from the 7-day combined LAGEOS-Etalon solutions, whereas the gravity field parameters are not provided. On the other hand, when estimating gravity field parameters from SLR data, the parameters related to geometry and rotation have typically been fixed so far and not simultaneously estimated.

We present the results from a simultaneous estimation of the gravity field up to d/o 10/10, Earth rotation parameters, and station coordinates from a combined SLR solutions incorporating spherical geodetic satellites: LAGEOS-1/2, Starlette, Stella, AJISAI, Beacon-C, Blits, Larets and LARES. These solutions cover all three pillars of satellite geodesy and ensure a full consistency between the Earth rotation parameters, gravity field coefficients, and geometry-related parameters.

Earth's Gravity Field from SLR

Figure 1 shows the time series of exemplary tesseral S_{42} and sectorial S_{44} and C_{66} coefficients of degree 4 and 6. The figure clearly proves that not only the zonal and degree 2 coefficients can be well established from SLR solutions, but also tesseral and sectorial terms, even of degree 6.

Figure 2 compares the monthly gravity field models obtained from GRACE up to d/o 60/60 (top), GRACE up to d/o 10/10 (middle) and SLR up to d/o 10/10 (bottom) w.r.t. reference field EGM2008. Figure 2 proves that the most pronounced temporal geoid deformations, e.g., in Greenland, Amazonia, North America agree well between GRACE and SLR solutions and thus can be well recovered also by SLR solutions. On the other hand, the smaller geoid deformations can be recovered by SLR only to a limited extent, e.g., in Southern Africa and Southeast Asia. SLR-derived deformations are smoothed as compared to GRACE results and the amplitudes of geoid deformations are reduced. Nevertheless, the large-scale mass redistribution can be also recovered from the SLR analysis.

Figure 3 shows the amplitudes of annual signals for low-degree coefficients in the SLR (left) and GRACE solutions (middle) and the differences of the amplitudes in both solutions (right). The amplitudes in SLR solutions are typically underestimated by about 10% as compared to the GRACE results. The agreement between SLR and GRACE is at 77% level in terms of low-degree coefficients.

Figure 4 reveals that the seasonal variations of, e.g., C_{50} in the SLR solutions are underestimated as compared to the GRACE results. The SLR-derived amplitude of annual signal is smaller by 48% than the amplitude from GRACE solutions. However, including LARES into the SLR solutions in February 2012 substantially improves the SLR solutions and, as a result, reduces the difference of annual signal to about 11% (in 2012-2013).

Figure 5 shows the benefit of the simultaneous estimation of ERPs and station coordinates on the estimated gravity field coordinates. It shows that wrong a priori values of coordinates of the stations in South America and Japan affected by earthquakes in 2010-2011 can influence the SLR-derived parameters.

The AIUB-SLR monthly gravity field solutions are available from the International Centre for Global Earth Models (ICGEM) website.

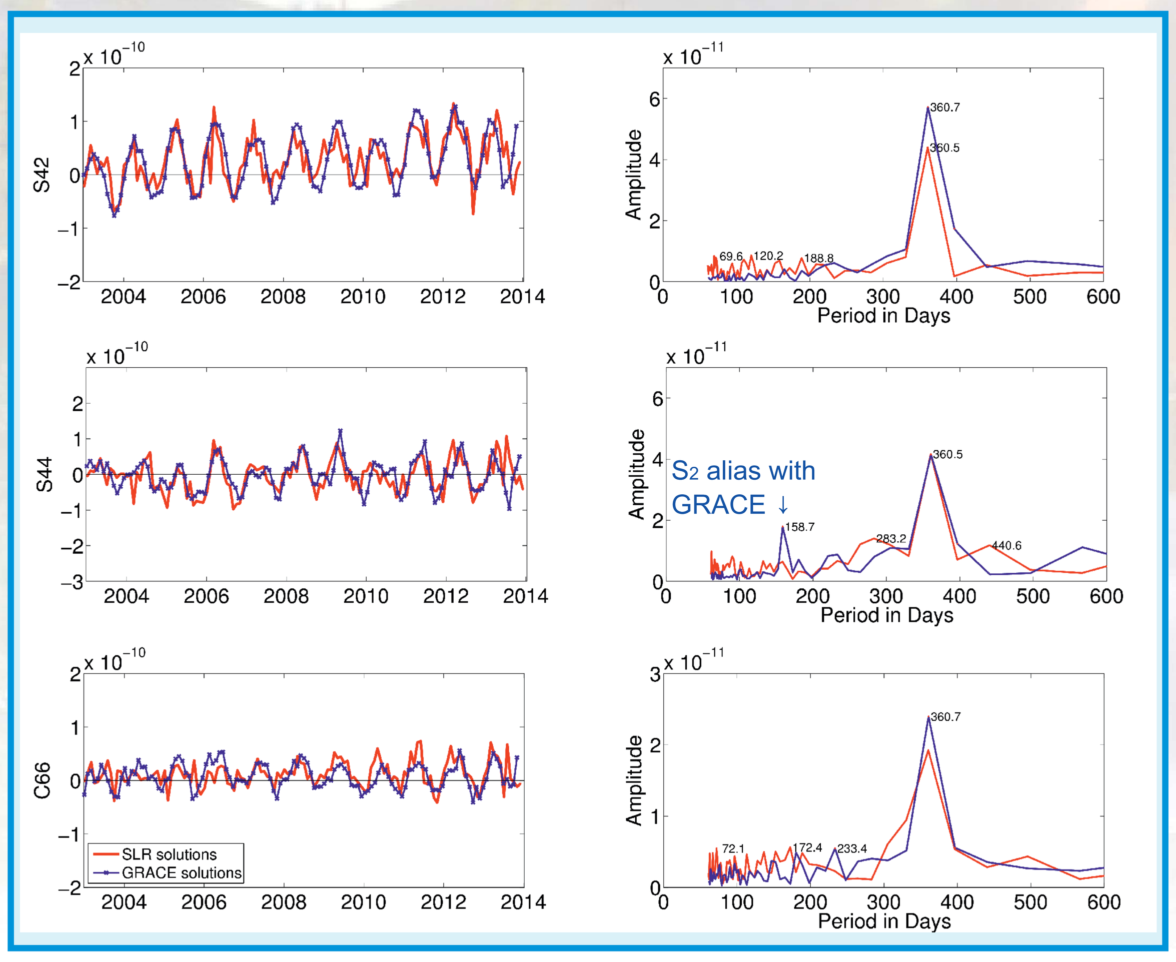

Fig: 1: S_{42} (top), S_{44} (middle), C_{66} (bottom) variations w.r.t. EGM2008 derived from SLR and GRACE AIUB-RL02 solutions (left) and the spectral analysis of the series (right).

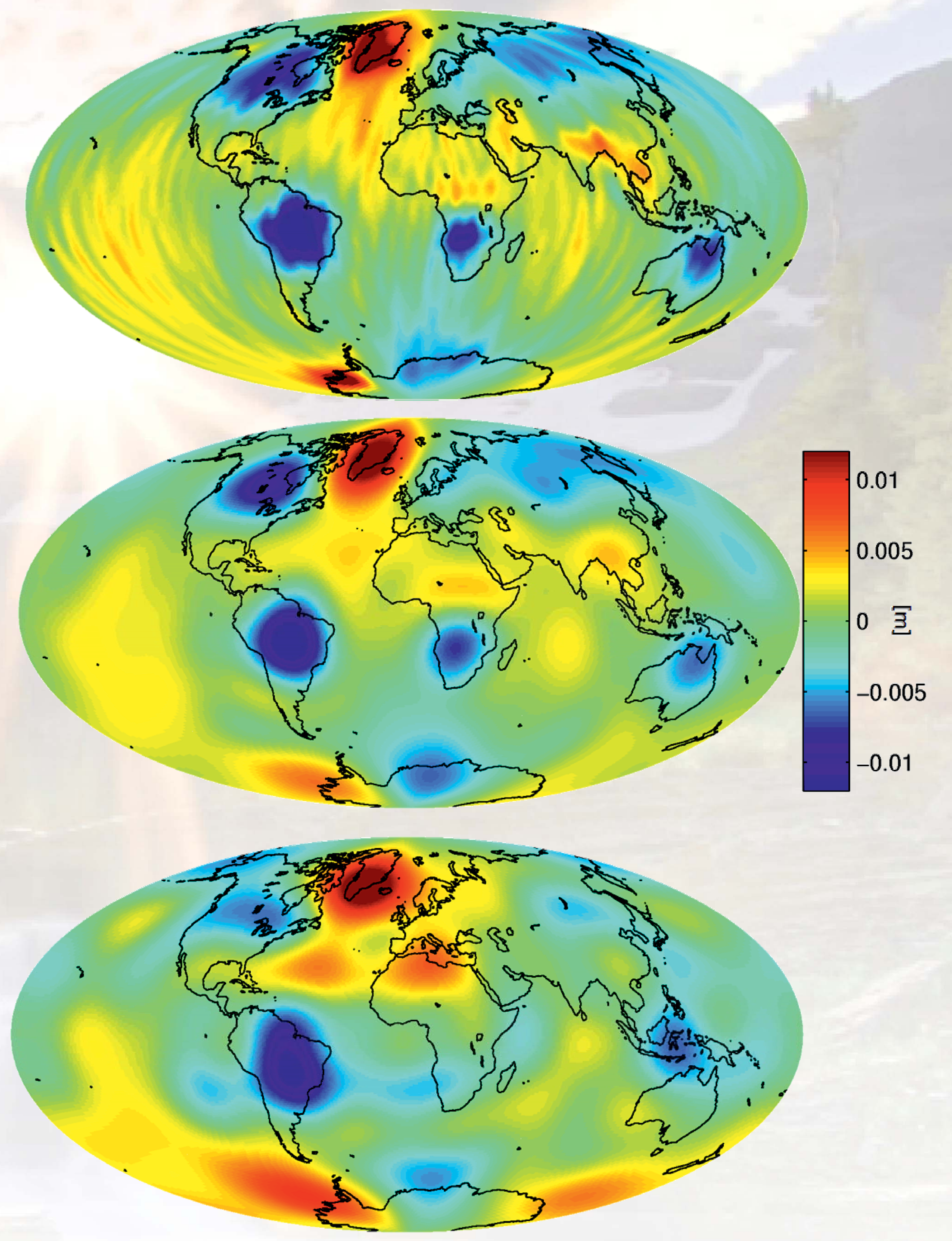

Fig: 2: Monthly gravity field models w.r.t. EGM2008 for March 2011, derived from GRACE (AIUB-RL02) solutions up to d/o 60/60 with Gaussian filtering of 300 km (top), GRACE solutions up to d/o 10/10 with no filtering (middle), and SLR solutions up to d/o 10/10 with no filtering (bottom).

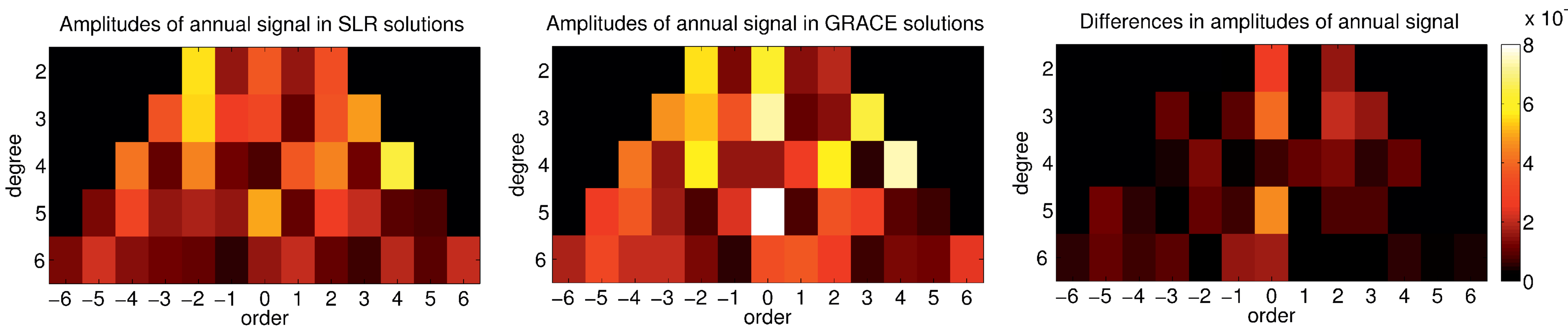

Fig: 3: Amplitudes of annual signals in GRACE solutions (left), SLR solutions (middle) and the difference (right).

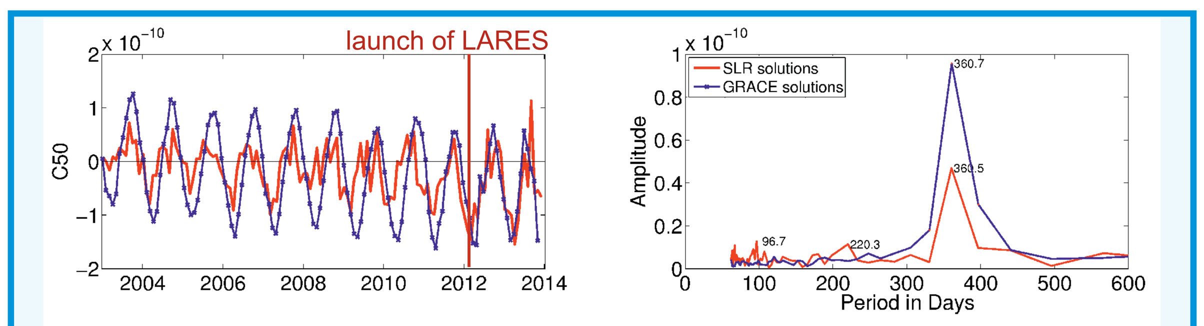

Fig: 4: C_{50} variations w.r.t. EGM2008 derived from SLR and GRACE solutions (left) and the spectral analysis of the series (right).

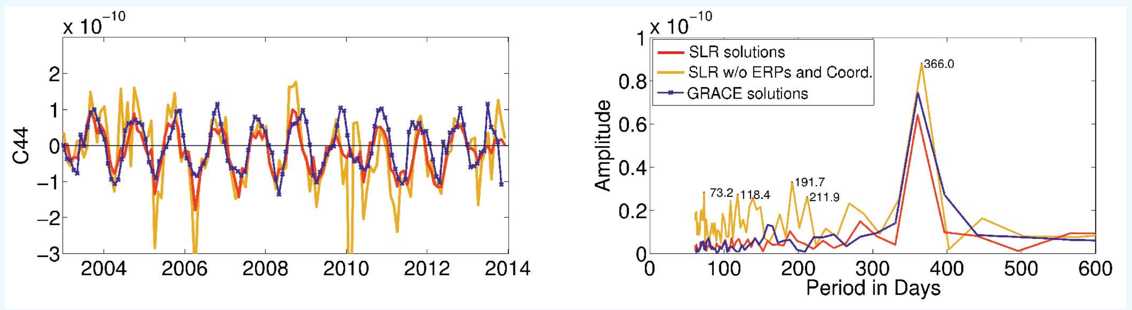

Fig: 5: C_{44} series w.r.t. EGM2008 from standard SLR solutions, SLR solutions without co-estimating ERPs and station coordinates and the GRACE solutions.

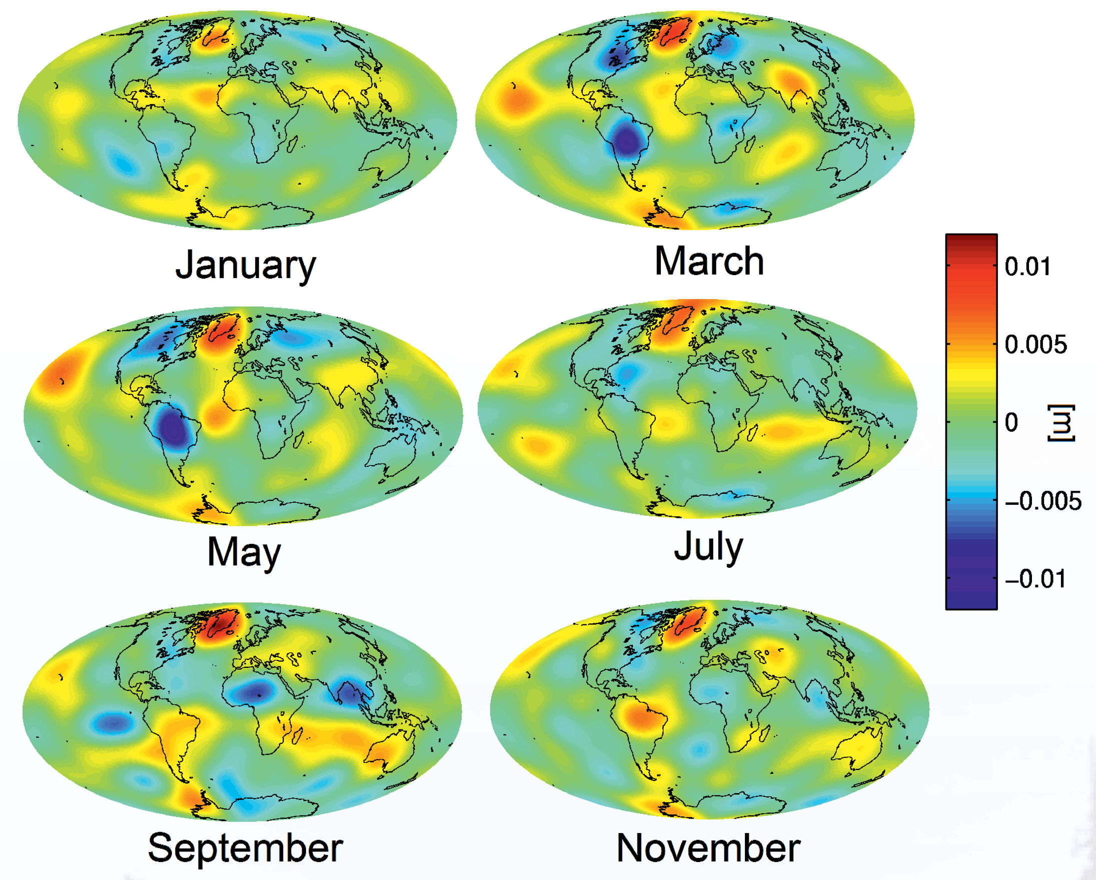

Fig: 6: Mean monthly gravity field variations from SLR solutions up to d/o 10/10 w.r.t. EGM2008, no filtering applied.

Earth Rotation Parameters

The simultaneous estimation of the gravity field parameters along with other geodetic parameters (e.g., pole coordinates, LoD, station coordinates):

(1) reduces the offset of Length-of-Day (LoD) estimates w.r.t. IERS-08-C04 series (Fig. 7, left), which is mostly due to absorption of the C_{20} variations by LoD estimates,

(2) reduces peaks in the spectrum analysis (Fig 7, middle), which correspond, e.g., to orbit modeling deficiencies (peaks of 222 days, i.e., a draconitic year of LAGEOS-2, 280 days, i.e., an eclipsing period of LAGEOS-1),

(3) substantially reduces the a posteriori error of estimated LoD (Fig. 7, right, notice a logarithmic scale for the y axis). The mean a posteriori error of LoD is 1.3, 16.9, 7.1, and 44.6 µs/day in the multi-SLR solution with gravity, multi-SLR solution without gravity, LAGEOS-1/2 solution without gravity, and SLR-LEO solution without gravity field parameters, respectively. The RMS of pole coordinates is, however, sligthly increased in the multi-SLR solution with estimating gravity as compared to the multi-SLR solution without gravity estimation.

The a posteriori error of LoD in the multi-SLR solutions (16.9 µs/day) is more than factor of two higher than in the LAGEOS solutions (7.1 µs/day) when the gravity field parameters are not estimated. This quality degradation implies that the estimation of the gravity field parameters is essential for high-quality LoD estimates when using SLR observations to low orbiting geodetic satellites.

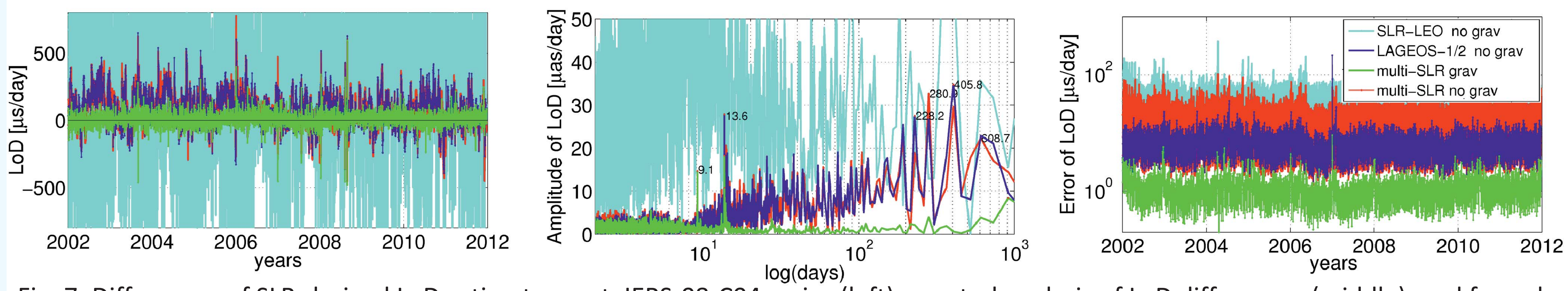

Fig: 7: Differences of SLR-derived LoD estimates w.r.t. IERS-08-C04 series (left), spectral analysis of LoD differences (middle), and formal errors. Following solutions are compared: Starlette+Stella+AJISAI (SLR-LEO), LAGEOS-1+LAGEOS-2, (both without estimating gravity field) Starlette+Stella+AJISAI+LAGEOS-1+LAGEOS-2 without estimating gravity (multi-SLR) and with estimating gravity field (multi-SLR).

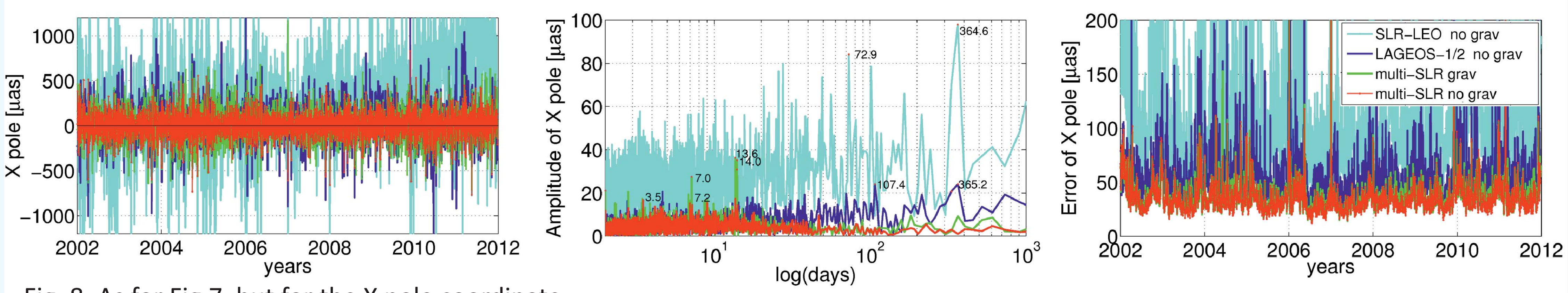

Fig: 8: As for Fig.7, but for the X pole coordinate.

Summary

- The low-degree gravity field coefficients up to d/o 10/10 can be very well established from the SLR observation to geodetic satellites.
- The largest seasonal variations in geoid deformations, e.g., in Amazonia, Southeast Asia, Greenland and Africa (see Fig. 6) can be well derived from the SLR solutions with the agreement at 77% level with the GRACE results in terms of amplitudes of seasonal signals.
- The simultaneous estimation of the gravity field parameters, ERP, and station coordinates leads to a minor degradation of the pole coordinate quality in the multi-SLR solutions (see Fig. 8), but substantially improves the quality of LoD estimates (see Fig. 7). The simultaneous estimation of all parameters is also beneficial for the Earth's gravity field determination (Fig. 5).

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