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Geocentre motion and Earth's dynamic oblateness time-series derived from GRACE CSR RL06 solutions and geophysical models

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1. Introduction

With the launch of the Gravity Recovery and Climate Experiment (GRACE) satellite mission in 2002 (http://www.csr.utexas.edu/grace), Satellite Gravimetry has become a unique tool to estimate hydrological water balance and mass balance of ice sheets, as well as to monitor mass re-distribution in the oceans and the solid Earth. However, satellite gravimetry still suffers from a poor estimation of temporal variations in the spherical harmonic coefficient C_{20} (which is associated with the Earth's dynamic oblateness). Therefore, these variations are typically extracted from Satellite Laser Ranging (SLR) data. Furthermore, satellite gravimetry is not sensitive to variations of degree-1 spherical harmonic coefficients (i.e., C_{10}, C_{11}, and S_{11}), which are associated with the geocentre motion. Swenson et al (2008) proposed to restore those coefficients using as a reference an area where the mass anomalies are known. Such an area was chosen as the entire world ocean; mass anomalies there were defined as variations of the Ocean Bottom Pressure based on an ocean circulation model. The Glacial Isostatic Adjustment signal was corrected for by applying a remove-restore approach.

Sun et al (2016) further developed the technique by Swenson et al (2008). First, the Self-Attraction and Loading (SAL) effects were additionally modelled in order to estimate water re-distribution in the ocean more accurately. Second, a buffer zone around the continents was excluded from the reference area in order to suppress the effect of "signal leakage" caused by a limited spatial resolution of satellite gravimetry. It was shown that the modified technique allows for an accurate estimation of both degree-1 and C_{20} variations.

2. Major goals and methodology

Major goals of this study: to assess the performance of the technique by Sun et al (2016) using GRACE RL06 monthly solutions that were released recently by the Center for Space Research (CSR) at the University of Texas at Austin.

The following research questions are addressed:

- At what degree should the monthly solutions be truncated in view of an increased noise level in high-degree spherical harmonic coefficients? How important is this choice?
- How do the obtained results compare with those produced in the conventional way (when variations of the degree-1 coefficients are estimated with the original methodology by Swenson et al (2008), whereas the C_{20} coefficients are based on SLR data)?
- How do the resulting mass anomalies compare with those based on the GRACE CSR RL05 data?

Validation methodology: the methodology proposed by Sun et al (2017) is adopted. After an estimation of the low-degree spherical harmonic coefficients (i.e., C_{10}, C_{11}, S_{11}, and C_{20}), mass anomaly time-series over test areas are produced. All those areas are located inside deserts. Since mass variations in these desert regions are minor, the recovered mass anomalies reflect, to a large extent, inaccuracies in the low-degree coefficients. Importantly, inaccuracies in a given coefficient do not manifest themselves everywhere. For instance, mass anomalies at the poles are not sensitive to inaccuracies in the C_{11} and S_{11} coefficients because the associated spherical harmonics turn there into zero. Therefore, it is essential to make a careful choice of the geographical distribution of the test areas. Both monthly mass anomalies themselves and mean mass anomalies per calendar month are analysed.

3. Results

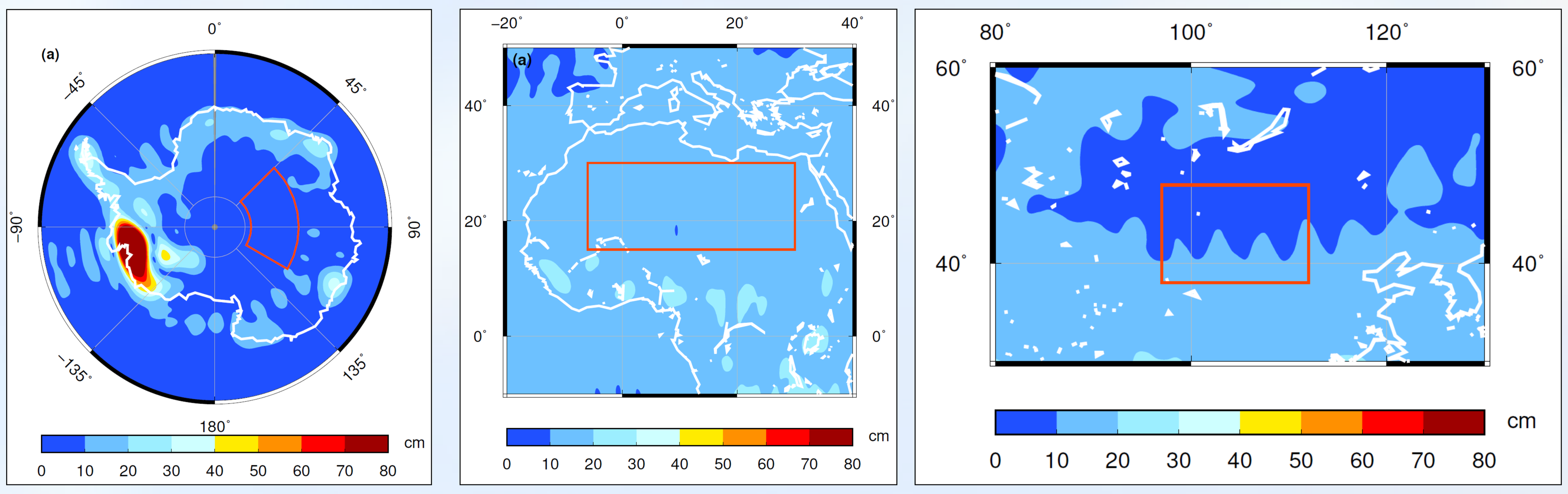

Fig. 1 RMS signal in the mass anomaly time-series estimated for three test areas (shown in red): within the East Antarctic Ice Sheet (EAIS, left), within the Sahara Desert (middle), and around the Gobi Desert (right). The East Antarctica area is mostly sensitive to inaccuracies in C_{10} and C_{20} coefficients. Sahara Desert is mostly sensitive to inaccuracies in C_{11}. Gobi Desert is mostly sensitive to inaccuracies in S_{11}. The estimates are produced from the GRACE CSR RL06 solutions with the technique of Sun et al (2016). The units are cm of Equivalent Water Heights (EWH).

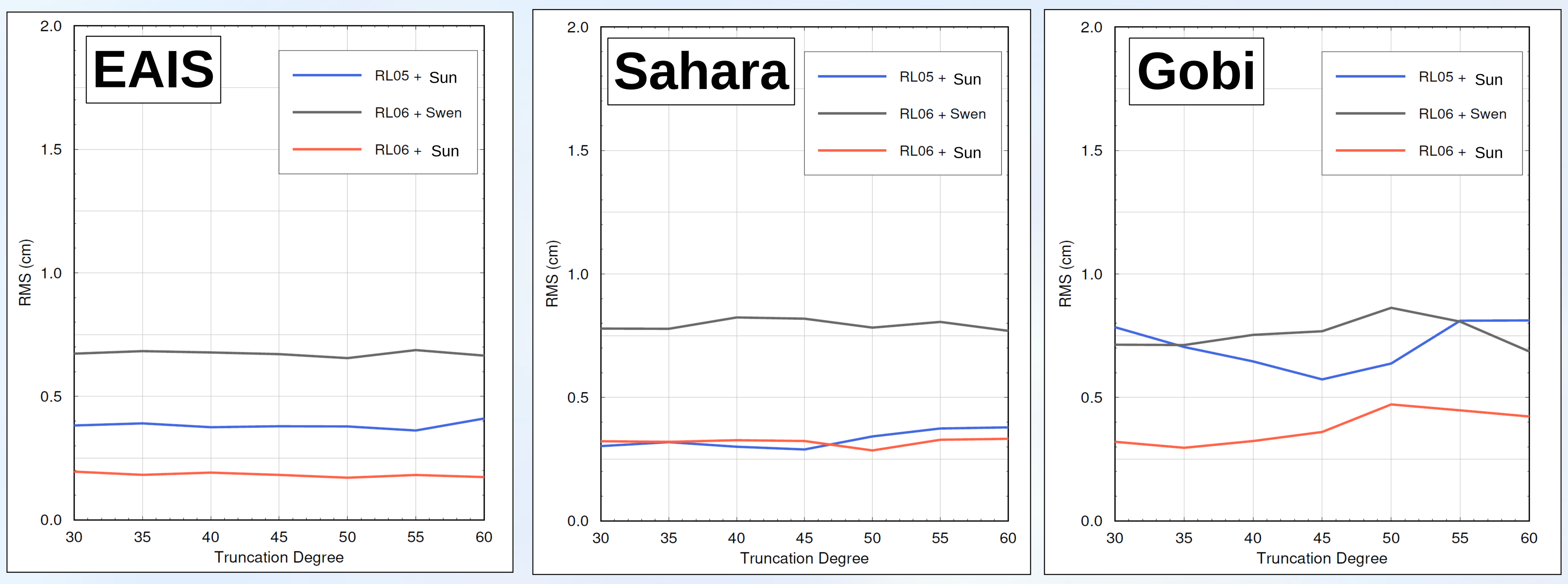

Fig. 2 RMS signal based on the time-series of mean mass anomalies in a test area, as a function of the truncation degree (the maximum degree retained in the GRACE monthly solutions when they are used as input for an estimation of the low-degree coefficients). For each area, three time-series are considered: (i) produced from the GRACE CSR RL06 solutions with the technique of Sun et al (2016) (in red); (ii) produced from the same solutions with the conventional approach (in black); and (iii) produced from the GRACE CSR RL05 solutions with the technique of Sun et al (2016) (in blue). On the basis of these results, the truncation degree of 45 was chosen for the further calculations. The units are cm (EWH).

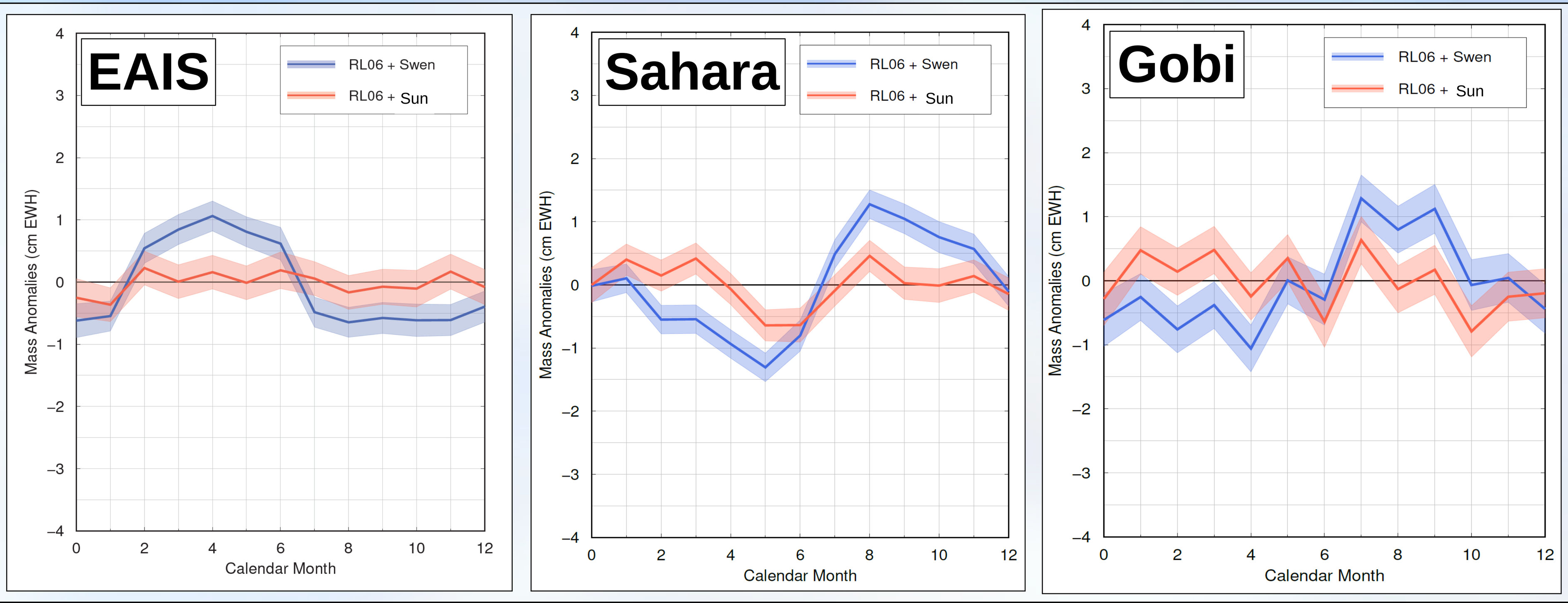

Fig. 3 RMS signal based on the time-series of mean mass anomalies in a test area, as a function of the calendar month. For each area, three time-series are considered: (i) produced from the GRACE CSR RL06 solutions with the technique of Sun et al (2016) (in red); (ii) produced from the same solutions with the conventional approach (in blue). The shadowed colour bands indicate the year-to-year spread of the mean mass anomalies in a given calendar month. The units are cm (EWH).

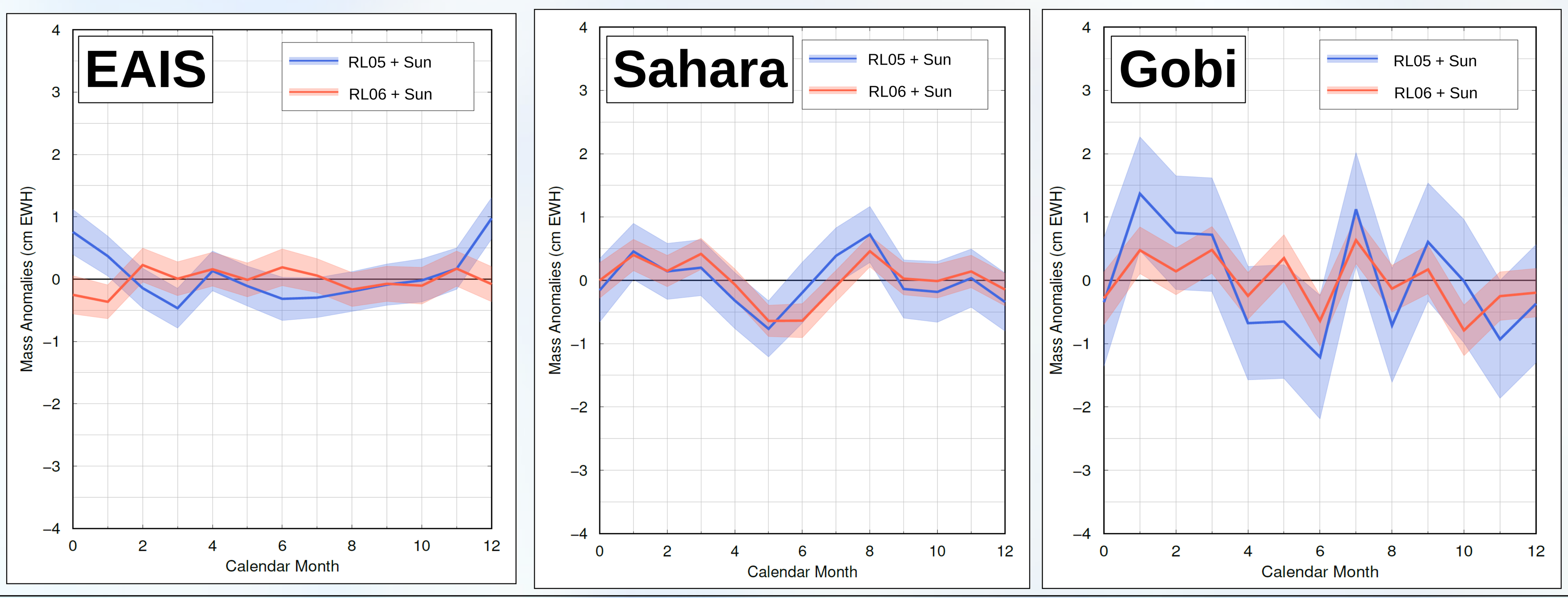

Fig. 4 Same as Fig. 3, but the considered mass anomaly time-series are: (i) produced from the GRACE CSR RL06 solutions with the technique of Sun et al (2016) (in red); (ii) produced from the GRACE CSR RL05 solutions with the same technique (in blue). The units are cm (EWH).

Table 1 RMS signal based on the time-series of mean mass anomalies in a test area, for the truncation degree 45 (the maximum degree retained in the GRACE monthly solutions when they are used as input for an estimation of the low-degree coefficients). For each test area, three time-series are considered: (i) produced from the GRACE CSR RL06 solutions with the technique of Sun et al (2016) ("RL06+Sun"); (ii) produced from the same solutions with the conventional approach ("RL06+Swen"); and (iii) produced from the GRACE CSR RL05 solutions with the technique of Sun et al (2016) ("RL05+Sun"). The best result for each test area is highlighted. The units are cm (EWH).

Data \ test area	EAIS	Sahara	Gobi
RL05+Sun	0.38	0.29	0.57
RL06+Swen	0.67	0.82	0.77
RL06+Sun	0.18	0.32	0.36

4. Major conclusions

- Truncation of GRACE monthly solutions at different maximum degrees has a minor effect onto the estimated low-degree coefficients. An exception is the Gobi desert area, where this effect is more pronounced. This indicates that the S_{11} coefficient is more sensitive to the truncation degree than the other low-degree coefficients.
- Estimation of the time-varying low-degree coefficients with the technique proposed by Sun et al (2016) leads to better results than the conventional approach (when variations in the degree-1 coefficients are estimated with the original technique by Swenson et al (2008), whereas variations in the C_{20} coefficient are extracted from SLR data) .
- GRACE CSR RL06 monthly solutions demonstrate a significant improvement of mass anomaly estimates, as compared to RL05. This is likely a combined effect of a lower noise level in GRACE solutions themselves and a more accurate estimation of the low-degree coefficients on their basis. An exception is the Sahara desert, where no improvement is visible. In view of a noticeable annual cycle in the test area, this outcome can be explained either by a still insufficient accuracy of the estimated C_{11} coefficients or by a signal leakage into the test area (a further analysis is pending).

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