LEO activities at AIUB

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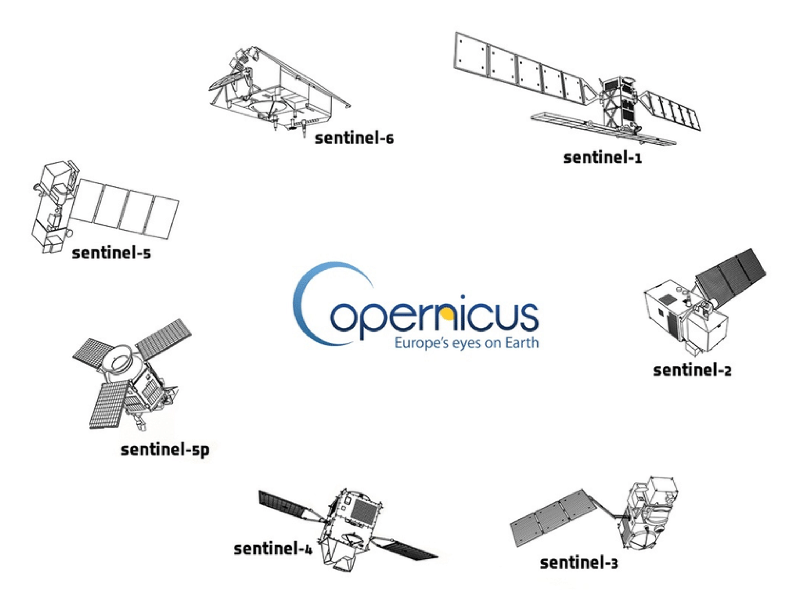
Introduction

GNSS data of spaceborne receivers on board different Low Earth Orbiting (LEO) satellites (scientific missions and CubeSats) are regularly processed at AIUB for (reduced-)dynamic and kinematic POD of these satellites for different purposes. Usually, our Center for Orbit Determination in Europe (CODE) final GNSS orbit, clock and bias products and the Bernese GNSS Software are employed. This poster gives an overview on a selection of currently ongoing activities in the domain of LEO data processing.

Copernicus POD Service

Copernicus is the European Union's Earth observation program (`https://www.copernicus.eu`) with the **Sentinel satellites** constituting its space segment.



AIUB is part of the **Copernicus Precise Orbit Determination Quality Working Group** (Fernández et al., 2024) and operationally computes orbits for all Sentinel-1, -2, -3 and -6 satellites for the purpose of orbit comparison and validation.

Sentinel-6A Michael Freilich (launched on 21 November 2020, at about 1330 km altitude) is the first Sentinel satellite equipped with a **multi-GNSS receiver**, tracking both GPS and Galileo signals.

The most stringent orbit accuracy requirements exists for the Sentinel-3A/B and Sentinel-6A satellites (2-5 cm in radial direction), because these are radar altimeter missions, and any radial orbit error degrades the derived sea level heights.

AIUB contributes with two different ambiguity-fixed GNSS-based orbit solutions (see Fig. 1):

- Reduced-dynamic solution ("AIUB"): Non-gravitational forces are not explicitly modeled, but only handled with empirical (constant and 6-minutes piecewise-constant) accelerations. Orbits are sensitive to any errors in, e.g., antenna offsets.
- Dynamic solution ("AING"): Employs physical modeling of air drag and radiation pressure, uses less empirical accelerations and tighter constraints. The latest COST-G FSM gravity field model (see right poster column) is used.

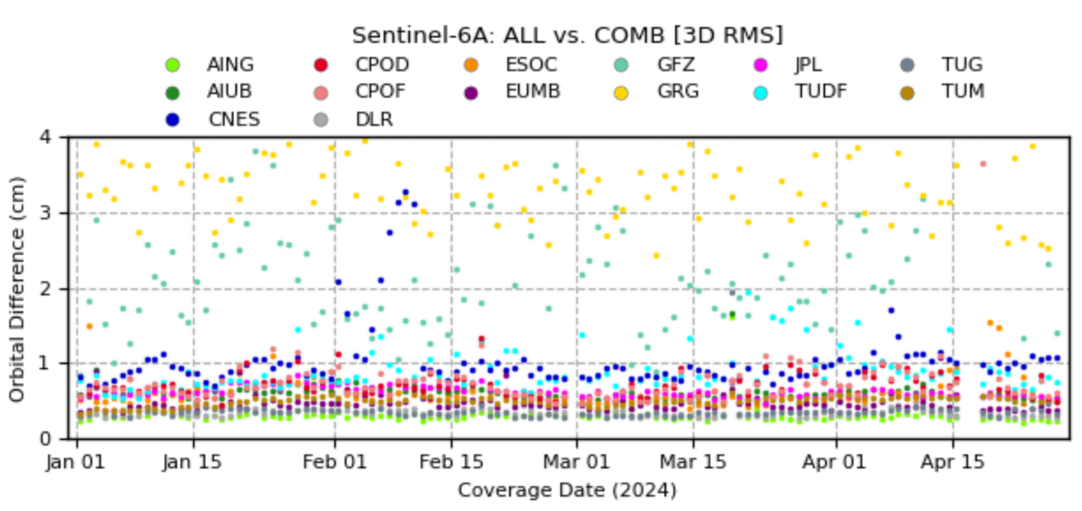


Figure 1: 3D orbit differences of individual orbit solutions for Sentinel-6A and a combined solution as computed for the regular service review (RSR) #31, spanning January-April 2024. The AING solution performs generally very well.

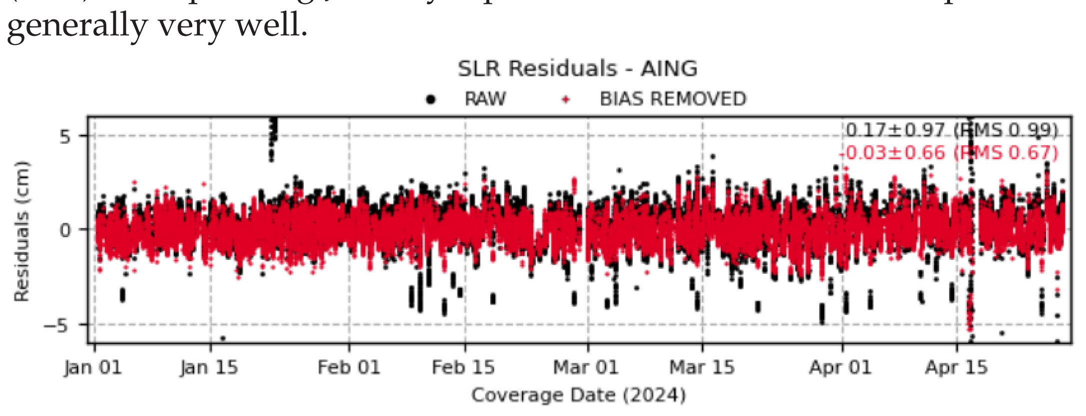


Figure 2: Satellite laser ranging (SLR) residuals of the AING Sentinel-6A orbits for RSR #31.

GRACE Follow-On

The Earth's gravity field causes the main force acting on the satellite and defines the shape of the orbit. This process may be inverted, thus, precisely measuring the motion of an artificial satellite in LEO over longer time spans allows to deduce information about Earth's gravity field. The latter is constant neither in space nor in time, but changes due to all-present mass re-distributions above, on or below the Earth surface. In short time scales, e.g., monthly, mostly water re-distributes, which means one is able to measure through satellite orbits the contribution of the increased water mass to sea level rise, ice capes melting, floods or draughts (see Fig. 3).

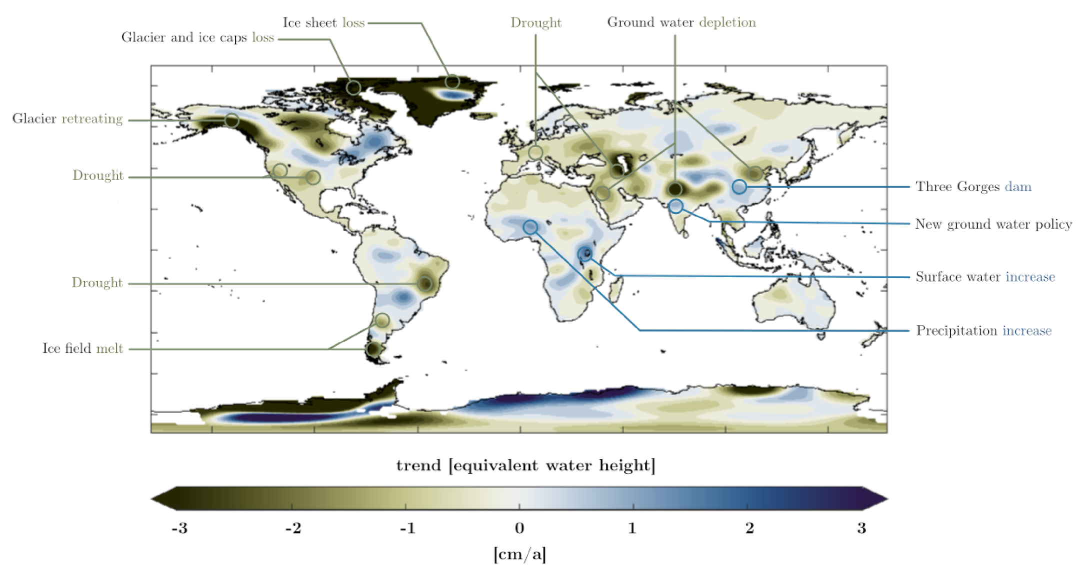


Figure 3: Geophysical signals observed by GRACE and GRACE Follow-On since 2002 expressed as a mass trend. Brown represents a loss of mass, e.g., caused by the ice capes melting or heavy use of ground water and droughts. Blue indicates a gain of water mass, e.g., through precipitation or man-made structures.

Observing tiny mass variations through the Earth's gravity field is nowadays primarily done with the GRACE Follow-On satellite mission through GPS, accelerometers and an ultra precise inter-satellite link (KBR) between the two satellites flying ~200 km apart. In addition, GRACE Follow-On carries a laser link with a precision resolving the 200 km distance with less than 10 nm. Figure 5 shows post-fit residuals of the inter-satellite ranging observations for the microwave link (KBR, left) and the laser interferometer (LRI, right).

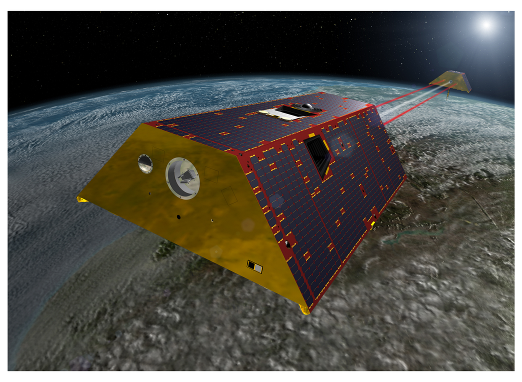


Figure 4: Gravity Recovery and Climate Experiment (GRACE) Follow-On (Credits: NASA)

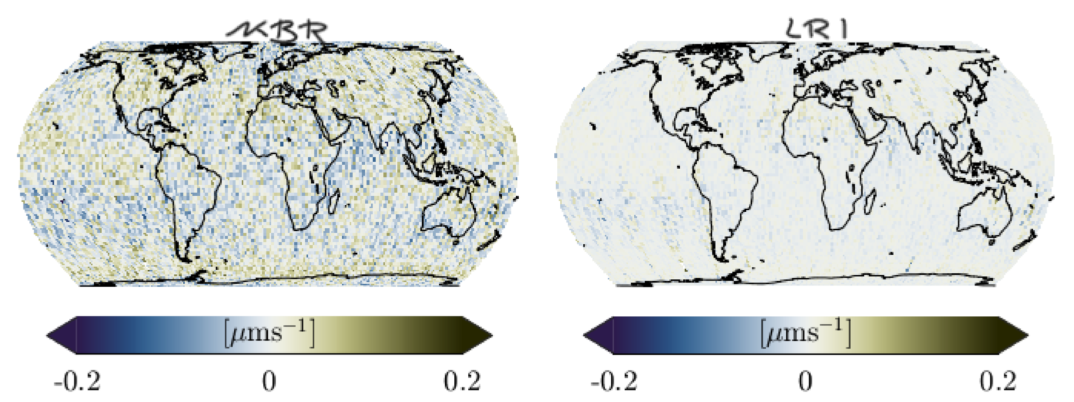


Figure 5: Post-fit residuals as an indicator of noise for KBR (left) and LRI (right).

GRACE Follow-On data is operationally processed at the AIUB to estimate monthly snapshots of the Earth's gravity field. A quality indicator is the dark blue line in Fig. 8 for the COST-G combination. We make use of recent developments by applying Variance Component Estimation (VCE) as automated data screening (see Fig. 6) and data weighting method and a noise covariance estimation from post-fit residuals to treat the stochastic nature of the observations more accurately.

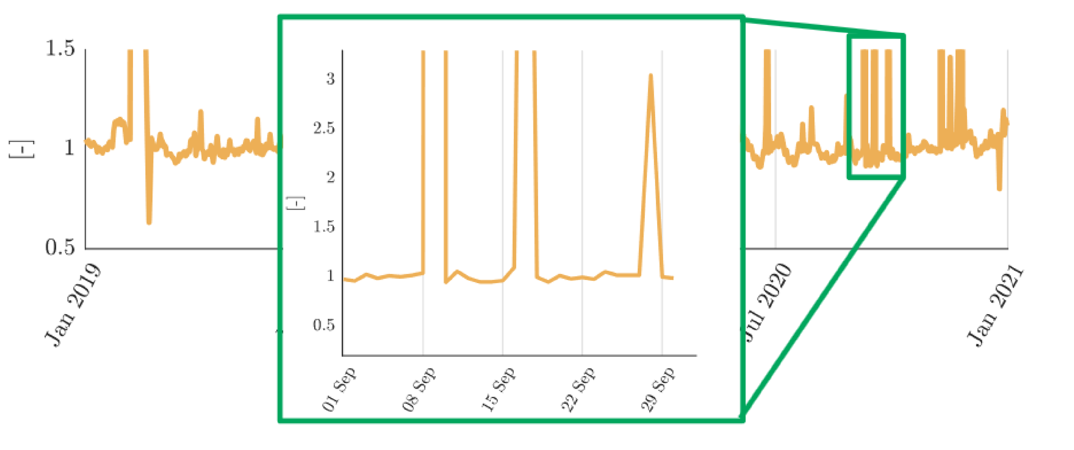


Figure 6: VCE factors for two years of GRACE Follow-On. The higher, the less contribution is assigned to the corresponding observations in the respective orbital arc. Note, e.g., the orbit manoeuvre (9 Sep) and KBR calibration manoeuvres (17 Sep and 28 Sep).

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COST-G

The Combination Service for Time-variable Gravity fields (COST-G, `https://cost-g.org`) is the official product centre of the International Gravity Field Service (IGFS) of the IAG. COST-G is dedicated to the combination of monthly gravity field models derived by the analysis centers of GRACE and GRACE Follow-On observations. To fill the gaps in the GRACE and GRACE Follow-On time-series, also monthly long-wavelength gravity fields derived from the kinematic orbit positions of the Swarm satellites are combined by COST-G.

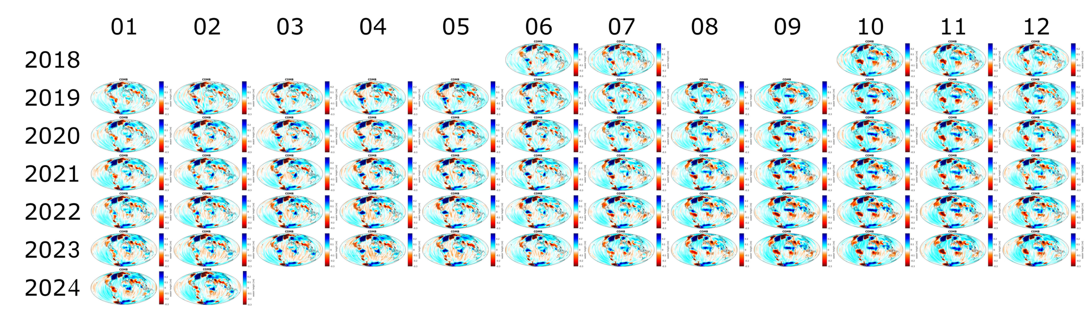

Figure 7: The main products of COST-G are monthly gravity field models operationally combined from the individual solutions of the GRACE-FO analysis centers.

COST-G performs quality control with a focus on the signal content of the individual time-series. Time-series with attenuated signal amplitudes due to regularization or implicit filters applied in the data analysis are excluded from the combination to avoid introducing signal biases. The noise of the individual monthly solutions is taken into account in the combination by relative weights that are determined by VCE on the solution level.

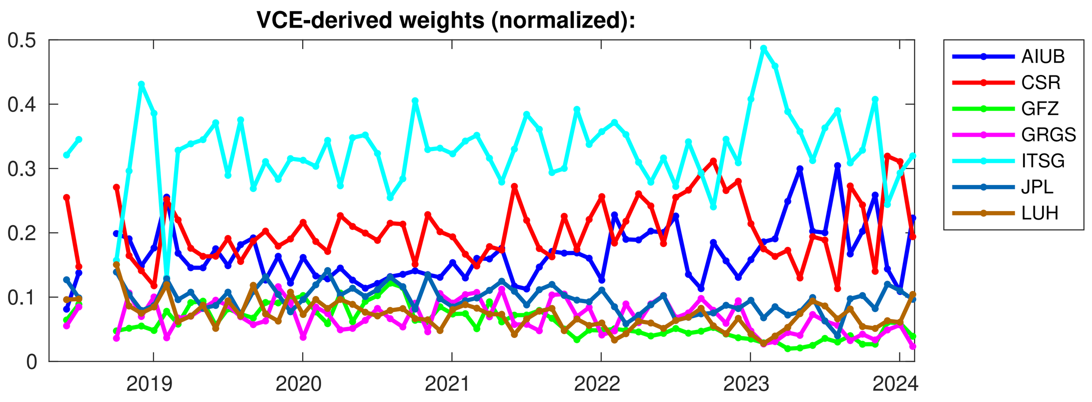

Figure 8: Monthly relative weights applied in the GRACE Follow-On combination.

The relative weights reflect the noise levels of the individual monthly gravity fields that can be independently assessed by the variability over areas, where no short-term mass-variations are expected, i.e. the quiet oceans. Periods of increased noise are related to near orbit repeats (March/April 2024) that negatively affect the density of the groundtrack coverage or to increased solar activity (rest of 2023).

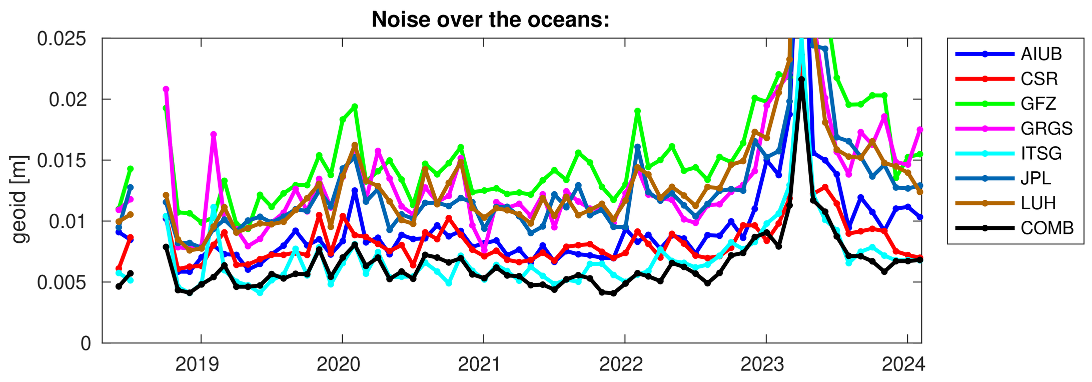

Figure 9: Noise assessment of monthly gravity fields by the variability over quite ocean areas.

The latency of the monthly GRACE Follow-On combinations is about 3 months. For application in operational POD of LEOs COST-G provides a Fitted Signal Model (FSM) that allows for an extrapolation of secular and seasonal gravity variations over several months. Contrary to the high-resolution multi-year gravity field solutions with added time-variations the COST-G FSM is updated quarterly with the newest GRACE Follow-On combinations to reduce extrapolation errors. The COST-G FSM is also used by the CODE analysis center for its IGS contributions. To download the COST-G FSM, check out the ICGEM portal: `https://icgem.gfz-potsdam.de`.

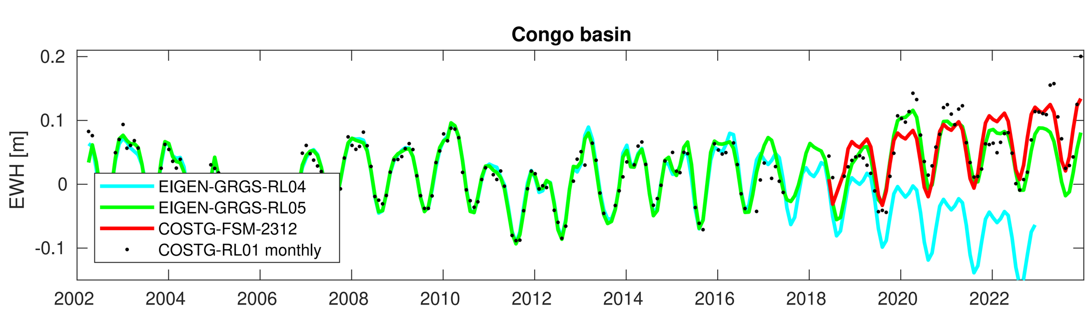

Figure 10: Mass variations in equivalent water height (EWH) within the Congo river basin as modeled/predicted by different gravity field models.

References

Jaime Fernández, Heike Peter, Carlos Fernández, Javier Berzosa, Marc Fernández, Luning Bao, Miguel Ángel Muñoz, Sonia Lara, Eva Terradillos, Pierre Féménias, et al. The Copernicus POD service. *Advances in Space Research*, 2024.

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