Precise Orbit Determination for Radio Occultation Climate Applications

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A R S C l i S y s

1 - Introduction

For observing the state of the climate system globally, remote sensing data from near-Earth orbiting satellites are indispensable. Global Navigation Satellite System (GNSS) radio occultation (RO) (Fig. 1) is such a highly valuable remote sensing technique for probing the Earth's atmosphere, due to its unique combination of global coverage, high accuracy, long-term stability, and essentially all-weather capability. For serving long-term climate monitoring and analysis, it is essential to safeguard the quality of the measurements derived from GNSS signal tracking by RO satellite receivers in low Earth orbit (LEO). It is therefore essential to also ensure the LEO orbit solutions to be of adequate quality, since they are one of the key inputs for the following derivation of essential climate variables (ECVs) such as temperature and water vapor from the RO low-level data.

2 - Processing setup

Here we present results towards the first long-term RO reprocessing from 2001 to present with the new Reference Occultation Processing System (rOPS) (Fig. 2) at WEGC, now including a setup for precise orbit determination (POD), which routinely and in parallel performs the LEO POD with two independent software packages, Bernese GNSS software and NAPEOS, employing two different GNSS orbit data products at the side of the GNSS orbit inputs. This POD setup enables mutual consistency checks of the calculated orbit solutions and is also used for position and velocity uncertainty estimation, including estimated systematic and random uncertainties (Innerkofler et al. 2020). The latter are co-derived for the reprocessed RO data record in order to help evaluate and ensure its long-term stability (Innerkofler et al. 2023).

3 - Orbit evaluation results

We provide a detailed evaluation based on multi-month POD results statistics, including intercomparison of the LEO orbit solutions with solutions from other leading orbit processing centers for cross-validation (Fig. 3). Satellites equipped with a retro-reflector for Satellite Laser Ranging (SLR), such as GRACE-A and CHAMP, facilitate an independent validation of the orbits and the estimation of (radial) systematic uncertainties (Fig. 4). Additionally, we evaluate the estimated uncertainties of the orbit solution time series data with respect to the LEO orbit uncertainty target specifications for RO (<5 cm in position and <0.05 mm/s in velocity), for ensuring highest quality of the retrieved ECVs. This allows identification of subsets of RO profiles of somewhat reduced quality, a potential benefit for adequate further use in climate monitoring and research.

4 - Summary and outlook

The LEO-POD results computed, which serve as a basis for the RO processing at WEGC, show a good consistency within orbit uncertainty target specifications for most of the days within the investigated test months. For days with a degraded LEO-POD solution, the estimated uncertainties and derived quality flags allow to label these days for quality-controlled use in the subsequent RO processing.

In a next step we will provide an evaluation of the entire rOPS-reprocessed time-series (2001-2024) following the approach presented here.

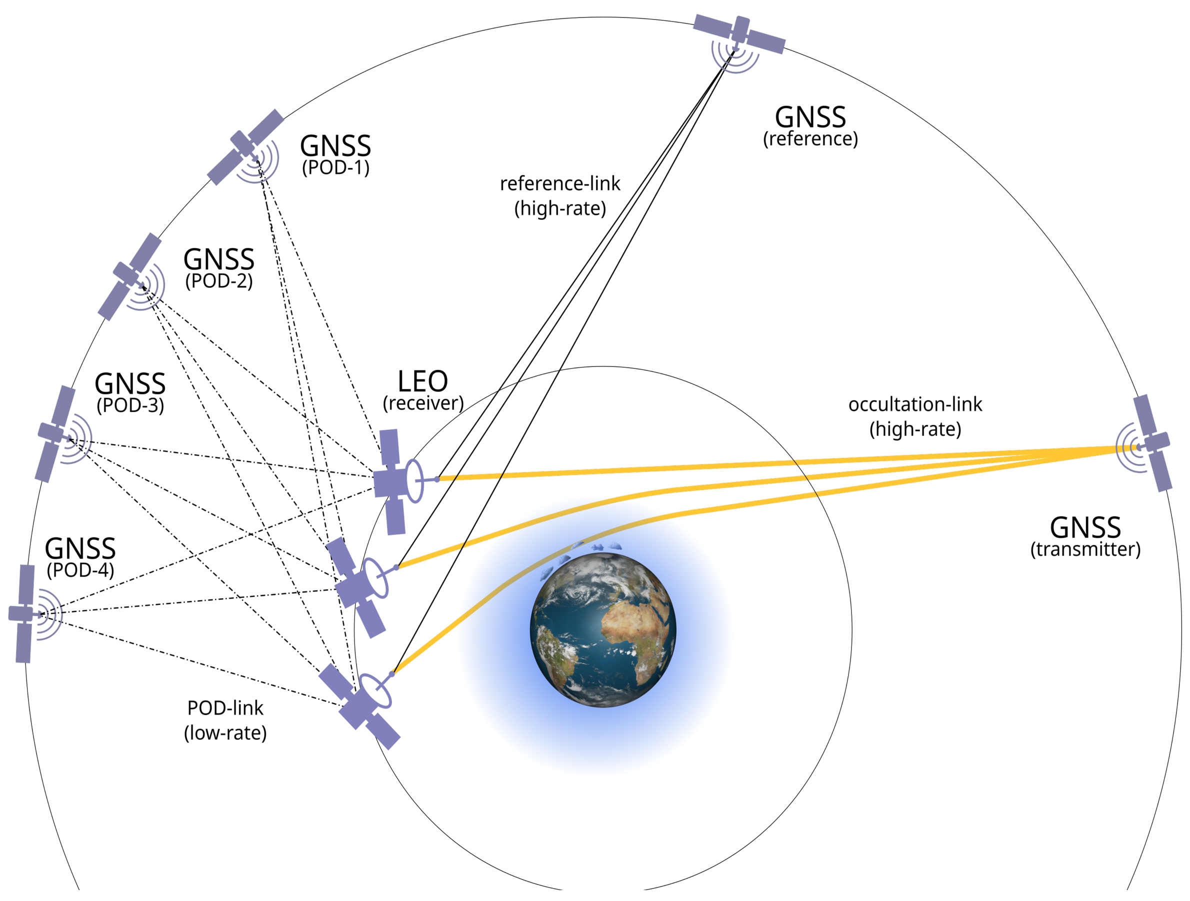

Fig. 1: Schematic view the of the RO measurement principle. Radio signals from the occulting GNSS satellite pass through the atmosphere and are refracted on their way to the faster moving LEO receiver satellite. Depending on the RO differencing method applied, additional measurements of a GNSS reference satellite are employed. The LEO POD is based on measurements obtained from the LEO zenith antenna.

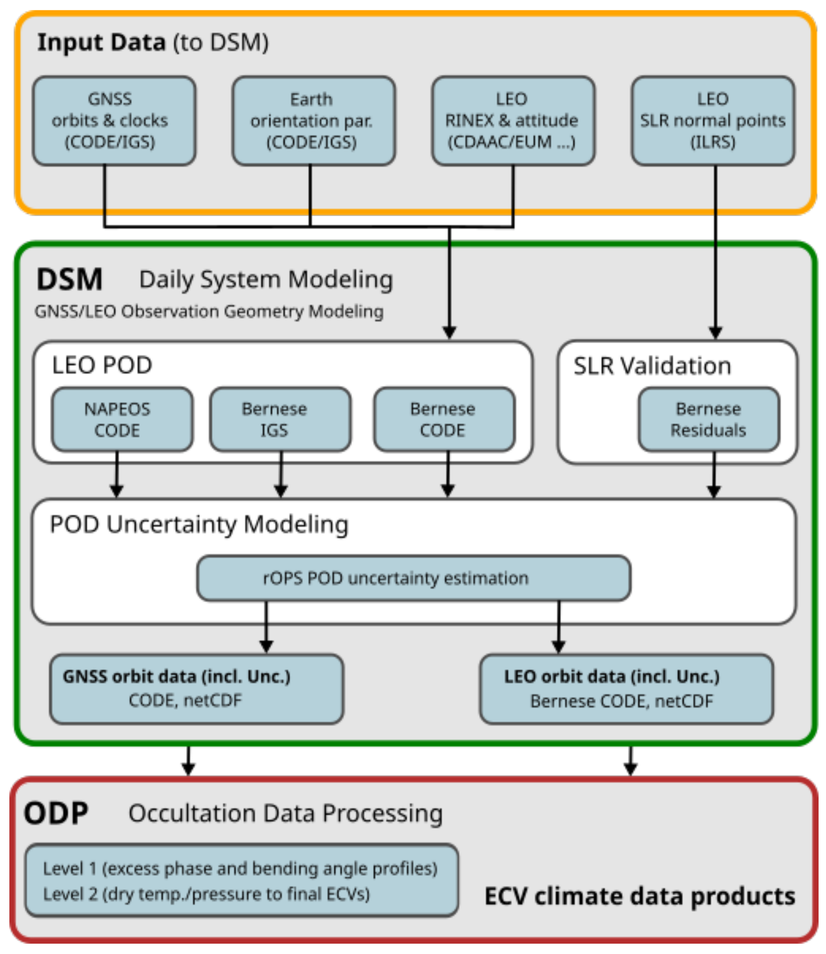

Fig. 2: Schematic overview of parts of WEGC's rOPS relevant to this study, comprising the input data for the precise orbit determination (orange), the daily system modeling (DSM; green), and the occultation data processing (ODP; red).

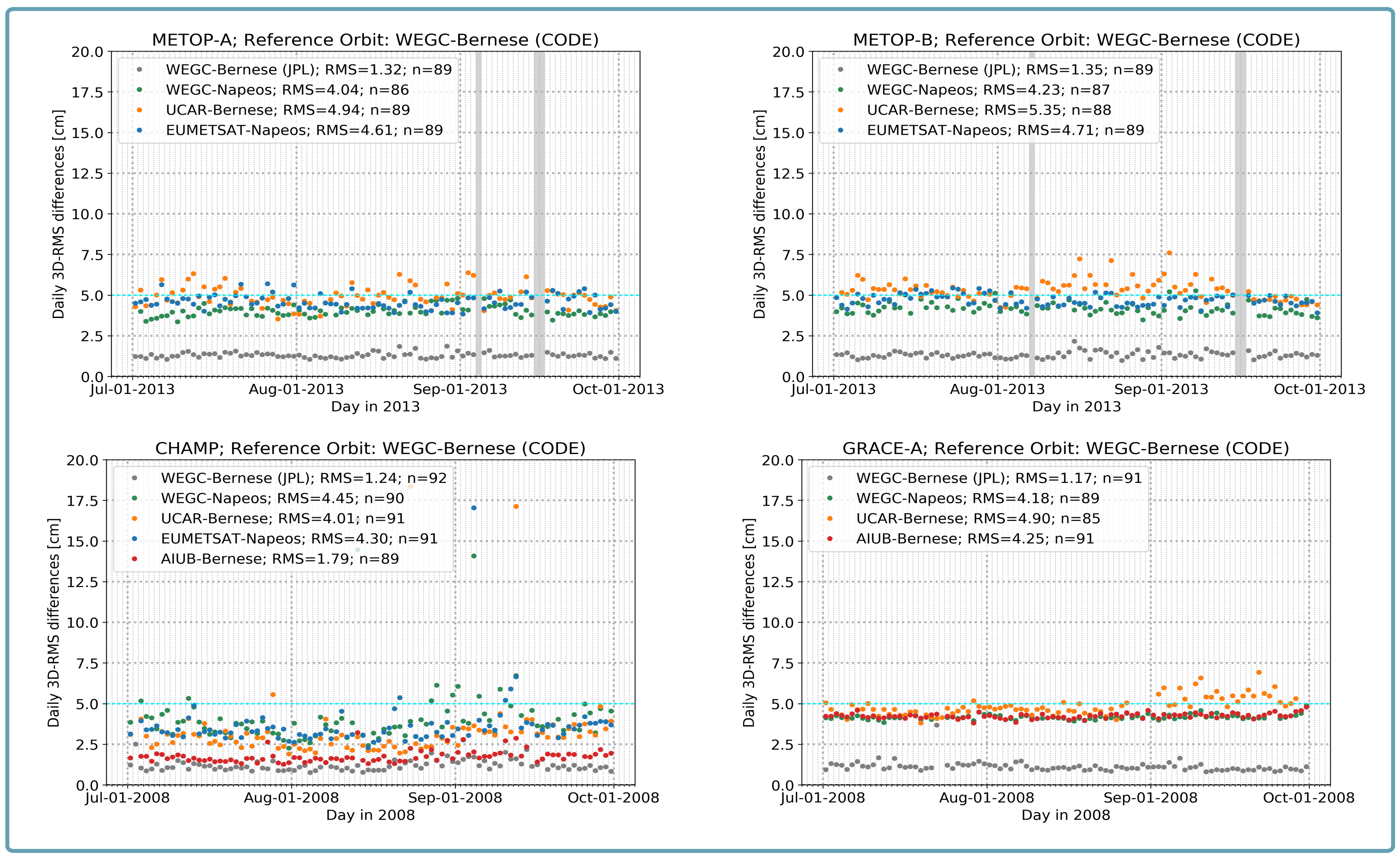

Fig. 3: Daily RMS position differences calculated at WEGC (with Bernese and Napeos), EUMETSAT, and UCAR for the MetOp-A/-B, CHAMP and GRACE-A satellites as examples. Grey shading indicates days where an orbit maneuver took place. Outliers exceeding 20 cm in 3D-RMS have been disregarded for the calculation of the overall RMS. The number of total days per period is denoted by "n".

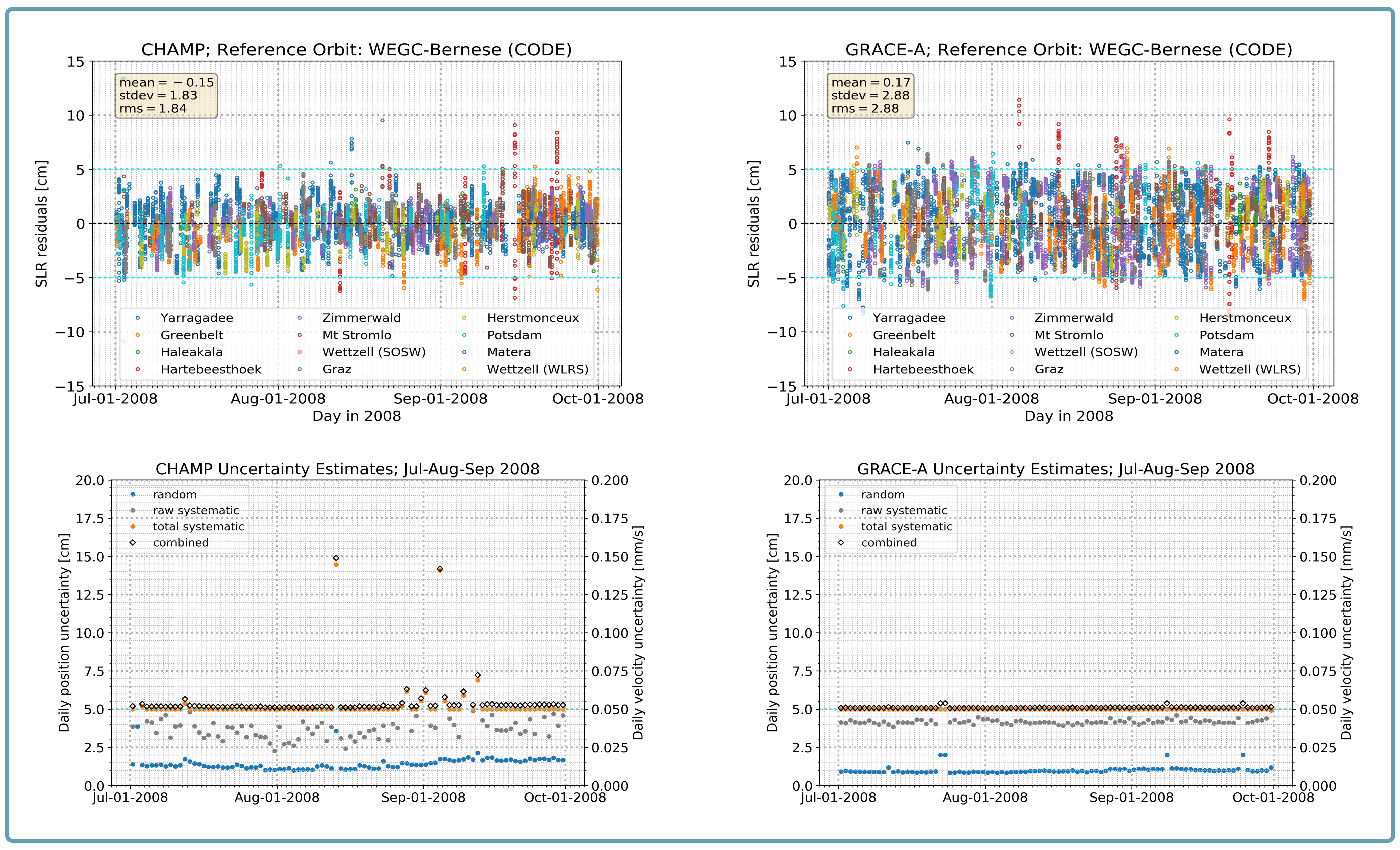

Fig. 4: SLR residuals (top panels) for CHAMP and GRACE-A in July 2008, calculated with Bernese using GNSS input from CODE for a set of 12 high-quality SLR stations. For outlier rejection a 20 cm threshold and a station's elevation mask of 10 degrees was applied. Daily position and velocity uncertainties (bottom panels) for the WEGC-Bernese (CODE) baseline solution for CHAMP and GRACE-A from July to September 2008. The "raw systematic" values denote the estimated systematic uncertainties before applying the conservative bound while the "total systematic" values show the estimates including this low-bounding.

References:

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