GNSS Radio Occultation Zero-differencing Excess Phase Processing with Integrated Uncertainty Estimation for Climate Applications

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A R S C l i S y s

Introduction

The GNSS radio occultation (RO) measurement technique is highly valuable for climate monitoring of the atmosphere as it provides accurate and precise measurements in the troposphere and stratosphere regions with global coverage, long-term stability, and virtually all-weather capability. The new Reference Occultation Processing System (rOPS) developed at the WEGC aims to process raw RO measurements into essential climate variables, such as temperature, pressure, and tropospheric water vapor (**Fig. 1**). As fundamental part of this rOPS climate-quality processing, accurate atmospheric excess phase profiles with new approaches integrating uncertainty estimation are derived from the raw occultation tracking data and orbit data.

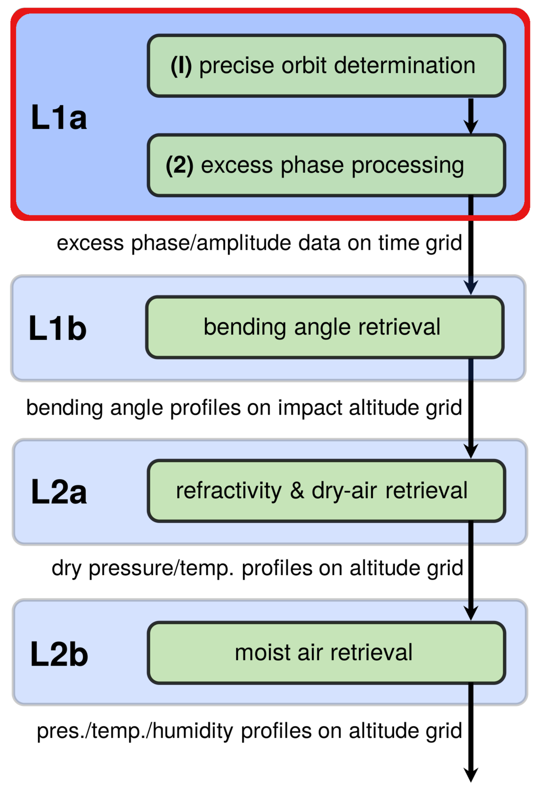

Fig. 1: Overview of the rOPS processing steps from Level 1a to Level 2b.

rOPS - Level 1a Processor

Within the rOPS Level 1a system (**Fig. 2**), the precise orbit determination (POD) subsystem derives highly accurate position, velocity, and clock estimates of the receiver satellite in low Earth orbit (LEO). Input for this process comprises the LEO navigation tracking data and GNSS orbit and clock data as provided by CODE or IGS. Subsequently the transmitter and receiver satellite orbits and clocks, together with the high rate occultation data from the LEO, serve as the input for the excess phase processing subsystem, which yields excess phase profiles as final output of the Level 1a processing.

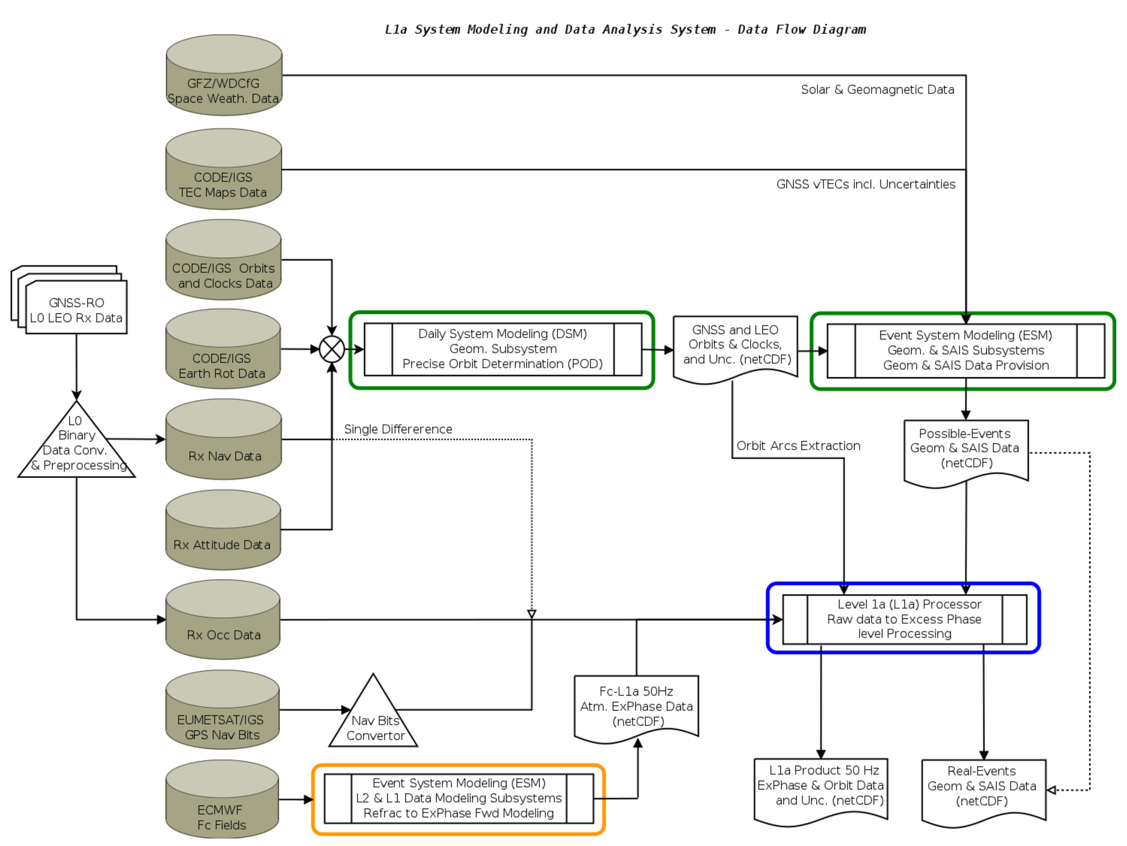

Fig. 2: Data flow of the Level 1a modeling and analysis system, including the geometry subsystems (green), the L2 & L1 data modeling subsystem (orange), and the L1a excess phase processor as core subsystem (blue).

Summary and Outlook

The rOPS Level 1a modeling and analysis system was introduced, including the POD subsystem and excess phase processing subsystem. POD results show a consistency within the orbit uncertainty target specifications for most of the days for the considered test months. The rOPS excess phases show a high consistency compared to existing processing systems for missions where zero-differencing is applicable. For missions with a more unstable clock (e.g., CHAMP, COSMIC) a single-differencing approach is implemented to eliminate the transmitter and receiver satellite clock biases by making use of an additional reference satellite.

Precise Orbit Determination

Employing the Bernese 5.2 and Napeos 3.3.1 software packages for the LEO orbit determination of the MetOp, GRACE, and CHAMP satellite missions, we found the majority of the test days within the target orbit uncertainty estimates of 5 cm (position) / 0.05 mm/s (velocity) for daily orbits in July 2008 (GRACE and CHAMP) and May 2013 (MetOp-A/-B). For daily COSMIC RO satellite orbits in July 2008, we found decreased accuracy estimates near to 20 cm (position) / 0.2 mm/s (velocity), due to less favorable attitude behavior and restrictions in processing observations from two antennas (**Fig. 3**).

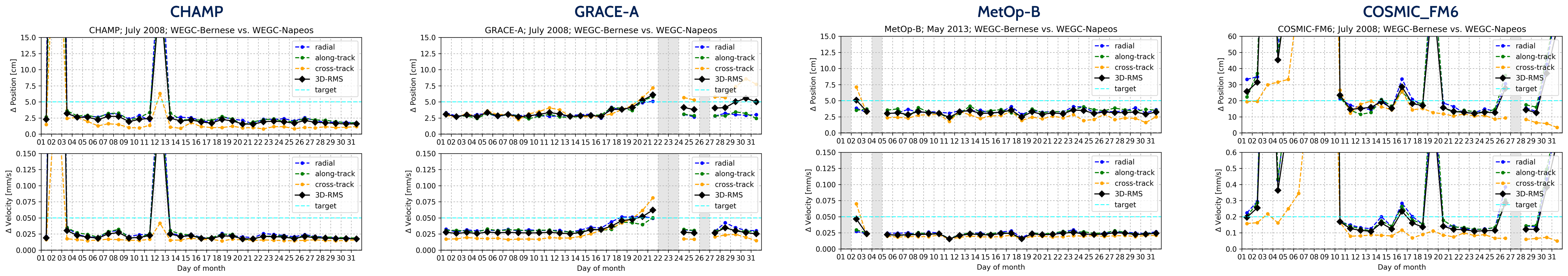

Fig. 3: Daily RMS differences for position and velocity calculated at WEGC with Bernese and Napeos, for the CHAMP, COSMIC-FM6, MetOp-B, and GRACE-A satellites as examples. Days shaded in grey indicate failure of either Bernese or Napeos in performing the orbit determination with standard settings.

Orbit comparison between orbits derived at WEGC and orbits from EUMETSAT for MetOp (**Fig. 4**) and from UCAR for GRACE (**Fig. 5**), respectively, also satisfy the specified 3D-RMS target bounds. Satellites equipped for satellite laser ranging (SLR), such as GRACE and CHAMP enable the opportunity for the estimation of (radial) systematic uncertainties. Furthermore, the Bernese 5.2 software was expanded for progagating random uncertainties from GPS orbit data und LEO navigation tracking data (typically near 1 cm).

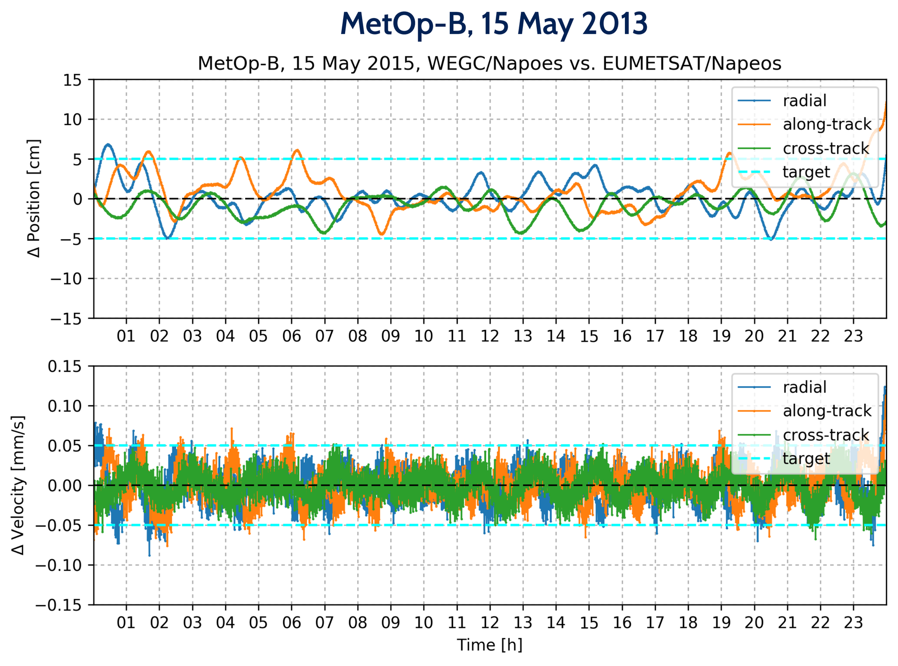

Fig. 4: Differences of position (top) and velocity (bottom) between orbits derived with WEGC-Napeos and EUMETSAT-Napeos for MetOp-B.

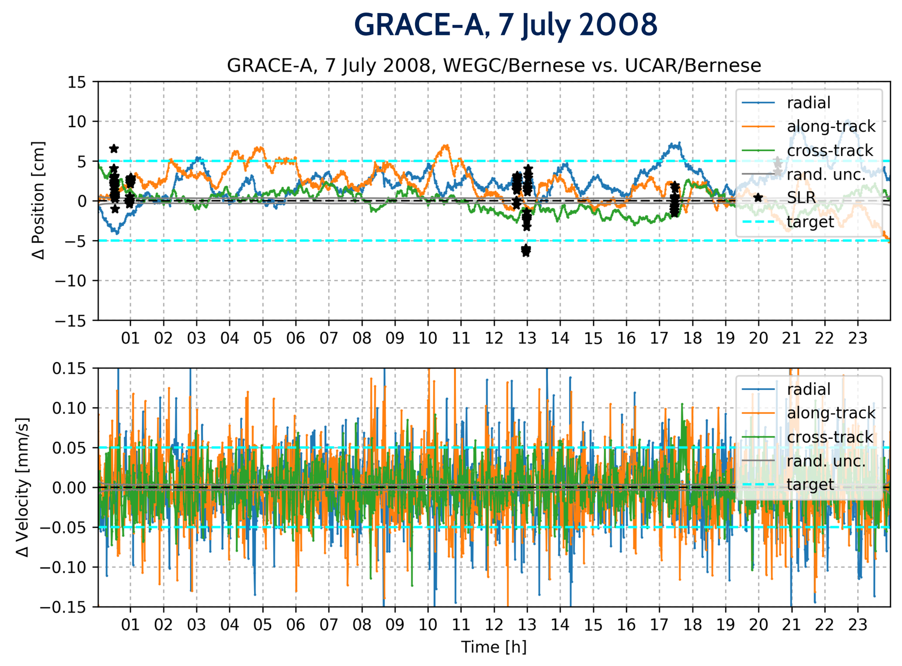

Fig. 5: Differences of position (top) and velocity (bottom) between WEGC-Bernese and UCAR-Bernese for GRACE-A, including SLR residuals (top) and random uncertainty estimates.

Excess Phase Processing

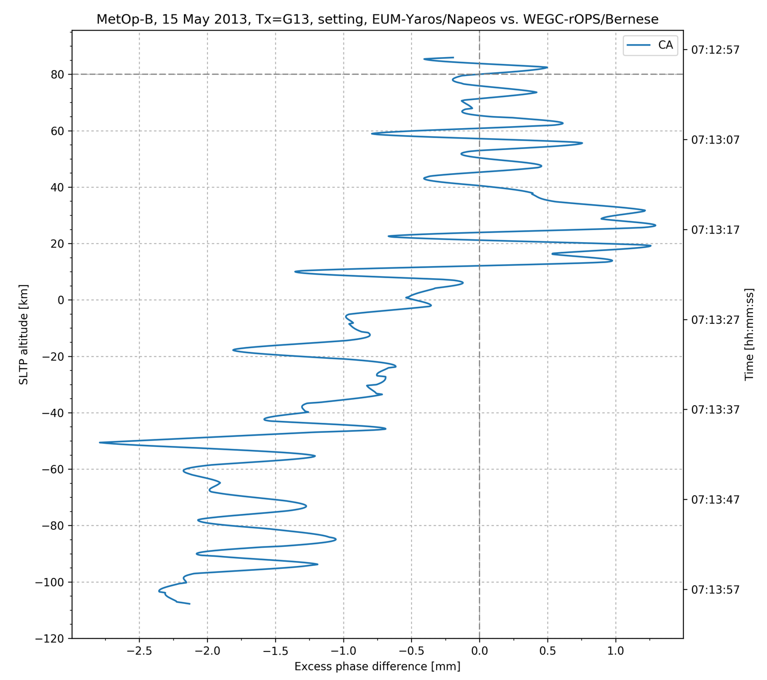

Fig. 6: MetOp-B excess phase difference between EUMETSAT and WEGC for a single event example on May 15, 2013.

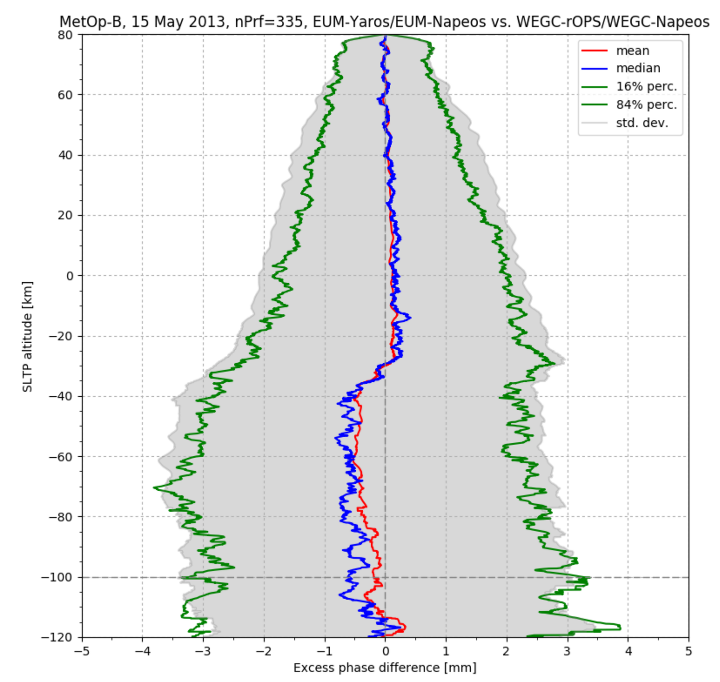

Fig. 7: Daily subset statistics for (L1 signal) excess phase difference for MetOp-B between EUMETSAT and WEGC on May 15, 2013.

Based on the precise orbit and clock determination, performed within the geometry subsystem of the Level 1a system, we employ a zero-differencing approach for missions with a sufficiently stable clock, such as MetOp-A/-B and GRACE-A, to eliminate the transmitter and receiver clock biases. The obtained excess phases from the rOPS Level 1a processor show good agreement with excess phases computed by EUMETSAT. **Figure 6** depicts the excess phase difference between WEGC and EUMETSAT for a typical RO event for MetOp-B on 15 May, 2013. Statistics for the same day (**Fig. 7**) show a high consistency of mean difference <0.1-0.2 mm at straight line tangent point (SLTP) altitudes down to about -30 km (middle troposphere). For the whole range below (lower troposphere) the mean difference stays <0.5 mm with the standard deviation below 4 mm.

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