Towards SI-traceable radio occultation excess phase processing with integrated uncertainty estimation for climate applications

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Introduction

Monitoring the Earth's atmosphere in order to obtain accurate and long-term stable records of Essential Climate Variables (ECVs) is the backbone of contemporary atmospheric and climate science. Global Navigation Satellite System (GNSS) Radio Occultation (RO) is highly valuable for this purpose as it provides accurate and precise measurements of ECVs in the troposphere and stratosphere globally with long-term stability and virtually all-weather capability. During an occultation event the GNSS signals scan the atmosphere in limb sounding geometry, and arrive with a time delay at the receiving RO satellite, which is due to the signal's refraction in the Earth's atmosphere (Fig. 2). The ECVs can be retrieved from the RO excess phase measurements that are related to this time delay.

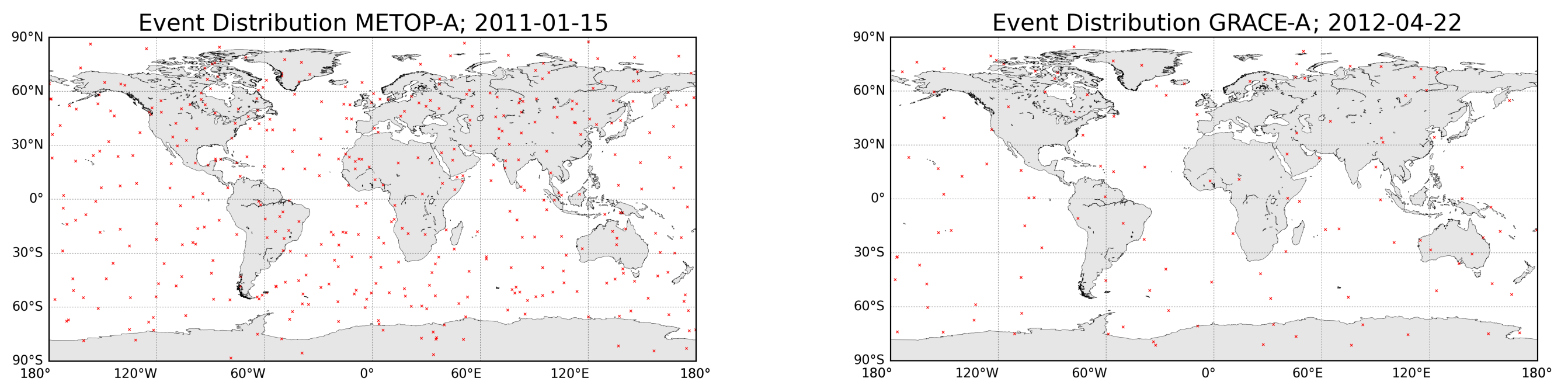

Fig. 1: Global RO event distribution maps for MetOp-A (left) and GRACE-A (right) for two representative test days in January 2011 and May 2012, respectively.

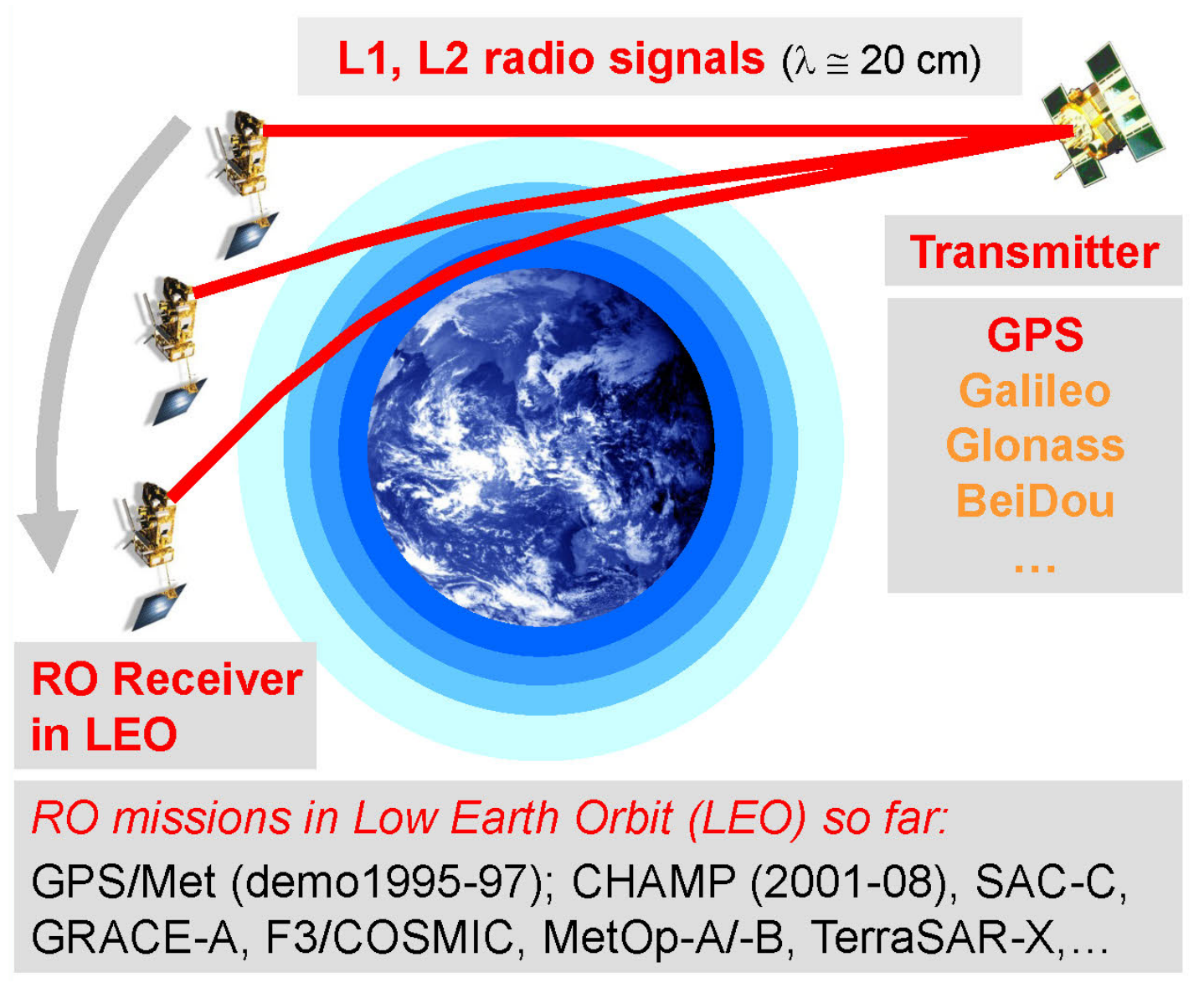

Fig. 2: Schematic principle of RO. Within the influence of the Earth's atmosphere the signal between GPS and LEO satellite is bent, whereas above the atmosphere it does not undergo refraction.

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Reference Occultation Processing System (rOPS)

The novel rOPS (Fig. 3), currently under development at the WEGC, aims to process raw RO measurements into ECVs in a way which is SI-traceable to the universal time standard and which includes rigorous uncertainty propagation. Within the L1a processing, shown in Fig. 4, this climate-quality processing system derives accurate atmospheric excess phase profiles integrating uncertainty propagation from the raw occultation tracking data and orbit data. In order to achieve high accuracy of the excess phase profiles, highly accurate orbit positions and velocities of the RO receiver satellites in low Earth orbit (LEO) need to be determined.

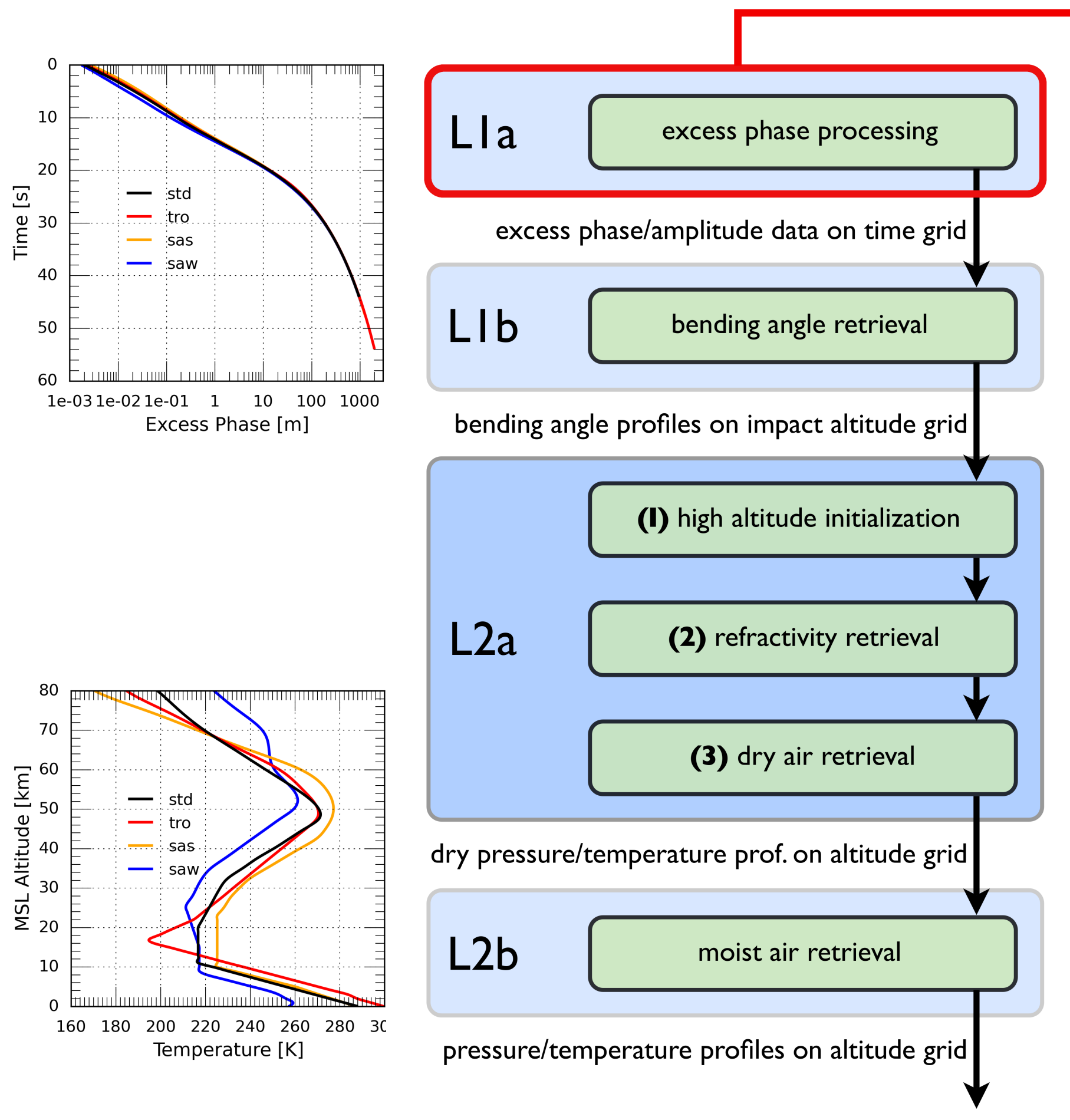

Fig. 3: Summary of rOPS processing steps from level 1a (excess phase) to level 2b (temperature, pressure, humidity). To the left simulated excess phase profiles (top) and temperature profiles (bottom) for different latitude bands are shown.

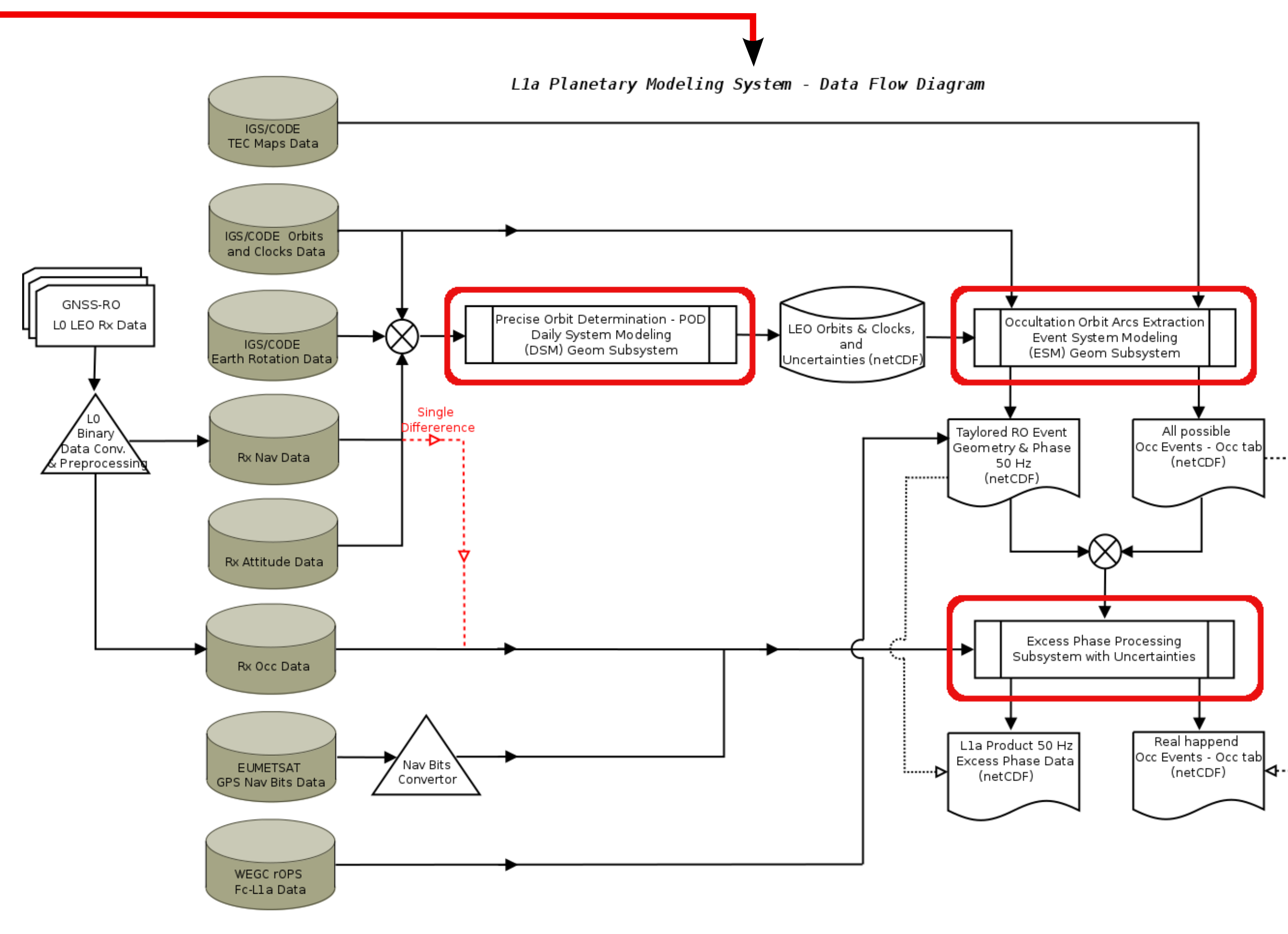

Fig. 4: Data Flow of the level 1a planetary modeling system including the three major subsystems (red), comprising the precise orbit determination subsystem, the occultation event orbit arcs extraction subsystem, and the excess phase processing subsystem.

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Precise Orbit Determination (POD)

Employing the Bernese 5.2 and Napeos 3.3.1 software package for the determination of LEO orbits, we achieved robust SI-traced LEO orbit uncertainties. Results for two representative test days (see Fig. 1) for the MetOp-A and the GRACE-A RO satellite missions show that the specified conservative bounds of 5 cm (position) and 0.05 mm/s (velocity) are satisfied by the 3D-RMS of the mutual orbit cross-check between orbits calculated with Bernese and Napeos (Fig. 5). To conduct the estimation of random uncertainties of the LEO orbits, the Bernese software was expanded and the functionality of propagating random uncertainties from GPS orbit data and LEO navigation tracking data input was added, based on Jaeggi (2007). However, the estimated random uncertainties are considered optimistic, as the estimation is essentially based on the satellite constellation geometry only. We therefore applied a coverage factor of 2, leading to a more realistic standard uncertainty estimate. Satellite Laser Ranging (SLR) measurements enable the opportunity for the determination of the systematic position uncertainty of the GRACE-A orbit, whereas this is not possible for MetOp-A, as the satellite is not equipped with a laser retro-reflector. The satellite clock error of GRACE-A is smaller compared to MetOp-A due to a preprocessing performed by the Jet Propulsion Laboratory (JPL) before the data is disseminated.

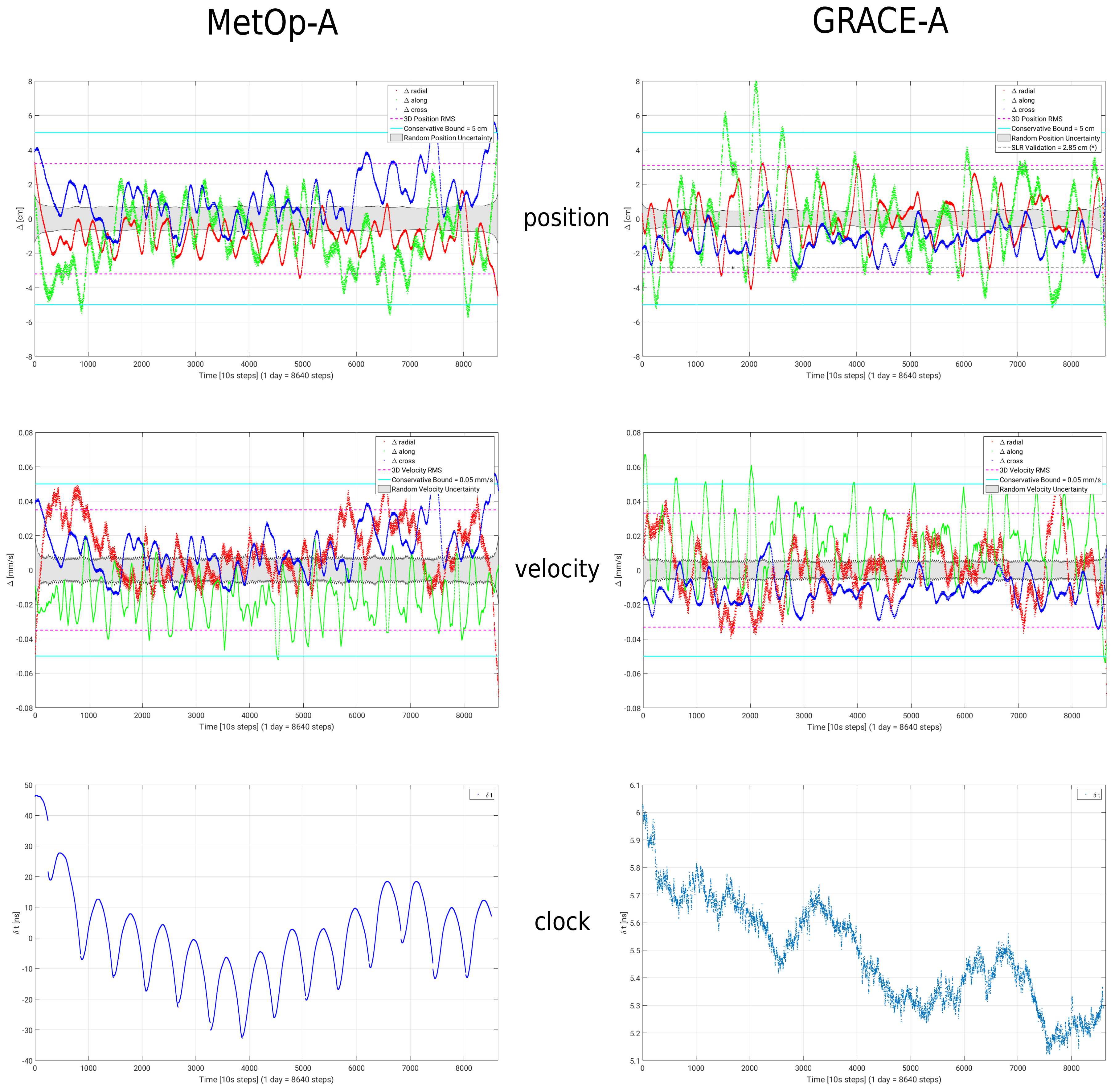

Fig 5: Orbit differences for MetOp-A (left) and GRACE-A (right) orbit positions (top) and orbit velocities (middle), including estimates for random and systematic uncertainties, between Napeos and Bernese results. Bernese clock errors are shown in the bottom row.

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Summary & Outlook

The careful evaluation and quality control of the position, velocity, and clock accuracies of daily LEO and GPS orbits, which significantly co-determine the excess phase uncertainties, yield to smallest achievable errors in the excess phase processing. Therefore, except for disturbed space weather conditions, we expect a robust performance at millimeter level for the derived excess phases. After these results are achieved, and after large-scale processing of the RO data of many years, these excess phase data can provide a new SI-traced fundamental climate data record, which can be examined for possible climate change signals.

References:
Jaeggi, A. (2007) Pseudo-Stochastic Orbit Modeling of Low Earth Satellites Using the Global Positioning System. PhD thesis. University of Bern

Acknowledgments:
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