Challenging the Precision
Impact and Comparison of Non-Gravitational Force Models on Sentinel-3A Orbit Determination

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Introduction

Since the beginning of satellite altimetry missions, the ocean surface topography community requires precise and accurate satellite orbits. With the start of the satellite Sentinel-3A on February 16, 2016, the altimeter onboard the satellite complements the Copernicus program with an ocean- and land monitoring mission, planned for a nominal mission lifetime of 7 years.

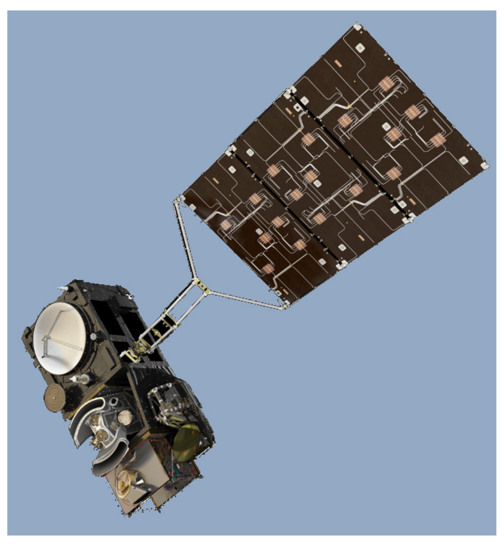

FIGURE 1: Illustration of Sentinel-3A. Courtesy: ESA/ATG medialab.

The satellite is orbiting the Earth on a polar, Sun-synchronous trajectory at an altitude of 815 km.
Routine Sentinel-3A orbits are generated by GMV, and the required satellite auxiliary data are kindly provided by the Copernicus Precise Orbit Determination (CPOD) solution service. As members of the Copernicus Quality Working Group, the Astronomical Institute of the University of Bern (AIUB), and the German Aerospace Center (DLR), are, among others, responsible for the orbit validation of Sentinel-3A. For the present study, both groups employed the satellite macro model and sophisticated non-gravitational force models within a reduced-dynamic approach but differ in the employed software solutions.

Precise Orbit Determination

For the purpose of precise orbit determination, the satellite is equipped with a geodetic-grade dual-frequency Global Positioning System (GPS) receiver. The GPS measurements are employed together with a set of gravitational and non-gravitational models in a Reduced-Dynamic Orbit Determination (RDOD) approach, which combines the advantages of a dynamic and a kinematic positioning for deriving precise satellite orbits. The operational 8-plate satellite macro model is introduced, which allows for a proper modeling of accelerations due to Solar Radiation Pressure (SRP), Earth Radiation Pressure (ERP), and atmospheric drag. Table 1 summarizes the employed methods, models, and settings. The model selection is widely consistent but differs in the employed gravity, and density models.

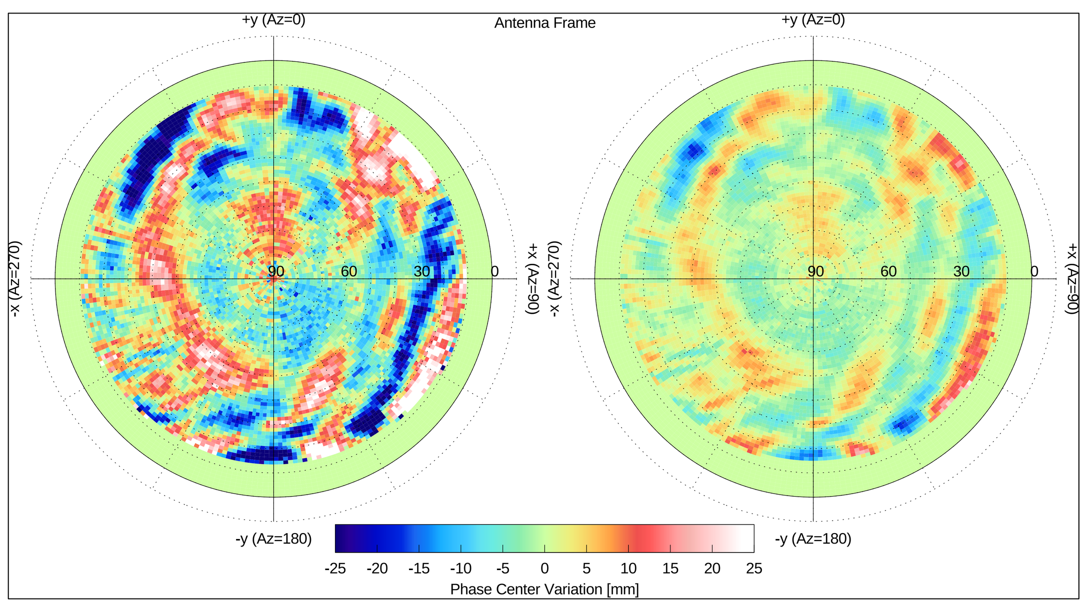

FIGURE 2: GPS antenna phase center variations from AIUB (left) and the operational CPOD service (right) employed by DLR.

The ionosphere-free linear combinations of the GPS observations are used to determine one set of initial conditions and three scaling factors for the non-gravitational force models per orbital arc, as well as a number of pseudo-stochastic orbit parameters in a classical least-squares parameter estimation. GPS antenna phase center variation maps are determined in-flight by the iterative stacking of carrier phase residuals of a RDOD. Figure 2 shows maps of the GPS antenna L1/L2 phase center variations. The solution from AIUB is estimated from the period Day Of Year (DOY) 84/2016 to 103/2016 (8 iterations), whereas DLR selects the operationally provided phase patterns (5 iterations). Both patterns show similar systematics with pronounced peaks and amplitudes in the AIUB pattern.

The required GPS orbit and high-rate clock offset products are utilized from the Center for Orbit Determination in Europe (CODE). The satellite attitude is defined by the provided quaternions, as measured by the on-board star trackers. Pseudo-stochastic orbit parameters are used to compensate for deficiencies in the employed force models. Both groups made use of piecewise-constant empirical accelerations in radial, tangential, and normal directions, estimated in fixed intervals of 10 minutes.

TABLE 1: Models and methods for orbit determination.

	AIUB	DLR
Software package	Bernese GNSS Software 5.3	GHOST
Gravity Model	GOCO05S (140 × 140)	GOCO03S (100 × 100)
Ocean Tides	EOT11A (80 × 80)	FES2004 (60 × 60)
Solid Earth/Pole Tides	IERS 2010	IERS 2003
Solar Radiation Pres.	Macro model	Macro model
Earth Radiation Pres.	CERES ES-4, macro model	CERES ES-4; macro model
Atmospheric Density	DTM 2013, macro model	NRLMSISE-00, macro model
Maneuver handling	no	yes
Reference Frame Conv.	IERS 2010	IERS 2010
Pseudo-stochastic Param.	Emp. Acc. 10 min const.	Emp. Acc. 10 min const.
Scaling Parameters	Drag, ERP, SRP	Drag, ERP, SRP
Arc length	24 h	30 h
Obs. sampling	10 s	10 s
GPS orbits, clocks	CODE, 5 s	CODE, 30 s

For the present study, an analysis period of 180 days between DOYs 80/2016 and 260/2016 was chosen.

Daily Root Mean Square (RMS) values of ionosphere-free carrier phase residuals are shown in Fig. 3 and amount to roughly 4 and 6 mm. The slightly increased noise level of the DLR solution results from the interpolation of 30 s clock offset values, whereas 5 s clocks are used by AIUB.

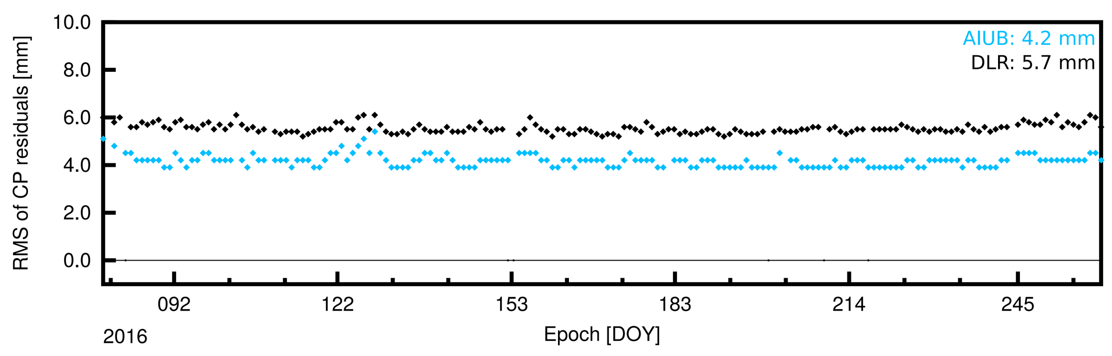

FIGURE 3: Daily RMS values of ionosphere-free carrier phase residuals.

Orbit Comparison

The direct comparison of both orbits in Fig. 4 shows the differences in radial, along-, and cross-track direction. Data gaps in the solutions are caused by days with maneuvers, where AIUB does not provide the orbits. Both solutions, tightly constrained in radial direction, do not show a radial offset w.r.t. each other, but a variation with an amplitude of approximately 1 cm. The overall good agreement in radial direction is of vital importance for the satellite altimetry.

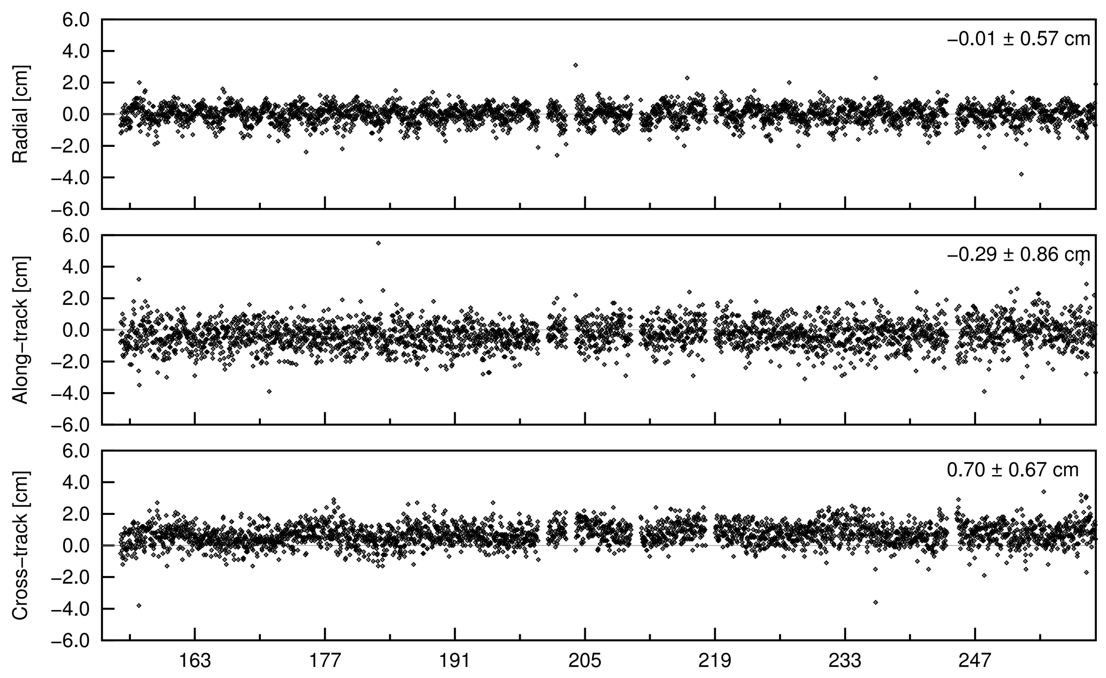

FIGURE 4: Orbit comparison of AIUB and DLR solution.

The amplitude of variation is even increased in along-tack component to 1.8 cm, whereas the cross-track component shows a variation of 1.3 cm but exhibits a bias of 7 mm. One reason for the differences in the lateral component could be caused by the atmospheric density models, and the associated drag and lift effect.

Satellite Laser Ranging Validation

The validation of satellite orbits by the two-way ranging space geodetic technique Satellite Laser Ranging (SLR) allows an independent validation of satellite orbits in order to determine the external orbit quality.

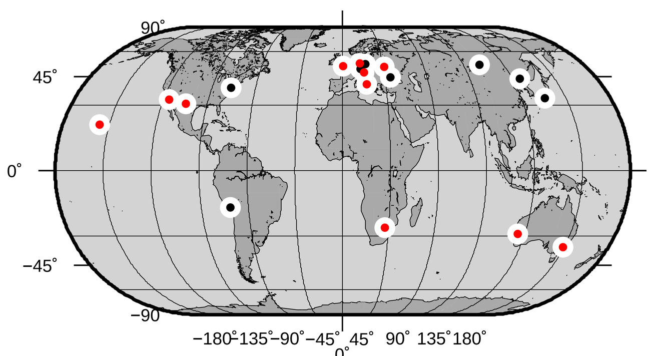

FIGURE 5: Available and selected (red) Satellite Laser Ranging stations for Sentinel-3A.

The employed International Laser Ranging Service (ILRS) network configuration for this analysis is shown in Fig. 5. Out of 20 possible ILRS station, which have tracked the satellite in the selected period, 11 reliable and stable SLR station were chosen for this quality assessment. The applied threshold of 6 cm for residual screening and elevation angle of 10 ° yields 18, 903 accepted Normal Points (NPs), 30 % were considered as outliers. The position of the tracking stations on ground is modeled with respect to the Satellite Laser Ranging Frame 2008 (SLRF2008), the effect of ocean loading is considered by GOT00.2.

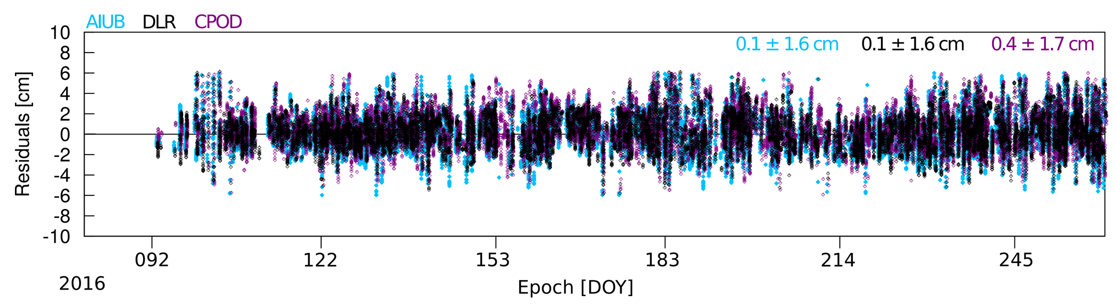

FIGURE 6: Long-term time series of Satellite Laser Ranging residuals.

The series of SLR residuals are shown in Fig. 6, the CPOD solution was added as an independent solution. Herein, the solutions show a good agreement in radial direction, which is of vital importance for satellite altimetry.
While SLR residuals provide an overall quality indicator, the series in Fig. 7 shows monthly, SLR-based position estimates, which give rise to corrections in radial, along-, and cross-track direction.

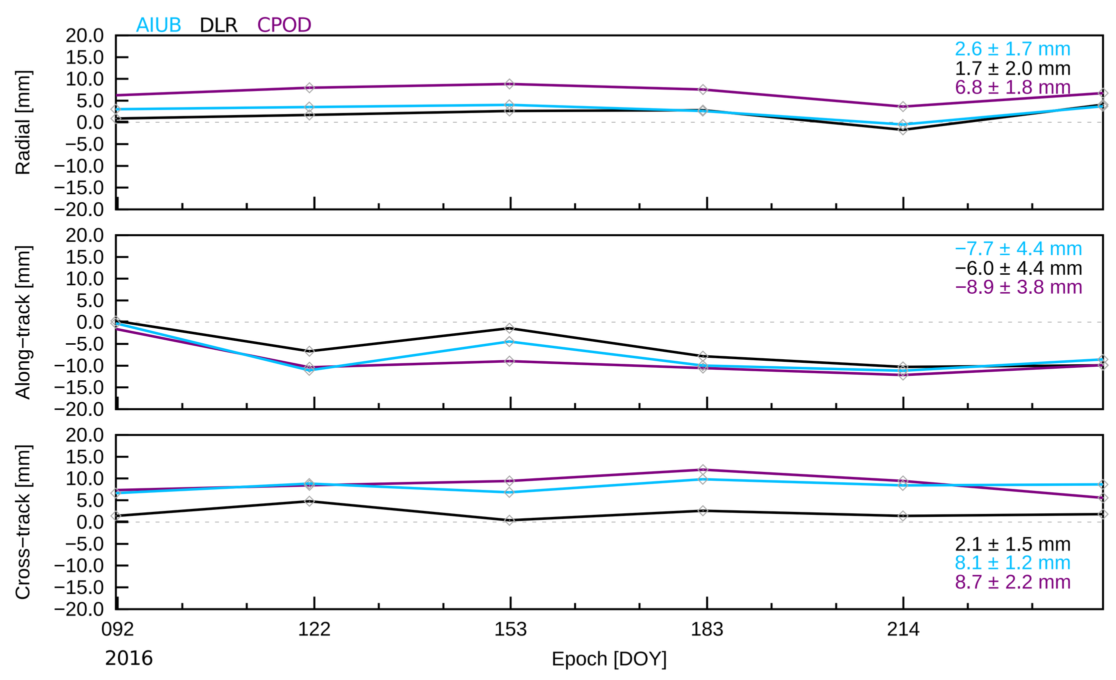

FIGURE 7: SLR-based, monthly position estimates of the Sentinel-3A solutions.

Herein, the radial component reflects the results from the SLR residuals. In along-track direction, all solutions exhibit a negative offset of approximately −7 mm with common systematics around DOY 153/2016. In cross-track direction, the AIUB and CPOD exhibit an offset of approximately 8 mm, DLR's solution 2 mm.
Both orbit solutions show a good agreement and stability. The minor differences might be attributable to slightly different modeling aspects in the employed software packages. Especially the radial component highlights the quality of the derived products, which is important for satellite altimetry.

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