Including of Sentinel-6A multi-GNSS observations into global GNSS solutions

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Introduction

The standard procedure of low earth orbiter (LEO) precise orbit determination (POD) based on data of Global Navigation Satellite Systems (GNSS) is to introduce the GNSS satellite orbits and clock corrections as known from separately established solutions based on data of a global network of terrestrial GNSS stations. However, it has been shown by several studies (Haines et al. 2015, Huang et al. 2020, Männel and Rothacher 2017) that combining Global Positioning System (GPS) data from LEOs and global GPS solutions has the potential to improve the quality of the resulting GPS products and geodetic parameters, e.g., the Earth's center of mass. So far, however, this could not yet be exemplified for the global Galileo solutions, because spaceborne LEO receivers were only tracking the GPS constellation before the launch of the Sentinel-6A (S6A) mission in November 2020. S6A is equipped with a PODRIX dual-constellation GNSS receiver collecting GPS and Galileo observations. S6A is therefore currently the most interesting LEO mission to combine LEO data with the Galileo data of the terrestrial station network.

Processing scheme

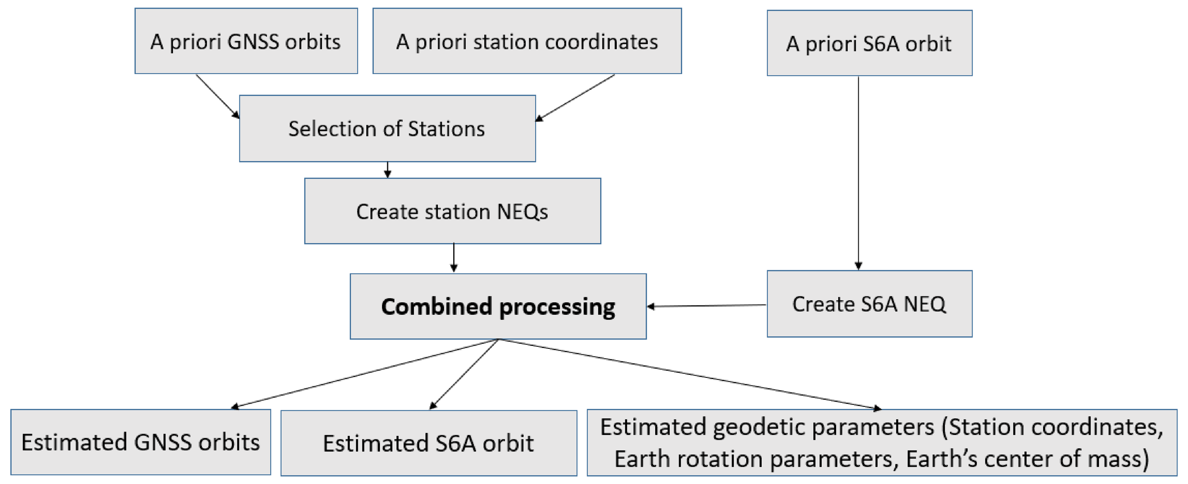

Figure 1: Scheme of combined processing

In this study, Galileo code and phase observations received from S6A PODRIX receiver are processed together with Galileo observations from ground stations of the International GNSS Service (IGS) in one joint least-squares adjustment to obtain a combined Galileo+LEO solution. S6A orbit parameters were estimated together with the Galileo satellite orbit parameters and geodetic parameters such as station coordinates, earth rotation parameters (ERPs), and Earth's center of mass coordinates (geocenter coordinates). To exploit the contribution of the S6A Galileo data, single-receiver ambiguity fixing is not only adopted to the terrestrial Galileo data but also to the S6A Galileo data. In this preliminary study the ambiguities are fixed on the level of separate LEO POD and separate ground station processings and are introduced as known in the combined processing. In order to investigate the impact of including LEO observations to the processing, separate solutions for Galileo+LEO and Galileo-only are compared.

Number of Parameters

In the combined processing various parameters are estimated. As an example, statistical information for a one day solution is given below. The implicit parameters are namely epoch-wise receiver clocks (ground stations and LEO) and unresolved ambiguities.

Solution	Galileo-only	Galileo+LEO
Number of stations	116	116
Number of satellites	E:24 L:0	E:24 L:1
Number of observations	795056	798396
Coordinates	348	348
Troposphere	1962	1962
Orbital parameters	360	366
Stochastic LEO orbit parameters	-	144
Epoch-wise (GNSS) satellite clocks	11520	11520
Earth orientation parameters	6	6
Earth's center of mass	3	3
Implicit parameters	56560	57317
Total number of parameters	70759	71666

Station selection

Nowadays there are over 300 IGS ground stations all over the globe. Due to geographical conditions, however, there are regions that are poorly covered, e.g., over the oceans. In this study, a subset from all the available ground stations is selected. Only ground stations are selected which provide both GPS and Galileo observations. Additionally, only stations which contributed to the CODE (Center for Orbit Determination in Europe) repro3 product series (Selmke et al. 2020) are selected. The reason for choosing a subset of ground stations is to increase the effect of including LEO data into the processing. In addition, a reduced ground station network drastically reduces the computation time. In the present study a subset with 132 ground stations is used indicated in Fig. 2, whereby on average 116 stations provided data to a one day solution.

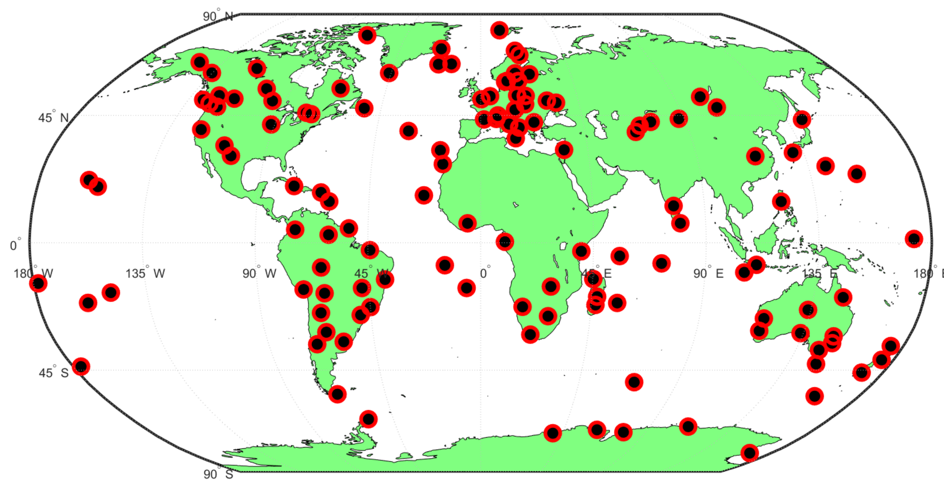

Figure 2: Selected ground stations

Sentinel-6A

At the Astronomical Institute of the University of Bern, orbit solutions for S6A are routinely computed in the frame of the Copernicus POD quality working group. These solutions are used for comparison purposes. The a priori orbits used in the combined processing differ from the routine solutions by a reduced observation sampling in the processing (180 sec instead of 10 sec). In this study, the S6A orbit solutions follow a dynamical orbit representation, whereby the orbit is parametrized by 6 Keplerian elements with additional piece-wise constant accelerations in along- and cross-track direction every 30 min, constrained to zero with $5.0 \cdot 10^{-10} m/s^2$. Non-gravitational force modelling, namely solar radiation pressure, earth radiation pressure and air drag, is applied. In order to verify that the reduced sampling does not lead to a significant deterioration of the orbit solution, an independent satellite laser ranging (SLR) validation was performed.

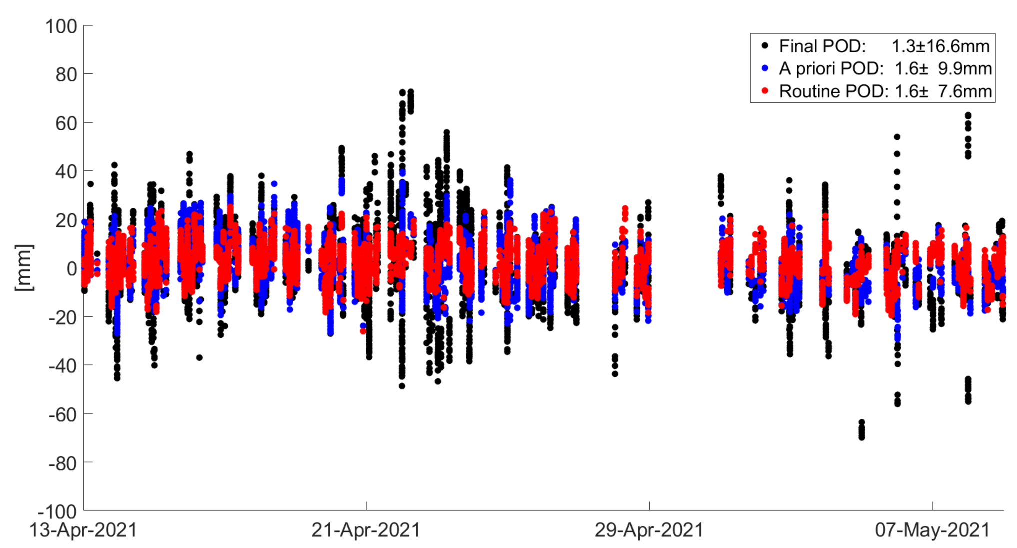

Figure 3: SLR Validation of AIUB routine S6A orbit solution with 10 seconds observation sampling, a priori orbit solution for combined processing with 180 seconds observation sampling and final orbit solution from combined processing

It is evident that the SLR residuals of the routine solution ('Routine POD') are of smaller standard deviation. The a priori solution ('A priori POD') used in the combined processing has a standard deviation of less than 1cm. This ensures that an observation sampling of 180 seconds is sufficient to generate accurate a priori orbit solutions. Fig. 3 additionally shows the SLR validation results of the final orbit solution for S6A resulting from the combined processing. This solution ('Final POD') shows a larger standard deviation which indicates a degradation of the orbit solution.

Earth's center of mass coordinates

The estimated Earth's center of mass coordinates for the Galileo-only and the Galileo+LEO solution are similar for the investigated time span.

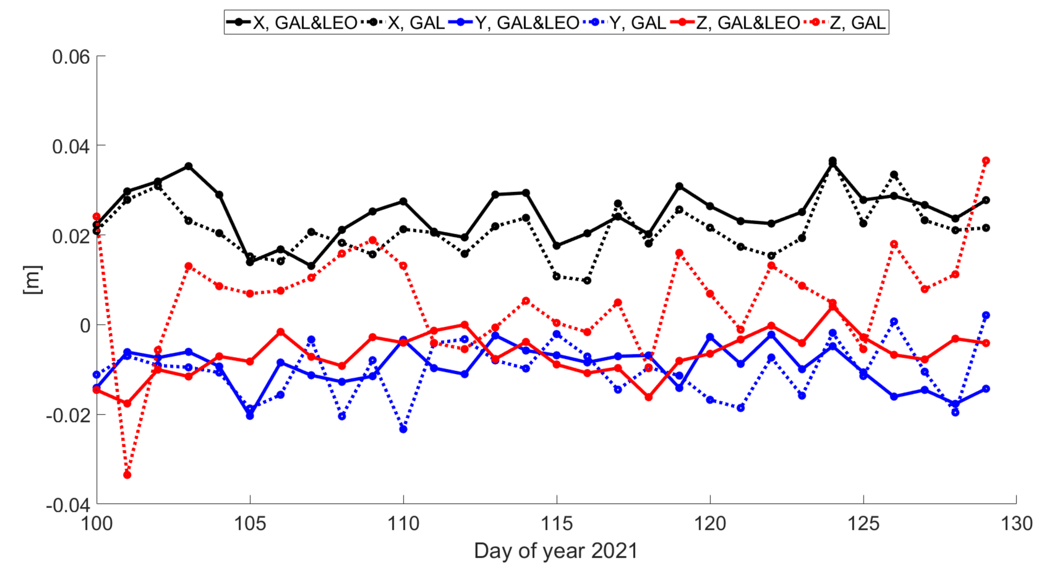

Figure 4: Estimated geocenter corrections

The estimated Z-component of the Earth's center of mass coordinates is more stable when S6A is included in the processing.

Earth orientation parameters

The estimated Earth orientation parameters, namely X and Y pole and dT, are compared to the combined reference solution C04 for earth rotation parameters consistent to ITRF14. For all of those parameters two values were estimated (beginning and end of day).

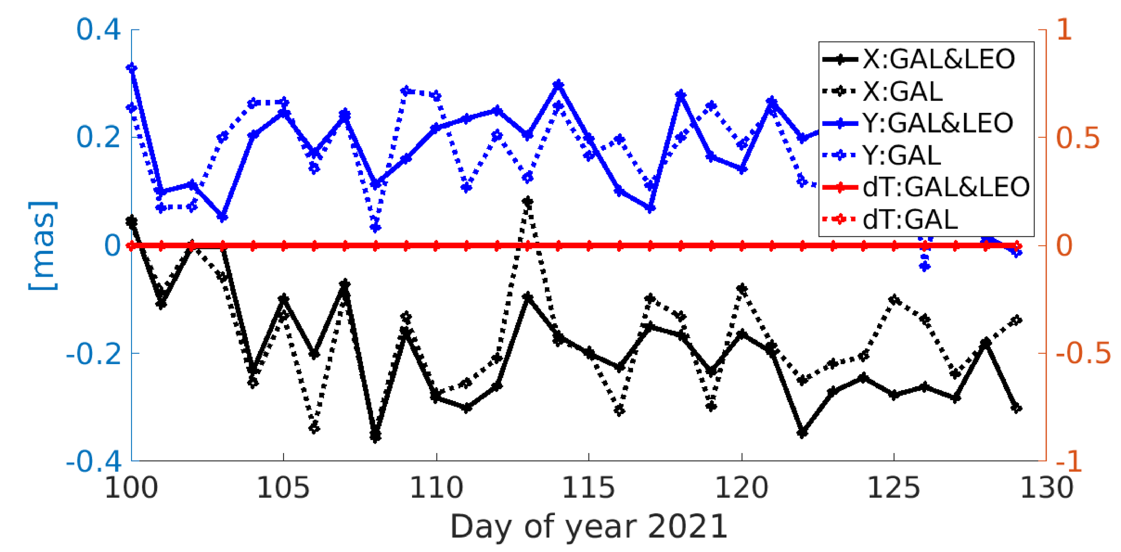

Figure 5: Differences of estimated ERP parameters to C04 reference series

Figure 5 indicates that including S6A into the network does not harm the estimation of ERP parameters. The parameter **dT** is nearly identical to the reference series for the investigated time span for both solutions.

Formal errors

An important quality measure of the solution are the formal errors of the estimated Earth's center of mass coordinates and Earth orientation parameters.

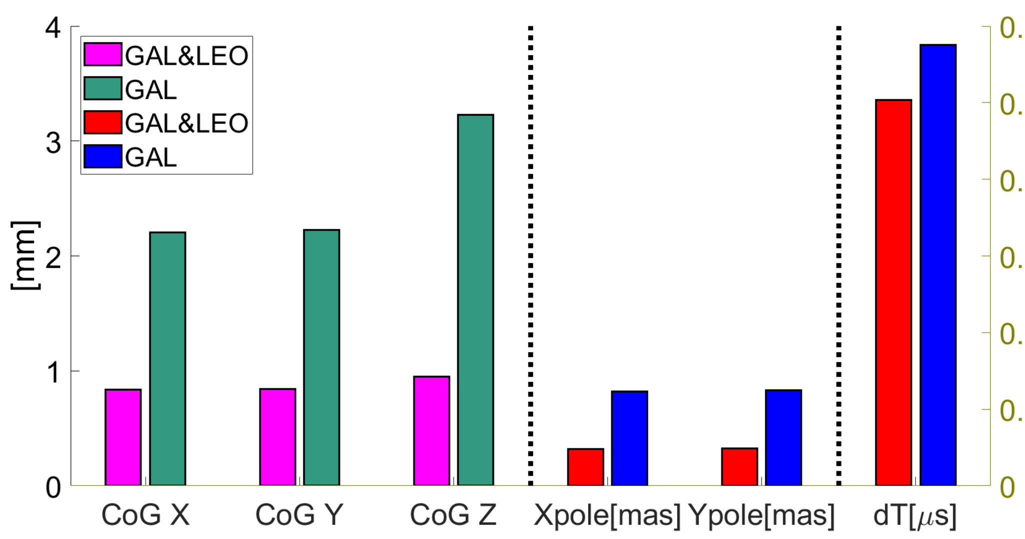

Figure 6: Formal errors of center of mass coordinates and Earth orientation parameters

Figure 6 reveals that including S6A into the solution, leads to reduced formal errors of the estimated Earth's center of mass coordinates and the Earth rotation parameters.

Ground station coordinates

The analyzed quality measures for the ground station coordinates are repeatability and formal errors of the estimated corrections. In terms of repeatability Fig. 7 shows that the inclusion of S6A does not harm the solution.

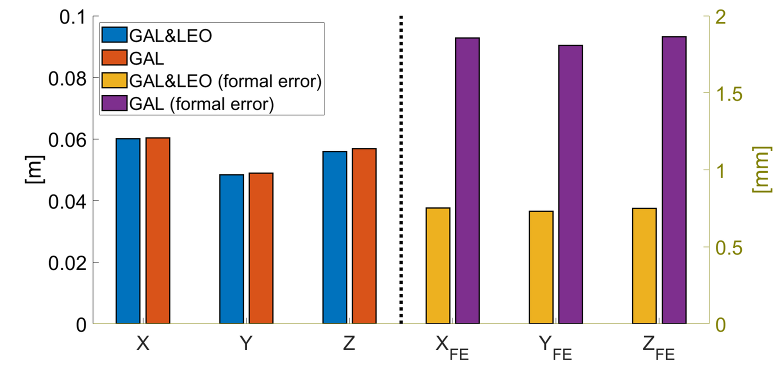

Figure 7: Station coordinates repeatability and formal errors

The formal errors (yellow&magenta) show that the solution clearly benefits from the information from S6A due to additional observation geometry.

Galileo orbit solutions

A representative quality measure of the resulting Galileo orbit solutions is the computation of orbit misclosures, which show the consistency at the day (arc) boundary. Daily RMS values over all satellites are shown in Fig. 8.

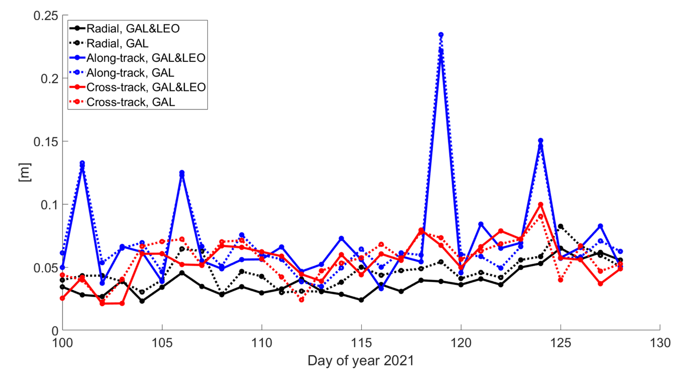

Figure 8: Orbit misclosures of Galileo solutions

In Figure 8 it is visible that the inclusion of S6A into the solution does not harm the resulting Galileo orbit solutions. The outliers, which are present in both of the solutions are due to specific Galileo satellites, whose along-track direction is of worse quality than for the other days. Further investigations are needed to find the reason for this.

Conclusions

The results of the orbit differences and misclosures, as well as those of the station coordinates repeatability allow the interpretation that if a LEO, in this case Sentinel-6A, is integrated into a reduced ground station network, the resulting solution does not deteriorate. The evaluation of the formal errors also shows that the determination of the geodetic parameters may benefit. This is particularly evident in the case of the Z-component of the Earth's center of mass coordinates, where the estimates are more stable and the formal error is halved if S6A is integrated into the system. Further research is needed to determine the reason for the decreased orbit precision of S6A. Additionally, it has to be confirmed that the formal errors reflect the quality of the determined geodetic parameters. Future investigations will also address how this procedure performs in multi-GNSS solutions.

References

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