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Handling of geocenter motion in the GNSS solutions

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1. Introduction

We analyze differences in GNSS products, such as in station coordinates, geocenter coordinates (GCC), and satellite orbits delivered from the double-difference multi-GNSS (GPS, GLONASS, and Galileo) processing using different approaches to the terrestrial reference frame (TRF) realization and different approaches to handling of the geocenter motion. The reference frame in the GNSS processing is realized by applying minimum constraint conditions on the network based on the set of datum-defining stations. We show the impact of using different set of constraints on the GNSS-based products. The theory clearly requires that the geocenter motion ought to be correctly considered in the processing. Thus, we test, whether the information about GCC can be included into the processing from external sources.

2. Solutions

Table 1 presents main differences between the analyzed solutions. In SOL-NG, only the NNR constraint is applied to remove the singularity from the normal equation system. The origin of the resulting reference frame is shifted in line with the apparent geocenter as seen by GNSS. In SOL-G, the geocenter vector is estimated as an additional parameter in the processing. Therefore, we have to impose the minimum NNT constraint on the network. The estimated station coordinates should then be consistent with the a priori reference frame by definition. In SOL-I, we apply both NNR and NNT conditions, while GCC are not estimated. We tied the origin of the realized TRF with the origin of the datum and assumed that the GCC is kept fixed to zero. We prepared also three solutions denoted as SOL-SLR, SOL-R, and SOL-GPS, which include geocenter motion from other, external sources. In SOL-SLR we apply GCC based on the 7-day SLR solution using LAGEOS-1/LAGEOS-2. In SOL-R we apply epochwise GCC from the annual geocenter motion (Ries, 2016). In SOL-GPS we apply GPS-based GCC.

Reference Frame Realization			
Solution	Estimation of GCC	NNR	NNT
SOL-NG "No Geocenter"	NO	YES	NO
SOL-G "Geocenter"	YES	YES	YES
SOL-I "IGS"	NO	YES	YES
Handling Geocenter Motion			
Solution	GCC Source	NNR	NNT
SOL-SLR	External 7-day LAGEOS 1/2 SLR solution	YES	YES/NO
SOL-R	External geophysical model (Ries, 2016)	YES	YES/NO
SOL-GPS	External based on GPS-only processing	YES	YES/NO

Table 1 Description of the solutions

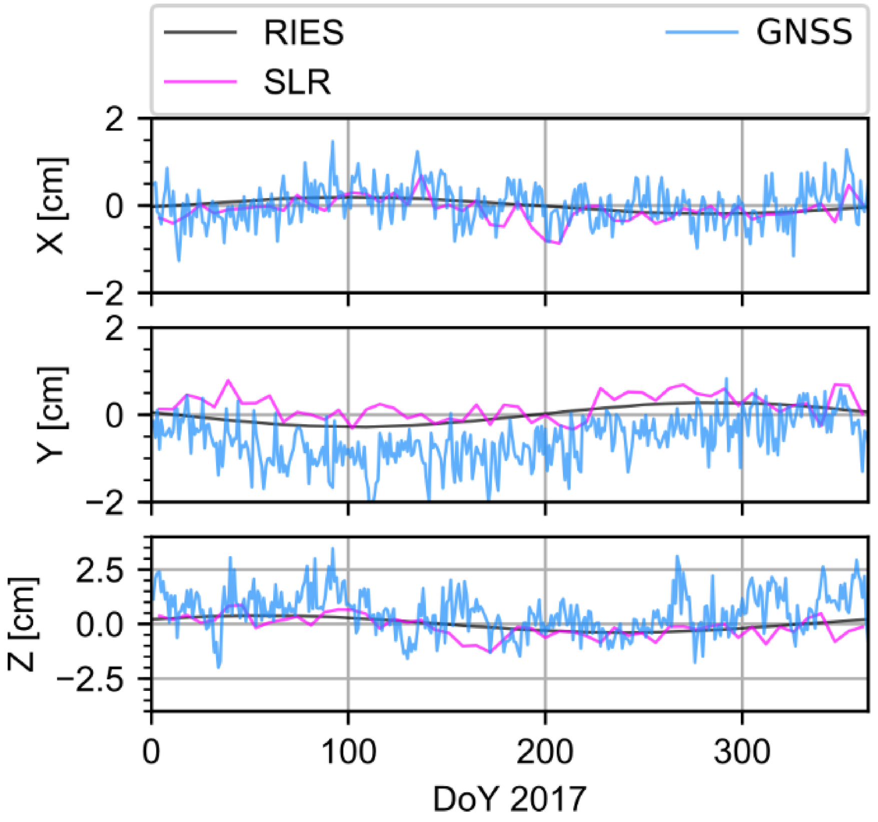

Fig. 3.1 Time series of GCC from SLR, Ries model and multi-GNSS.

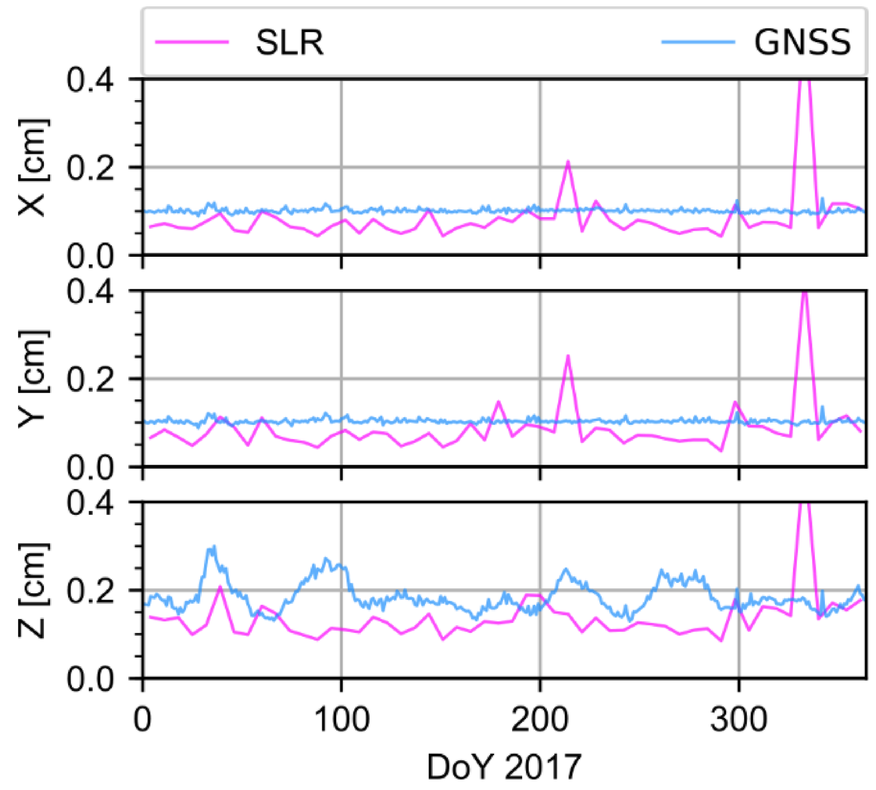

Fig. 3.2 Time series of GCC formal errors for multi-GNSS and SLR solutions.

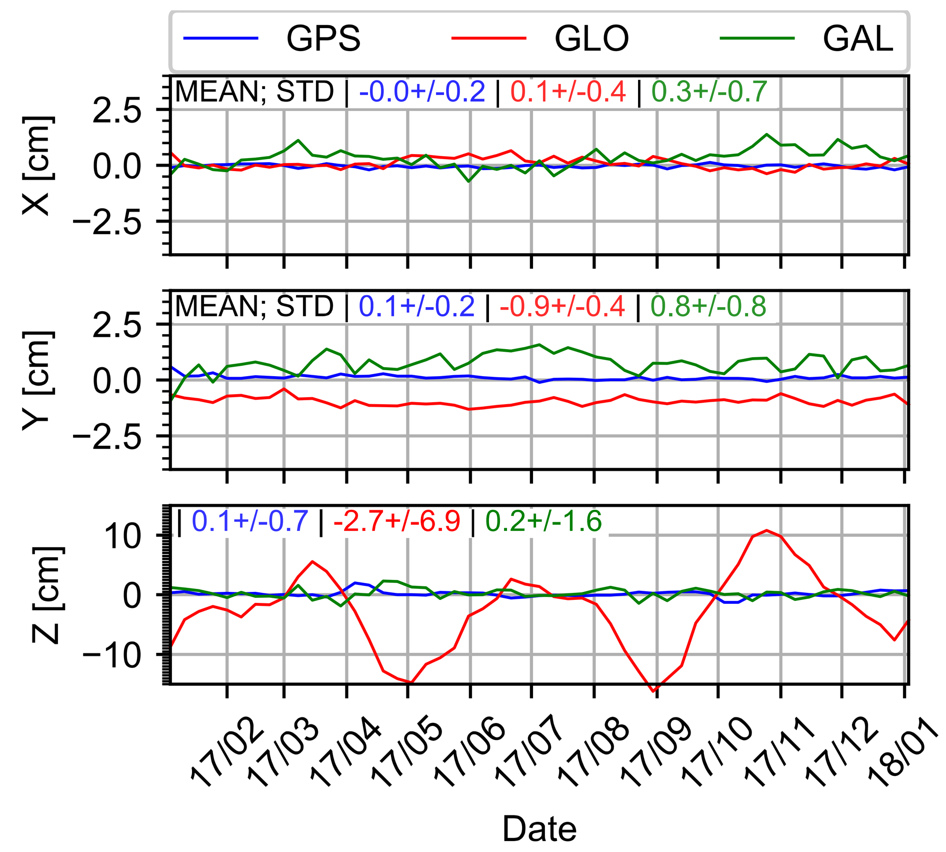

Fig. 3.3 Differences between system-specific GCC and combined multi-GNSS series. The scale for the Z geocenter component is changed for the sake of readability.

3. Geocenter

Figures 3.1, 3.2 show the the time series of GNSS-based GCC wrt the SLR-based results. The GNSS-based GCC contain not only geophysical signal but also accumulate other errors originating from, i.e., orbit modeling issues. Fig 3.3 shows the time series of differences between GPS-only (GPS), GLONASS-only (GLO), and Galileo-only (GAL) GCC with respect to the combined GPS+GLONASS+Galileo solution. The GCC are estimated based on the same normal equation system as the combined solution using the approach described by Scaramuzza et at. (2018). The combined GCC product is most consistent with GPS-based estimates. The standard deviation of the residuals for X, Y, and Z geocenter components equal 4, 4, and 69 mm for GLONASS and 7, 8, and 16 mm for Galileo. The system-specific Y component of GCC is systematically shifted depending on the system. The mean offsets equal 8 and −9 mm for Galileo and GLONASS, respectively. The 3-cpy signal with the amplitude of almost 8 cm is still dominant in the time series of the GLONASS-only Z geocenter component. Moreover, the signal with a period close to 3.4 days and the amplitude of ~2.5 mm is visible in the Galileo series for the X and Y components (Fig 3.4). The signal is related to the combination of the frequencies of the satellite revolution period and the Earth rotation. The formal errors of the X and Y GCC are quite regular over time with average values of 1.9, 1.4, 1.0, and 0.9 mm for Galileo, GLONASS, GPS, and the combined solution (Fig. 3.5). The formal errors of the Z component depend on the mutual orientation of the orbital planes with respect to the Sun (consistent with Scaramuzza et al., 2018).

Scaramuzza, S., et al. (2018). Dependency of geodynamic parameters on the GNSS constellation. Journal of Geodesy, 92(1), 93–104. https://doi.org/10.1007/s00190-017-1047-5

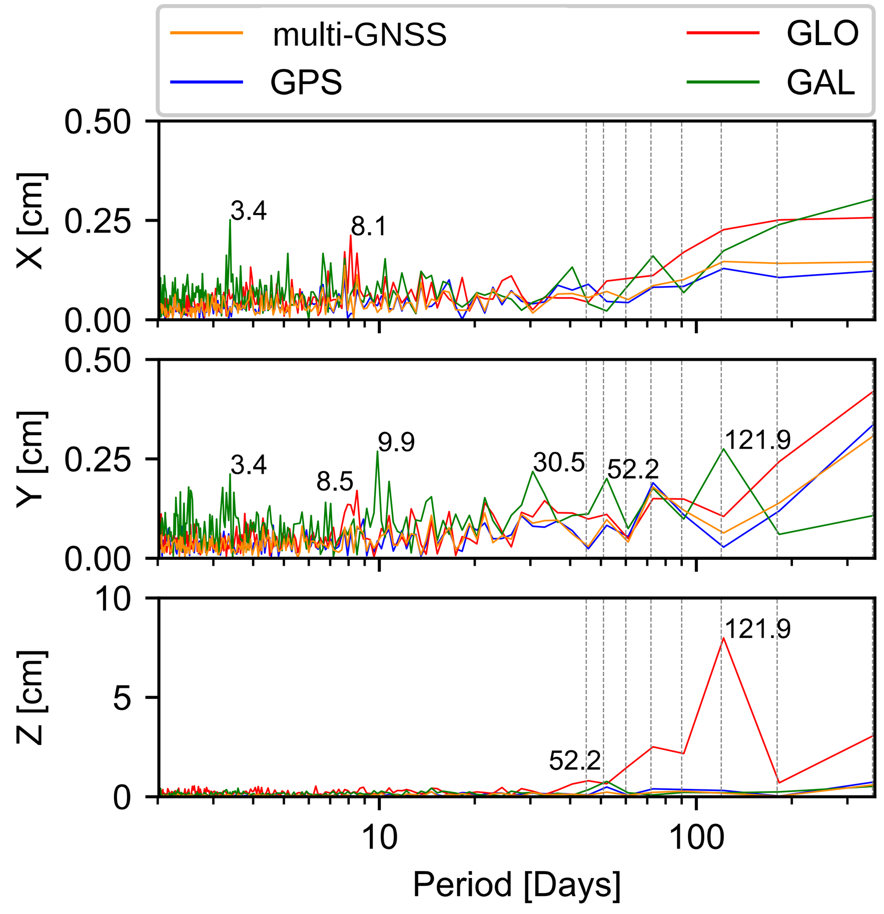

Fig. 3.4 Spectrum analysis of the GCC. The scale for the Z geocenter component is changed for the sake of readability. GLO denotes GLONASS; GAL denotes Galileo.

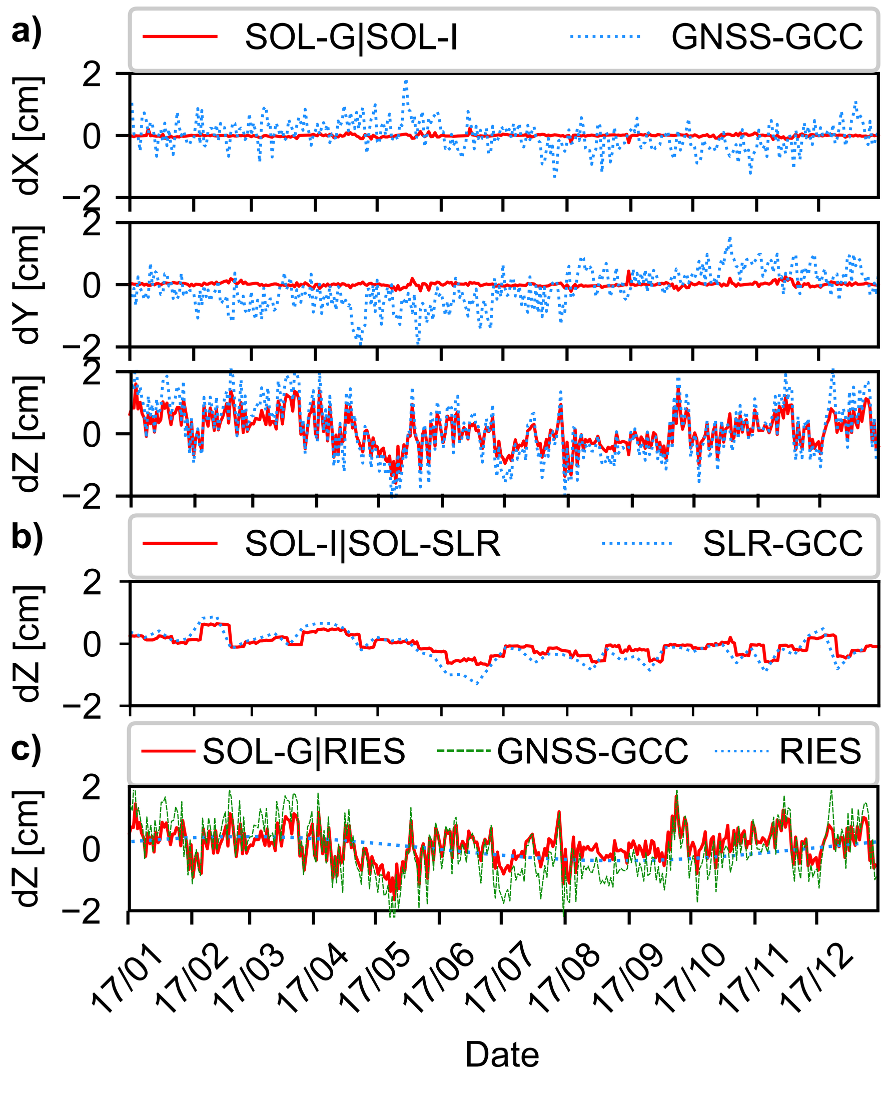

Fig. 4.1 The time series of the orbit translations in the X, Y, and Z directions between the particular solutions. (a) Translations between SOL-G and SOL-I compared to GCC derived from SOL-G. (b) Translation between SOL-I and SOL-SLR compared to GCC derived from SLR. (c) Translation between SOL-G and SOL-R compared to GCC model (Ries, 2016) and the GCC derived from GNSS. GCC = geocenter coordinates; GNSS = Global Navigation Satellite Systems;

4. Including Geocenter Motion in GNSS Processing

Figure 4.1 illustrates how the orbits change between SOL-I, SOL-SLR, and SOL-R with respect to the SOL-G solution. We have compared the satellite positions in the Earth-fixed frame using seven-parameter Helmert transformation. The SOL-I orbit (NNR+NNT) is shifted in reference to the standard SOL-G (NNR+NNT+GCC estimated) orbit in the Z direction with the pattern, which corresponds to the apparent GCC (see Figure 4.1a). The translations in X and Y direction do not correspond to the geocenter signal and are at the submillimeter level. Next, we have checked what happens with the orbit translation when the external GCC is included in the processing. First of all, the impact of the apparent GCC is reduced when including external GCC values. Figure 4.1b shows that when the 7-day GCC from SLR is included in the processing, the translation of the orbit roughly corresponds to the time series of the SLR-GCC in Z direction. As in the previous case, there is no translation neither in X nor in Y directions. Next, Figure 4.1c presents that the shift of SOL-R orbit in reference to SOL-G is smaller than for SOL-I, because the annual signal delivered from the geophysical model was subtracted from the apparent GCC as seen by GNSS.

5. Differences in station coordinates

Station coordinates obtained in the SOL-NG are referenced to the instantaneous CoM. This means that it is equivalent to the solution SOL-G apart from a shift from the origin of the TRF into the instantaneous CoM, which corresponds to the GCC vector from the SOL-G solution. Taking into consideration all stations, which have been considered in the solution, the median repeatability of common station coordinates decreases from 5.9 to 1.7 mm (by 71%), from 4.0 mm to 2.0 (by 50%), and from 6.2 to 4.3 mm (by 29%) for the north, east, and up components, respectively, between SOL-NG and SOL-G. Figure 5.1 shows the time series of coordinates for the BRUX station. The time series reflects the variation of the estimated GCC parameters. The NNT condition imposed on the GNSS network is beneficial for the estimation of station coordinates and stabilizes the coordinate repeatability. We checked the formal errors of estimated station coordinates for selected solutions. The reduction of formal errors is 43% for the X and Y, and 65% for the Z component for SOL-G when compared to SOL-NG (Figure 10). Moreover, there are irregular periods of increased values of the Z coordinate errors in the time series for the SOL-NG solutions. The pattern is consistent with the time series of the formal errors of the Z geocenter (Figure 5.2). If we transform the error variations from the geocentric into the topocentric system, we see that both north and up components are affected to the greatest extent, which is due to the errors in the Z geocenter component. When the NNT condition is not imposed on the network (SOL-NG), we actually subordinate the accuracy of station coordinates with the geographical position of the station.

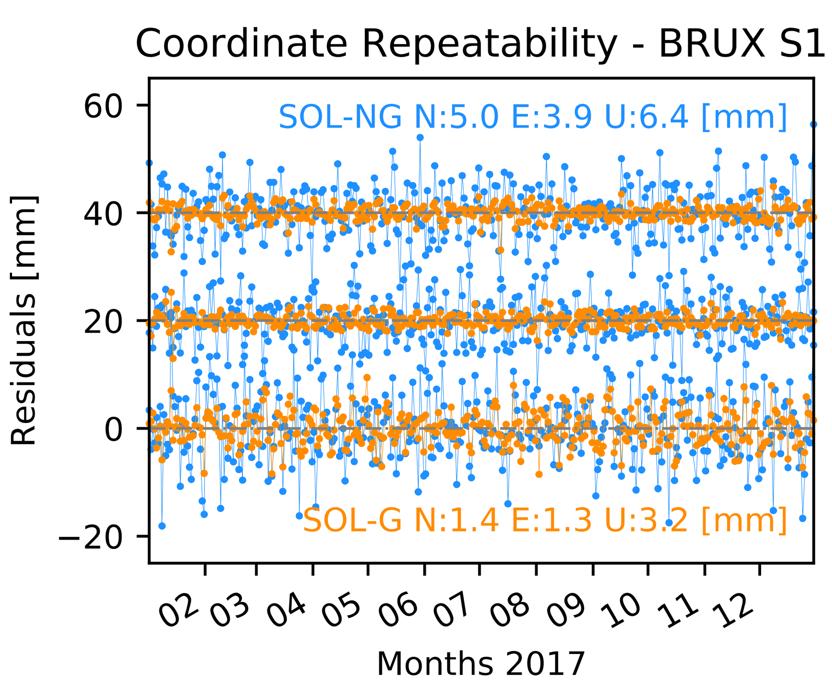

Fig.5.1 The time series of daily coordinate residuals with respect to the weekly mean for the station BRUX decomposed into the north (top), east (middle), and up (bottom) components from SOL-NG and SOL-G. SOL-G mostly corresponds to SOL-I.

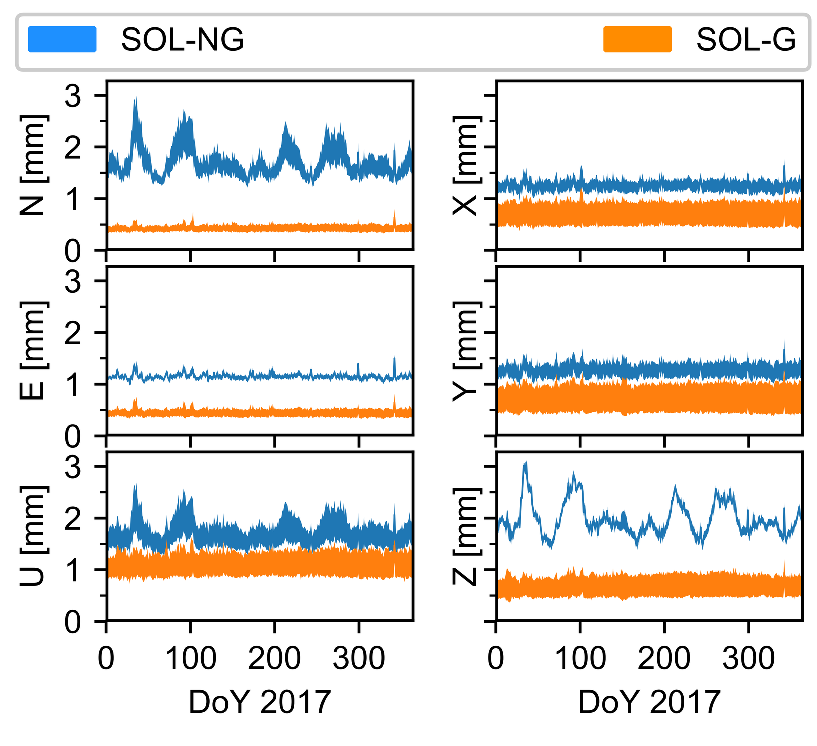

Fig.5.2 Time series of formal errors of station coordinates transformed into topocentric NEU (left block) and geocentric XYZ (right block) for the solutions without the geocenter (SOL-NG) and with the geocenter determination (SOL-G). SOL-I corresponds to SOL-G.

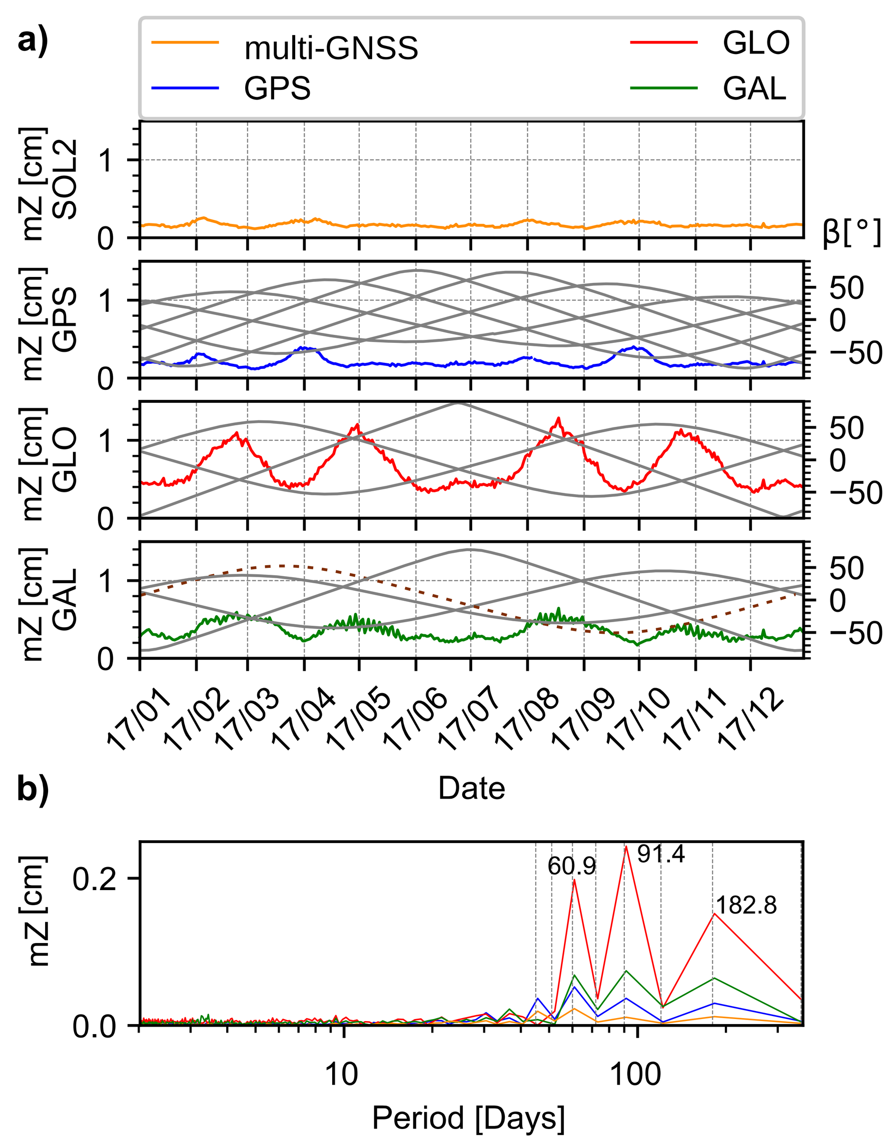

Fig. 3.5 Formal errors of the Z geocenter component (a) Time series of the particular parameters with the β angles of the corresponding GNSS constellations (right axis). (b) Spectrum analysis of the formal errors of the Z component.

6. Conclusions

The results show that we cannot realize reliable Center-of-Mass (CoM) frame in global GNSS analyses with the accuracy better than 4 mm. Estimation of station coordinates in the CoM frame is questionable, because of the spurious nature of GNSS-based GCC. Moreover, we see non-trivial differences in the GCC delivered by GPS, GLONASS and Galileo. This aspect should be further investigated. When NNR+NNT are used and the GCC are not estimated, the impact of apparent GCC as seen by GNSS is spread over the estimated parameters such as station coordinates, ERPs and orbits. Nonetheless, the orbit cannot be represented in instantaneous CoM frame until geocenter motion will not be taken into account properly. So far, we recommend that the NNT condition should be applied on the GNSS network, whereas the GCC should be estimated as an additional parameter.

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Zajdel, R., Sośnica, K., Dach, R., Bury, G., Prange, L., & Jäggi, A. (2019). Network effects and handling of the geocenter motion in multi-GNSS processing. Journal of Geophysical Research: Solid Earth, 124, 5970– 5989. https://doi.org/10.1029/2019JB017443