Impact of the multi-GNSS station distribution and datum definition on station coordinates

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1. Introduction

The network configuration affects the quality of the products delivered from the global GNSS processing. Nowadays, International GNSS Service (IGS) has the well-developed and a global covarage network of multi-GNSS receivers. However, most of the operational solutions performed by IGS Analysis Centers are based on the network, serving also other purposes instead resulting in an inhomogeneous density of stations. The purpose of this study is to analyze the differences in GNSS products, such as orbits and global geodetic parameters delivered in the double difference multi-GNSS processing, which may arise from using different sets of global GNSS networks. Moreover, different approaches to the definition of datum have been tested. We checked how the estimation of the geocenter coordinates with a simultaneous No-Net-Translation condition imposed on the network affects the coordinates of the stations.

2. Network and processing

We have prepared two solutions with different configurations of global multi-GNSS stations: (1) 56 stations, homogeneously distributed – SOL1, and (2) 106 stations with redundant sites in Europe and in Asia-Pacific Region – SOL2 (see Fig. 1,2). All stations from SOL1 are also considered in SOL2, thus are denoted as „common stations". All the selected stations track GPS, GLONASS, and Galileo that are used in the processing. The analysis covered the whole year 2017, using latest multi-GNSS models consistent with the current processing scheme used in the Center for Orbit Determination in Europe (CODE) MGEX operational solutions. In the prepared solutions following parameters are set up and estimated: station coordinates, troposphere parameters, geocenter coordinates, Earth rotation parameters, orbit parameters. On average, 70 satellites were available.

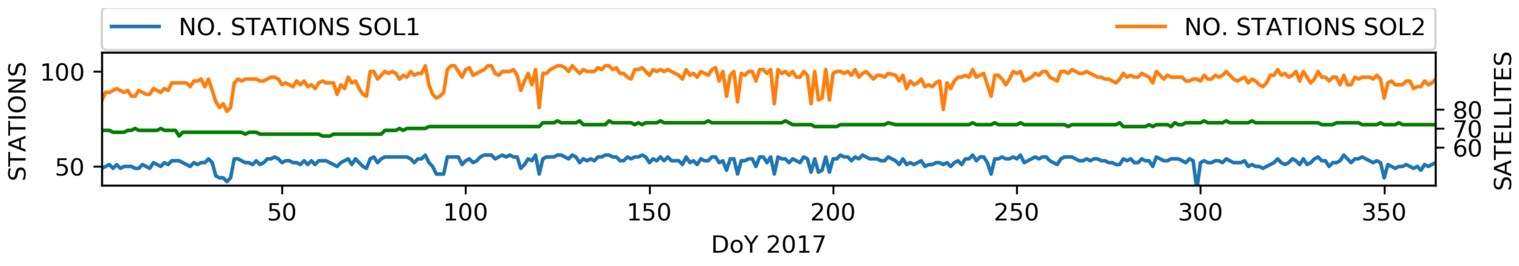


Fig. 2. Number of stations considered in each 1-day processing for SOL1 (blue) and SOL2 (orange). Total numer of GPS, GLONASS and Galileo satelites available in the period of analysis (green).

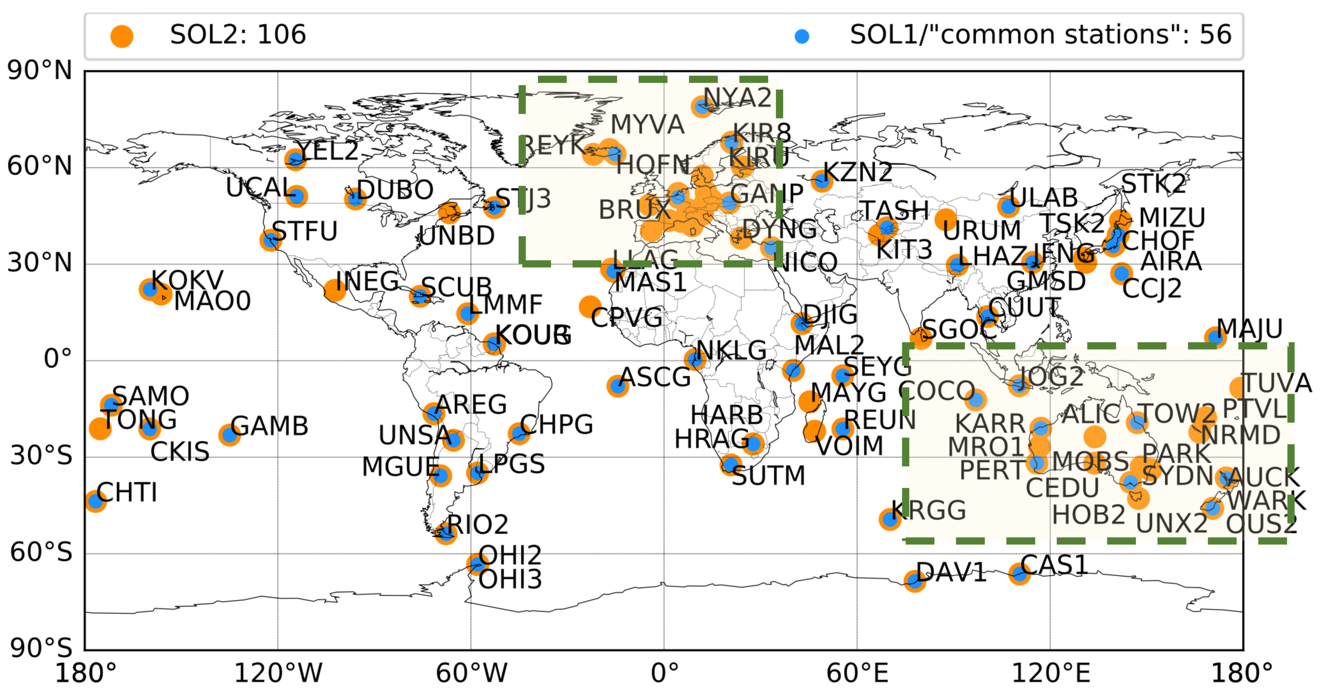


Fig. 1. Distribution of stations in SOL1 and SOL2. The stations which were included in SOL1 are denoted also as „common stations".

3. Datum definition

Datum definition has been realized using minimum constraints based on Helmert parameters imposed on the network. Only common stations which participated in the realization of IGS14 were used for the datum definition, whereas the coordinates of remaining stations were freely estimated in the solutions without any constraints. Two different types of parametrization have been tested and described in Table 1. In each solution, a No-Net-Rotation condition was applied. Solution A is similar to standard IGS processing routine, with geocenter coordinates fixed to the origin of IGS14. In Solution B, geocenter coordinates were estimated and No-Net-Translation condition was imposed on the network.

	NNR	NNT	GCC
SOLA	YES	NO	NO
SOLB	YES	YES	YES

Table 1. Description of the solutions in terms of minimum constaint parametrization imposed on the network

4. Station coordinates

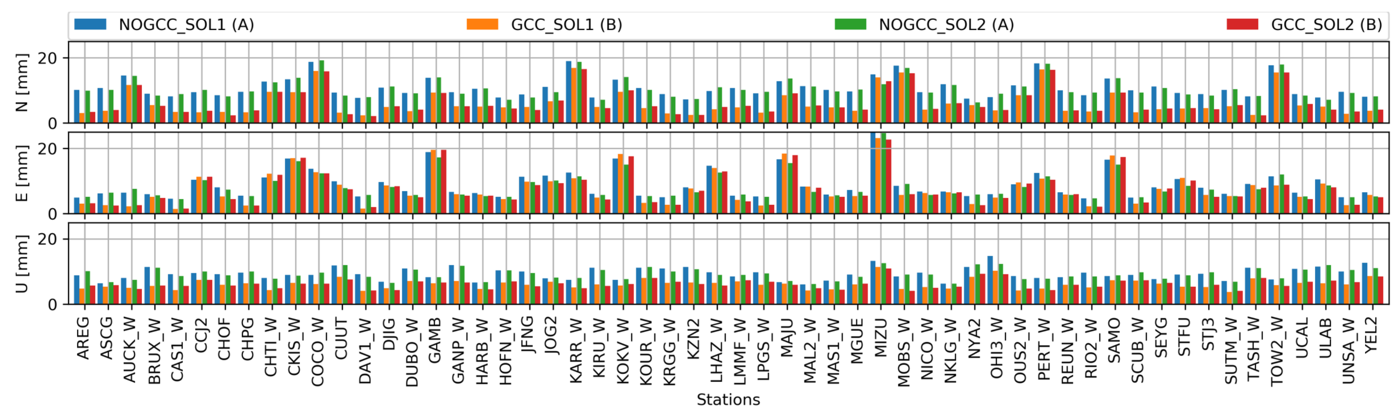


Fig. 4 RMS of coordinate repeatability for particular common stations, decomposed to North, East and Up components. The suffix „_W" means that the station contributed in the realization of the IGS14 datum.

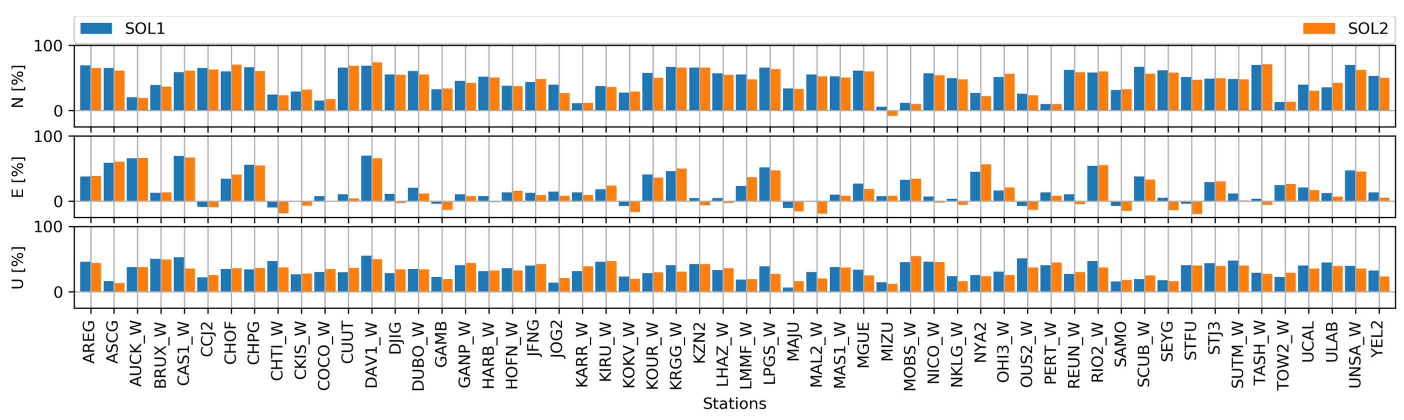


Fig. 5. The percentage change of the coordinate repeatability, between SOLA and SOLB. The higher values, the greater improvement for the solution with geocenter estimation. The suffix „_W" means that the station contributed in the realization of the IGS14 datum.

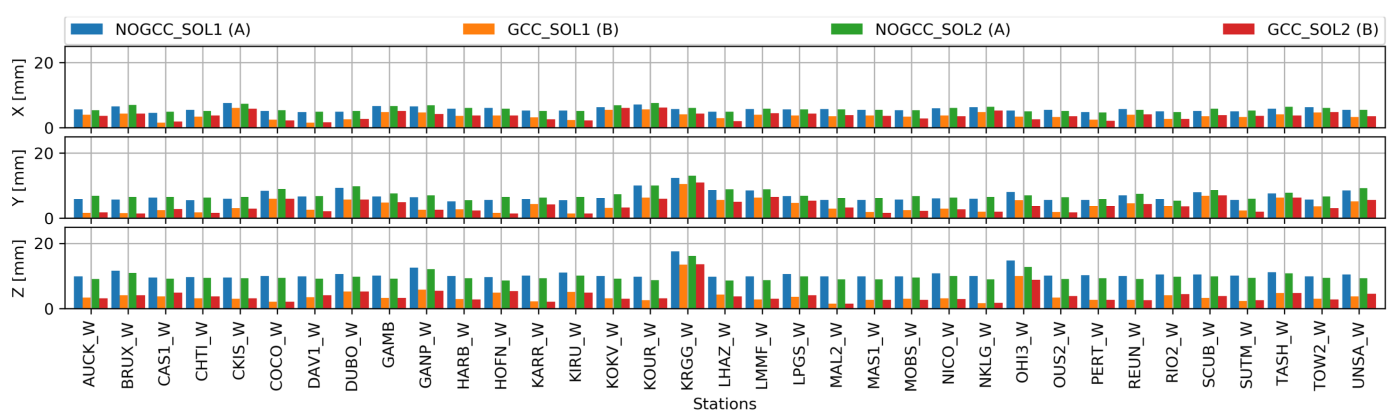


Fig. 6. The consistency of the coordinates w.r.t. a priori IGS14 values, decomposed to X, Y, Z components. The consistency measured as standard deviation of residuals.

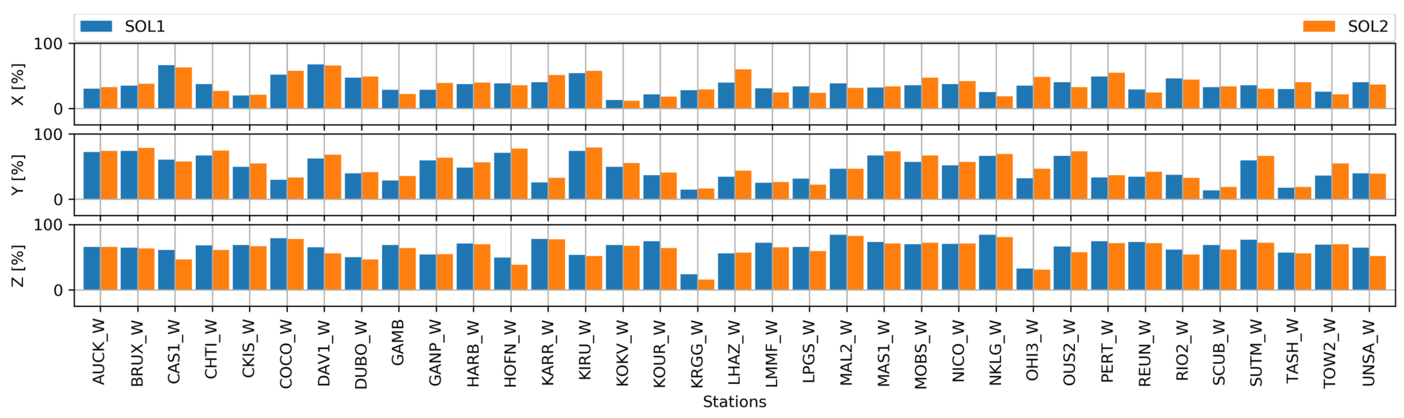
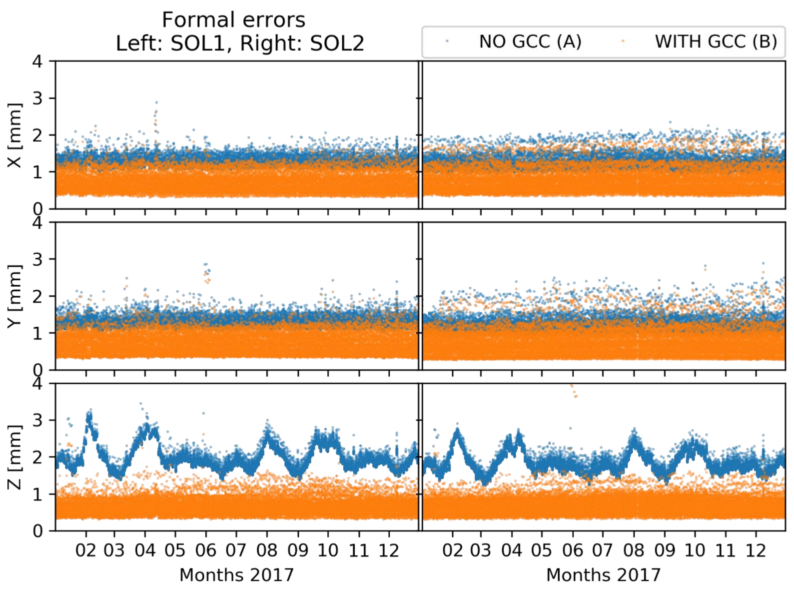


Fig. 7. The percentage change of the consistency of the coordinates w.r.t. a priori IGS14 values, between SOLA and SOLB. The higher values, the greater improvement for the solution with geocenter estimation.

		North	East	Up
„_W" suffix	SOL1:	13	13	13
„_W" suffix	SOL2:	8	10	7
Other	SOL1:	34	37	31
Other	SOL2:	35	35	30

Table 4. Percentage change of the coordinates repeatability RMS between SOLA and SOLB. Results decomposed to North, East and Up components for both SOL1 and SOL2. All values in %.



Formal errors

Applying square-root-law to the number of observations used for particular solutions we should expect a decrease of formal errors for SOL2 w.r.t. SOL1. More stations cause a decrease of the formal errors by 4, 7 and 7 % for X, Y and Z coordinates, respectively in SOLA, however, increase the formal errors by 3, 2 and 2 % for X, Y, and Z coordinates, respectively in SOLB (Table 2). We can observe the reduction of formal errors by 43 % for X and Y, and 65 % for Z component in SOL1 as well as 38 % for both X and Y, and 62 % for Z component in SOL2 between SOLA and SOLB (Fig. 3). When we do not estimate geocenter coordinates in global GNSS processing the signal with the period of about 58 days is clearly visible in the time series of formal errors of Z coordinates of GNSS stations. The same signal is dominant in the time series of GNSS-based geocenter Z coordinate (see Section 5). That could mean that the orbital errors and geocenter motion are partially absorbed by the coordinates of the stations.

Fig 3. Formal errors of X, Y and Z coordinates for all „common stations" as a funtion of time for SOL1 (left), SOL2 (right), SOLA (blue dots), SOLB (orange dots).

SOLA/ SOLB	SOL1	SOL2	SOL1/ SOL2	SOLA	SOLB
X	43	38	X	3.9	-3.1
Y	43	38	Y	7.5	-1.8
Z	65	62	Z	7.4	-1.7

Table 3. Percentage change of the values of formal errors of X, Y, Z coordinates between SOL1 and SOL2 (right) as well as SOLA in reference to SOLB (left). All values in %.

Coordinate repeatabilities

For each solution, the coordinate repeatability was calculated as the indicator of the quality of the coordinate solution. Figure 4 presents the overall RMS for particular common stations decomposed into the North, East and Up components w.r.t. the 1-year mean values. There is a marginal decrease of the RMS of the coordinate repeatabilities for SOL2 w.r.t. SOL1. On the other hand, the differences between SOLA and SOLB (see Tab. 4 and Fig. 5) are significant. The median of RMS values for SOLB is reduced by about 13% w.r.t. SOLA in SOL1 for the stations which contributed to the datum definition. For the remaining stations, the median of RMS values for SOLB is also reduced by 30-40%. The same level of magnitude applies to SOL2 (see Table 4). Imposing the No-Net-Translation condition on the network and estimation of the geocenter coordinates as an unconstrained parameter is beneficial for the estimation of station coordinates and stabilizes the coordinate repeatability.

Coordinate corrections w.r.t. IGS14 coordinates

Figure 6 illustrates the standard deviation of corrections w.r.t. IGS14 coordinates for all common stations. In general, the contribution from adding extra GNSS stations to a homogeneously distributed network is minor. However, the differences between SOLA and SOLB are significant again (see Fig. 7). Considering SOL1 (see Table 5), the median of RMS values for SOLB w.r.t. SOLA is reduced by 36, 48 and 68% for X, Y, Z coordinates, respectively. The similar level of magnitude applies to SOL2. We can say that the errors of the corresponding geocenter coordinates are absorbed by the stations. The greatest improvement is visible for the Z coordinates which partially confirms the above statement.

		X	Y	Z
MEDIAN	SOL1:	36	48	68
	SOL2:	36	55	64
MIN | MAX	SOL1	13 | 67	14 | 73	24 | 84
	SOL2	12 | 66	16 | 79	16 | 82

Table 5. Percentage change of the coordinate consistency w.r.t. a priori IGS14 between SOLA and SOLB. Results decomposed to X, Y and Z components for both SOL1 and SOL2. All values in %.

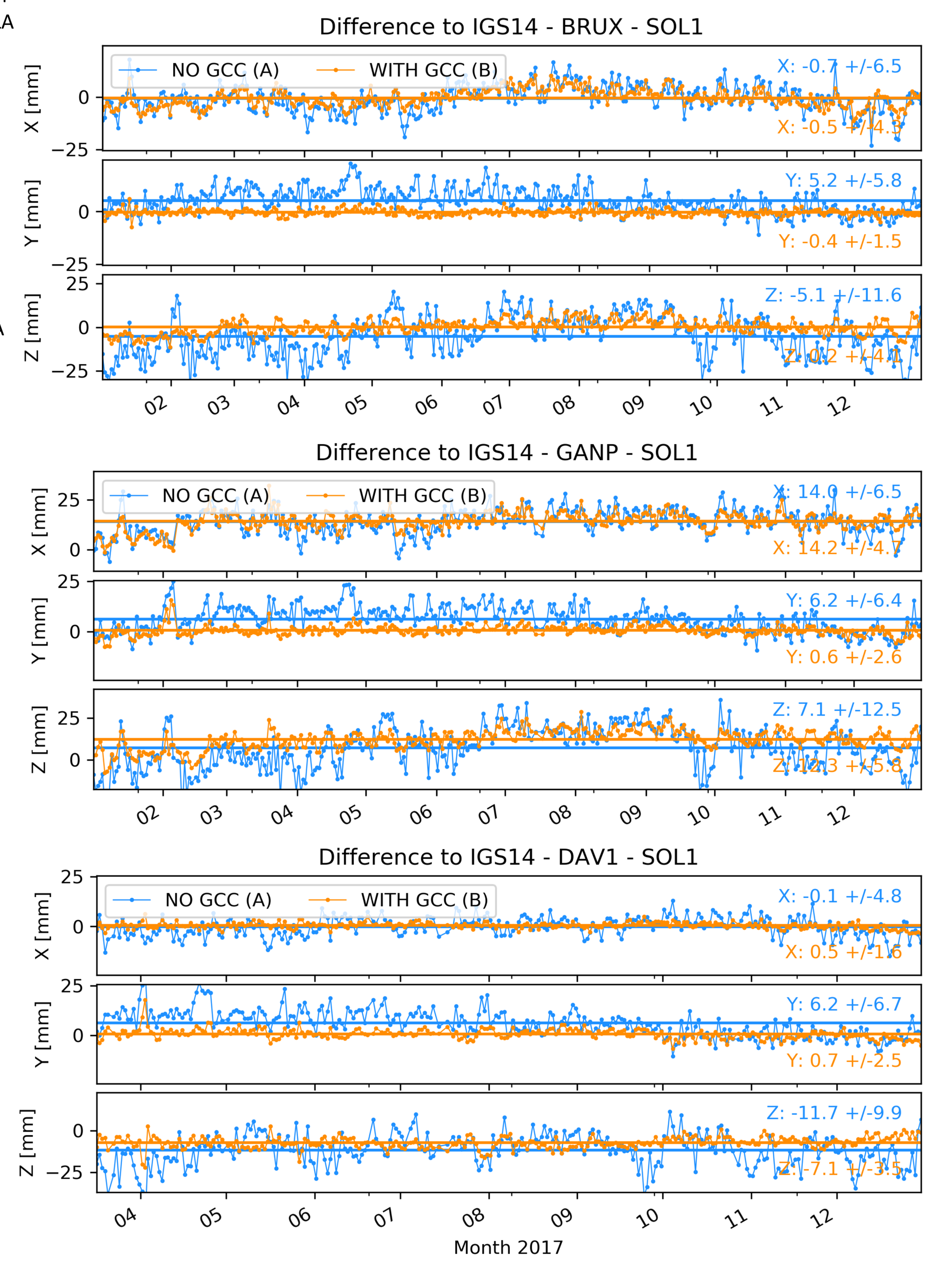


Fig. 8 Time series of station residulas w.r.t. yearly mean for the stations BRUX (top), GANP (central) and DAV1 (bottom), decomposed to X, Y, Z components.

Figure 8 shows the time series of corrections w.r.t. IGS14 coordinates for stations BRUX, GANP, and DAV1. Despite the reduction of standard deviation, the mean offset of corrections is significantly reduced. The coordinates of the stations derived in SOLB are more consistent with the IGS14 frame than the SOLA.

5. Geocenter coordinates

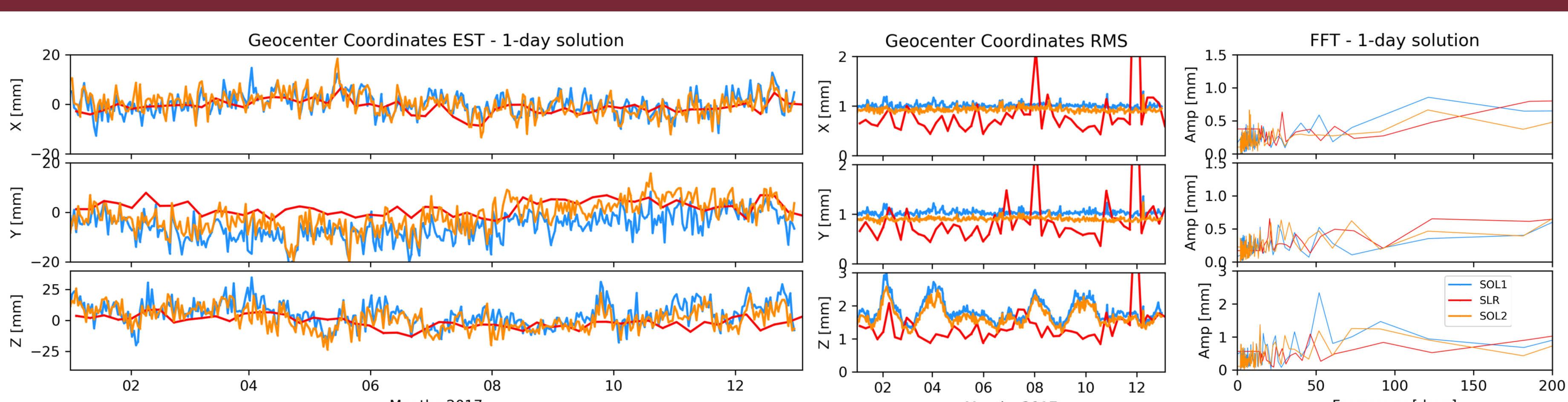


Fig 9. Time series of geocenter coordinates (left) and formal errors (middle); spectra analysis using FFT algorithm of the geocenter coordinates (right).

Figure 9 shows the geocenter coordinates delivered in SOL1 and SOL2 compared to the 7-day SLR solution based on Lageos-1/2 satellites. The formal errors of each coordinate for SOL2 is about 10 % lower compared to SOL1. The main signal is consistent between GNSS and SLR at the level of a few mm, especially for the X coordinate. In case of the Y coordinate, the time series derived from SOL1 is shifted in reference to SOL2, although SOL2 is more consistent with SLR solution. The enhanced consistency between SOL2 and SLR may indicate a consequence of uneven distribution of the stations. Similarly to SLR in SOL2 we have more observations from Europe and Australia which can cause deviations. The dominant signal of about 58 days visible in the spectrum analysis may be caused by (1) modeling of GNSS-orbits and correlation between Z coordinate of the geocenter and empirical parameters of the solar radiation pressure model of ECOM2 (as noted by [1],[2]), (2) a strong dependency of the geocenter Z-coordinate on the β-angle and mutual geometry of orbital planes (as noted by [3]).

[1] Meindl et al. 2013: Geocenter coordinates estimated from GNSS data as viewed by perturbation theory
[2] Arnold et al. 2015: CODE's new solar radiation pressure model for GNSS orbit determination
[3] Scaramuzza et al. 2018: Dependency of geodynamic parameters on the GNSS constellation

6. Summary and discussion

Using only homogeneously distributed set of stations we can achieve the quality of station and geocenter coordinates at the comparable level as with the subset of stations that include more dense distribution in some regions of the globe. Imposing a No-Net-Translation condition on the network and estimation of the geocenter coordinates as the unconstrained parameters are beneficial for estimation of stations coordinates when estimated together with GNSS satellite orbits. It both stabilizes the coordinate repeatability and improves the consistency between estimated coordinates and IGS14 coordinates. The impact of such a parametrization should be further investigated, especially in the context of other global geodetic parameters and orbits. There is not yet a proper answer to the question „How the geocenter should be handled in global GNSS processing ?". That analysis partially proves that the geocenter has to be correctly considered. The one idea is to estimate it just like other parameters. However, there are some clear limits e.g. the Z component is correlated to orbit parameters (see Fig. 9). Therefore, it is not the right way to simply estimate geocenter parameters from GNSS data. Alternatively, it could be also beneficial for the solution to introduce an external geocenter product (e.g. geophysical model or SLR product) to the processing and realize the datum with a No-Net-Translation condition. However, we cannot treat SLR-based geocenter as flawless. We see the instability of formal errors and possibility of „network effect" in SLR-based geocenter. In summary, the influence of the parametrization and proper consideration of geocenter coordinates in a processing of global GNSS network is clearly visible on the time series of station coordinates.

This work has been realized in the frame of the „Innovative Doctorate" project from the Wrocław University of Environmental and Life Sciences: "Determination of geocenter and Earth rotation parameters in multi-GNSS solution" granted on the basis of the contract nr: D220/0010/18. Authors are supported by the Polish National Science Centre (NCN), grant UMO-2015/17/B/ST10/03108.