Influence of station distribution on GNSS satellite orbits

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1. Introduction

The International GNSS Service (IGS, Dow *et al.*, 2009) aims to provide, amongst others, the highest quality GPS & GLONASS orbit products. Each Analysis Center (AC) contribute with their own solution, which is then combined by the Analysis Center Coordinator (ACC) into the IGS combined solution.

Precise orbit determination (POD) is undertaken using various strategies within each AC. The Center for Orbit Determination in Europe (CODE) and the European Space Operations Center (ESOC), which both provide fully combined GPS & GLONASS orbit products, are following the strategies described in their respective Analysis Center processing strategy summary (ACN). Some of the significant features extracted from their respective ACN are shown in **Table 1.**

Table 1: *Some processing features from CODE and ESOC Analysis Centers ACN`s for the final orbit product generation.*

	CODE	ESOC
Software	Bernese GNSS Software (BSW)	Navigation Package for Earth Orbiting Satellites (NAPEOS)
Differencing	Double difference	Undifference
Orbit sampling	3 min	5 min
Elevation cutt-off angle	3 degrees	10 degrees
# station in network	**270**	**150**
Ambiguity Resolution	GPS & GLONASS	GPS
SRP model	Extended ECOM (Arnold *et al.,* 2015)	A priori box wing model

A common reference scenario was implemented in both softwares, in order to understand the impact of the different processing scheme settings on the orbit solution. It was detected that both softwares showed a similar sensitivity to the station network selection.

2. Motivation

A software independent tendency - a systematic effect - was identified when comparing two orbit solutions computed with different station networks. This matter drove the motivation for the research, in order to understand the observed effect.

3. Station network configurations

In order to understand the magnitude and behavior of the station network impact in the orbit solutions, three different station network (SNW) distributions were selected. The station networks will be refered to, as: SNW1, SNW2 and SNW3. All of the configurations are a subset of the IGS available network. The description and details from each SNW are as follows:

- ✶ SNW1 is displayed in **Fig. 1**. It is based on the SNW from the IGS final processing scheme used in CODE AC.
- ✶ SNW2 in **Fig. 2** is a subset of SNW1, with the addition of a few stations to enhance global coverage, especially in the Ocean Pacific area, where SNW1 has a better GPS coverage.
- ✶ SNW3 in **Fig. 3** was designed based on the available IGS network, selecting an equally distributed set of stations. The criteria for selection was as such, that the high variation of ground track coverage observed in Fig. 4 and Fig. 5, for instance in the Northern and Southern part, was lowered as much as possible. As a result, it can be observed in Fig. 6, that the SNW3 has a considerably lower ground track coverage variation than that in SNW 1 and SNW2.

Figure 1, 2 and 3 show the station distributions of SNW1, SNW2 and SNW3. The network ground track coverages are shown in **Fig. 4, 5, and 6.** A SNW summary from the three different configurations is shown in **Tab. 2.**

	SNW1		SNW2		SNW3	
	GPS	**GLONASS**	**GPS**	**GLONASS**	**GPS**	**GLONASS**
# stations	221	163	123	84	66	66

Table 2: *Networks (SNW1, SNW2 and SNW3) number of stations for GPS (left column) and GLONASS (right column) systems.*

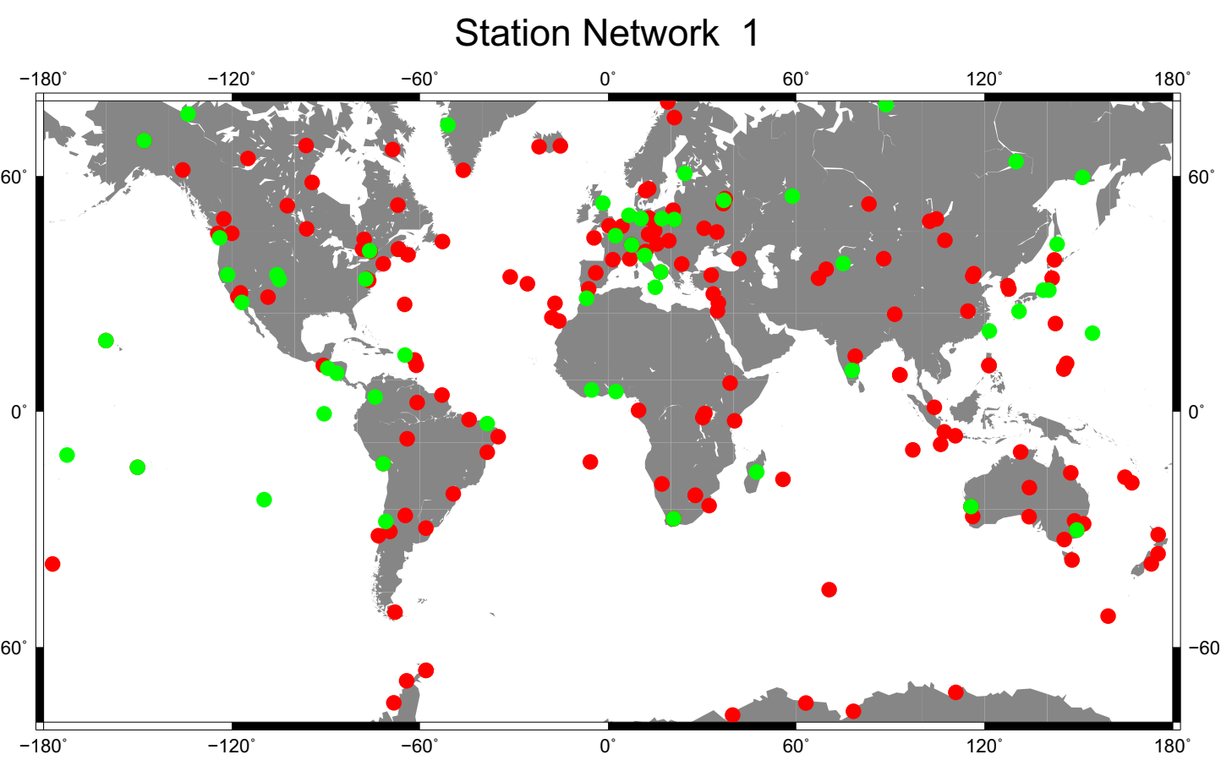


Fig. 1: *SNW1 stations distribution. GPS tracking capable stations in **green**, GLONASS tracking capable stations in **red.***

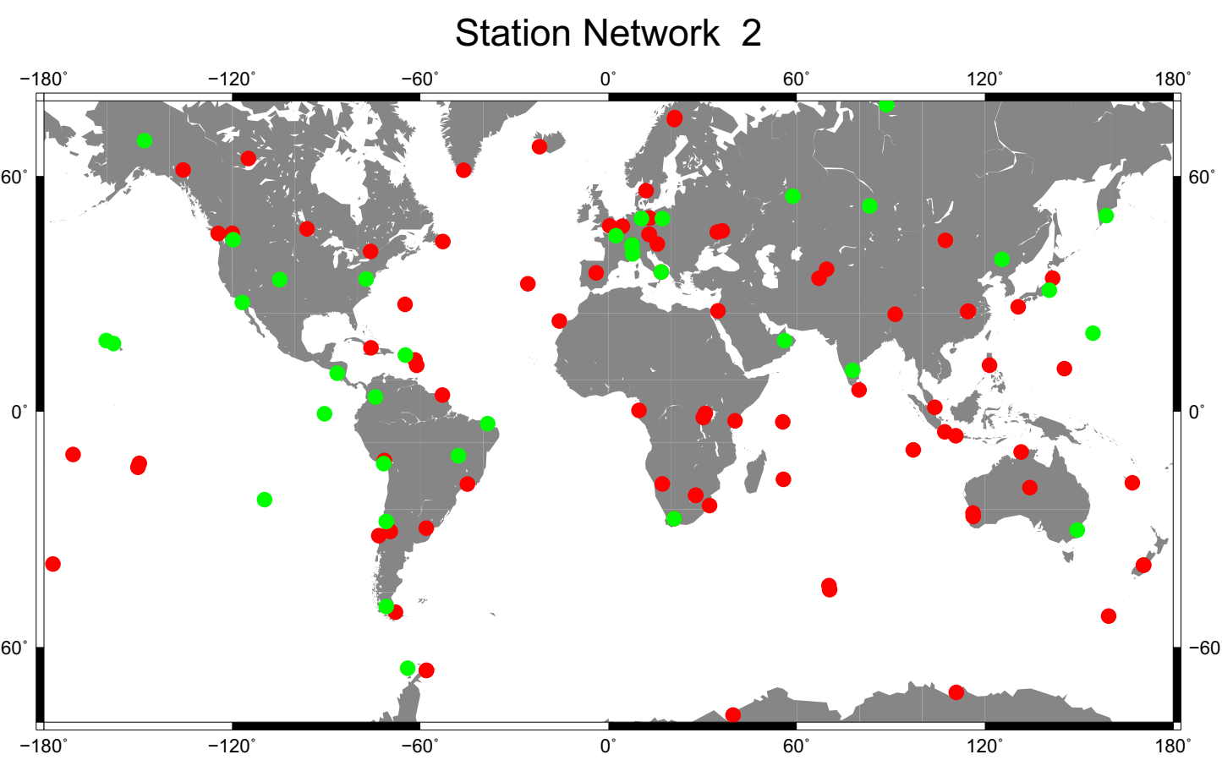


Fig. 2: *SNW2 stations distribution. **GPS** tracking capable stations in **green**, **GLONASS** tracking capable stations in **red.***

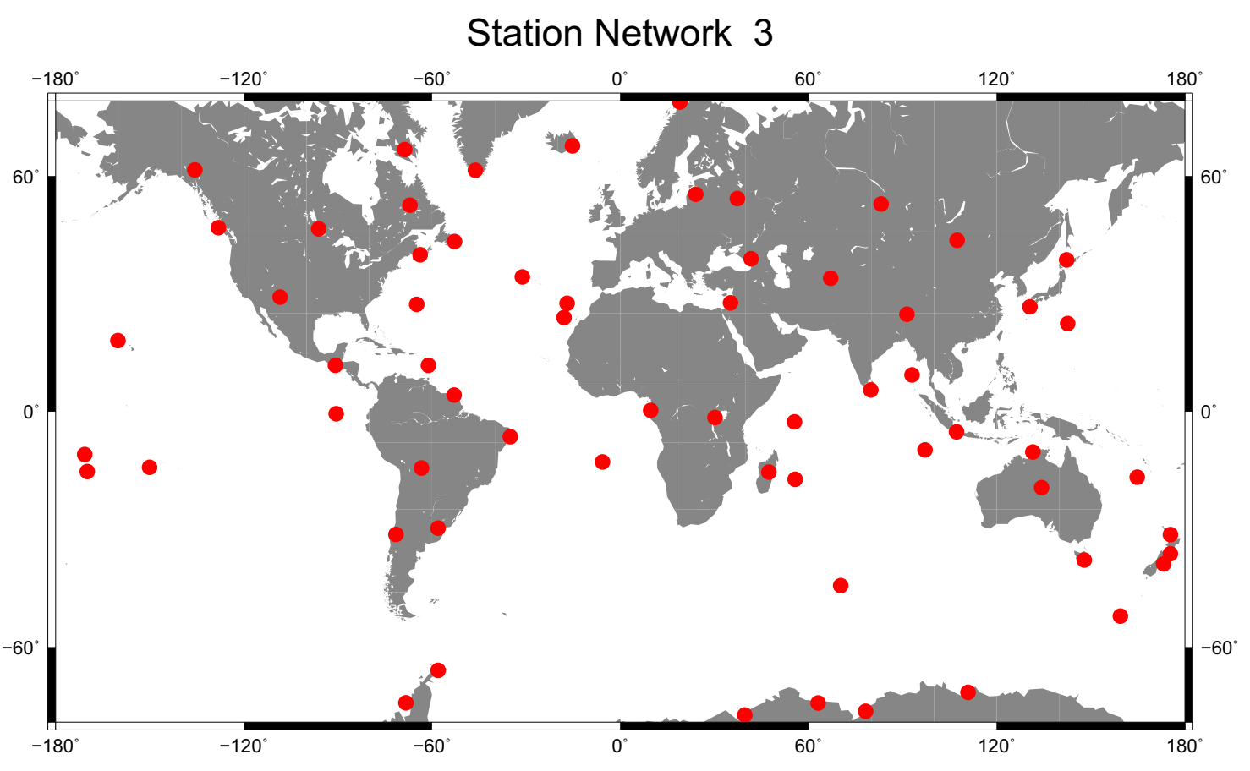


Fig. 3: *SNW3 stations distribution. All of the stations are **GLONASS** tracking capable (shown in **red**).*

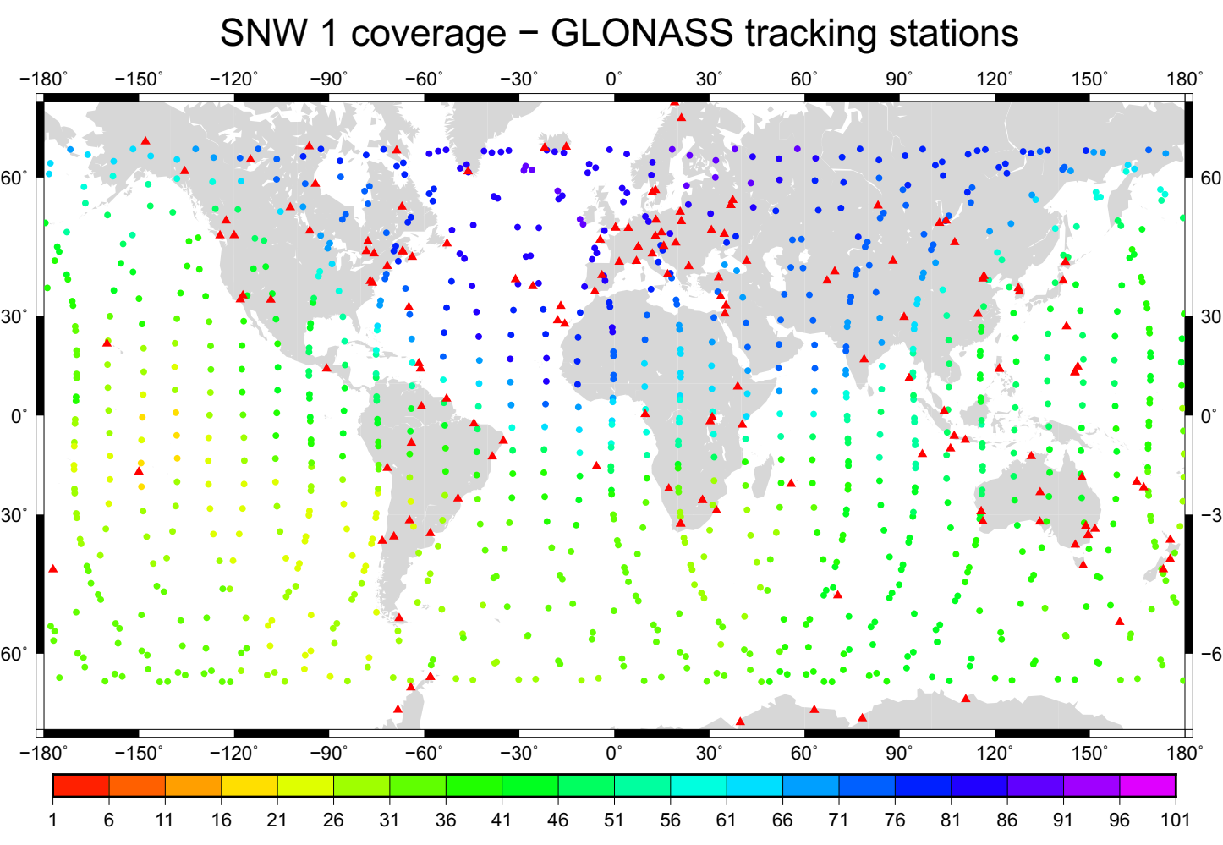


***Fig. 4**: SNW 1 coverage plot. The number of stations covering a particular **GLONASS** satellite - epoch wise- is given by the color from the scale bar.*

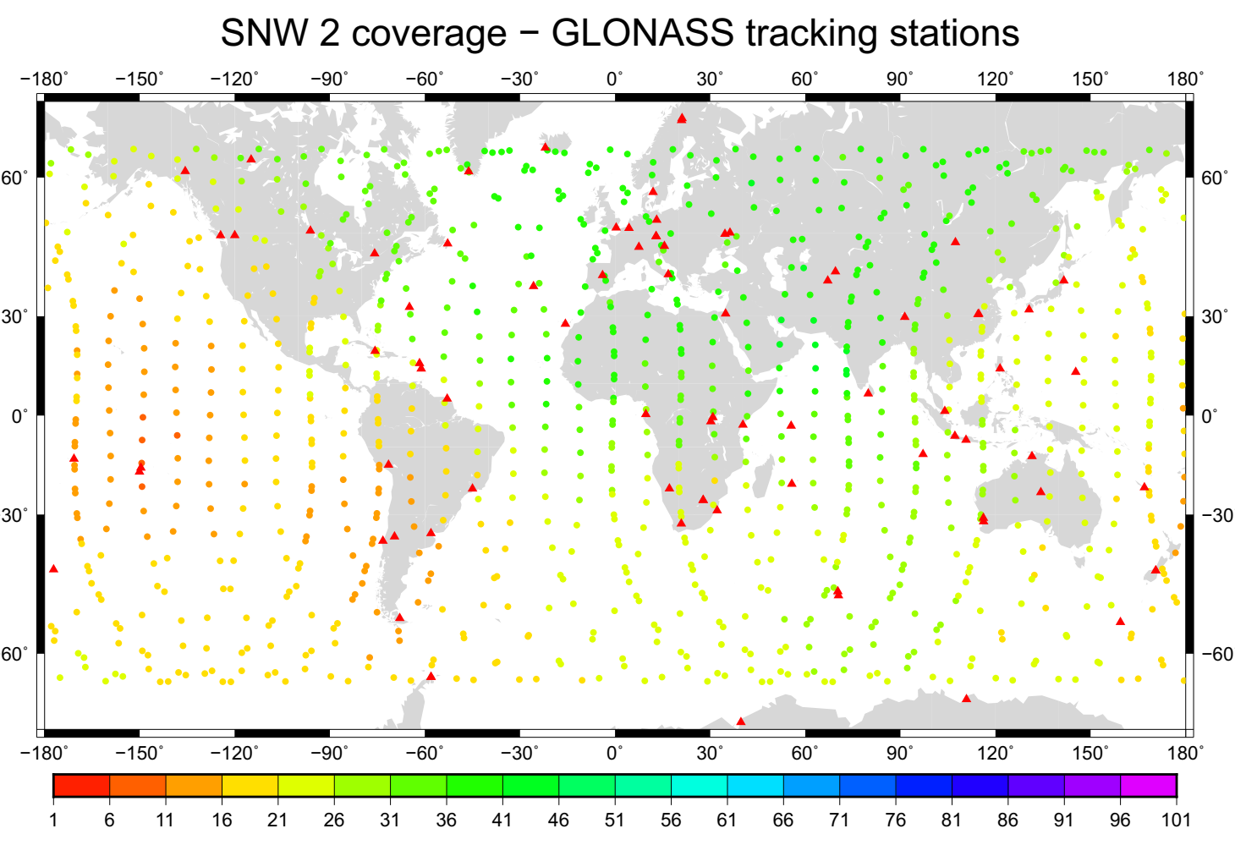


***Fig. 5**: SNW 2 coverage plot. The number of stations covering a particular **GLONASS** satellite - epoch wise- is given by the color from the scale bar.*

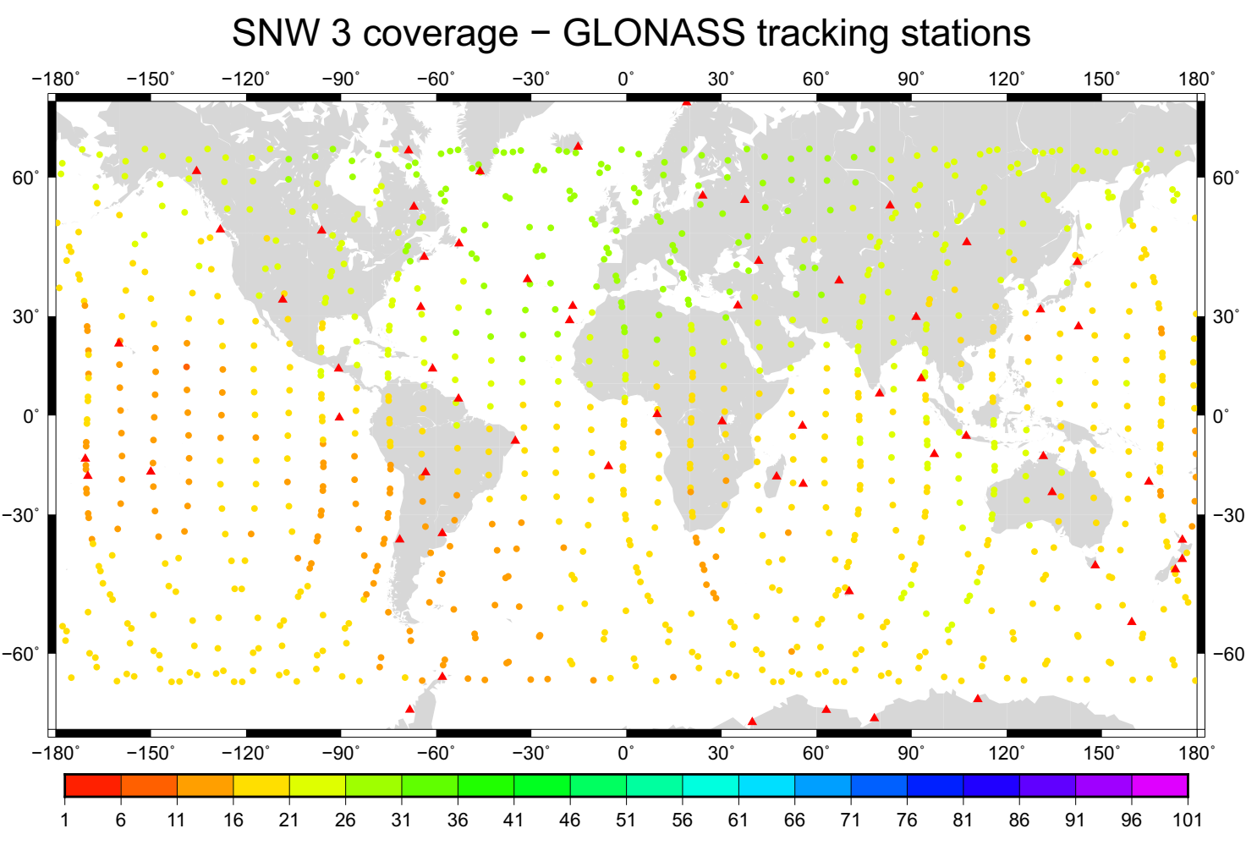


***Fig. 6**: SNW 3 coverage plot. The number of stations covering a particular **GLONASS** satellite - epoch wise- is given by the color from the scale bar.*

4. Results

The data processed covers the time period of one month [DOY:007/2015 to DOY:036/2015]. The precise orbit solutions computed will follow the given nomenclature: the orbits estimated using the default CODE processing strategy with the different SNW will be refered to as: SNW1(CODE), SNW2(CODE), SNW3(CODE); on the other hand, the solutions computed using the default ESOC processing strategy: SNW1(ESOC), SNW2(ESOC), SNW3(ESOC). The comparisons were done between 1-day arc solutions in the radial (R), along-track (S), and cross-track (W) directions in a 15 minute tabular spacing. Given two orbit solutions, seven Helmert transformation parameter - 3 translations, 3 rotations and scale - were calculated, to compensate for differences in the realization of the datum definition due to the station selection.

In the case of GLONASS, when looking into the comparisons between SNW1(CODE) vs SNW2(CODE) (see **Fig. 7**), the most typical max/min residual values range in the interval [-10cm,10cm]. Nevertheless, a significant amount of ~15% of the max/min values are in the range of [-15,-10] and [10,15]cm. For the comparison SNW1(ESOC) vs SNW2(ESOC) in **Fig. 8**, as in the previous comparison, an amount of around 15% of the max/min residuals are in the interval of [-15,-10] and [10,15]cm.

In the case of GPS, the first comparison (see **Fig. 7**) shows that the most typical values gather around ±5cm, whereas ~20% of the max/min are within [-10,-5] and [+5,+10]cm. **Figure 8**, which shows the max/min residual values histogram for SNW1(ESOC) vs SNW2(ESOC) has an amount of around 10% of residual values within [-10,-5] and [5,10]cm. In the overall, the radial component suffers less variation from one station configuration to the other when estimating the orbits with ESOC IGS final processing scheme. GPS orbits, on the other hand, show a bigger percentage of max/min around a higher residual value in the case of SNW1(CODE) vs SNW2(CODE) than that in SNW1(ESOC) vs SNW2(ESOC). It can be concluded that GLONASS is affected about 2 to 3 times more than GPS. SNW 1 and SNW 2 GLONASS solutions comparison have a very similar consistency for both software. In the case of GPS, ESOC solutions seem to be more consistent to one another. On the other hand, when looking into SNW 1 and SNW 3 solutions comparison, GPS and GLONASS have a similar consistency for both software solutions. In the overall, the station network impact can be observed in both processing scheme solutions. Nevertheless, the visibility in the orbit components is different depending on the orbit and the processing models used.

It can be observed in **Fig. 9** that for the CODE solutions comparisons, for both, GPS and GLONASS, the RMS from SNW 1 vs SNW 2 shows a lower value than the other two SNW comparisons. The solution computed with SNW3 has less resolved GLONASS ambiguities than SNW1 and SNW2. In SNW1 and SNW2 the solution is expected to be more stable - at least in those regions with a more dense network. It is unclear whether this amplifies the inconsistency wrt. regions with less stations with a negative impact on the orbit. On the other hand, the ESOC solutions comparisons show that SNW2 vs SNW 3 has the biggest RMS value for both, GPS and GLONASS. There is a better consistency between solutions computed with SNW 1 and SNW 2 when using CODE processing scheme. Nevertheless, the solutions computed with SNW 2 and SNW 3 show a similar consistency to that computed with SNW 3 and SNW 1. When performing POD with ESOC processing scheme, the solutions from SNW 2 and SNW 3 appear to have worse consistency than the ones compued with SNW 1 and SNW2 as well as SNW 3 and 1. It can be concluded that the station network selection has a different impact depending on the constellation and the processing scheme. Furthermore, even though there is a bigger reduction in the number of stations tracking GPS from SNW1 (221) to SNW3 (66) than for GLONASS (from 163 to 66), the RMS is not affected accordingly, meaning that the 3D RMS from SNW1 (ESOC & CODE) vs SNW3 (ESOC & CODE) for GPS is not bigger than that for GLONASS. Therefore, there is still a better agreement between SNW1 and SNW3 for GPS than GLONASS.

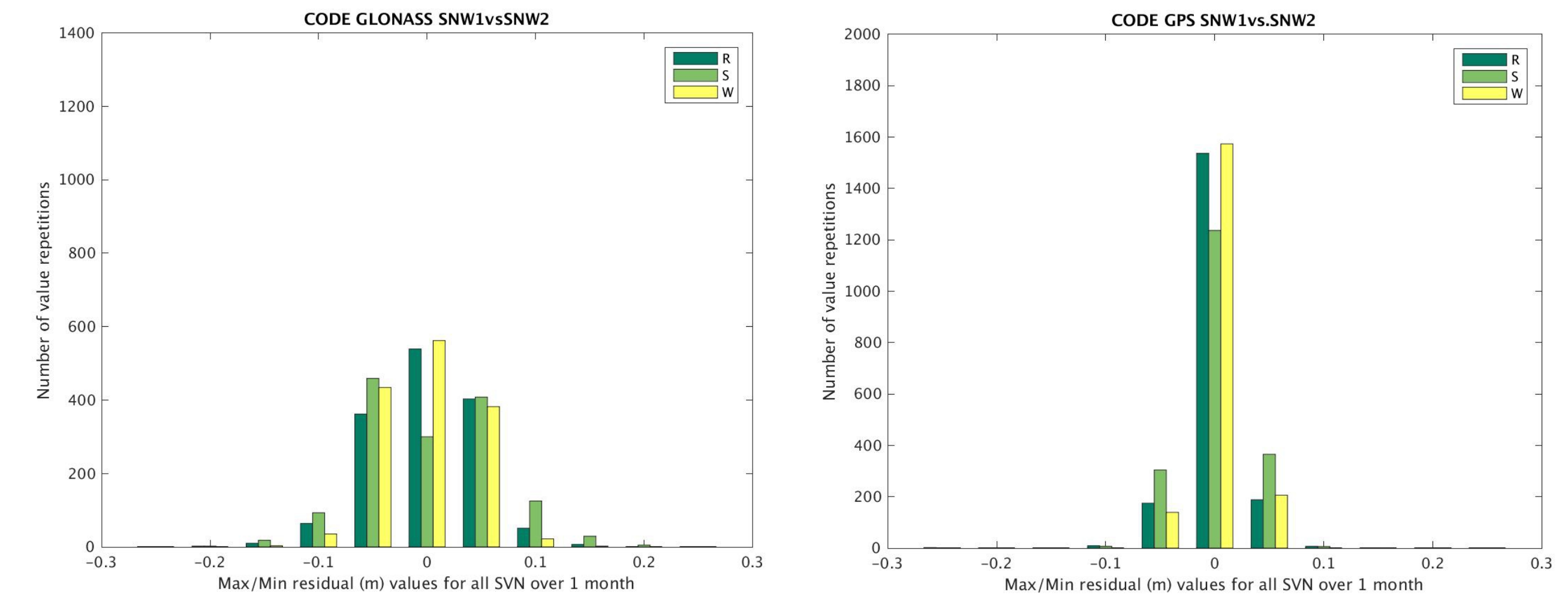


***Fig. 7**:The figures above correspond with the histogram for the maximum and minimum residual (for the radial, along-track and cross-track coponents) values - between SNW1 (CODE) and SNW2(CODE) - for (a) all the GLONASS satellites (b) all the GPS satellites ,over the one month period. The residuals are in (m). Outliers y<-30cm &30cm<x are rejected in the histogram.*

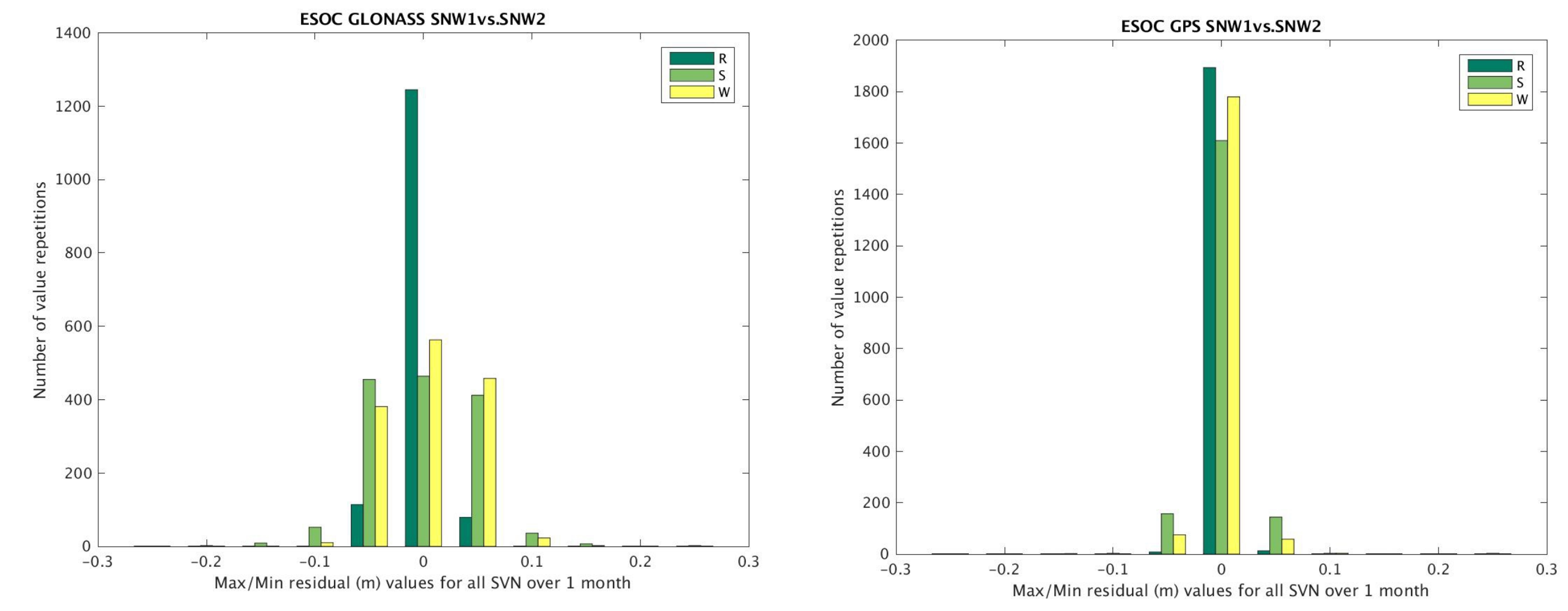


***Fig. 8**:The figures above correspond with the histogram for the maximum and minimum residual (for the radial, along-track and cross-track coponents) values - between SNW1 (ESOC) and SNW2(ESOC) - for (a) all the GLONASS satellites (b) all the GPS satellites ,over the one month period. The residuals are in (m). Outliers y<-30cm &30cm<x are rejected in the histogram.*

When looking into the ground track residual plots, it can be observed that the SNW impact is a geometry dependant effect. **Figures 10 and 11** show R09 ground track residual (R component) plots for SNW1 vs SNW2. The highest residual values (according to the color scale bar) are, in both cases reached in the indicated area. **Figures 4 and 5** reveal that both areas have a worst coverage with respect to other areas. This effect is seen in most of the GLONASS satellites.

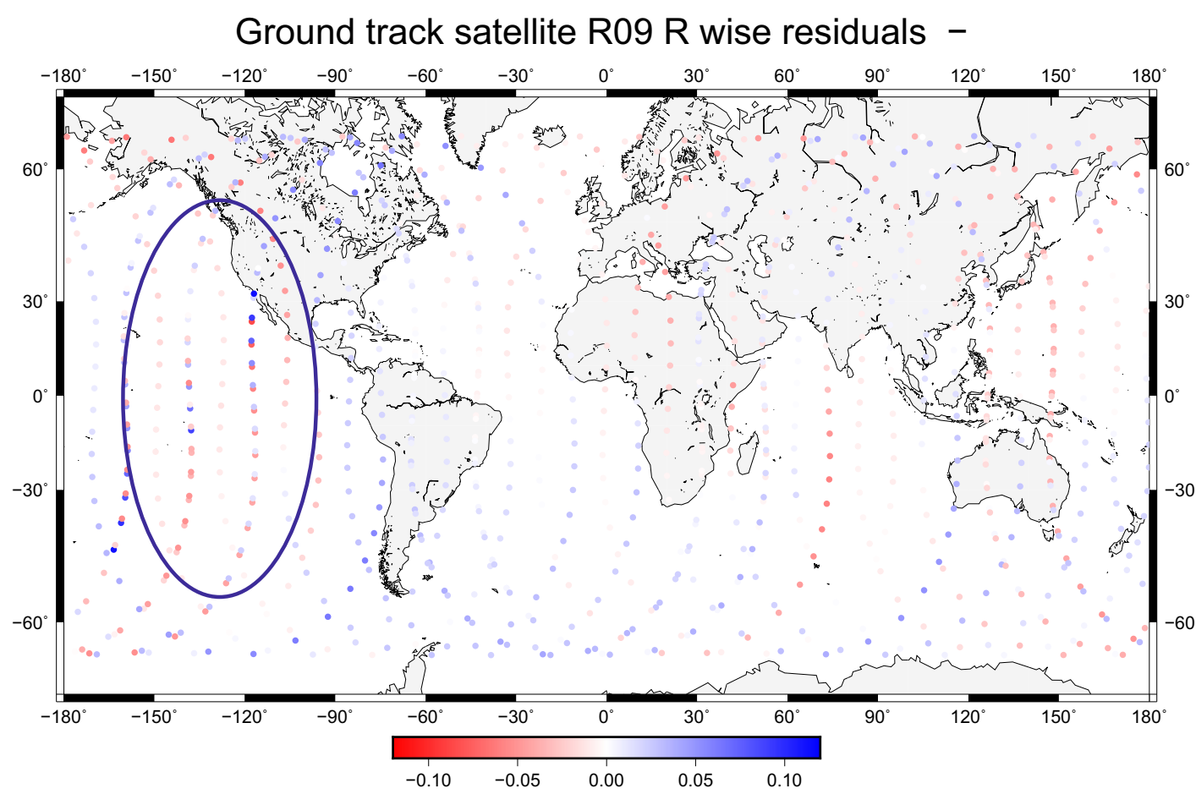


***Fig. 10**: Ground track residual from orbit solutions SNW1(CODE) and SNW2(CODE) - radial & epoch wise- plots for satellite R09. The color scale bar [12cm,-12cm] indicates the residual values.*

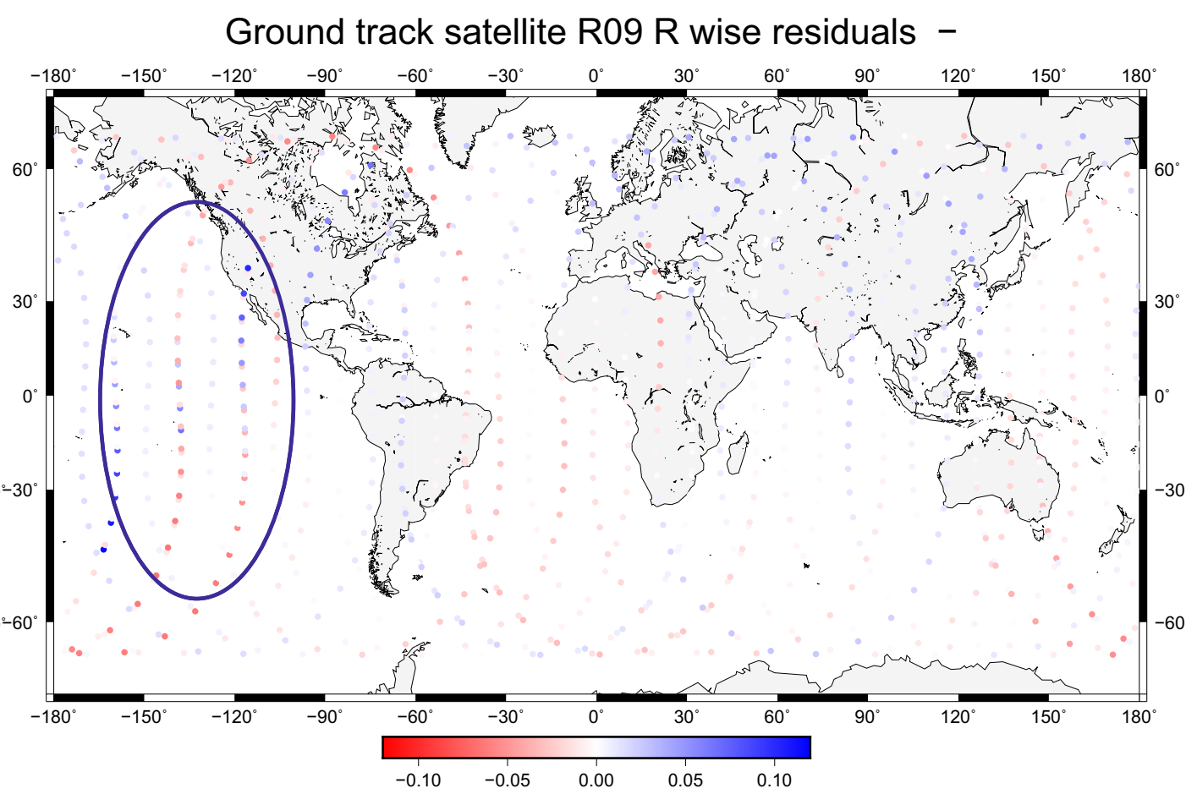
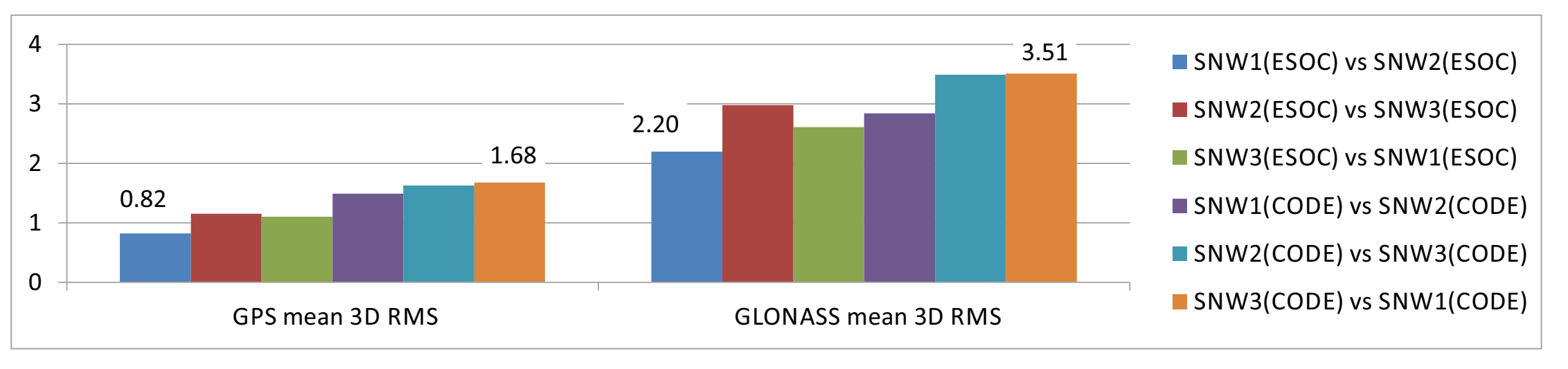


***Fig. 11**: Ground track residual from orbit solutions SNW1(ESOC) and SNW2(ESOC) - residual & epoch wise- plots for satellite R09. The color scale bar [12cm,-12cm] indicates the residual values.*

***Fig. 9**: GPS & GLONASS only mean 3D RMS values (cm) for all the comparisons*



5. Conclusions

The station network selection has a bigger impact on the POD than expected. The orbit solutions computed with different software and processing schemes, but with the same SNW selection, show the same tendency behaviour, which implies it is a systematic effect. The cross-check between the software solutions has to be further investigated; this will give a better understanding of the impact of the Ambiguity Resolution in the orbit solutions. On the one hand, the balanced distribution of stations should be considered, as far as possible, when selecting the station network to process. On the other hand, other aspects, such as the observation quality, need to be considered, as well, when performing POD.

6. Outlook

The IGS should take into account the station network selection, which affects the orbit accuracy, in a potential multi-GNSS combination orbit scheme. A weighting scheme would be suggested to address the issue.

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