Impact of multi-GNSS satellite coverage on 3D position estimates and reference frame definition

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Abstract

Continuous evolution of Global Navigation Satellite Systems (GNSS) provides the opportunity of using observations from multi-GNSS constellations for geodetic applications. It is a well-known fact that the use of multi-GNSS observations improves the robustness and reliability of the position estimates while providing enhanced spatial coverage due to increased number of available satellites. The combined use of the ground-based observations from GPS and GLONASS, for example, significantly adds to the coverage in both azimuth and elevation of the ground-based stations. The aim of this study is, firstly, to assess the geographical variations in the improvement (of position estimates) offered by the use of multi-GNSS observations, and secondly, to assess implications of multi-GNSS position estimates for improvements and robustness of the terrestrial reference frame. A GPS-only double-differenced positioning solution for a global network of stations will be used as a reference in this study. Furthermore, two precise point positioning (PPP) solutions i.e. one with GPS-only and one with GPS+GLONASS observations, will be computed and compared to the reference solution. To study the geographical variation, the differences between the simulated and reference North/East/Up components will be analyzed as a function of latitude. Eventually, the various positioning solutions will be analyzed in terms of their application in terrestrial reference frame definition.

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Introduction

Continuous evolution of Global Navigation Satellite Systems (GNSS) provides the opportunity of the combined use of observations from multiple GNSS constellations for geodetic applications. It is a well-known fact that the use of multi-GNSS observations improves the robustness and reliability of the position estimates while providing enhanced spatial coverage due to increased number of available satellites. The combined use of the ground-based observations from GPS and GLONASS, for example, significantly adds to the coverage in both azimuth and elevation of the ground-based stations. However, this improvement in the coverage varies with the station location (prominently latitude).

A study is underway which comprises of two parts, i.e. i) assessment of the geographical variations in the position estimate improvements offered by the use of multi-GNSS observations, and ii) assessment of the implications of multi-GNSS position estimates in terrestrial reference frame definition. This poster presents the preliminary results from the first part of the study. Although this study will be expanded to include other GNSS, the current results are based on GPS and GLONASS observations.

Figure 1 shows the coverage of both GPS and GLONASS in azimuth and elevation as observed by ground-based stations in 4 different regions (please refer to the next section for the definition of these 4 regions).

It can be seen from Figure 1 that the each region observes a different azimuth/elevation coverage.

For example, the CONUS region sees an azimuthal gap in the coverage whereas the polar regions don't see an azimuthal gap. Such differences lead to different constellation geometry in different regions and can possibly have an influence on the position accuracy.

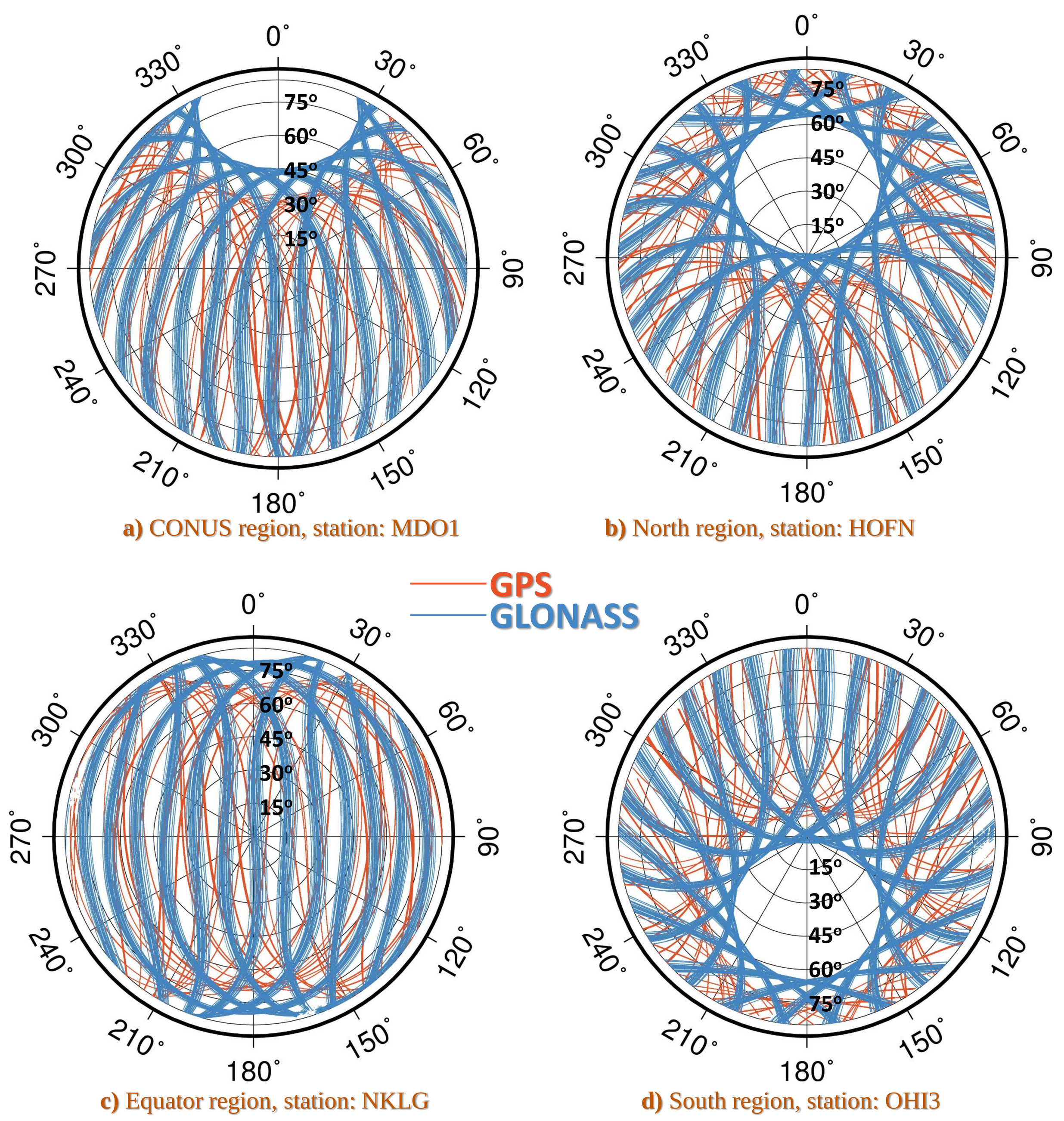

Figure 1. GNSS coverage in different geographical regions: Tracks of GPS (red) and GLONASS (blue) satellites as function of azimuth and elevation from the ground-based station.

This effort will focus on quantifying the influence of constellation geometry on position estimates (and eventually on reference frame definition).

Methodology

Ground-based GNSS Stations

A total of 17 multi-GNSS stations from the IGS MGEX network were selected for this study. These stations were grouped as 4 regions, namely, North (Northern Polar), CONUS (Conterminous United States), Equator, and South (Southern Polar). Figure 2 shows the 4-character identifiers and locations of these stations.

Positioning Solutions

For the stations shown in Figure 2 and for a period of July 1 – 31, 2017, two positioning solutions were generated using NRCan's CSRS-PPP[1] online tool. One solution (denoted by 'G') was based on GPS-only, whereas another solution (denoted by 'GR') was based on GPS+GLONASS observations. The main processing characteristics of these solutions are listed in Table 1.

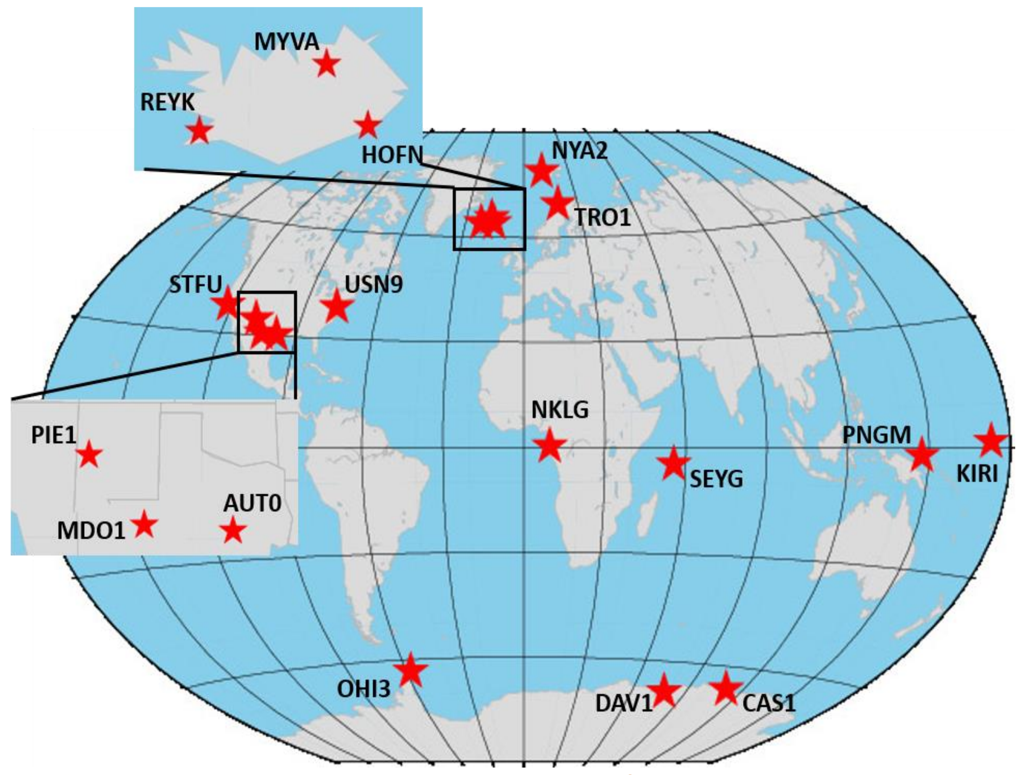

Figure 2. The 4-character IDs and locations of the 17 ground-based multi-GNSS stations used in this study

Table 1. Characteristics of the GNSS PPP solutions used for this study

Parameter	Value
Processing Strategy	Precise Point Positioning
Output Interval	15 minute
Processing Session Length	24 hours
GNSS Used	GPS, GLONASS
A-Priori Coordinates	RINEX Header
A-Priori Troposphere Model	GPT
Orbits, Clocks	IGS Final
Antenna Models	IGS14
Elevation Cut-Off Angle	7.5º
Integer Ambiguity Resolution (IAR)	Yes
Reference Frame of the Position	ITRF14

Preliminary Results

Positioning Accuracy

The mean Geometric Dilution of Precision (GDOP) for each region computed from 1 month of observations (both G and GR) is shown in Table 2. As expected, addition of GLONASS observations reduces the GDOP values.

Table 3 shows the RMS vertical, 2D horizontal and 3D errors in the positions obtained in the G and GR solutions in the 4 regions. The difference GR-G shows the improvement in accuracy by adding GLONASS observations with GPS.

Table 2. GDOP for GPS-only and GPS+GLONASS observations in the 4 regions (Gain is the % reduction in GDOP by including GLONASS)

Region	GDOP		
	G	GR	Gain
North	2.05	1.42	30.73%
CONUS	2.03	1.61	20.69%
Equator	1.90	1.42	25.26%
South	2.07	1.51	27.05%

Table 3. RMS error in position estimates from the GPS-Only (G) and GPS+GLONASS (GR) solutions for the 4 regions (Gain is the % reduction in error by including GLONASS)

Region	RMS Vertical Error [cm]			RMS 2D Horizontal Error [cm]			RMS 3D Error [cm]		
	G	GR	Gain	G	GR	Gain	G	GR	Gain
North	1.62	1.12	30.86%	1.33	0.71	46.62%	2.10	1.33	36.67%
CONUS	1.54	1.43	7.14%	1.42	1.30	8.45%	2.09	1.93	7.66%
Equator	1.77	1.24	29.94%	1.41	1.06	24.82%	2.26	1.63	27.88%
South	1.14	0.84	26.32%	0.89	0.60	32.58%	1.45	1.03	28.97%

Tropospheric Delay

This sections shows a comparison of the Zenith Tropospheric Delay (ZTD) obtained from the G and GR solutions, to the ZTD obtained from the ERA-Interim climate reanalysis model (ZTD_{era})[2],[3]. The goal is to see how does the addition of GLONASS impacts the ZTD accuracy in the 4 regions. Figure 3 shows the ΔZTD_G (=ZTD_G - ZTD_{era}) and ΔZTD_{GR} (=ZTD_{GR} - ZTD_{era}) time series for one station in each region. Table 4 provides the statistics from this comparison. It can be seen from Table 4 that regardless of the region, ΔZTD_G and ΔZTD_{GR} agree to each other within 0.5 mm.

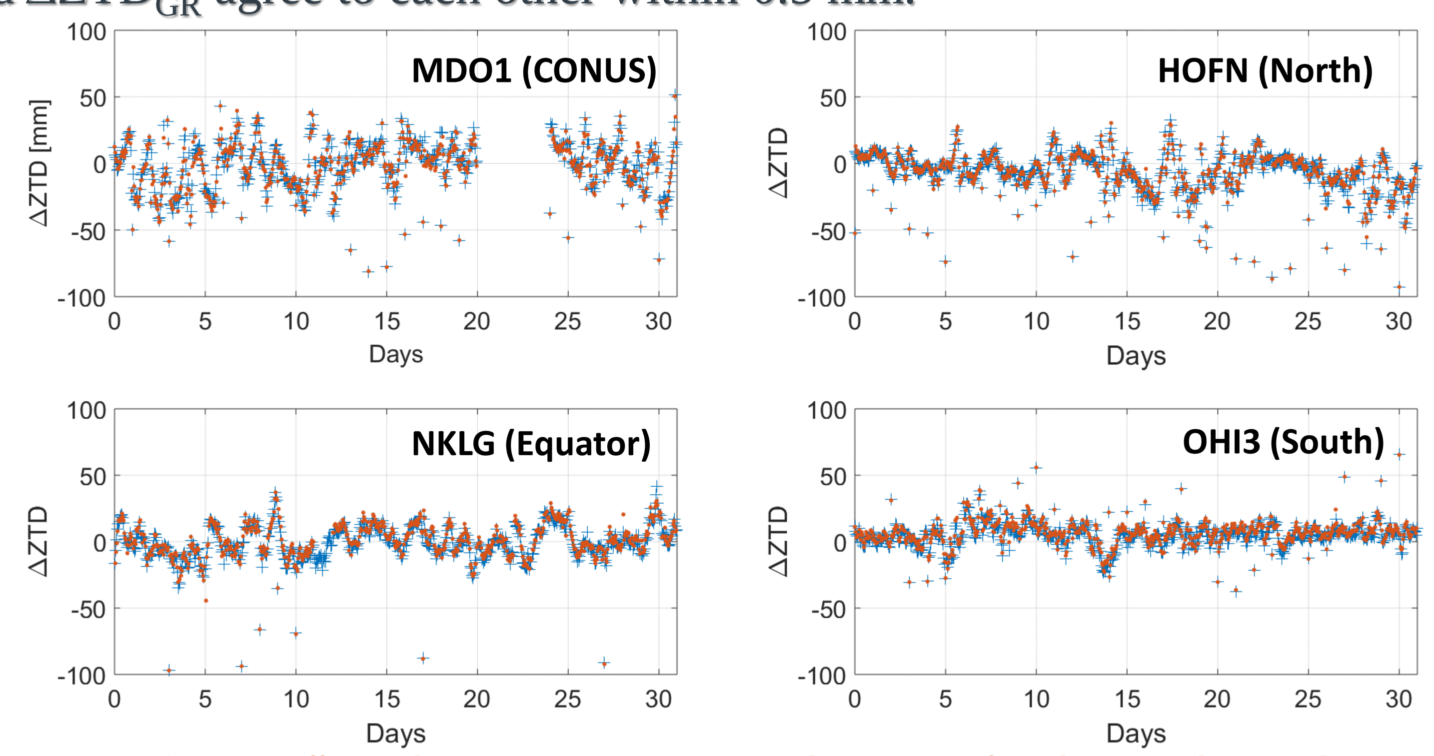

Figure 3. Difference between ERA-Interim ZTD and GNSS ZTD from the GPS-only (G) and GPS+GLONASS (GR) solutions

Table 4. Statistics of comparison between ERA-Interim ZTD and GNSS ZTD (ZTD_G, ZTD_{GR}) in the 4 regions defined in this study

Region	ΔZTD_G			ΔZTD_{GR}		
	Mean [mm]	Std [mm]	RMS [mm]	Mean [mm]	Std [mm]	RMS [mm]
North	-7.75	14.65	16.57	-7.96	14.68	16.69
CONUS	1.62	21.04	21.10	1.69	21.02	21.09
Equator	-2.18	35.19	35.26	-2.71	34.88	34.99
South	-2.17	13.39	13.56	-2.90	13.19	13.50

Discussion and Future Work

Previous research has demonstrated the potential of GLONASS observations for geodesy when used in combination with GPS in the PPP-IAR mode[4]. The preliminary results from our study also support the hypotheses that the inclusion of GLONASS observations in addition to GPS improves the position accuracy, and impacts the positioning errors differently in different geographical locations. The positioning improvement offered by GLONASS was found to be the lowest in magnitude in the CONUS region, and highest in the North region.

Therefore, this study will continue by investigating what portion of these improvements can be attributed to the increased azimuth/elevation coverage, and what portion to other factors (e.g. number of resolved ambiguities, etc.). To achieve the millimeter-level positioning precision as required for terrestrial reference frame definition, the GNSS data processing will be performed in longer batches using the NASA GipsyX[5] software. Furthermore, observations from other GNSS (e.g. GALILEO, BeiDou) will also be included in the analysis.

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