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Accuracy Assessment Study of GLONASS-based Precise Point Positioning

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Abstract: Precise Point Positioning (PPP) has been used for the last decade as a cost-effective alternative to the ordinary DGPS (Differential GPS) with an estimated precision sufficient for many applications. For many years, PPP systems are mainly based on GPS system due to its reliability. GLONASS's contribution in PPP techniques has been limited due to non availability of full constellation. As GLONASS has reached its full constellation since two years, GLONASS-based PPP systems could be implemented independent of GPS as well as PPP systems using combined GPS/GLONASS could be investigated. PPP precision varies based on observation type (GPS or GLONASS) and the duration of observations among other factors. This paper presents an accuracy assessment study of GLONASS-based Static-PPP using three consecutive days' observations from four IGS stations. The observation residuals from GLONASS-based PPP are analyzed and compared to those from GPS-based PPP. The paper also presents an evaluation study for the variability of GLONASS-based Static-PPP precision based on different observation durations and comparison with GPS-based PPP.

Keywords: GLONASS, GPS, Precise Point Positioning (PPP), Observation duration

1. Introduction

Precise Point Positioning (PPP) is an enhanced single point positioning technique for code or phase measurements using precise orbits and clocks instead of broadcast data. PPP became viable with the existence of the extremely precise ephemerides and clock corrections, offered by different organizations such as the IGS (International GNSS Service) (Zumberge et al., 1997; Le and Tiberius, 2007; Ge et al., 2008; Geng et al., 2010; Li et al., 2011). The PPP technique (Zumberge et al., 1997) aims at correcting the observations errors and overcome the DGPS limitations.

Current PPP techniques are mainly based on GPS which has been the only reliable system for the past many years. Limited observations form GLONASS could be integrated into GPS-based PPP to improve availability and precision (Pı´riz et al., 2009; Tolman et al., 2010). As GLONASS reached its full constellation in early 2013 (GLONASS, 2014), there has been wide interest in PPP systems based on GLONASS without using GPS. Further, the investigation of GLONASS-based PPP will help the development of GPS and GLONASS combined PPP systems for improved precision and reliability (Cai and Gao, 2013).

A few studies presented the use of GLONASS-PPP systems (Melgard et al., 2009; Pı´riz et al., 2009; Cai and Gao, 2013). This paper presents an accuracy assessment study of GLONASS-based Static-PPP. Using three consecutive days' observations from four IGS-stations, the behavior of static-PPP using GPS system alone and GLONASS system alone could be investigated. The study presents also the precision variability with observation duration for static PPP using combined GPS/GLONASS.

2. Precise Point Positioning (PPP)

IGS has been providing the most precise satellite ephemerides and clock corrections (IGS, 2013). To compensate for ionospheric effects (the largest source of error for GPS observations), dual frequency measurements are used. In the case of single frequency observations, some kind of ionosphere modeling has to be applied. For better accuracy, PPP users are advised for the dual frequency measurements as it takes care of the errors due to ionospheric delay.

PPP can provide positioning accuracy of centimeters or millimeters using un-differenced carrier phase observations. Ambiguities are usually estimated as float values because the fractional cycle biases (FCB) contained in the carrier phase observations cannot be separated from the integer ambiguities.

The Canadian Spatial Reference System (CSRS) PPP service provides post-processed position estimates on Internet based on the GPS observation files submitted by the user. Precise position estimates are referred to the CSRS standard North American Datum of 1983 (NAD83) as well as the International Terrestrial Reference Frame (ITRF). Single station position estimates are computed for users operating in static or kinematic modes using precise GPS orbits and clocks. The online PPP positioning service is designed to minimize user interaction while providing the best possible solution for the given observation availability. Currently, users need to specify only the mode of processing (static or kinematic) and the reference frame for position output (NAD83 (CSRS) or ITRF). CSRS-PPP service is processing both single and dual frequency observations from GPS and GLONASS (CSRS-PPP, 2014),

3. Test study

To assess the performance of GLONASS-based PPP, datasets from four geographically well distributed IGS stations (ADIS, ANKR, BARH and DAKR), (Table 1 and Fig. 1) and collected on three consecutive days (8–10 August 2014) (IGS, 2014), have been used. Table 2 provides the average number of visible satellites as well as the average PDOP for the tested stations during the three days (8–10 August 2014). The observation residuals from GLONASS-based PPP are analyzed and compared to those from GPS-based PPP. The paper also presents an evaluation study for the variability of GLONASS-based Static-PPP precision based on different observation durations and comparison with GPS-based PPP for IGS station (BARH) (8 August 2014). The different sets of observations were processed and the PPP solutions were obtained through Canadian Spatial Reference System (CSRS) Precise Point Positioning (PPP) service (CSRS-PPP, 2014).

Table 1: Geographical positions of tested IGS stations

Station	Latitude	Longitude	Ellipsoidal Height (m)
ADIS	+09º 02' 06.48241''	+38º 45' 58.68596''	2439.154
ANKR	+39º 53' 14.5396''	+32º 45' 30.4918''	976.026
BARH	+44º 23' 42.1747''	-68º 13' 18.0915''	6.756
DAKR	+14º 43' 16.4487''	-17º 26' 22.0740''	51.809

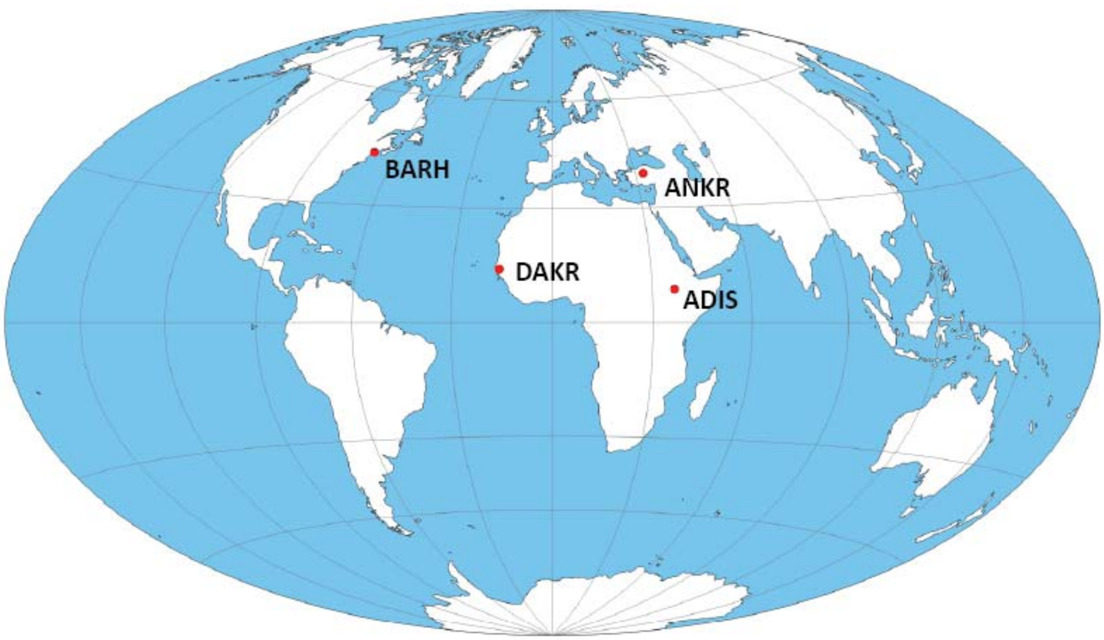

Figure 1: GPS/GLONASS tested stations selected from IGS tracking network

Table 2: The average PDOP and number of visible satellites for tested IGS stations

Station	ADIS		ANKR		BARH		DAKR	
Character	**PDOP**	**no. of visible satellites**	**PDOP**	**no. of visible satellites**	**PDOP**	**no. of visible satellites**	**PDOP**	**no. of visible satellites**
GPS	2.29	8	2.64	7	2.25	8	2.07	8
GLONASS	3.40	5	3.28	6	2.48	7	2.60	6

4. Results and discussion

Tables 3, 4 and 5 present static-PPP coordinates from both systems GPS and GLONASS for tested IGS stations on dates (8-10/8/2014). Tables 6, 7 and 8 present static-PPP accuracy from both systems GPS & GLONASS for tested IGS stations on dates (8-10/8/2014).

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Table 3: Static-PPP coordinates from GPS & GLONASS for tested IGS stations on date (8/8/2014)

Station ID	GNSS system	Static-PPP coordinates		
		Latitude	Longitude	Ellipsoidal height (m)
ADIS	GPS	09º 02' 06.4913"	38º 45' 58.6980"	2439.129
	GLONASS	09º 02' 06.4913"	38º 45' 58.6979"	2439.147
ANKR	GPS	39º 53' 14.5396"	32º 45' 30.4918"	976.026
	GLONASS	39º 53' 14.5396"	32º 45' 30.4919"	976.037
BARH	GPS	44º 23' 42.1747"	-68º 13' 18.0915"	6.756
	GLONASS	44º 23' 42.1749"	-68º 13' 18.0917"	6.749
DAKR	GPS	14º 43' 16.4487"	-17º 26' 22.0740"	51.809
	GLONASS	14º 43' 16.4489"	-17º 26' 22.0740"	51.833

Table 4: Static-PPP coordinates from GPS & GLONASS for tested IGS stations on date (9/8/2014)

Station ID	GNSS system	Static-PPP coordinates		
		Latitude	Longitude	Ellipsoidal height (m)
ADIS	GPS	09º 02' 06.4914"	38º 45' 58.6981"	2439.120
	GLONASS	09º 02' 06.4914"	38º 45' 58.6979"	2439.145
ANKR	GPS	39º 53' 14.5396"	32º 45' 30.4919"	976.031
	GLONASS	39º 53' 14.5396"	32º 45' 30.4918"	976.024
BARH	GPS	44º 23' 42.1748"	-68º 13' 18.0914"	6.758
	GLONASS	44º 23' 42.1750"	-68º 13' 18.0916"	6.759
DAKR	GPS	14º 43' 16.4489"	-17º 26' 22.0740"	51.812
	GLONASS	14º 43' 16.4488"	-17º 26' 22.0741"	51.828

Table 5: Static-PPP coordinates from GPS & GLONASS for tested IGS stations on date (10/8/2014)

Station ID	GNSS system	Static-PPP coordinates		
		Latitude	Longitude	Ellipsoidal height
ADIS	GPS	09º 02' 06.4914"	38º 45' 58.6981"	2439.127
	GLONASS	09º 02' 06.4914"	38º 45' 58.6974"	2439.132
ANKR	GPS	39º 53' 14.5396"	32º 45' 30.4919"	976.029
	GLONASS	39º 53' 14.5395"	32º 45' 30.4918"	976.032
BARH	GPS	44º 23' 42.1748"	-68º 13' 18.0913"	6.755
	GLONASS	44º 23' 42.1750"	-68º 13' 18.0916"	6.752
DAKR	GPS	14º 43' 16.4488"	-17º 26' 22.0739"	51.805
	GLONASS	14º 43' 16.4488"	-17º 26' 22.0739"	51.829

Table 6: Static-PPP accuracy from GPS & GLONASS for tested IGS stations on date (8/8/2014)

Station ID	GNSS system	Static-PPP accuracy		
		Sigma (95%) Latitude (m)	Sigma (95%) Longitude (m)	Sigma (95%) Ellipsoidal height (m)
ADIS	GPS	0.002	0.007	0.016
	GLONASS	0.003	0.007	0.018
ANKR	GPS	0.003	0.007	0.014
	GLONASS	0.007	0.015	0.027
BARH	GPS	0.003	0.007	0.013
	GLONASS	0.003	0.005	0.017
DAKR	GPS	0.003	0.007	0.017
	GLONASS	0.003	0.007	0.018

Table 7: Static-PPP accuracy from GPS & GLONASS for tested IGS stations on date (9/8/2014)

Station ID	GNSS system	Static-PPP accuracy		
		Sigma (95%) Latitude (m)	Sigma (95%) Longitude (m)	Sigma (95%) Ellipsoidal height (m)
ADIS	GPS	0.002	0.007	0.016
	GLONASS	0.003	0.007	0.017
ANKR	GPS	0.003	0.007	0.013
	GLONASS	0.008	0.015	0.030
BARH	GPS	0.003	0.007	0.013
	GLONASS	0.003	0.005	0.017
DAKR	GPS	0.003	0.008	0.018
	GLONASS	0.004	0.01	0.02

Table 8: Static-PPP accuracy from GPS & GLONASS for tested IGS stations on date (10/8/2014)

Station ID	GNSS system	Static-PPP accuracy		
		Sigma (95%) Latitude (m)	Sigma (95%) Longitude (m)	Sigma (95%) Ellipsoidal height (m)
ADIS	GPS	0.002	0.007	0.016
	GLONASS	0.003	0.008	0.018
ANKR	GPS	0.003	0.007	0.013
	GLONASS	0.006	0.015	0.026
BARH	GPS	0.003	0.007	0.013
	GLONASS	0.003	0.005	0.017
DAKR	GPS	0.002	0.006	0.016
	GLONASS	0.003	0.008	0.019

From tables 6, 7 and 8 it can be inferred that the GLONASS system is offering accuracy similar to GPS despite the less number of satellites visible in case of GLONASS . GLONASS is able to offer PPP-accuracy down to the millimeter level for latitude and longitude coordinates as well as PPP-accuracy to the centimeter level for the height coordinate. It can be noted also that GLONASS could offer comparable accuracy to GPS even with only 5 visible satellites comparing with 8 visible GPS satellites (ADIS station). The static-PPP accuracy results are consistent for the three tested days (8, 9 and 10 August, 2014).

The number of working GPS satellites on tested dates were 30 satellites comparing to 24 working satellites for GLONASS (IGS, 2014). This fact justifies values for average no. of visible satellites and average PDOP from both systems at each tested IGS station shown in table 2. GPS in general offers more visible satellites than GLONASS in the range (1 to 3) over the four-tested stations.GPS also offers better PDOP values in the range (0.23 to 1.11).

For BARH station, where GPS offers 8 visible satellites and GLONASS offers only 7 visible satellites, PDOP offered by GPS and GLONASS are 2.25 & 2.58 respectively. Both systems are offering the same latitude (sigma 95%). While GLONASS is offering better longitude (sigma 95%) than GPS by 2mm on average. GPS is offering better height (sigma 95%) than GLONASS by 4mm on average.

For the other tested three stations (ADIS, ANKR and DAKR) GPS is offering better (sigma 95%) than GLONASS for latitude, longitude and height by (1 to 4mm; 1 to 8 mm and 1 to 17 mm) respectively.

The accuracy of static-PPP solution depends upon the observation types (GPS or GLONASS or mixed) as well as on the observation duration. So present research studied the GLONASS Static-PPP accuracy variations with the observation durations. Tables 9 and 10 present Static-PPP accuracy variation with observation duration using GLONASS and GPS respectively for BARH station on date (8/8/2014).

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Table 9: Static-PPP accuracy variation with observation duration from GLONASS (BARH station) on date (8/8/2014)

Duration of observations	Static-PPP accuracy variation		
	Sigma (95%) Latitude (m)	Sigma (95%) Longitude (m)	Sigma (95%) Ellipsoidal height (m)
10 min.	0.418	1.985	2.602
20 min.	0.161	0.772	2.194
30 min.	0.088	0.498	1.223
45 min.	0.052	0.292	0.366
1 hour	0.037	0.198	0.173
1.5 hour	0.025	0.119	0.079
2.0 hours	0.021	0.096	0.062
2.5 hours	0.019	0.074	0.057
3.0 hours	0.017	0.051	0.053
4 .0 hours	0.013	0.029	0.044
6.0 hours	0.008	0.012	0.036
8.0 hours	0.005	0.009	0.029
10.0 hours	0.005	0.009	0.026
12.0 hours	0.004	0.008	0.023
14.0 hours	0.004	0.007	0.022
16.0 hours	0.004	0.006	0.020
18.0 hours	0.003	0.006	0.019
20.0 hours	0.003	0.006	0.018
22.0 hours	0.003	0.006	0.018
24.0 hours	0.003	0.005	0.017

Table 10: Static-PPP accuracy variation with observation duration from GPS (BARH station) on date (8/8/2014)

Duration of observations	Static-PPP accuracy variation		
	Sigma (95%) Latitude (m)	Sigma (95%) Longitude (m)	Sigma (95%) Ellipsoidal height (m)
10 min.	0.804	1.340	1.530
20 min.	0.305	0.621	0.597
30 min.	0.165	0.388	0.333
45 min.	0.093	0.261	0.201
1 hour	0.065	0.197	0.156
1.5 hour	0.045	0.127	0.111
2.0 hours	0.034	0.083	0.084
2.5 hours	0.027	0.061	0.075
3.0 hours	0.020	0.046	0.065
4 .0 hours	0.012	0.032	0.044
6.0 hours	0.009	0.023	0.031
8.0 hours	0.006	0.018	0.025
10.0 hours	0.005	0.014	0.023
12.0 hours	0.005	0.011	0.021
14.0 hours	0.005	0.010	0.020
16.0 hours	0.004	0.009	0.018
18.0 hours	0.004	0.009	0.017
20.0 hours	0.003	0.009	0.015
22.0 hours	0.003	0.008	0.014
24.0 hours	0.003	0.007	0.013

It can be concluded that GLONASS observations offers static-PPP accuracy variation with observation period comparable to GPS. Forty-five minutes of GLONASS observations offers static PPP accuracy at the centimeter level for the latitude coordinates and at the decimeter level for longitude and height coordinates. One hour of GLONASS observations offers similar static PPP accuracy as GPS. Two hours of GLONASS observations offers static PPP accuracy at the centimeter level for the latitude, longitude and height coordinates which is similar to GPS behaviour. Eight hours of GLONASS observations offers static PPP accuracy at the millimeter level for the latitude and longitude coordinates but still at the centimeter level for height coordinate. It can be noted that GLONASS offers better accuracy than GPS (in horizontal coordinates) for observation periods starting from 6 hours and up to 24 hours.

Table 11 presents Static-PPP accuracy variation with observation duration using mixed GLONASS/GPS observations for BARH station on date (8/8/2014).From table 11, it can be concluded that mixed observations offers better accuracy than GPS alone or GLONASS alone for latitude, longitude and height coordinates by 1mm, 2mm and 4mm respectively.

Table 11: Static-PPP accuracy variation with observation duration from mixed GPS/GLONASS (BARH station) on date (8/8/2014)

Duration of observations	Static-PPP accuracy variation		
	Sigma (95%) Latitude (m)	Sigma (95%) Longitude (m)	Sigma (95%) Ellipsoidal height (m)
10 min.	0.367	1.100	0.957
20 min.	0.141	0.500	0.382
30 min.	0.076	0.303	0.217
45 min.	0.044	0.193	0.137
1 hour	0.031	0.136	0.095
1.5 hour	0.021	0.079	0.054
2.0 hours	0.016	0.052	0.041
2.5 hours	0.013	0.038	0.038
3.0 hours	0.011	0.028	0.035
4 .0 hours	0.009	0.018	0.028
6.0 hours	0.006	0.010	0.022
8.0 hours	0.004	0.008	0.018
10.0 hours	0.004	0.007	0.016
12.0 hours	0.003	0.006	0.015
14.0 hours	0.003	0.006	0.014
16.0 hours	0.003	0.005	0.013
18.0 hours	0.002	0.005	0.012
20.0 hours	0.002	0.005	0.011
22.0 hours	0.002	0.004	0.011
24.0 hours	0.002	0.004	0.010

5. Conclusions

Current GLONASS system provided static-PPP accuracies comparable with the GPS inspite of having less number of working satellites as compared to GPS (24 working satellites as compared to 30 working satellites in case of GPS). Similar static-PPP accuracy could be achieved using GLONASS-based PPP systems. Therefore, the need for GLONASS-based PPP system that offers a PPP implementation independent of GPS is viable. GLONASS offers static-PPP accuracy variation with observation period comparable to GPS. One hour of GLONASS observations offers similar static PPP accuracy as GPS. For shorter observation periods, GPS proves to be better than GLONASS, especially for height coordinates. More studies needs to be carried out to assess the PPP accuracy improvement resulting from mixed observations.

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