Leadership in Sustainable Infrastructure

Leadership en Infrastructures Durables

Vancouver, Canada

May 31 – June 3, 2017/ *Mai 31 – Juin 3, 2017*

CONTRIBUTION OF GLONASS SATELLITES TO GNSS SOLUTIONS

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Abstract

Although GLONASS satellite system has been around for a while, the contribution of these satellites to solutions needs further investigation. For this purpose, GPS and GLONASS data collected at five points are analyzed. For the analyses, GPS only, GLONASS only and combined solutions are tested and also the effects of observation period and precise ephemeris are examined. The results indicate that for short observation periods if GPS satellites are not available, inclusion of GLONASS satellites to the solutions may be considered. Otherwise, the contribution of GLONASS satellites to the solutions is questionable for short surveys.

Keywords: GPS, GLONASS, Horizontal Coordinates, Vertical Coordinates, Standard Deviation, RMSE

Introduction

Not wanting to stay behind in the space race, Soviet Union started the development of GLONASS during the 1970s. In fact, GLONASS was follow up to the “Cicada” system of four satellites. GLONASS experimental tests were completed between 1983 and 1985. Between 1986 and 1993 an orbital constellation of 12 satellites was achieved and initial system operation was declared. Since 1993 a deployment of nominal orbital constellation of 24 satellites has been underway to achieve full system operation (Hoffmann-Wellenhof et al., 2001; Leick, 2004 and VanSickle, 2008). Even though a full constellation was achieved in 1995, the economic collapse that followed the fall of the Soviet Union led to its underfunding and eventual decline to only seven operational satellites by 2001 (Insidegnss, 2016). By reassessment of its commitment to space-based positioning, navigation, and timing, on August 21, 2001, the Russian government implemented 2002-2011 program to rebuild and modernize GLONASS (Gibbons, 2006). On March 3, 2012 a new federal program “GLONASS Sustainment, Development and Use for 2012-2020” was launched. Since 2012, GLONASS system has been modernized to meet defense needs, security and social and economic development of Russia in the future (GLONASS, 2017).

As of the beginning of year 2017, GLONASS system has 24 satellites with 1 spare. By design these 24 satellites are equally distributed in 3 orbital planes inclined at 64.8° to the equator. The GLONASS satellites are placed in roughly circular orbits with the nominal orbit altitude of 19,100 km and an orbital period of 11 hours, 15 minutes, 44 seconds (GLONASS, 2017). Similar to GPS, there are three elements of GLONASS: Space segment (satellites), Earth segment (control center and monitoring stations) and User segment (any user of the system). Acting like a beacon, satellites constantly send radio signals whereby satellite coordinates are transferred to the user. Having calculated the signal time delay, users can determine their positions on the earth by intersecting four or more satellite range measurements. The control center monitors the health of the system including satellites coordinates.

As mentioned above, 24 GLONASS satellite orbit the Earth in 3 planes whereas more than 24 GPS satellites circle the globe in 6 orbital planes. Since GLONASS satellites revolve in 3 planes, for GLONASS only users, it may be difficult to lock on the necessary number of satellites thereby reduced positioning accuracy is achieved. The accuracy of GLONASS varies with location as well, for instance, better accuracy is achieved in the northern hemisphere than southern hemisphere because of the ground control stations being in the northern hemisphere more specifically across former Soviet Union territory (Bolduc, 2015).

Like GPS signals, GLONASS signals are right-hand circularly polarized, and have comparable signal strength (Perillat, 2007). Each GPS satellite broadcasts a distinct code on the same frequency whereas GLONASS satellites broadcast the same code on different frequencies. Under GLONASS modernization program, a third frequency will be introduced in the L-band to improve reliability and accuracy of user navigation solutions (Gibbons, 2006).

If only GPS and GLONASS satellites are considered, around 55 satellites in the sky, observations to satellites will be possible in obstructed areas such as urban canyons. Clearly, addition of GLONASS satellites to the GPS system increases the number of visible satellites and as a consequence more observations to satellites are made, and this translates to a better positioning for the user (Perillat, 2007).

By making use of atomic clocks on board both GPS and GLONASS satellites broadcast their time within their navigation messages. GPS uses its own time – GPS time system, and GLONASS uses UTC (Coordinated Universal Time) time system. Both GPS time and UTC are based on an atomic time scale and at the outset GPS Time was designated as being coincident with UTC; nonetheless, GPS Time does not count leap seconds, and therefore an increasing offset exists between UTC and GPS Time (Perillat, 2007).

The datums used for GLONASS system are the Soviet Geodetic System 1985 (SGS85) and its successor SGS90 (introduced in 1995 and alternatively referred to as PZ90). The shape and size of SGS90 are very similar to those of WGS84 which is the datum used by GPS system (Iliffe, 2003). Several attempts have been made to determine the transformation parameters between SGS90 and WGS84 (Misra and Abbot, 1994 and Rossbach et al., 1996). These attempts have generally given similar results within the accuracy limitations that have been imposed by the use of relatively small networks of points used (Iliffe, 2003). The best current indications are that PZ90 has a zero meridian that is rotated 0.6” to the east with respect to that of WGS84 and an equatorial plane that lies around 4 m to the north of WGS84’s. These discrepancies would show up directly between absolute determinations of position by the two systems. In terms of relative positioning between two receivers, the rotation of 0.6” is the only relevant parameter and is equivalent to 1 cm over a distance of about 3.5 km. If a receiver makes use of satellites from both systems, the differences in the datums is not a problem for short distance or low accuracy applications; for high-precision baselines over long distances, better transformations will have to be developed (Walsh and Daly, 1998 and Iliffe, 2003).

From the foregoing it is clear that there are similarities and differences between GPS and GLONASS systems. It is presumed that inclusion of GLONASS satellites to positioning solutions will increase the precision. Yet, inclusion of GLONASS satellites to solutions has not been fully investigated. In this study, GPS and GLONASS data collected at five points are analyzed and compared.

Methods

In order to calculate deviations from a known quantity, standard deviations and RMSE (Root Mean Square Error) values are employed. Standard deviation is calculated as follow (Ghilani, 2010).

$$s = \sqrt{\frac{\sum_{i=1}^{n}(x_i - \hat{x})^2}{n-1}} \qquad (1)$$

where x_i is an observation in the data set, x with a circumflex is the mean value of the data set and n is the number of the observations. RMSE is calculated as follow (Ghilani, 2010).

$$\mathrm{RMSE} = \sqrt{\frac{\sum_{i=1}^{n}(x_i-\hat{x})^2}{n}} \quad (2)$$

where x_i is an observation in the data set, x with a circumflex is the values predicted by a model and n is the number of the observations.

The definition of RMSE requires knowing the correct (or believed to be correct) value. In surveying, this usually happens when control values are held to be correct. Without knowledge of the true value, RMSE is not defined (Meyer, 2012). In this study, known coordinates of the points are held to be correct and the differences between computed coordinates and these coordinates are used to calculate standard deviations and RMSE values for the solutions produced in the following section.

Although Eqs. (1) and (2) seem similar, these two statistics are conceptually quite different. Because RMSE is dispersion around a true value, it is a measure of accuracy. In contrast, because standard deviation is dispersion around the observation set's own mean, it is a measure of precision. This means that standard deviation is used to measure the precision and RMSE is used to measure the accuracy of an observation set (Meyer, 2012).

Applications and Results

Five GNSS points approximately centering Fresno (see Fig. 1) is part of a permanent reference network in California. 24 h data with 1 s interval are downloaded for these points. All five sites are equipped with Trimble Zephyr Geodetic antennas. 10º elevation mask is used for baseline processing. To process the GNSS data Trimble Business Center (TBC) software is used.

Figure 1. Five GNSS sites approximately centering Fresno, CA (image from Google).

For the analyses, Fresno point is held fixed and the other four points' coordinates are determined. Although for entire 24 h data for the four baselines processed (Fresno-Madera, Fresno-Oneals, Fresno-Hanford and Fresno-San Joaquin) maximum number of observed satellites 30 and 23 for GPS and GLONASS respectively, maximum number of observed satellites are listed in Table 1 for the observation periods used for the analyses. Approximate distances from Fresno station to the other four stations are given in Table 2.

Table 1. Maximum number of satellites observed.

	GPS	GLONASS
10m	8	7
20m	8	8
30m	9	8
45m	9	8
1h	9	9
2h	11	10
4h	15	13
8h	20	19

Table 2. Approximate distances from Fresno station.

Station	Distance (km)
Hanford	58
Madera	29
Oneals	40
San Joaquin	35.5

For the analyses, known coordinates of the five points used (see Fig. 1) are considered the "truth" and the coordinates obtained by processing the baselines are compared against the known coordinates. Using the discrepancies, standard deviations and RMSE values are computed for each observation period.

Table 3. GPS only solution

	Standard Deviation (mm)			RMSE (mm)		
	Latitude	Longitude	Ellip. H.	Latitude	Longitude	Ellip. H.
10m	10.2	11.5	80.7	8.9	9.9	69.9
20m	9.9	10.1	82.2	8.6	8.8	71.2
30m	10.0	9.1	83.6	8.7	7.8	72.4
45m	8.4	7.7	83.2	7.3	6.7	72.1
1h	9.5	7.3	84.1	8.2	6.3	72.8
2h	10.3	6.6	89.2	8.9	5.7	77.2
4h	7.3	5.1	87.5	6.3	4.4	75.8
8h	6.7	6.1	78.9	5.8	5.3	68.3

As can be seen in Table 3, with GPS only solution, as expected, with increasing observation period, standard deviations and RMSE values are going down; however, decrease is not smooth for some solutions; for instance, 1 h and 2 h latitude solutions. Ellipsoidal height solutions are not predictable since they go up and down throughout the solutions. Small RMSE values imply unbiased solutions.

Table 4. GLONASS only solution

	Standard Deviation (mm)			RMSE (mm)		
	Latitude	Longitude	Ellip. H.	Latitude	Longitude	Ellip. H.
10m	N/A	N/A	N/A	N/A	N/A	N/A
20m	N/A	N/A	N/A	N/A	N/A	N/A
30m	N/A	N/A	N/A	N/A	N/A	N/A
45m	10.4	8.0	102.7	9.0	6.9	88.9
1h	10.7	7.6	103.9	9.2	6.6	90.0
2h	8.5	5.2	87.0	7.4	4.5	75.3
4h	8.6	5.6	81.4	7.5	4.9	70.5
8h	7.9	6.1	80.7	6.8	5.3	69.9

As can be seen in Table 4, there is no solution available for 10, 20 and 30 min data. Only after 45 m data, TBC was able to solve the baselines. In general, with increasing observation period, standard deviations and RMSE values are decreasing. Standard deviations and RMSE values for latitudes and longitudes are slightly larger compared to GPS only solutions. Nevertheless, ellipsoidal height results are worse. Smaller RMSE values than standard deviations indicate that there is no bias in the data.

Table 5. GPS and GLONASS solution

	Standard Deviation (mm)			RMSE (mm)		
	Latitude	**Longitude**	**Ellip. H.**	**Latitude**	**Longitude**	**Ellip. H.**
10m	7.4	12.0	83.3	6.4	10.4	72.1
20m	8.0	10.4	84.2	6.9	9.0	72.9
30m	8.7	9.4	84.1	7.6	8.1	72.8
45m	8.4	8.0	84.3	7.3	7.0	73.0
1h	9.2	7.3	85.1	7.9	6.3	73.7
2h	9.0	5.9	87.9	7.8	5.1	76.1
4h	7.7	5.1	86.1	6.6	4.4	74.6
8h	6.6	5.7	79.4	5.7	5.0	68.7

The results in Table 5 indicate that with GPS and GLONASS solution, standard deviations and RMSE values are slightly smaller compared to GPS only and GLONASS only solutions for latitudes and longitudes; yet, the same thing cannot be said for ellipsoidal heights.

Table 6. GPS only solution using precise orbital data.

	Standard Deviation (mm)			RMSE (mm)		
	Latitude	**Longitude**	**Ellip. H.**	**Latitude**	**Longitude**	**Ellip. H.**
10m	9.0	11.6	81.8	7.8	10.1	70.8
20m	9.1	10.3	83.4	7.9	8.9	72.3
30m	9.5	9.3	84.0	8.2	8.0	72.7
45m	8.4	8.3	84.9	7.2	7.2	73.5
1h	9.4	7.8	85.2	8.1	6.7	73.8
2h	8.5	6.2	81.0	7.4	5.4	70.1
4h	7.8	5.8	85.4	6.7	5.0	73.9
8h	6.2	5.0	83.1	5.3	4.3	72.0

If we compare the results in Table 6 against the results in Table 3, it is seen that the results are generally slightly better for latitudes and longitudes but not for ellipsoidal heights.

Table 7. GLONASS only solution using precise orbital data.

	Standard Deviation (mm)			RMSE (mm)		
	Latitude	**Longitude**	**Ellip. H.**	**Latitude**	**Longitude**	**Ellip. H.**
10m	N/A	N/A	N/A	N/A	N/A	N/A
20m	N/A	N/A	N/A	N/A	N/A	N/A
30m	N/A	N/A	N/A	N/A	N/A	N/A
45m	7.5	9.5	98.3	6.5	8.2	85.1
1h	8.4	7.3	99.4	7.3	6.4	86.0
2h	7.8	5.3	79.4	6.8	4.6	68.7
4h	7.6	5.8	79.7	6.6	5.1	69.1
8h	6.8	6.1	82.3	5.9	5.3	71.3

Again, there is no solution available for 10, 20 and 30 min data. If we compare the results in Table 7 against the results in Table 4, it appears that similar to GPS only solutions, the results are generally slightly better for latitudes and longitudes but not for ellipsoidal heights.

Table 8. GPS and GLONASS solution using precise orbital data.

	Standard Deviation (mm)			RMSE (mm)		
	Latitude	**Longitude**	**Ellip. H.**	**Latitude**	**Longitude**	**Ellip. H.**
10m	7.0	11.5	82.0	6.1	10.0	71.0
20m	7.5	10.1	83.3	6.5	8.7	72.1
30m	8.4	9.0	83.4	7.3	7.8	72.3
45m	8.4	8.3	85.3	7.3	7.2	73.9
1h	9.3	7.8	85.5	8.1	6.7	74.0
2h	8.3	6.2	80.0	7.2	5.3	69.3
4h	7.9	5.8	84.6	6.8	5.0	73.3
8h	6.2	5.0	82.6	5.3	4.3	71.5

If we compare the results in Table 8 against the results in Table 6 and 7, most of the time the results are slightly better. If we compare the results in Table 8 against the results in Table 5, it is seen that the results are generally slightly better for latitudes and longitudes and also for ellipsoidal heights.

Neither with broadcast nor with precise orbital data inclusion of GLONASS satellites to the solutions contributed significantly. On top of this, ellipsoidal heights are unpredictable. On the other hand, precise orbital data produced slightly better results. It should be clarified here that in this study single baseline solutions are used. It means that for the solutions given in the above tables only the baselines between Fresno station and the point of interest is solved using TBC and consequently no adjustment involved. This approach is utilized in this study in order to be able to monitor the contribution of each satellite constellation. Otherwise, it would not be possible to follow or it would be more complicated to identify the contribution of the satellites to the solutions from the constellations involved. Because of this approach, the results turned out larger. In any case, the purpose of this study was to see the contribution of satellites to the solutions from the constellations involved with varying baseline length and observation period along with precise orbital data.

Conclusions

Inclusion of GLONASS satellites to GNSS solutions is examined on a five point network. For solutions 10, 20, 30, 45 min and 1, 2, 4, and 8 h data are processed using broadcast and precise orbital data. For the analyses, standard deviations and RMSE values are calculated for each solution. For all solutions, generally, RMSE values are smaller including ellipsoidal heights. Smaller RMSE values imply that there is no bias in the data. When precise orbital data are employed, slightly better results are obtained. Nonetheless, neither with broadcast nor with precise orbital data inclusion of GLONASS satellites to the solutions contributed significantly. These results indicate that for short observation periods if GPS satellites are not available due to obstructions or so, one may want to include GLONASS satellites to the solutions. Other than that contribution of GLONASS satellites to the solutions is questionable for short surveys.

Acknowledgements

Authors would like to thank Chris Bardon and Ed Morrison of California Surveying and Drafting Supply, Inc. for providing the GNSS data.

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