

ASSESSMENT OF THE MULTI-GNSS PPP PERFORMANCE USING PRECISE PRODUCTS FROM THE WUHAN ANALYSIS CENTRE

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Abstract

Performance of the Precise Point Positioning (PPP) technique for GNSS positioning is strongly dependant on a quality of used satellite orbit and clock product. Within this study, three different versions of precise products provided by the analytical centre of the Wuhan University were evaluated by processing various combinations of GNSS systems constellations over a five months long period in 2020 with RTKLIB software. The results show that final and rapid version of the precise products could offer a centimetre level of positioning accuracy in static daily PPP while the ultra-rapid version utilizing 24 hours of predicted products performed significantly worse. In this regard, a positive effect on positioning accuracy was reached when including Galileo signals in processing of the ultra-rapid version product. When studying coordinate's repeatability over the selected time period, the best results were obtained for a combination of GPS and GLONASS signals.

Keywords: Precise Point Positioning, multi-GNSS, precise products

1. INTRODUCTION

Development of new Global Navigation Satellite Systems (GNSS) as Galileo (GAL) or BeiDou Navigation Satellite System (BDS) as well as a modernization of legacy systems GPS and GLONASS (GLO) is linked with a transition from single or dual constellation solutions to multi-GNSS combined solutions. Alongside, advanced positioning techniques based on undifferenced observations as the Precise Point Positioning (PPP) technique (Zumberge et al., 1997) can provide accurate results only if high-quality precise products (satellite ephemerides and satellite clock error corrections) are available as they cannot cancel some of the significant errors by differencing observations from pairs of receivers.

Various evaluations of GNSS post-processing precise products quality were published in recent years. Their authors focused either on an evaluation of the satellite orbits and clocks themselves (i.e. Guo et al., 2017, Montenbruck et al., 2017, Li et al., 2020, Steigenberger and Montenbruck, 2020) or on quantifying their impact on positioning in terms of coordinates accuracy, precision and optionally also on a convergence time of PPP solutions (Li et al., 2017, Geng et al., 2018, Bahadur and Nohutcu, 2019 or Zhou et al., 2020). The purpose of this study is to provide an idea on which version of precise product provided by the analytical center at Wuhan University and what combination(s) of GNSS constellations can currently

provide the most accurate PPP positioning in Europe and in China.

2. MATERIALS AND METHODS

2.1 Dataset

Wuhan University (<http://www.igs.gnsswhu.cn/>) run two analysis centres (ACs) belonging to the International GNSS Service (IGS). One of them is a standard IGS analysis centre with an abbreviation *WHU* while the other one with an abbreviation *WUM* belongs to the IGS Multi-GNSS Experiment (MGEX). Existing analysis centres (ACs) including the Wuhan's standardly provide three versions of precise products labelled as final, rapid and ultra-rapid, which differ in accuracy, update rate and sampling rate. Within the presented study, the final product from the Wuhan University MGEX solution (Guo et al., 2016) and the rapid and ultra-rapid products from the Wuhan University IGS solution were used. In case of the ultra-rapid product, its predicted part including extrapolated satellite ephemerides and satellite clock error corrections was utilized.

Table 1. Overview of the different type products from WUHAN ACs.

Institution	Product type	ID	Constellations	File period	Sampling rate	Update rate
Wuhan Univ. MGEX	final	WUM0MGX FIN	GPS+GLO+GAL+B DS2+BDS3+QZSS	24h fitted	15min	weekly
	ultra-rapid	WUM0MGX ULA	GPS+GLO+GAL+B DS2+BDS3+QZSS	24h fitted +24h predicted	5min	1 hour
Wuhan Univ. IGS	final	whs	GPS+GLO+GAL+B DS2+QZSS	24h fitted	15min	weekly
	rapid	whr	GPS+GLO+GAL+B DS2+QZSS	24h fitted	15min	daily
	ultra-rapid	whu	GPS+GLO+GAL+B DS2+QZSS	24h fitted +24h predicted	15min	3 hours

Data collected at eight GNSS stations over 152 consecutive days from January till May 2020 were used in this study. All eight GNSS stations are part of the global IGS MGEX network and equipped with multi-GNSS hardware. Position of stations is presented in Figure 1.

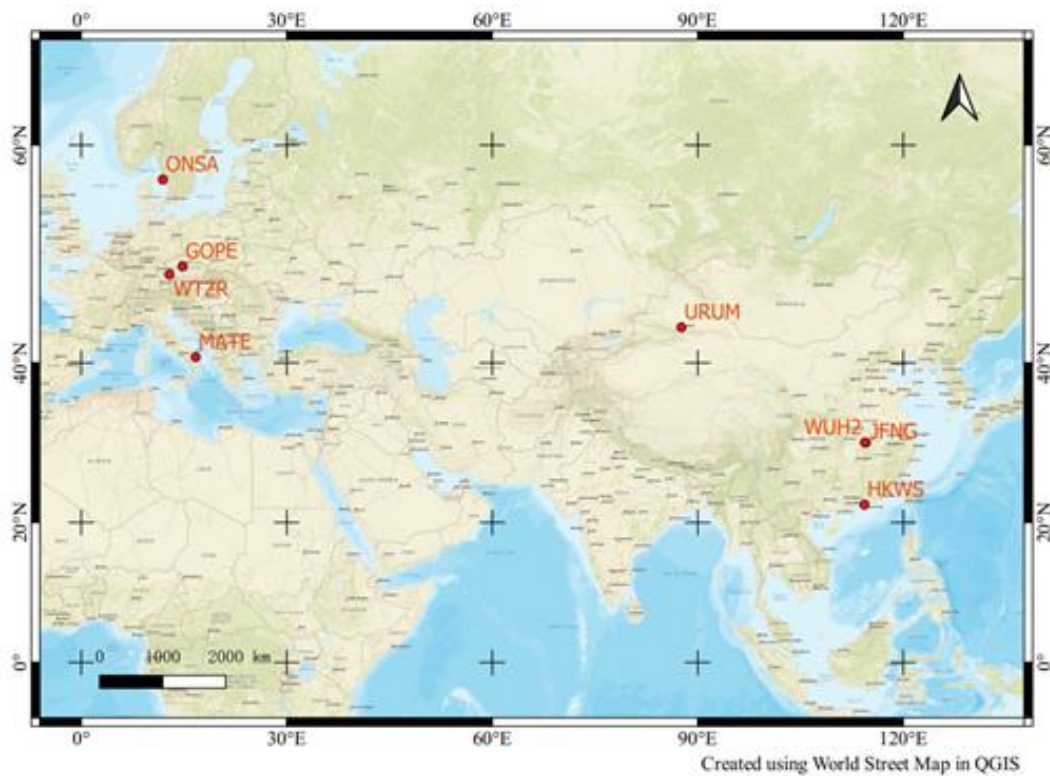


Fig. 1. Geographical distribution of the selected eight GNSS stations used in the study.

2.2 Data processing

RTKLIB open source library for GNSS navigation and positioning (Takasu, 2009, <http://www.rtklib.com>) in version 2.4.3 b34 was used for GNSS processing. It supports various undifferenced and double-differenced positioning techniques for real-time and post-processing solutions while supporting GPS, GLO, GAL, BDS and QZSS signals. Basic information about PPP processing strategy applied in this study are presented in Table 2. Daily observation files from individual GNSS stations were processed to estimate their coordinates in the static mode. Although the ultra-rapid product is being updated hourly by the AC at Wuhan University, a single file available before the processing run for a given day was entering the processing. It therefore corresponds to using 24 hours of predicted product.

Table 2. The processing strategy for PPP used for the three different types of precise products from the Wuhan university analysis center.

Processing mode	PPP-static in 24h window
Strategy	forward extended Kalman filter
Observation sampling rate	30s
Precise products	multi-GNSS final, rapid and ultra-rapid products from WUH university center
Frequency	L1, L2 and L5
Ionosphere	ionosphere-free linear combination
Troposphere	a priori ZHD Saastamoinen model, ZTD corrections and tropospheric gradients estimated epoch-wisely
Cut-off elevation angle	5°
Antenna model	igs14_2062.atx
Ocean tidal loading	applied (FES2004)
Differential code biases (DCB) files	CODE DCB monthly product

2.3 Methodology of the evaluation

The study focuses on two ways of PPP performance evaluation while using three different multi-GNSS products from the Wuhan university AC and various combinations of GNSS constellations (G, GC, GE, GR, GRC, GRE, GREC). In the first step, data from all eight GNSS stations were processed over the full period and obtained daily coordinates were compared with those from the official IGS final weekly solution (International GNSS Service, 2020). 3d differences of daily positions from own processing and IGS final weekly solution were computed using the formula:

$$3d_difference = ((X_{own} - X_{igs})^2 + (Y_{own} - Y_{igs})^2 + (Z_{own} - Z_{igs})^2)^{1/2}$$

where X , Y , Z correspond to individual coordinates, index own to a coordinate from own PPP solution and index igs to a coordinate from the IGS final weekly solution.

The IGS solution represent a robust positioning product computed as a combination of GPS+GLO solutions delivered by individual IGS ACs. In the second step, coordinates repeatability was computed and assessed for the full time period, again for various constellation combinations.

Days where any version of the precise product was not available were fully excluded from the presented statistical comparisons. No outlier elimination was applied for the final and rapid version of the product. A following approach was applied to exclude outlying values from the results provided by the ultra-rapid version of the product: if a difference in position from the own RTKLIB processing and the IGS final weekly solution exceeded a threshold of 30 cm at some GNSS station and at some day, results from this GNSS station at the particular day were completely excluded.

3. RESULTS

3.1 Comparison of own PPP coordinates with the IGS final weekly solution

Overall statistics of comparisons for three tested versions of precise products are presented in Figure 2. Most of the combinations processed with final and rapid product stayed below or at the level of 6 mm for standard deviation (STD) and 14 mm for Root-Mean-Square error (RMS) in 3D positioning what indicates a good quality of PPP static positioning in RTKLIB with precise products from the Wuhan university AC.

While final and rapid version of products reached mostly similar performance in terms of STD and RMS, ultra-rapid version performed approximately five to ten times worse. This is caused by using a single ultra-rapid file with predicted product available before the processing run for a 24h window and not updating it with newer files published hourly by the AC. If always using the newest file with an ultra-rapid product with predicted orbits and clocks, the situation should be improved. Performance of PPP positioning based on the ultra-rapid product still could be improved while using a constellation combination including Galileo, as STD and RMS values obtained for GE, GRE, GREC were significantly lower than for other solutions. A potential reason of this situation might be a high stability of atomic clocks at Galileo satellites. On the contrary, the impact of using different constellations while utilizing rapid and final product was minimal. An exception for this was brought by the BDS

system which inclusion always worsened the overall results, mainly for the rapid product. Although a variability of statistics at individual stations for the final version of precise product (see table 3) impacts the mean results, one signal seem to apparent. European stations performed closer to the IGS final weekly solution than stations in China while using GRE constellation and the situation was exactly opposite for the GRC constellation.

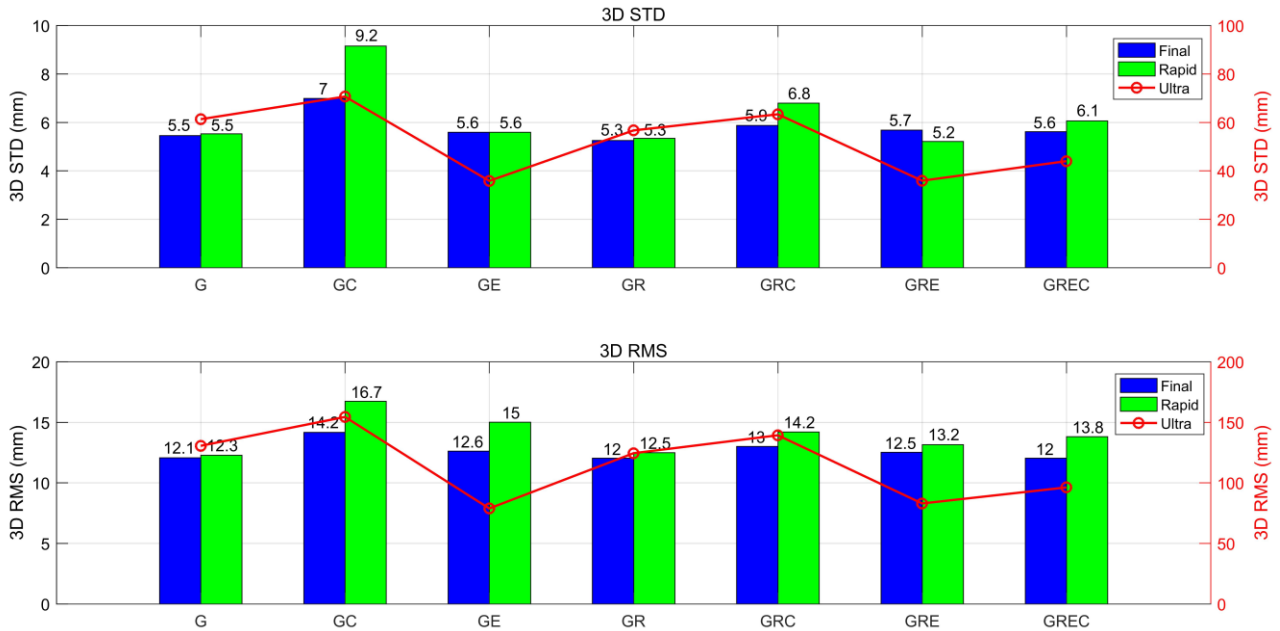


Fig. 4. STD (top) and RMS (bottom) values of 3D positioning difference between coordinates from own PPP processing using the three different types precise products (blue for final, green for rapid and red for ultra-rapid version) and IGS weekly combined solution for selected eight GNSS stations.

Table 3. The Mean, RMS and STD values of the 3D positioning difference between PPP coordinates from own solution based on the final product from WUHAN analysis centre and the IGS final weekly solution, all values are in mm.

	GR			GRE			GRC			GREC		
	Mean	RMS	STD	Mean	RMS	STD	Mean	RMS	STD	Mean	RMS	STD
GOPE	9.8	11.5	6.1	8.1	9.5	5.0	10.7	12.5	6.6	8.9	10.5	5.6
MATE	7.4	8.3	3.7	6.7	7.5	3.4	8.2	9.3	4.3	7.2	8.2	3.9
WTZR	15.2	16.9	7.5	12.5	14.4	7.1	15.8	17.6	7.7	13.3	15.1	7.3
ONSA	9.0	10.6	5.6	8.0	9.5	5.0	9.3	11.0	5.8	8.4	9.9	5.2
Mean Europe	10.4	11.8	5.7	8.8	10.2	5.1	11.0	12.6	6.1	9.4	10.9	5.5
URUM	12.4	13.2	4.5	19.1	20.9	8.4	11.1	12.2	5.1	15.5	16.7	6.4
JFNG	7.6	8.4	3.6	10.4	11.5	5.0	9.2	10.4	4.8	8.3	9.6	4.8
WUH2	11.0	11.8	4.2	12.6	13.9	5.7	12.9	14.2	5.8	10.7	11.7	4.7
HKWS	14.1	15.7	6.8	11.7	13.1	5.9	15.4	16.9	6.9	12.8	14.7	7.1
Mean China	11.3	12.3	4.8	13.5	14.9	6.3	12.2	13.4	5.7	11.8	13.2	5.8
Mean all	10.8	12.1	5.3	11.1	12.5	5.7	11.6	13.0	5.9	10.6	12.1	5.6

3.1 Repeatability of coordinates estimated with various satellite constellation combinations

An impact of using various constellation combinations on coordinate's repeatability was examined and the results are provided in Table 4. Lower values represent a better stability of positioning while occurring differences can be attributed to a quality of individual GNSS stations, GNSS systems and to a quality of precise products provided for them by the Wuhan University AC. Since the lowest coordinate's repeatability was mostly reached by the GR combination or when processing GPS-only signals, inclusion of Galileo and BDS satellites did not provide any visible advantage for the realized daily static PPP positioning. Nevertheless, the situation can be very much different when processing data from a shorter observation time and/or in real-time mode and/or in locations with a limited view over the sky. Slightly lower coordinate's repeatability values reached by the final version product compared to the rapid version support their usage in the most critical applications.

Table 4. Mean position repeatability for final and rapid version of the precise products for individual constellation combinations. Two best results in each column are shown in bold.

Final precise product									
Constellation	All stations			European stations			China stations		
	North	East	Height	North	East	Height	North	East	Height
G	3.0	6.0	7.6	3.2	6.5	6.6	2.8	5.5	8.5
GR	2.9	5.3	7.4	2.8	5.4	6.7	2.9	5.2	8.0
GE	4.2	7.1	9.2	4.7	7.1	7.5	3.6	7.1	10.8
GC	3.7	8.4	7.8	4.1	8.8	7.0	3.3	8.0	8.6
GRE	3.6	6.3	8.9	3.7	5.5	6.9	3.6	7.1	10.8
GRC	3.2	6.0	7.4	3.3	6.2	7.0	3.1	5.9	7.9
GREC	3.6	6.0	8.1	4.0	6.2	7.0	3.2	6.3	9.2

Rapid precise product									
Constellation	All stations			European stations			China stations		
	North	East	Height	North	East	Height	North	East	Height
G	3.9	7.2	8.2	3.6	7.0	7.1	4.3	7.4	9.3
GR	3.6	6.2	8.0	3.4	6.1	7.3	3.8	6.4	8.7
GE	5.7	9.4	9.6	6.0	9.7	7.9	5.4	9.0	11.3
GC	5.3	12.4	10.0	4.6	12.0	7.6	6.0	12.8	12.3
GRE	4.4	7.3	8.9	4.7	7.3	7.2	4.1	7.4	10.5
GRC	4.1	8.4	8.7	3.7	8.0	7.5	4.5	8.9	9.9
GREC	4.8	8.6	8.9	4.9	8.5	7.4	4.7	8.6	10.4

4. CONCLUSIONS

We evaluated performance of PPP static daily positioning based on various constellation combinations and three different precise products provided by the Wuhan University AC. Through the data analysis of the two groups of stations, we found that European stations performed closer to the IGS final weekly solution than stations in China while using GRE constellation and the situation was exactly opposite for the GRC constellation. In the realized assessment, when utilizing rapid and final version of the products the constellation combination of GPS and GLO signals provided the best positioning results. On the other

hand, an inclusion of Galileo to the processing utilizing ultra-rapid version of the product brought always a significant improvement in the coordinates accuracy and stability.

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