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EVALUATION OF THE PERFORMANCE OF MULTI-GNSS ADVANCED ORBIT AND CLOCK AUGMENTATION – PRECISE POINT POSITIONING (MADOCA-PPP) IN JAPAN REGION

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Abstract. For users of Precise Point Positioning (PPP), Multi-GNSS Advanced Orbit and Clock Augmentation PPP signals provide corrective data. When using the PPP approach and/or PPP-Ambiguity Resolution (AR) method, the QZSS signal provides globally applicable error corrections on satellite orbit, clock offset, and code/phase biases. In addition, from FY2024, as a part of the MADOCA-PPP technology demonstration, wide-area ionospheric correction data will be provided for the Asia-Oceania region. A software estimator of precise satellite information developed by JAXA, Multi-GNSS Advanced Demonstration Tool for Orbit and Clock Analysis (MADOCA), allows u-blox CO99-ZED-F9P and MSJ 3008-GM4-QZS utilizing MADOCA-PPP to be used in GNSS applications that need sub-decimetre precision but don't have to be expensive. Errors caused by positioning satellites are computed by using observation data from domestic and overseas GNSS monitoring station networks such as IGS and MIRAI, and obtained correction data is transmitted from QZSS signal to provide highly precise positioning augmentation services that can be used in the Asia-Oceania Region. Users may utilize the PPP technique for high-precision locating by employing a GNSS receiver that supports the QZSS signals. This paper describes an experiment carried out with the static method to combine GPS, GLONASS, and QZSS signals in the project site (ISHI, USUD and MIZU stations in Japan). This paper examines the GPS/GLONASS/QZSS obtainable accuracy. These obtained results indicate that integrating GPS system with GLONASS and QZSS is favoured for surveying applications. It appears that integrating GPS/GLONASS/QZSS (MADOCA precise ephemeris file) static measurements in the study area between 0–4 millimetres accuracy can be guaranteed on all occasions.

Keywords: GPS, GLONASS, QZSS, MADOCA, accuracy, PPP, improvement.

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1. Introduction

Using JAXA's Multi-GNSS Advanced Demonstration Tool for Orbit and Clock Analysis (MADOCA), a software estimator of accurate satellite information, u-blox CO99-ZED-F9P and MSJ 3008-GM4-QZS may be used in GNSS applications that need sub-decimetre precision without being pricey. The service is set to commence trial service on September 30, 2022, and operational service in FY2024, after the introduction of QZS 5-7. This service, in addition to location, may be used to estimate the quantity of water vapour in the atmosphere, and it is predicted to improve the accuracy of weather predictions. The augmentation data's very accurate clock inaccuracy information is likely to be employed in areas where exact time synchronization is needed. To create MADOCA-PPP augmentation data, real-time data from a network of GNSS monitoring stations in Japan and overseas is required. The GNSS Integrated Data Sharing System (called MIRAI, Multi-GNSS Integrated Real time and Archived Information system) collects this real-time data, with assistance from domestic and international organizations and universities in supplying monitoring station data. This real-time data acquired by MIRAI is meant to be extensively utilized for GNSS research and development across the globe, not only to create augmentation data for MADOCA-PPP. The information is freely accessible on the Internet. Users may check the status of MIRAI-connected monitoring stations on the Web, get real-time data (RTCM 3 format) from monitoring stations, and download archived data (registration needed) (RINEX format). The following website provides free access to archived data. The Cabinet Office is currently creating a new augmentation service known as MADOCA-PPP (Multi-GNSS Advanced Orbit and Clock Augmentation – Precise Point Positioning). By supplying GNSS augmentation data through QZSS satellites, this service will enable Precise

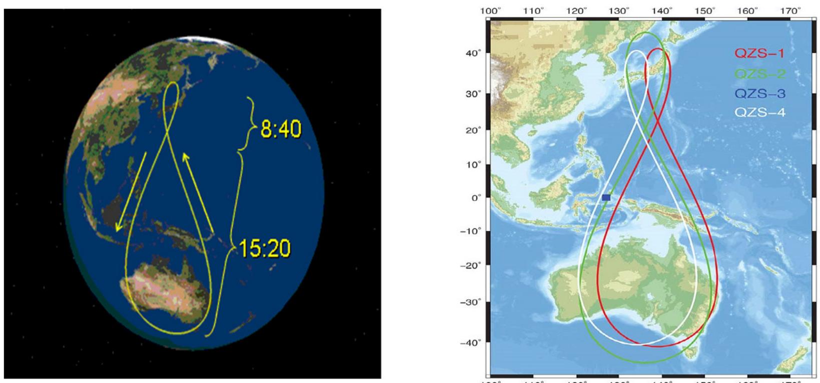
Point Positioning (PPP) across the Asia-Oceania area. The MADOCA-PPP pilot service will begin on September 30th, 2022 (Choy et al., 2015). The draft version of the MADOCA-PPP performance standard (PS-QZSS-MDC) and user interface specification (IS-QZSS-MDC-001) is issued prior to the commencement of the trial operation. There is also reference material available for the Technology Demonstration for Wide-area Ionospheric Corrections Information, which is scheduled to be implemented after the launch of the QZS-5 (Choy et al., 2015; Wang et al., 2018; Reyes et al., 2017; Fredeluces et al., 2020; Katsigianni et al., 2019). As an example, the wide-range ionospheric adjustment for Asia and Oceania is communicated via L6D messages to reduce the TTFF (Time to First Fix) of MADOCA-PPP. This document describes the demonstration's reference information. The technology Demonstration (ionospheric correction) augments the following GNSSs: QZSS, GPS, GLONASS and Galileo. The demonstration using the QZS-5, 6 and 7 will be performed in 2024 to 2026. A lot of studies about MADOCA (Harima et al., 2014; Lou et al., 2016; Miyoshi et al., 2012; Steigenberger et al., 2018; Zhang et al., 2019) have been performed up to now. The convergence time measures the amount of time that passes between a receiver receiving augmentation messages via QZSS (MADOCA-PPP) signals and the PPP calculation result satisfying the following accuracy obtained (Vietsel et al., 2014):

- Accuracy in the horizontal plane <30 cm (95%), in the vertical plane ≤50 cm (95%).
- The convergence time must meet the requirements listed below: Time of convergence ≤600 sec.
- Premises: The surveying environment is open sky, and the antenna and receiver are dual-frequency. In this paper the test was conducted at three IGS stations (MIZU, ISHI and USUD) to process the MADOCA precise ephemeris file. This paper examines GPS/GLONASS/QZSS obtainable accuracy by using MADOCA precise ephemeris file.

2. Materials and methods

Figure 1a shows the ground track of the QZSS constellation, which consists of four satellites, as of December 4, 2017. The sub-satellite location of the geostationary QZS-3 satellite (Figure 1b) is shown by the blue square (Steigenberger et al., 2018).

The Japanese government created the Quasi-Zenith Satellite System (QZSS) to address the GPS positioning issue in Japan's urban and hilly regions. To improve location availability and accuracy, a constellation of three inclination geosynchronous orbit (IGSO) satellites and one geostationary satellite transmits signals compatible with GPS (Figure 1). The IGSO satellites have figure-eight ground tracks and a one-sidereal-day orbit cantered on apogee. They spend the majority of their orbital period above the Japanese archipelago. The satellites spend a lot of time hiding around the zenith of the sky. Additionally, the satellites transmit both basic and sophisticated augmentation signals. Three more Block I QZSS satellites were launched in 2017, completing a constellation of four satellites, based on the spacecraft's successful test findings. 2010 saw the launch of the first Block I QZSS satellite, or prototype. The Japanese Quasi-Zenith Satellite System (QZSS) launched two more spacecraft in August and October 2017, increasing the constellation's total number of satellites to four. 2018 is when fully functional services are expected to start. On August 19, 2017, QZS-3, the first spacecraft in geostationary Earth orbit (GEO), was launched. On October 10, 2017, QZS-4, the third spacecraft in inclination geosynchronous orbit (IGSO), was launched. Table 1 displays the ground pathways of the four QZSS satellites. Because of the considerable orbit eccentricity of 0.075, all IGSO satellites have earth tracks with a distinctive figure-eight form that allows users in the northern hemisphere to watch content for longer periods of time. However, there is an inconsistency in the ground traces. In particular, the orbit inclinations of QZS-1 and QZS-4 with respect to the equator are 40.9° and 40.5°, respectively. In contrast, QZS-2's higher 44.5° inclination results in a larger ground track extension from north to south. Furthermore, the central longitude of the ground tracks indicates that the figure-eight pattern's center changes between 130° and 140° E. Although the ground track's center longitude is set at 135° 5° E and the inclination is set at 43° 4°, these deviations are still within the parameters allowed by the QZSS



a) b)

Figure 1. a – The ground track of the QZSS constellation, which consists of four satellites, as of December 4, 2017;
b – The sub-satellite location of the geostationary QZS-3 satellite is shown by the blue square (Steigenberger et al., 2018)

Interface Specification, version 1.8, published on October 3, 2016. Since forming its initial orbit, QZS-3, a geophysical satellite, has been regulated to remain within a 0.1° inclination window. Notably, all QZSS satellites provide GPS-compatible navigation signals in the bands L1 C/A, L1C, L2C, and L5 (the Positioning, Navigation, and Timing, or PNT service). Signals unique to QZSS are broadcast in the L1, L5, and L6 bands. Sub-meter Level Augmentation Service, or SLAS (formerly known as Submeter-Class Augmentation with Integrity Function, or SAIF), signals are received by Block II satellites on L5 and all satellites on L1 (Steigenberger et al., 2018; Miyoshi et al., 2012; Teunissen & Monterbruck, 2017; Reyes et al., 2019).

3. Description of the experiment

In the project area, an experiment was carried out to look at MADOCA and the effect of QZSS positioning. For this purpose, the project area's three IGS points – MIZU, ISHI, and USUD in Japan – were chosen because of their lengths, which range from 167 km (USUD-ISHI) to 413 km (USUD-MIZU) (see Figure 2). Satellite data from GPS, GLONASS, and QZSS was used to capture all three IGS sites. The IGS website was used to get the coordinates of the three spots from a static GNSS survey that was conducted on August 20, 2022. A 24-hour observation period was observed at three places where static measurements were obtained. To handle data and make network modifications, use the Topcon Magnet Tools Software (version 7.3.0-commercial software). Tables 1 and 2 show USUD (IGS station) ITRF 2014 (Epoch 2021.1658) coordinates are fixed throughout the adjustment. Standard deviations and locations for each of the three IGS sites are included in each table. Using two SEPT POLARX5s and a Trimble Alloy receiver, the GNSS equipment was used to measure three IGS sites. For these three places, the cut-off elevation mask angle is set to 10

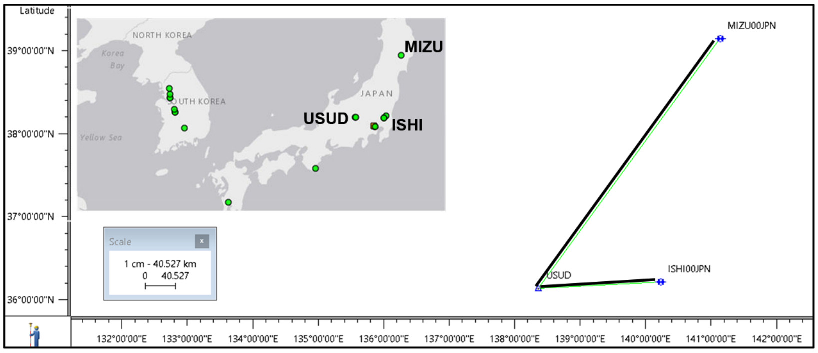


Figure 2. GNSS network in the study region

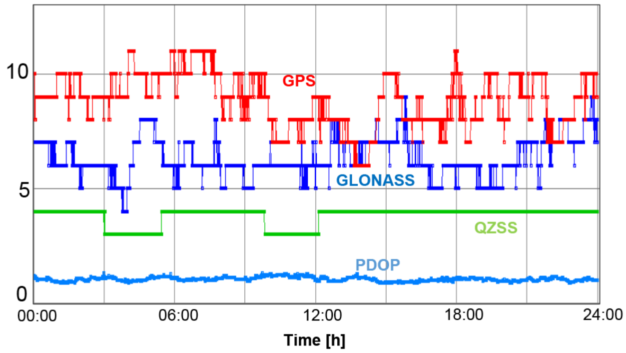


Figure 3. The number of GPS, GLONASS and QZSS satellites and PDOP values of the USUD station in the study region

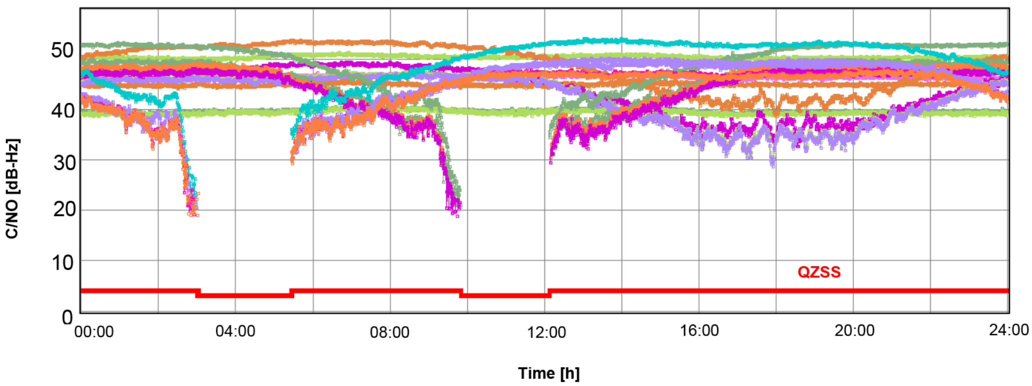


Figure 4. The number of QZSS satellites and SNR values of USUD station

degrees, and the data receiving and processing rate is set to 30 seconds for static GNSS measurements. At the same time, on August 20, 2022, however, two processing tests (GPS/GLONASS/QZSS and GPS/GLONASS/QZSS (with a MADOCA file)) were carried out for the static survey. From 16 to 22 satellites were spotted during these two tests, and the Precision Position Dilution (PDOP) ranged from 1 to 1.30 (Figure 3). These results are considered "normal" for the number of GPS/GLONASS/QZSS-monitored satellites and their distribution.

The number of QZSS satellites and SNR values belonging to the USUD point are given Figure 4. L1 C/A, L1 SAIF, L1CP, L2CL, L5Q signals broadcast by QZSS satellites are used in the processing. Topcon Magnet Tools v. 7.3.0 was performed by using GPS/GLONASS/QZSS satellites to compute the coordinate calculations. The obtained results are given in Table 1. Also, MADOCA 22232.sp3.gz file was downloaded from https://mgmds01.tksc.java.jp/ web page and installed in Topcon Magnet Tools v.7.3.0 Software. The obtained results in the process (with the downloaded MADOCA precise ephemeris file) are shown in Table 1. When the obtained results in Table 1 are compared with each other, the standard deviation values of the ISHI point, which is 167 km away from the USUD point, were computed as the same as the result of both process. Moreover, the coordinate differences of ISHI point (for latitude, longitude and height) are shown in Table 2. The obtained coordinate differences in the process by using the MADOCA precise ephemeris file were generally gained as very small values (in the comparison made by considering the coordinates obtained with AUSPOS and CSRS-PPP software).

In addition the obtained base lengths from both processing are compared; the horizontal standard deviation values obtained from the initial process are 0.078 m and 0.440 m for the ISHI-USUD and MIZU-USUD baselines. The vertical standard deviation values of these two baselines were obtained as 0.080 m and 0.800 m (Table 3). The horizontal standard deviation values of the baselines obtained from the second process are 0.078 m and 0.078 m for ISHI-USUD and MIZU-USUD. The vertical standard deviation values were obtained as 0.080 m and 0.102 m (Table 3). The improvement values of the standard deviations between two processing were computed in the range of 79-87%. Standard deviations obtained in process by using CSRS-PPP and AUSPOS online GNSS Software are in the range of 2 mm to 17 mm (Tables 4 and 5). When analysed as coordinate differences between CSRS-PPP and AUSPOS, the obtained values were calculated between 0 mm and 14 mm (Table 6).

Table 1. Standard deviation and coordinate values of the three points by processing without MADOCA file and with MADOCA file (Topcon Magnet Tools Version 7.3.0, ITRF 2014 at Epoch 2022.64)

Topcon Magnet Tools v.7.3.0 Software						
Name	Latitude (°)	Longitude (°)	Ell.Height (m)	Std Lat. (m)	Std Long. (m)	Std h (m)
USUD	36°07′59,19683″N	138°21′43,38152″E	1508,693	0.000	0.000	0.000
ISHI00JPN	36°12′31,80868″N	140°13′08,22621″E	155,204	0.049	0.060	0.081
MIZU00JPN	39°08′06,56263″N	141°07′58,30423″E	115,779	0.332	0.294	0.798
Topcon Magnet Tools v.7.3.0 Software (Madoca22232.sp3.gz file)						
Name	Latitude (°)	Longitude (°)	Ell.Height (m)	Std Lat. (m)	Std Long. (m)	Std h (m)
USUD	36°07′59,19683″N	138°21′43,38152″E	1508,693	0.000	0.000	0.000
ISHI00JPN	36°12′31,80874″N	140°13′08,22634″E	155,221	0.049	0.060	0.081
MIZU00JPN	39°08′06,55258″N	141°07′58,33595″E	116,864	0.071	0.038	0.100

Table 2. The cartesian coordinate differences among the three points by using without MADOCA file and with MADOCA file (Topcon Magnet Tools Version 7.3.0, ITRF 2014 at Epoch 2022.64)

Topcon Magnet Tools v.7.3.0 Software						
Name	X (m)	Y (m)	Z (m)			
USUD	–3855263,489	3427432,138	3741020,336			
ISHI00JPN	–3959648,021	3296836,057	3747005,531			
MIZU00JPN	–3857169,605	3108692,514	4004039,724			
Topcon Magnet Tools v.7.3.0 Software (Madoca22232.sp3.gz file)						
Name	X (m)	Y (m)	Z (m)	dX [m]	dY [m]	dZ [m]
USUD	–3855263,489	3427432,138	3741020,336			
ISHI00JPN	–3959648,033	3296836,062	3747005,542	–0.012	–0.005	–0.011
MIZU00JPN	–3857170,891	3108692,572	4004040,169	1.286	0.058	–0.445

Table 3. The obtained two baseline values by using Topcon Magnet Tools Software v. 7.3.0 in the two tests in the study site (without MADOCA file and with MADOCA file)

Topcon Magnet Tools v.7.3.0 Software														
Point From	Point To	Start Time	Hz. Std (m)	V. Std (m)	Solution Type	Orbit	GDOP	S (m)	GPS	GLONASS	QZSS	Galileo	BDS	PDOP
ISHI00JPN	USUD	20.08.2022 00:00	0.078	0.080	Code Diff	Precise	2.071	167.294.021	31	22	4	24	0	1.406
MIZU00JPN	USUD	20.08.2022 00:00	0.440	0.800	Code Diff	Precise	1.958	413.252.683	32	22	4	27	31	1.351
Topcon Magnet Tools v.7.3.0 Software (Madoca22232.sp3.gz file)														
Point From	Point To	Start Time	Hz. Std (m)	V. Std (m)	Solution Type	Orbit	GDOP	S (m)	GPS	GLONASS	QZSS	Galileo	BDS	PDOP
ISHI00JPN	USUD	20.08.2022 00:00	0.078	0.080	Code Diff	Precise	2.071	167.294.025	31	22	4	24	0	1.406
MIZU00JPN	USUD	20.08.2022 00:00	0.078	0.102	Fixed,Wide Lane	Precise	1.958	413.252.927	32	22	4	27	31	1.351

Table 4. Standard deviation and coordinate values of the three points by processing CSRS-PPP Software (ITRF 2014 at Epoch 2022.64)

CSRS-PPP						
Name	Latitude (°)	Longitude (°)	Ell.Height (m)	Std Lat. (m)	Std Long. (m)	Std h (m)
USUD	36°07′59,19683″N	138°21′43,38152″E	1508,693	0.002	0.003	0.011
ISHI00JPN	36°12′31,79011″N	140°13′08,24207″E	155,912	0.002	0.002	0.008
MIZU00JPN	39°08′06,54480″N	141°07′58,33468″E	117,117	0.002	0.002	0.008

Table 5. Standard deviation and coordinate values of the three points by processing AUSPOS Software (ITRF 2014 at Epoch 2022.64)

AUSPOS						
Name	Latitude (°)	Longitude (°)	Ell.Height (m)	Std Lat. (m)	Std Long. (m)	Std h (m)
USUD	36°07′59,19695″N	138°21′43,38100″E	1508,688	0.009	0.006	0.017
ISHI00JPN	36°12′31,79010″N	140°13′08,24158″E	155,921	0.009	0.006	0.013
MIZU00JPN	39°08′06,54486″N	141°07′58,33406″E	117,124	0.009	0.006	0.013

Table 6. The values (ITRF 2014, 2022.64) of the Cartesian coordinate differences between AUSPOS Software results and CSRS-PPP Software results for the test in the study site

	CSRS-PPP					
Name	X	Y	Z	dX [m]	dY [m]	dZ [m]
USUD	–3855263,489	3427432,138	3741020,336	–0.013	–0.006	0
ISHI00JPN	–3959648,973	3296836,334	3747005,487	–0.002	–0.014	–0.005
MIZU00JPN	–3857171,142	3108692,814	4004040,142	–0.006	–0.014	–0.006
	AUSPOS					
USUD	–3855263,476	3427432,144	3741020,336			
ISHI00JPN	–3959648,971	3296836,348	3747005,492			
MIZU00JPN	–3857171,136	3108692,828	4004040,148			

4. Conclusions

In this study, it is not observed that the MADOCA precise ephemeris file has a significant effect on the USUD-ISHI (~167 km) baseline length, station coordinates and standard deviation values. However, the effect of the MADOCA precise ephemeris file on the USUD-MIZU (~413 km) baseline length is quite remarkable. On the basis of USUD-MIZU, both the baseline length and the coordinates and standard deviation values underwent an improvement in the range of 79–87%. In addition, when the processing results by using CSRS-PPP and AUSPOS were compared among themselves, the coordinate differences were calculated in the range of 0–14 mm. When the processing was performed by using the MADOCA precise ephemeris file in Topcon Magnet Tools v.7.3.0 software and the obtained results from the AUSPOS and CSRS-PPP software were compared with each other, and then the three-dimensional coordinate differences were found in the range of 3–26 cm. The positive effect of using MADOCA precise ephemeris file on long baseline has been demonstrated in this study.

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