Accuracy Evaluation of QZS-1 Precise Ephemerides with Satellite Laser Ranging

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Introduction

The Quasi-Zenith Satellite System (QZSS) is a Japanese navigation satellite system and its first satellite, QZS-1, was launched in 2010. JAXA is promoting Precise Point Positioning (PPP) experiments using precise GNSS orbit and clock information obtained from QZSS-LEX (L-Band Experiment) signals for the purpose of providing PPP service. In order to provide the precise GNSS orbit and clock products, JAXA has developed a precise orbit determination tool (named MADOCA) [1]. Figure 1 shows the configuration of real-time PPP service provision using MADOCA and LEX signals. The required accuracy of QZSS orbit is 7 cm. Therefore, it is necessary to evaluate QZS-1 ephemeris with an accuracy of a few centimeters. In this paper, we assess the orbit accuracy of QZS-1 ephemeris from two different approaches: one is to compare QZS-1 ephemerides provided by different agencies (JAXA, ESOC and TUM), and the other is to assess the accuracy of QZS-1 ephemeris with SLR residuals, which indicate absolute accuracy along the line of sight.

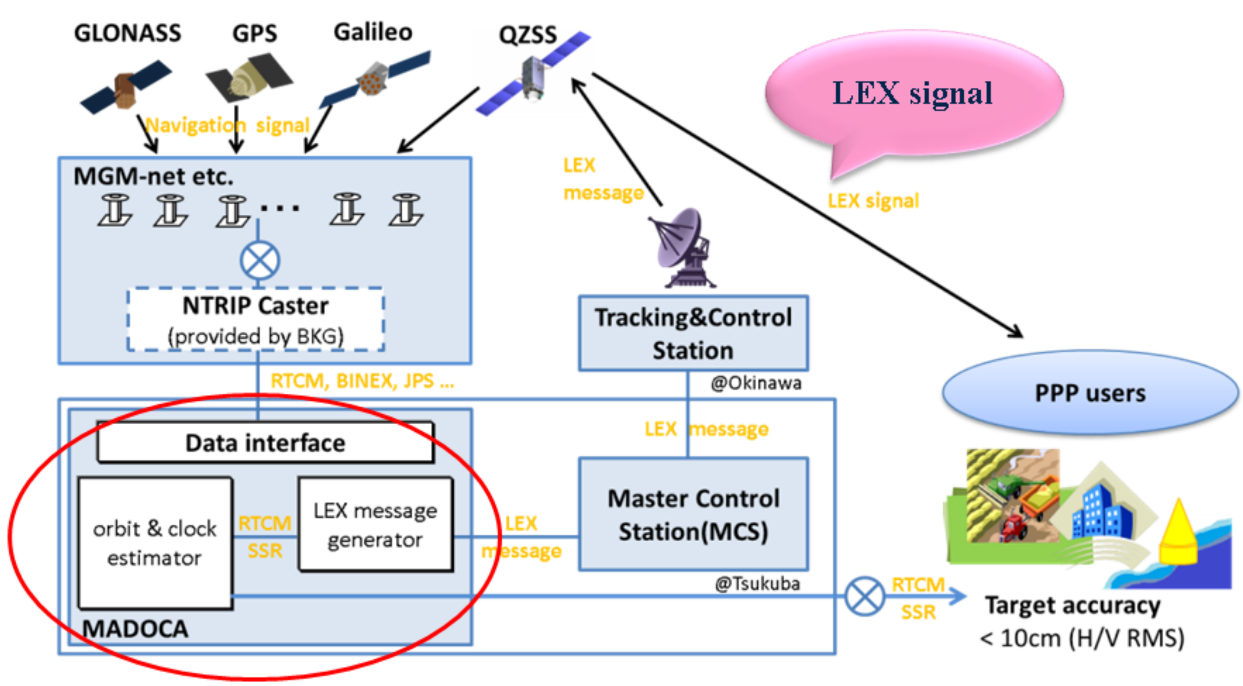


Figure 1. Configuration of Real-Time PPP Service Provision

Evaluation conditions

Table 1 shows the QZS-1 ephemerides used for this analytical evaluation. The evaluation period was 26 days of June 16 to July 12, 2013. In contrast to GPS and GLONASS, QZS-1 uses two different attitude modes depending on the orbital plane [2]. Throughout this period, the standard Yaw-Steering (YS) mode, where β−angle is more than 20deg, was used. In this mode, the satellite z-axis points toward the center of the earth while the satellite rotates such that the solar panels are oriented normal to the sun vector (see Figure 2).

Table 1. QZS-1 Ephemerides Description

Name	Description and reference
MAD	Orbit processed with MADOCA
QZF	JAXA final products http://qz-vision.jaxa.jp/USE/archives/final/
TUM	TUM Multi-GNSS EXperiment products ftp://cddis.gsfc.nasa.gov/pub/gps/products/mgex
ESOC	Orbit processed with ESOC software

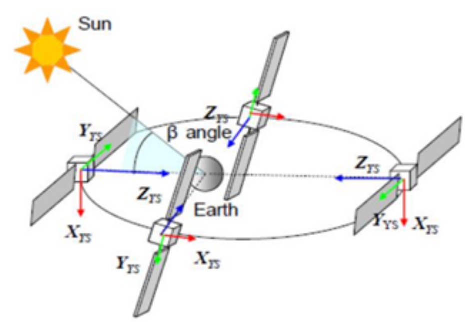
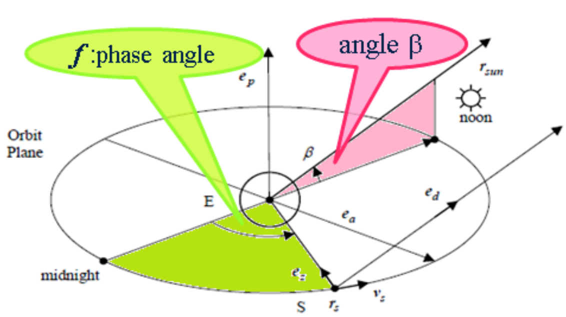


Figure 2. Yaw-Steering Mode

Table 2 shows the comparison of estimation conditions among the four ephemerides provided by different agencies. Solar radiation pressure (SRP) is one of the most critical accelerations to estimate GNSS orbit. The MAD ephemeris employs Modified-DBY model for SRP acceleration model. Acceleration from SRP can be expressed as Eq.(1), where a total of 9 parameters –three in each of D (toward the Sun direction), Y (along the spacecraft's solar panel axis) and B (direction of vector product of D and Y) directions– are estimated. A-priori SRP coefficients are obtained empirically and made dependent on angle beta. On the other hand, a total of 13 SRP parameters are estimated in QZF ephemeris. For QZS-1 ephemerides in TUM and ESOC, less numbers of SRP parameters are estimated than those in JAXA ephemerides (see Table 2).



$$\mathbf{a}_{srp} = S\left(D\mathbf{e}_d + B\mathbf{e}_b + Y\mathbf{e}_y\right)\times 10^{-9}\ \left(m/s^2\right)$$

$$\begin{aligned} D &= D_0 + D_c \cos f + D_s \sin f \\ B &= B_0 + B_c \cos f + B_s \sin f \\ Y &= Y_0 + Y_c \cos f + Y_s \sin f \end{aligned} \qquad (1)$$

Table 2. Estimation Conditions of Ephemerides

Ephemeris	MAD	QZF	TUM	ESOC
System	GPS + QZS	GPS + QZS	GPS+Galileo+QZS	GPS + QZS
Stations	(Figure 3)	(Figure 4)	QZSS/Galileo/GPS: 6 CONGO sta + 3 MGEX sta Galileo/GPS: 18 CONGO sta + 13 MGEX sta	QZSS/GPS: 20 sta, GPS: 20 sta
Frequencies	L1&L2	L1&L2	L1&L5	L1&L2
Arc	24 H+48 H+24 H	7 days	3 days	2 days
SRP model	GPS: IGS final (Fixed) QZS-1: 12 para. D,Y, B(const)+ D,Y, B(1/rev)+ X,Y,Z (piece-wise const.)	GPS: CODE model QZS-1: 13 para. D,Y, B(const)+ D,Y,Z(1/rev)+ D,X(2/rev)	5 para. :	QZS-1: 5 para. D,Y, B(const)+ B(1/rev)

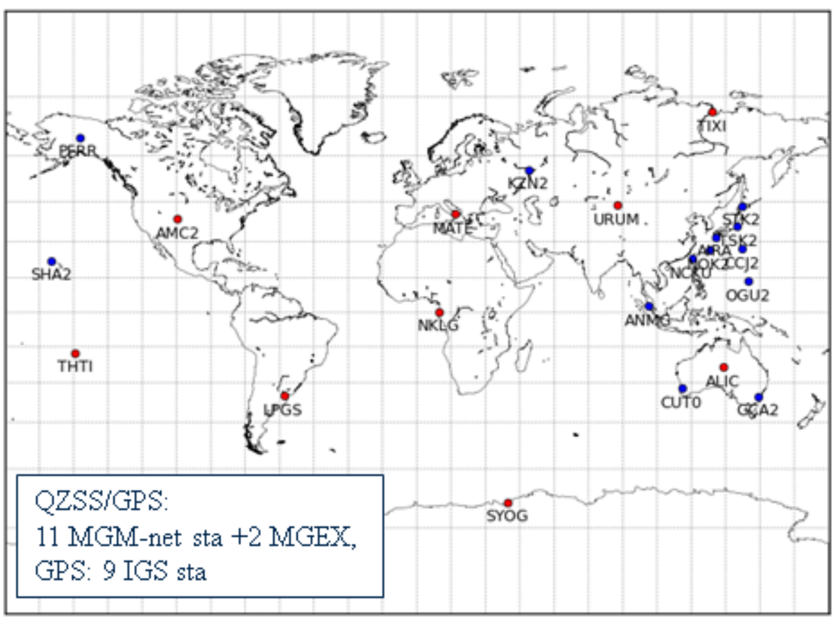


Figure 3. Map of Stations Used in MADOCA

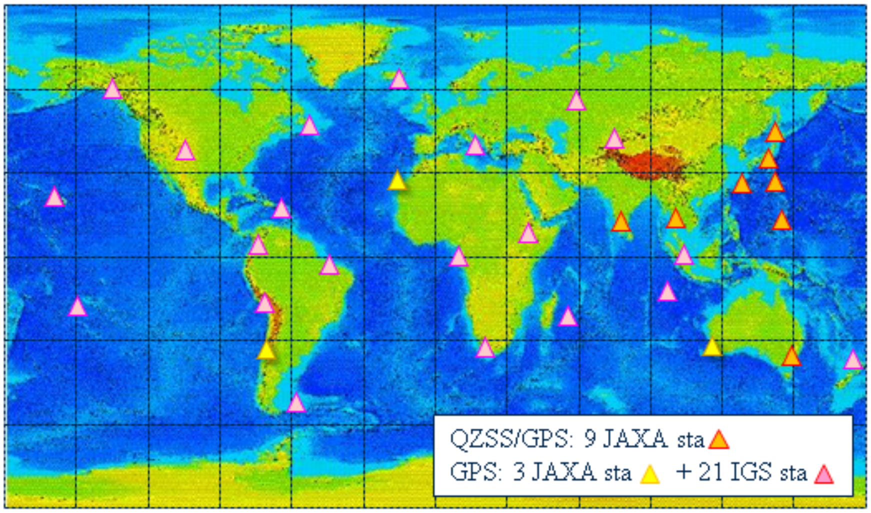


Figure 4. Map of Stations Used in Making QZF

Result

Tables 3 to 6 show the statistics of difference between ephemerides and Figure 5 shows the orbit differences of MAD and ESOC ephemeris against QZF ephemeris. As shown in these results, MAD ephemeris most closely matched with QZF ephemeris but seems to have around 30 cm biases in radial. ESOC ephemeris had periodic variations of one-day cycle in cross track (see Figure 5b). Therefore, orbit determination in cross direction might have low accuracy. QZF ephemeris closely matched with TUM and ESOC ephemeris in radial direction. Accordingly, it appeared that QZF is the definitive ephemeris at present.

Table 3. Mean Differences in Radial (m)

MEAN(R)	MAD	QZF	TUM	ESOC
MAD	-	0.290	0.279	0.326
QZF	-	-	-0.010	0.028
TUM	-	-	-	0.046
ESOC	-	-	-	-

Table 4. Mean Differences in Cross Track (m)

MEAN(C)	MAD	QZF	TUM	ESOC
MAD	-	0.005	-0.177	-0.119
QZF	-	-	-0.183	-0.136
TUM	-	-	-	0.058
ESOC	-	-	-	-

Table 5. Mean Differences in Along Track (m)

MEAN(A)	MAD	QZF	TUM	ESOC
MAD	-	0.020	-0.135	1.075
QZF	-	-	-0.172	0.854
TUM	-	-	-	1.209
ESOC	-	-	-	-

Table 6. Differences 3D-RMS (m)

3D-RMS	MAD	QZF	TUM	ESOC
MAD	-	0.386	0.685	1.492
QZF	-	-	0.663	1.026
TUM	-	-	-	1.689
ESOC	-	-	-	-

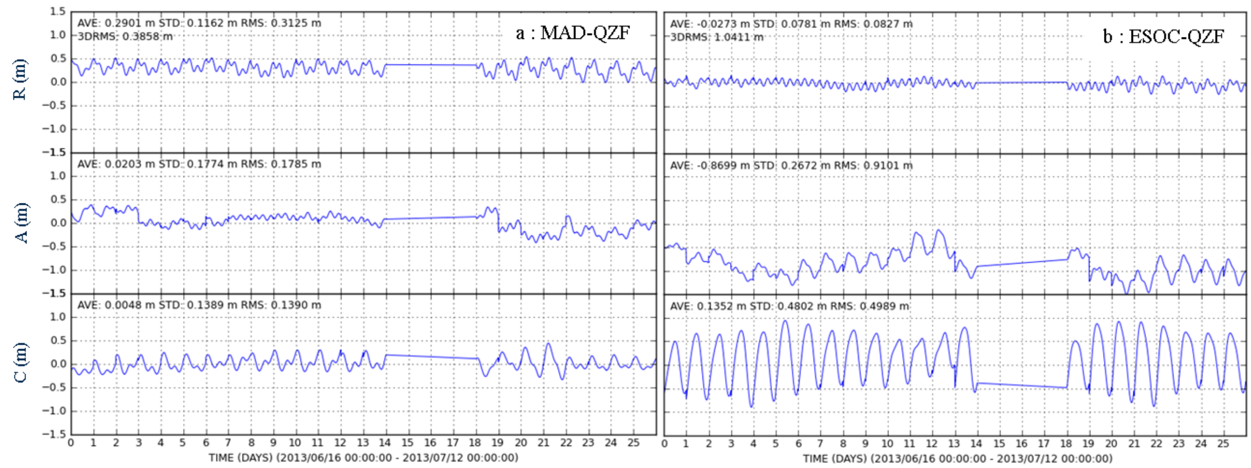


Figure 5. Orbit Differences (a : MAD-QZF, b : ESOC-QZF)

For the SLR residuals evaluation, SLR observation data in 7 stations as shown in Figure 6 were used. Figure 7 shows SLR residuals of each ephemeris. As shown in these results, MAD ephemeris had a large bias (30–40 cm). The other ephemerides (QZF, TUM, and ESOC) also had a bias but its magnitude was smaller than the one with MAD and they matched each other in radial.

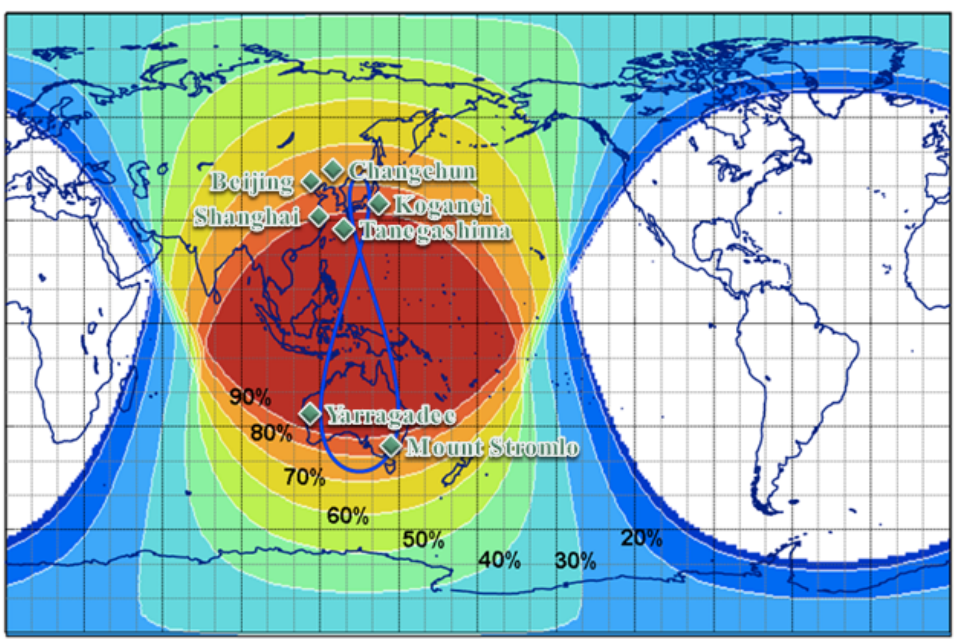


Figure 6. SLR Stations

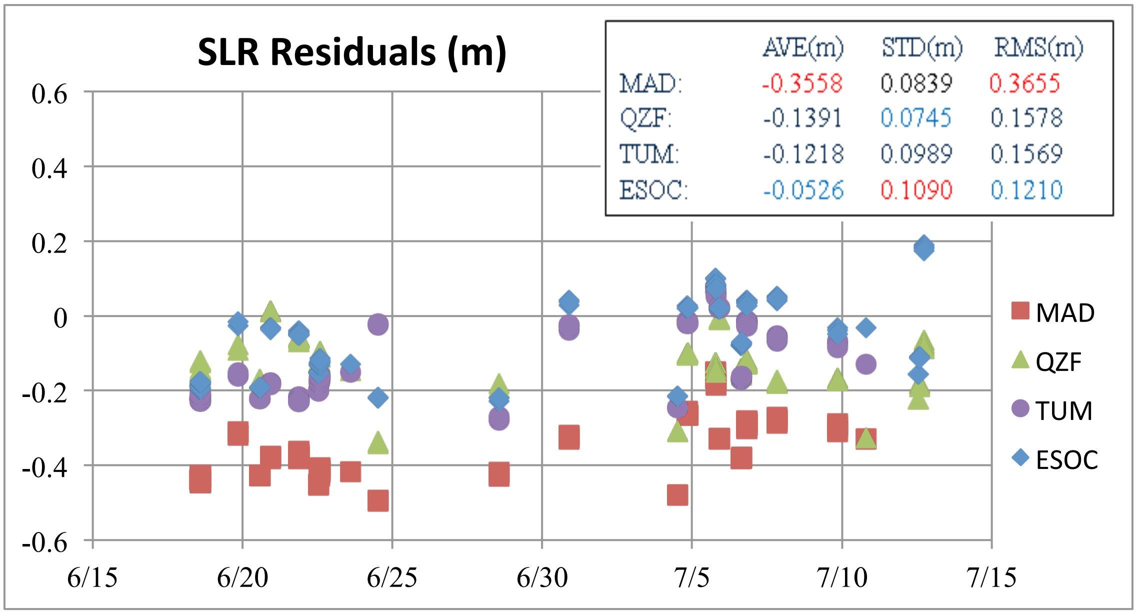


Figure 7. SLR Residuals (m)

Summary

SLR data allow reliable accuracy evaluations. This result indicates that ephemeris processed with MADOCA achieves the accuracy within 40 cm, and QZF ephemeris achieves the accuracy within 20 cm. MAD ephemeris, however, had a large bias in radial. There is a need to investigate this issue over a long term. The bias could be eliminated by reviewing parameters or models, thus leading to a further improvement in accuracy.

Acknowledgment

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Reference

[1] M. Miyoshi, S. Kogure, S. Nakamura, K. Kawate, H. Soga, Y. Hirahara, A. Yasuda and T. Takasu: The orbit and clock estimation result of GPS,GLONASS and QZSS by MADOCA, ISSFD, 2012.

[2] Y. Ishijima, N. Inaba, A. Matsumoto, K. Terada, H. Yonechi, H. Ebisutani, S. Ukawa, T. Okamoto, "Design and Development of the First Quasi-Zenith Satellite Attitude and Orbit Control System"