Satellite Laser Ranging Evaluation to Quasi-Zenith Satellite System

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Abstract

The Quasi-Zenith Satellite System (QZSS) that is operated by Japan (Cabinet Office(CAO)) is a regional satellite positioning system in Asia-Pacific region. The QZSS are constructed by Quasi-Zenith orbit (QZO) satellite, Geostationary orbit (GEO) satellite and grand station. Four satellites constellation(3-QZO, 1-GEO) was established in 2017, and the full operational service will be started in Nov.2018.

One of the most important feature of the QZSS is, it can be sending the positioning signal with fully compatible with US-GPS. The QZSS at high elevation angles reduces the multipath effect especially in near JAPAN Area. The service users can obtain to improve Dilution Of Precision (DOP) by mutual use with US-GPS and QZSS.

The QZS-1, which was launched on Sep. 2010 by Japan Aerospace Exploration Agency (JAXA), was transferred from JAXA to CAO on Mar. 2017 and the parameter tuning for precise orbit determination by the new ground control system was carried out by using the SLR tracking data.

Furthermore, the QZS-2, 3 and 4 were launched on June, August and October respectively in 2017, and the parameter tuning to improve the precise orbit determination was also carried out thanks to the SLR data.

This paper will show the feature of Japanese QZSS system and also the evaluation result of each QZS's ephemeris error with reference to the SLR tracking data after the four satellite constellation started.

1. Overview of the Quasi-Zenith Satellite System

The Quasi-Zenith Satellite System (QZSS: MICHIBIKI) are constructed four satellites. The Block I-Q (MICHIBIKI No.1) and Block II-Q (MICHIBIKI No.2 and No.4) are the QZO satellites. The QZO draw a eight (8)-sharped loops over Japan and Oceania region. The Block II-G is the GEO satellites. The orbital elements and orbit of each satellites are as figure 1. The MICHIBIKI No.1 is launched by JAXA in sep.11, 2010. After the checking system, alert flag was OFF in Jun. 2011. MICHBIKI No2 is launched in Jun.1, 2017. No. 3 is launched in Aug.19, 2017. No.4 is launched in Oct.10, 2017. After about three-months, each satellite was the alert off. We will be started the full operational service in Nov.2018.

The Satellite Positioning, Navigation & Timing Service (PNT) is one of QZSS services. The service to provide satellite positioning as same as US-GPS. PNT service realized high-elevation angle and reduced multipath. Fig.2 shows the QZSS elevation angle in Tokyo in the 2018. As you can see on this chart, at least 2-QZO satellites and one GEO satellite will always be visible in a relatively high elevation angle. By adding QZSS, the positioning and timing are improved the GNSS satellites allocate uniformly in the sky and the number of visible satellites increased. QZSS at high elevation angles reduces the multipath effect especially in Japan.

Fig. 1 Orbital elements and orbit of QZSS.

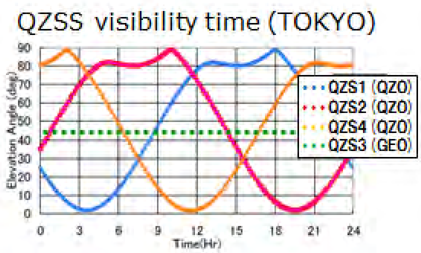

Fig.2 QZSS visibility time of Tokyo.

2. Improve orbit determination accuracy by SLR data

2.1 Tuning routine on QZSS operation

The QZSS carry out the parameter tuning for improvement of positioning accuracy. Fig.3 shows the flow of generation of positioning data and parameter tunings. In the master control station generate navigation products (Almanac and ephemeris and more), which are sent for QZS via uplink station. And each navigation data is broadcast for users from QZS. And, we carry out SRP (solar radiation pressure) parameter tuning for improvement on QZSS orbit determination accuracy. QZSS in the orbit are tracked by SLR tracking station (Fig.4: SLR visible stations for QZSS). We obtain SLR data from ILRS and carry out the Orbit estimation parameter tuning by SLR data. We carry out the parameter tunings every three months for each satellites.

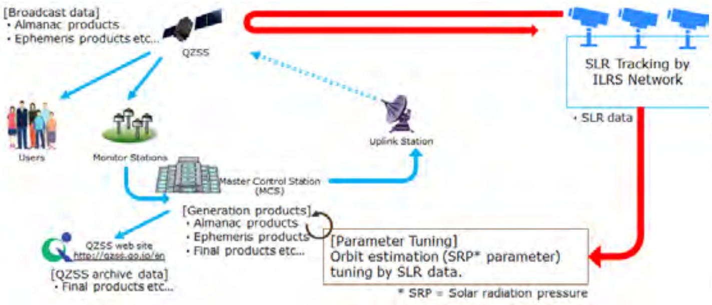

Fig.3 Tuning routine on QZSS operation

Fig.4 SLR visible station for QZSS

2.2 SRP parameter tunings for QZSS by SLR data

The solar radiation pressure is a kind of force models for satellites. This is key factor for precise orbit determination and estimation. Table.1 is the force models for satellite.

Table.1 Force models for satellite

Gravity	Geopotential, Third-Body potentials, etc...	It is not necessary to estimate the models. Can be applied the same models for satellites. (For example, DE430).
Non-gravity	SRP, Atomospheric Drag, etc...	It is necessary to estimate the model for each satellite (especially SRP).

Gravity models such as Geopential, Third-body potentials, are not necessary to estimate the models. Because It can be applied the same models for satellites. But Non-gravity models such as SRP are necessary to estimate the models for each satellites. Especially, SRP can have a major influence effect on orbit estimation. There are two types of SRP models for orbit determination. First, Analysis model. This model is calculate the model from the satellite shape. Secondly, Empirical model. Empirical model is adopted in QZSS. SRP model for QZSS, which is the empirical CODE orbit model (ECOM), is as follows:

$$a_{srp} = S \times (D(u)\boldsymbol{e}_D + Y(u)\boldsymbol{e}_Y + B(u)\boldsymbol{e}_B) \times 10^{-9}$$

$$D(u) = D_0 + D_c cosu + D_s sinu$$

$$\mathrm{Y}(u) = Y_0 + Y_c cosu + Y_s sinu$$

$$B(u) = B_0 + B_c cosu + B_s sinu$$

$$\mathrm{S} = F_{shadow} \times AU^2/|r - r_s|^2$$

F_shadow = Penumbra/umbra of earth/moon
AU = Astronomical unit

We should optimize these 9 parameters (Dx, Bx, Yx) for each satellites. Fig. 5 shows the determination flow of SRP coefficients. First, we obtain RINEX nav/obs by GNSS receiver. Next, our MCS's orbit estimation system generate orbit estimation data and SRP 9-parameters (It is a real-time). In the offline system, SRP fitting system determinate SRP 9-parameters. Input data is Orbit estimation data and SRP parameters (old) in QZSS system and SLR NPT data by ILRS. SRP fitting system can found the SRP parameter which minimize the residual error for the difference between the SP3-orbit and SLR data and orbit overlap (SP3 format) of successive generation. Especially, orbit and SLR residuals contribute to improve the orbit estimation accuracy. The system repeats the process and obtains the new SRP parameters.

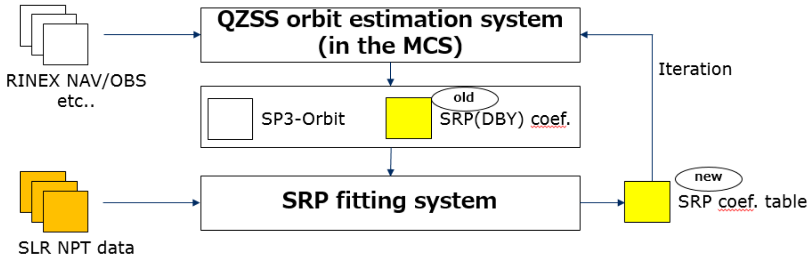

Fig.5 the determination flow of SRP coefficients

2.3 Result of SRP parameter tunings by SRP fitting

The adjustment result of the SRP parameter is shown in the fig. 6. Each graph are the off-line analysis results of the SLR residuals and orbit overlap accuracy of before tuning and after tunings for MICHIBKIKI No.2. Left figures are orbit estimation results of old SRP parameter. Right figures are orbit estimation results of new SRP parameter. This is after fitting results. Compared before tunings, SLR residual and orbit overlap improved accuracy of about 10cm rms. Fig.7 shows the accuracy evaluation of all QZS products (From No.1 to No.4) by SLR data. Fig.6, we shows MICHIBIKI No.2 results, we also optimize the MICHIBIKI No.4 in Fig.7. Result of No.2 and 4 carried out SRP parameter tunings over three months, we improved residual accuracy. We will carry out continuous tuning for Other QZS.

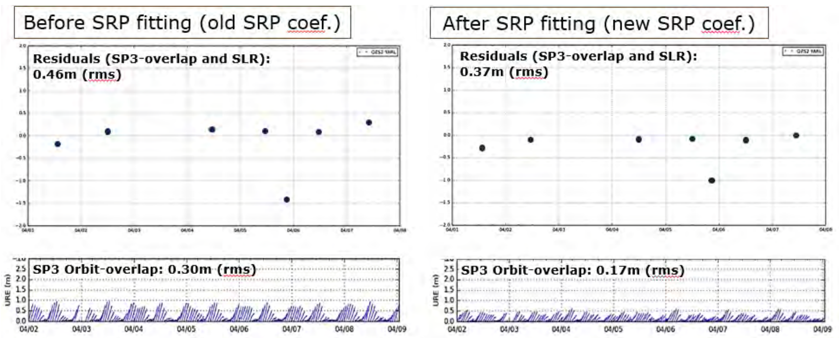

Fig.6 Result of SRP parameter fitting for MICHIBIKI No.2

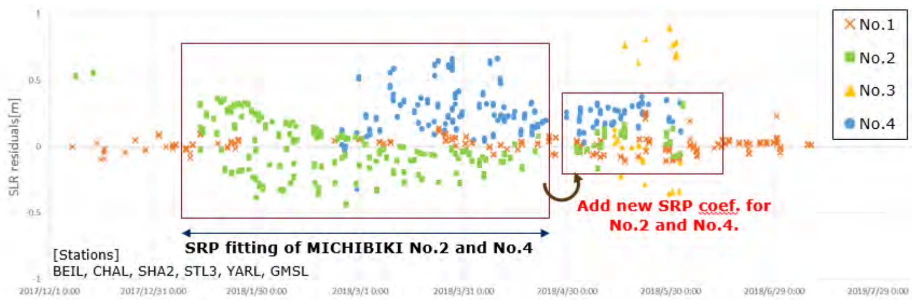

Fig.7 Orbit accuracy evaluation of all QZS products by SLR data

3. Conclusion

In this paper we introduced QZSS Overview and SRP parameter tuning. The three-points of summary for this paper as follows:

・ The QZSS are 4-satellites constellation system for satellite positioning services. QZSS achieved high-performance positioning results as GPS complemental system.

・ We optimize the SRP parameter (ECOM) for improvement on QZSS orbit determination accuracy. The evaluated results of SRP fittings by SLR data is quite a good result.

In the future plans of QZSS, From the November.1, 2018, 4-constellation QZSS are operating as Japanese regional navigation satellite system. Moreover, by the beginning of 2023, QZSS will be add 3-satellites. QZSS will be established 7-satellites constellation system in 2023.