様式２

参考配布

Impact of SLR tracking on QZSS

概要

国際レーザレンジング機構(ILRS)2009 年秋の Workshop が「SLR と測位衛星」をテーマとして開催される。JAXA も、かねてより ILRS の枠組みの中で準天頂衛星(QZS)への SLR 実施を依頼してきたため、この Workshop に対して資料を作成し、説明する義務が生じた。このたび、QZS の概要、SLR の必要性、搭載反射器の概要、SLR 運用の在り方等を整理した、ILRS 向けの資料を作成したので文書として制定するものである。

キーワード	SLR, QZS, ILRS, LRA

情報の区分						
■一般	□取扱指定	□社外 開示制限	□部外 開示制限	□秘	□極秘	□特殊 (TSS SSS SS)
	開示制限解除年月： 年 月					

配付先	ILRS	統合追跡 NW 技術部	準天頂プロジェクト
配付種類	正	正	参
部数	1	1	1

関連 QZS プロ	承認	点検	作成	技術資料番号	改訂符号
寺田 沢辺 野田 岸本 (続)	成田 H21・8・17	加 中村(續) 井上	中村信一 H21・8・11	QNX-090036	
				統合追跡 NW 技術部	

QNX-090036

Impact of SLR tracking on QZSS

Japan Aerospace Exploration Agency (JAXA)

Flight Dynamics Division

QZSS Project

August/2009

1 What is QZS (Quasi-Zenith Satellites)

1.1 Background

Recently, services using GPS, such as car navigation, mobile navigation, etc. have become essential for our life. Since Japanese geographical feature (mountains and tall buildings in urban areas) causes the interruption of satellite positioning or degradation of positioning accuracy, GPS is not useful in mountainous and urban areas, in which there is a strong requirement for using GPS. We suppose that there are many solutions to solve above-mentioned issues. One choice of the solutions is the QZSS (Quasi-Zenith Satellite System). At concept of the QZSS, there are more navigation satellites with high elevation angle.

1.2 Overview of QZSS

The Quasi-Zenith Satellite System (QZSS) is a regional space-based positioning system that uses a constellation of satellites placed in multiple orbital planes. The satellites have the same orbital period as a traditional equatorial geostationary orbit, however, they have a large orbital inclination and therefore have a dynamical ground track on the earth. The QZS orbits are also elliptical and are sometimes known as “highly-inclined elliptical orbits” or HEO. The system covers regions in East Asia and Oceania centering on Japan and is designed to enable users in the coverage area to receive QZS signals from a high elevation angle at any times.

The QZSS enhances GPS services in the following two ways:

1) Availability enhancement, that is, improving the availability of GPS signals,

and

2) Performance enhancement, that is, increasing the accuracy and reliability of GPS signals.

By broadcasting signals that are similar to and compatible with GPS, the QZSS enhances standalone GPS availability for any user that has visibility to, and can track one or more QZS. This enhancement will be the greatest for users in the region of Japan because the constellation design is optimized for that area. However, users in many other Asia-Pacific will also benefit from the enhanced geometric arrangement made possible by the QZSS. This increases the area and times at which positioning is possible in both urban and mountainous areas where a portion of the sky is often blocked from view.

To ensure interoperability and compatibility with the modernized GPS civil signals, GPS enhancement signals transmitted from QZS use modernized GPS civil signals as a base, transmitting the L1C/A, L1C, L2C and L5 signals. This minimizes changes to specifications and receiver designs.

The QZSS further improves standalone GPS accuracy by means of ranging correction data provided through the transmission of submeter-class performance enhancement signals L1-SAIF and LEX from QZS. It also improves reliability by means of failure monitoring and system health data notifications. The QZSS also provides other support data to users to improve GPS satellite acquisition. (see Appendix A)

The JAXA QZSS project will be implemented incrementally in accord with the official policy of the Government of Japan released on March 31, 2006 as follows.

- Phase One: The first QZSS satellite will be launched to conduct the technical validation and application demonstration:
- Phase Two: Following the successful completion of Phase One, the 2nd and 3rd QZSS satellites will be launched. Full system operation will be demonstrated.

1.3 QZSS System

The QZSS consists of

(a) the QZSS Space Segment (SS) comprised of a constellation of Quasi-Zenith Satellites (QZS) orbiting the Earth,

and

(b) the QZSS Ground Segment (GS) comprised of Monitoring Stations (MS), a Master Control Station (MCS), Tracking Control Stations (TCS) and Time Management Station (TMS). [Fig. 1.3-1]

QZS signals are transmitted from QZS and monitored by the MS. The MCS collects the MS monitoring results and estimates and predicts the QZS time and orbit. The MCS also gathers other data as well and generates navigation messages, and uplinks to QZS via the Tracking Control Station.

The Tracking Control Stations constantly monitor the status of QZS and function in cooperation with the MCS to provide appropriate services as needed. In addition, approximately once per year, the TCS exercise orbital control to ensure that QZS is maintained in the correct orbital position.

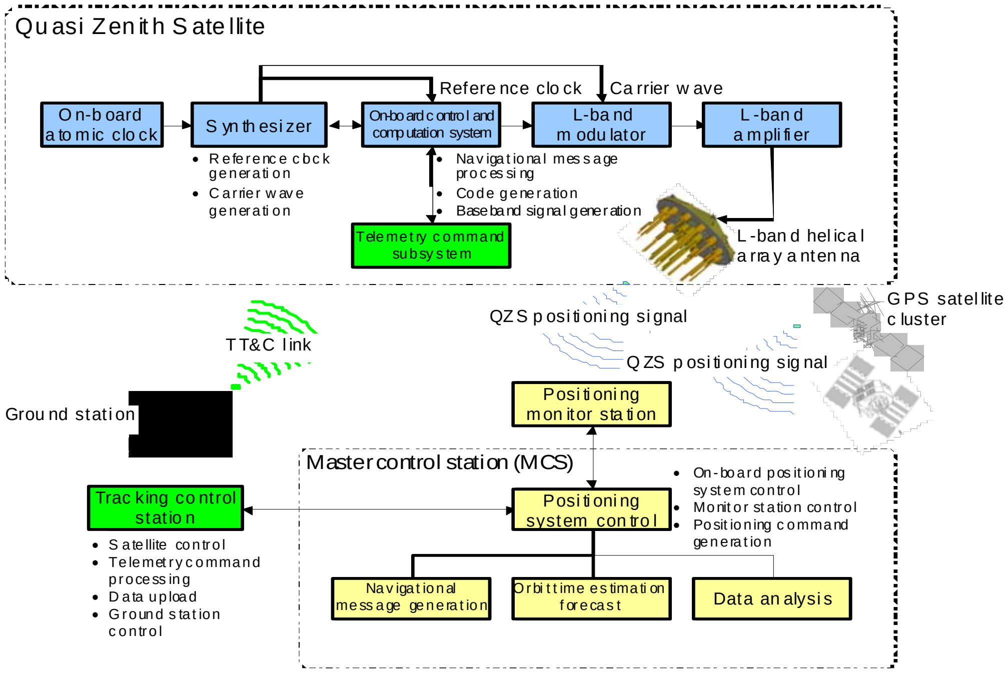


Fig.1.3-1 Configuration of the QZSS system

1.3.1 Space Segment

Space segment means Quasi-Zenith Satellite (QZS).

Three satellites are in elliptical and inclined orbits in different orbital planes to pass over the 8-shaped ground track. The QZSS is designed so that, at least, one satellite out of three satellites exists near zenith over Japan.

Navigation payload of QZS consists of (a) the rubidium Atomic frequency standard (RAFS), (b) the L-band signal transmission subsystem (LTS), (c) the time transfer subsystem (TTS), and (d) the laser reflector array (LRA).

Functions of navigation payload are defined by reception of the navigation message from the satellite, generation and transmission of the navigation signals, generation and transmission of the time comparison signals to ground stations, and laser reflection for laser ranging.

1.3.2 Ground Segment

Ground segment means Master Control Station(MCS), Monitoring Stations (MSs) and satellite tracking and control system.

1.3.2.1 Master Control Stations (MCS)

MCS is developed at Tsukuba Space Center in Japan. The role of MCS is defined by determination and prediction of QZS's orbit and timing, planning of the Navigation experiment and Control of the navigation system, generation and upload of navigation message, judgment and notification of the integrity, evaluation and analysis of navigation data, and data recording and distribution.

1.3.2.2 Monitor Stations (MSs)

Ten MSs are developed at the area according to QZS visibility. [Fig. 1.3-2]

MSs receive signal data from QZS and GPS, and acquire the environmental data like weather data. Observed data is transmitted to the MCS in JAXA Tsukuba Space Center.

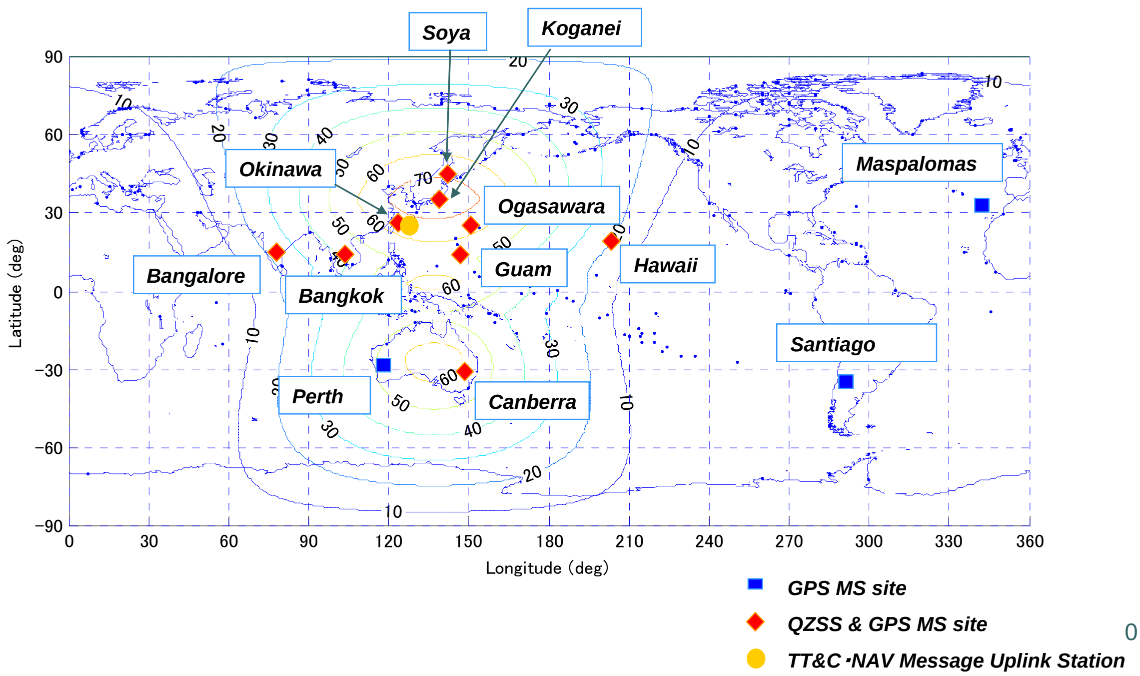


Figure 1.3-2　Location of MSs

1.4 Orbit Information

Typical orbital elements are shown in Table 1.4. Three satellites are in elliptical and inclined orbits in different orbital planes to pass over the same ground track. The QZSS is designed so that at least one satellite out of three satellites exists near zenith over Japan [Fig. 1.4-1].

Table 1.4 Orbit during QZS operation

Semimajor Axis (a)	Eccentricity (e)	Inclination (i)	RAAN (Ω)	Argument of Perigee (ω)	Center Longitude
42164.17km (average)	0.075 +/- 0.015	43 deg +/-4 deg	NA	270 deg +/-2 deg	135 degE +/- 5 deg

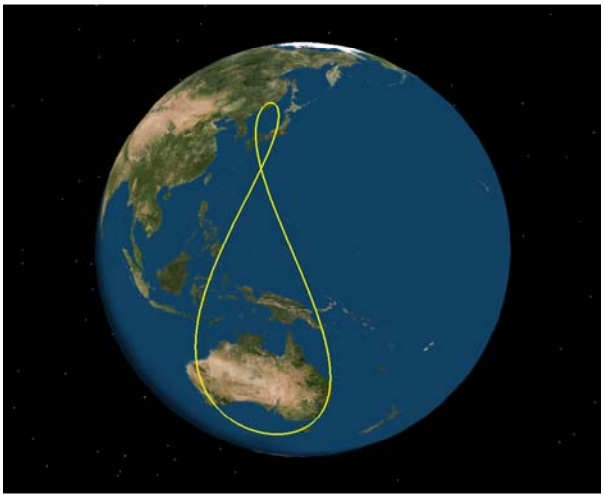
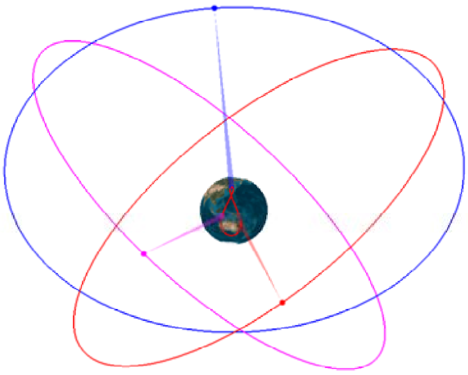



Fig. 1.4-1 Image of ground track (left) and orbital planes (right) of QZS.

1.5 QZSS Service

1.5.1 QZS Service Objectives

Since the QZSS can provide a seamless service from high elevation angle, we expect that the availability of PNT (positioning, navigation and timing) services in urban and mountainous areas will be increased. The QZSS enhances GPS services in the following two ways: 1) Availability enhancement (improving the availability of GPS signals) and 2) Performance enhancement (increasing the accuracy and reliability of GPS signals).

1.5.2 QZSS Service Area

The following figures show the availability (the percentage of time during which the specified minimum elevation angle condition is fulfilled) of a single QZS across the surface of the Earth due to the QZSS constellation. For the 3-satellite QZSS constellation, at least one QZS is available 100% of the time not only in Japan but in almost all parts of Southeast Asia and Oceania at an elevation angle of 10° or more. In Japan, at least one QZS is available 100% of the time at an elevation angle of 60 degrees or more (see Figs. 1.5.2-1 and 1.5.2-2).

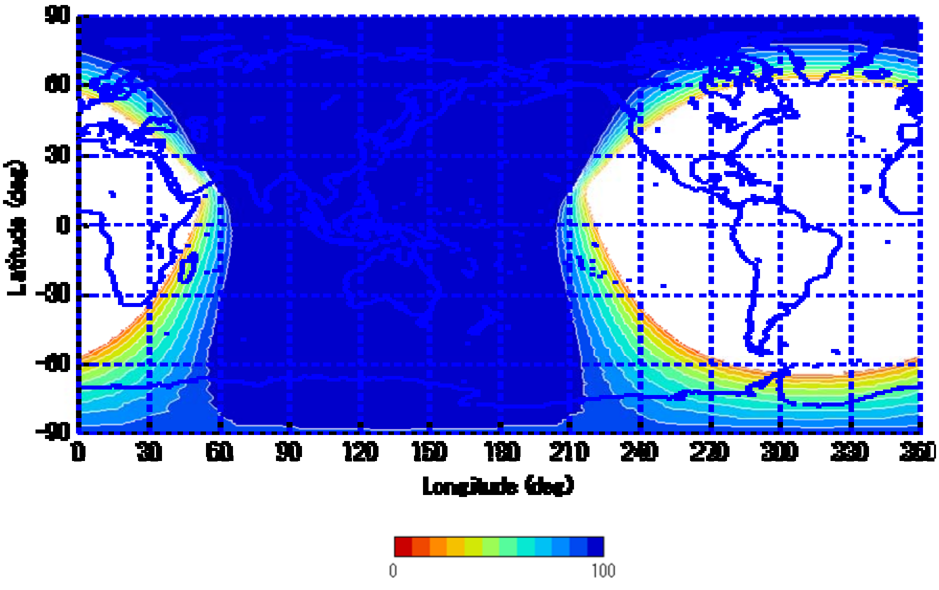


Figure 1.5.2-1: Percentage of time during which at least one QZS in the 3-satellite QZSS constellation can be seen at an elevation angle of 10° or more

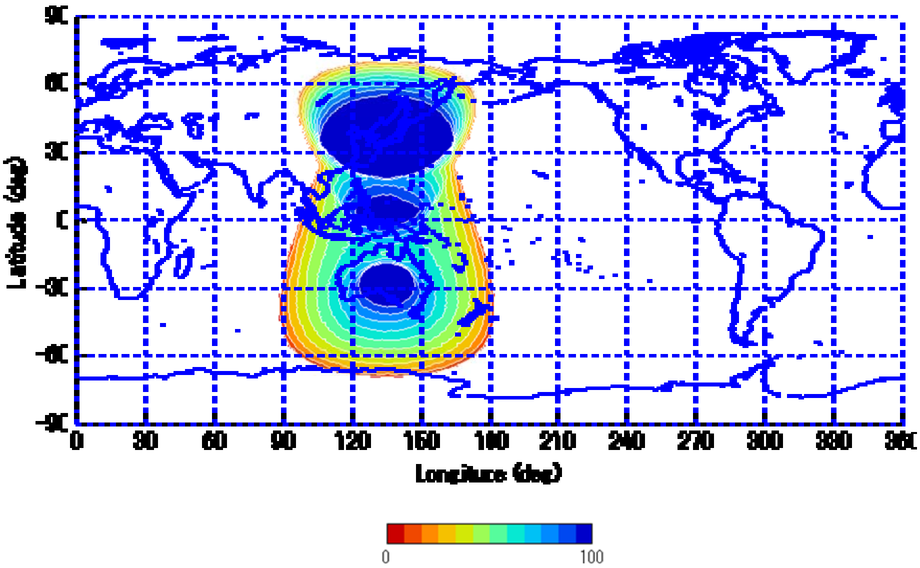
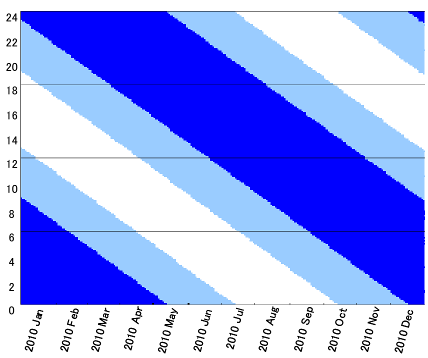


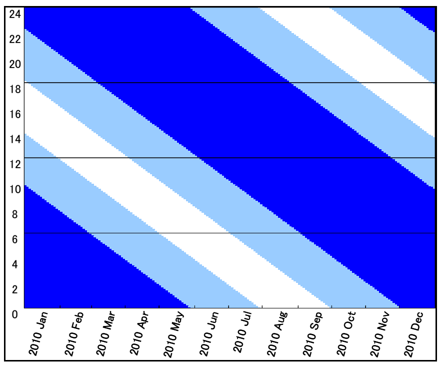
Figure 1.5.2-2: Percentage of time during which at least one QZS in the 3-satellite QZSS constellation can be seen at an elevation angle of 60° or more

1.5.3 Service Time / Interval

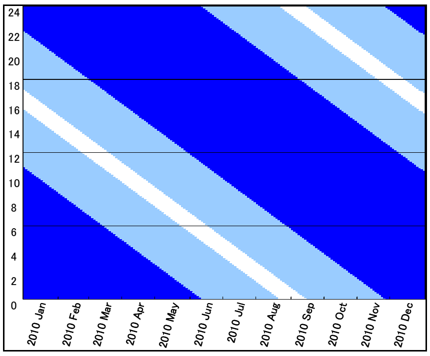
Each QZS transmits positioning signals 24 hours a day, 365 days a year. However, the time of day during which a particular QZS is visible to a given location varies with the date. This can be seen in following figure which shows the QZS visibility time bands for eight reference locations [Fig. 1.5.3].



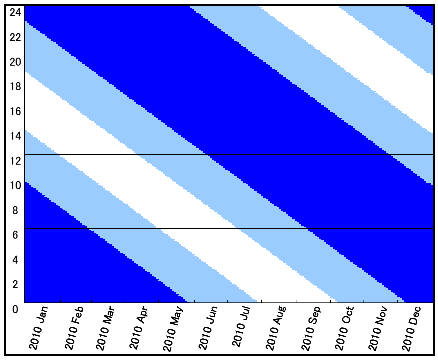
Wakkanai (Hokkaido, Japan)



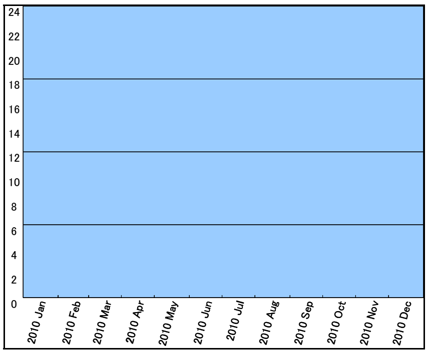
Tokyo



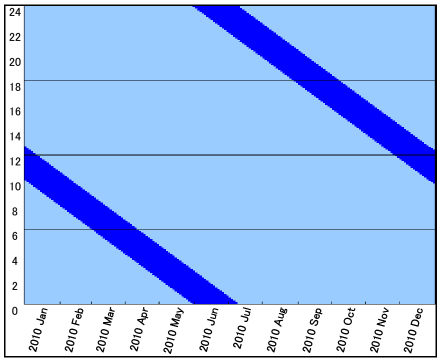
Okinawa



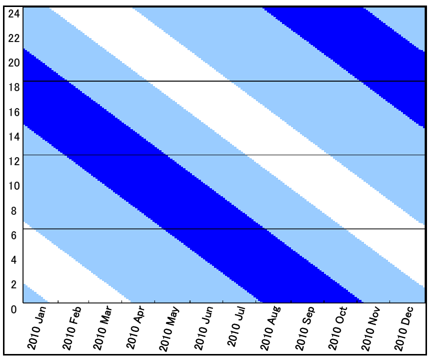
Seoul



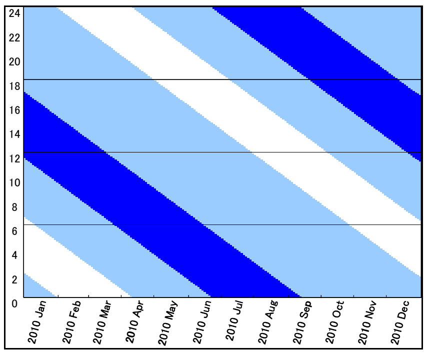
Bangkok



Singapore



Sydney



Perth

Figure 1.5.3: Initial Single-satellite QZSS visibility time for eight reference locations (dark shaded areas represent elevation angles of 60° or more; light blue areas represent elevation angles of 10° to 60°; vertical scale is hours)

1.5.4 Accuracy

The Signal-in-Space (SIS) accuracy is less than 1.6 m (95%) for all GPS interoperable signals. Horizontal positioning accuracy using GPS interoperable signals of QZS and combination with the GPS signals [Table 1.5.4].

Table 1.5.4 List of Accuracy

Positioning accuracy (95%)	Note
Single frequency: 21.9 m	Single frequency (User Ranging Error: 7.3 m)
Dual frequency: 7.5 m	Dual frequency (User Ranging Error: 2.5 m))

1.6 Schedule of QZS

The QZSS will be developed in a step by step manner.

1st step: Launch the 1st QZS and accomplish technical validation and application demonstration. Now, 1st QZS (QZS-1) will be launched in 2010.

2nd step: Launch the 2nd and 3rd QZS several years later and demonstrate system operation.

1.7 Anticipated Launch Date

Summer/2010 (TBD)

1.8 Expected Mission Duration

10 years or more

2 Letro reflector Array (LRA) on QZS s/c

2.1 Detail of Array

Appearance of QZS's LRA is given in Figure 2.1.

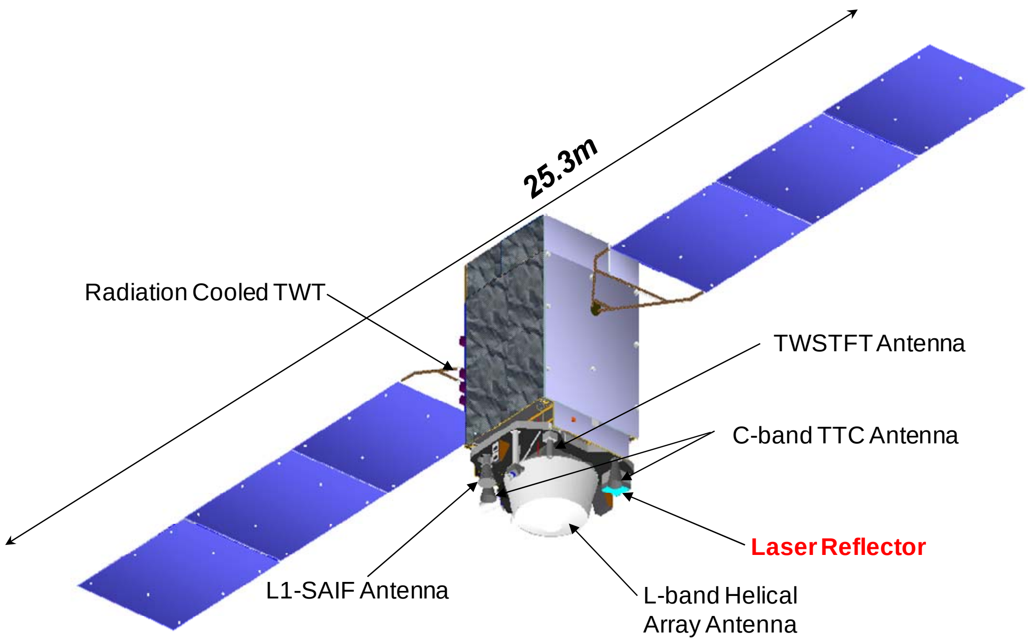
- planar type
- 56 CCRs (7rows * 8 lines)
- Diameter of each cube is 1.6 inch.

Fig. 2.1 Appearance of QZS's LRA

2.2 Details of Cube

- Suprasil
- index of refraction 1.46
- Dihedral Angle 0.8 arcsec
- Non coating

2.3 Location of LRA on QZS s/c



Satellite Configuration on Orbit

LRA is located at the bottom of satellite body. LRA always faces to the earth.

Specific position (x,y,z) relative to center of gravity will be provided.

2.4 Link Analysis

Before considering the link analysis, it is useful to use an analogy of ETS-8 tracking.

At first, we reviewed the ETS-8, which is gestational satellite located at 146 deg longitude, and its LRA. ETS-8 had mounted similar LRA to QZS, however, some properties were different from those of QZS. The following tables (Table 2.4-1 and 2.4-2) summarize the difference and common properties between LRA of ETS-8 and that of QZS.

Table 2.4-1 Difference between QZS LRA and ETS-8 LRA

	Number of CCR	Dihedral Angle
ETS-8	36	0.5 arcsec
QZS	56	0.8 arcsec

Table 2.4-2 Common properties between QZS LRA and ETS-8 LRA

	Shape	Diameter of CCR	Coat/Non Coat	Materials	Ref Index
ETS-8/QZS	Circle	1.6 in	Non coating	Sprasil	1.46

Tanegashima, Koganei, Yaragadee, Changchun, and Mt. Stromlo are success fully tracking for ETS-8. [Note that ETS-8 located 146 deg East longitude]

Tracking results is shown in Table 2.4-3.

Table 2.4-3 Summary of ETS-8 Tracking

Station Name	Return Rate	Note
Tanegashima	5% to 15 %	250mJ laser, 10Hz fire
Koganei	typically 1 %	50mJ laser, 20Hz fire
Yaragadee	1% to 3 %	100mJ laser, 5Hz fire
Changchun	0.1% to 1 %	150mJ laser, 20Hz
Mt. Stromlo	0.1 % to 1%	21mJ laser, 60Hz

Here, we pay attention to the expected return rate from QZS. At tracking QZS, compared to ETS-8, there is a big difference in the range between SLR station and satellite. According to the inverse fourth power of range, it shows a decrease in the number of expected return photoelectron.

Calculation result of the maximum slant range from each SLR station is shown in the following table. Here, JAXA calculated maximum slant range from each SLR stations.

Table 2.4-4 Some properties for ETS-8 tracking

	Maximum Slant Range of QZS	Elv	Slant Range of ETS-8	QZS/ETS8
Yarragadee	41,872.12 km	20	37,804.4 km	1.107
Mt. Stromlo	41,590.77 km	20	37,228.7 km	1.117
Tanegashima	39,146.86 km	75	37,138.6 km	1.054
Koganei	38,906.96 km	80	37,294.8 km	1.043

Slant range is about 10% longer than ETS-8 case at Yarragadee and Mt. Stromlo.

If we need similar return signal photoelectrons from QZS at Yarragadee and Mt. Stromlo during low elevation, we need bigger LRA.

LRA on ETS-8 consists of 36 cubes (6*6 array). Here, JAXA calculated equivalent LR of ETS8 for QZS. At first, I estimated necessary cube number for QZS,

$$N = 36 \times \left(\frac{11}{10}\right)^4 = 52.7\,.$$

On the above calculation, SLR link equation depends on slant range as $1/r^4$ =0.683

During our discussion, JAXA ignores effect of cirrus. This cirrus effects strongly on low elevation. Considering cirrus effect, QZS needs large LRA, which has, at least, 53 cubes

(7*8 array is better).

In order to compensate the decrease by long range, QZS LRA has bigger reflective area than ETS-8, that is, (56/36)=1.56 times.

Comparing with ETS-8 case, expected return photoelectron is changes 0.683*1.56=1.065 times without considering atmospheric absorption.

As a result, apart form decreasing effect by atmosphere absorption, we expect the similar return rate to ETS-8 in spite of longest range (lowest elevation). Even at higher elevation, we expected higher return rate than ETS-8.

Here, expected return rate from QZS is shown in Figs. 2.4-1 and 2.4-2. In both Figures, observed return rate from ETS-8 is shown by arrow.

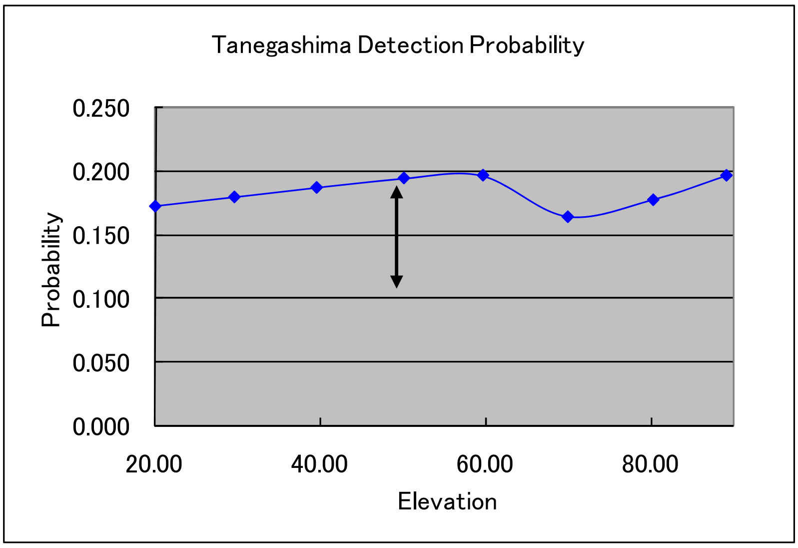


Fig.2.4-1 Expected Return rate at Tanegashima

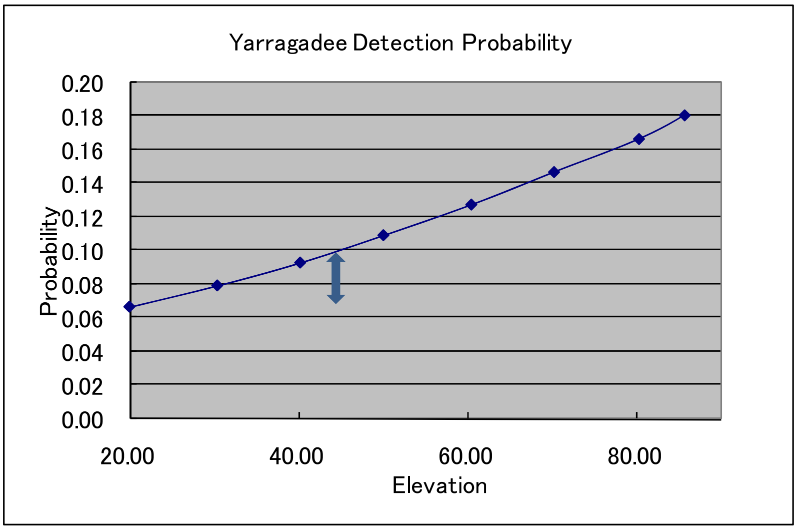


Fig.2.4-2 Expected Return rate at Yaragadee

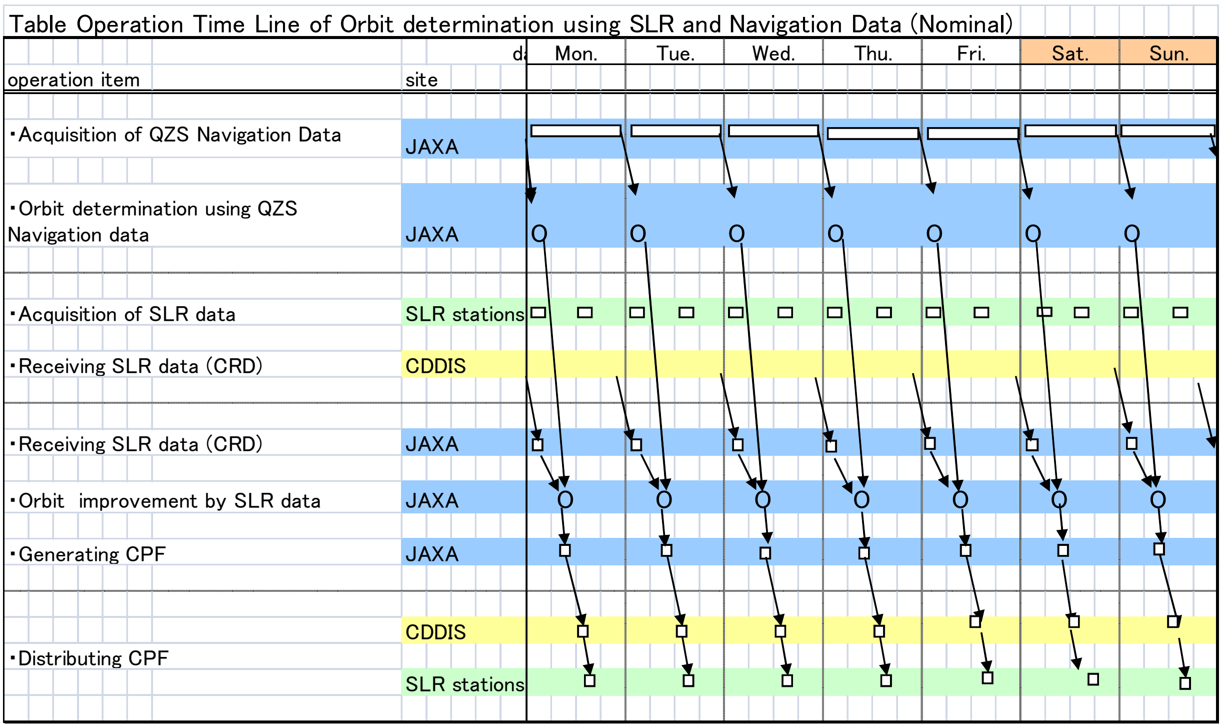
3 SLR Tracking and QZS Operations

3.1 General Information for Precise Orbit Determination of QZS

During QZS operations, JAXA uploads the ephemeris periodically [Table 3.1]. The ephemeris is calculated by real-time QZS navigation data which is observed at 10 monitor stations (see 1.3.2.2).

As for the SLR operations, orbit determination is performed on daily basis. Operational time line is shown in the following table. Using daily QZS navigation data from 10 monitoring stations, orbit determination is performed every morning. Also, JAXA downloads SLR observational data (CRD) from CDDIS on daily basis. At JAXA, orbit improvement is performed by combining SLR data to QZS navigation data. After orbit improvement, JAXA calculates the SLR prediction file (CPF) and distributes it via CDDIS server.

Table 3.1 Timeline of SLR operation



3.2 Satellite Laser Ranging Role of Mission

SLR tracking plays an important role in QZS mission, that is, precise orbit determination for QZS. In order to contribute to geodesy and earth science, JAXA distributes precise orbit of QZS (QZS final orbit), which is similar to the final orbit of GPS. In order to calculate QZS final orbit, JAXA needs to determine QZS clock bias and orbit simultaneously. As well known, since SLR data helps to eliminate the error (bias) from observed data, JAXA estimates QZS final orbit with high accuracy.

3.3 Tracking Schedule

JAXA hopes 2 stages tracking;

- 1st stage (Campaign):

  Purpose : confirmation of precise orbit determination, clock estimation, estimation of bias for each monitor station, QZS checkout

  Priority : High such as GIOVE-A campaign

  Frequency : in-orbit initial phase, checkout phase for satellite performance, ground system performance and every 6 months

  Core Time: For example, 0:00-0:15, 4:00-4:15, 8:00-8:15, 12:00-12:15, 16:00-16:15, 20:00-20:15 (UT).

- 2nd stage (Nominal Operation):

  Purpose : increasing orbit determination accuracy of ordinary operation

  Priority : low such as GPS35,36, Glonass, GIOVE-A

  Frequency : all day, but we hope core time ; For Example, 9:00-9:15, 12:00-12:15, 15:00-15:15 (UT)

Tracking information will be notified to all SLR stations by web and/or SLR-mail. Tracking prediction file (CPF) will be distributed by CDDIS server.

3.4 Success Criteria

- 1st stage (Campaign)

As success criteria, the accuracy of orbit determination, accuracy of clock estimation, and bias for each monitor stations during 1st stage should be preformed only by SLR data.

Precise orbit determination have to be performed only by SLR data for long arc, such as 1 day arc.

- 2nd stage (Nominal Operation)

In order to distribute reliable QZS final orbit/clock, it is better to add SLR data on QZS navigation data.

However, since accuracy validation is performed at 1st stage tracking, it is not always necessary to obtain SLR tracking data from ILRS western pacific ocean network. But, at least, JAXA Tanegashima SLR station always tracks QZSS.

As success criteria, SLR data acquisition is frequently done.

3.5 Spatial Coverage

Only Around Western Pacific Ocean. Visible Area from Tanegashima and Yarragadee SLR stations are shown in Figs. 3.5-1 and 3.5.2, respectively. In this figures, minimum elevation angle is set to 20 degree.

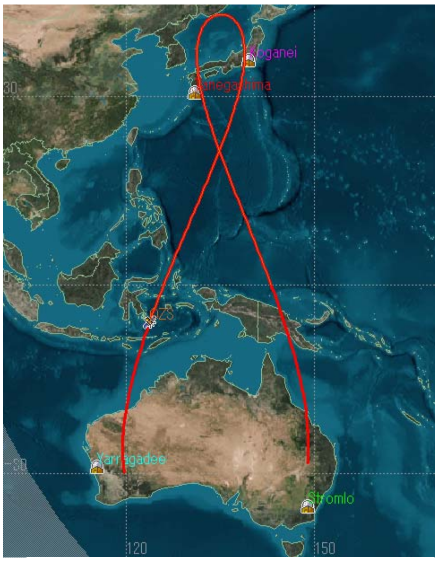


Fig.3.5-1 Visible Area from Tanegashima

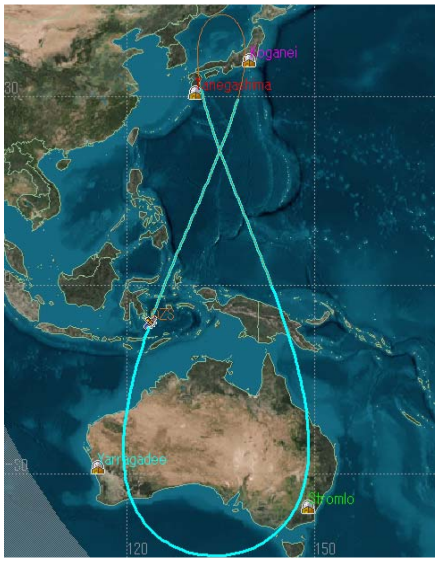


Fig. 3.5-2 Visible Area from Yarragadee

3.6 Temporal Coverage

At any time,

However, in order to grow in efficiency of precise orbit determination process, JAXA hopes to make core time of tracking, for example, 9:00-9:15 (UT), 12:00-12:15(UT), and 15:00-15:15 (UT).

3.7 Data Accuracy

Millimeter to Centimeter ranging accuracy

3.8 Data Delivery Time Requirements

Sub-Daily to CDDIS and/or EDC on Nominal Operation

4 Conclusion

JAXA summarizes the impact of SLR tracking on QZSS, which is the main title of this document.

4.1 For Global Navigation System around Western Pacific Ocean

In order to distribute reliable QZS final orbit/clock, it is better to add SLR data on QZS navigation data. At this process, SLR data plays an important role. Since SLR data is quite high accurate, we can decouple the ambiguity between range bias and time bias. Thus, introducing SLR data, the accuracy of QZS final orbit/clock can be significantly improved.

4.1.1 For SLR stations and ILRS tracking network

JAXA hopes to get support of ILRS western pacific ocean network tracking.

- At 1st stage (campaign)

  Enough SLR data is needed to perform precise orbit determination only by SLR data.

  Core Time Tracking : 0:00-0:15, 4:00-4:15, 8:00-8:15, 12:00-12:15, 16:00-16:15, 20:00-20:15 (UT).

  Candidate SLR stations : ILRS western pacific ocean

- At 2nd stage (nominal operation)

  In order to improve accuracy of final QZS orbit/clock, SLR data is needed. However, it is not always necessary to get SLR data.

  Core Time Tracking : For Example, 9:00-9:15, 12:00-12:15, 15:00-15:15 (UT)

  Candidate SLR stations : ILRS western pacific ocean.

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Appendix A

As references, QZS broadcast some signals as followings;

Signal name	I/Q channel identification	Center frequency	Frequency Bandwidth	Received Minimum Power Level*	
L1C/A	$L1_{CA}$	1575.42 MHz	24 MHz (±12 MHz)	-158.5 dBW	
L1C	$L1_{CD}$		24 MHz (±12 MHz)	-163.0 dBW	-157.0 dBW (Total)
	$L1_{CP}$			-158.25 dBW	
L1-SAIF*	-		24 MHz (±12 MHz)	-161.0 dBW	
L2C	-	1227.60 MHz	24 MHz (±12 MHz)	-160.0 dBW (total)	
L5	$L5_I$	1176.45 MHz	25 MHz (±12.5 MHz)	-157.9 dBW	-154.9 dBW (Total)
	$L5_Q$		25 MHz (±12.5 MHz)	-157.9 dBW	
LEX	-	1278.75 MHz	42 MHz (±21.0 MHz)	-155.7 dBW (total)	

* L1-SAIF: L1-Submeter-class Augmentation with Integrity Function