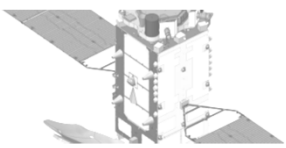
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The latest status of Quasi-Zenith Satellite System (QZSS) and its future expansion


ION GNSS+ 2019 on Sep. 18, 2019 @Miami, Florida

Takeyasu Sakai
National Institute of Maritime, Port and Aviation Technology, Japan


Satoshi Kogure
Cabinet Office, Government of Japan



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1. QZSS Overview
2. Recent Evaluation Results
 - ◆ *Official Services*
 - ◆ *Expected Services*
3. Expansion to 7-SV Constellation
4. International Collaborations
5. Summary

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1. QZSS Overview

QZSS Overview -System-

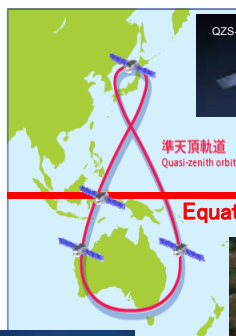


■ Constellation:

- 1 GEO Satellite, 127E
- 3 QZO Satellite (IGSO)

■ Ground System

- 2 Master Control Stations
 - Hitachi-Ota and Kobe
- 7 Satellite TTC Stations
 - Located south-western islands
- Over 30 Monitor Stations around the world



QZSS Overview -Services-

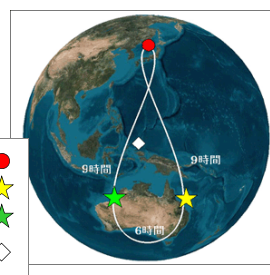
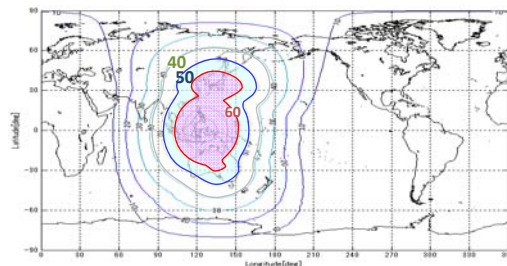
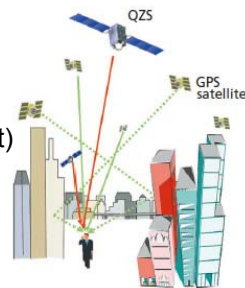


■ Functional Capability:

- PNT Service (GPS complementary ranging signals)
- Augmentation Service (GNSS error corrections)
- Messaging Service (EWS and disaster management)

■ Coverage: Asia and Pacific Region

- Augmentation service covers only Japan
 - Experimental service provides error corrections in Asia Pacific region



- QZSS-1 ●
- QZSS-2 ★
- QZSS-4 ★
- QZSS-3 (127E) ◇

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QZSS Overview -Services-



Functional Capability 1 PNT Service

QZSS improves positioning availability

- Navigation signals L1-C/A, L1C, L2C, and L5 coming from high elevation (near zenith) improve PNT availability.
- QZSS is the first L1C and L5 signals provider offering interoperability among other GNSS.
- SIS-URE: 2.6m (95%)



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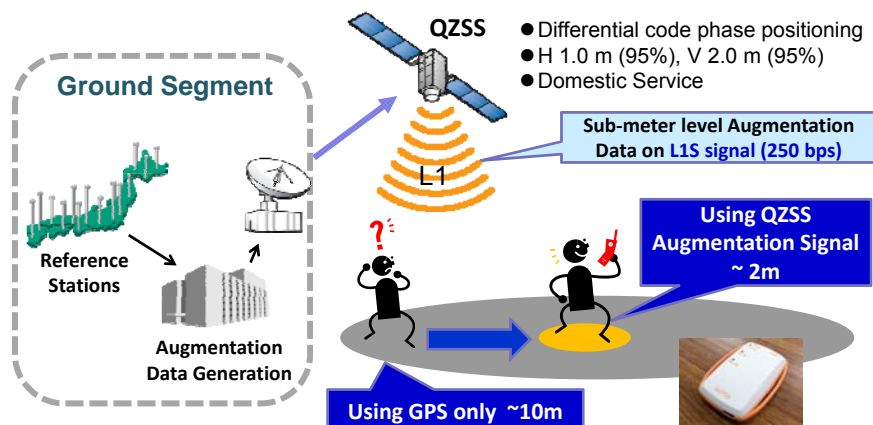
5

QZSS Overview -Services-



Functional Capability 2 Augmentation Service

Sub-meter Level Augmentation Service: SLAS



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✓ Plus Standard SBAS Service from 2020

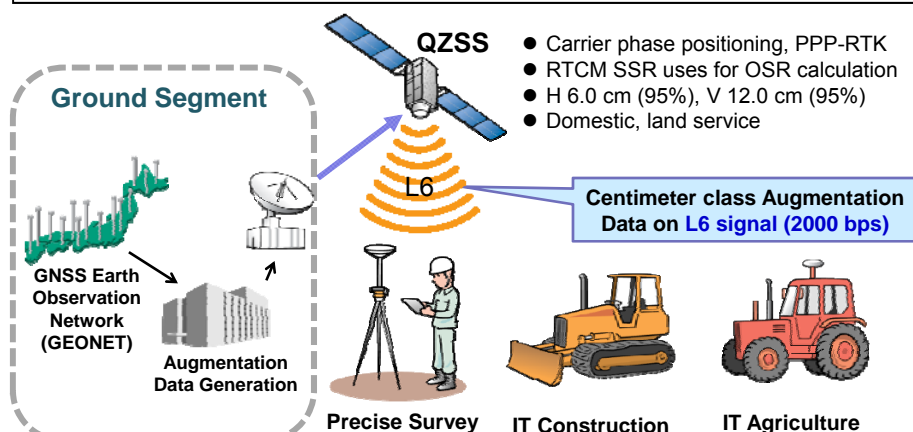
6

QZSS Overview -Services-



Functional Capability 2 GNSS Augmentation Service

Centimeter Level Augmentation Service: CLAS



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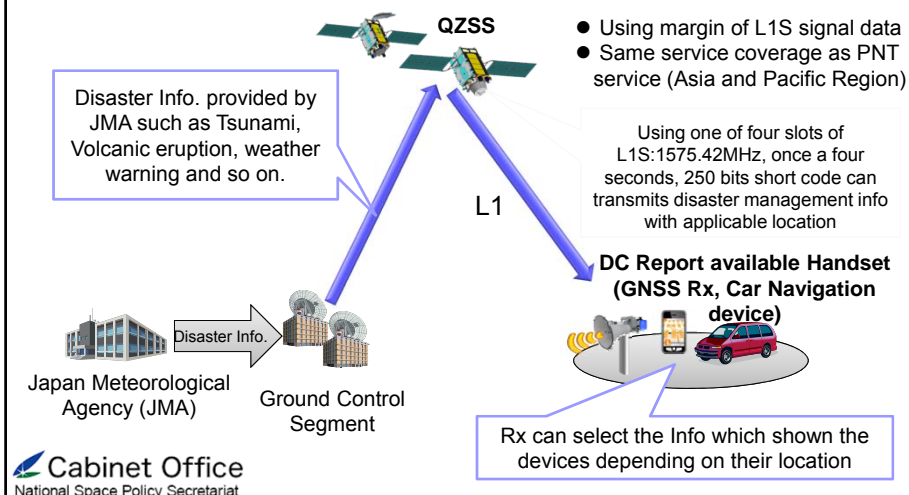
7

QZSS Overview -Services-



Functional Capability 3 Messaging Service

Satellite Report for Disaster and Crisis Management (DC Report)

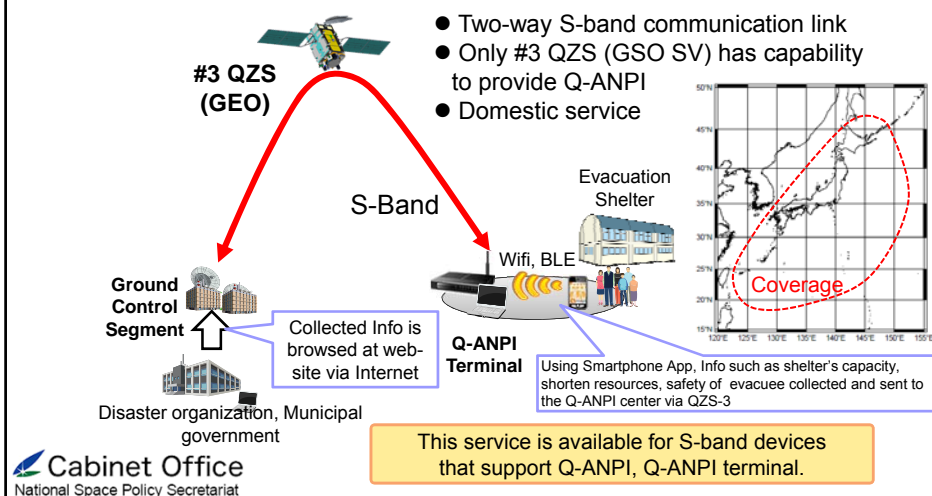


QZSS Overview -Services-




Functional Capability 3 Messaging Service

QZSS Safety Confirmation Service (Q-ANPI)




QZSS Overview -Signals-

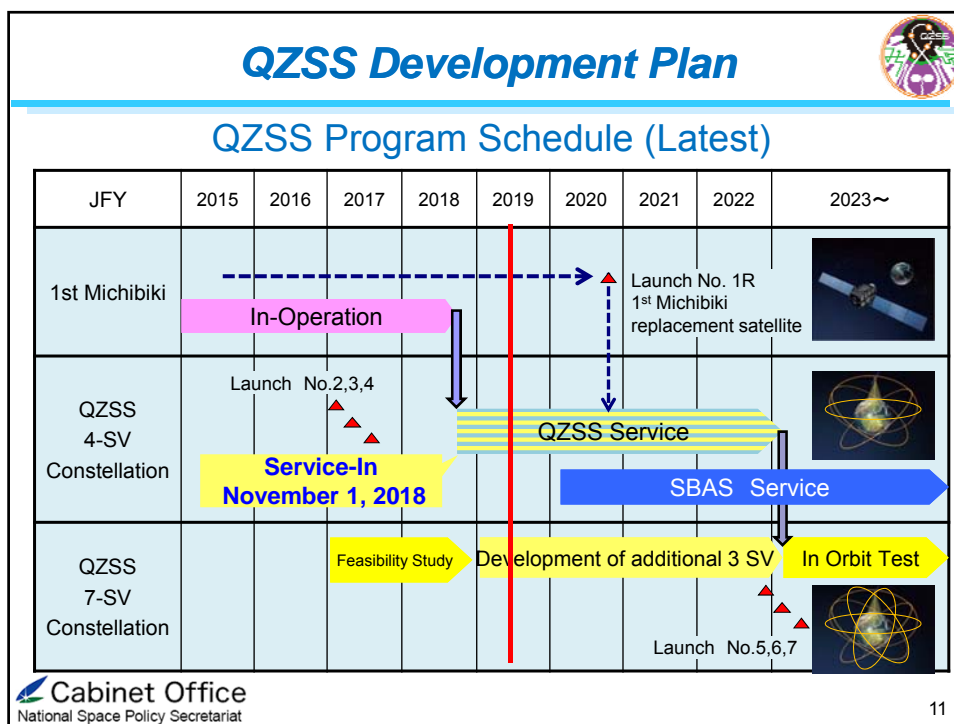


Ranging Signals of QZSS

Signal	Frequency MHz	Service	Contents	QZS-1	QZS-2/4	QZS-3
				IGSO	IGSO	GEO
L1C/A	1575.42	PNT	Ranging	✓	✓	✓
L1C		PNT	Ranging	✓	✓	✓
L1S		Augmentation (SLAS)	DGPS (Code Phase Positioning)	✓	✓	✓
		Messaging	DC Report	✓	✓	✓
L1Sb		Augmentation (SBAS)	SBAS (L1) Service	-	-	✓
L2C	1227.60	PNT	Ranging	✓	✓	✓
L5 I/Q	1176.45	PNT	Ranging	✓	✓	✓
L5S		Experimental (L5 SBAS)	L5 SBAS (DFMC)	-	✓	✓
L6D	1278.75	Augmentation (CLAS)	PPP-RTK (Carrier Phase Positioning)	✓	✓	✓
L6E		Experimental (MADOCA)	PPP, PPP-AR (Carrier Phase Positioning)	-	✓	✓

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Latest Status of QZSS Service Provision and Future Expansion



Official Service Launch

- On November 1st 2018, Prime Minister Shinzo Abe attended the ceremony to commemorate the launch of QZSS Service.



Latest status for the next generation system deployment

- The procurement process for QZS-5, 6, and 7 has started in 2018.
- The contract for update of ground control segment will follow soon.

Contents

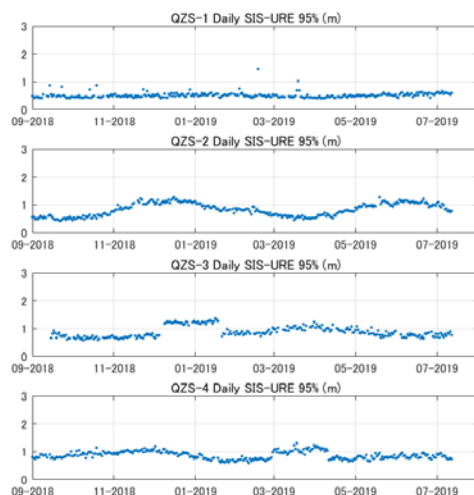


2. Recent Evaluation Results *Official Services*

QZSS Performance -PNT Service-



Performance (SIS Accuracy)



[Evaluation Period]

2018/09/01 ~ 2019/07/12

[Evaluation Results]

Specification: Less than 2.6 m (95%)

SV	Average	Best day	Worst day
QZS-1	0.54 m	0.41 m	4.61 m*
QZS-2	0.82 m	0.43 m	1.28 m
QZS-3	0.88 m	0.58 m	1.37 m
QZS-4	0.87 m	0.59 m	1.30 m

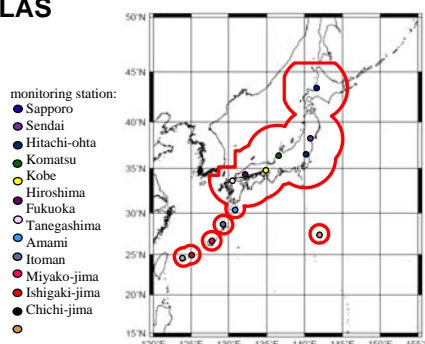
* Due to the anomaly of a onboard atomic clock

Improvement of the ranging accuracy of QZS-1 to 4 is now on going.

Performance Evaluation -SLAS Service-



Service Area of SLAS



Service Area is the area surrounded by the red line.

Accuracy of SLAS

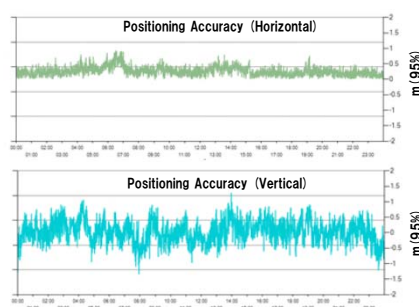
Positioning error (95%)		Remarks
Horizontal	Vertical	
≤ 1.0 m	≤ 2.0 m	EL mask : 10° User range error caused by user's receivers and user's situation : 0.87 m (95%)

Performance Evaluation -SLAS Service-



Test results

- Using the GNSS-based control stations in GNSS Earth Observation Network System (GEONET) operated by Geospatial Information Authority of Japan as a rover.
- Evaluation period: 2018 May 10 (24 hours)
- Evaluation point: Gushikawa, Okinawa Pref.
- Signal subject to augmentation: GPS (L1-C/A), QZSS (L1-C/A)
- The graph shows error figures by time transition, the table shows statistical figures.



Positioning Accuracy (95%)

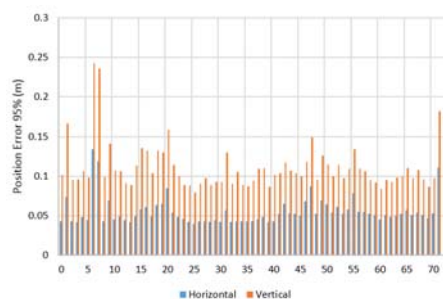
Horizontal	0.66 m
Vertical	0.88 m

Performance Evaluation -CLAS Service-

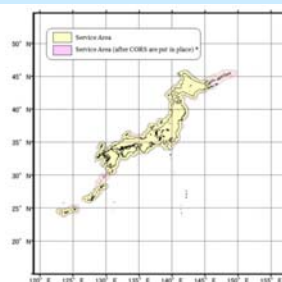


Recent results of CLAS (PPP-RTK)

- Evaluation period: 1 month of April 2019
- Evaluation points: 72 points in Japan area
- Used Kinematic mode of CLASLIB, open source software for CLAS users
- Horizontal and vertical error as well as TTFF are within the performance specifications.



Horizontal/Vertical Error of 72 evaluation points



Statistics of 72 evaluation points

Positioning Accuracy (95%)

Horizontal	5.3 cm
Vertical	10.7 cm

Time to First Fix: 38 sec (95%)

Contents



2. Recent Evaluation Results

Expected Services

Performance Evaluation -QZSS PPP-

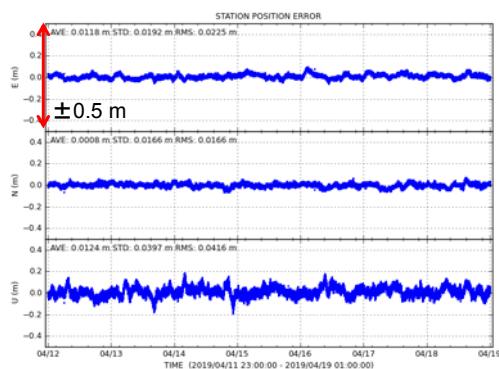


Recent Test results of QZSS-PPP

- Evaluation period: 1 week in the middle of April 2019
- Evaluation point: TKS2 in Japan (shown in right fig.)
- Used Kinematic PPP mode of RTKLIB
- Positioning results are quite stable throughout the period



Site: TKS2(Japan)



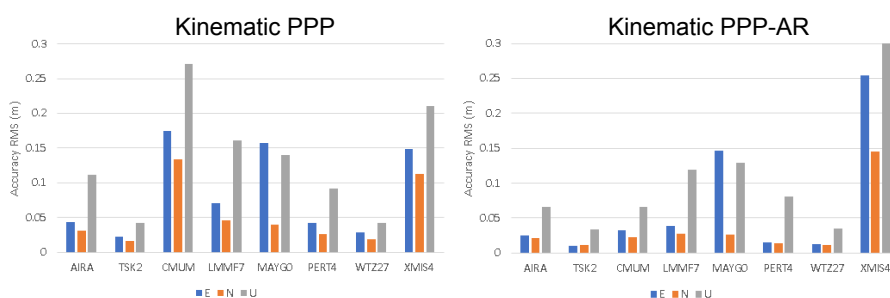
Directions	Error (RMS)
East-West	2.3 cm
North-South	1.7 cm
Vertical	4.2 cm

Performance Evaluation -QZSS PPP-



Recent Test results of QZSS-PPP

- Positioning result at each evaluation point around the world
- These result simulates the case where the augmentation message is used all over the world. (e.g. via internet)
- Positioning error is less than 20 cm (RMS) except for some evaluation points.
- Positioning accuracy improves at most points using PPP-AR.



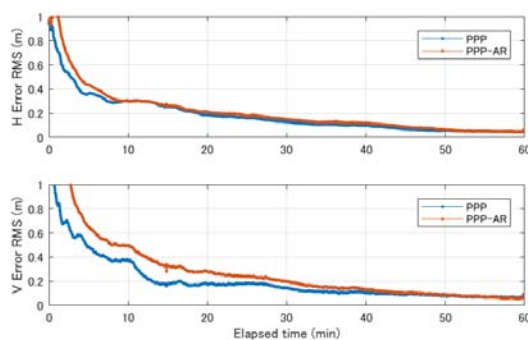
Horizontal/Vertical Error in global network

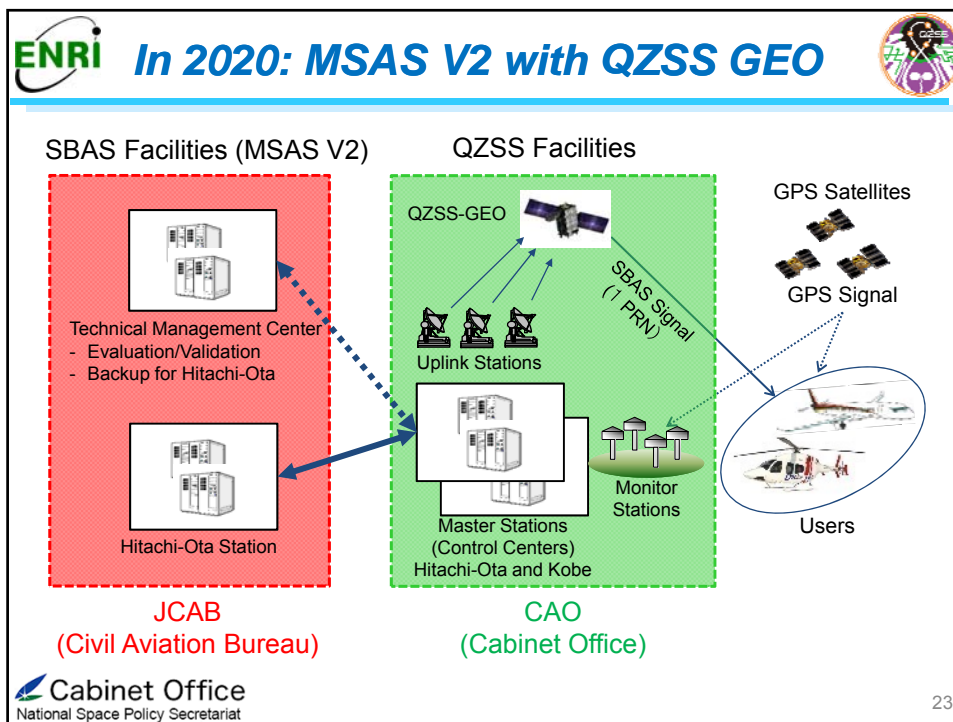
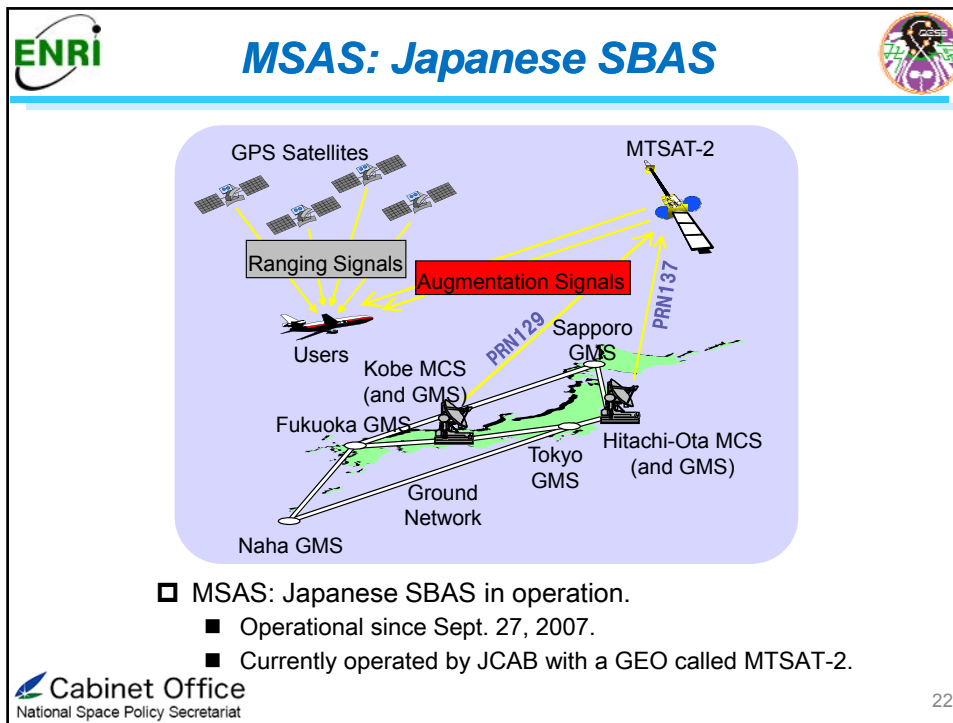
Performance Evaluation -QZSS PPP-

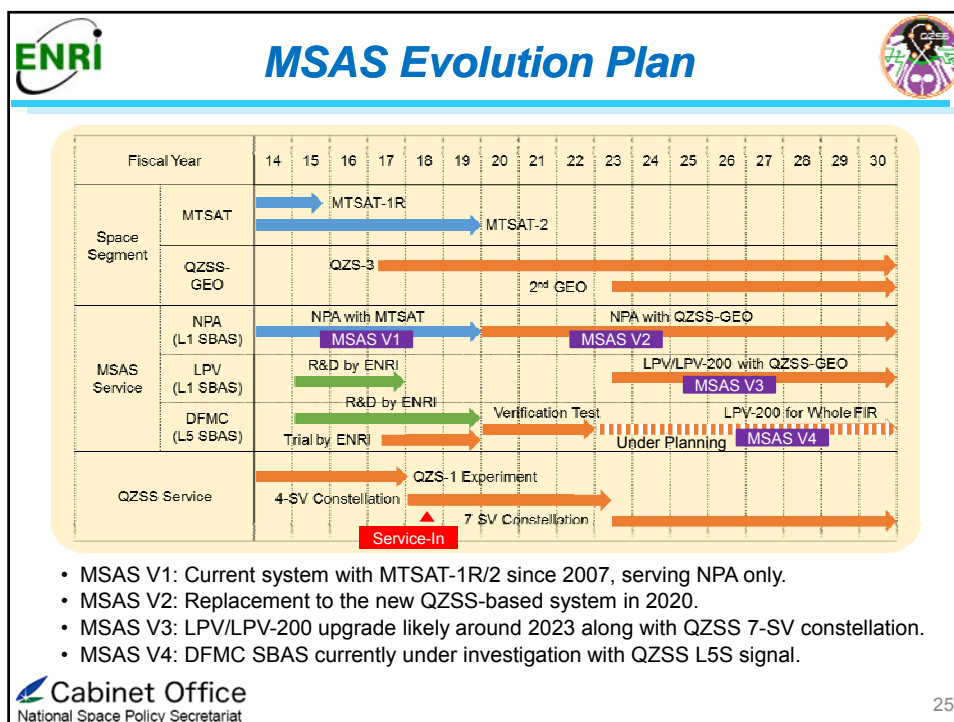
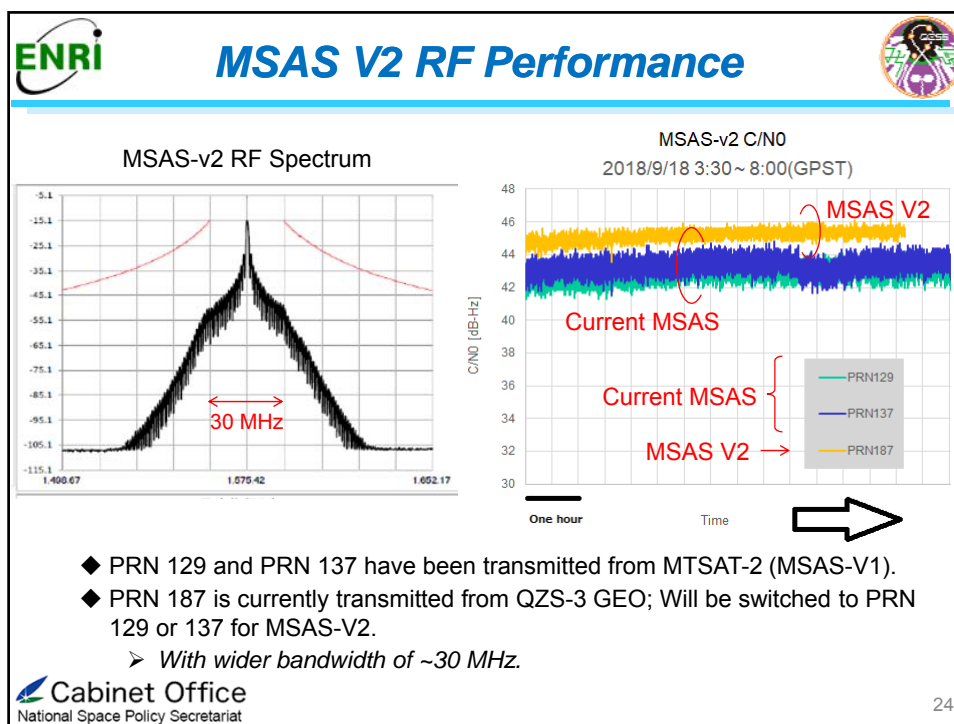



Recent Test results of QZSS-PPP

- Relationship between elapsed time and positioning accuracy of PPP
- Evaluation point: TKS2 in Japan (shown in right fig.)
- Blue line and orange line show the convergence time of PPP and PPP-AR, respectively.
- Horizontal error converges to less than 20 cm within about 20 minutes.
- Vertical error also converges within about 30 minutes.











DFMC SBAS Experiments




- **DFMC (Dual-Frequency Multi-Constellation) SBAS**
 - International standard augmentation system using L5 signal.
 - *Following L1 single-frequency single-constellation SBAS.*
 - Eliminates ionospheric effects dramatically.
 - *Vertical guidance service everywhere in the coverage.*
 - Allows SBAS signal transmission from non-GEO (IGSO) satellites.
 - *Improved SBAS signal availability in polar regions and urban canyons.*
- **ENRI/MPAT is now conducting DFMC SBAS Experiment**
 - The first L5 SBAS experiment with live L5 signal from the space.
 - *Using QZSS L5S signal transmitted from GEO and IGSO satellites.*
 - The prototype DFMC SBAS for experiments has been developed.
 - *GPS/GLONASS/Galileo/QZSS-capable dual-frequency SBAS.*
 - *Compliant with the draft ICAO L5 SBAS SARPS.*
 - Transmission since 23 Aug., 2017 using L5S signal of QZS-2/3/4.
 - *Expects participation to this experiments. Contact: <sakai@mpat.go.jp>*




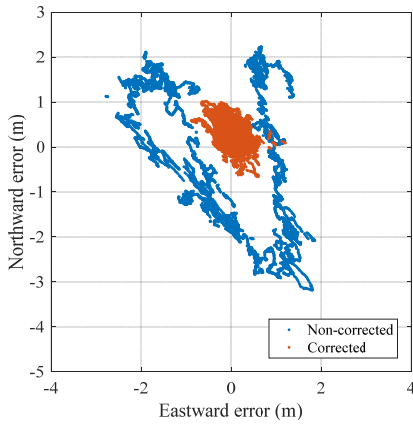
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Realtime Result

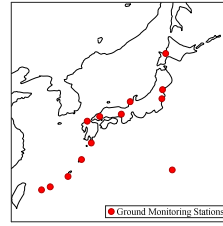




Northward error (m)

Eastward error (m)


Legend: Non-corrected (blue), Corrected (orange)



Monitor Stations

- GPS+Galileo+QZSS
- Dual Frequency (L1+L5)
- DFMC L5 SBAS
- Location: GEONET 950369 (Wakayama)
- Period: 2017/11/13 01:00 - 07:00 (6H)

- Evaluation of L5 SBAS message generated in real time.
 - *Supporting GPS, Galileo, and QZSS in L1/L5 dual-frequency mode.*
- Confirmed that L5 SBAS augments multi-constellation of GPS+Galileo+QZSS.



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3. Expansion to 7-SV Constellation

Expansion to 7-SV constellation



Service Requirement for 7-SV constellation (1/2)

1. Position, Navigation and Timing (PNT) services

- Open service with Navigation Message Authentication (NMA)
 - Step by step approach to improve performance, as new observables, ranging measurements with using Inter Satellite Ranging (ISR) as well as two-way ranging system, are to be applied.
 - Final goal of SIS-URE specification is 30 cm (95% probability)

Phase (Year)	SIS-URE(95%)*	Note
2023 to 2026	2.6m	Only L-band observables collected at monitoring sites.
2027 to 2035	1.0m	After JAXA's validations for new POD engine with ISR and two-way ranging between SV and ground TTC station
After 2036	0.3m	After all 7 SVs will have ISR and two-way ranging on board equipment

*: Average of 7SVs

- Authorized service (Encrypted signals for authorized users)

Expansion to 7-SV constellation



Service Requirement for 7-SV constellation (2/2)

2. Augmentation services

- Both existing services, Sub meter Level Augmentation Service (SLAS) and Centi-meter Level Augmentation Service (CLAS) are to be provided in domestic area via current four SVs with same specifications.
- MADOCA based PPP augmentation service will cover Asia Pacific region. (TBD: see next slide)

3. Messaging services

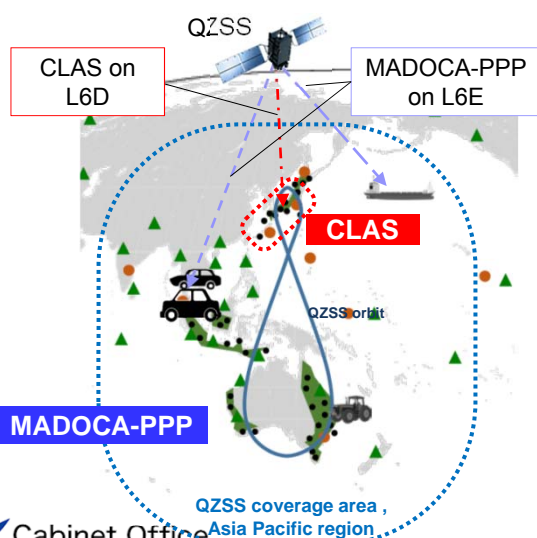
- Disaster and Crisis management Report (DCR) service, a kind of Early Warning Service (EWS) may be expanded to Asia Pacific region. (TBD)
 - Common format is now being investigated with EC and other provides under ICG correspondence group.

Investigation for extension of augmentation and Early Warning Service into wider area in Asia Pacific region is on going

Expansion to 7-SV constellation



Domestic Service and Wide Area Service for carrier phase positioning

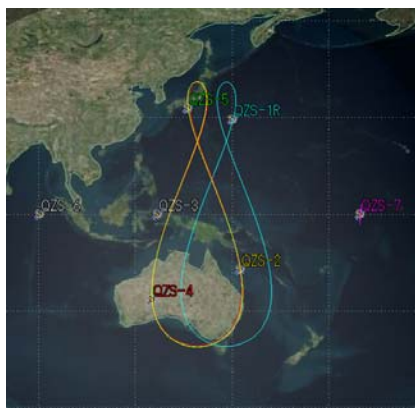


- Domestic Service**
 - CLAS (Centimeter Level Augmentation Service) is already operational via L6D signal.
 - Employs the dense GNSS CORS in service area.
- Wide Area Service**
 - Experimental augmentation by PPP with MADOCA has been provided via L6E signal on QZS-2/3/4.
 - MADOCA: Multi-GNSS Advanced Demonstration tool for Orbit and Clock Analysis, POD engine developed by JAXA.
 - Operational service will begin around 2023 (TBD, at the latest) with same Compact SSR format as CLAS.

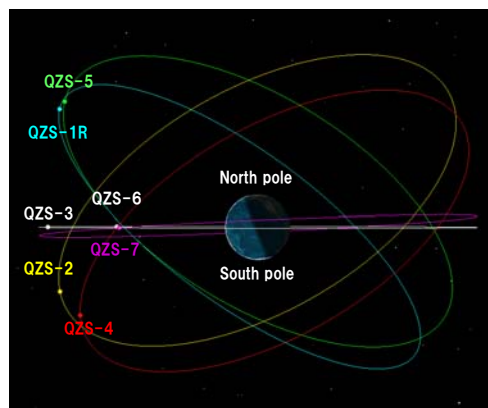
QZSS 7-SV Constellation Design



QZSS Constellation Plan



7-QZSS Ground Track



7-QZSS orbits view
from the equatorial plane

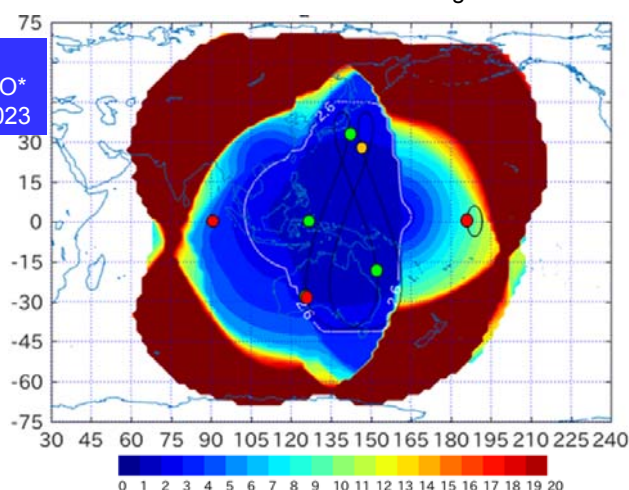
QZSS 7-SV Constellation Design



95% HDOP for 7-SV constellation with 10 degree EL mask

7-SV Constellation
4 IGSO + 2 GSO + 1 QGSO*
to be completed around 2023

- Operating 3 SVs (QZS-2, 3 and 4)
- Replacement SV for QZS-1 launched in 2020
- Additional 3 SVs launched in 2022-23



*: QGSO Quasi-Geo Synchronous Orbit
Geosynchronous orbit with small eccentricity and inclination

Contents



4. International Collaborations

International Collaborations



□ US - JP

- Continuous discussion on Interference Mitigation on L1C/A.
- Cooperation on Ground Segment (Monitoring Site) for future extension.

□ EU - JP

- Cooperation Agreement relative to Satellite Navigation Applications between Japan (National Space Policy Secretariat, Cabinet Office) and EU (DG-GROW, European Commission) was established on March 8, 2017.
- Current Activities
 - Definition of common EWS message format is on going.
 - Galileo-QZSS joint EWS trial in Australia was successfully completed in Sept. 2018.
 - Joint R&D activity on DFMC SBAS supporting IGSO SBAS concept:
 - The first trial was done successfully in March 2019 at GSA HQ, Prague.
 - The next trial is being planned for next Spring in the Nordic Region.

■ ICG (International Committee on GNSS)

- Continuous participation to ICG and support MGA activity in Asia Oceania region

International Collaborations



Multi-GNSS Asia (MGA)

- MGA 11th Conference :
 - ◆ has been held successfully in Bangkok, Thailand on 27-29 Aug. 2019.
 - ◆ Thanks a lot to all providers for your contributions and participations.



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International Collaborations



Two MGA events in 2020 !!

- (1) MGA regional seminar :
 - A tailor made seminar will be held in **Singapore** on **February 5-6 or 6-7, 2020**
 - In conjunction with Global Space and Technology Convention
 - Co-organized with Singapore Space and Technology Association (SSTA) and Singapore Land Authority (SLA)
- (2) Full Package Conference
 - **MGA 12th Conference** will be held in **Bangkok, Thailand** in August 2020
 - In conjunction with Thailand Space Week 2020
 - Co-organized with GISTDA

Visit MGA website for more information !!

- <MGA website> <https://www.multignss.asia/>



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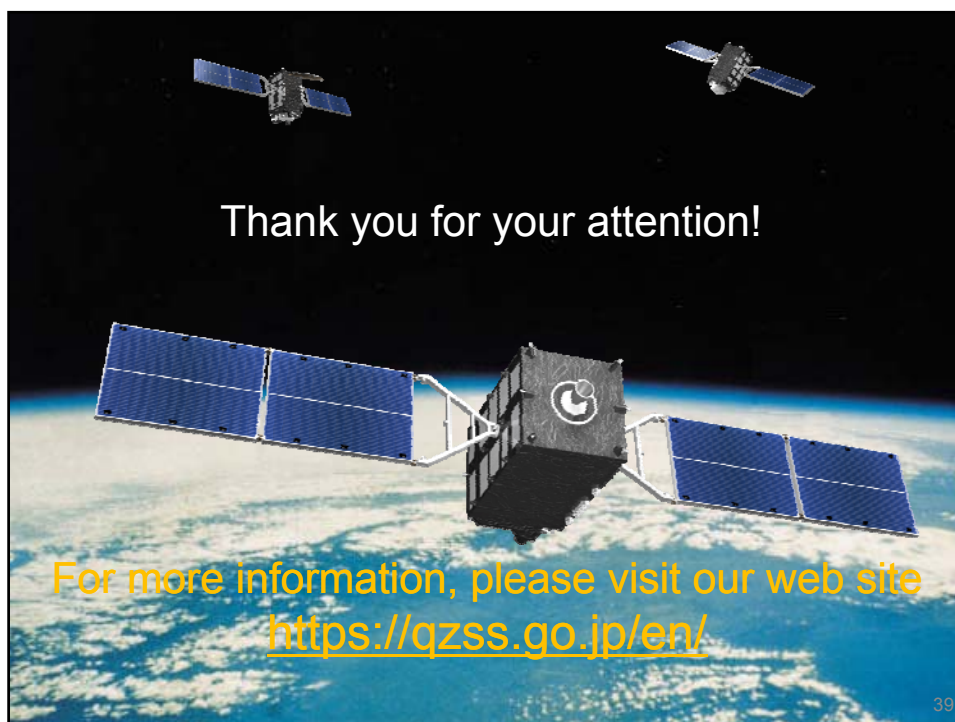
Summary



- QZSS is Japanese regional navigation satellite system to improve not only GNSS availability but also accuracy and reliability.
 - Currently 4-satellite constellation: Three IGSO and one GEO satellites.
- On 1st Nov., 2018, Japanese Government officially launched QZSS service.
 - PNT Service, Augmentation Service, and Messaging Service.
- Expansion to 7-satellite constellation
 - Has begun the procurement process for additional 3 satellites
 - An IGSO, a GEO and a QGSO satellites will be added to the existing constellation.
 - The service requirement has been established.
 - Covering Asia Oceania region for PNT services.
 - Investigation for extension of augmentation and Early Warning Service into Asia-Pacific region is on going.
- International collaborations
 - Bilateral cooperation with US and EC, as well as continuous contribution to ICG.

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