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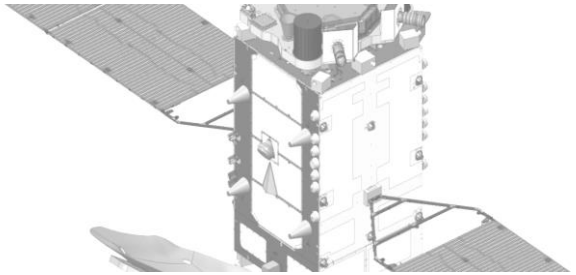


The latest status of Quasi-Zenith Satellite System (QZSS) and its future expansion

ICG-14 Providers System and Service Updates

on December 9, 2019 @Bengaluru, India

Masaharu Kugi

National Space Policy Secretariat

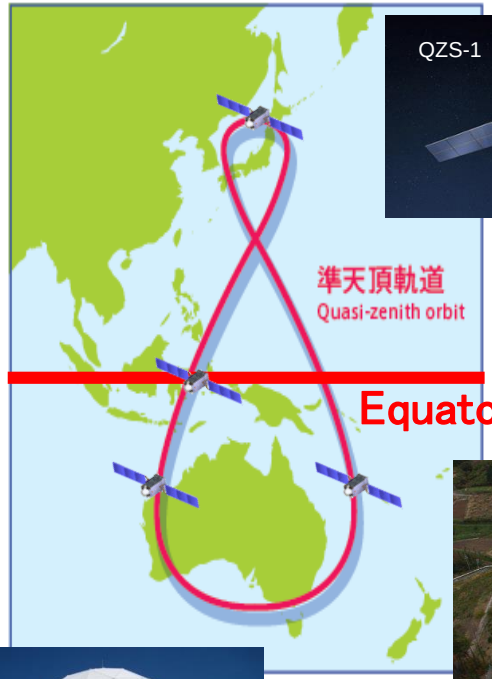
Cabinet Office, Government of Japan

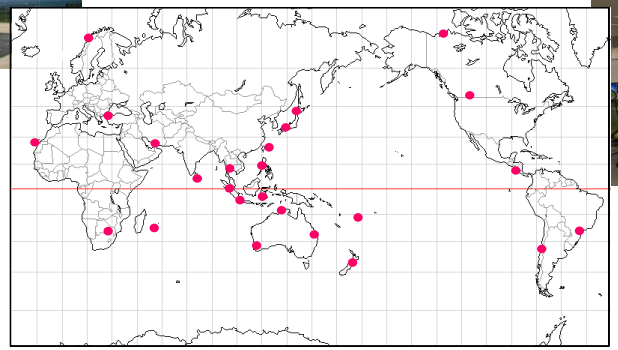
Contents

1. QZSS Overview
   - System
   - Services and Performances
   - Program schedule
     - ✓ Official service launch
2. Future Expansion to 7SV constellation
3. Application demonstrations
4. Summary

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





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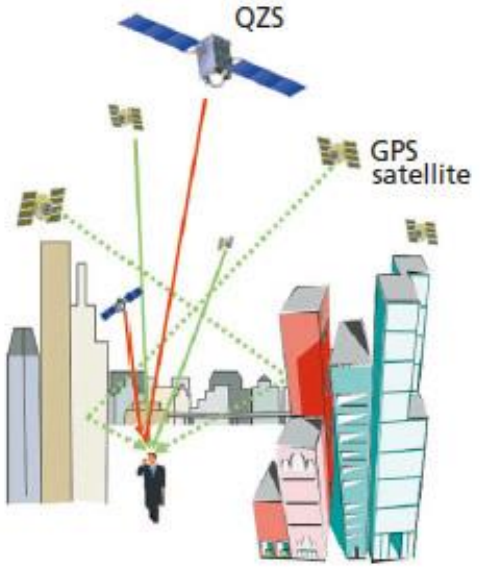
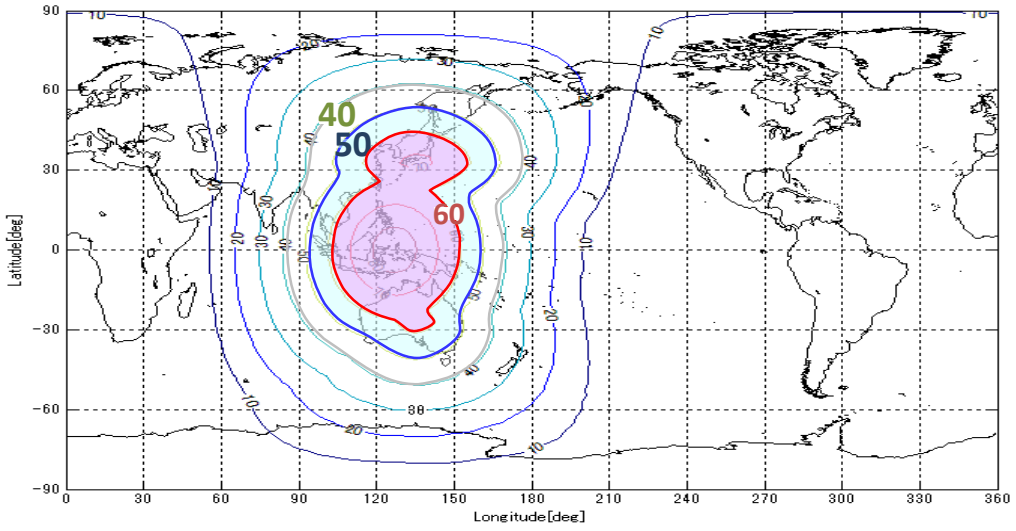
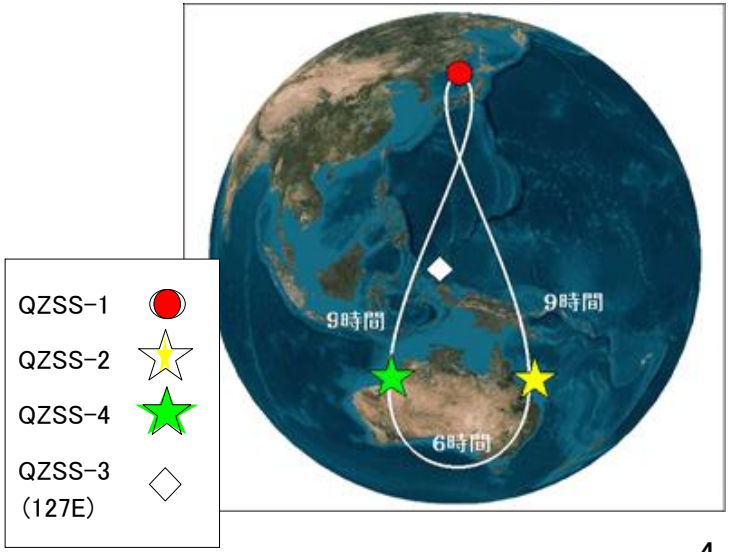
QZSS Overview –Services-

- ***Functional Capability:***
  - GPS Complementary (Ranging signals)
  - GNSS Augmentation (Error corrections)
  - Messaging Service (Disaster relief, management)
- ***Coverage:*** Asia and Pacific region
  - Augmentation service covers only Japan
    - Experimental service provides error corrections in Asia Pacific region







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QZSS PERFORMANCES

- Improvement of the ranging accuracy of QZS-2-4 is now on going.

Ranging Accuracy

Sep-2018 ~ Mar-2019 (6 months)

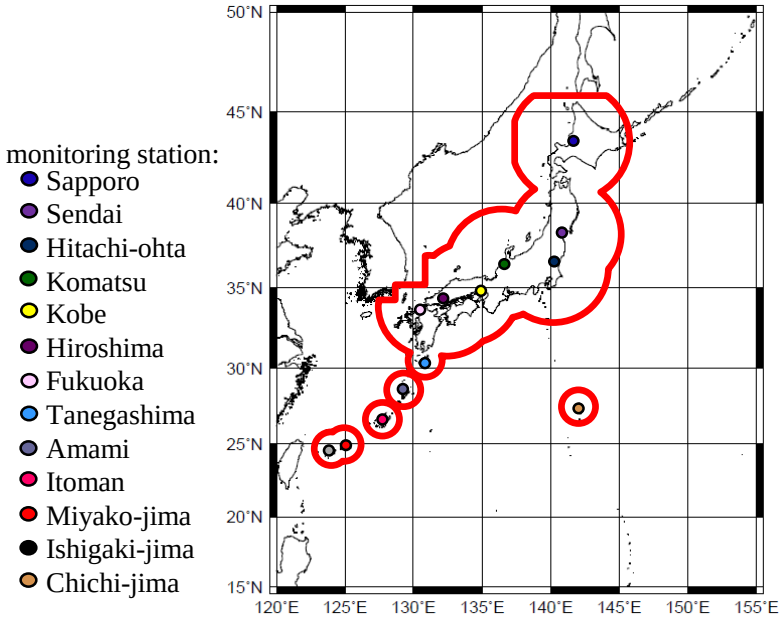
SIS-URE(95%)	Spec.	@ All Age	@ Zero Age
QZS-1	2.6	0.77 m	0.56 m
QZS-2		1.22 m	0.60 m
QZS-3(GEO)		1.31 m	0.61 m
QZS-4		1.15 m	0.62 m

Apr-2019 ~ Oct-2019 (6 months)

SIS-URE(95%)	Spec.	@ All Age	@ Zero Age
QZS-1	2.6	0.64 m	0.37 m
QZS-2		1.10 m	0.45 m
QZS-3(GEO)		0.93 m	0.42 m
QZS-4		0.90 m	0.45 m

QZSS Performance -SLAS Service-

Service Area of SLAS



Service Area is the area surrounded by the red line.
The left-axis is latitude, and lower-axis is longitude.

Accuracy of SLAS

positioning errorm(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%)

QZSS Performance -SLAS Service-

Recent Test results

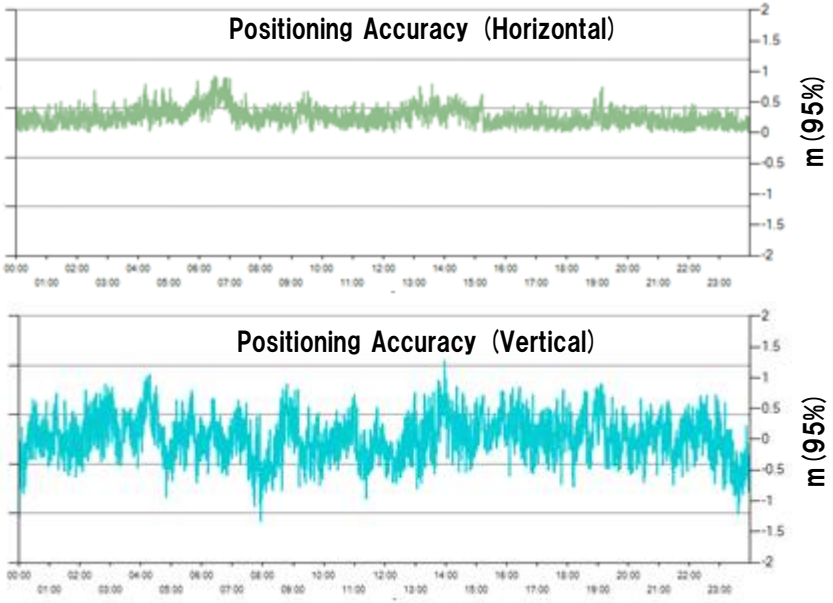
・Using the GNSS-based control stations in GNSS Earth Observation Network System (GEONET) operated by Geospatial Information Authority of Japan as a rover.

・Evaluation period： 2018 May 10 (24 hours)

・Evaluation point： Gushikawa, Okinawa Pref.

・Signal subject to augmentation：GPS(L1-C/A),QZSS(L1-C/A)

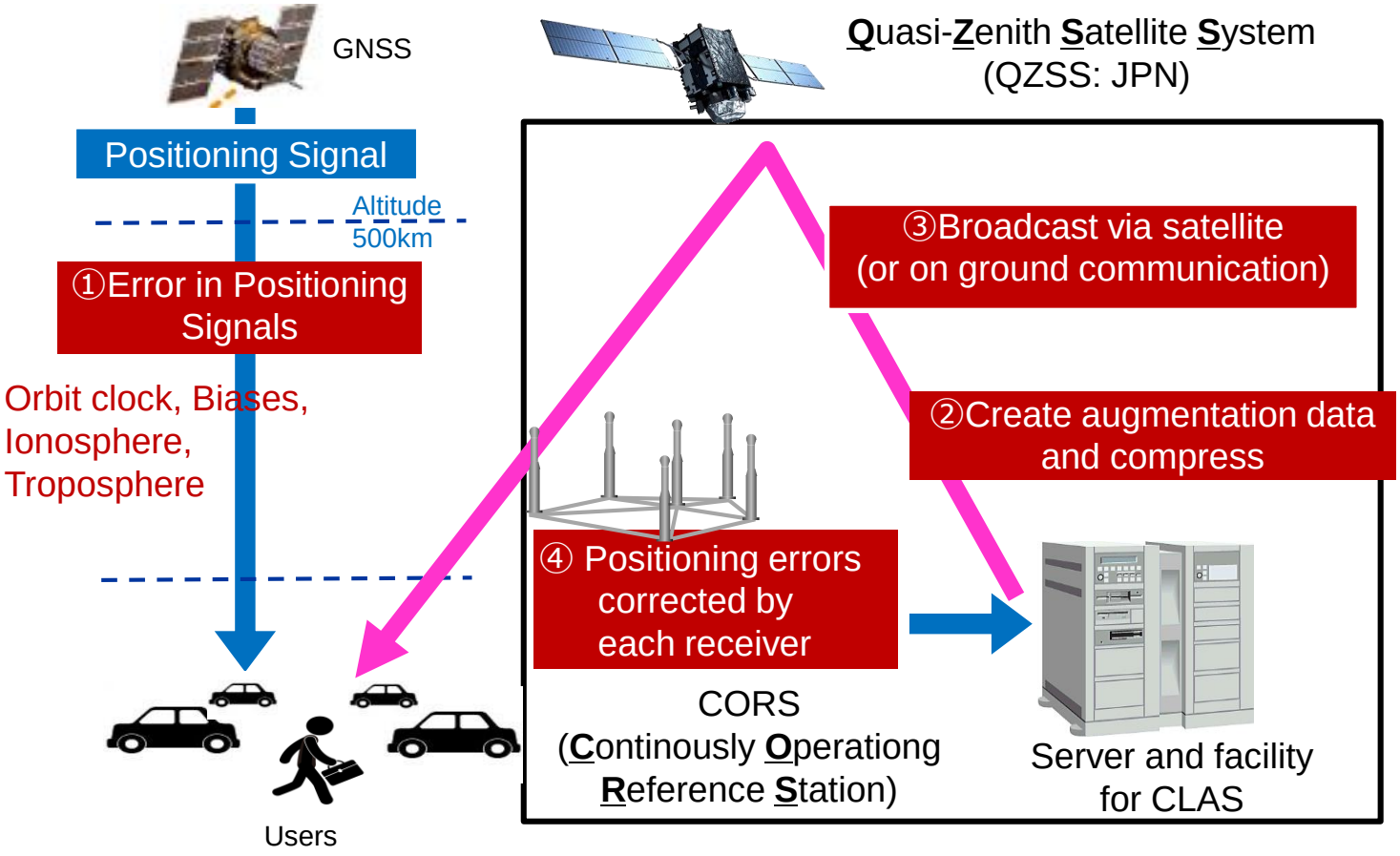
・The graph shows error figures by time transition, the table shows statistical figures.



Positioning Accuracy	m (95%)
Horizontal	0.66
Vertical	0.88

QZSS Performance -CLAS Service-

Overview of CLAS (Centimeter Level Augmentation Service)



Specification on positioning accuracy

H ≤ 6.0 cm (95%), V ≤ 12.0 cm (95%) (Static)

H ≤ 12.0 cm (95%), V ≤ 24.0 cm (95%) (Kinematic)

QZSS Performance -CLAS Service-

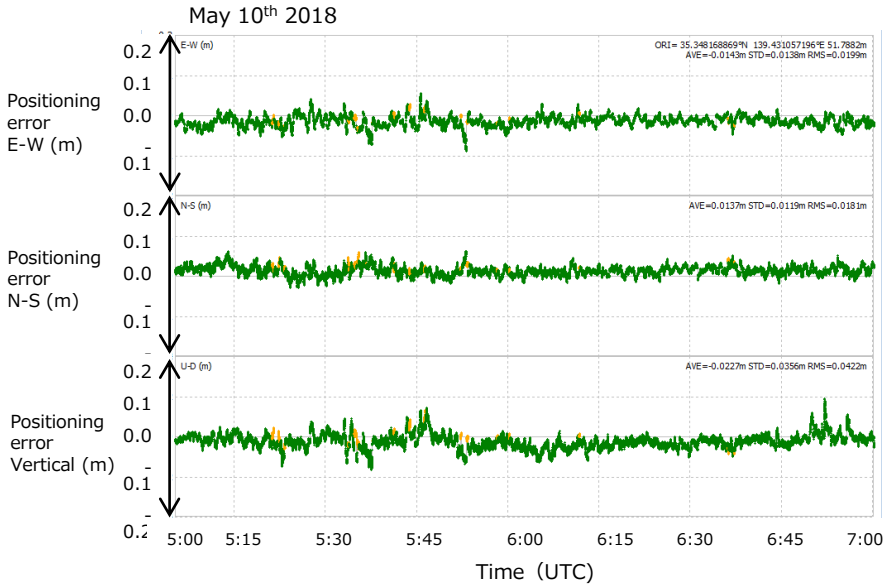
Recent Test results (mobile use)

・Evaluated from positioning results earned from a mobile vehicle mounting both general RTK and CLAS receivers in open-sky condition maneuver.

・Difference between CLAS positioning results and RTK positioning results are evaluated (defined as error figures)

・Error is evaluated by content (direction),

the graph shows error figures by time transition, the table shows statistical figures



Error content (Direction)	cm (rms)
East-West	2.0
North-South	1.8
Vertical	4.2

QZSS Development Plan

QZSS Program Schedule (latest)

JFY	2015	2016	2017	2018	2019	2020	2021	2022	2023～
1st Michibiki	Replacement of Michibiki → Launch No.1R satellite								
	In-Operation								
QZSS 4-Sat. Constellation			Launch No.2,3,4						
			Official Launch on Nov 1, 2018		QZSS Service				
						SBAS Service			
QZSS 7-Sat. Constellation					Development / Design (Additional 3 Sats.)				QZSS Service
									

Latest status of QZSS Service provision and future expansion

Official Service Launch

- On November 1st 2018, Prime Minster 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.
- Update of ground control segment will follow soon.

Future Expansion to 7SV constellation

Development Policy and objective for the 7 SV expansion

- Considering social and users' requirements, demands as well as competitiveness with other PNT infrastructures;

1. **Early deployment and realization of the service provision around 2023**
2. **Reliable and sustainable PNT service provision around Japan**
3. **Improvement of service performances and functions**
   - QZSS standalone PNT function with 1.0 meter (horizontal RMS error) for dual frequency code phase positioning
   - Navigation Message Authentications for anti-spoofing capability
   - Augmentation service area extension from domestic only to Asia Pacific and increment of augmented GNSS (TBD)
   - Robust authorized service (TBD)
   - Back up function of two way communications for disaster relief operation (Q-ANPI)
4. **Continuity of the existing services (backward compatibility)**
   - Services provided by current 4SV constellation basically are to be supported continuously via 7 SV constellation.
   - As the result of RFI compatibility discussion with US GPS, L1C/A may not be transmitted after QZS-1R (TBD)
5. **Development and maintenance cost reduction**

NOTE: TBD means that the item has not determined when it would be implemented at this moment.

Future Expansion to 7SV constellation

Service Requirement for future 7SV 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
2023-2026	2.6m	Only L-band observables collected at monitoring sites.
2027-2035	1.0m	After JAXA's validations for new POD engine with ISR and two-way ranging between SV and ground TTC station
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) is under investigation.

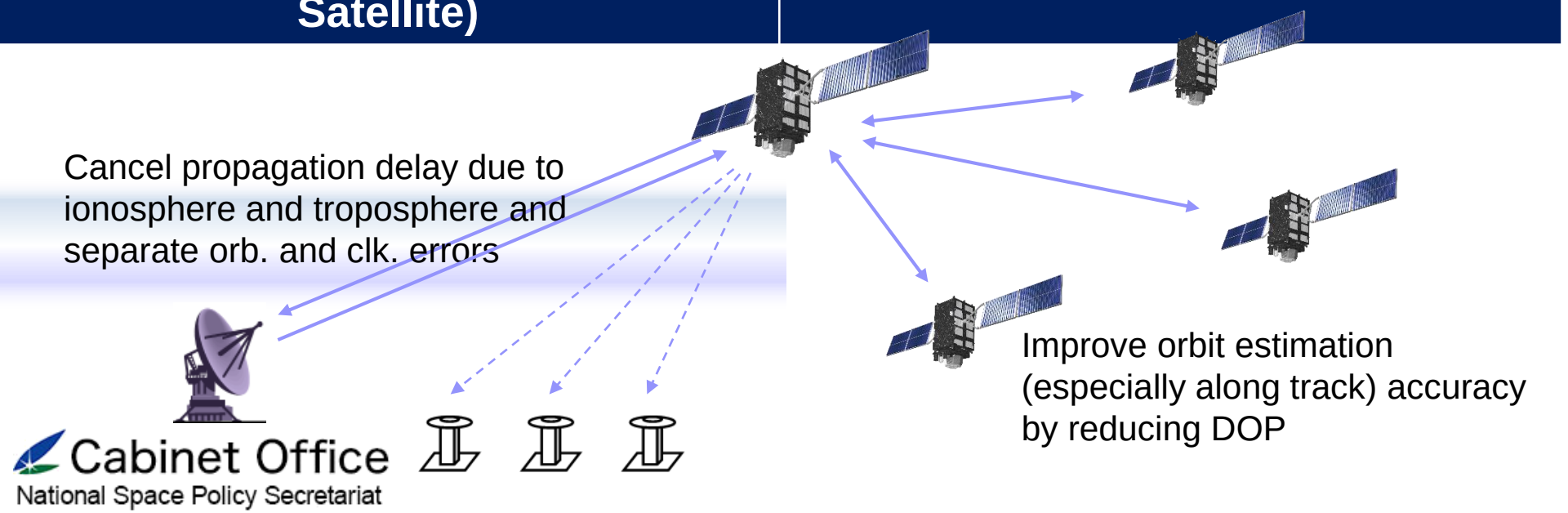
Future Expansion to 7SV constellation

R&D for 7SV QZSS – additional observables for precise POD and integrity monitoring on board

- Technical goals to improve accuracy, availability, integrity:
  - Improving orbit and clock estimation accuracy by adding new observation data
  - Improving availability by robust satellite system design
  - Enhancing integrity by monitoring L-band signal on orbit

2-Key Technologies

Two-way Ranging (Ground - Satellite)	Inter Satellite Ranging



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Future Expansion to 7SV constellation

Service Requirement for future 7SV 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)

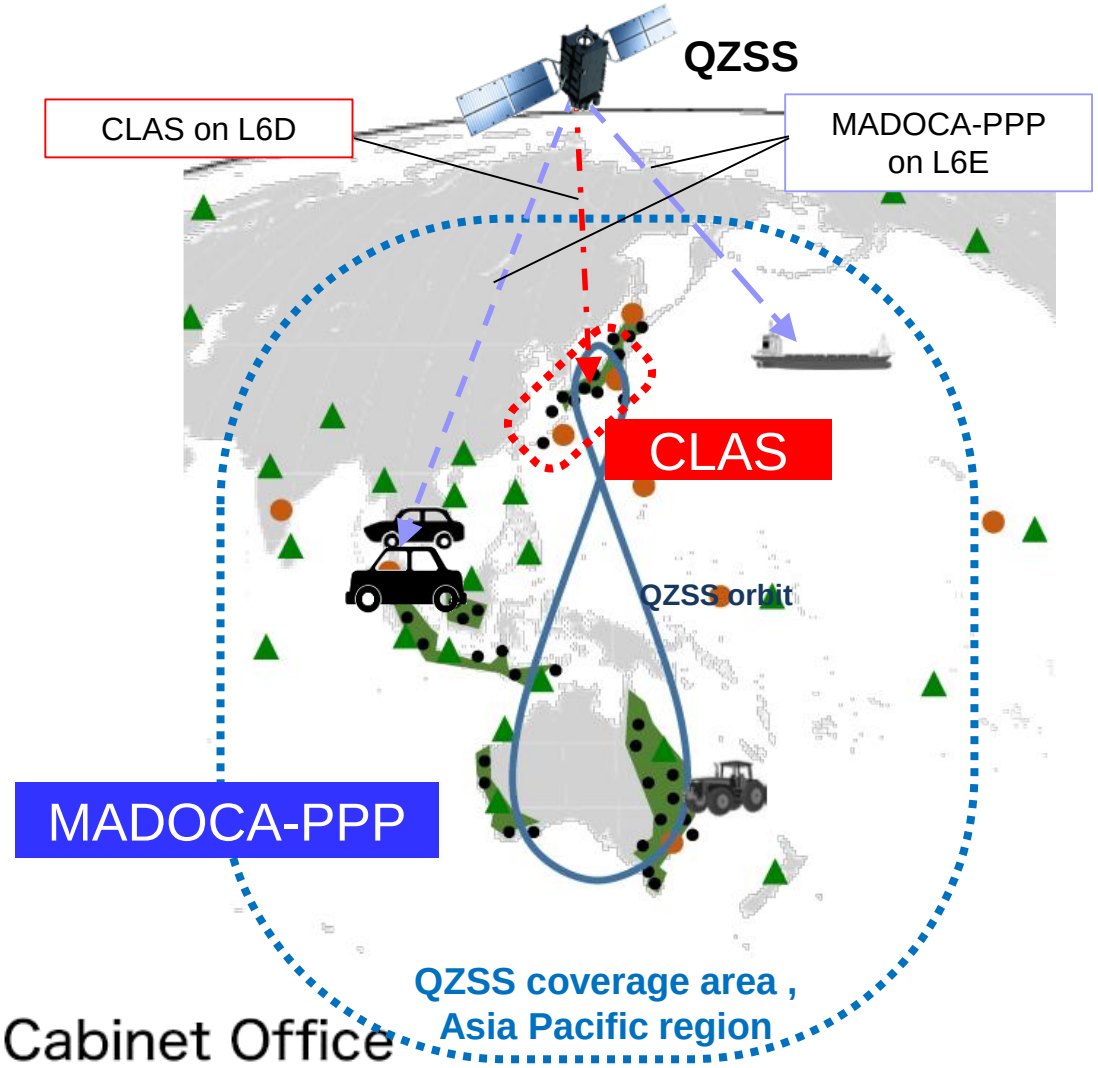
3. Messaging services

- 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

Future Expansion to 7SV constellation

Domestic Service and Wide Area Service for carrier phase positioning



: region

- CLAS (Centimeter Level Augmentation Service) is being provided via L6D signal.
- Employs the dense GNSS CORS in service area.
- CLAS for Japanese territory started in 2018.

: region

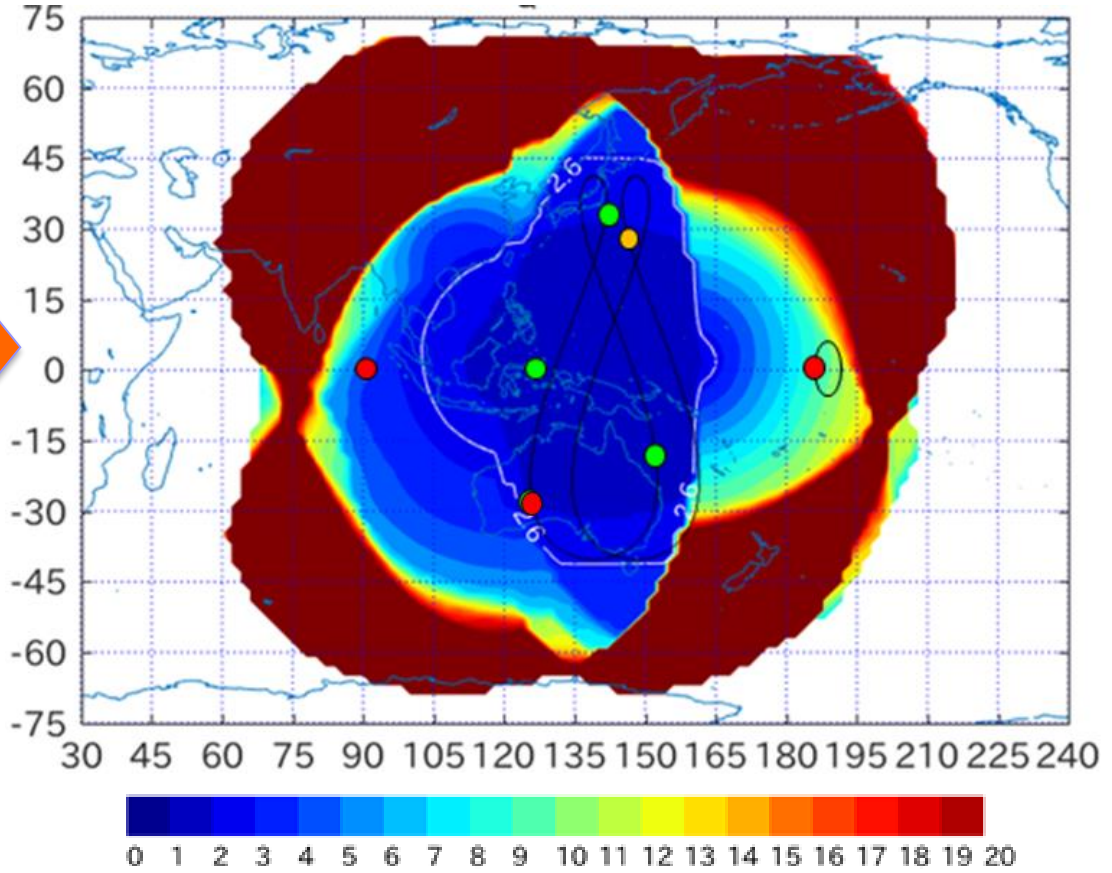
- Experimental augmentation on PPP with MADOCA has been provided via L6E signal on QZS-2/3/4.
- MADOCA: Multi-GNSS Advanced Demonstration tool for Orbit and Clock Analysis is a precise POD engine developed by JAXA.
- Operational service will start around 2023 (TBD, at the latest) with same Compact SSR format as CLAS

QZSS 7SV Constellation Design

- The highest priority is to provide good geometry (HDOP).
  - Japan and surrounding area should have good HDOP, less than 2.6 on 95 time percentile.
- SBAS user requirements on the number of GSO satellites is satisfied.
  - More than 2 GSO SV for LPV service to be provided by Japanese Civil Aviation Bureau

4 IGSO + 2 GSO +1 QGSO* constellation will be completed around 2023

95% HDOP for 7 healthy SV with 10 degree EL mask



3 operating SVs (QZS-2,3 and 4)

Replacement SV for 1st SV

3 additional SVs launched 2022-23

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

Future Expansion to 7SV constellation

Latest status

- The procurement process for QZS-5, 6, and 7 has started in the end of JFY2018.
- Update of ground control segment will follow soon.

Further challenges for future expansion

- Reliability, availability improvement for whole total system
  - Long-term replacement plan
  - Back-up satellites, less ground infrastructure for system resilience improvement
- Sustainable system architecture
  - further reductions satellite weight, size and cost, and more effective ground control segment
- Alternative PNT

Applications demonstrations

Autonomous driving

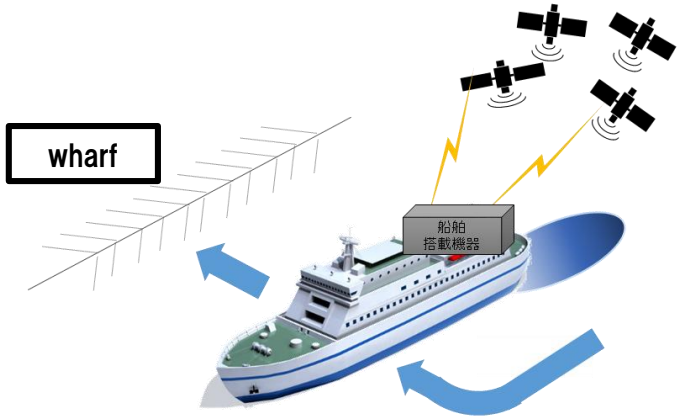
Smart Agriculture

Autonomous sailing

Drone logistics

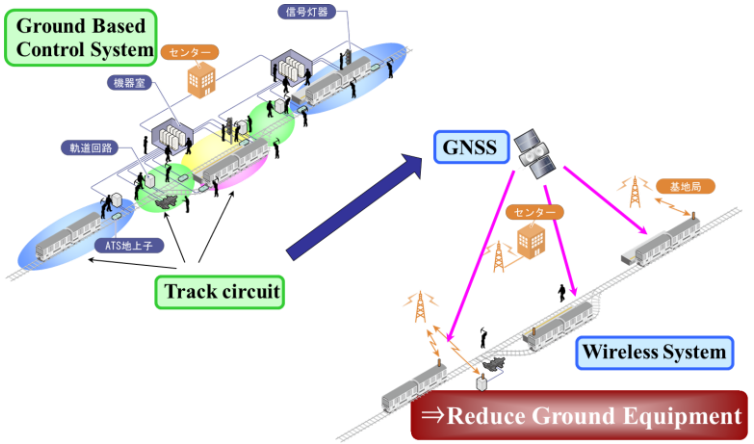
Other Applications

Automatic Berthing System



http://www.mlit.go.jp/common/001215815.pdf

Simplification of Rail Traffic Management System



KYOSAN ELECTRIC

Construction in the ocean

TOA Corporation

Wearable Devices for Sports

MASA

International Collaboration

JP-US

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

JP-EU

- Cooperation Agreement relative to Satellite Navigation Applications between Japan (National Space Policy Secretariat, Cabinet Office) and EU (DG-Glow, European Commission) was established on March 8, 2017.
- Current Activities
  - Definition of common EWS message format is on going.
  - Joint R&D activity on DFMC SBAS supporting IGSO SBAS concept will be planned.
  - Standardization activity on RTCM and 3GPP for high precision positioning

JP-AU

- Continuous discussion between Japan (National Space Policy Secretariat, Cabinet Office) and Australia(Geoscience Australia) for future collaboration

ICG

- Continuous participation and support MGA activity in Asia Oceania region

International Collaboration

Multi-GNSS Asia (MGA)

- **MGA 11th Conference :**

  has been finished successfully in Bangkok, Thailand on 27-29 August 2019

  Thanks a lot to all providers for your contributions and participations

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International Collaboration

- **Two MGA events in 2020 !!**
  - **(1) MGA regional seminar :**
    - **A tailor made seminar will be held in Singapore on February 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 on 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/**

Summary

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

Thank you for your attention!

For more information, please visit our web site

https://qzss.go.jp/en/