Cabinet Office
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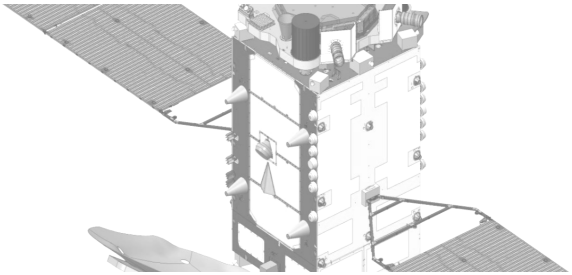


# QZSS System and service Updates

Quasi-Zenith Satellite System,
Japanese Regional Navigation Satellite System

First Plenary Session of the 17th ICG

16 October, 2023


**Kenji NUMATA**

Director and deputy head of QZSS Strategy Office

National Space Policy Secretariat

Cabinet Office, Government of Japan

# Contents

1. Topics
2. QZSS Overview
3. Toward seven-satellite constellation
4. Research and Development
5. Applications
6. Conclusions

# 1. Topics

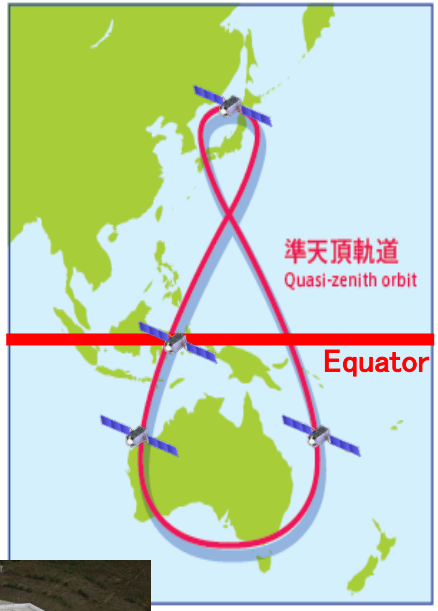
- The main topics in the ICG are as follows:

1. Publication of the antenna pattern data of each satellite
2. QZS-1 termination
3. QZS-5, 6 and 7 development status
4. Completion of the ground system for the 7-satellite constellation
5. QZS-5 launch timing?
6. Transmission of the QZNMA signal(L6E) as trial
7. Promotion activities for MADOCA-PPP and EWS
8. Revised Basic Plan on Space Policy ～ toward the 11-satellite constellation
9. Plan for the 11-SV constellation
10. Applications

# 2. QZSS Overview (1/2)

- The four-satellite constellation has been under operation to provide following services since 2018:
  - GPS Complementary Service（PNT* service） * Position, Navigation and Timing
  - GNSS Augmentation Service, i.e. SLAS, CLAS and SBAS
  - Messaging Service
- The constellation consists of one GEO satellite, QZS-3, 127E Longitude and three QZO satellites (IGSO*) * Inclined Geosynchronous Orbit
- There are two master control centers, located in Hitachi-Ota and Kobe, seven TT&C stations, and over 30 monitor stations around the world with the cooperation of countries.
- The antenna patterns of the QZSs for SSV users have been published since 10 August, 2023.
  https://qzss.go.jp/en/technical/antenna-patterns.html





# 2. QZSS Overview (2/2)

Topic No.2

- The QZS-1 has been finally terminated.
  - The QZS-1, which was launched in 2010 and had already reached its life-time, has been changed its orbit and terminated its transmission of all signals on 15 September 2023.
  - In compliance with the ISO 24113 Space debris mitigation requirements, it has been placed into the orbit in the below table that remains outside the GEO Protected Region for at least 100 years.
  - The NAQU message, Notice Advisory to QZSS Users, was also issued after termination on the same day as follows:

NAQU Message 2023134
GENERAL

NOTICE ADVISORY TO QZSS USERS (NAQU) 2023134 NAQU
TYPE: ALL_GENERAL
*** GENERAL MESSAGE TO ALL QZSS USERS ***
The operation of QZS-1(SVN001) was completely terminated on September 15, 2023 after re-orbiting.
*** GENERAL MESSAGE TO ALL QZSS USERS ***

POC:- QZSS Services, HTTPS://QZSS.GO.JP

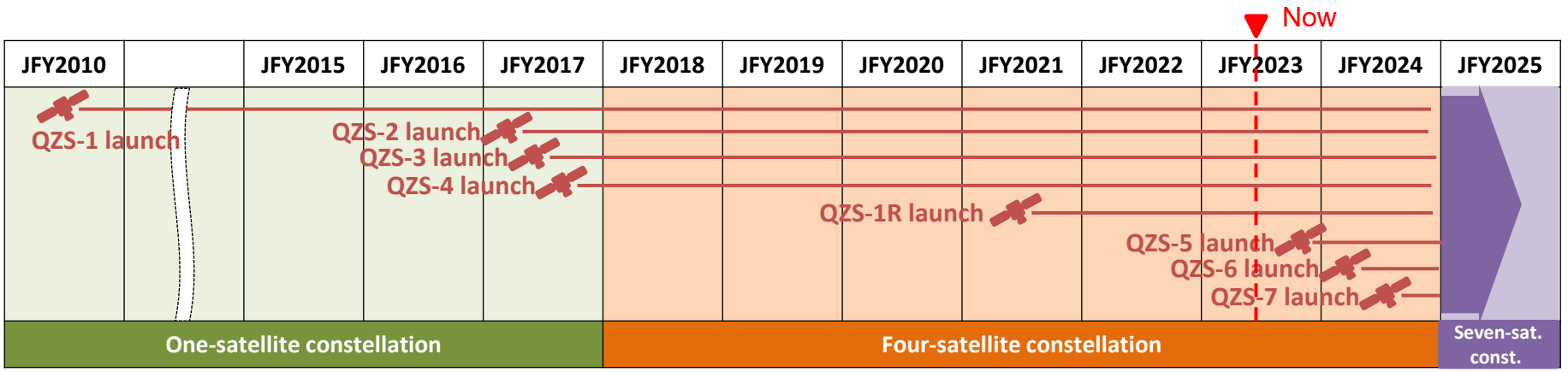
https://sys.qzss.go.jp/dod/naqu.html

| | |
|---|---|
| EPOCH | 2023/09/14/08:00:00.000 |
| STD_COORDINATE | TOD |
| COORDINATE_SYSTEM | KEP |
| ELEMENT_TYPE | OSCULATE |
| SEMI_MAJOR_AXIS | 46096.132946674326 |
| ECCENTRICITY | 0.000341721896 |
| INCLINATION | 42.912644264606 |
| RA_OF_ASC_NODE | 127.619716180791 |
| ARGUMENT_OF_PERIGEE | 78.998145195917 |
| MEAN_ANOMALY | 36.356787570309 |

After the fuel was discharged

# 3. Toward Seven-satellite constellation (1/13)

- The launches of additional three satellites are still scheduled for JFY2023 to JFY2024 on the formal plan as follows:




- Once the constellation is initiated, users will be:
  - capable of finding their position using just only QZSS, and
  - able to utilize QZNMA service, MADOCA-PPP service and extended EWSSs.
- Next slides show the status of development both new satellites and ground system.



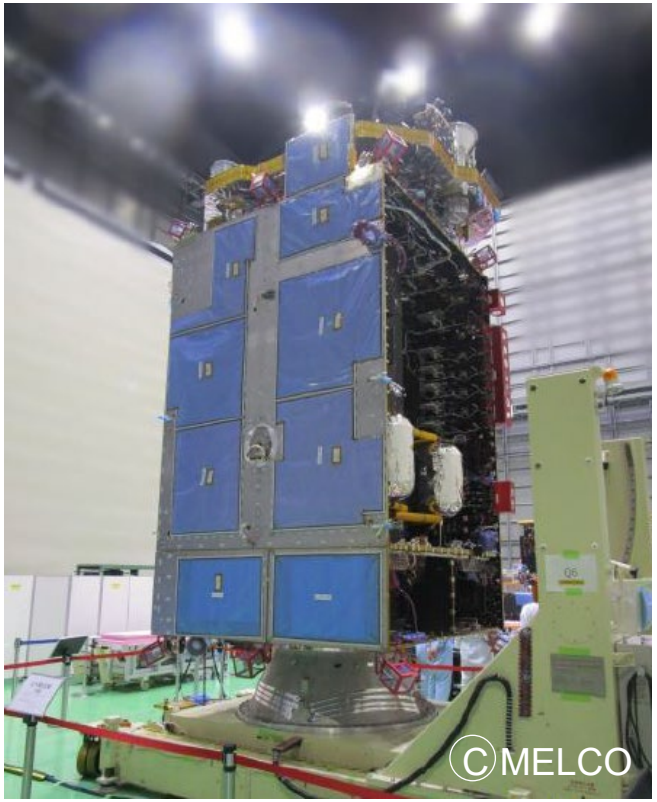
QZNMA: QZSS Navigation Message Authentication
MADOCA-PPP: Multi-GNSS Advanced Orbit and Clock Augmentation - Precise Point Positioning
EWSS: Emergency Warning Satellite Service

# 3. Toward Seven-satellite constellation (2/13)

Topic No.3

- Three new satellites are now on developing:
  - QZS-5 and QZS-6 are under system testing
  - QZS-7 is under assembling at system level


During the vibration test (X-axis) for QZS-5




Preparation for the mechanical environment test for QZS-6

# 3. Toward Seven-satellite constellation (3/13)

Topic No.4

- The ground system, at Hitachi-Ota and Kobe for the seven-satellite constellation, has been completed by the end of August, 2023:
- Two-thirds of the newly stations, Tanegashima-island and Miyakojima-island, have been completed by the end of June, 2023.

  * One-third of the newly station, Amamiohshima-island, will be completed by the end of March, 2025.
  * A radio-license is required to use those stations.

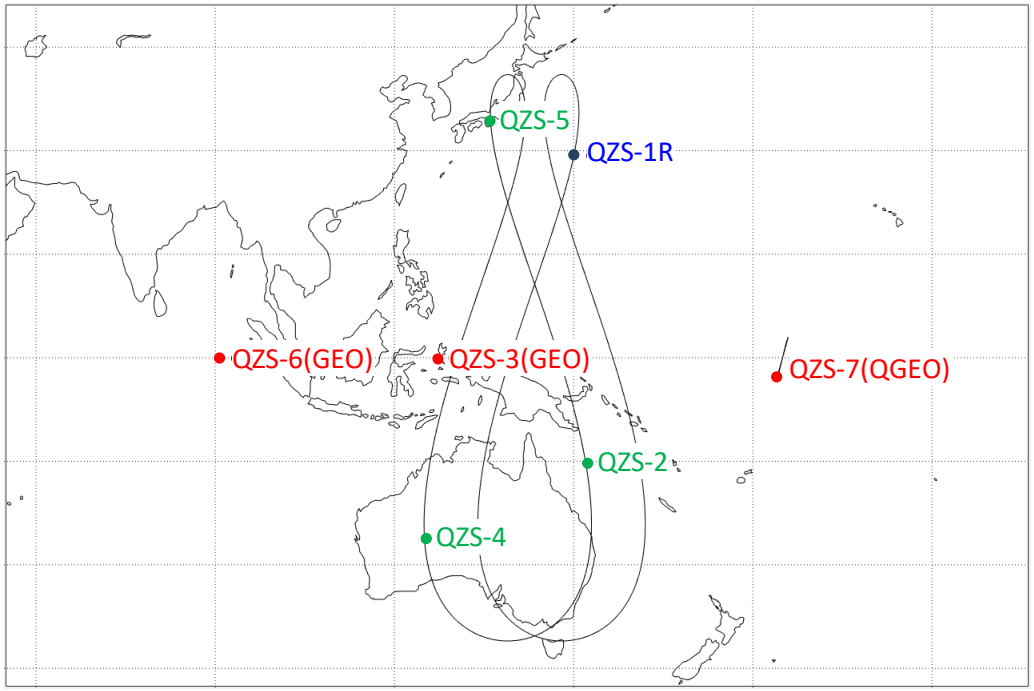
The state of the acceptance test at Hitachi-Ota

The new TT&C station at Tanegashima-island
(Photo taken during construction)

The new TT&C station at Miyakojima-island

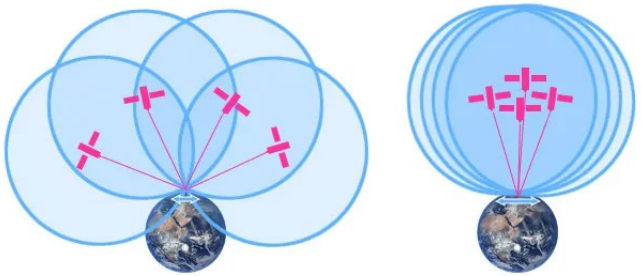
# 3. Toward Seven-satellite constellation (4/13)

- The three additional satellites will be placed on an IGSO, a GEO on 90.5 East Longitude and a Quasi-Geostationary Orbit on 175 West Longitude. This constellation aims:
  - to be visible more than one satellite at high elevation angle.
  - to be visible more than four satellites for a long time.
  - to get more better DOP, Dilution Of Precision.




Seven-QZS Ground Track

| Satellite orbit | Satellite Number | Orbital Position |
|---|---|---|
| IGSO（4 satellites） | QZS-1R<br>QZS-2<br>QZS-4<br>QZS-5 | 148 deg E<br>139 deg E<br>139 deg E<br>139 deg E |
| GEO（2 satellites） | QZS-3<br>QZS-6 | 127 deg E<br>90.5 deg E |
| QGEO（1 satellite） | QZS-7 | 175 deg W |



Low DOP　　High DOP

# 3. Toward Seven-satellite constellation (5/13)

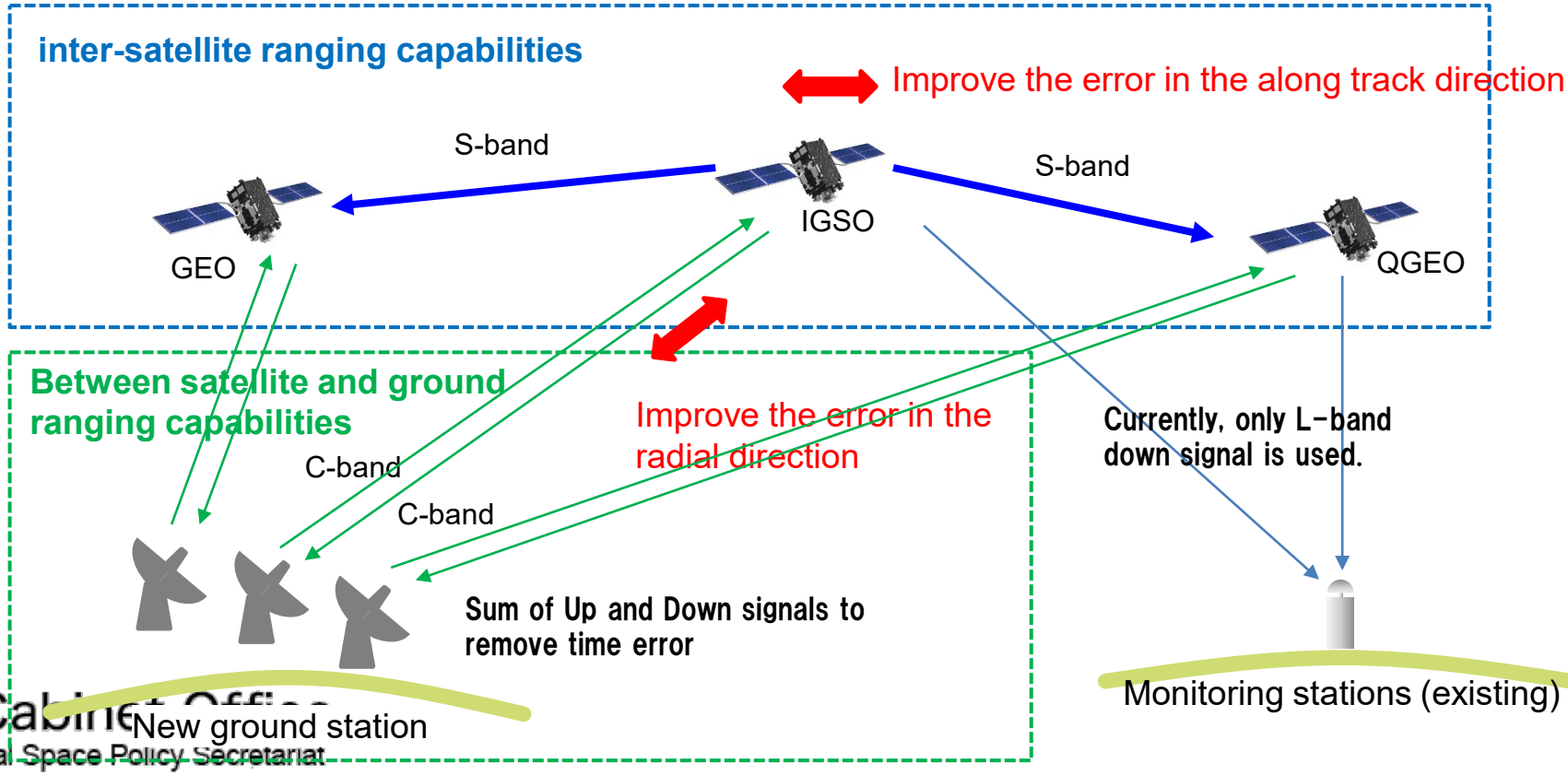
- The first launch as a test flight of our next-generation H3 launch vehicle failed after liftoff on 7 March 2023 due to the failure of its second stage ignition.
- JAXA and MHI are desperate to address the failure, and in order to launch the second launcher by the end of March 2024.
- Thus, the launch of QZS-5 is now uncertain.

Topic No.5


H3 rocket lifts off from the Tanegashima Space Center on 7 March.

# 3. Toward Seven-satellite constellation (6/13)

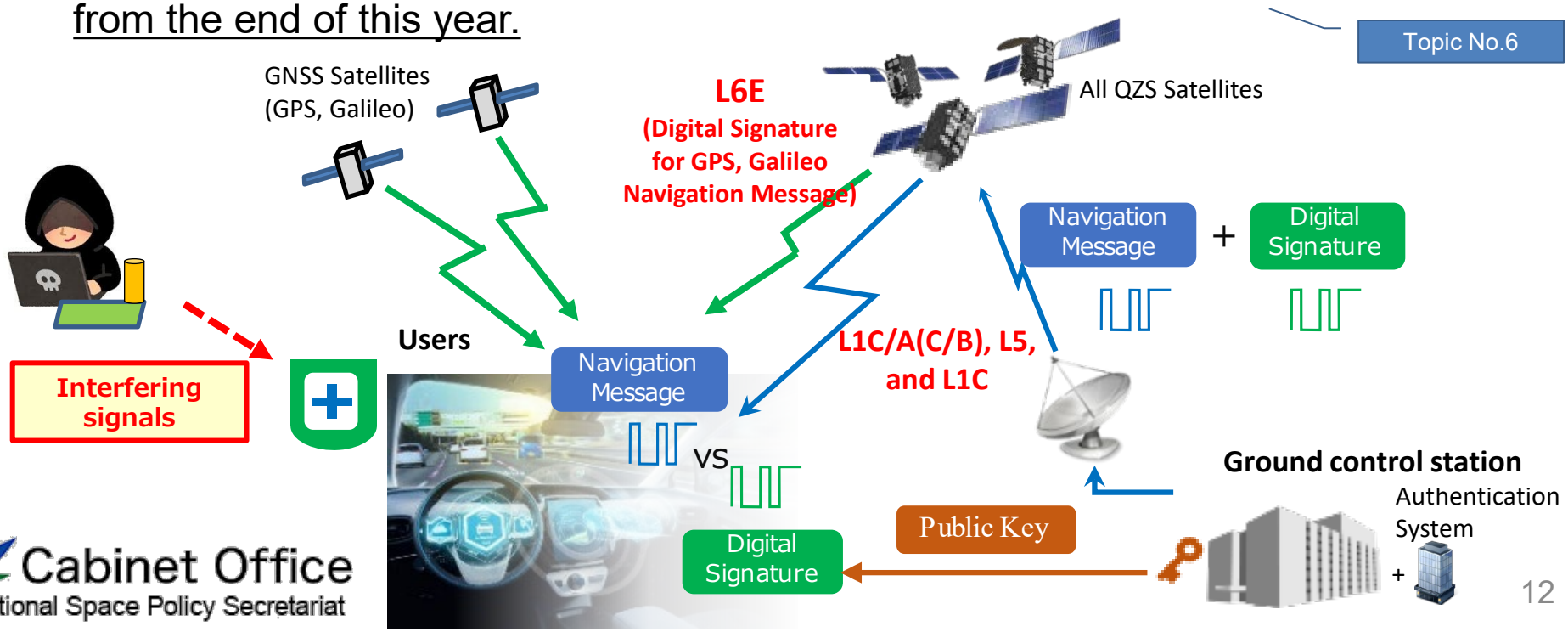
- To improve the accuracy of user positioning, it is necessary to estimate the orbit and clock of each satellite more accurately. In order to improve these,
  - The three new satellites will be equipped with inter-satellite ranging capabilities.
  - The three new satellites and the upgraded ground system will be equipped with ground-satellite ranging capabilities as well.



# 3. Toward Seven-satellite constellation (7/13)

- QZNMA will launch in JFY2024 to enhance the resilience against spoofing attacks.
- Navigation messages in the following signals are authenticated with using Elliptic Curve Digital Signature Algorithm (ECDSA P256).
  - QZSS signals (L1C/A(C/B), L1C, L5) are directly protected by self-authentication
  - GNSS signals (GPS: L1C/A, L1C, L5, Galileo:E1b, E5a) are protected by cross-authentication (L6E)
- The Interface Specification, IS-QZSS-SAS-001(draft-002), is now available on our website, "https://qzss.go.jp/en/technical/ps-is-qzss/is_qzss_sas_agree.html", and trial transmission of L6E has started since the end of July 2023 and the self-authentication signal will transmit from the end of this year.

Topic No.6

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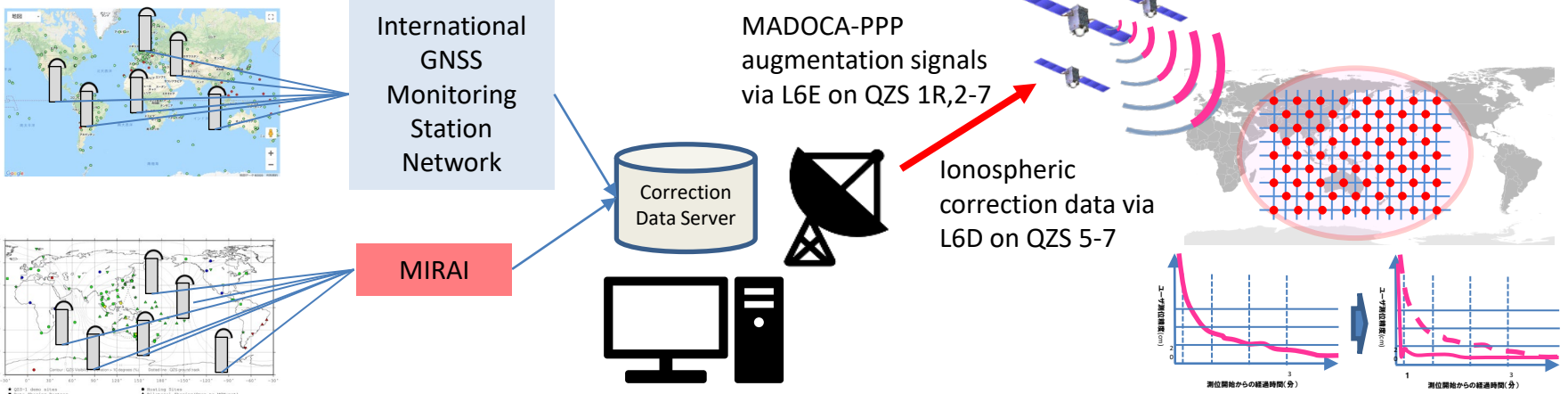
# 3. Toward Seven-satellite constellation (8/13)

- MADOCA-PPP has started on September 30, 2022 as a trial service.
- The operational service will start no later than JFY2024.
  - GNSS Monitoring Station Network, MIRAI (Multi-GNSS Integrated Real time and Archived Information system), has been released since April 2022.
  - To reduce initial convergence time of MADOCA-PPP, the ionospheric correction data for Asia Pacific region will be broadcasted from JFY2024 as an experiment.
- <u>Demonstrations have been conducted in cooperation with partners in Asia-Oceania region in order to expand users as shown the next slide.</u>




Fast PPP convergence time would be able to reduce with QZSS wide area ionospheric correction.

# 3. Toward Seven-satellite constellation (9/13)

Topic No.7-1

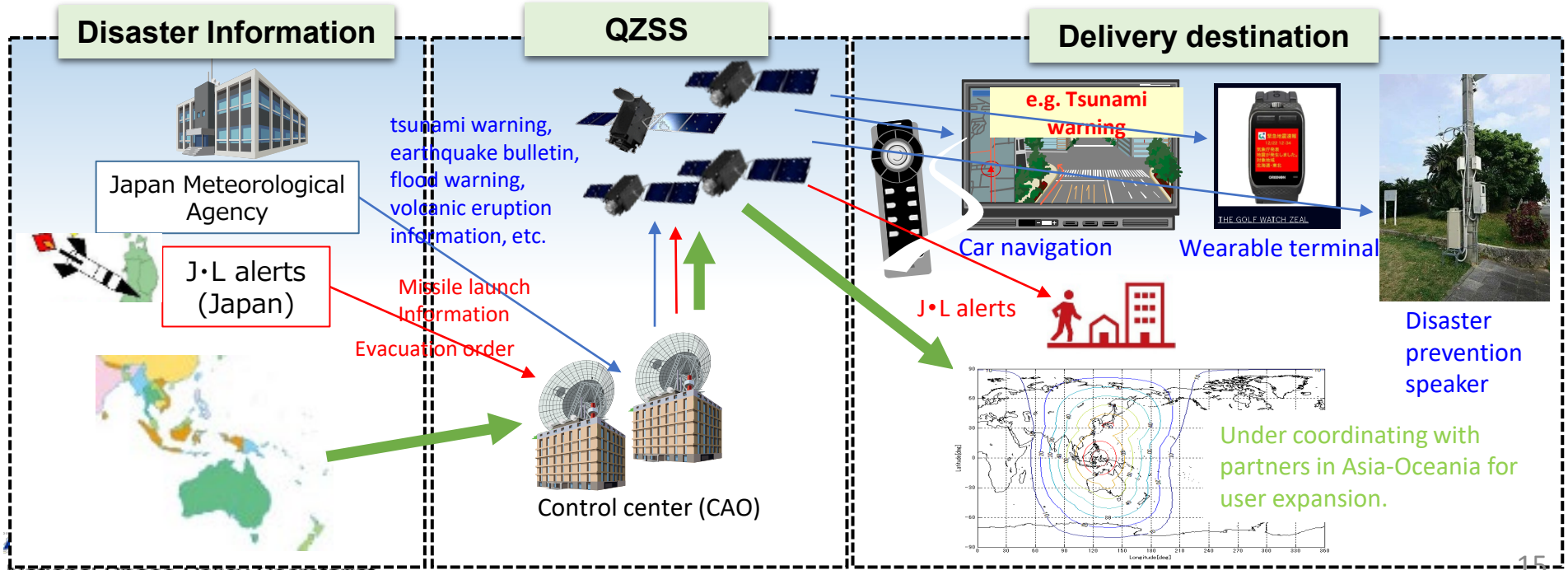
- CAO is building relationships with countries in Asia-Oceania:
  - to look for the needs and seeds of MADOCA utilization for application,
  - to conduct demonstration to confirm MADOCA applicability.
  - to ask for cooperation in providing CORS data or generating ionospheric correction data.
- We have agreements with Australia (GA), Indonesia (BIG, BRIN), Thailand (GISTDA), Philippines (NAMRIA), and Vietnam (VNSC).
- Since MADOCA-PPP can provide highly accurate positioning without reference stations, CAO would like to promote its use on remote areas such as remote islands.

Performance demonstration in Indonesia

MADOCA Training in the Philippines

# 3. Toward Seven-satellite constellation (10/13)

- EWSS has been distributed disaster-related information created by the Japan Meteorological Agency, JMA, since 2018 using its positioning signal (L1S).
- The other disaster-related information called L-alert and J-alert will be delivered as only domestic service, such as an evacuation order, after JFY2024.
- Demonstrations have been conducted in cooperation with partners in Asia-Oceania region in order to verify to be useful during disaster as shown the next slides.
- The common EWSS message has been fixed with dedicated work from EC.



# 3. Toward Seven-satellite constellation (11/13)

Topic No.7-2

- In Thailand; evacuation notifications for **forest fires and air pollution** to residents and fire notification to rangers (Fire extinguishing) were conducted in January, 2023.

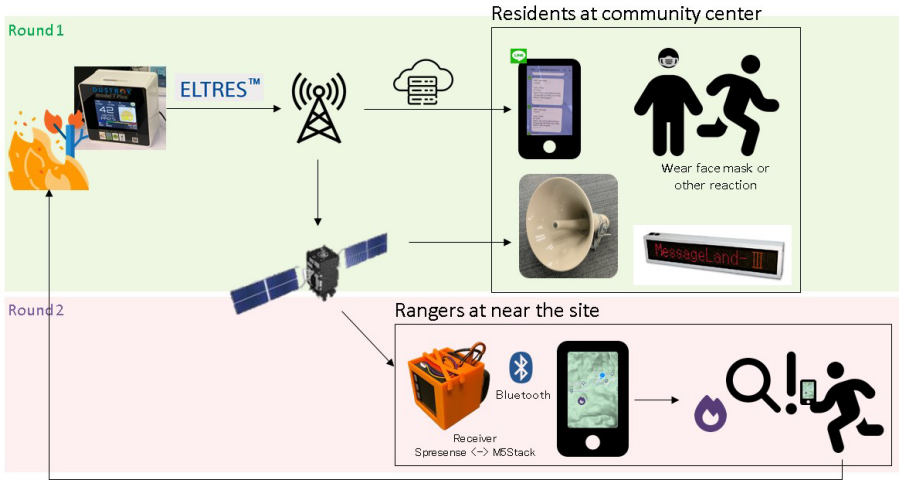
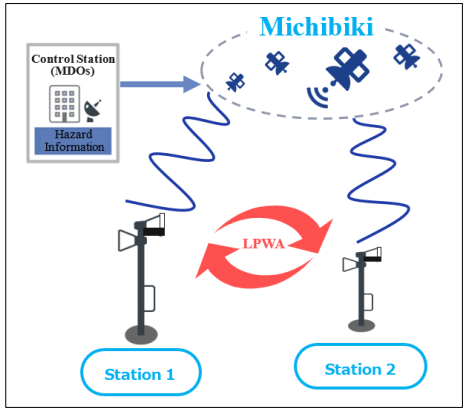



Image of demonstration

Site of demonstration (Chang Mai, Silanna National Park)

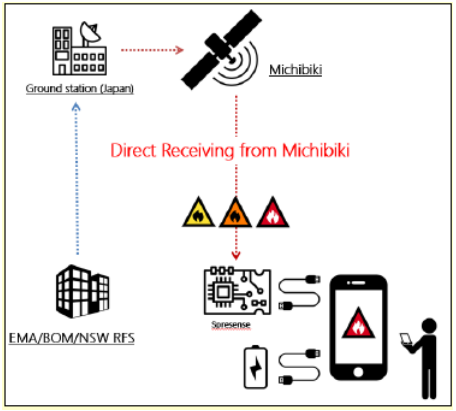
- In Fiji; evacuation notification for Tsunami was conducted in February 2023.




Fiji(Tsunami warning)

# 3. Toward Seven-satellite constellation (12/13)

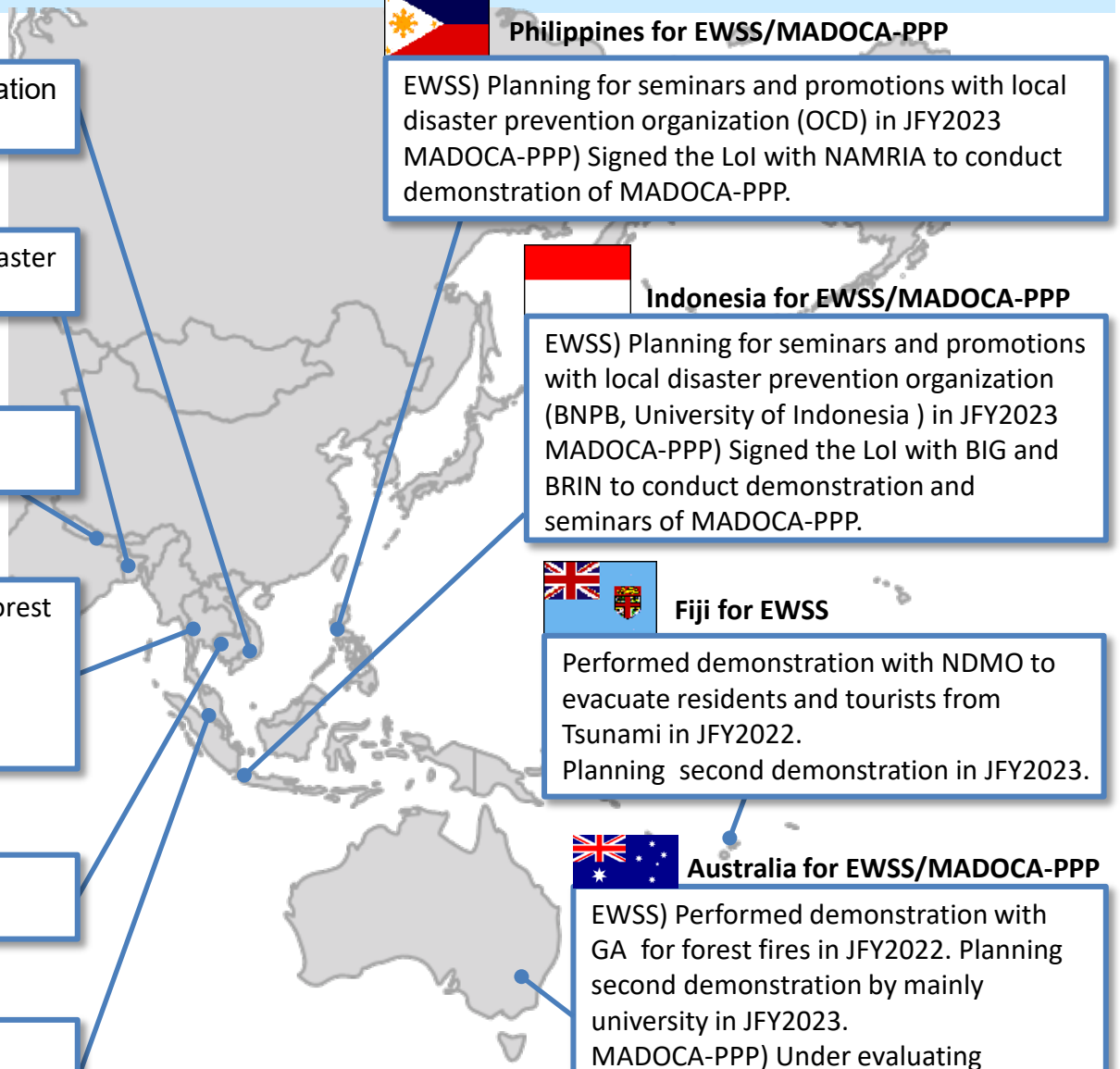
- In Australia; evacuation notification for bushfire was conducted in March 2023.
- Second demonstrations will be conducted in these three countries in early 2024 with reflecting the feedback of previous demonstration.
- Aside from above demonstrations, seminars and promotions are also scheduled to disseminate QZS/EWSS in Indonesia, Bangladesh, Nepal, Philippines, and Cambodia, and were already performed in Malaysia in August 2023.




Australia (Bushfire warning)

Seminar and Promotional Demo
In Malaysia

# 3. Toward Seven-satellite constellation (13/13)



**Vietnam for MADOCA-PPP**

Signed the LoI with VNSC to conduct demonstration of MADOCA-PPP.

**Bangladesh for EWSS**

Planning for seminars and promotions with local disaster prevention organization (MDMR, etc) in JFY2023

**Nepal for EWSS**

Planning for seminars and promotions with local organizations (MOHA, etc) in JFY2023

**Thailand for EWSS/MADOCA-PPP**

EWSS) Performed demonstration with GISTDA for forest fires in JFY2022. Planning second demonstration in JFY2023.
MADOCA-PPP) Under evaluating positioning performance with GISTDA.

**Cambodia for EWSS**

Planning for seminars and promotions with local organization (NCMD) in JFY2023

**Malaysia for EWSS**

Performed of seminars and promotions with local disaster prevention organization (NADMA, etc) in August, 2023

**Philippines for EWSS/MADOCA-PPP**

EWSS) Planning for seminars and promotions with local disaster prevention organization (OCD) in JFY2023
MADOCA-PPP) Signed the LoI with NAMRIA to conduct demonstration of MADOCA-PPP.

**Indonesia for EWSS/MADOCA-PPP**

EWSS) Planning for seminars and promotions with local disaster prevention organization (BNPB, University of Indonesia ) in JFY2023
MADOCA-PPP) Signed the LoI with BIG and BRIN to conduct demonstration and seminars of MADOCA-PPP.

**Fiji for EWSS**

Performed demonstration with NDMO to evacuate residents and tourists from Tsunami in JFY2022.
Planning second demonstration in JFY2023.

**Australia for EWSS/MADOCA-PPP**

EWSS) Performed demonstration with GA for forest fires in JFY2022. Planning second demonstration by mainly university in JFY2023.
MADOCA-PPP) Under evaluating ionospheric correction performance using GA CORS data.

# 4. New Basic Plan on Space Policy

Topic No.8

- **Human activities are expanding into outer space in earnest**, **the space system contributes to solving various issues on the earth** as well as to strengthening security-related efforts.
- As the economic and social transformation brought about by activities on the frontier of space (**i.e., space transformation**) is becoming a global trend, Japan needs to **maintain and strengthen its independence in space activities and lead the world**. To realize this, the Basic Plan on Space Policy was revised on **June 13th, 2023**.

## Goals and Future Vision

(1) Ensure Space Security

(2) Ensure national resilience, tackle global-scale issues and achieve innovation

(3) Create new knowledge and industries in space science and exploration

(4) Strengthen the industrial base to support space activities

## Basic Principles for Space Policy Promotion

(1) Implement policies for actual deployment in missions such as those of security, space science and exploration as well as commercialization

(2) Strengthen technology R&D based on the “Space Technology Strategy”

(3) Strengthen international partnerships with allies, like-minded countries and others

(4) Support and develop internationally competitive companies in a strategic manner

(5) Strengthen JAXA's role and functions as a core agency for space development

(6) Use human, financial and other resources in an effective and efficient manner

## Specific Approaches to Space Policy

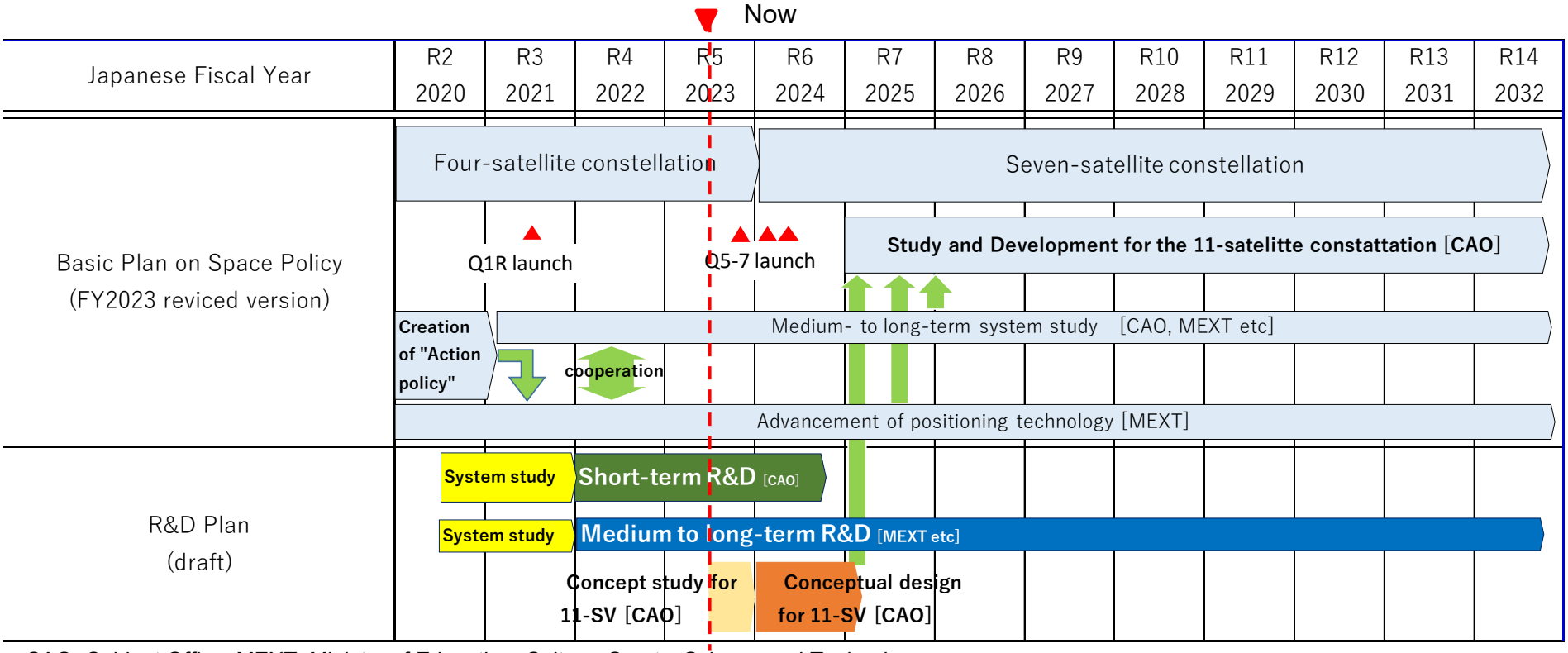
Start study and development toward an 11-satellite system

# 4. Plan for the 11-satellite constellation (1/2)

■ Based of the new basic plan on space policy, CAO will start the concept study for the 11-satellite constellation from October 2023.

Topic No.9

– Toward JFY2032, when the currently operating satellites, QZS-2, 3, and 4, will reach the end of their design life, CAO is now in "short-term R&D period" and developing some prototypes to improve the TRL, Technology Readiness Levels.




CAO: Cabinet Office, MEXT: Ministry of Education, Culture, Sports, Science and Technology

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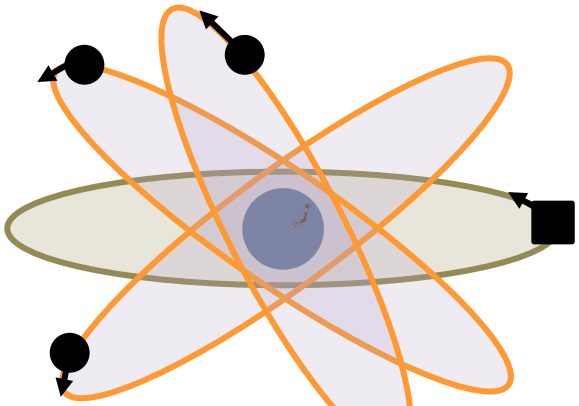
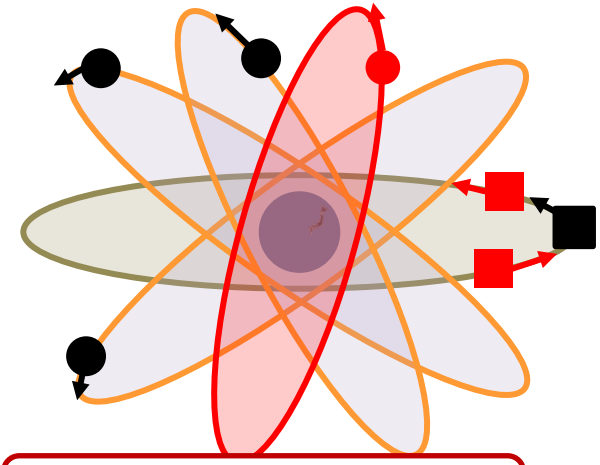
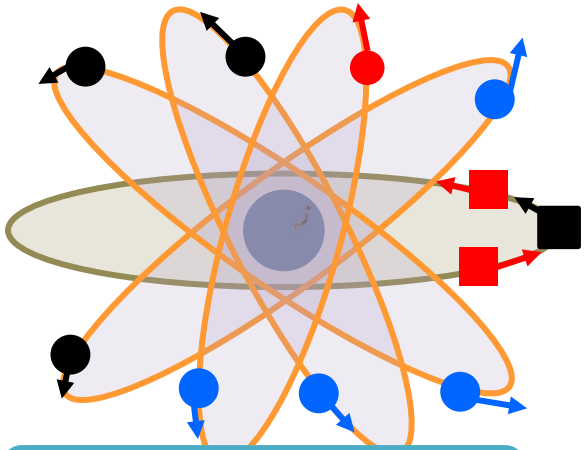
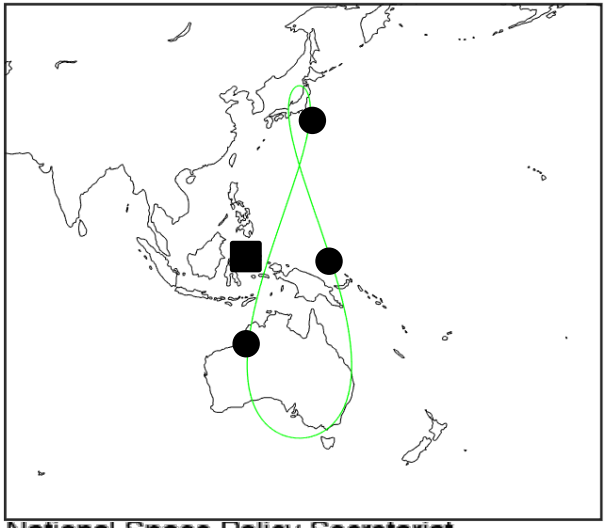
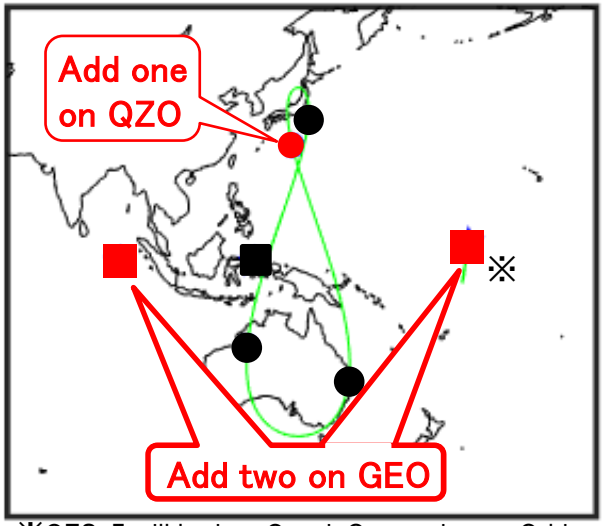
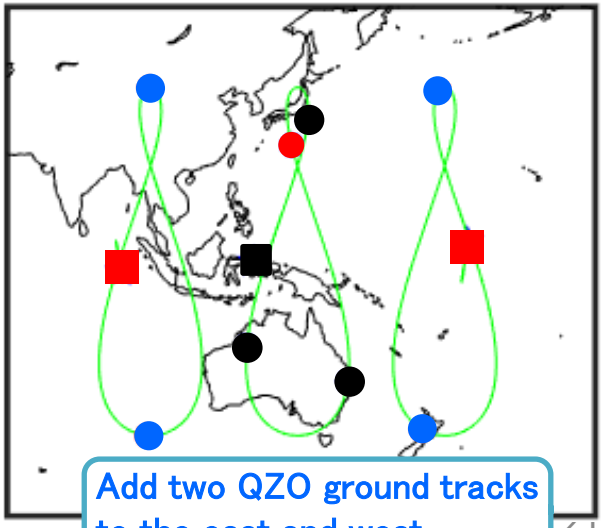
※QZS-2 Launch on July 1st 2017, QZS-3 Launch on August 19th 2017, QZS-4 Launch on Oct 10th 2017

# 4. Plan for the 11-satellite constellation (2/2)

| Four-satellite const. (current status) | Seven-satellite const. (current plan) | 11-satellite const. (future plan) |
|---|---|---|
| orbit planes: 4 (QZO: 3, GEO: 1) | orbit planes: 5 (QZO: 4, GEO: 1) | orbit planes: 5 (QZO: 4, GEO: 1) |
|  |  |  |
| 1 satellite on each plane<br>●: QZO satellite, ■: GEO satellite | 1 satellite on each QZO plane,<br>**3** satellites on GEO plane | **2** satellites on each QZO plane,<br>3 satellites on GEO plane |
|  |  |  |

※QZS-7 will be in a Quasi-Geostationary Orbit.

# 5. QZSS Applications (1/2)

Topic No.10

■ As of the end of September 2023, **425 products** are compatible with QZSS.

* it was 390 products last year.

## ☐ Autonomous driving

QZSS compatible antenna (Built in shark fin)

QZSS compatible antenna (Built in shark fin)

©Honda R&D Co., Ltd.

© Nissan Motor Co., Ltd.

## ☐ Snowplow

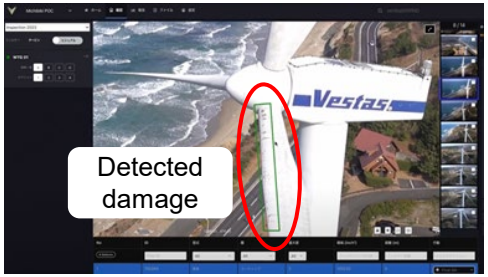

Demonstration of snow removal operation
© Hokkaido Regional Development Bureau

## ☐ autonomous navigation vessels

Robotic AI Cruiser with AI CAPTAIN
「Eight Knot I」

## ☐ Drones for wind farm inspection

Eagle15 by Drone Work System




## ☐ Automated management for construction work

Antenna mounted on helmet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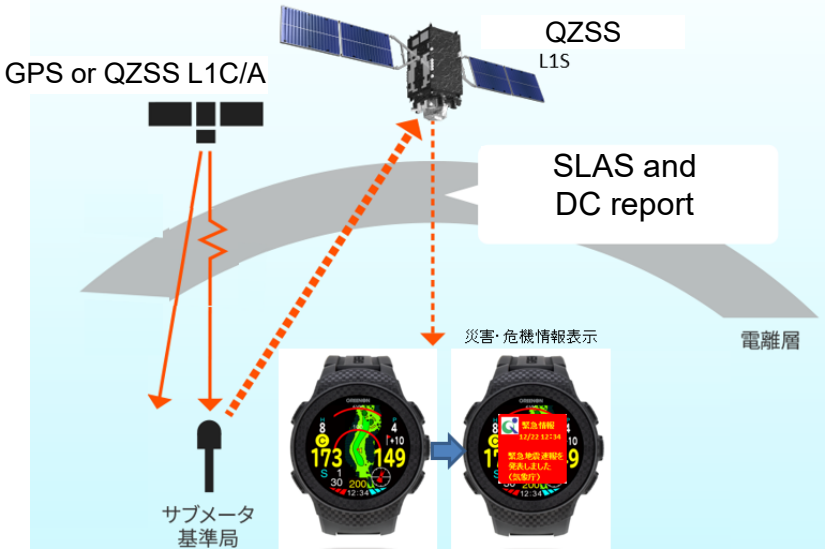
# 5. QZSS Applications (2/2)

- A wristwatch-type wearable device supports golfers by displaying the distance to the green. It can also display the EWSS messages via QZSS.

## To display distance to the green


## Disaster and crisis management notification indication

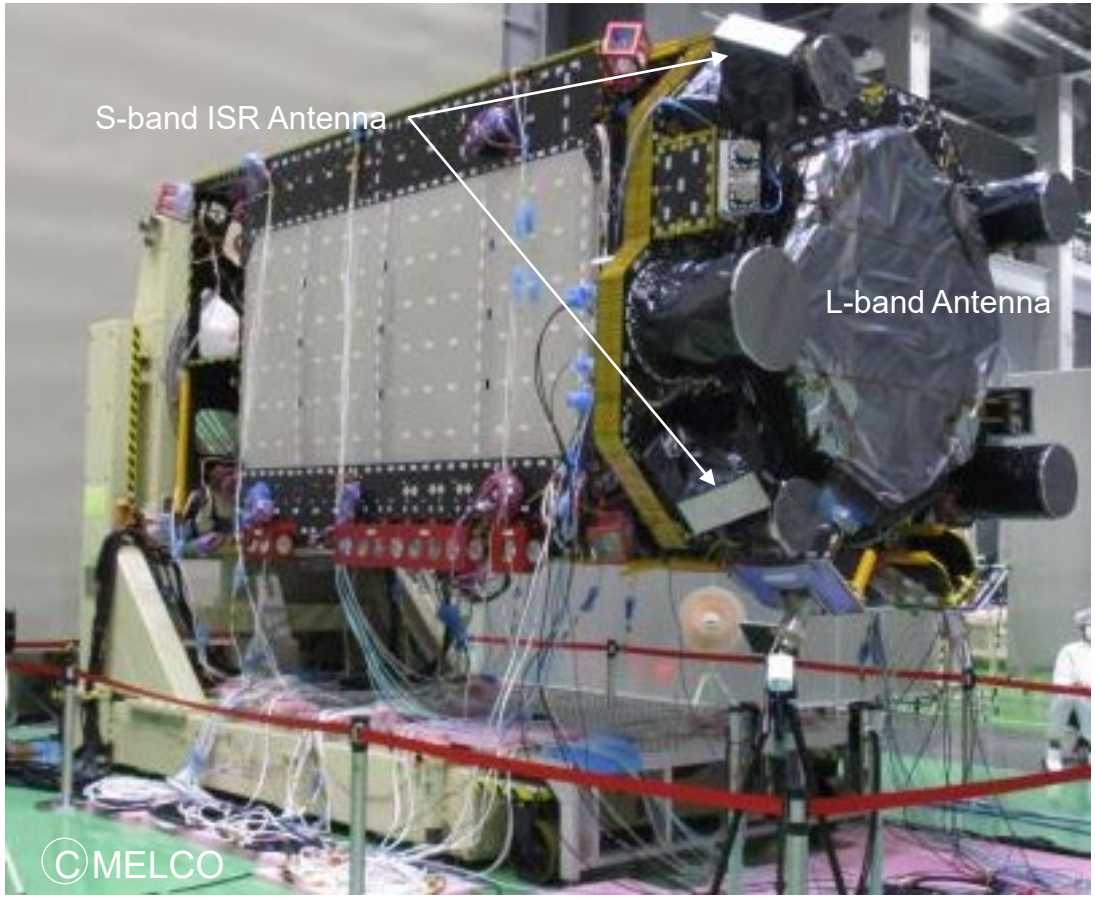


# 6. Conclusions

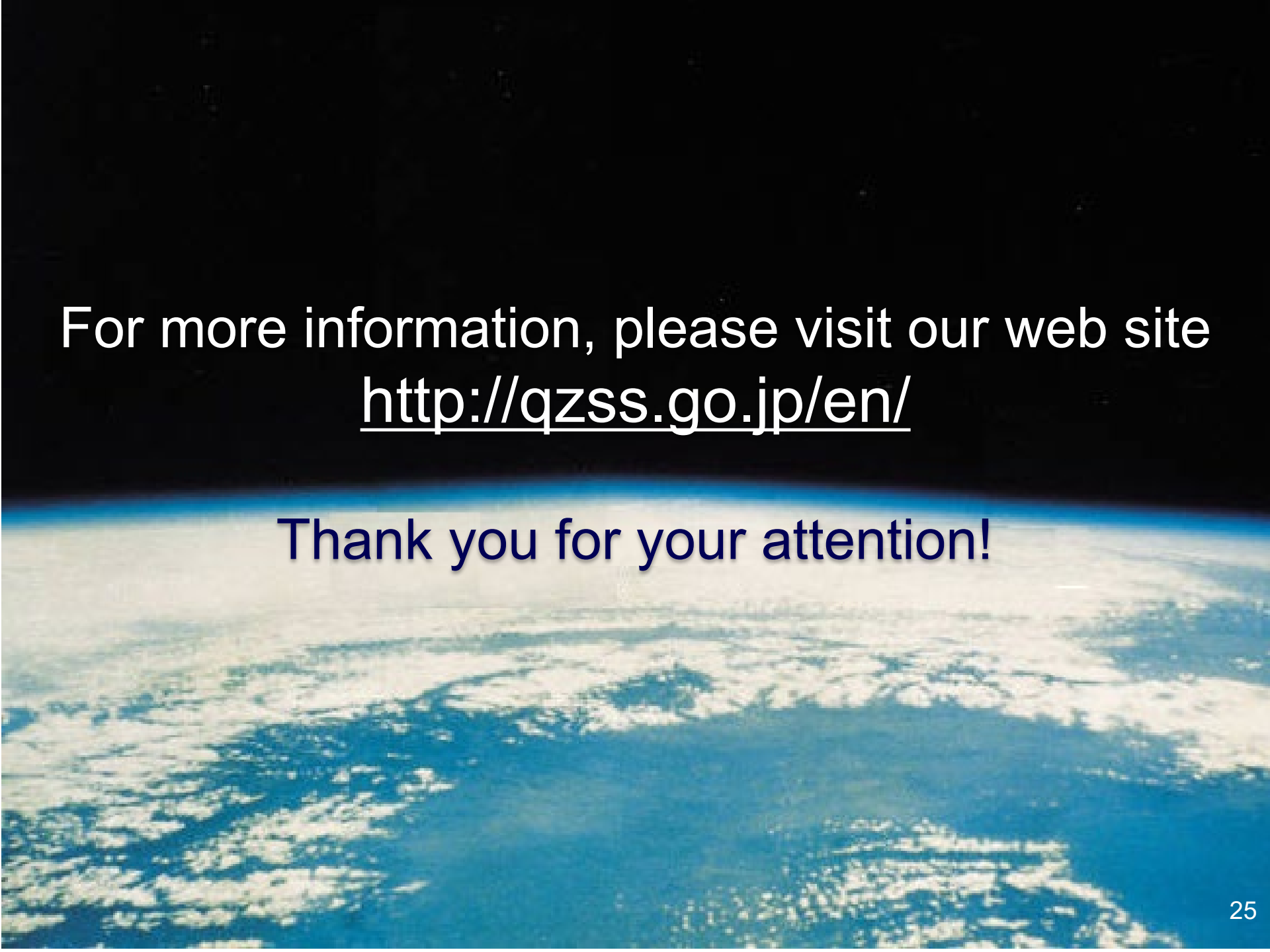
Since the QZSS has become gradually rooted in our society, it is expected that the seven-satellite constellation system will be operated as soon as possible.

Furthermore, future expansion 11-satellite constellation system based on the new policy will be implemented and can contribute greatly to our society as part of Digital Transformation.

We are looking forward to the development of society with QZSS.




Electrical performance test for QZS-6



For more information, please visit our web site
http://qzss.go.jp/en/

Thank you for your attention!

# *Supporting Information*

# QZSS Overview -System Architecture-

## Ranging Signals of QZSS

| Signal | Frequency MHz | Service | Compatibility | QZS-1/1R IGSO | QZS-2/4 IGSO | QZS-3 GEO |
|---|---|---|---|---|---|---|
| L1C/A | 1575.42 | Positioning | Complement GPS | ✓ | ✓ | ✓ |
| L1C | | Positioning | Complement GPS | ✓ | ✓ | ✓ |
| L1C/B | | Positioning | Complement GPS | ✓ *only QZS1R | - | - |
| L1S | | Augmentation(SLAS) | DGPS (Code Phase Positioning) | ✓ | ✓ | ✓ |
| | | Messaging | Short Messaging | ✓ | ✓ | ✓ |
| L1Sb | | Augmentation(SBAS) | SBAS (L1) Service | - | - | ✓ |
| L2C | 1227.60 | Positioning | Complement GPS | ✓ | ✓ | ✓ |
| L5 I/Q | 1176.45 | Positioning | Complement GPS | ✓ | ✓ | ✓ |
| L5S | | Experimental(L5 SBAS) | L5 SBAS (DFMC) | ✓ *only QZS1R | ✓ | ✓ |
| L6D | 1278.75 | Augmentation(CLAS) | PPP-RTK (Carrier Phase Positioning) | ✓ | ✓ | ✓ |
| L6E | | Experimental(MADOCA) | PPP, PPP-AR (Carrier Phase Positioning) | ✓ *only QZS1R | ✓ | ✓ |

# 1. QZSS Overview

- GPS Complementary Service

  – In order to obtain stable position information, it is necessary to see more satellites.

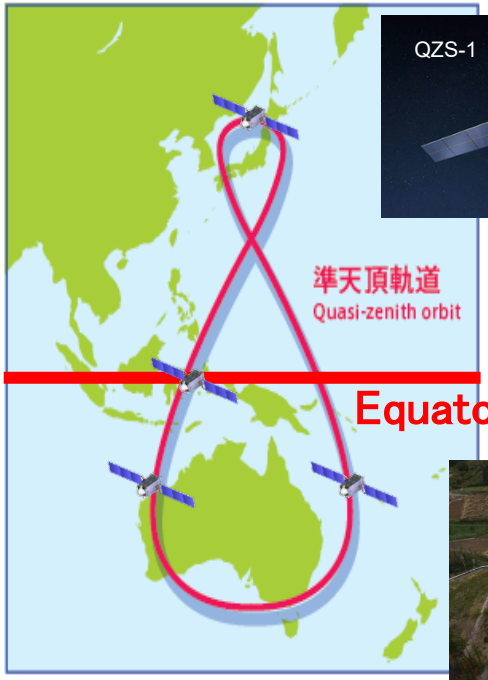
  – However, we cannot receive the enough signals from GPS satellites in particular areas, such as urban areas and mountainous areas, because radio waves are blocked by buildings and trees.

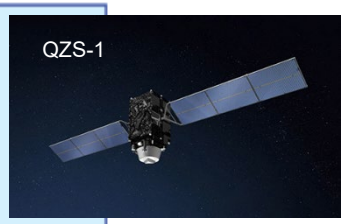
  – QZSS has been operating four satellites since November 2018, three of which are located for constant observation at all points in the Asia-Oceania region.

  – For this reason, QZSS can be used together with GPS/GNSS to secure the required number of satellites.

# 1. QZSS Overview

- ***Constellation:***
  - One GEO satellite, QZS-3, 127E Longitude
  - Three QZO satellites (IGSO*)
- ***Ground System***
  - Two master control centers
    - Hitachi-Ota and Kobe
  - Seven TTC Stations
    - Located south-western islands
  - Over 30 monitor stations around the world with the cooperation of countries

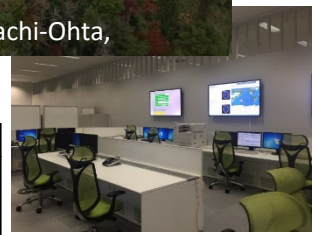


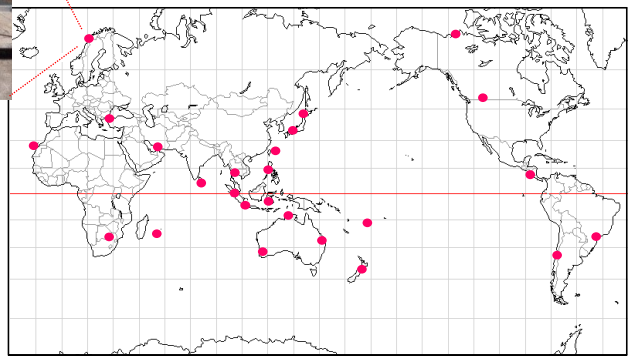







QZSS Control Center, Hitachi-Ohta,

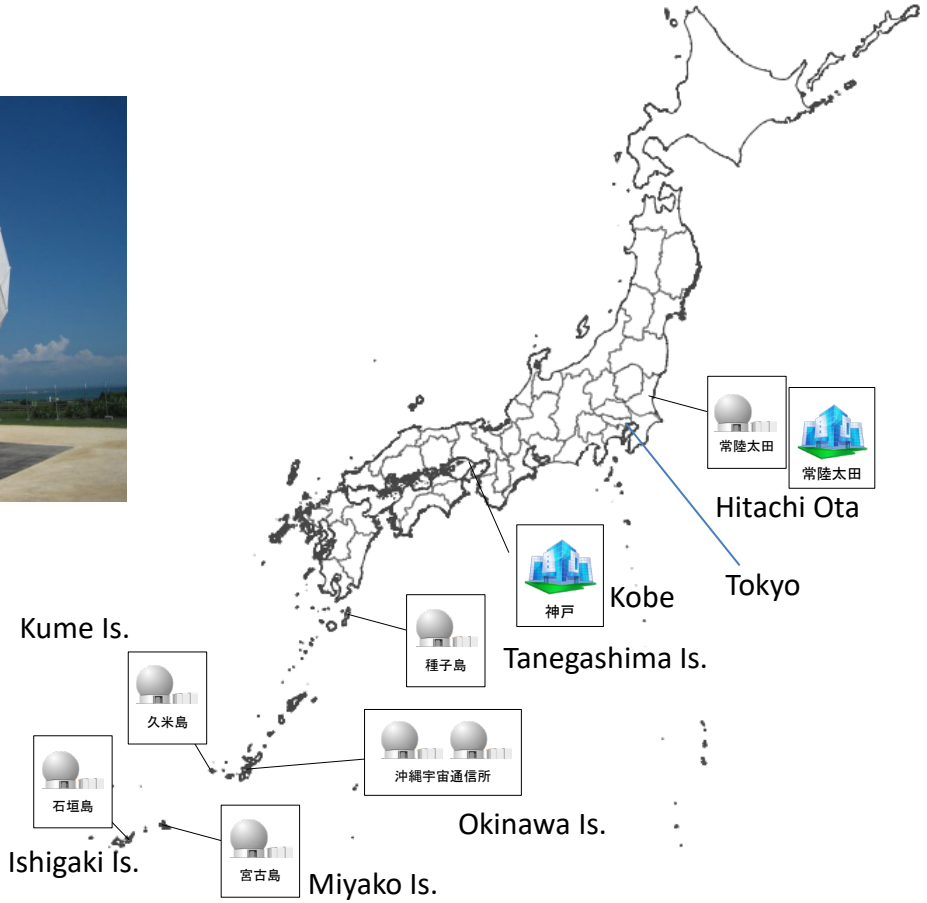




* Inclined Geosynchronous Orbit

# 1. QZSS Overview

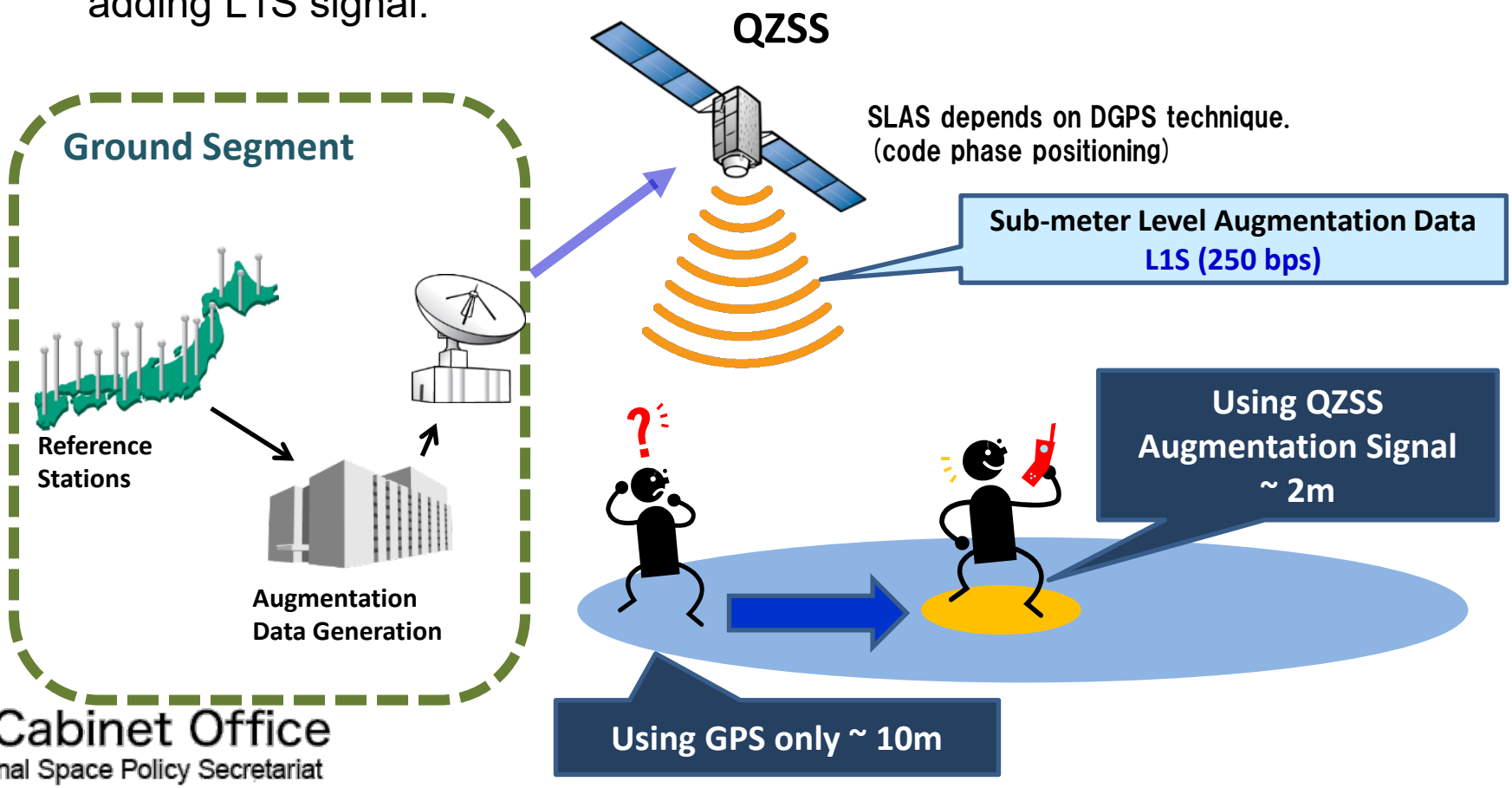
- QZSS TTC Stations




  - Seven TTC (Telemetry, Tracking and Command) stations: Most are at the southern part of Japan to ensure continuous visibility of satellites .
  - All the stations have been built and set for operation by the end of 2016.

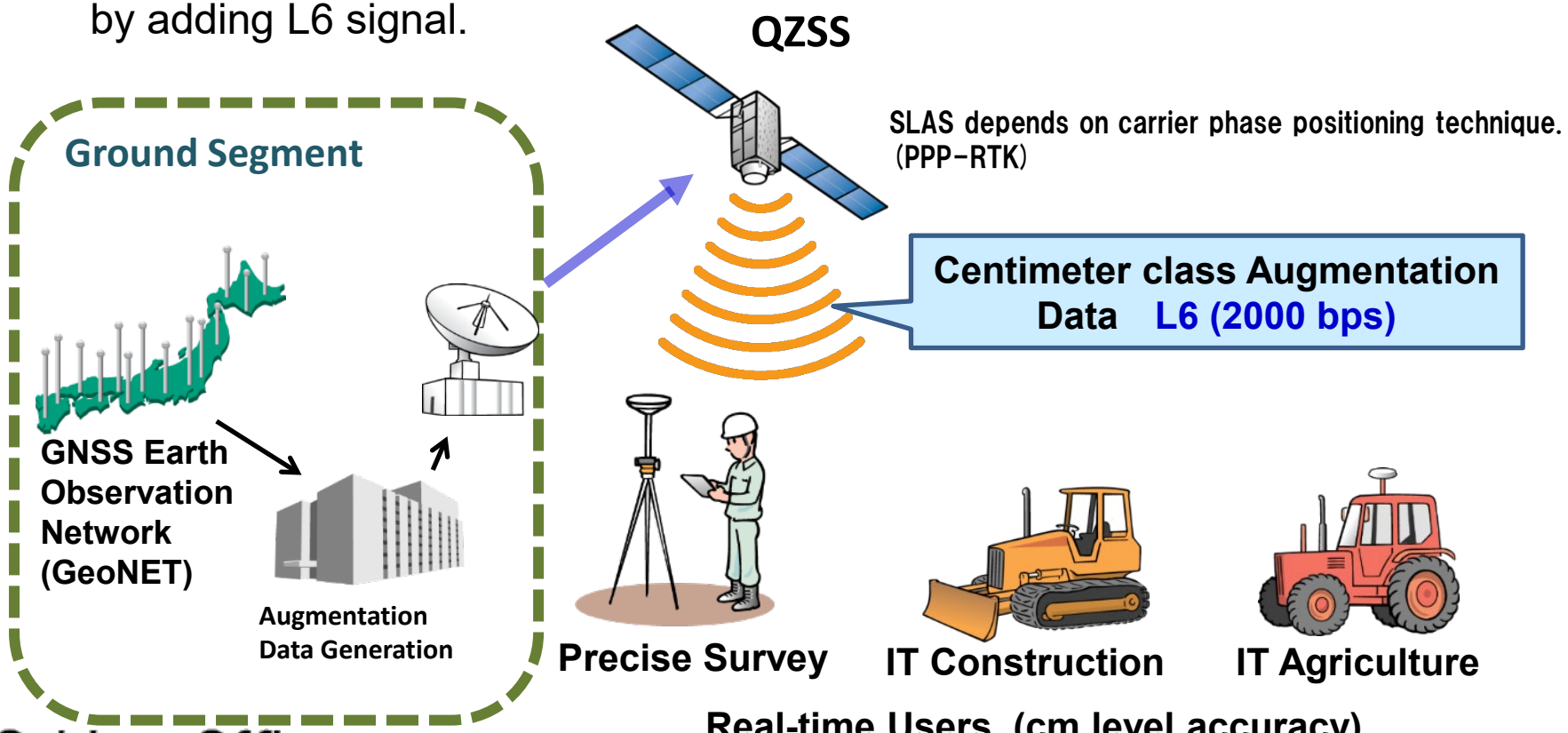
# SLAS

- GNSS Augmentation Service (1/2)
  - One of the augmentation service is SLAS, Sub-meter Level Augmentation Service, for domestic.
  - SLAS achieves an error within 1-m in horizontal and 2-m in vertical by adding L1S signal.



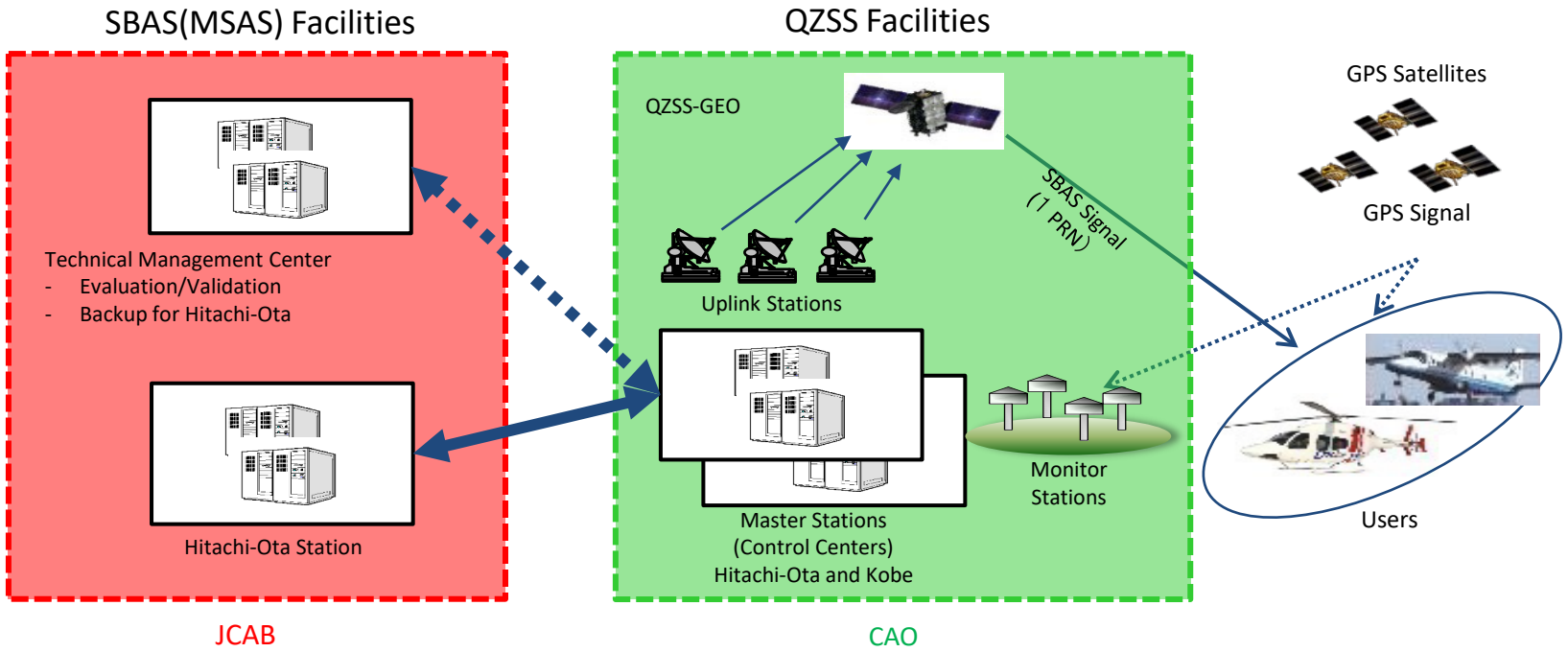
# CLAS

- GNSS Augmentation Service (2/2)
  - Another one is CLAS, centimeter cLass Augmentation Service, for domestic.
  - CLAS achieves an error within 6.0-cm in horizontal and 12.0-cm in vertical by adding L6 signal.



# SBAS

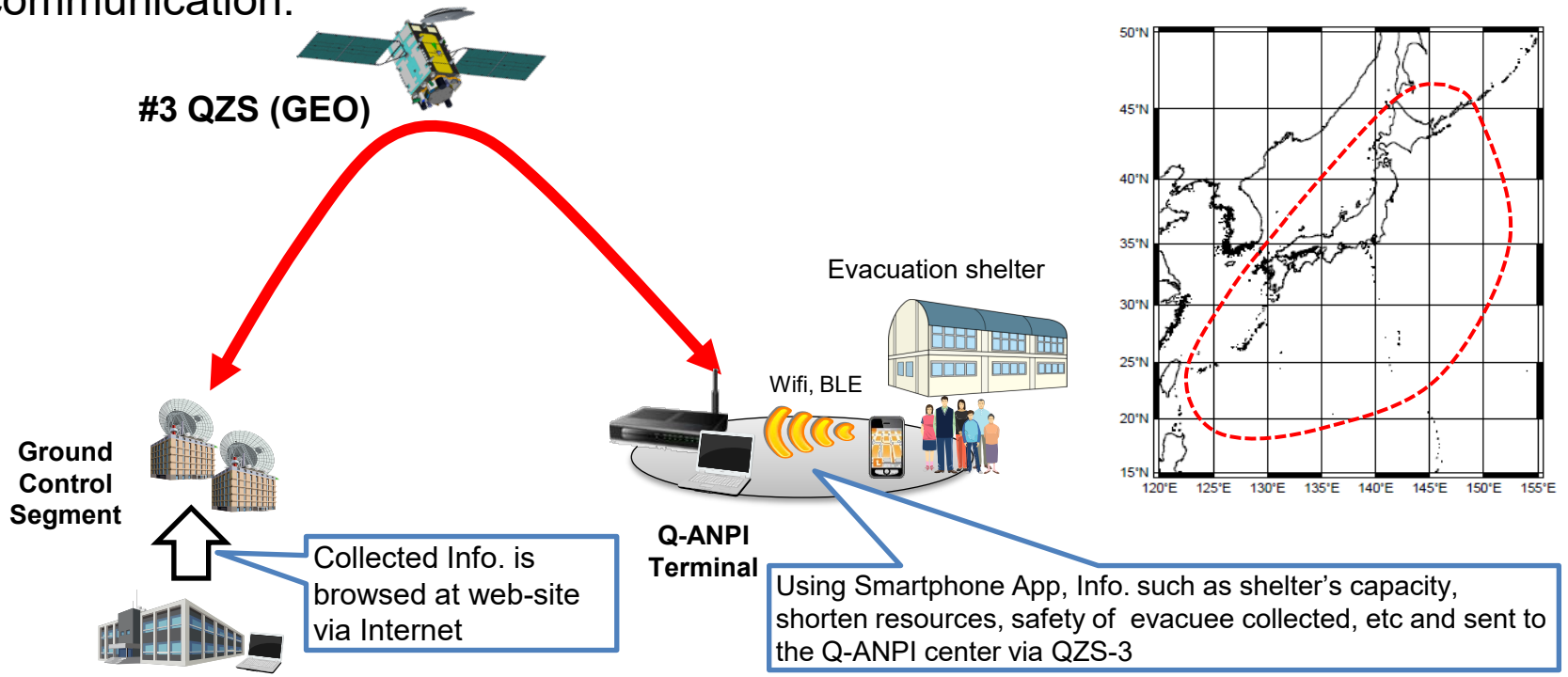
- MSAS: Japanese SBAS
  - MSAS is provided by JCAB, Japanese Civil Aviation Bureau, with QZS-3 operated by CAO from April 2020 which is augmented GPS for utilizing reroute, terminal and approach phase of aircrafts.
  - As addition update plan of MSAS, it will improve performance to LPV 200 like as ILS-CAT 1 (precision approach) under seven constellation system.




MSAS: MTSAT Satellite-based Augmentation System
LPV: Localizer Performance with Vertical guidance
ILS-CAT 1 :Instrument Landing System – Category 1

# Q-ANPI

- Messaging Service
  - The QZSS safety confirmation service, Q-ANPI, is also available as a communication service for domestic.
  - It is achieved via GEO satellite, QZS-3, and performed S-band two-way communication.




This service is available on S-band devices that support Q-ANPI, Q-ANPI terminal.