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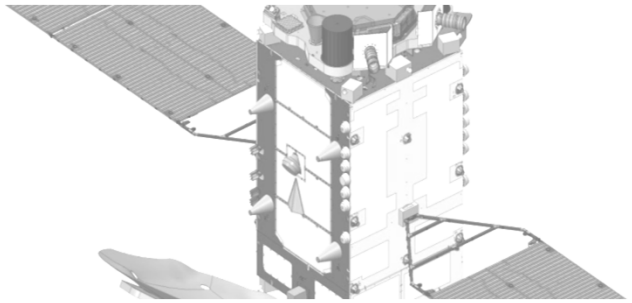


QZSS Status Update

Quasi-Zenith Satellite System,
Japanese Regional Navigation Satellite System

First Plenary Session of the 16th ICG
October 10th, 2022

Kenji NUMATA
Director for QZSS Strategy Office
National Space Policy Secretariat
Cabinet Office, Government of Japan

Contents

1. QZSS Overview

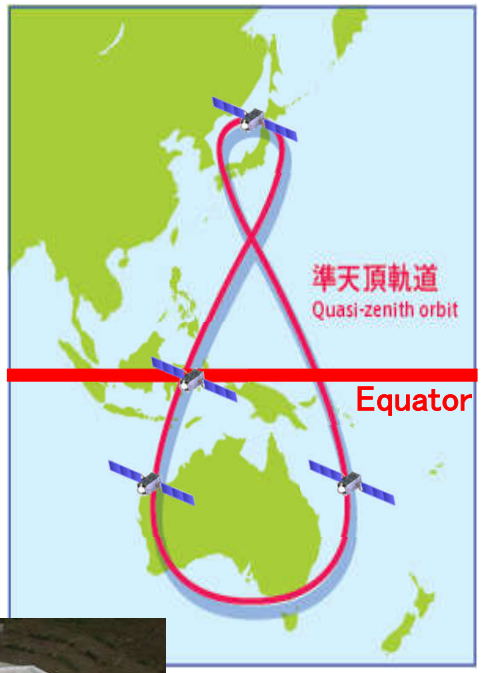
- We are now operating the four-satellite constellation to provide following services:
  - GPS Complementary Service（PNT* service）
  - GNSS Augmentation Service, i.e. SLAS, CLAS and SBAS
  - Messaging Service

* Position, Navigation and Timing

- 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.




QZSS Control Center, Hitachi-Ohta,

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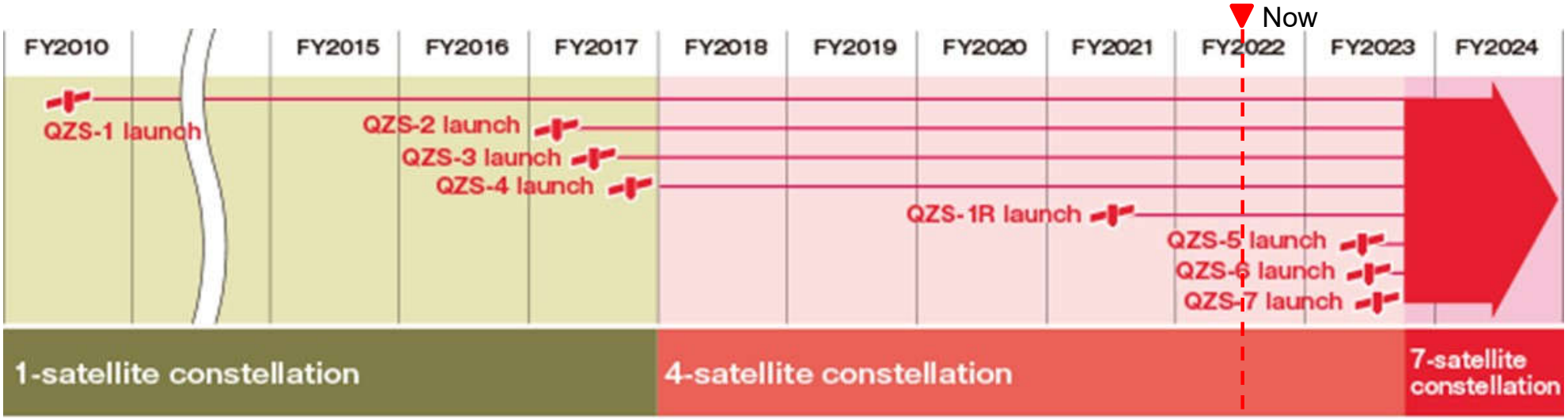
1. QZSS Overview

- The QZS-1R, which is the successor of the first QZS, was launched by H-IIA Launch Vehicle on October 26, 2021 at the Tanegashima Space Center.
- The launch was successful and the QZS-1R has been in service since March 24, 2022.

H-IIA Launch Vehicle No. 44 (provided by MHI)

2. QZSS Seven-satellite constellation

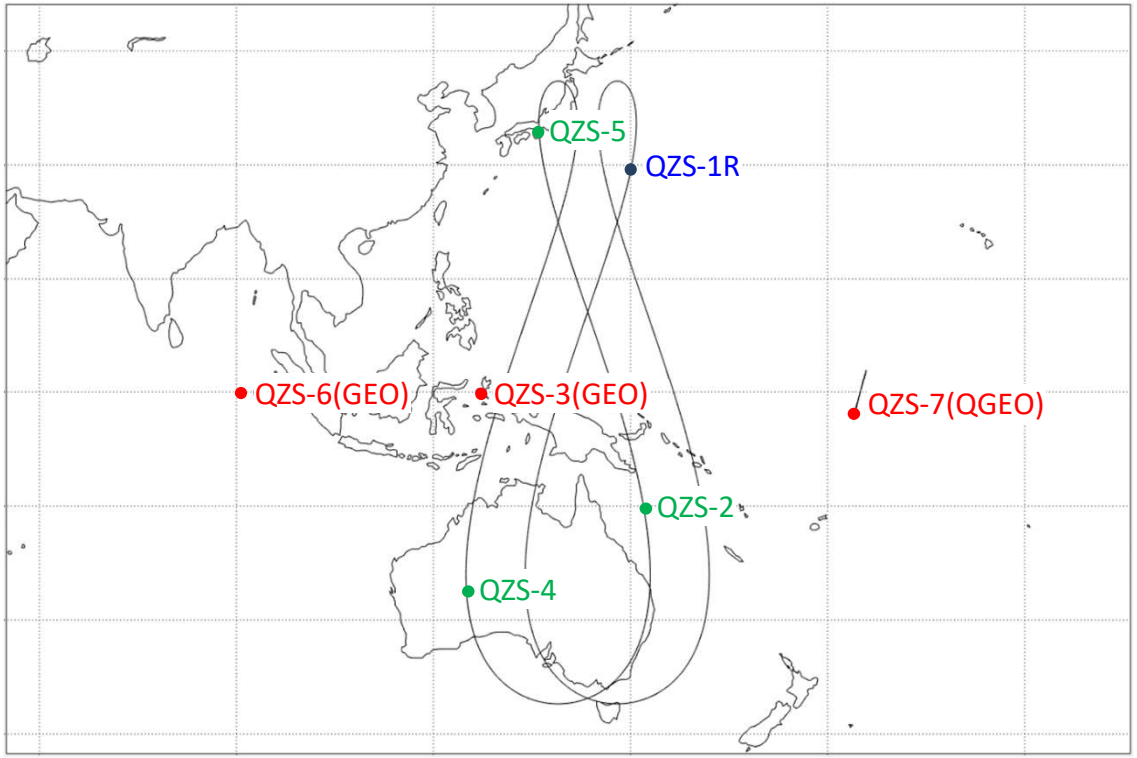
- The seven satellites constellation is scheduled to complete around JFY2023. We are currently developing three new satellites and upgrading the ground system for them.



- With the completion of three more new satellites, we will be able to provide a positioning/timing by ourselves under certain conditions and new services, a message authentication service, MADOCA-PPP and extended EWSs.

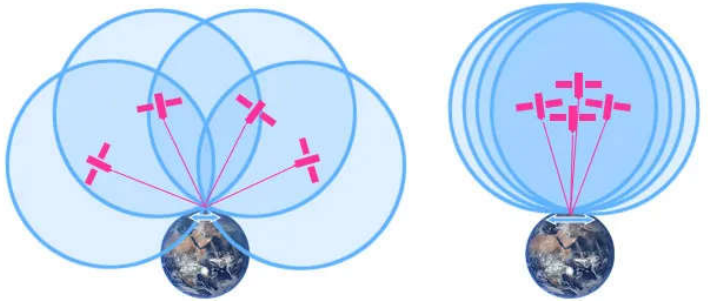
2. QZSS Seven-satellite constellation

- 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 as follows:
  - More than one satellites can always be seen at high elevation angle.
  - More than four satellites can be seen as long as possible.
  - The DOP, Dilution Of Precision, can be as low as possible



Seven-QZS Ground Track

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



Low DOP　　High DOP

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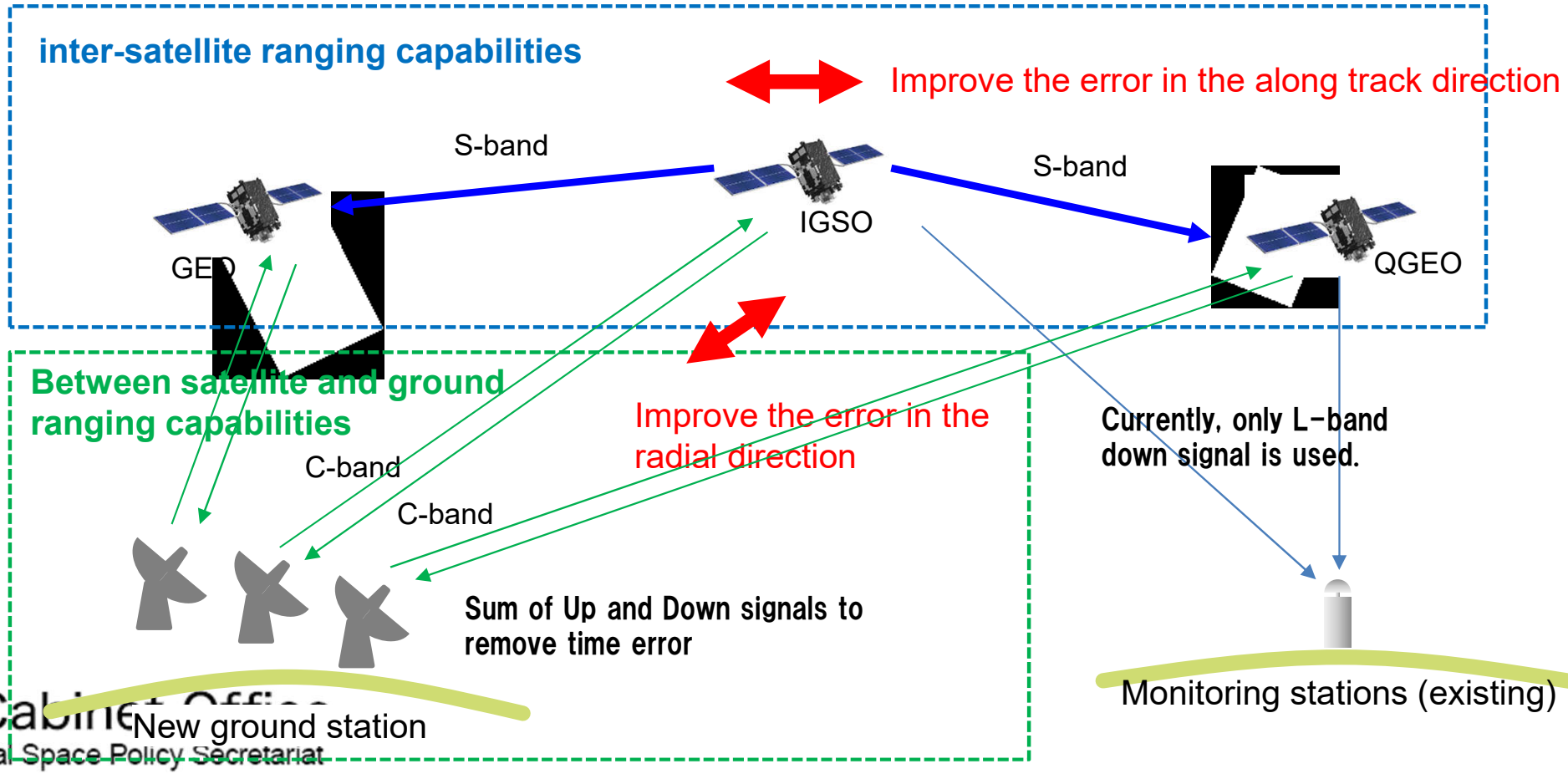
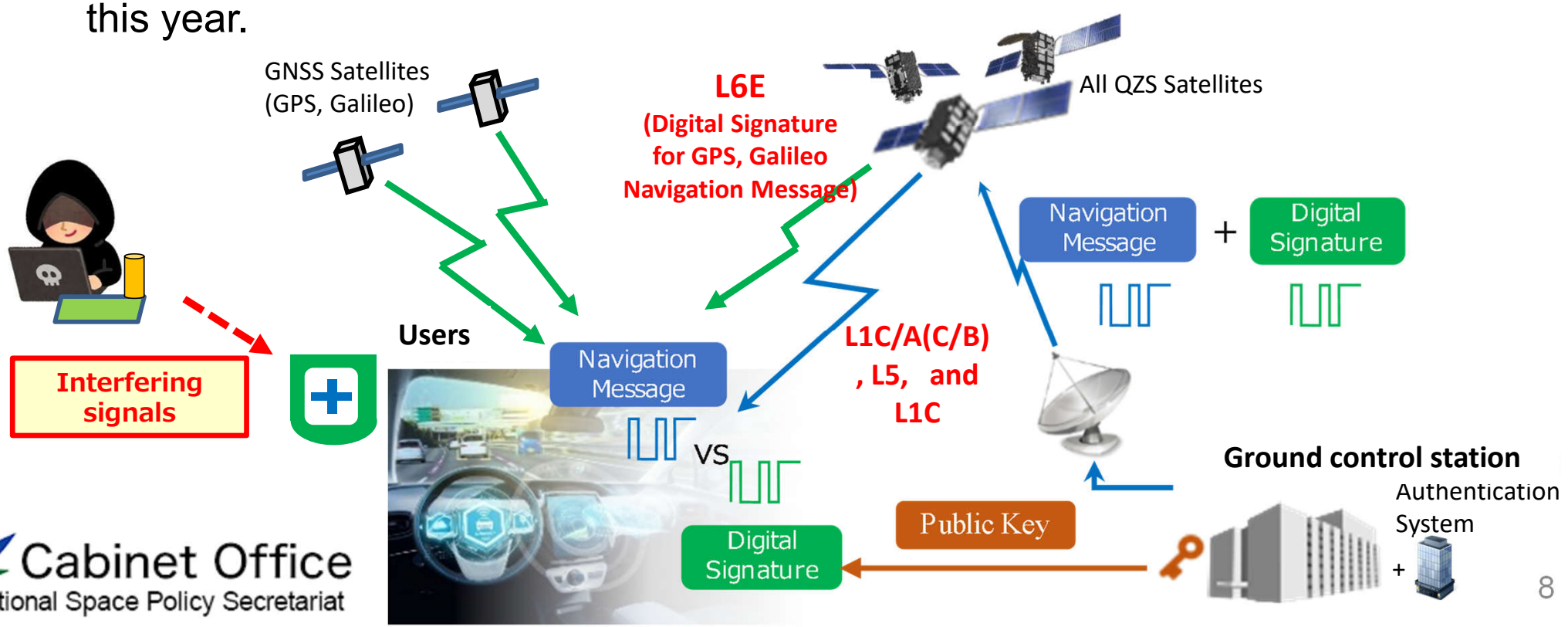
2. QZSS Seven-satellite constellation

- 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.



2. QZSS Seven-satellite constellation

- QZSS Navigation Message Authentication service, QZNMA, will be lunched in 2024 as part of the resilience enhancement 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)
- A tentative Interface Specification (IS-QZSS-SAS) will be issued by the end of this year.



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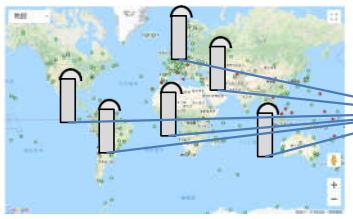
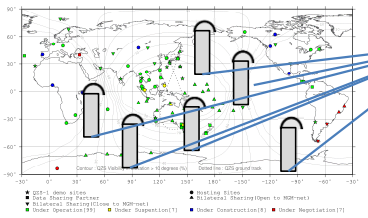
2. QZSS Seven-satellite constellation

- MADOCA-PPP, Multi-GNSS Advanced Orbit and Clock Augmentation - Precise Point Positioning, has begun 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.
- Demonstrations will be conducted in cooperation with partners in Asia-Oceania region for user expansion.



International GNSS Monitoring Station Network

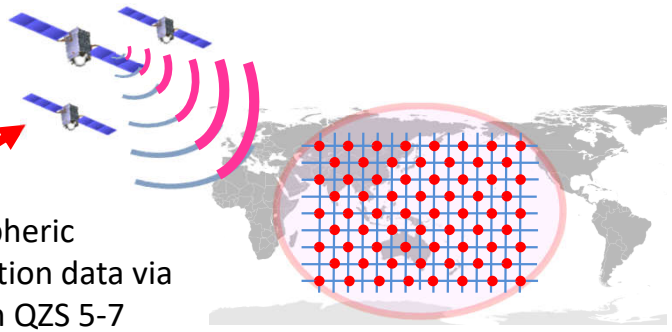


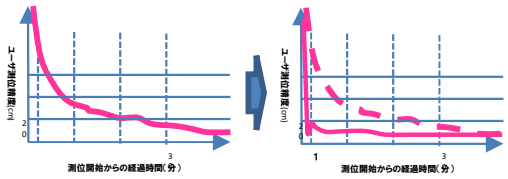
MIRAI

Correction Data Server

MADOCA-PPP augmentation signals via L6E on QZS 1R,2-7

Ionospheric correction data via L6D on QZS 5-7

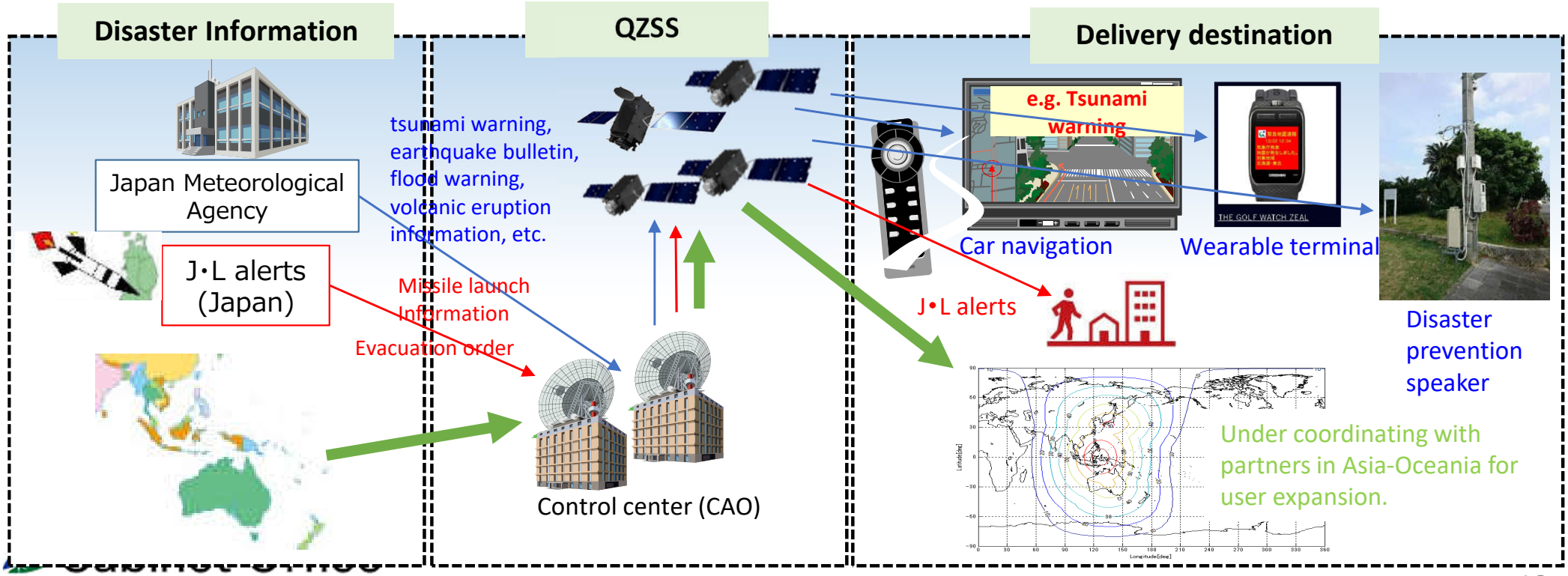




Fast PPP convergence time would be able to reduce with QZSS wide area ionospheric correction.

2. QZSS Seven-satellite constellation

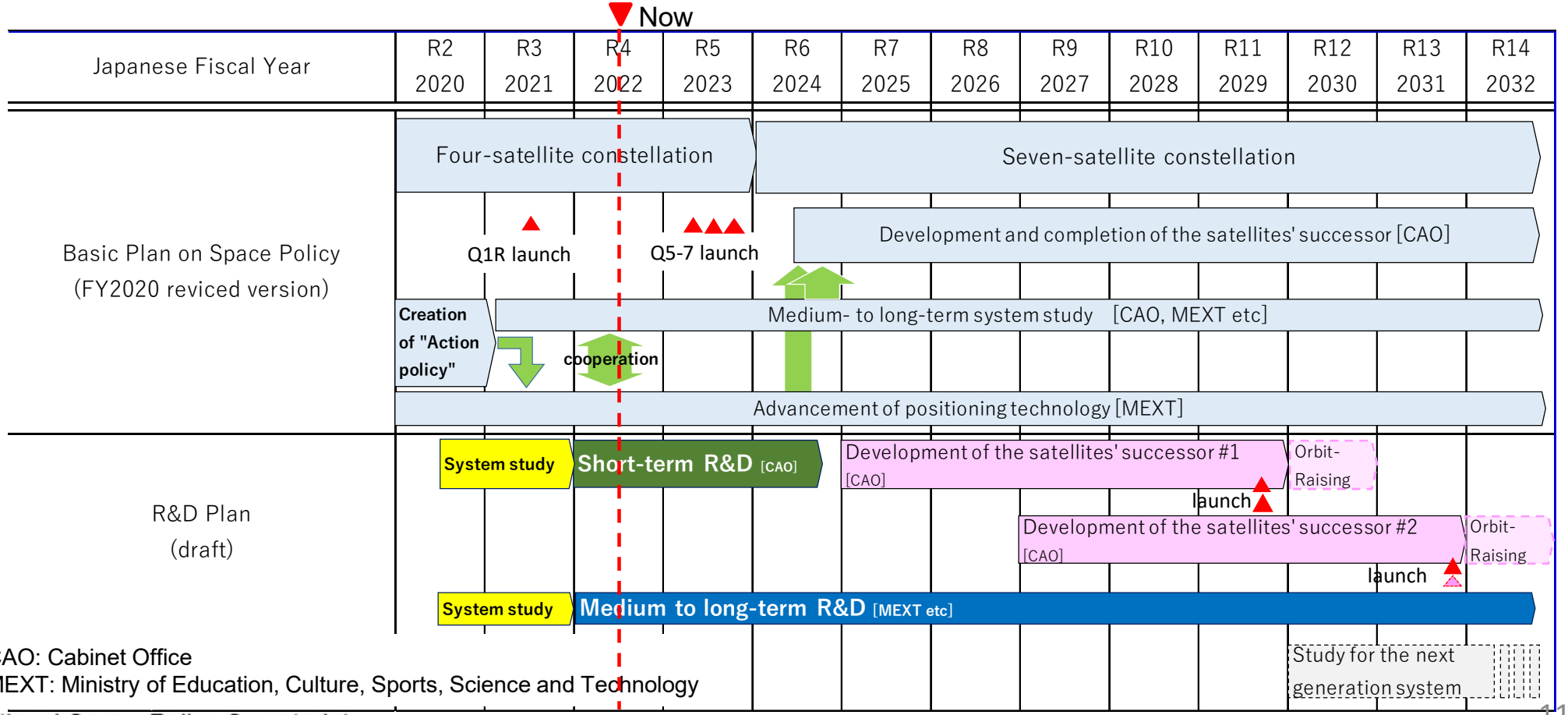
- As for Early/Emergency Warning Service, EWS, QZSS has distributed disaster-related information created by the Japan Meteorological Agency, JMA, since 2018 using its positioning signal (L1S).
- In addition, we will deliver other disaster-related information called L-alert or J-alert as only domestic service, such as a missile launch information or an evacuation order.
- While, we will also broadcast disaster-related information in Asia-Oceania region after JFY2022 as demonstrations in cooperation with partners in the region.



3. Research and Development

Future system performance directions and elemental technologies

- We have selected technical issues for future QZS system and summarized the direction of research and development since JFY2021.
  - The below tentative R&D schedule has been taking account of JFY2032, when the currently operating satellites, QZS-2, 3, and 4, will reach the end of their design life.
  - We are now in "short-term R&D period" and developing some prototypes to verify technical issues.



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

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

4. QZSS Applications

■ As of September 2022, approximately 390 products are compatible with QZSS.

☐ Autonomous driving

QZSS compatible antenna (Built in shark fin)

(©Honda R&D Co., Ltd.)

QZSS compatible antenna (Built in shark fin)

(© Nissan Motor Co., Ltd.)

☐ Buoy for real-time ocean tide monitoring

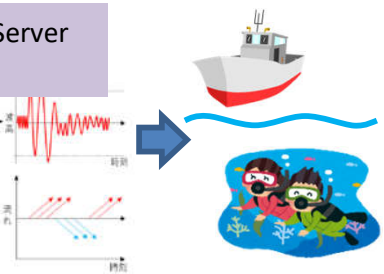
QZSS

Buoy

mobile / satellite communications

Cloud Server

AI



☐ Wearable terminals

display the distance to the green

display the EWS message

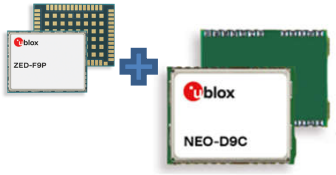
☐ Drone

Agricultural Drone

Logistics drone

☐ GNSS Receiver and Chipset

CORE Corp.
Cohac∞Ten+
(for CLAS,MADOCA)
150*210*55mm
(*available in September, 2022)



u-blox
ZED-F9P + **NEO-D9C**
(for CLAS)

u-blox
NEO-M9N/L/V
(for SLAS)
12.2*16.0*2.4mm

Septentrio
Mosaic-CLAS
31*31*4mm

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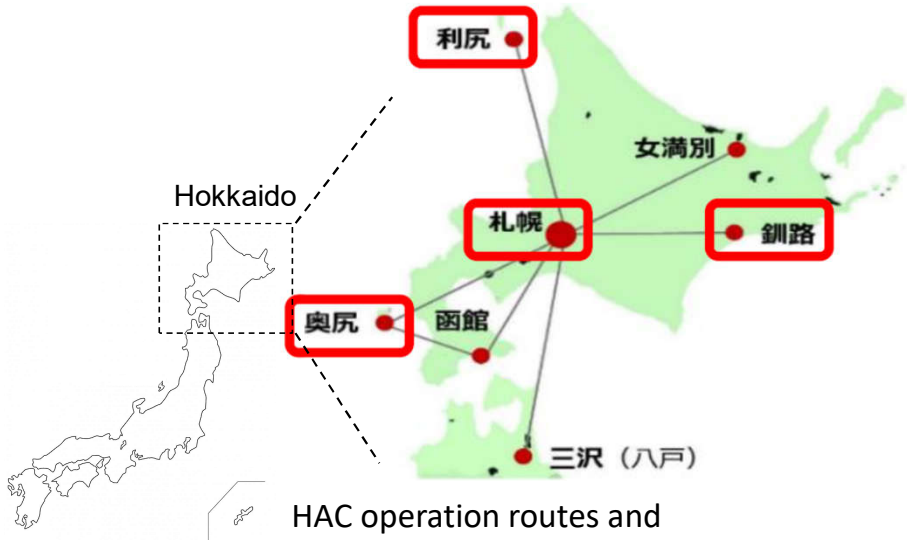
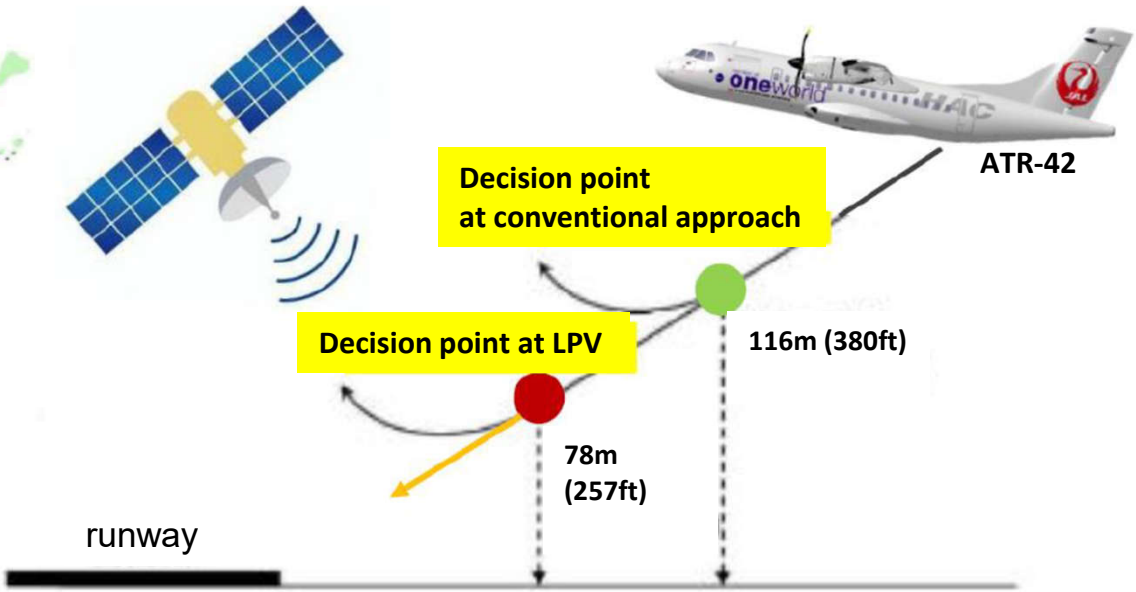
4. QZSS Applications

Example use case : LPV Approach using SBAS

- In September 2022, one of the Japan's regional airline, Hokkaido Air System (HAC), has started operating the LPV (Localizer Performance with Vertical guidance) approach when their aircrafts, ATR-42, are landing at some airports in Hokkaido, Japan.
- The LPV is an operational method of horizontal and vertical approach using GNSS and SBAS augmentation.
- For example, with the conventional approach method, the aircraft can only enter the runway at an altitude of approximately 116m (380ft) when visibility is poor, however, with LPV approach, it can enter there at that of approximately 78m (257ft).
- This technology is expected to increase convenience for users in order to increase the rate of aircraft in service.



HAC operation routes and
LPV approachable airports (red boxes)



* Figures provided by HAC

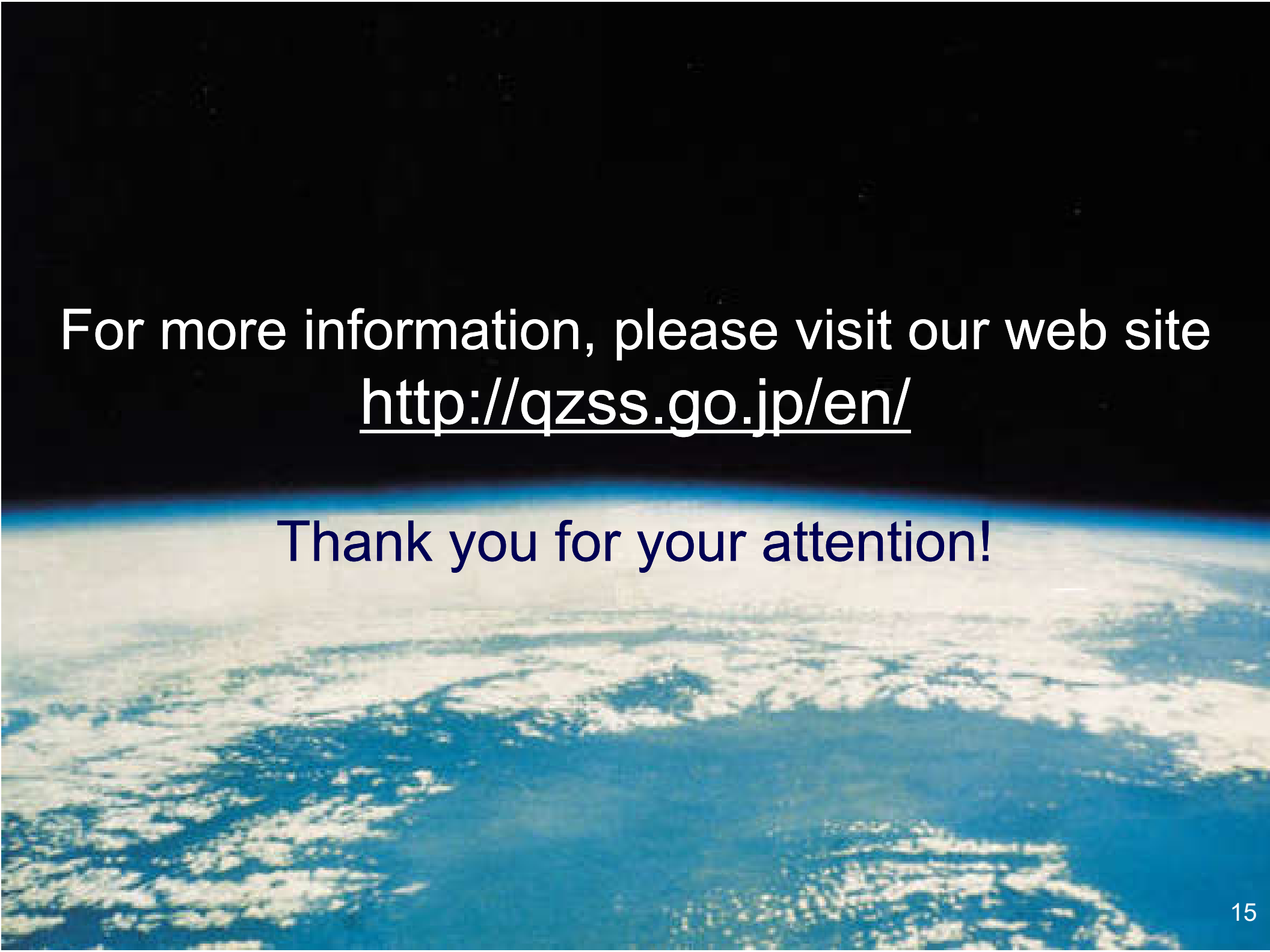
5. Summary

1. QZS-1R, launched on Oct. 26, 2021, is in service.

2. Next generation seven-satellite constellation after around JFY2023;
   - Additional three satellites and related ground system are under development
   - MADOCA-PPP is in trial service
   - QZNMA and Additional EWSs are under development

3. Utilization of the QZSS services is definitely spreading.

4. R&D for the future system, after 2033, has already started.



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	✓	✓

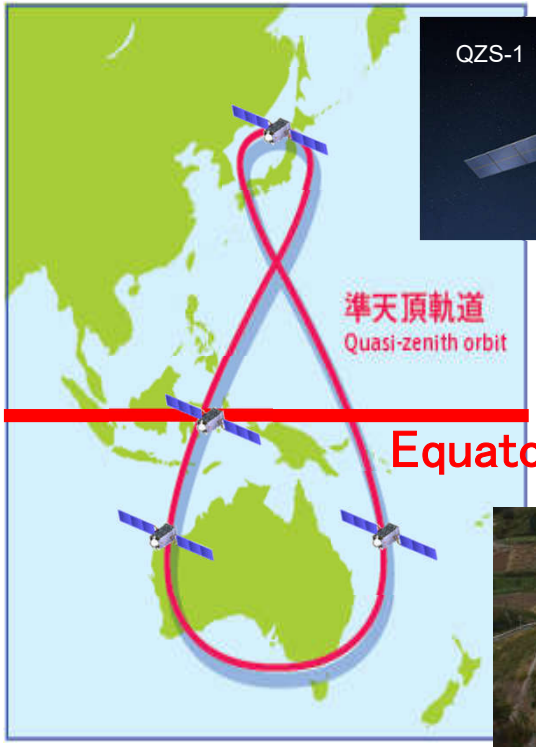
1. QZSS Overview

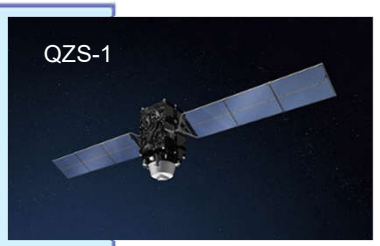
- GPS Complementary Service

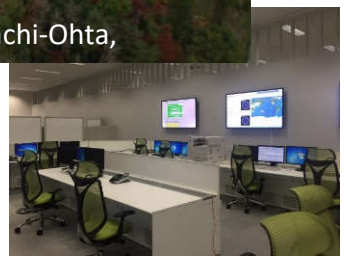
  - In order to obtain stable position information, it is necessary to see more satellites.
  - However, we cannot receive the enough signals from GPS satellites in particular areas, such as urban areas and mountainous areas, because radio waves are blocked by buildings and trees.
  - QZSS has been operating 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.

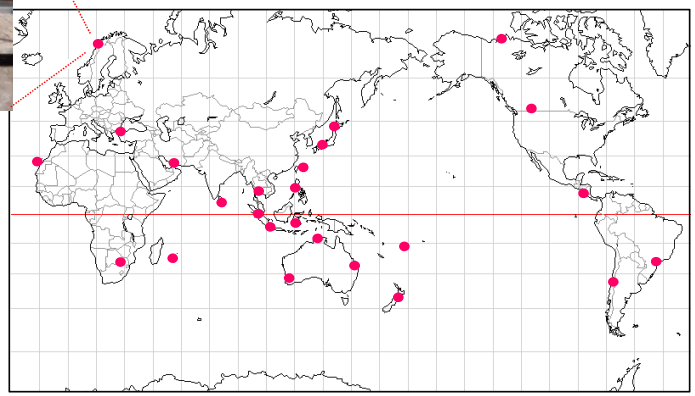
1. QZSS Overview

- ***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









* Inclined Geosynchronous Orbit

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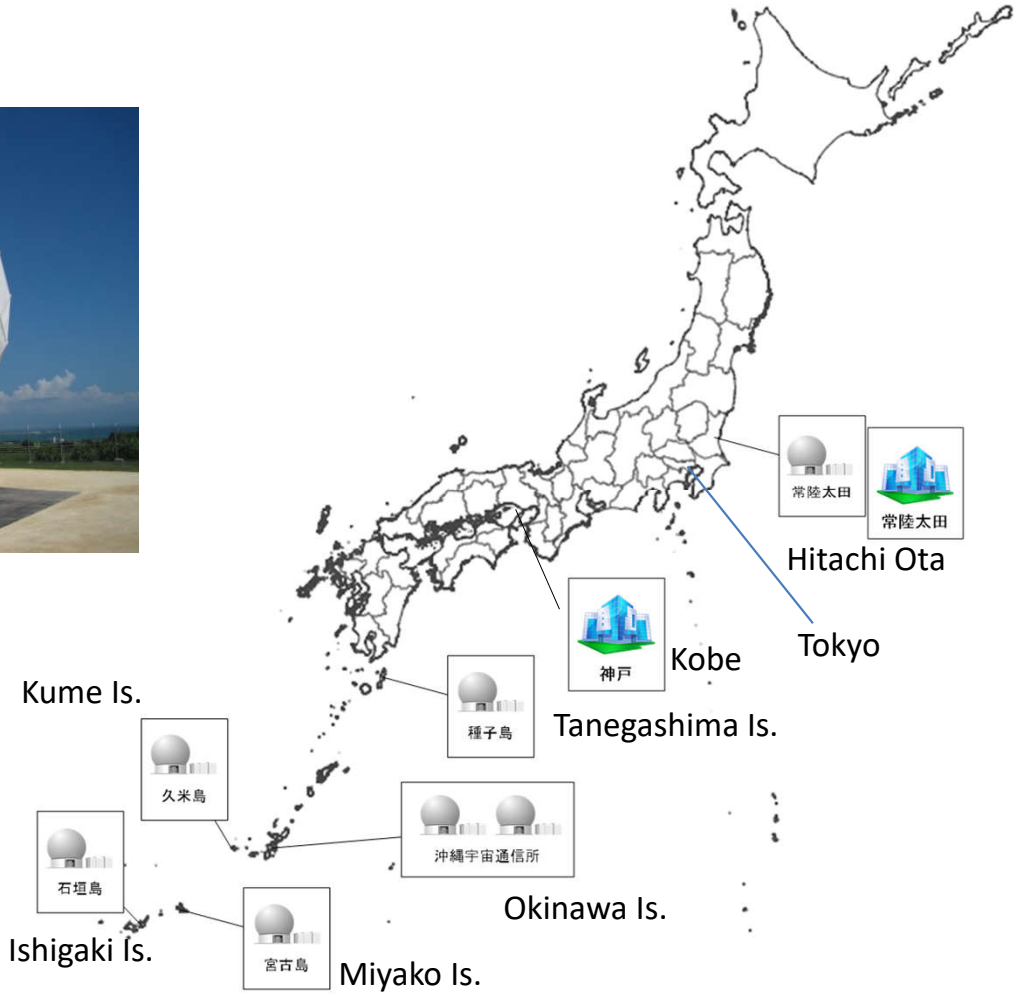
1. QZSS Overview

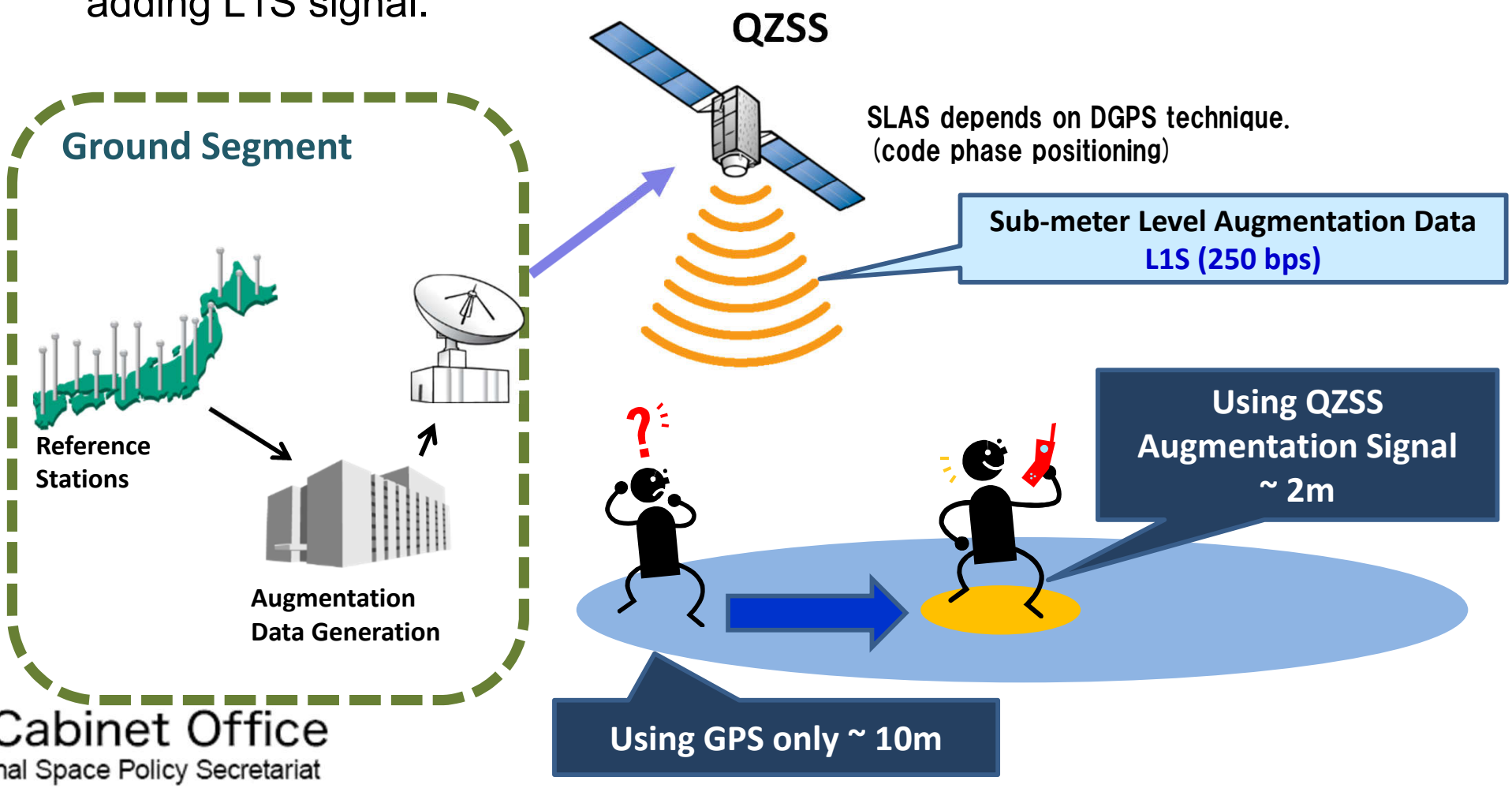
- QZSS TTC Stations



  - 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.

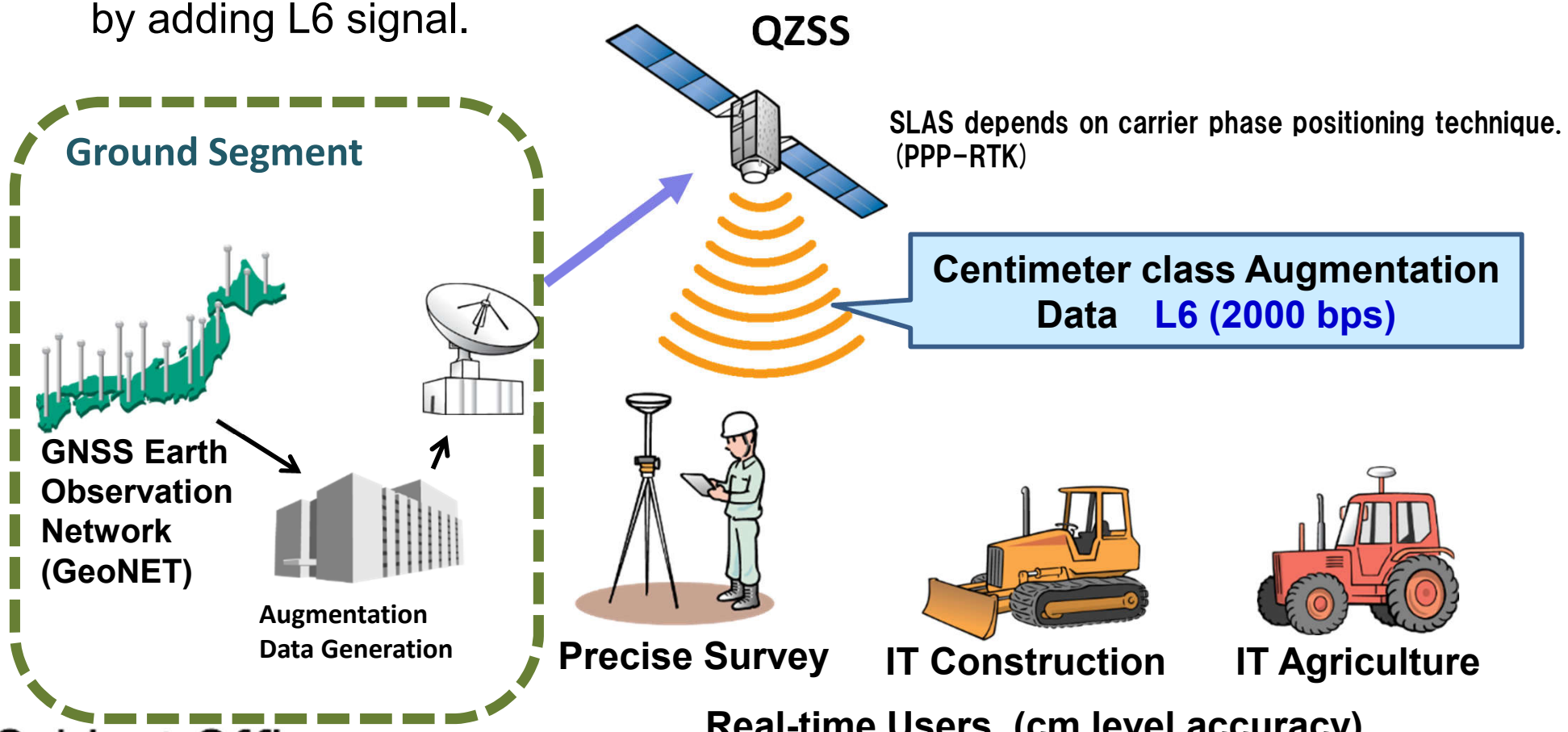
SLAS

- 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.



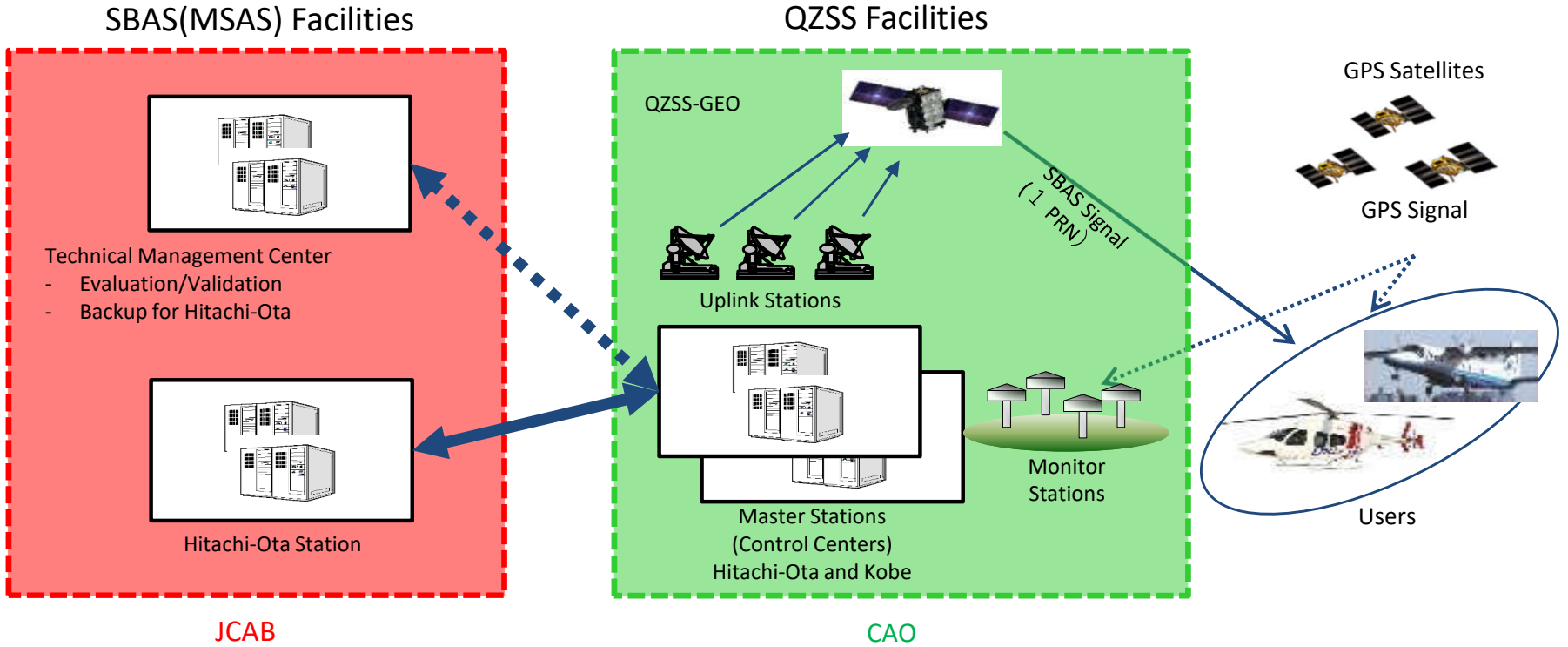
CLAS

- 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

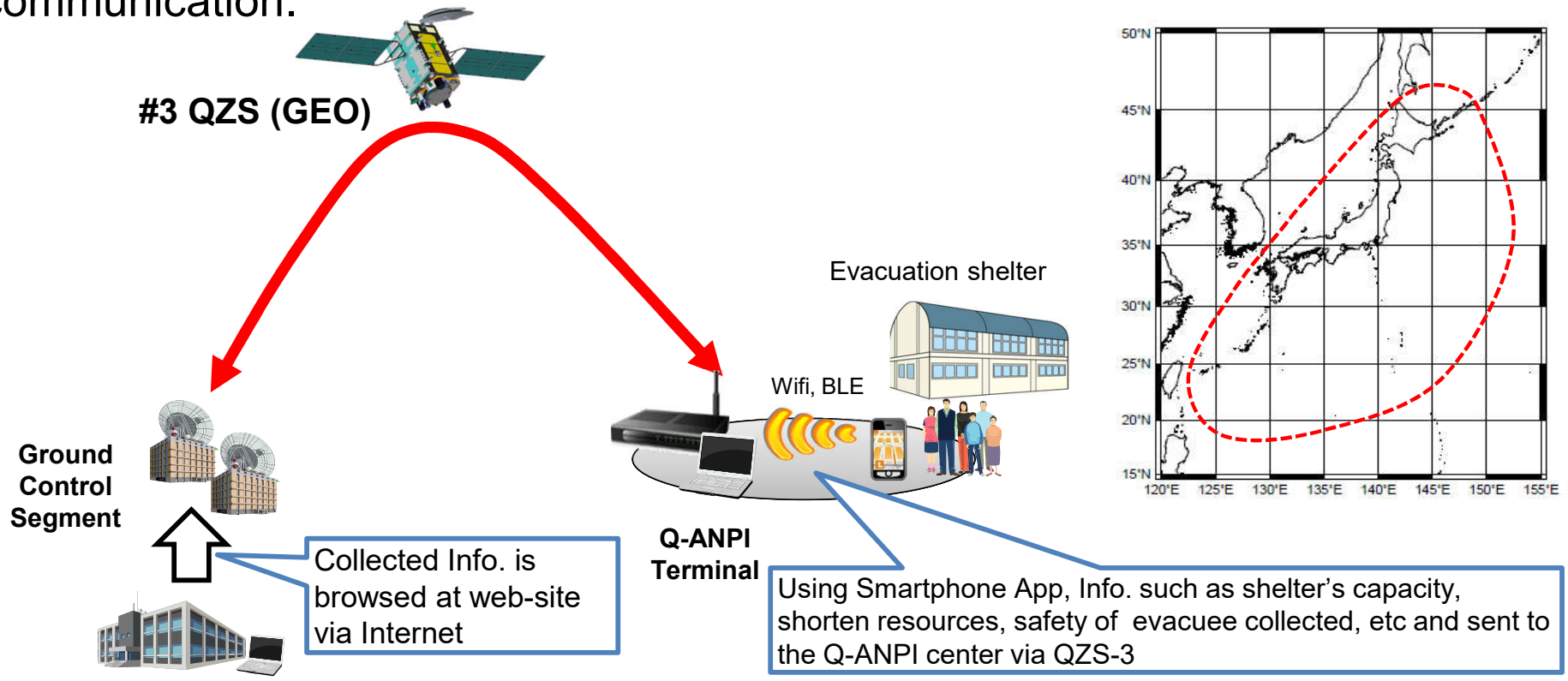
- MSAS: Japanese SBAS
  - MSAS is provided by JCAB, Japanese Civil Aviation Bureau, with QZS-3 operated by CAO from April 2020 which is augmented GPS for utilizing reroute, terminal and approach phase of aircrafts.
  - As addition update plan of MSAS, it will improve performance to LPV 200 like as ILS-CAT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