Quasi Zenith Satellite System (QZSS) Update

January 28, 2025

UNOOSA/UT Global Navigation Satellite System (GNSS) Trainning

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On behalf of Cabinet Office, Government of Japan

Japan Aerospace Exploration Agency (JAXA)

# QZSS Overview -Current Services-

■ **Functional Capabilities:**

  □ GPS Complementary (Ranging signals)

  □ GNSS Augmentation (Error corrections)

    ■ CLAS, SLAS, MADOCA-PPP, MSAS

  □ Messaging Service (Disaster relief, management)

    ■ Q-ANPI, DC Report and EWSS

■ **Coverage:** Asia and Pacific region

  □ Additional GPS satellites on the AP region

  □ CLAS and SLAS for Japan and MADOCA-PPP, EWSS for AP region
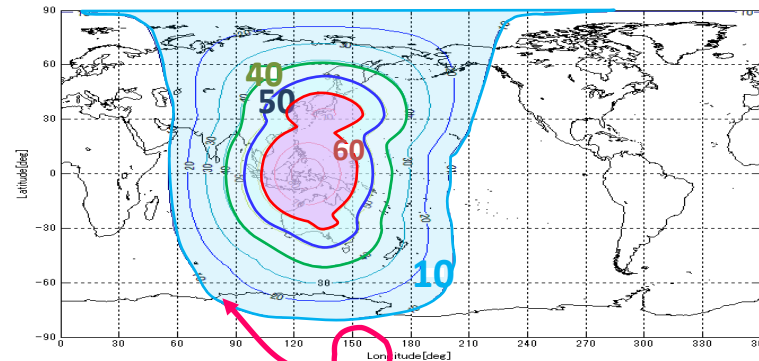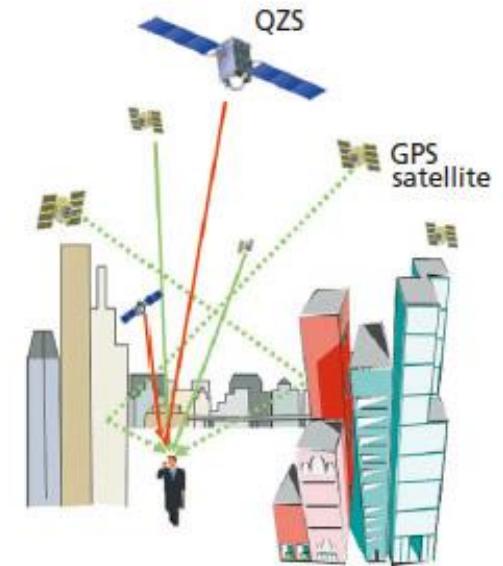
QZSS-1 ● (red circle)
QZSS-2 ★ (yellow star)
QZSS-4 ★ (green star)
QZSS-3 ◇ (diamond)
（127E）
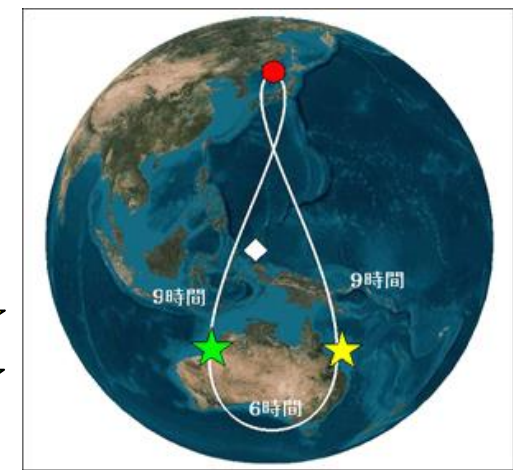
One or more QZSS SVs over 10 degrees elevation angle
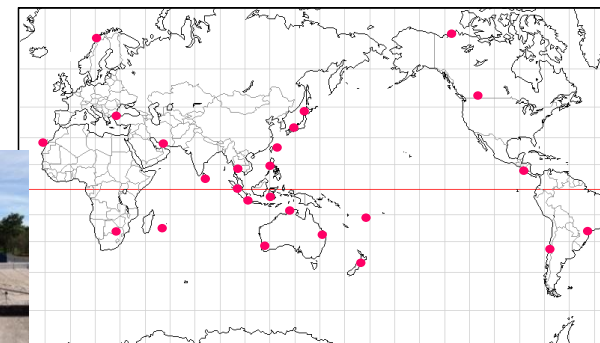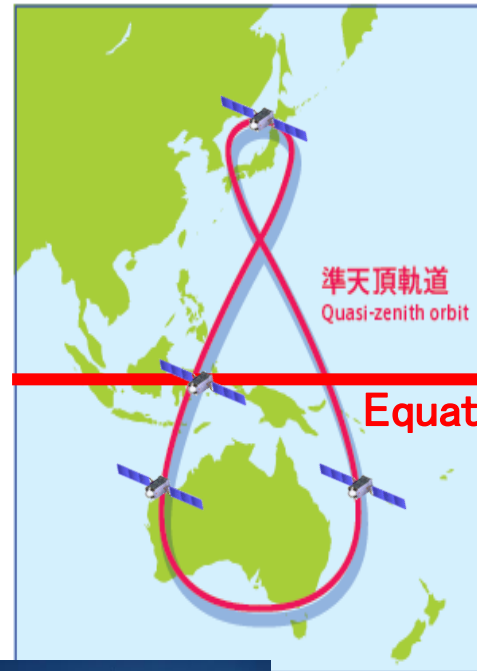
QZSS Overview -System-

- ## Constellation:
  - ☐ 1 GEO Satellite, 127E
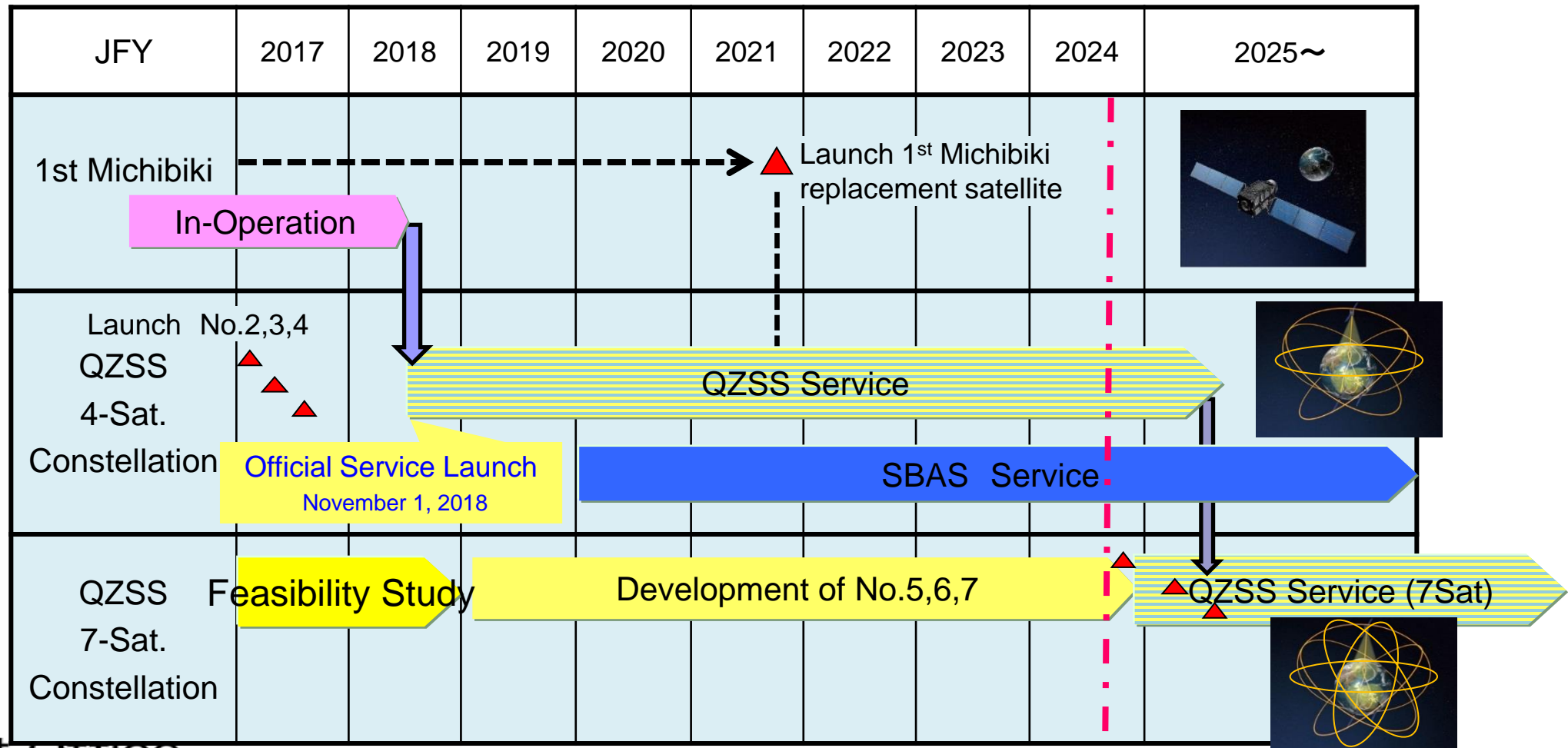 - ☐ 3 QZO Satellite (IGSO)
- ## Ground System
  - ☐ 2 Master Control Stations
    - Hitachi-Ota and Kobe
  - ☐ 7 Satellite TTC Stations
    - Located south-western islands
  - ☐ Over 30 Monitor Stations around the world

準天頂軌道
Quasi-zenith orbit

Equator

QZS-1R

QZS-2, 4

QZS-3

QZSS Control Center, Hitachi-Ohta,

QZSS Development Plan

- Development of 3 additional satellites are on-going.
- QZSS will start 7 satellite constellation service around 2025.

JFY	2017	2018	2019	2020	2021	2022	2023	2024	2025~
1st Michibiki					▲ Launch 1st Michibiki replacement satellite				
	In-Operation								
Launch No.2,3,4 QZSS 4-Sat. Constellation	▲ ▲ ▲	QZSS Service							
		Official Service Launch November 1, 2018		SBAS Service					
QZSS 7-Sat. Constellation	Feasibility Study	Development of No.5,6,7						▲	▲ QZSS Service (7Sat) ▲

Today

4

Satellites Status

- **QZS5-7 development is now ongoing**. System-level test is in progress. QZS 5-7 are planned to launch around 2025.
    - QZS-5 and 6 have almost finished system-level test.
    - QZS-7 finished electrical test, and now QZS-7 is under the environmental test phase.
- QZSS Antenna Patterns for SSV users have been published since Aug 2023.
    - *https://qzss.go.jp/en/technical/antenna-patterns.html*
- QZSS Satellite Information for POD users was also updated in the following site.
    - *https://qzss.go.jp/en/technical/qzssinfo/index.html*

QZS-1R

Ground System Status

- QZSS ground system that could operate 7sats completed by Aug 2023. <u>There only remains sat-ground RF compatibility test</u>.

- QZSS has the following ground system.
  - ☐ 2 Master Control Stations
    - Hitachi-Ota and Kobe
  - ☐ 10 Satellite tracking and control stations (TT&C and NAV message uplink stations)
    - Mainly located in south-western islands
    - Amami-island station will be completed by the end of March 2025
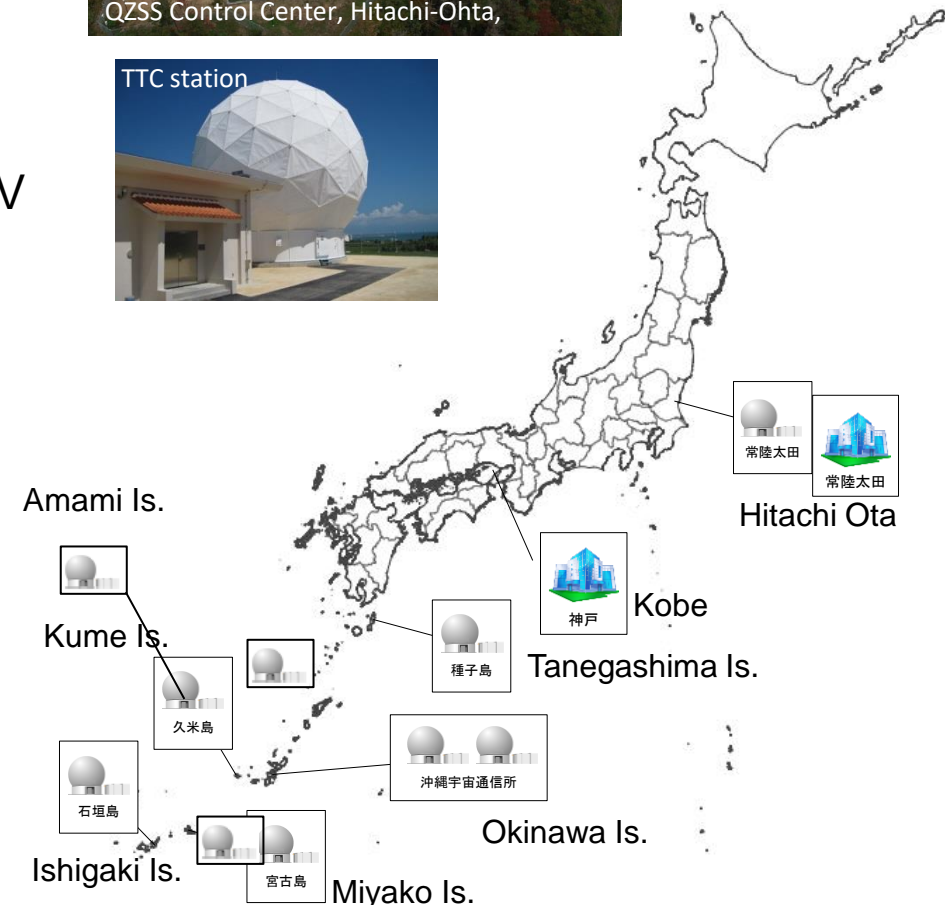 - ☐ Over 30 Monitoring Stations around the world
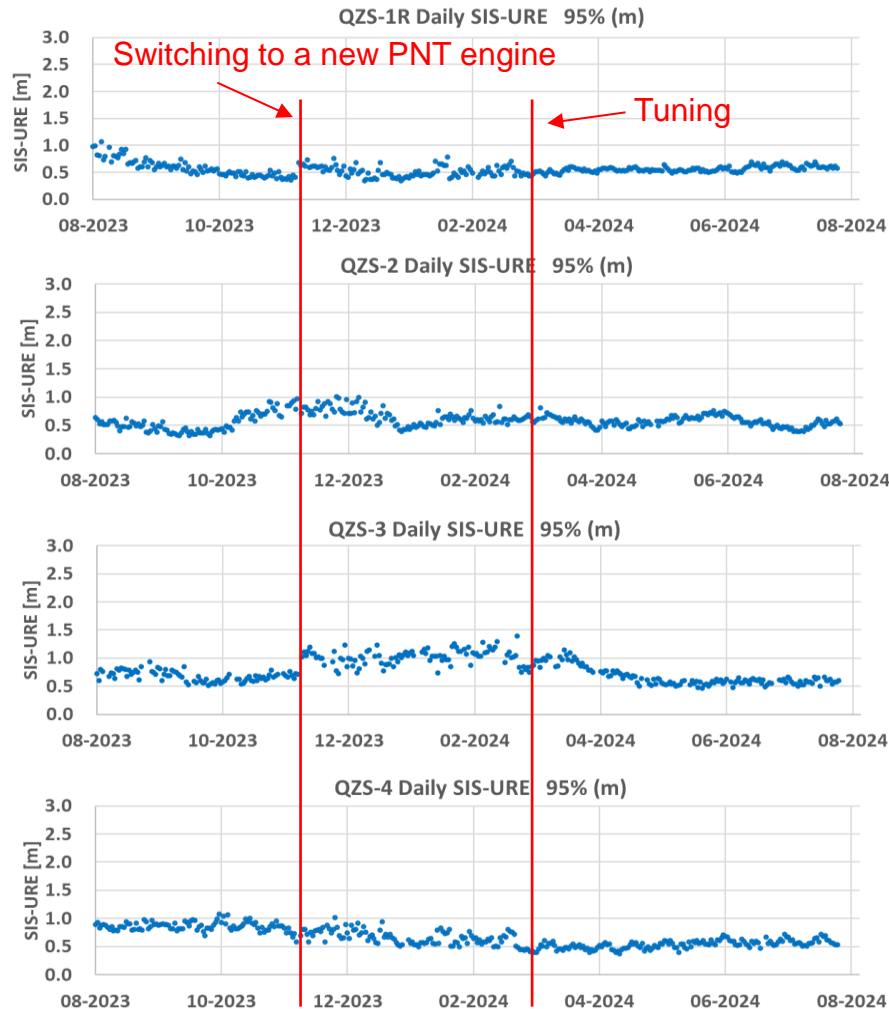

QZSS Control Center, Hitachi-Ohta,

TTC station

The new TT&C station at Miyakojima-island

常陸太田 / 常陸太田
Hitachi Ota

Amami Is.

神戸 Kobe

Kume Is.
久米島

種子島
Tanegashima Is.

石垣島
Ishigaki Is.

沖縄宇宙通信所
Okinawa Is.

宮古島 Miyako Is.

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SIS Accuracy

QZS-1R Daily SIS-URE 95% (m)

QZS-2 Daily SIS-URE 95% (m)

QZS-3 Daily SIS-URE 95% (m)

QZS-4 Daily SIS-URE 95% (m)

[Evaluation Period]
2023/08/01〜2024/07/31

[Evaluation Results]
Specification: Less than 2.6 m (95%)

	Average	Best day	Worst day
QZS-1R	0.55 m	0.34 m	1.06 m
QZS-2	0.58 m	0.31 m	1.00 m
QZS-3	0.78 m	0.46 m	1.39 m
QZS-4	0.66 m	0.37 m	1.08 m

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

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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 visible more than one satellite at high elevation angle.
– To be visible more than four satellites for a long time.
– To get better DOP, Dilution Of Precision.
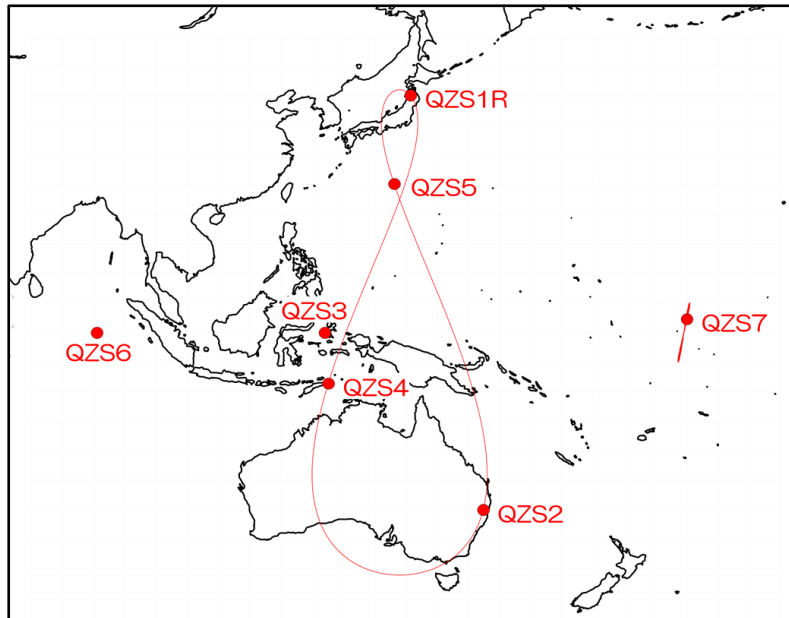
Seven-QZS Ground Track

| Satellite orbit	Satellite Number	Orbital Position
IGSO（4 satellites)	QZS-1R	133 deg E
	QZS-2	139 deg E
	QZS-4	139 deg E
	QZS-5	139 deg E
GEO（2 satellites)	QZS-3	127 deg E
	QZS-6	90.5 deg E
QGEO（1 satellite)	QZS-7	175 deg W

4 IGSO + 2 GEO +1 QGEO constellation will be completed around 2025.
Next QZS will be launched in early 2025.
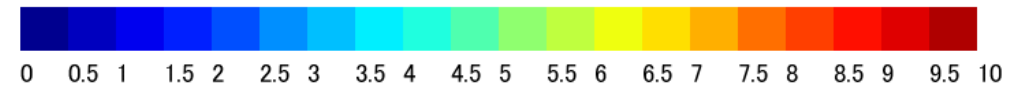
QZSS Seven-satellite constellation

A Regional Navigation Satellite System: QZSS 7 satellite constellation

View angle
(right hand movie)

View angle (left hand movie)
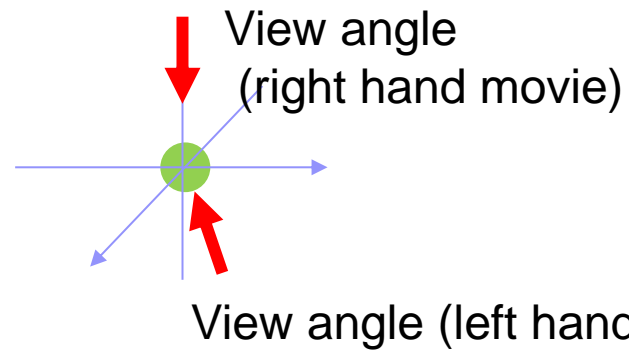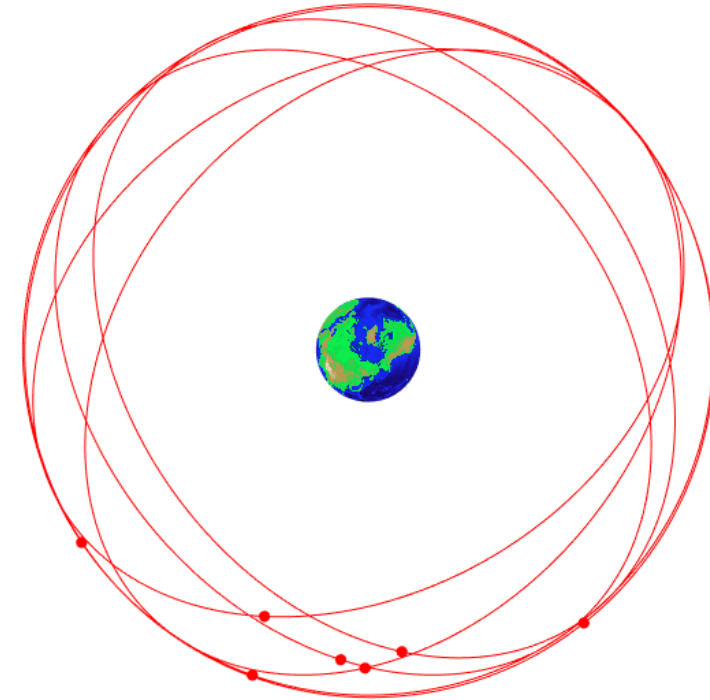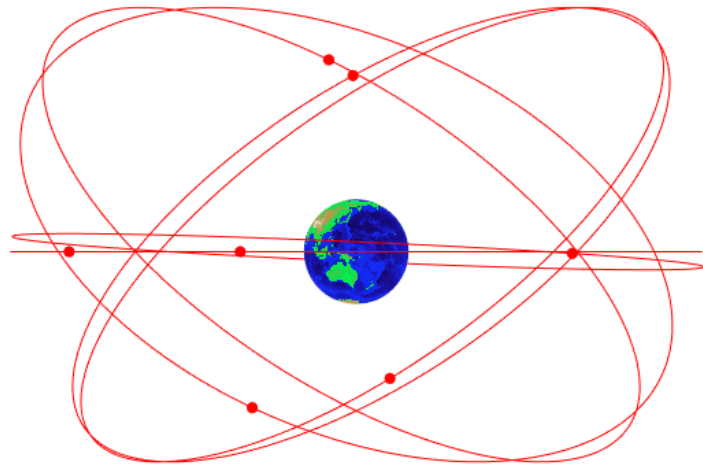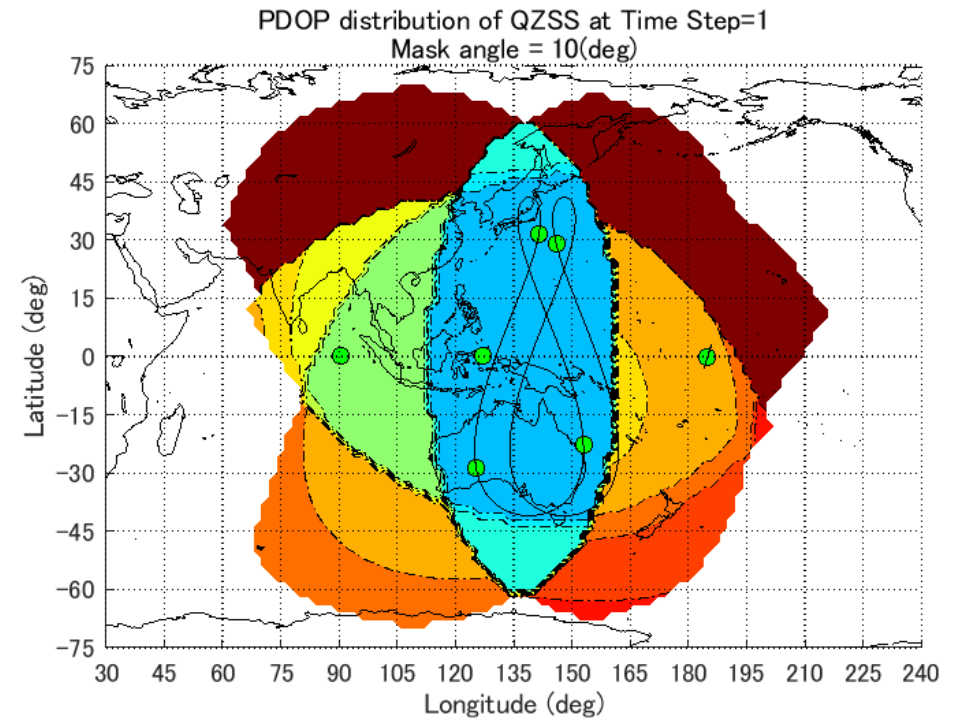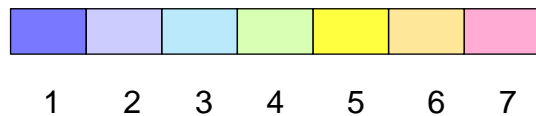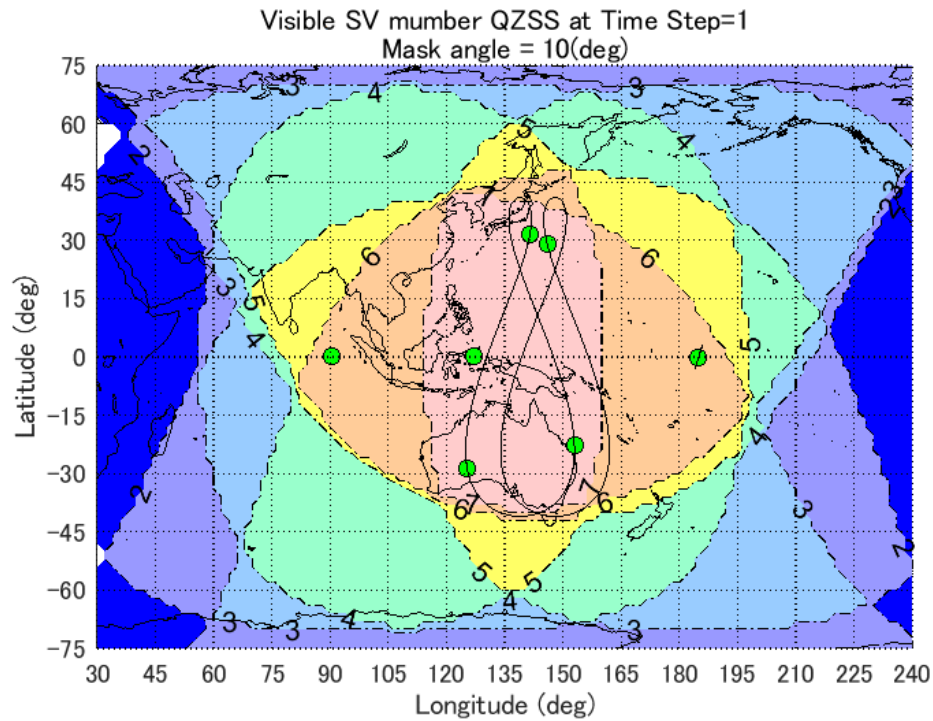
QZSS Seven-satellite constellation

A Regional Navigation Satellite System: QZSS 7 satellite constellation

QZSS Seven-satellite constellation

A Regional Navigation Satellite System: QZSS 7 satellite constellation
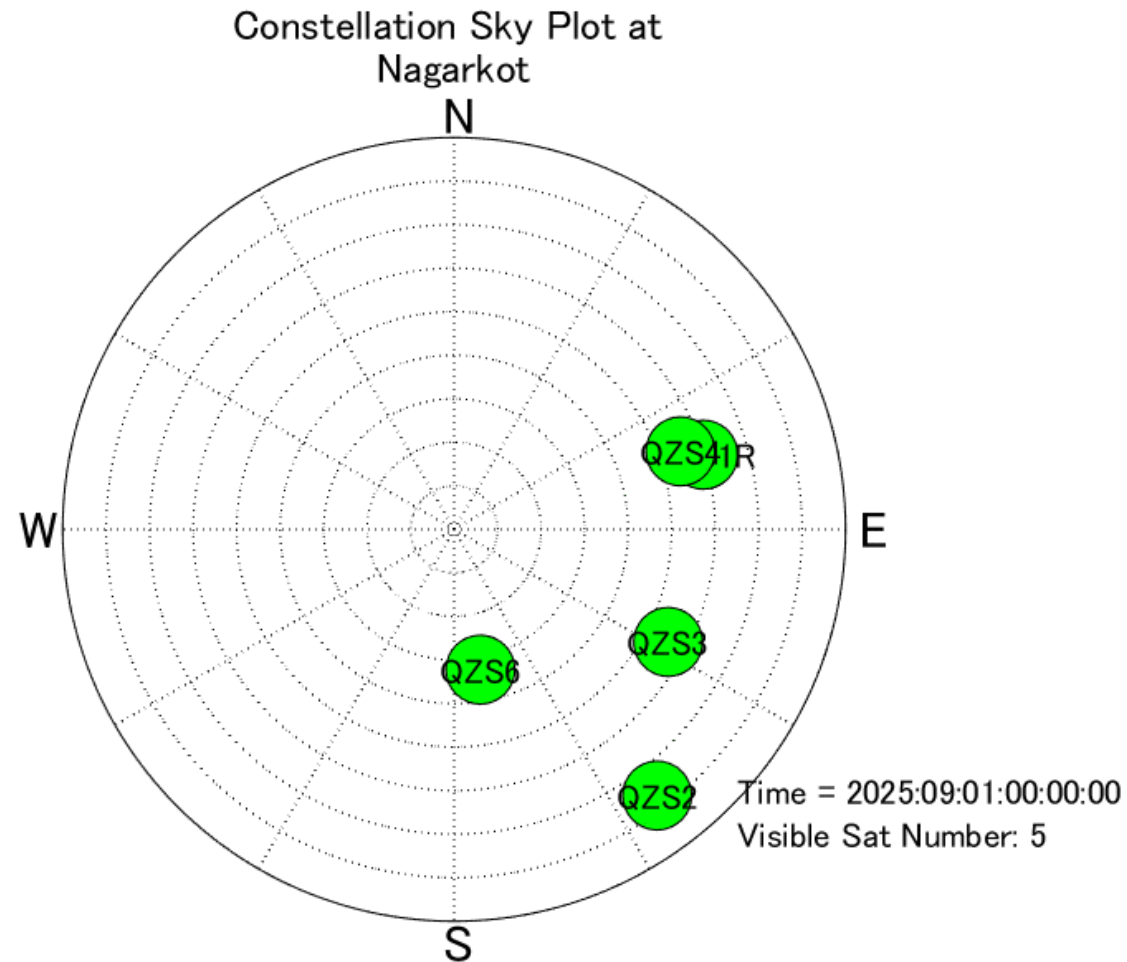
Visibility in Nagarkot, Nepal

QZSS Seven-satellite constellation

A Regional Navigation Satellite System: QZSS 7 satellite constellation
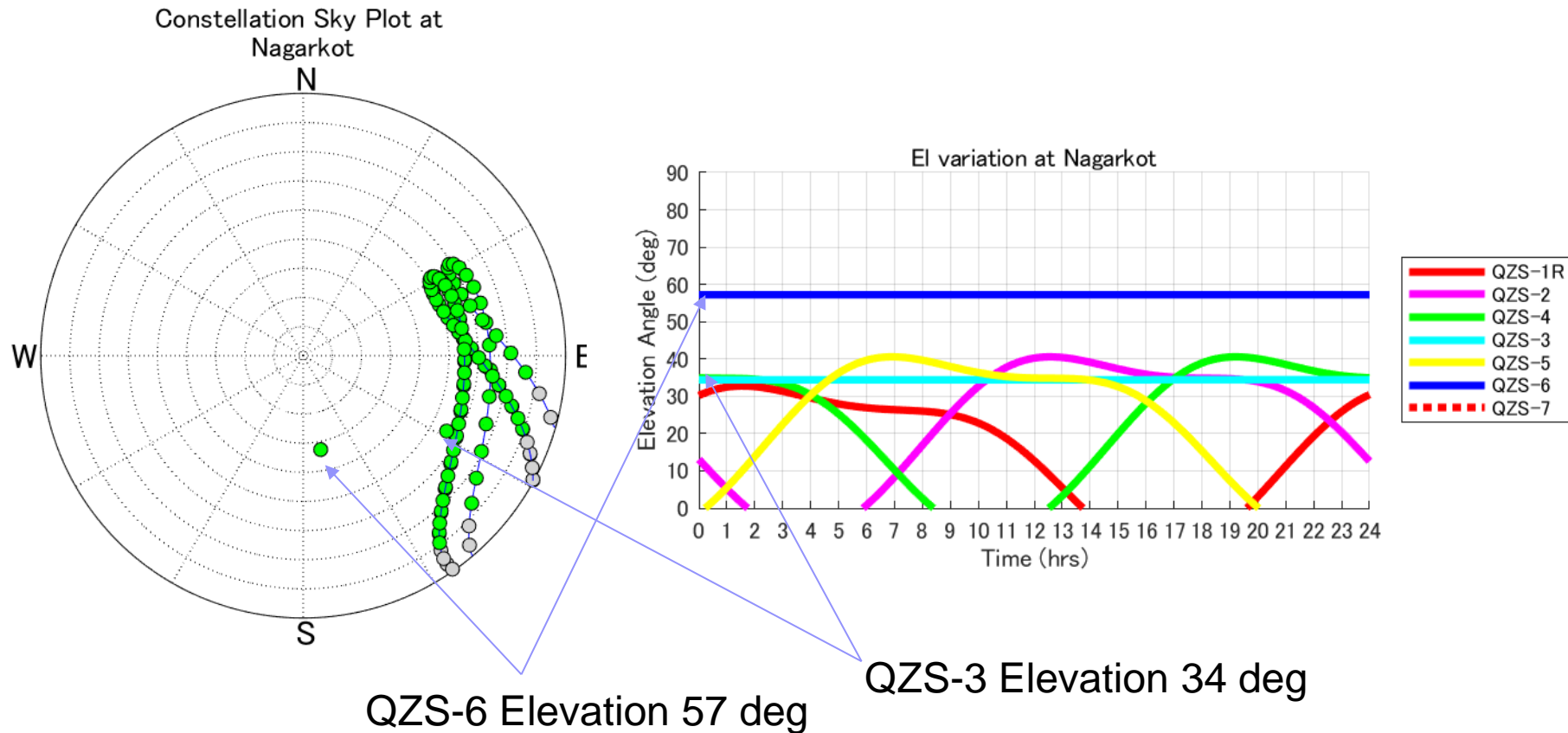
Visibility in Nagarkot, Nepal

Constellation Sky Plot at Nagarkot

El variation at Nagarkot

QZS-6 Elevation 57 deg

QZS-3 Elevation 34 deg

7 Satellites Constellation of QZSS

- **Additional services start around 2024-2025**

  ☐ PNT service

  - Users obtain PVT solution with using ranging signals provided by QZSS only 7 SV constellations in 2025-2026 after the QZS 5-7 launch.
  - Navigation Message Authentication (NMA) service has started since April 1st, 2024.
  - QZS-5-7 have ISR(Inter-satellite ranging) and Sat/Gnd bi-directional ranging function that improve the SIS-URE and robustness.

  ☐ MADOCA-PPP service

  - Covering major part of eastern hemisphere and providing PPP error corrections on L6 signal.
  - Trial service has begun since Sep 2022, and operational service has started since April 1st, 2024.
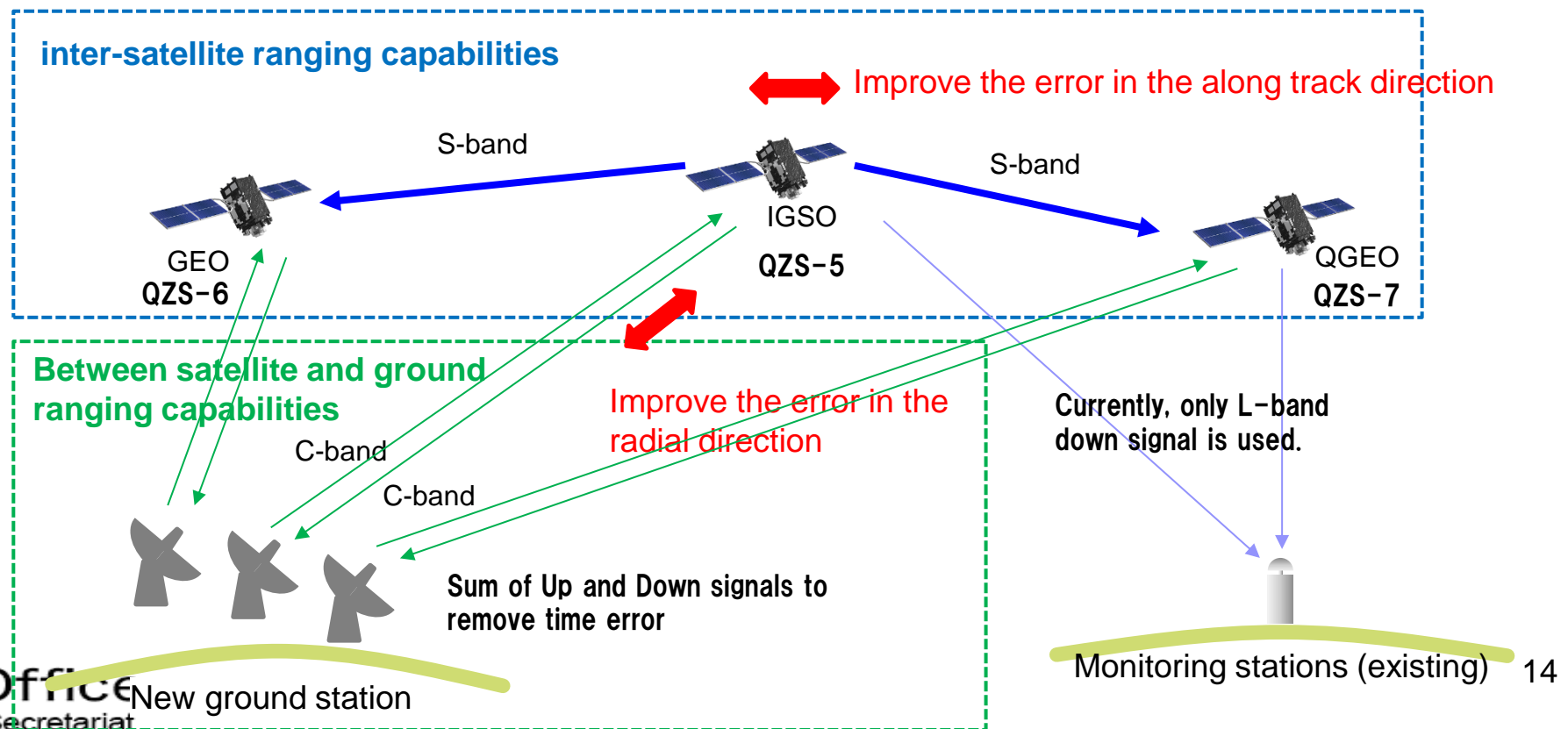 - Internet distribution of MADOCA-PPP has just started since July, 2024.

  ☐ Early/Emergency Warning Satellite Service (EWSS)

  - Four out of seven SVs will transmit 122 bits common EWS message on L1S signal.
  - Common EWS message was developed and published under collaboration with EC, Cabinet office, available on https://www.gsc-europa.eu/sites/default/files/sites/all/files/EWSS-CAMF_v1.0.pdf
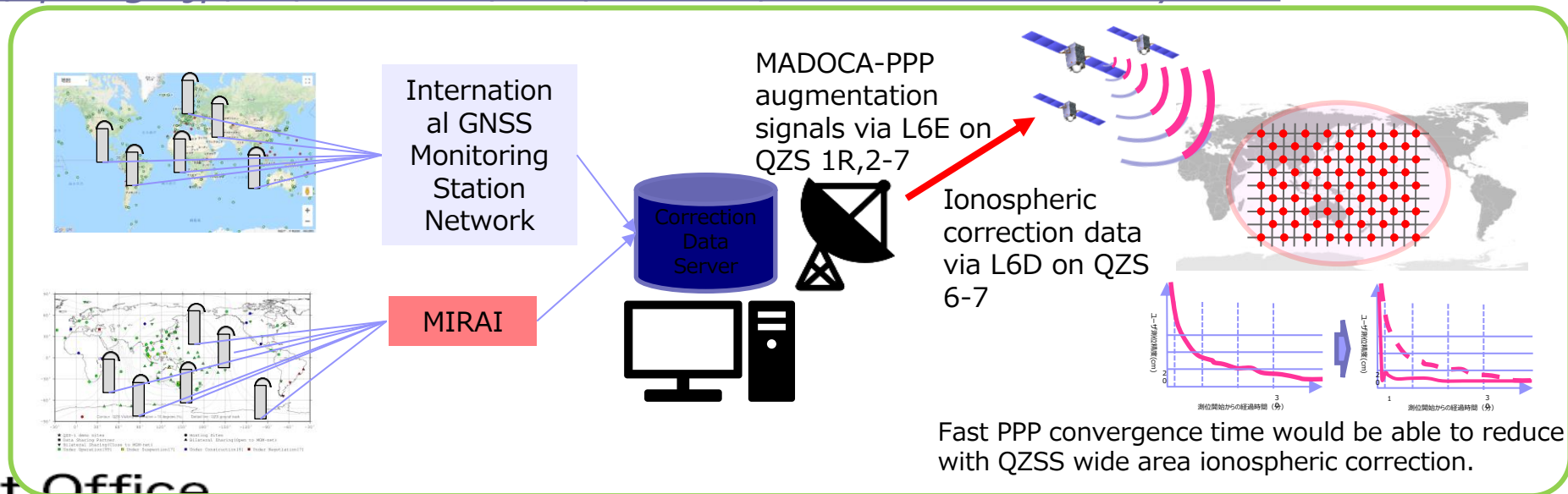
PNT Service Improvement by new SVs

■ 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 (QZS5-7) will be equipped with <u>inter-satellite ranging</u> capabilities.
- The three new satellites and the upgraded ground system will be equipped with <u>satellite-ground bi-directional ranging capabilities</u> as well.

inter-satellite ranging capabilities

Improve the error in the along track direction

S-band

S-band

IGSO
QZS-5

GEO
QZS-6

QGEO
QZS-7

Between satellite and ground ranging capabilities

Improve the error in the radial direction

C-band

C-band

Currently, only L-band down signal is used.

Sum of Up and Down signals to remove time error

New ground station

Monitoring stations (existing)

MADOCA-PPP

- MADOCA-PPP, Multi-GNSS Advanced Orbit and Clock Augmentation - Precise Point Positioning, has started operational service since April 1st 2024, for Asia Pacific region.
  - MIRAI, GNSS Monitoring Station Network, has been released since April 2022.
  - To reduce initial convergence time, the ionospheric correction data will be broadcasted by QZS-6,7 from 2025.
- Internet distribution of MADOCA-PPP including ionospheric correction data has started since July 2024 for promoting MADOCA-PPP utilization.
  - https://qzss.go.jp/en/technical/dod/madoca/madoca_internet_distribution.html
- MADOCALIB, test library of MADOCA-PPP, has been open-sourced and made available on GitHub this April, and updated to process ionospheric correction data in July 2024.
  - https://qzss.go.jp/en/technical/dod/madoca/madoca_test-library.html

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 6-7

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

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MADOCA-PPP

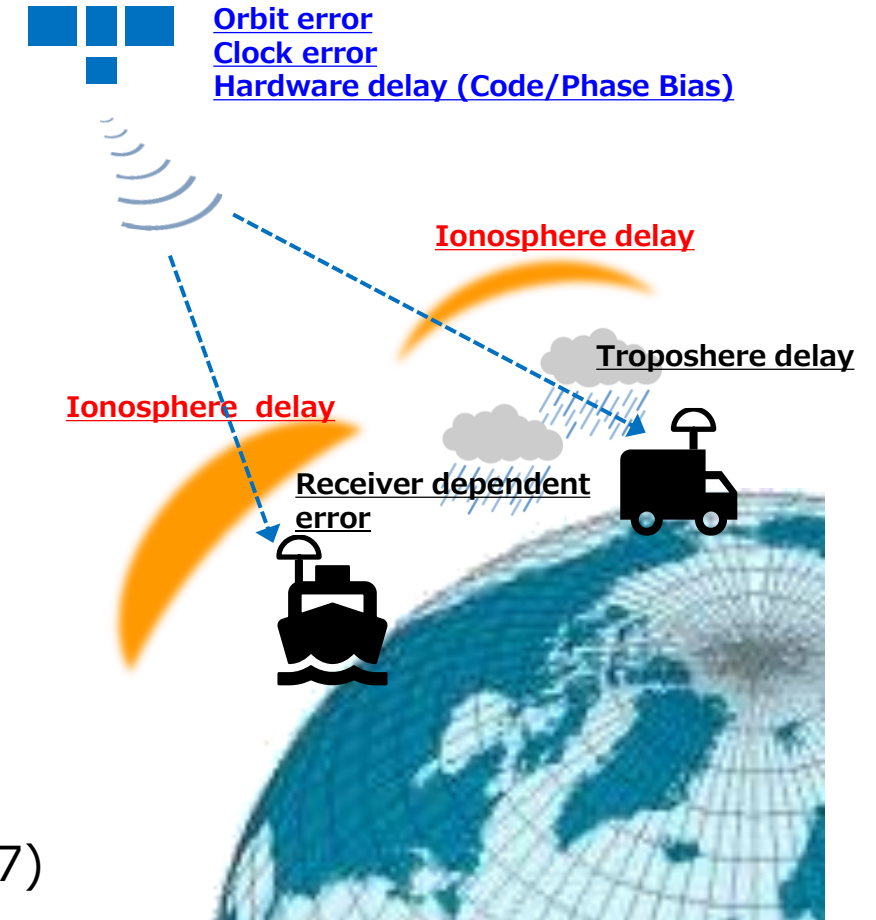MADOCA-PPP enables high precise positioning by augmenting some of GNSS errors.

MADOCA-PPP provides 2 levels of service.

- **Global PPP**
  - ☐ Highly precise positioning anywhere signals can be received
  - ☐ Provides <u>satellite dependent error corrections</u> (orbit, clock, code/phase bias) by QZSS L6E

- **Fast PPP with ionospheric correction**
  - ☐ <u>Faster</u> PPP with using regional/nation wide CORSs (Continuously Operating Reference Stations) observation data.
  - ☐ In addition to global PPP, <u>regional error corrections (ionospheric correction)</u> provided by QZSS L6D (QZS-6 and 7)

Orbit error
Clock error
Hardware delay (Code/Phase Bias)

Ionosphere delay

Troposhere delay

Ionosphere delay

Receiver dependent error

Errors of GNSS positioning

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MADOCA-PPP specification (Global PPP)

MADOCA-PPP service defined and described on **PS-QZSS 003** was published on Mar. 17, 2022. <u>IS-QZSS-MDC-003, in which supplemental information on user processing is added, was published in Aug 2024.</u>

https://qzss.go.jp/en/technical/ps-is-qzss/ps-is-qzss.html

- Defines augmented constellations and signals

|	
QZSS	L1C/A, L2C, L5, L1C
GPS	L1C/A, L2C, L5, L1C, L1P, L2P
Galileo	E1b, E5a
GLONASS	G1C/A, G2C/A, G1P, G2P

- Service area
  - At least one QZS is visible more than 10 degrees elevation angle
  - Error corrections for more than 20 satellites over 10 degrees elevation angle are available in the service area.
- <u>Minimum</u> performance level
  - Positioning Accuracy
    Horizontal 30cm (95%)
    Vertical 50cm (95%)
  - Convergence time
    1800 sec

Actual Performance
·<10 cm （enough time passed）

Actual Performance
·< 900 sec
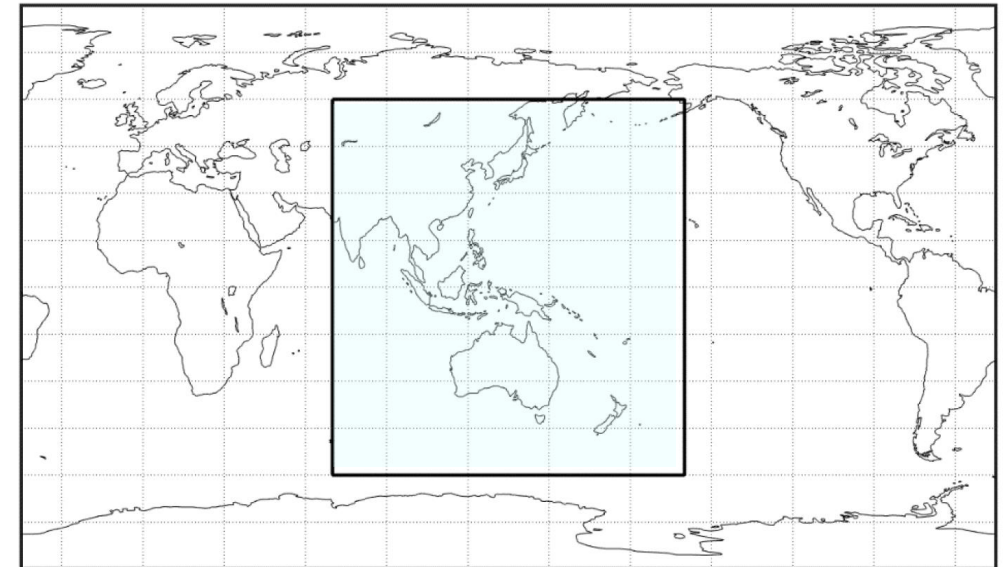
± 60 latitude and 70E to 200E longitude

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MADOCA-PPP specification (Fast PPP)

MADOCA Ionospheric Correction Function defines its target specification as below.

- **Service area**

  Where CORS data or ionospheric correction products are available area

- **Minimum performance level**
  - Positioning Accuracy

    Horizontal   30cm (95%)
    Vertical   50cm (95%)
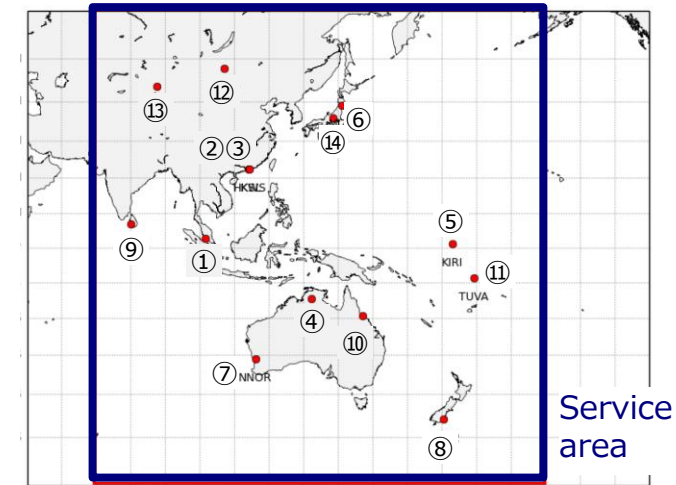
  - Convergence time

    600 sec (Target)

- Some CORS data in MIRAI is used for generating ionospheric correction data.
- CAO is building relationships with countries in Asia-Oceania to ask for cooperation in providing data.
- CAO provides dedicated software for countries which cannot provide data outside so that they can operate that software to generate ionospheric correction data and send it to Japan.

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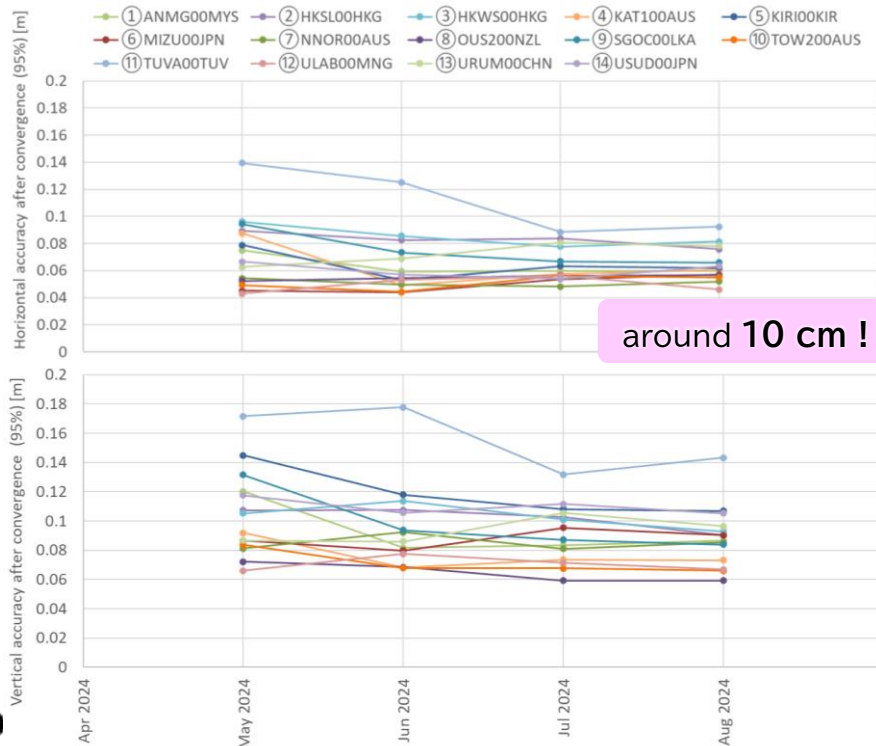National Space Policy Secretariat

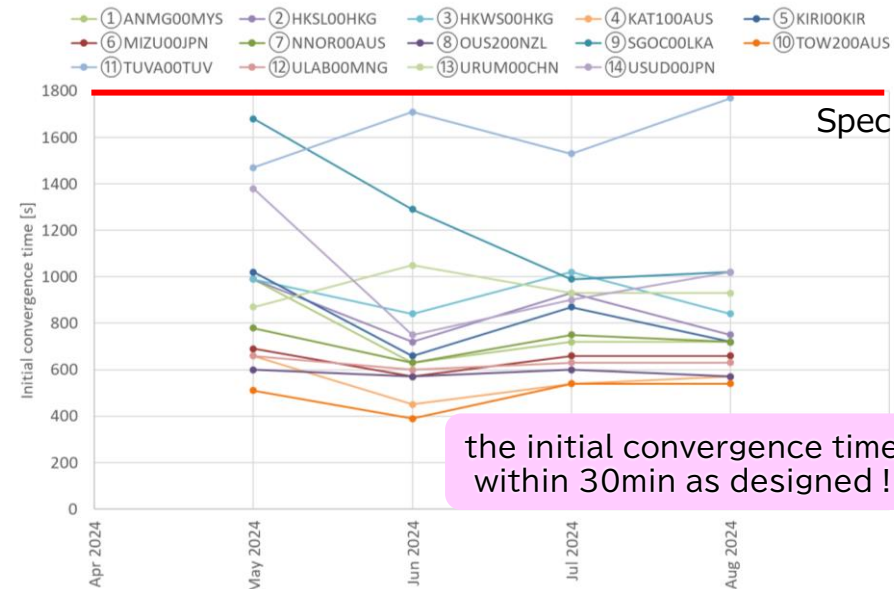# MADOCA-PPP Performance(1/2)

PPP results using <u>IGS monitoring station</u> with MADOCALIB after starting operational service are as shown below. <u>Better initial convergence time</u> than the defined specification and <u>approximately 10 cm of accuracy</u> are confirmed.

Service area
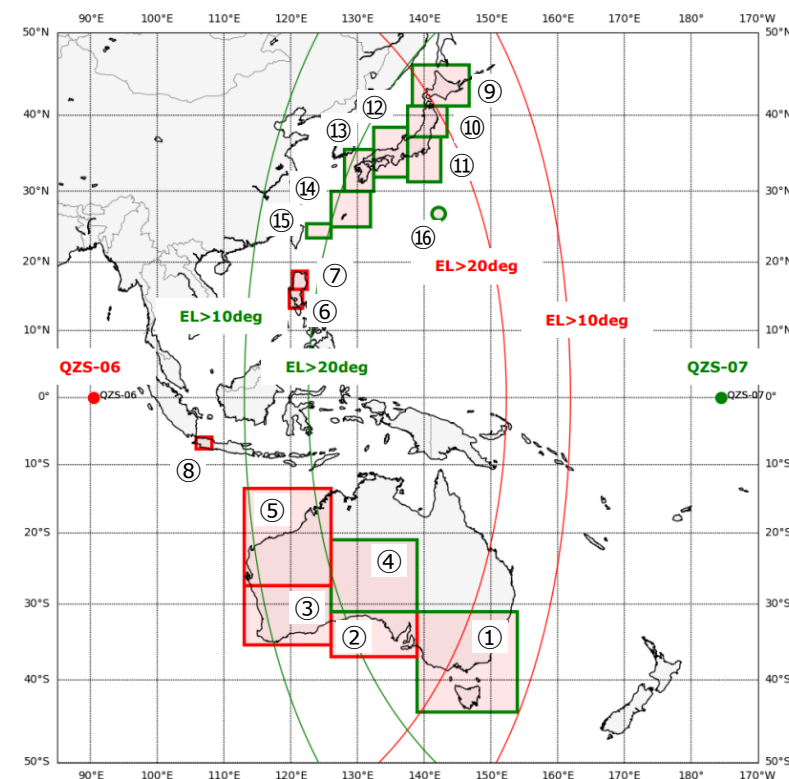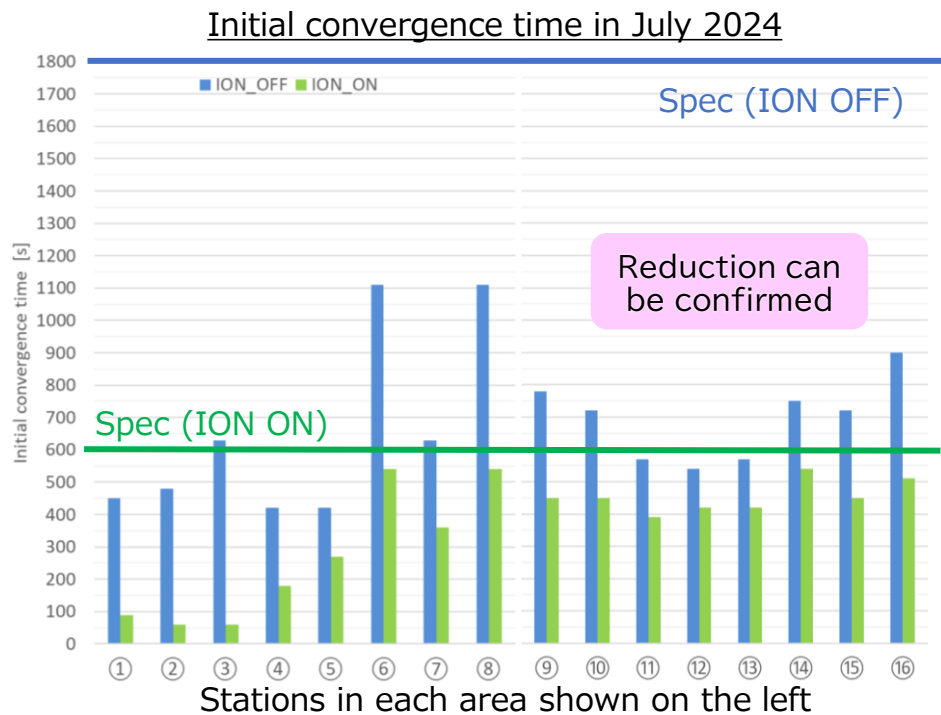
Accuracy after convergence

- ① ANMG00MYS
- ② HKSL00HKG
- ③ HKWS00HKG
- ④ KAT100AUS
- ⑤ KIRI00KIR
- ⑥ MIZU00JPN
- ⑦ NNOR00AUS
- ⑧ OUS200NZL
- ⑨ SGOC00LKA
- ⑩ TOW200AUS
- ⑪ TUVA00TUV
- ⑫ ULAB00MNG
- ⑬ URUM00CHN
- ⑭ USUD00JPN

around **10 cm !**

Initial convergence time

- ① ANMG00MYS
- ② HKSL00HKG
- ③ HKWS00HKG
- ④ KAT100AUS
- ⑤ KIRI00KIR
- ⑥ MIZU00JPN
- ⑦ NNOR00AUS
- ⑧ OUS200NZL
- ⑨ SGOC00LKA
- ⑩ TOW200AUS
- ⑪ TUVA00TUV
- ⑫ ULAB00MNG
- ⑬ URUM00CHN
- ⑭ USUD00JPN

Spec

the initial convergence time within 30min as designed !

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- Thanks to the cooperating countries, ionospheric correction data can be generated, and reduction of the initial convergence time was confirmed in all areas.
- CAO started the internet distribution including the ionospheric correction data for these areas.

Initial convergence time in July 2024

Stations in each area shown on the left

Reduction can be confirmed

Spec (ION OFF)

Spec (ION ON)

Coverage area as of Aug. 2024
(Only Internet distribution available now.)

CAO welcomes cooperation in providing GNSS data!
Please contact us from https://go.gnss.go.jp/

Unlimited Ways to GO with GNSS!
GO! GNSS GO! JAPAN
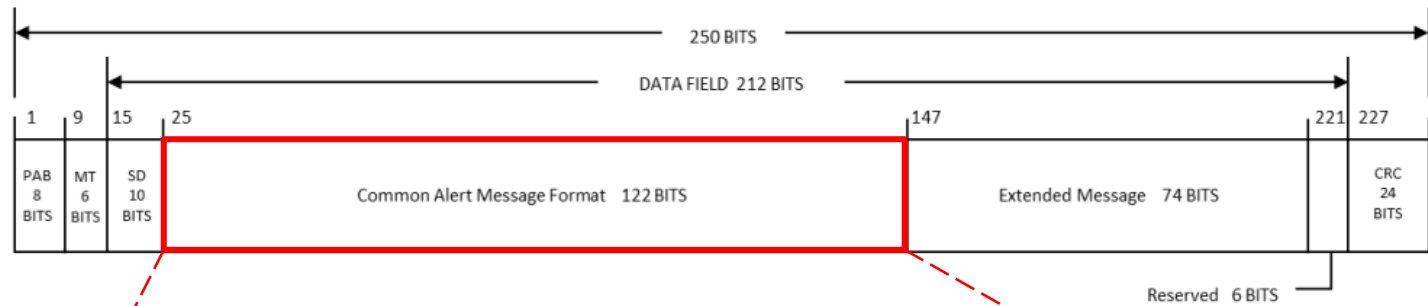
EWSS (Early Warning Satellite Service)

Alert message from satellite to end-user equipment

- Add more redundancy for a disaster alert system. Even in the case ground-based communications systems are down when a disaster occurs, satellite system can broadcast alert messages.

- 122 bits common alert message format includes disaster category, alert issuing organization, suffered area, severity and guidance to react.
  - ☐ Common standardized alert message format published by EC as Galileo EWSS uses.

- Regional/national authorities can define specific guidance according with their own protocols.

- QZSS EWSS covers Asia Pacific region, currently test and demonstration phase
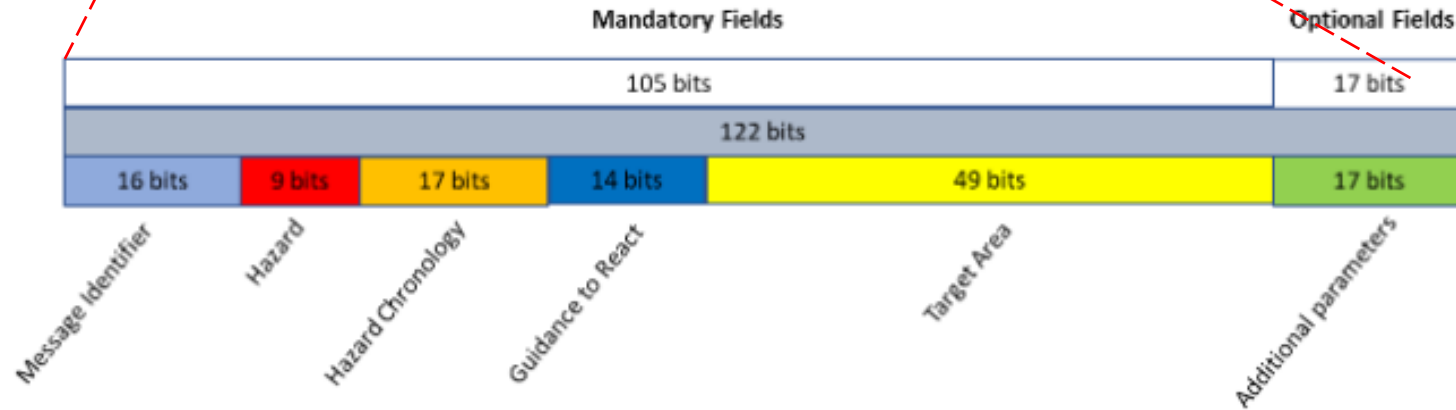 - ☐ Real-time practical operation will start around 2025.

Overview of QZSS EWSS embedded in L1S

- EWSS content format : EWSS follows **same alert message format with Galileo**.

Japan - Michibiki document

EU - Galileo document

Reference:
IS-QZSS-DCX-001, Cabinet office of Japan
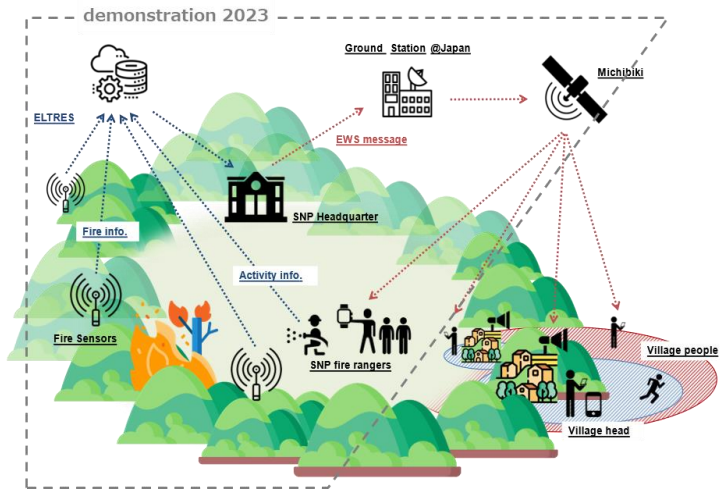https://qzss.go.jp/en/technical/ps-is-qzss/ps-is-qzss.html
Emergency Warning Satellite Service - Common Alert Message Format Specification, EUROPA
https://www.gsc-europa.eu/sites/default/files/sites/all/files/EWSS-CAMF_v1.0.pdf

Examples of Situations Where QZSS EWSSs Can Be Used
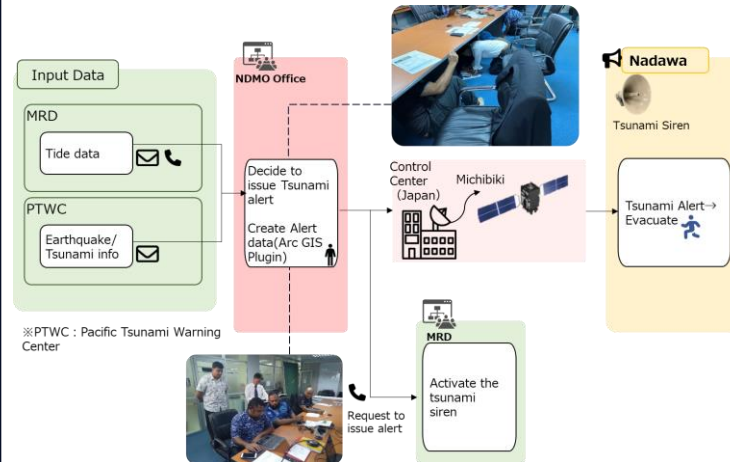

• Scenario Implemented in Thailand

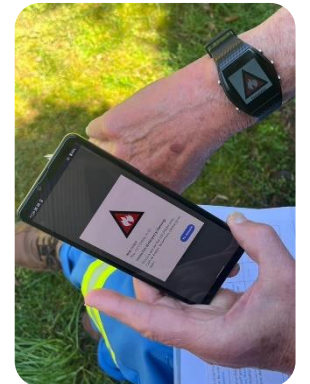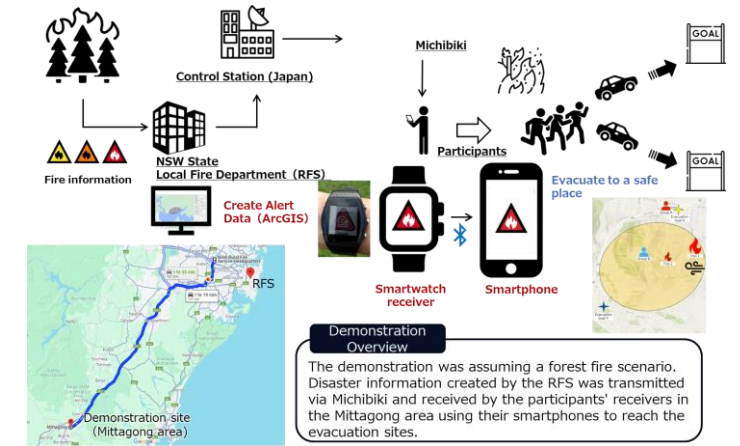Notification on smartwatch and route and map on smartphone application
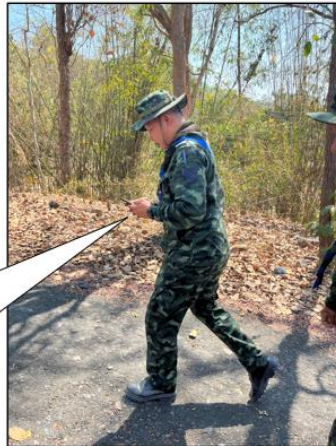
Ranger rushing to the dummy fire while checking the information received

• Scenario Implemented in Fiji

• Scenario Implemented in Australia

QZNMA

- QZSS Navigation Message Authentication service, QZNMA, is 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) is now available on our website (https://qzss.go.jp/en/technical/ps-is-qzss/is_qzss_sas_agree.html).
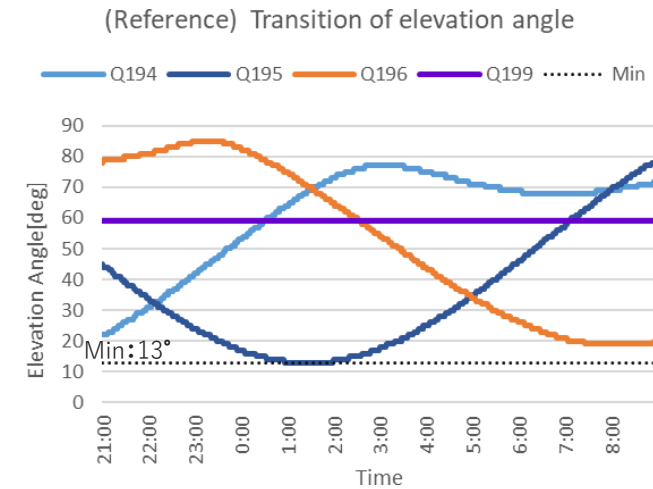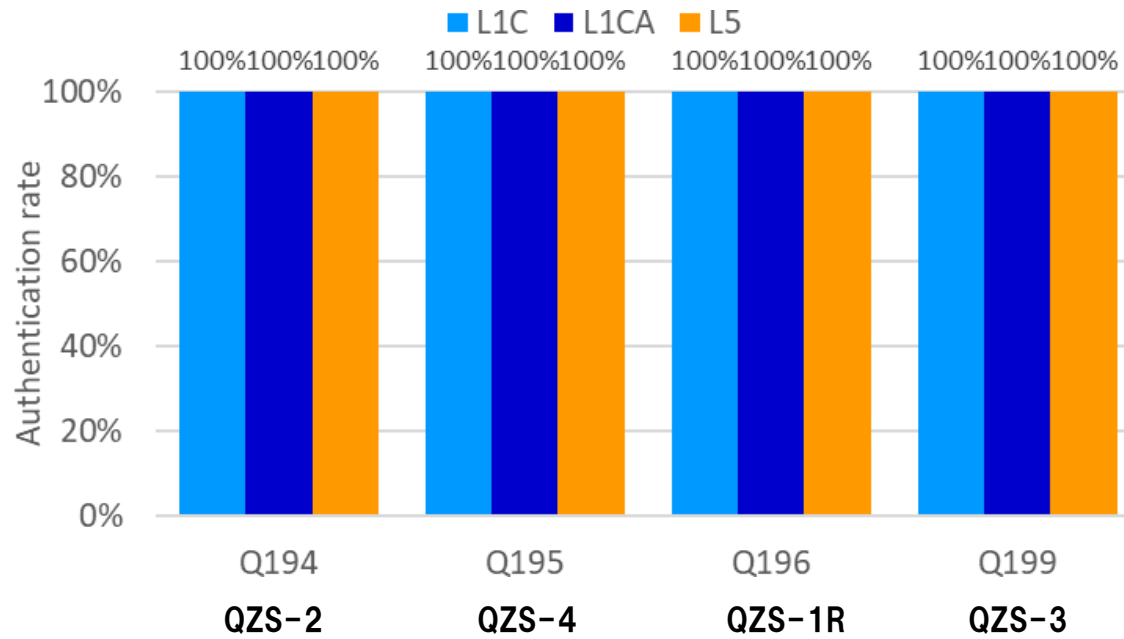- Operational Service of QZNMA started from April 1st, 2024.
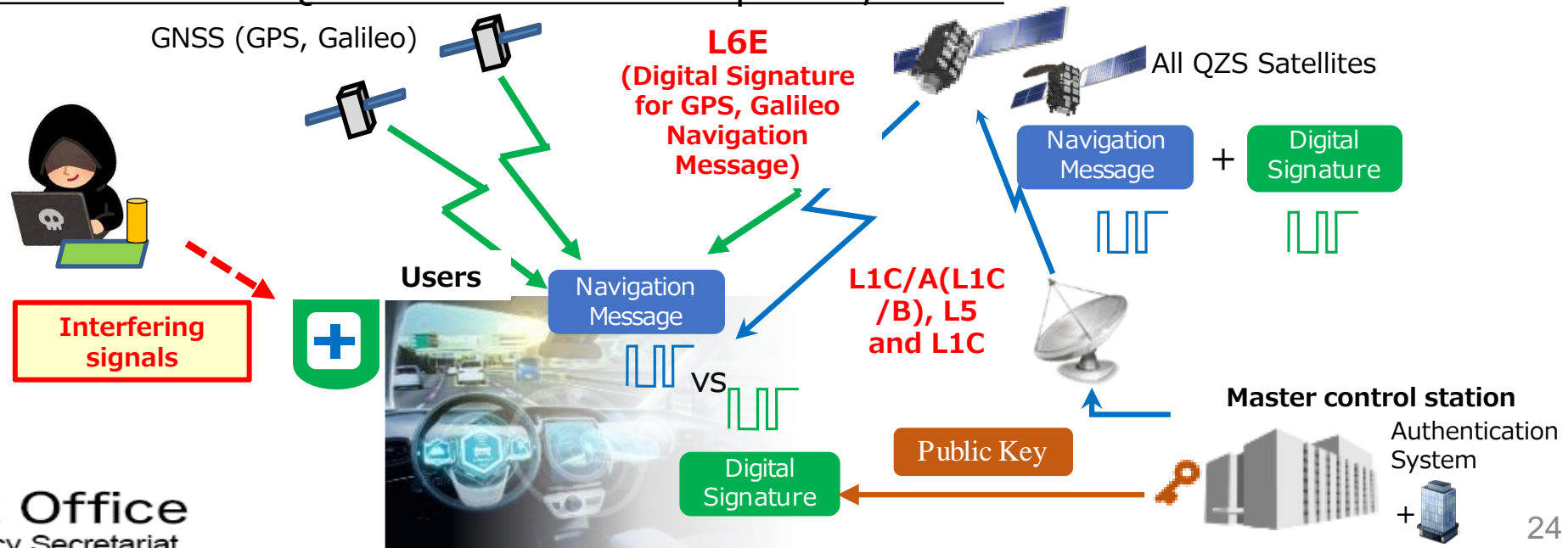
QZNMA:Authentication Rate

■**QZSS** Authentication Rate of "**Fixed point under open sky**"

- All of verifications* were succeeded.

*: - 12H in OKINAWA (12 hours × 15 times x 4 satellites × 3 signals = 2,160 verifications)
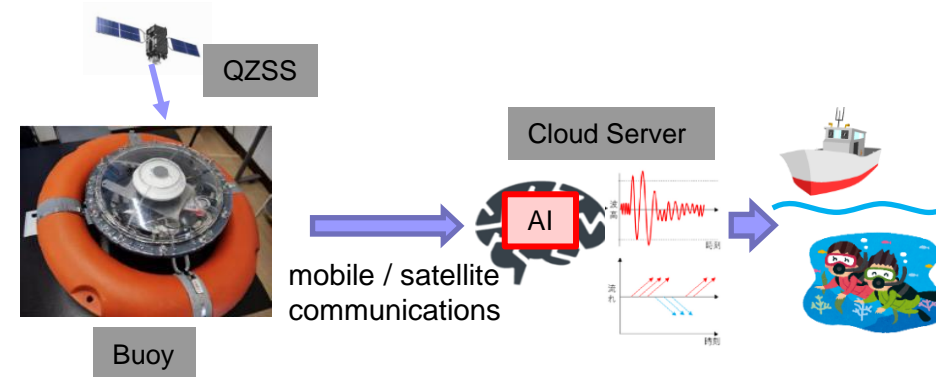
QZSS Applications

■ As of September 2024, approximately 434 products are compatible with QZSS.

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.)

Buoy for real-time ocean tide monitoring

QZSS

Buoy

Cloud Server

AI

mobile / satellite communications

Wearable terminals

display the distance to the green

display the EWS message

Drones

Agricultural Drone

Logistics drone

GNSS Receiver and Chipset

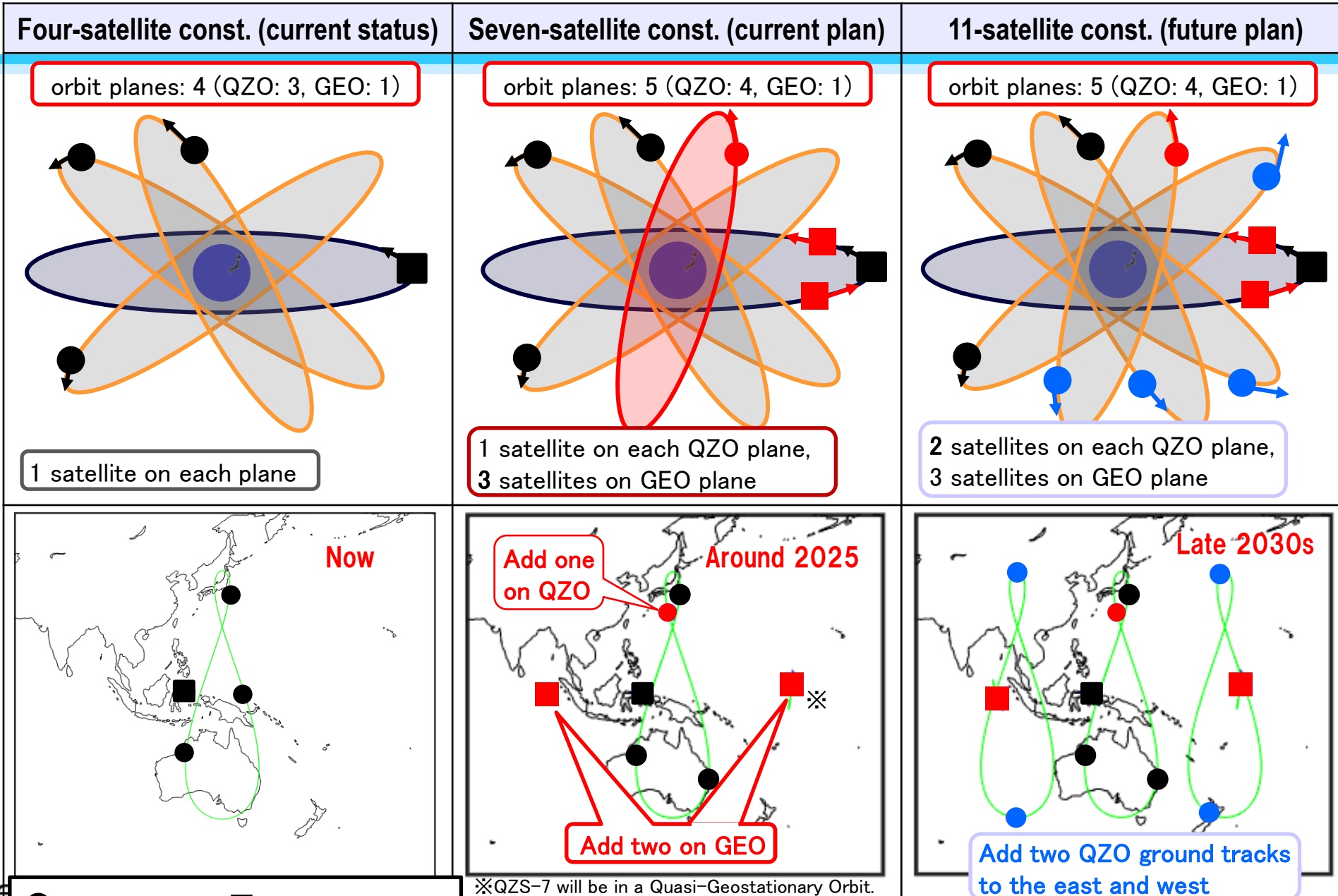| CORE Corp. Cohac∞Ten+ (for CLAS,MADOCA) 150*210*55mm	Bizstation Corp. RWS.DC (for CLAS,MADOCA) 50*51.5*13.1mm	Magellan Systems Japan MJ-3021-GM4-QZS-EVK (for CLAS,MADOCA) 130*90*42 mm
Septentrio Mosaic-CLAS 31*31*4mm	u-blox ZED-F9P + **NEO-D9C** (for CLAS)	Magellan Systems Japan Digital ASIC** (for CLAS,MADOCA) Less than 30*40 mm

*   Additional android software for MADOCA-PPP   ** to be available in the end of March 2023

Cabinet Office
National Space Policy Secretariat

Space Policy and QZSS Plan

☐ Currently, CAO has been developing the 7 SV constellation.

☐ The cabinet revised our new basic plan of space policy on June 2023.

☐ It defines that the number of satellites for the <u>QZSS should be increased from seven to eleven</u> to achieve the followings:

> ➢ Improving stability and reliability as one of the social infrastructures by securing backup function for coming full-scale use.
> ➢ Expanding usable area.

☐ On June 12th, 2024, <u>the act plan for the satellite positioning system has been revised</u> for the first time in three years by National Space Policy Secretariat. In this plan, <u>QZSS 11 SV constellation should be completed by late 2030s</u>.

QZSS Constellation Expansion Plan

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	1 satellite on each QZO plane, 3 satellites on GEO plane	2 satellites on each QZO plane, 3 satellites on GEO plane
Now	Add one on QZO — Around 2025 — Add two on GEO	Late 2030s — Add two QZO ground tracks to the east and west

●: QZO satellite, ■: GEO satellite

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

Conceptual Design of 11 satellite constellation has started since 2024.

The 15th Multi-GNSS Asia Annual Conference 2025

4th to 7th March 2025 : Phuket, Thailand
## Duangjitt Resort and Spa

Navigating the Future: Enhancing Connectivity, Sustainability & Safety

https://www.multignssasia.com/

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
- Expansion to 7 satellite constellation
  - Three additional satellites will be launched around 2025. QZSS will provide independent PNT capability for more reliable applications.
    - An IGSO(QZS-5), a GEO(QZS-6) and a QGEO(QZS-7) satellite will be added to the existing constellation.
    - QZS 5-7 have Inter-Satellite ranging and Sat/Gnd bi-directional ranging function to improve SIS-URE accuracy.
  - MADOCA-PPP, QZNMA started operational service from April 2024.
    - These services are available in Asia Pacific region.
    - MIRAI, a GNSS observation data collection and sharing system, was established and started its operation in April 2022.
    - MADOCA-PPP distribution via internet started from July 2024.
    - Operational service for Fast-PPP and EWSS will start after 2025.
- Conceptual Design of 11 satellite constellation has started since 2024.
- Emerging new applications such as autonomous driving, drone operation with some commercial devices.

Cabinet Office
National Space Policy Secretariat
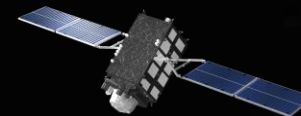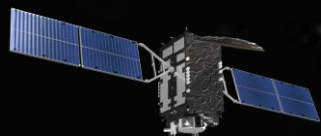
धन्यवाद
Thank you for your attention!
For more information, please visit our web site
https://qzss.go.jp/en/

Question? ✉ kogure.satoshi@jaxa.jp

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