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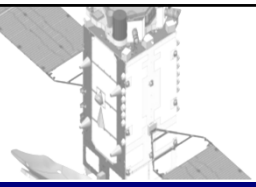

# QZSS Update

**ION GNSS+ 2018 on Sep. 26, 2018 @Miami, Florida**

**Takeyasu Sakai**
*National Institute of Maritime, Port and Aviation Technology, Japan*
**Satoshi Kogure**
*Cabinet Office, Government of Japan*

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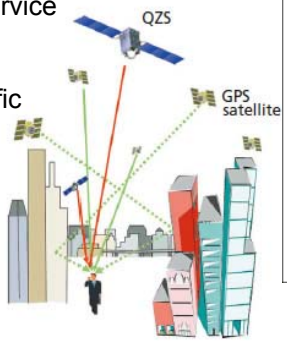
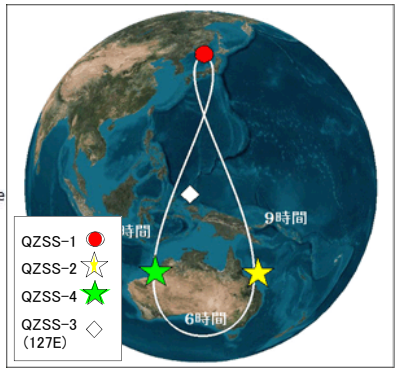
# QZSS Overview -Services-

- ***Japanese Regional Satellite Navigation System***
- ***QZSS: Quasi-Zenith Satellite System***
- ***Functional Capability:***
  - GPS Complementary Service
  - GNSS Augmentation Service
  - Messaging Service
- ***Coverage:***
  - Asia and Pacific Region

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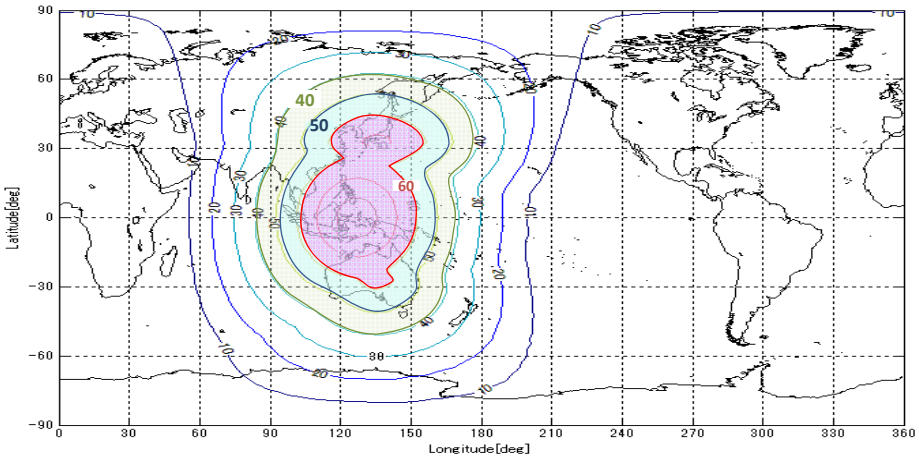
# QZSS Overview -Services-

- ***Coverage:*** Asia and Pacific region




*Minimum of Highest Elevation Angle Contour for the QZSS 4-SV Constellation*

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# QZSS Overview -Services-

## Functional Capability 1 GPS Complementary 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 inter-operability among other GNSS.
- SIS-URE: 2.6m (95%)


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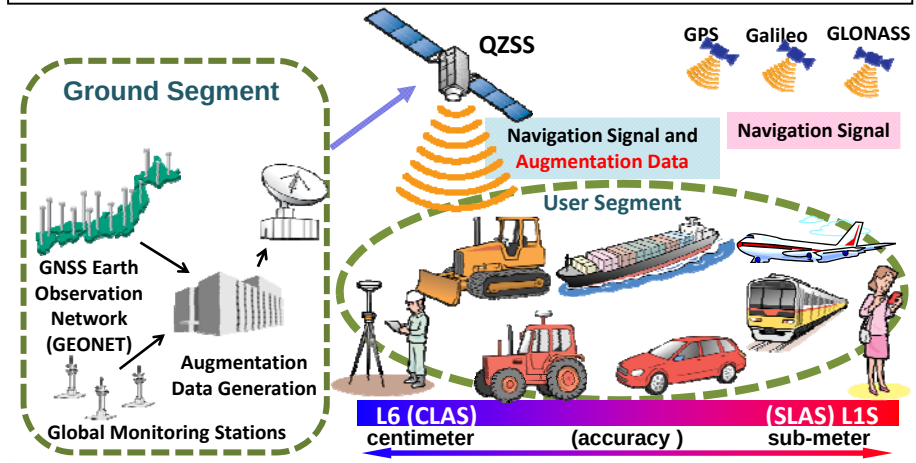
# QZSS Overview -Services-

## Functional Capability 2 GNSS Augmentation Service

**QZSS improves positioning accuracy and reliability**




✓ Plus Standard SBAS Service

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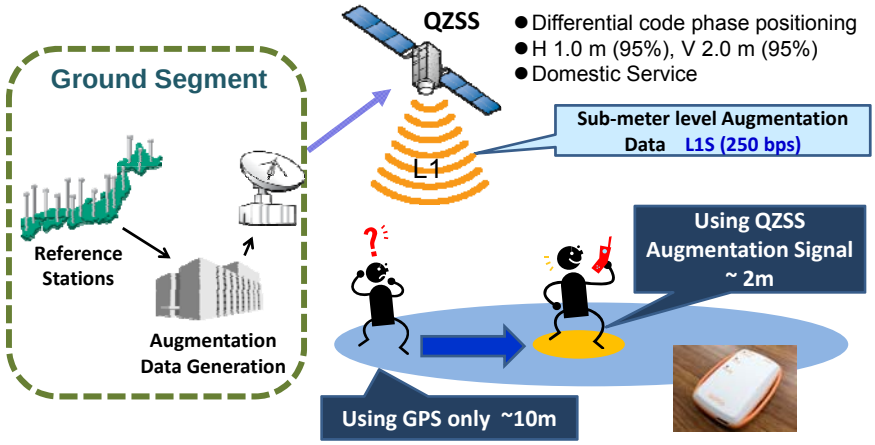
# QZSS Overview -Services-

## Functional Capability 2 GNSS Augmentation Service

**Sub-meter Level Augmentation Service: SLAS**




- Differential code phase positioning
- H 1.0 m (95%), V 2.0 m (95%)
- Domestic Service

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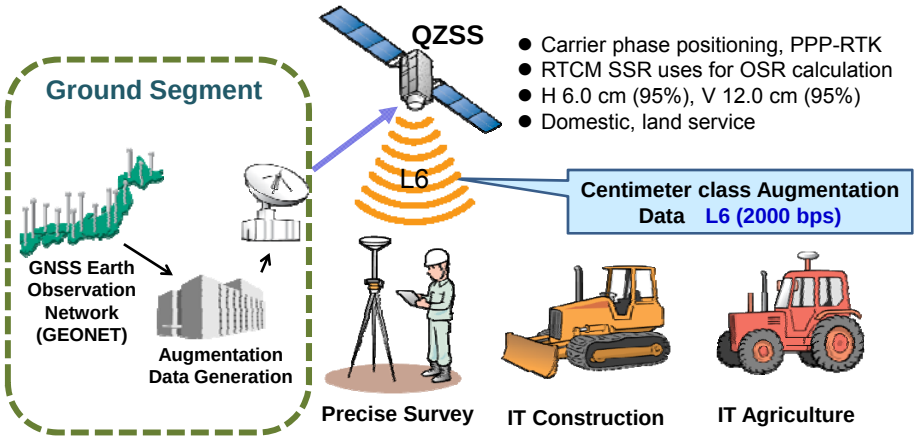
# QZSS Overview -Services-

## Functional Capability 2 GNSS Augmentation Service

**Centimeter Level Augmentation Service: CLAS**




- Carrier phase positioning, PPP-RTK
- RTCM SSR uses for OSR calculation
- H 6.0 cm (95%), V 12.0 cm (95%)
- Domestic, land service

**Real-time Users (cm level accuracy)**

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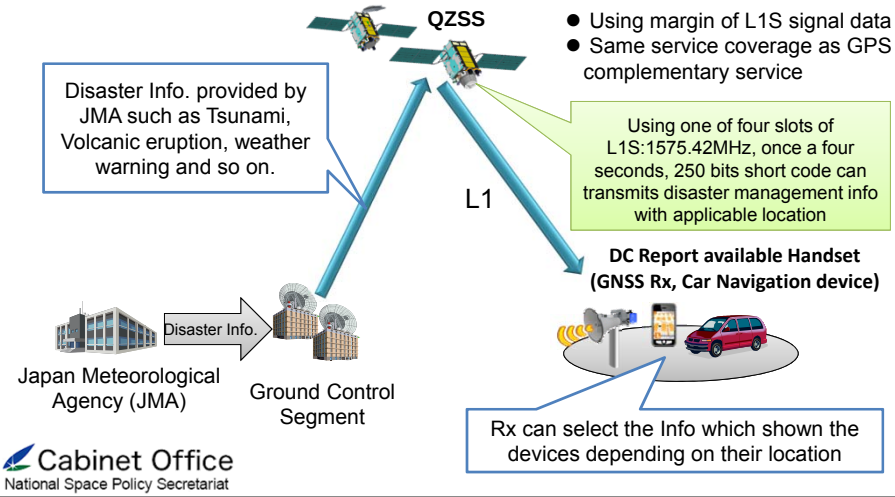
# QZSS Overview -Services-

## Functional Capability 3 Messaging Service

Satellite Report for Disaster and Crisis Management (DC Report)




- Using margin of L1S signal data
- Same service coverage as GPS complementary service

Using one of four slots of L1S:1575.42MHz, once a four seconds, 250 bits short code can transmits disaster management info with applicable location

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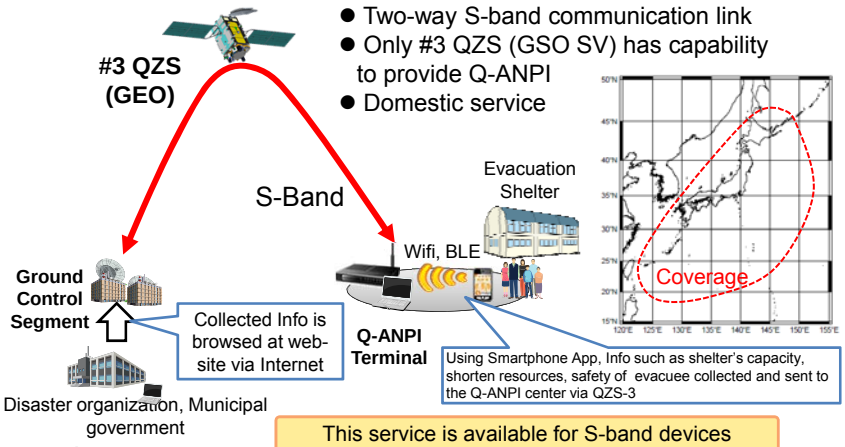
# QZSS Overview -Services-

## Functional Capability 3 Messaging Service

QZSS Safety Confirmation Service (Q-ANPI)




- Two-way S-band communication link
- Only #3 QZS (GSO SV) has capability to provide Q-ANPI
- Domestic service

Using Smartphone App, Info such as shelter's capacity, shorten resources, safety of evacuee collected and sent to the Q-ANPI center via QZS-3

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

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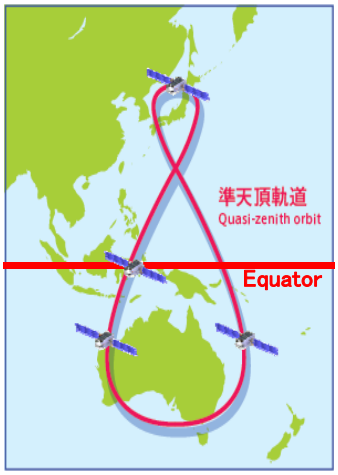
# QZSS Overview -System-

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

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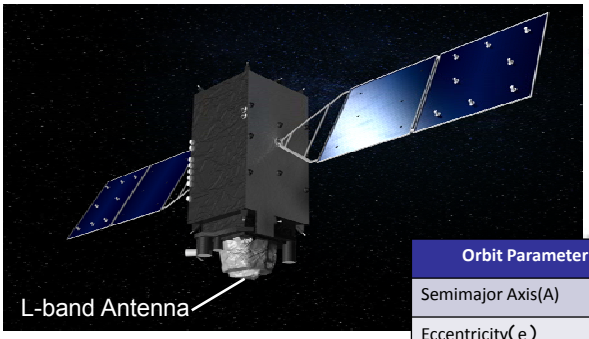
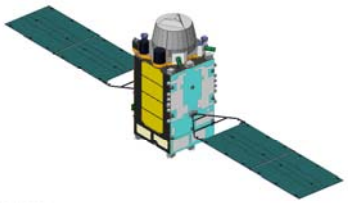
# QZSS Overview -System-

## QZSS Satellite (#2 and #4)



Launch Vehicle : H-IIA
Mass Dry/Launch : 1.6t/4.0t
Lifetime : 15+ years

| Orbit Parameter | Nominal Allocation |
|---|---|
| Semimajor Axis(A) | 42164km |
| Eccentricity(e) | 0.075 |
| Inclination (i) | 41 degree |
| Argument of Perigee(w) | 270 degree |
| RAAN(Ω) | Block I_Q: 117 degree<br>Block II_Q: 117±130 degree |
| Central Longitude (λ) | 136 degree |

RAAN: Right Ascension of the Ascending Node

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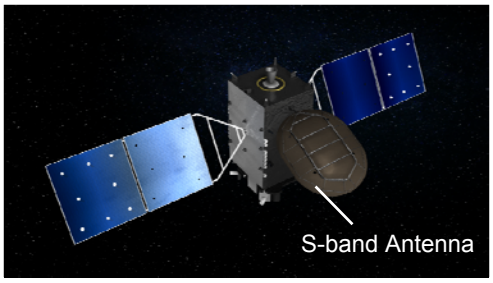
# QZSS Overview -System-

## QZSS Satellite (#3 GEO)




Launch Vehicle : H-IIA
Mass Dry/Launch : 1.8t/4.7t
Lifetime : 15+ years

| Orbit Parameter | Nominal Allocation |
|---|---|
| Longitude | 127 E |
| Latitude | 0 |

- Additional S-band antenna for two-way communication for emergency safety report (Q-ANPI service).
- L1Sb signal for SBAS service.

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# QZSS Overview -System-

## QZSS Master Ground Station

QZSS Control Center, Kobe

- ✓ Two-Ground Station (Control Center) are available with site diversity.
- ✓ Hitachi-Ohta station is main operation site and Kobe is a redundant site.


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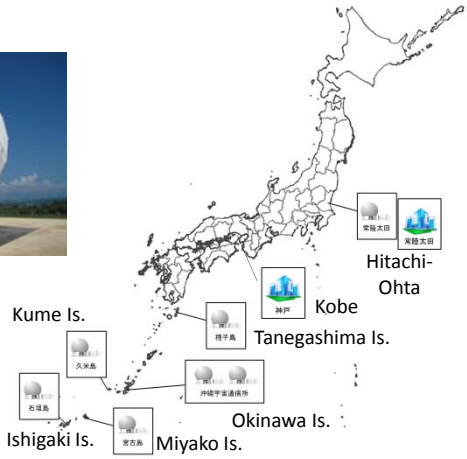
# QZSS Overview -System-

## QZSS TTC Stations




- 7 TTC (Telemetry, Tracking, and Command) stations: Most are at the southern part of Japan for satellite continuous visibility.
- All TTC stations were built and set operational by the end of 2016.

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# QZSS Overview -System-

## QZSS Monitor Stations Distribution




- 25 monitor stations for POD of both QZSS and GPS satellites
- Additional 10 domestic stations for SLAS (totally 13 sites)
- CLAS uses GEONET, Japanese CORS more than 1200 stations

:Monitor Site

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# QZSS Overview -System-

## Ranging Signals of QZSS

| Signal | Frequency MHz | Service | Compatibility | QZS-1 IGSO | QZS-2/4 IGSO | QZS-3 GEO |
|---|---|---|---|---|---|---|
| L1C/A | 1575.42 | Positioning | Complement GPS | ✓ | ✓ | ✓ |
| L1C | | Positioning | Complement GPS | ✓ | ✓ | ✓ |
| 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) | - | ✓ | ✓ |
| L6D | 1278.75 | Augmentation(CLAS) | PPP-RTK (Carrier Phase Positioning) | ✓ | ✓ | ✓ |
| L6E | | Experimental(MADOCA) | PPP, PPP-AR (Carrier Phase Positioning) | - | ✓ | ✓ |

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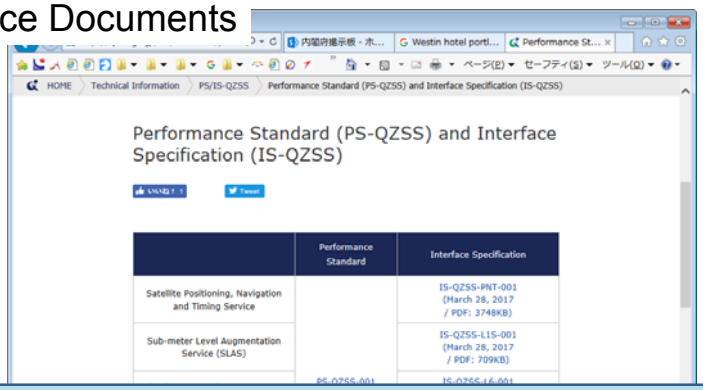
## QZSS Overview -System-

Interface Documents




Performance Standard (PS-QZSS) and Interface Specification (IS-QZSS) are available in our website
http://qzss.go.jp/en/technical/ps-is-qzss/ps-is-qzss.html

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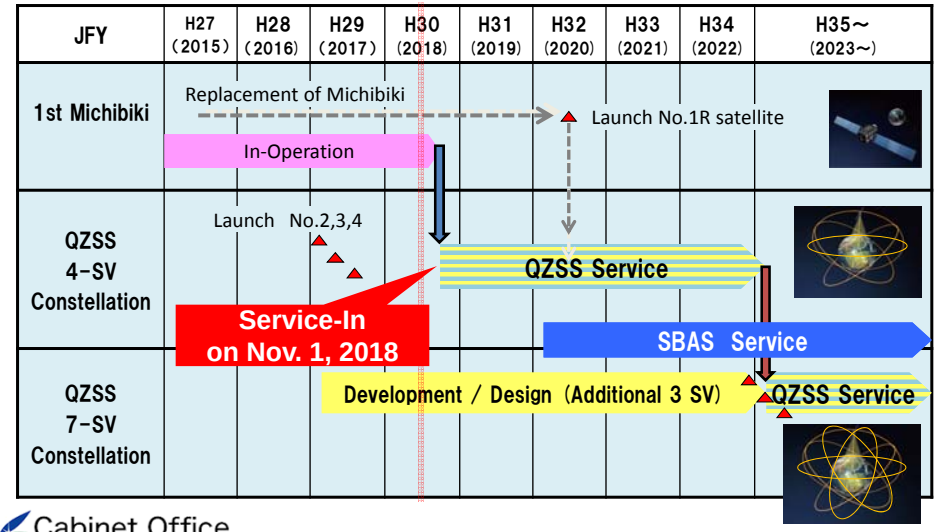
# QZSS Overview -Development Status-

## QZSS Program Schedule (Latest)

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# QZSS Overview -Development Status-

## Three consecutive launches: Ready for service-in!

© 三菱重工/JAXA

| #2 satellite: Jun. 1, 2017 00:17:46(UCT) | #3 satellite: Aug. 19, 2017 05:29:00(UTC) | #4 satellite: Oct. 9, 2017 22:01:37 (UTC) |
|---|---|---|

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## *QZSS Performance -PNT Service-*

### Performance (SIS Accuracy)

[ Specification ] less than 2.6m(95%)

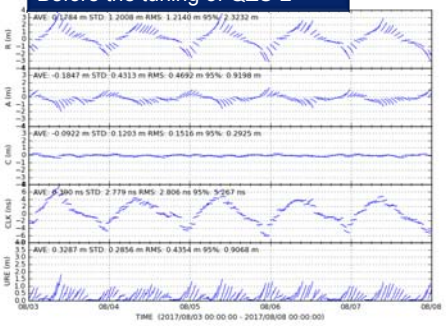
[ Evaluation (2018/5/11～ 2018/5/17) ]

QZS-1: 0.61m(95%), QZS-2: 1.11m(95%), QZS-3: 0.96m(95%), QZS-4: 1.01m(95%)

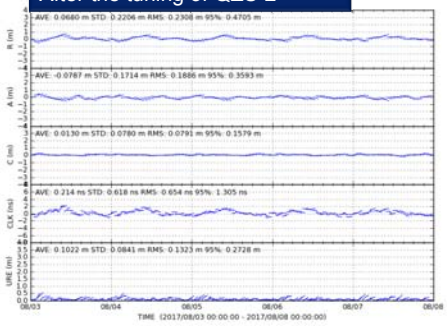
### The improvement by the tuning

In order to improve SIS Accuracy (i.e. orbit error and clock error), parameters in our estimation engine were adjusted.

Before the tuning of QZS-2



After the tuning of QZS-2



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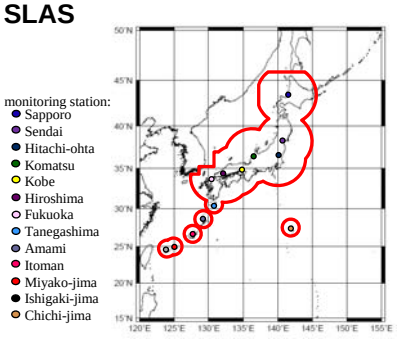
# QZSS Performance -SLAS Service-

## 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°<br>User range error caused by user's receivers and user's situation : 0.87 m(95%) |

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# QZSS Performance -SLAS Service-

## Recent Test results

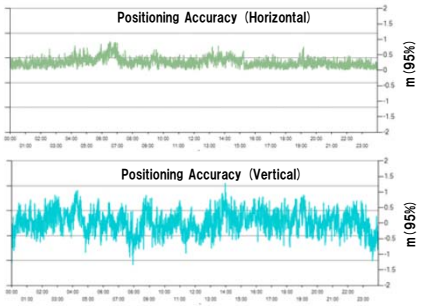
・Using the GNSS-based control stations in GNSS Earth Observation Network System (GEONET) operated by Geospatial Information Authority of Japan as a rover.

・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 |

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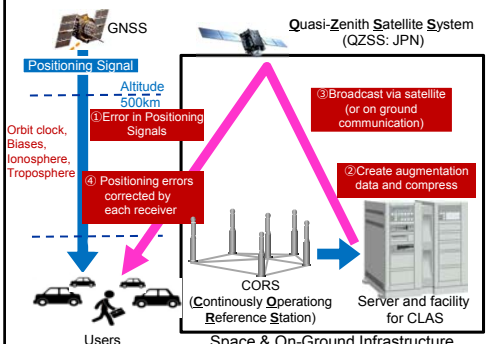
# QZSS Performance -CLAS Service-

**1. CLAS (Centimeter Level Augmentation Service)**




Space & On-Ground Infrastructure for High-Precision Positioning

**2. Technical features**

1)Augmentation data is created from CORS data
2)Error resulting from Ionosphere, Troposphere conditions can be corrected
3)Augmentation data is broadcasted from QZSS free of charge

**3. Servicing situation**

1) Present: Test service on running
2) From 1st Nov 2018: Public service distribution
・Range of service: Japanese domain and 800,000km² area off shore
・Accuracy:
H ≤ 6.0 cm (95%), V ≤ 12.0 cm (95%) (Static)
H ≤ 12.0 cm (95%), V ≤ 24.0 cm (95%) (Kinematic)

**4. Examples of use and demonstration**

1) Automobile
Precise positioning used in combination with HD Maps for automated control

2) Agriculture
Precise positioning used for automated control of tractors

3) Snowplough
Assists recognition of self position in comparison with HD maps

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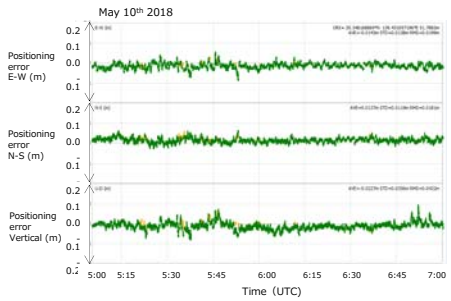
# QZSS Performance -CLAS Service-

## 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 |

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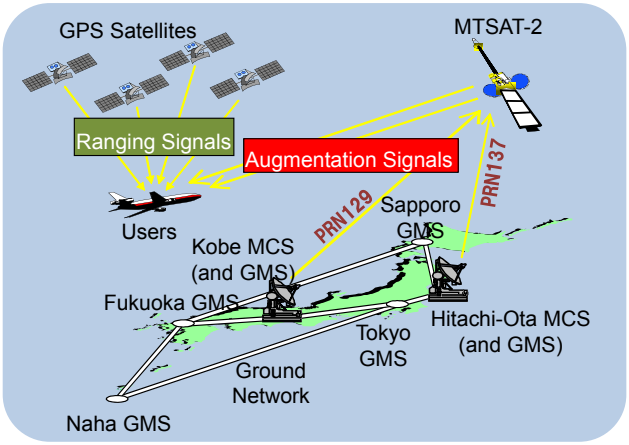
## MSAS: Japanese SBAS




- MSAS: Japanese SBAS in operation.
  - Operational since Sept. 27, 2007.
  - Currently operated by JCAB with a GEO called MTSAT-2.

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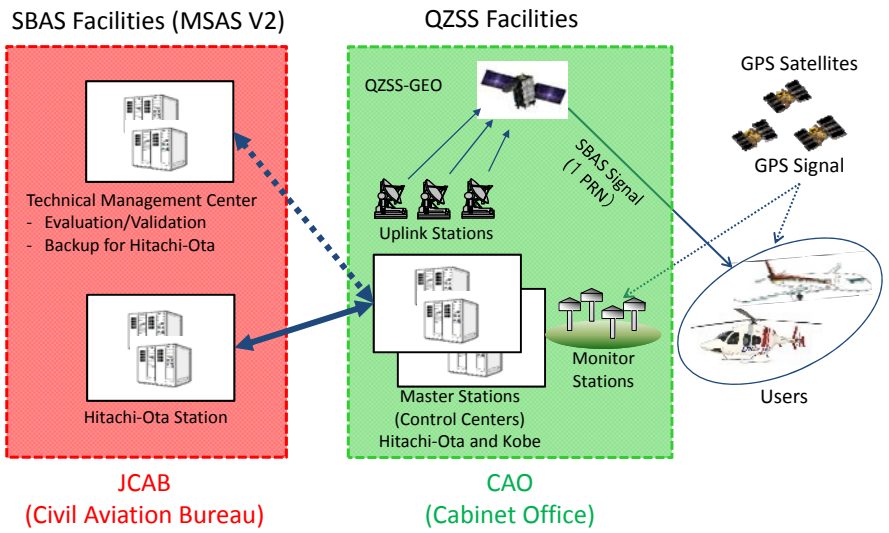
# In 2020: MSAS V2 with QZSS GEO

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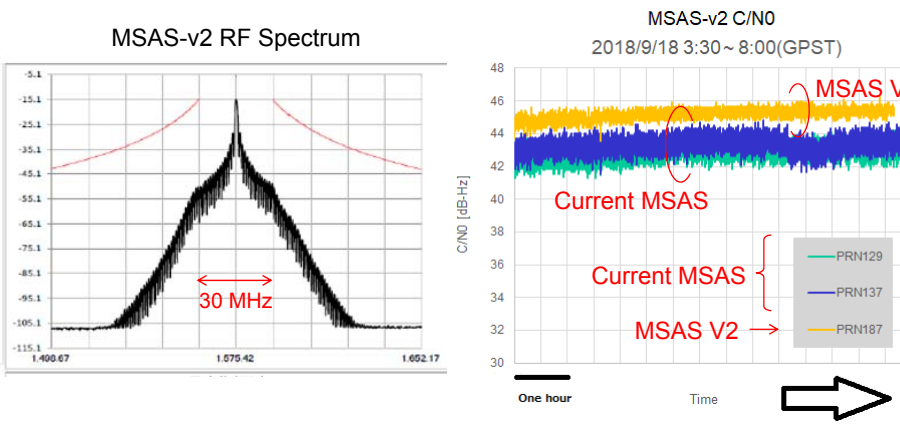
# MSAS V2 RF Performance




- PRN 129 and PRN 137 are transmitted from MTSAT-2 (MSAS-v1).
- PRN 187 is currently transmitted from QZS-3 GEO; Will be switched to PRN 129 or 137 for MSAS-v2.

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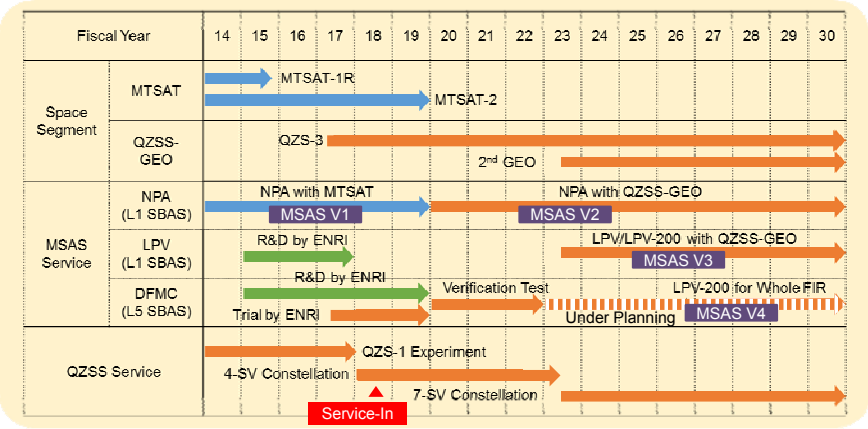
# MSAS Evolution Plan




- DFMC SBAS trial began in summer 2017 with QZS-2 L5S signal.
- MSAS V2: Replacement to the new QZSS-based system in 2020.
- MSAS V3: LPV/LPV-200 upgrade likely around 2023 and DFMC SBAS (MSAS V4) will follow.

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# DFMC SBAS Experiment

- 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.*
- 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.*
  - Began the initial test on 23 Aug., 2017 using L5S signal (PRN 196) of QZS-2 IGSO.
    - *Expects participation to this experiments. Contact: <sakai@mpat.go.jp>*

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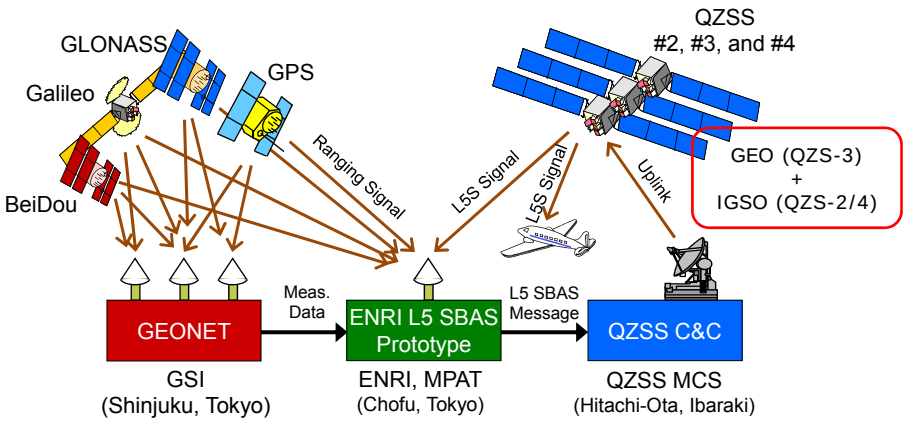
# System Configuration




- Supports DFMC
- Provides observation in real time
- Operates in real time
- Supports GPS+GLONASS +Galileo+QZSS
- Relays L5S message data

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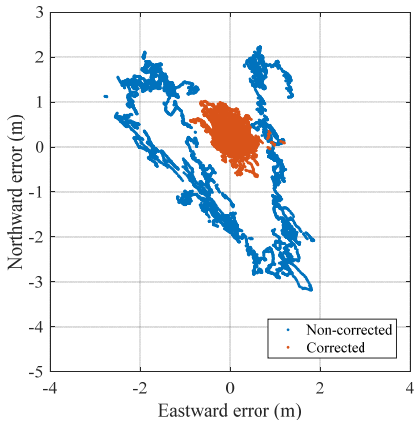
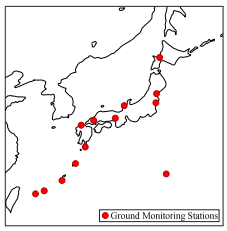
# Realtime Experiment




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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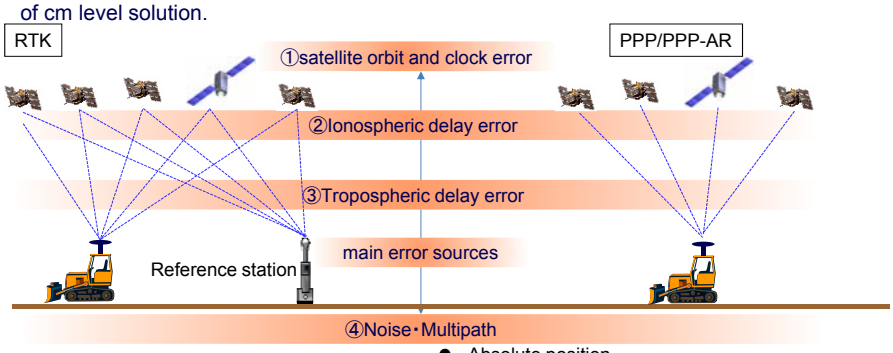
# PPP Experiment using MADOCA

## Precise Point Positioning (PPP)

- A precise positioning methodology obtaining absolute location with deci-meter level
- Resolving Integer ambiguity of carrier phase is called “PPP-AR” which can reach a couple of cm level solution.




- Relative position wrt. reference station
- Double Difference between satellites and ref stations cancels errors above shown ①②③
- cm level accuracy with instant convergence time
- Dense reference network required

- Absolute position
- Precise orb and clk are indispensable
- Iono-error ② is canceled by using Iono-free combination or estimated by using some models
- cm（PPP-AR）～deci meter（PPP) accuracy but long convergence time (30-40 minutes)
- Global coverage with global ref. network

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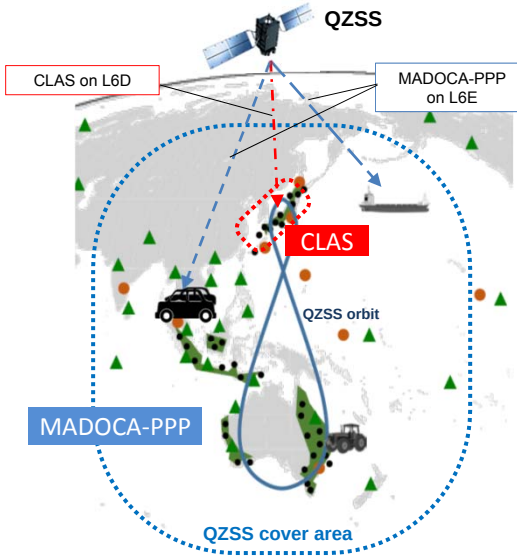
# CLAS Service and MADOCA Experiment

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- CLAS (Centimeter Level Augmentation Service) will be provided via L6D signal.
- Employs the dense GNSS monitoring network in service area.
- CLAS for Japanese territory begins in 2018.
- Service for other regions is under consideration.

:region

- Experimental augmentation based on PPP with MADOCA will be conducted using L6E signal on QZS-2/3/4.
- MADOCA: Multi-GNSS Advanced Demonstration tool for Orbit and Clock Analysis.
- Global GNSS monitoring network.
- Will also begin in 2018.

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# QZSS Satellite Information

- Considering ICG WG-D recommendation and IGS White Paper, Satellite Property Information (SPI) and Operational History Information (OHI) for each QZS SV was published on our web-site.

  http://qzss.go.jp/en/technical/qzssinfo/index.html

- Following info are included;

■Satellite Property Information(SPI)
- Reference Frame
- Attitude Law
- Mass and Center of Mass
- Navigation Antenna Phase Center Corrections
- Geometry
  - Satellite dimension
- Optical Property
- Laser Retro Reflector Location
- Differential Code Bias

■Operational History Information(OHI)
- Attitude Change history
  - mode/start・end
- Orbit maintenance maneuver history
  - time/duration/delta-V/direction
- Estimated mass history

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## *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.
  - Annual Round Table and Working Group discussions
  - Emergency Warning Services, Autonomous driving and 3D mapping, E6/L6 signals, DFMC SBAS, Knowledge sharing about Operations
- Current Activities
  - Definition of common EWS message format is on going.
  - Galileo-QZSS joint EWS trial in Australia was successfully completed on 19 Sept.
  - Joint working team activity will begin soon: Joint R&D activity on DFMC SBAS supporting IGSO SBAS concept will be planned.

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## Summary

- QZSS is Japanese regional satellite navigation system to improve not only GNSS availability but also accuracy and reliability.
  - 4 satellite constellations: Three IGSO and one GEO satellites.
  - Three consecutive launches have successfully been conducted in 2017; All four satellites are now ready on their orbits.
- Operational Service begins on November 1, 2018.
  - GPS complement service, GNSS augmentation service including SBAS, and messaging service.
  - Precise positioning service can be utilized in many applications with Multiple GNSS as well as multi-sensors.
  - Some experiments including DFMC SBAS and PPP are also ongoing.

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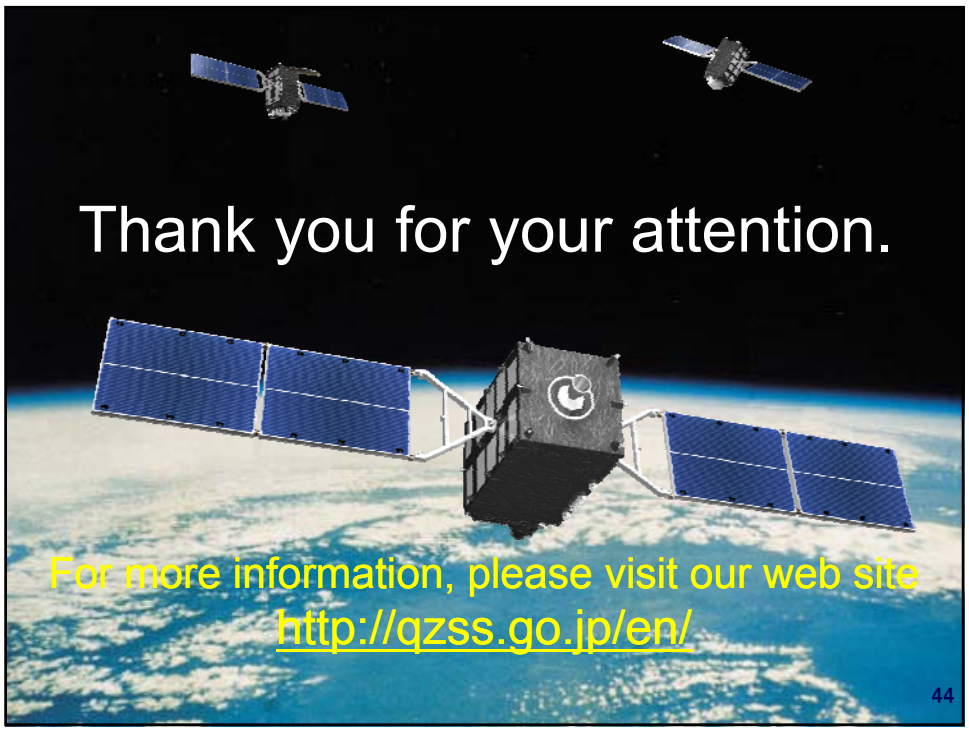
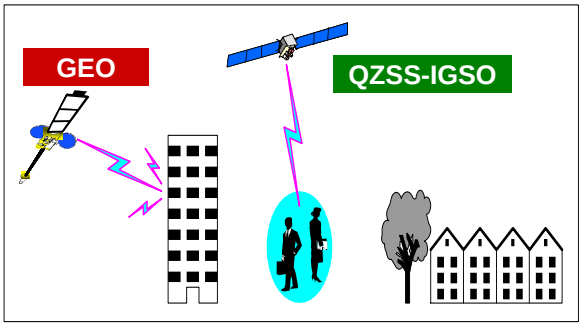


# Backup: IGSO SBAS Concept




- DFMC SBAS could be transmitted by non-GEO satellites like QZSS IGSO.
- Transmission from the Zenith: Improves availability of augmentation signals where GEO signal is blocked.
  - *Polar regions, mountain area, urban canyons, building on the south side, approaching aircraft, and so on.*

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