



ID: 6917

Precise Orbit Determination of QZSS Satellites Integrated with LEO Onboard GNSS Observations

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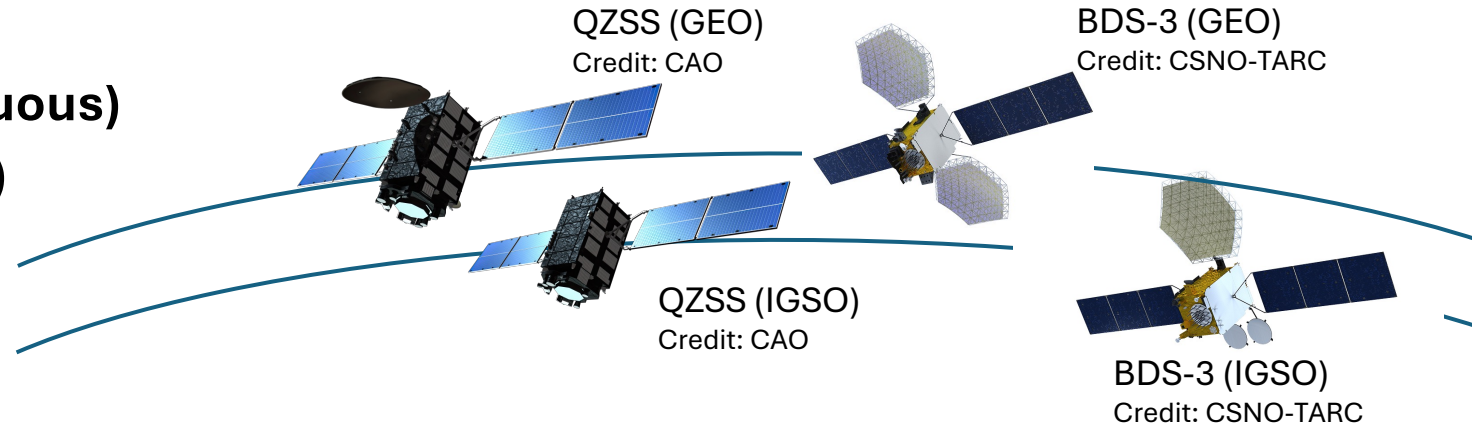
Agenda

- Introduction
- On-orbit monitoring stations
- Data quality assesment
- Integrated POD validation
- Summary and future plans

Introduction

- **GNSS satellite motion as seen from the ground**

- **GEO: stable (Continuous)**
- **IGSO: very slow (Half-day to continuous)**
- **MEO: moderate (max. 4 hours/pass)**
- **LEO: quick (max. 10 min/pass)**



GPS (MEO)
Credit: Lockheed Martin



Galileo (MEO)
Credit: ESA



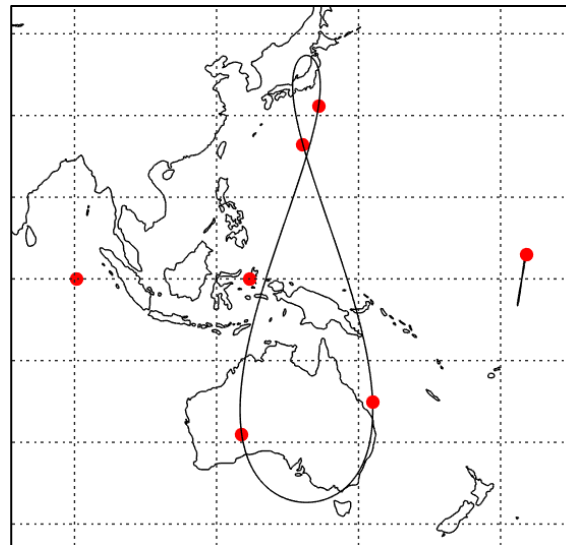
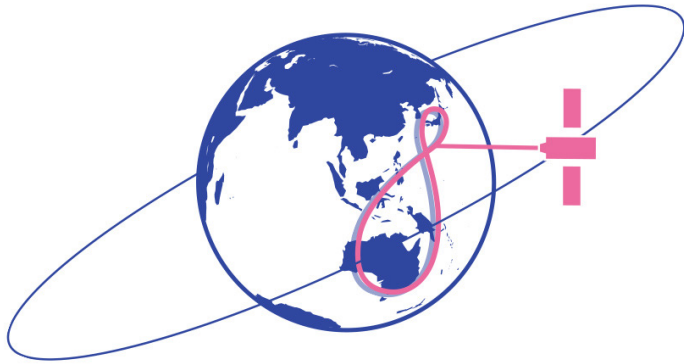
GLONASS (MEO)
Credit: ISS Reshetnev



BDS-3 (MEO)
Credit: CSNO-TARC

POD for IGSO and GEO satellites

- **Poor observation geometry** with respect to the ground tracking stations compared with MEO GNSS satellites
- **Strong correlations** occur between the orbital elements, clock offset, and range biases (e.g., receiver inter system biases, phase ambiguities).



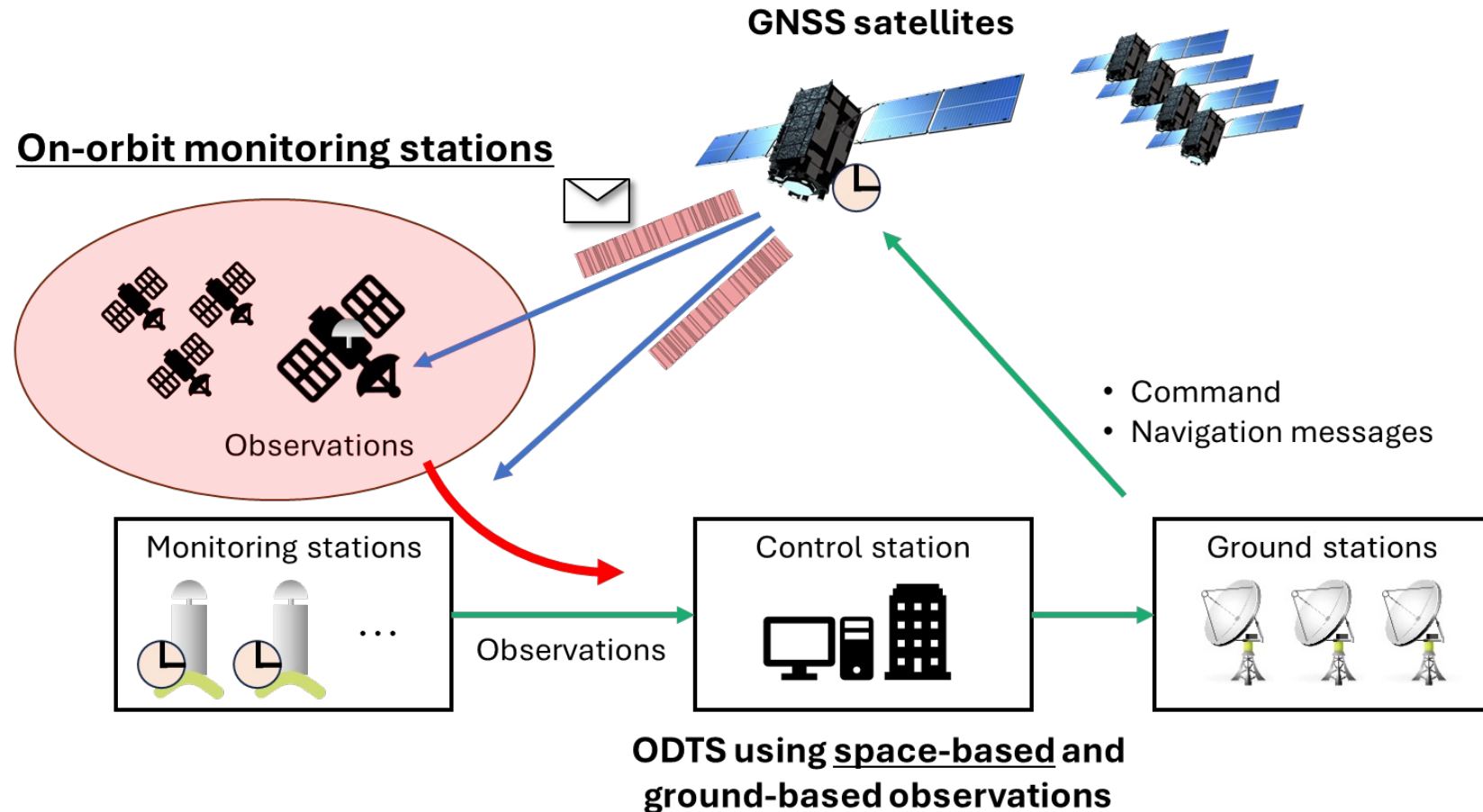
QZSS 7-SV constellation

- 4 QZOs (Quasi-zenith orbit)
- 2 GEOs (Geostationary Earth orbit)
- 1 QGEO (Quasi GEO)

On-orbit monitoring stations

- **Main components**

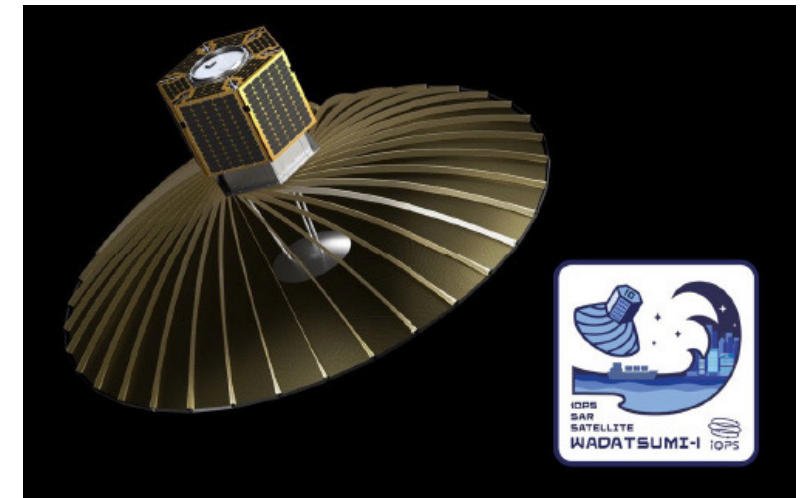
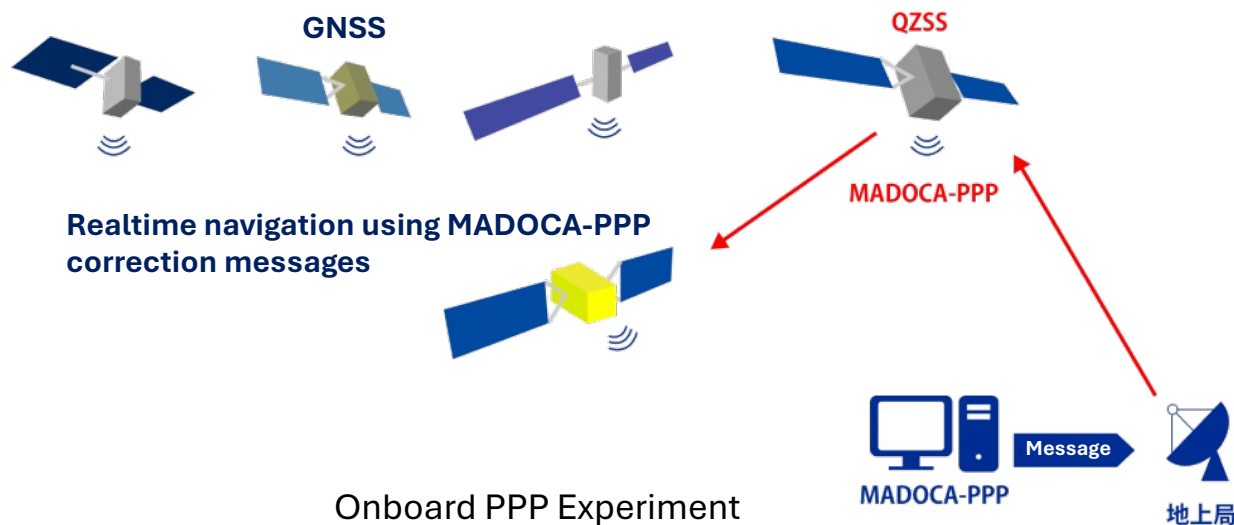
- LEO constellation
- Multi-GNSS receivers
- POD software integrating space-based observations



On-orbit monitoring stations

- **Data opportunity**

- As a part of JAXA's "Onboard PPP experiment", where the real-time navigation using MADOCA-PPP augmentation from QZSS satellites is performed.
- GNSS receivers and antennas for the experiment are mounted on the QPS-SAR-10 satellite as a hosted payload.

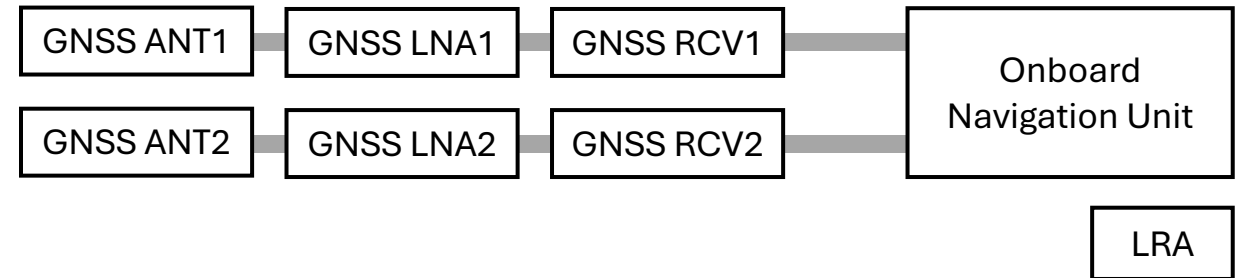


QPS-SAR-10 (credit: iQPS, inc.)

On-orbit monitoring stations

- **GNSS receivers and antennas**

- Multi-GNSS and multi frequencies (GPS, QZSS, Galileo, BDS-3, GLONASS)
- COTS tested for space use
- Two redundant lines

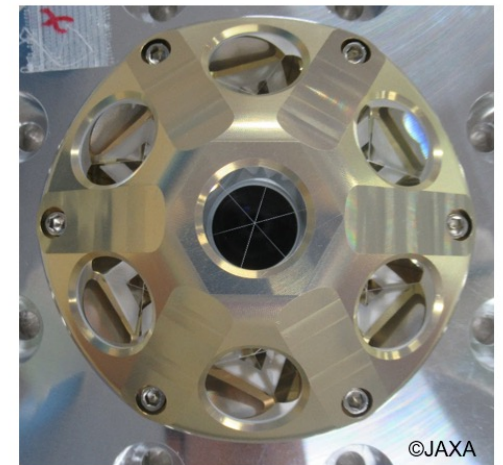


- **Laser reflector array (LRA)**

- Mt. FUJI developed by JAXA
- For LEO POD validation



GNSS receiver module



LRA (Mt. FUJI)

Data Quality Assessment

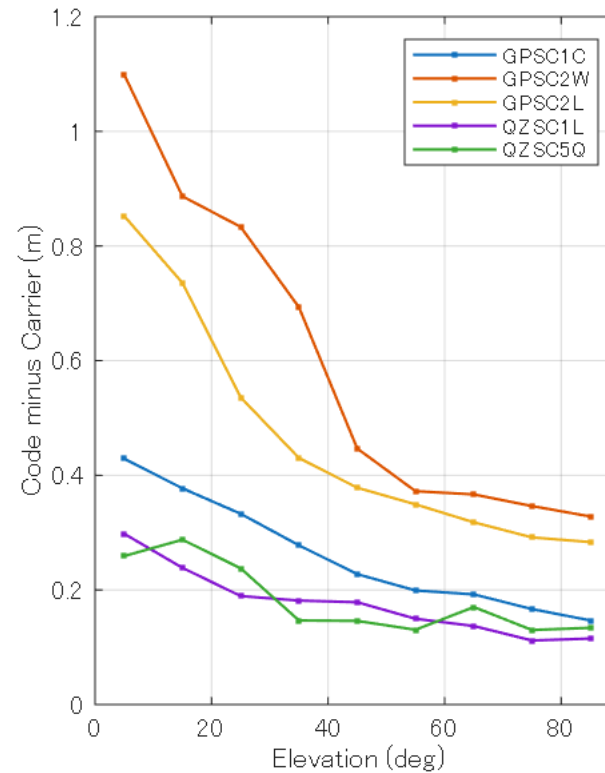
• Noise and Multipath

- Code minus carrier combination with ionospheric correction

$$MP_i = (P_i - L_i) - \frac{2f_j^2}{f_i^2 - f_j^2} (L_i - L_j) - \text{Bias}$$

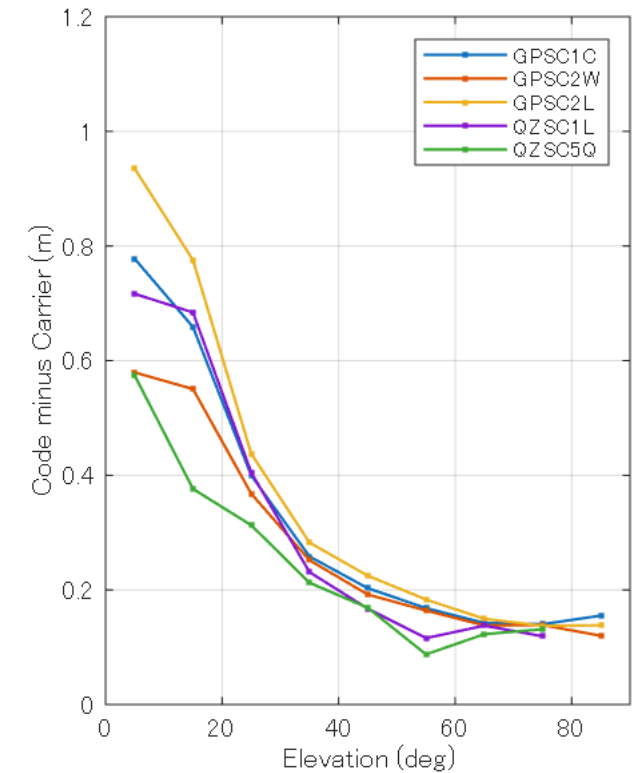
- Relatively higher errors in L2 band compared with the station on ground (e.g., IGS stations)
- Less multipath errors at low elevation in L1 and L5 band

20 Jan. 2026, 05 Feb. 2026,
10 Mar. 2026, 23 Mar. 2026



Onboard data (ANT1)

15 March 2026

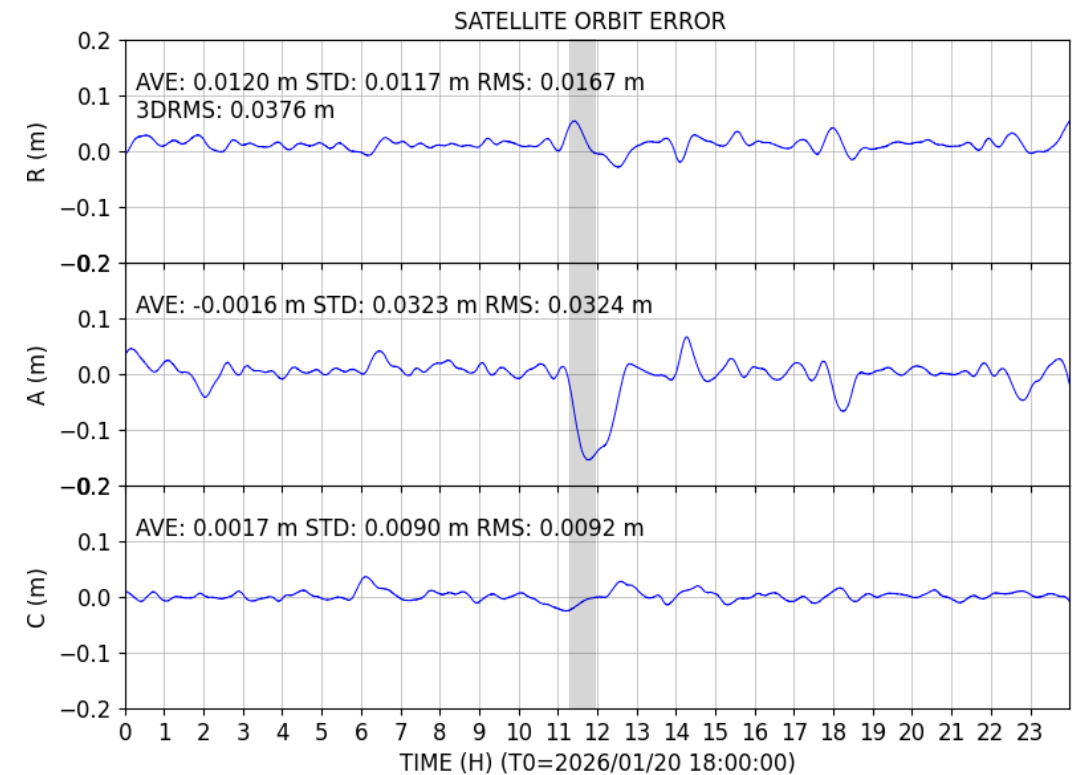


IGS station (NNOR)

Data Quality Assessment

- **POD validation for LEO satellite**
 - **Excellent agreement** between the solutions using independent GNSS observations (Ant1/Rcv1 vs. Ant2/Rcv2)
 - LEO orbits are estimated with an accuracy of **a few centimeters**

	Orbit Differences (3DRMS) [cm]	SLR Residuals (ave $\pm$ std) [cm]
ANT1/RCV1	2.97	-0.74 $\pm$ 2.08
ANT2/RCV2		-0.93 $\pm$ 2.06

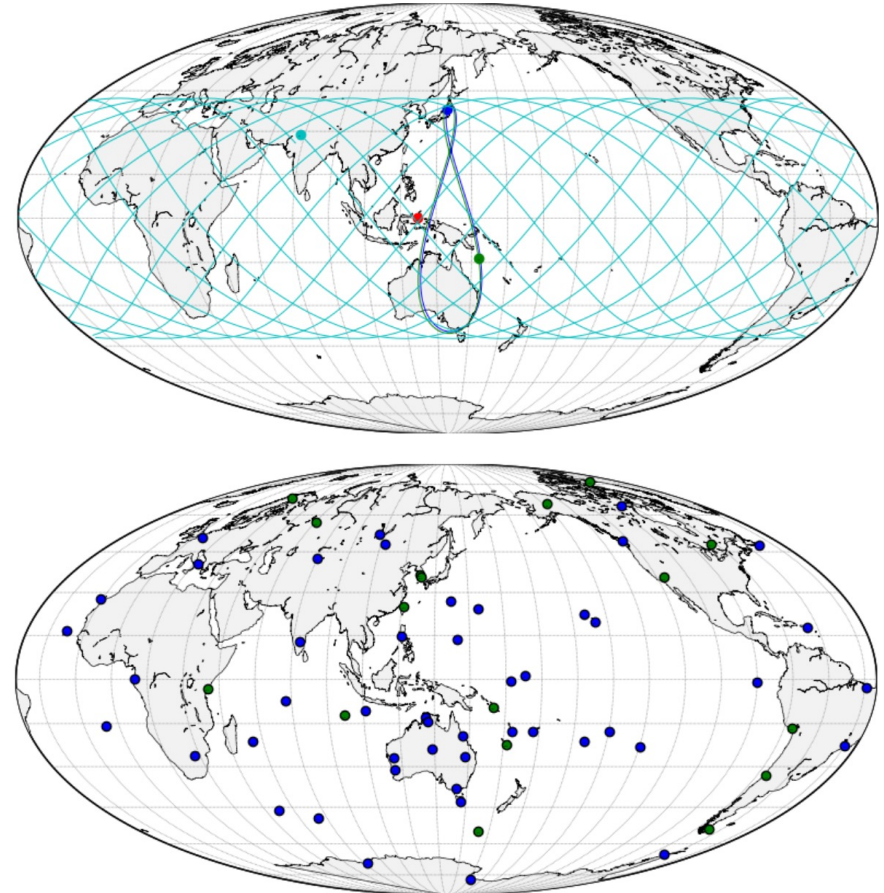


Missing observation data

Integrated POD with Onboard Obs.

- **Data Input**

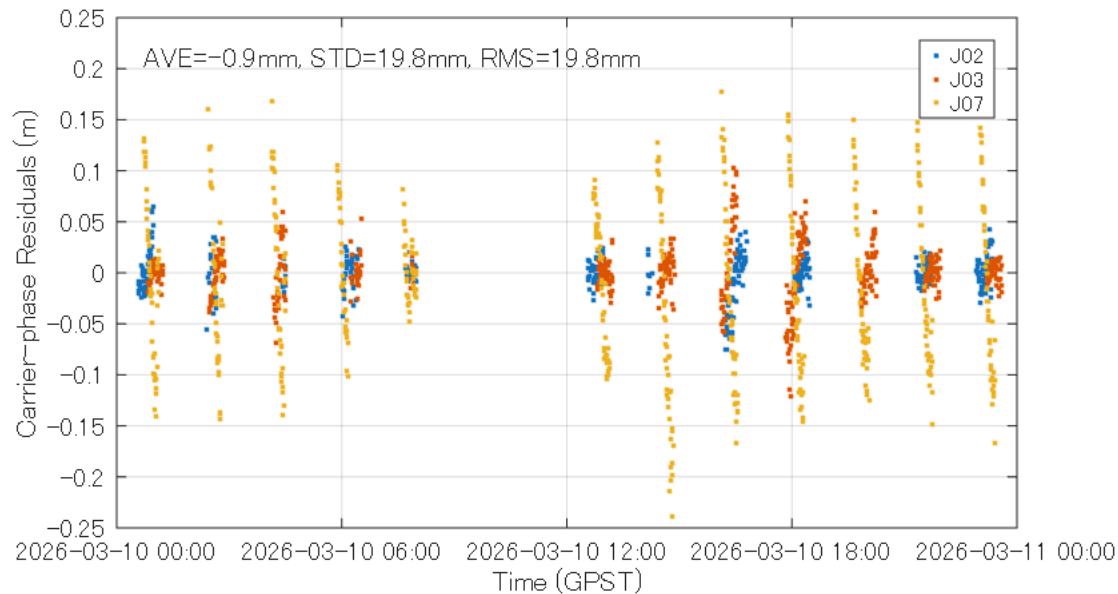
- LEO onboard observations
 - GPS: L1C/A & L2P(Y)/L2C
 - QZSS: L1C & L5
 - Satellite attitude: Considered
 - PCO/PCVs: calibrated on ground
- IGS network
 - Max. 70 stations
 - Approx. 40 stations tracks QZSS signals
 - Aligned to IGc20 reference frame



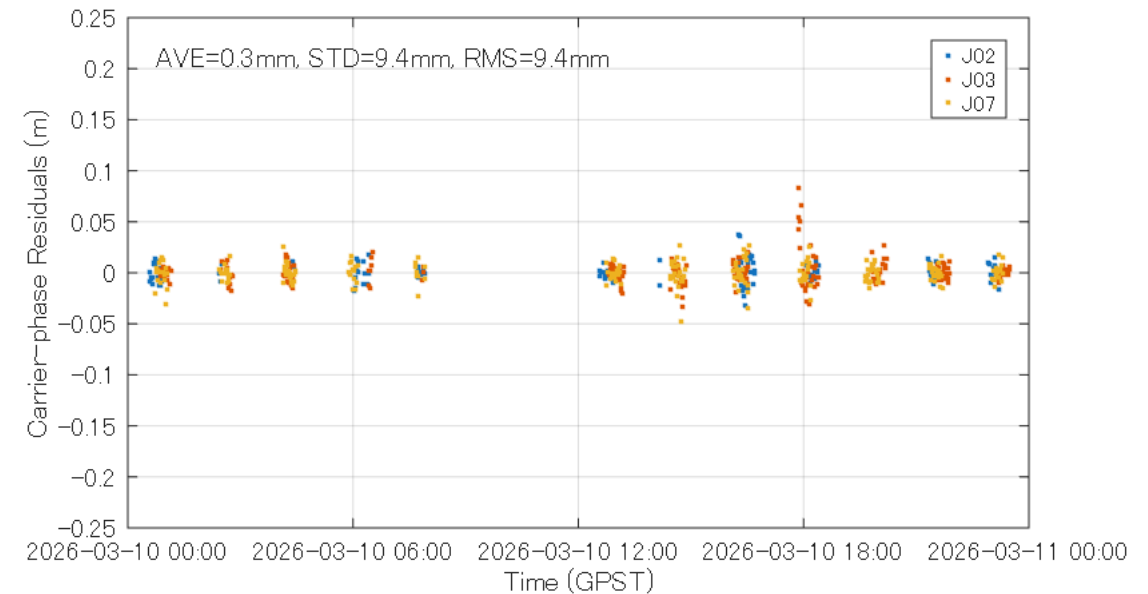
Integrated POD with Onboard Obs.

- **Phase Residuals**

- **Systematic errors** are found in the residuals when fixed to MGEX products (e.g., JAX0MGXFIN)
- **No significant systematic errors** are observed after applying the integrated POD



Fixed to JAX0MGXFIN

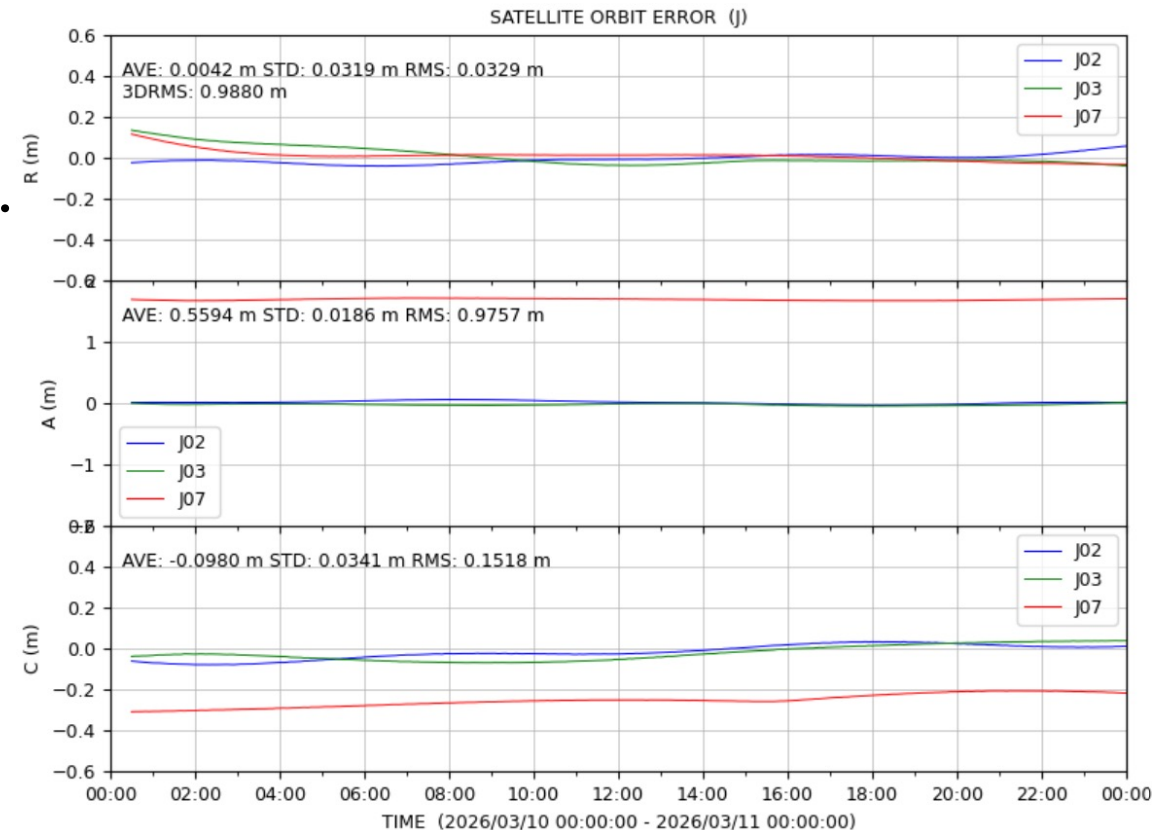


Integrated POD

Integrated POD Validations

• Orbit differences

- Significant impact on **along-track** and **cross-track** of QZSS GEO satellite (J07).
- Along-track position of the satellite changed by **more than 1 meter**
- Improved observation geometry allowed us to identify systematic errors in the residuals, which can correct the orbit errors.



Orbit differences between integrated POD solution and JAX0MGXFIN

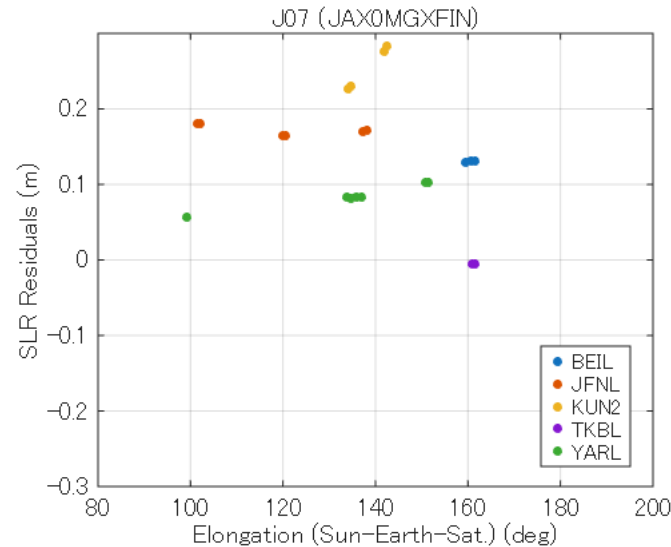
Integrated POD Validations

• SLR residuals

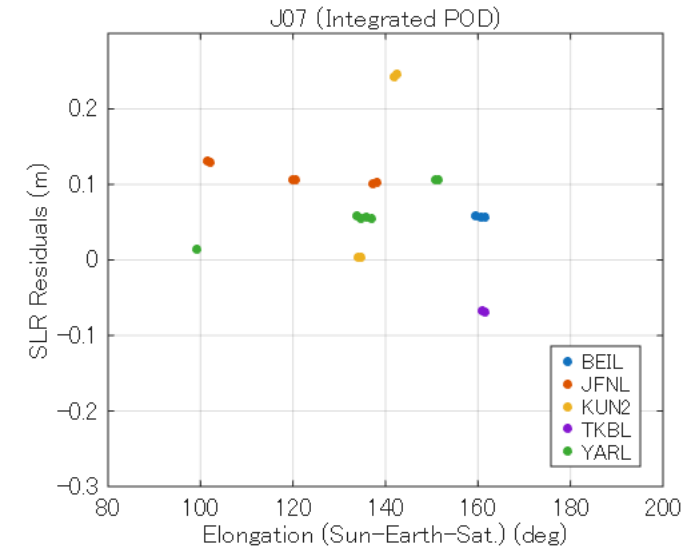
- The offset of the residuals for QZSS GEO satellite (J07) improved from **13.7 cm** to **7.5 cm** when space-based observation is applied.
- This change is attributed to the change in the along-track position of the satellite.

	SLR Residuals (ave $\pm$ std) [cm]
JAX0MGXFIN	13.7 ± 7.8
Integrated POD	7.5 ± 7.8

2026-01-20 18:00:00 ~ 2026-01-21 18:00:00 (24H)
 2026-02-05 07:45:00 ~ 2026-02-06 07:45:00 (24H)
 2026-03-10 00:30:00 ~ 2026-03-11 00:30:00 (24H)
 2026-03-23 15:30:00 ~ 2026-03-24 15:30:00 (24H)

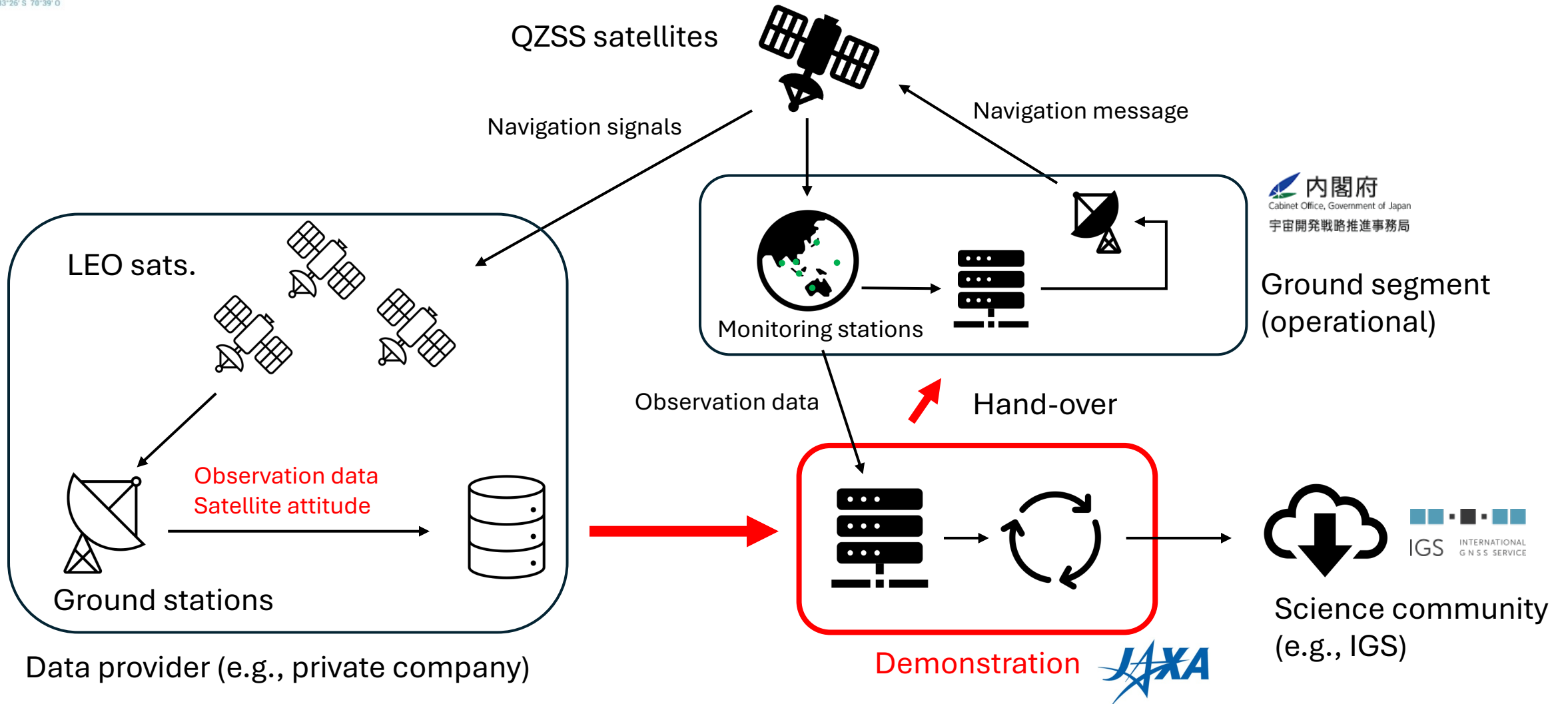


JAX0MGXFIN



Integrated POD

[Plan] Concept of demonstration



Summary and Conclusion

- On-orbit monitoring station(s) has great benefit to **improve the observation geometry for GEO and IGSO satellites.**
- Incorporation of space-based observations reveals the systematic errors in the phase residuals of the QZSS GEO satellite (J07), which can be vanished **by correcting the along-track position with integrated POD.**
- The offset of the SLR residuals for J07 satellite improved **from 13.7 cm to 7.5 cm** when space-based observation is applied.



Questions?