



OVERVIEW OF MADOCA : ARCHITECTURE AND RECENT DEVELOPMENTS

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WHAT IS MADOCA?

Multi-GNSS Advanced Demonstration tool for Orbit and Clock Analysis (MADOCA) is a Japanese precise orbit and clock determination tool for GNSS.

MADOCA estimates satellite orbits and clock offsets in both post-processing with iterative weighted least squares and real-time processing with extended Kalman filter (EKF), supporting GPS,GLONASS, Galileo, QZSS, and BeiDou constellations. For recent updates, see Table 1. MADOCA is used in the JGX analysis center jointly operated by the Geospatial Information Authority of Japan (GSI) and the Japan Aerospace Exploration Agency(JAXA). JGX routinely provides GPS, GLONASS, and Galileo Final, Rapid, and Ultra Rapid products to the IGS. In addition, JAXA distributes a Final product that covers these constellations as well as QZSS and BeiDou to MGEX.

In addition to product distribution via CDDIS, JAXA publishes its products and other datasets on the MADOCA website. Moreover, PPP processing using MADOCA products can be performed with MALIB (MADOCA-PPP Library), an open-source software package publicly available on GitHub. We welcome feedback and collaboration!

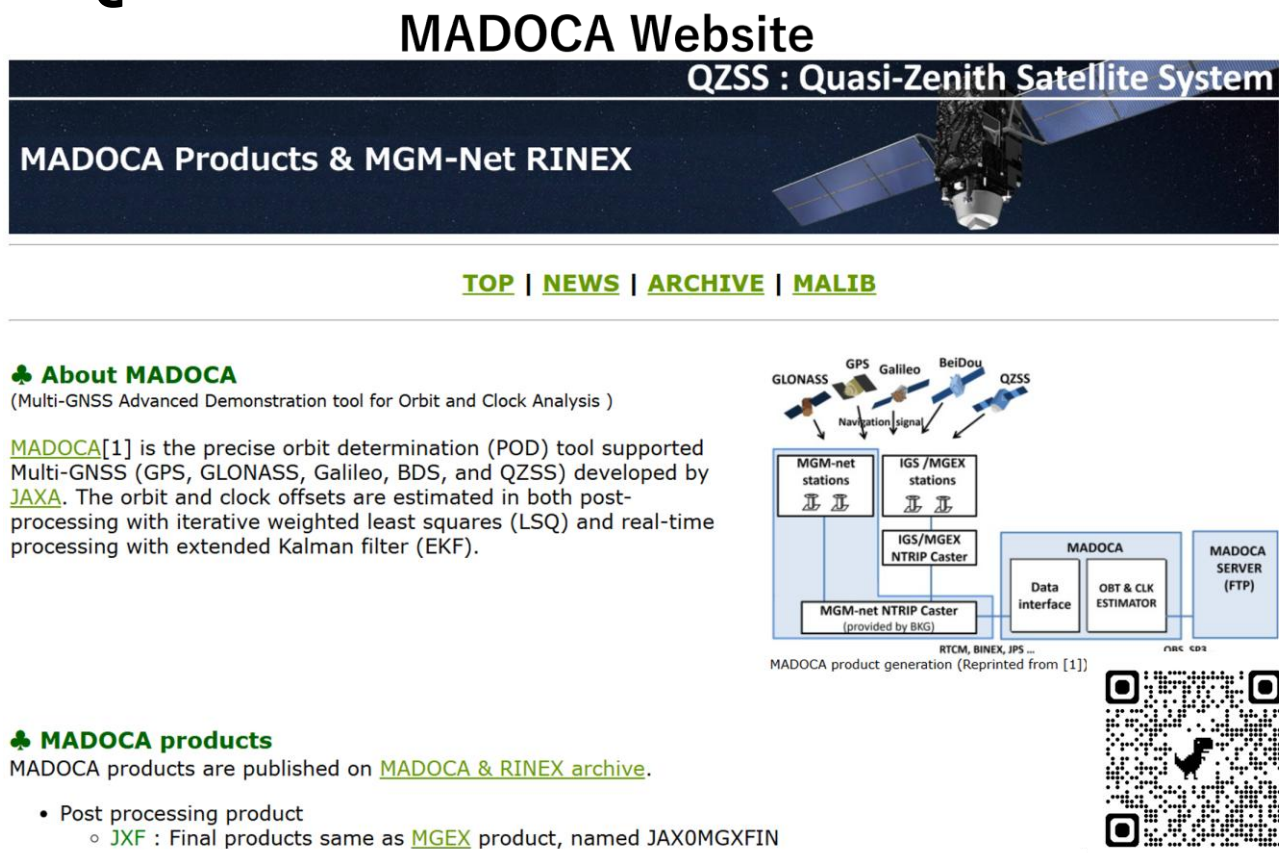
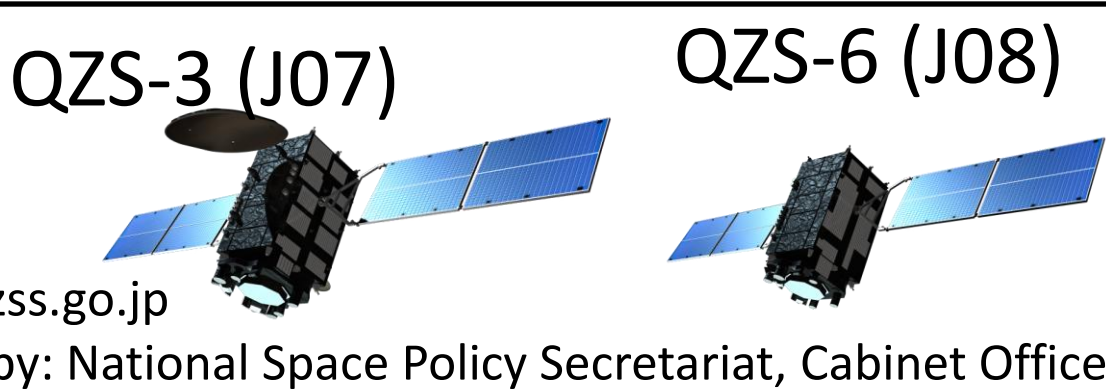


Table1. Recent updates

Date	Content
October 2024	• Incorporation of BeiDou into JAXA MGEX products • Application of physical models to the SRP and thermal radiation of QZSS, Galileo, and BeiDou satellites
September 2025	• Release of satellite attitude data in the ORBEX format
October 2025	• Addition of OSB product output
March 2026	• Incorporation of QZS-6 into JAXA MGEX products
March 2026	• Addition of clock reference station selection • Support for RINEX v4

QZSS ORBIT VALIDATION



Quasi-Zenith Satellite System (QZSS) is a regional navigation satellite system currently consisting of five operational satellites: three IGSO (QZS-2, QZS-4, QZS-1R) and two GEO (QZS-3, QZS-6).The most recent satellite, QZS-6, was launched from the Tanegashima Space Center on February 2, 2025. To assess the quality of QZSS orbit products, the MADOCA-estimated QZSS orbits were validated using SLR residuals and orbit overlap analysis.

The SLR residuals for the IGSO satellites show in Figures 1 to 3 are approximately 6 cm (RMS). For GEO satellites, the residuals for QZS-3 exhibits an RMS of about 20 cm (see Figure 4), while QZS-6 has an RMS of about 11 cm (see Figure 5). The residuals for the QZS-3 presents a mean offset, indicating a mis modeling of the satellite. In contrast, QZS 6 shows no significant bias but has a larger standard deviation compared to other satellites, likely due to the limited number of IGS stations that can track the satellite; an increase of the number of stations is desirable.

The orbit overlaps shown in Figure 6 indicate that QZS-6 has greater scatter in the along-track direction than QZS-3. Conversely, the overlaps for QZS-3 exhibits beta-angle-dependent periodic variations in the radial and cross-track directions. Although both are GEO satellites, QZS-3 carries a large communication antenna, making it more difficult to model non-gravitational accelerations. Further model improvement is required.

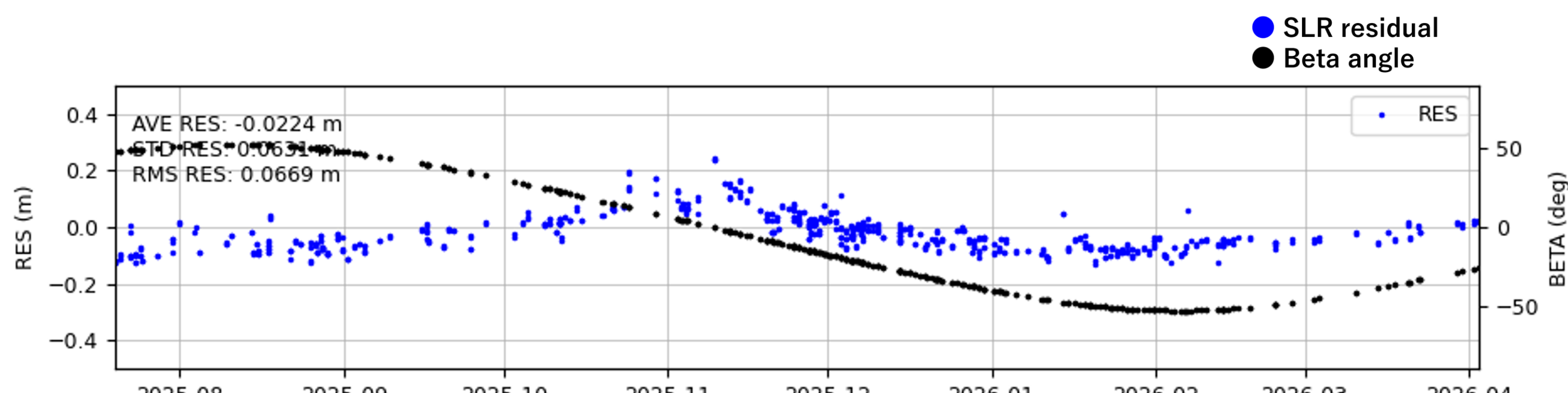
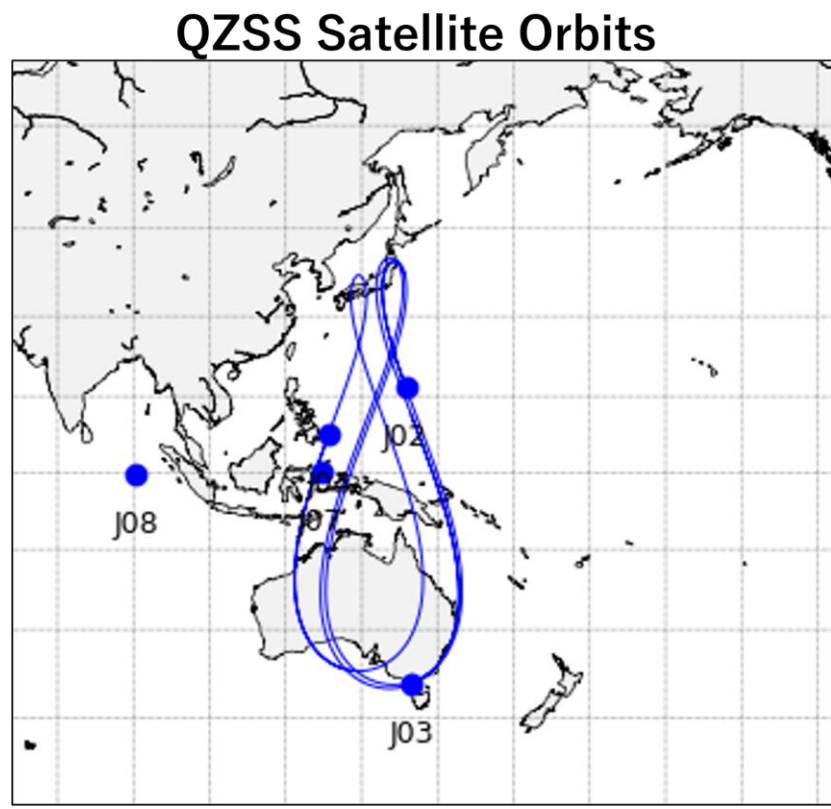


Figure 1. SLR residuals of QZS-2 (J02)

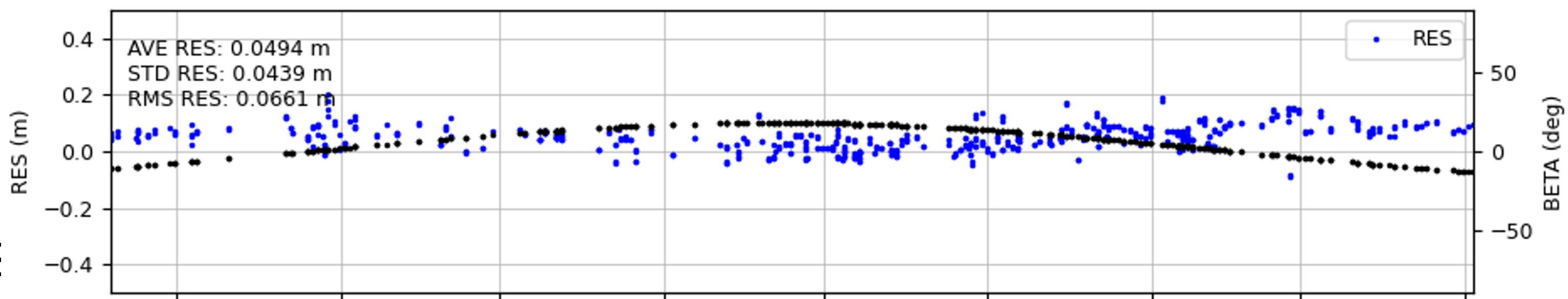


Figure 2. SLR residuals of QZS-4 (J03)

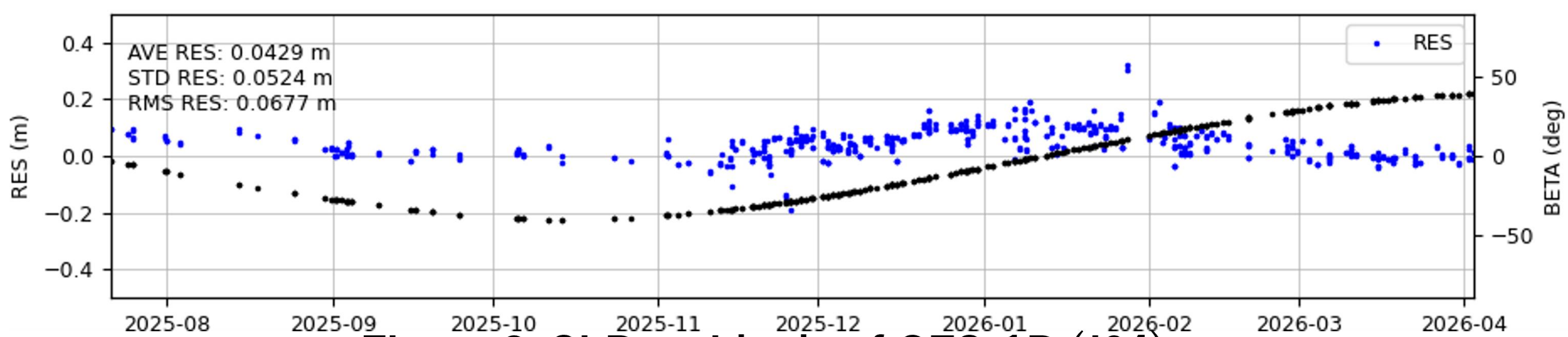


Figure 3. SLR residuals of QZS-1R (J04)

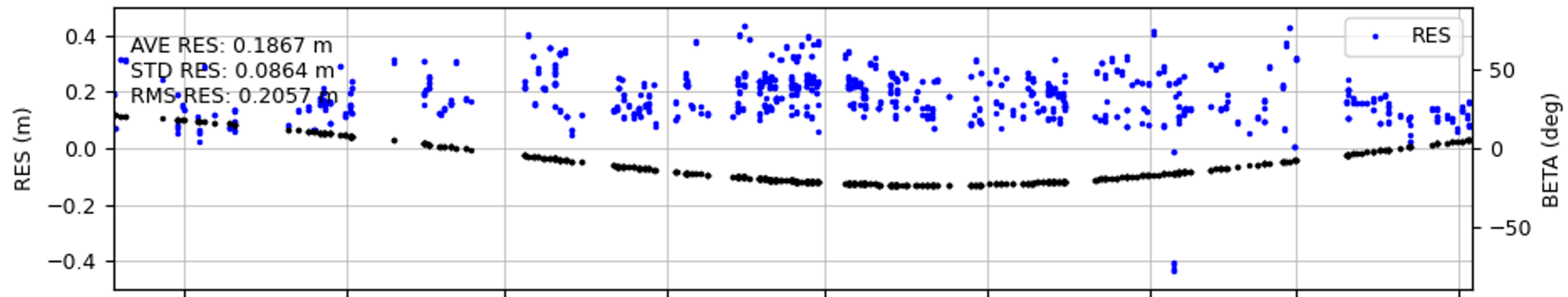


Figure 4. SLR residuals of QZS-3 (J07)

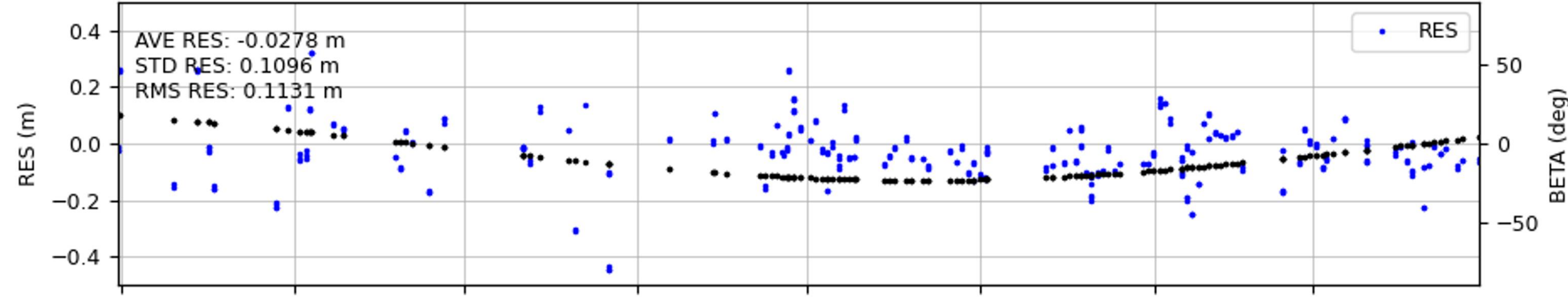


Figure 5. SLR residuals of QZS-6 (J08)

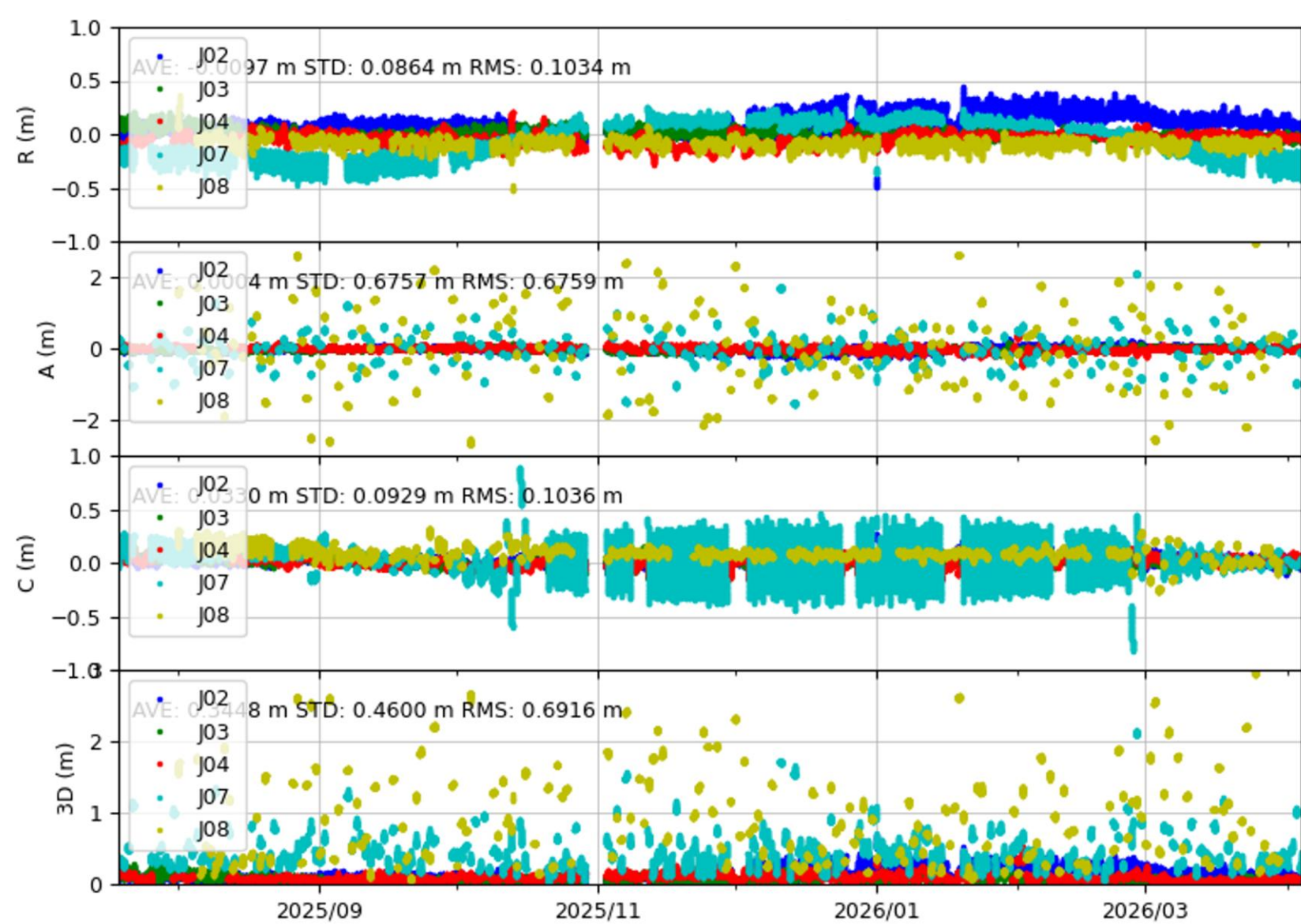


Figure 6. Orbit overlap analysis of QZSS satellites

BEIDOU3 ORBIT VALIDATION

The products provided by JAXA to MGEX include BeiDou-3 MEO and IGSO satellites.

Figure 7 shows the SLR residuals of BeiDou-3 MEO satellite orbits estimated using MADOCA. Satellites outlined in red are manufactured by the Shanghai Engineering Center for Microsatellites (SECM), while the others are produced by the China Academy of Space Technology (CAST).

The residuals for SECM satellites are approximately 3 cm, whereas those for CAST satellites are about 4–5 cm (except for M23). These results are comparable to the orbit accuracy achieved by other analysis centers (ACs).

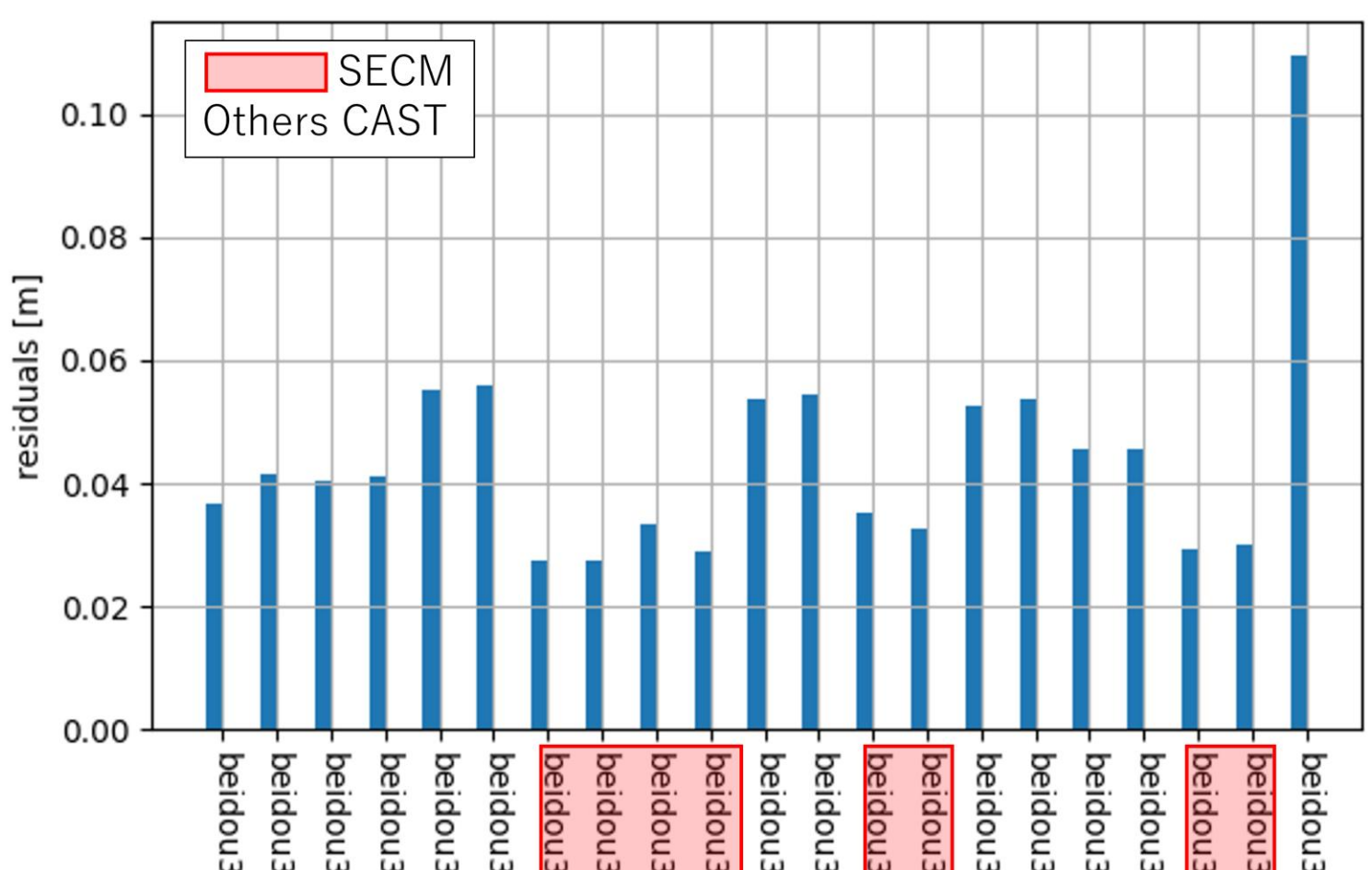


Figure 7. SLR residuals of BeiDou-3 satellites

FUTURE WORK

Further improvement of QZSS orbit determination accuracy will be pursued through enhancement of physical model parameters.

In addition, JGX is preparing to apply the latest version of MADOCA, upgraded in FY2025, for the generation of JGX products.

In particular, an OSB (observable-specific signal bias)–based phase bias estimation was implemented in the previous fiscal year.

Performance evaluation is currently underway, and public release is planned in the near future.