# Accuracy evaluation of QZS-1 orbit solutions with Satellite Laser Ranging

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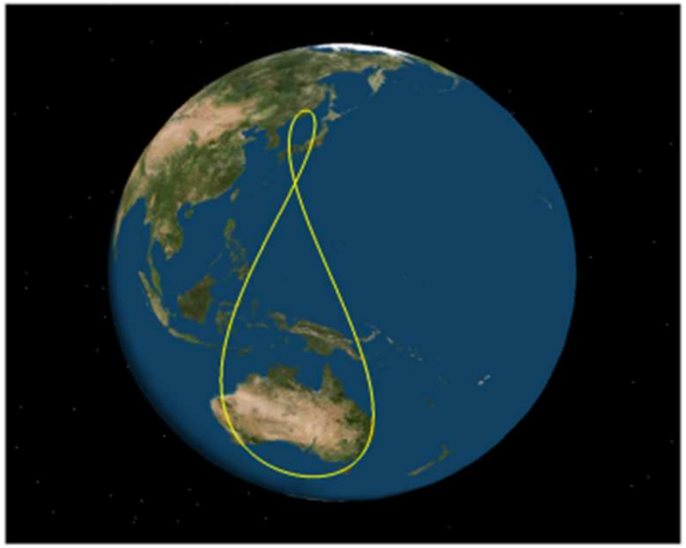
# Introduction

## QZSS-1(Quasi-Zenith Satellite-1) launched in Sep.2010

- A Japanese original positioning system using multiple satellites that have the same orbital period as geostationary satellites with about 45deg inclinations.
- Transmit GPS compatible signal and LEX comm. signal based on Multi-GNSS scheme.



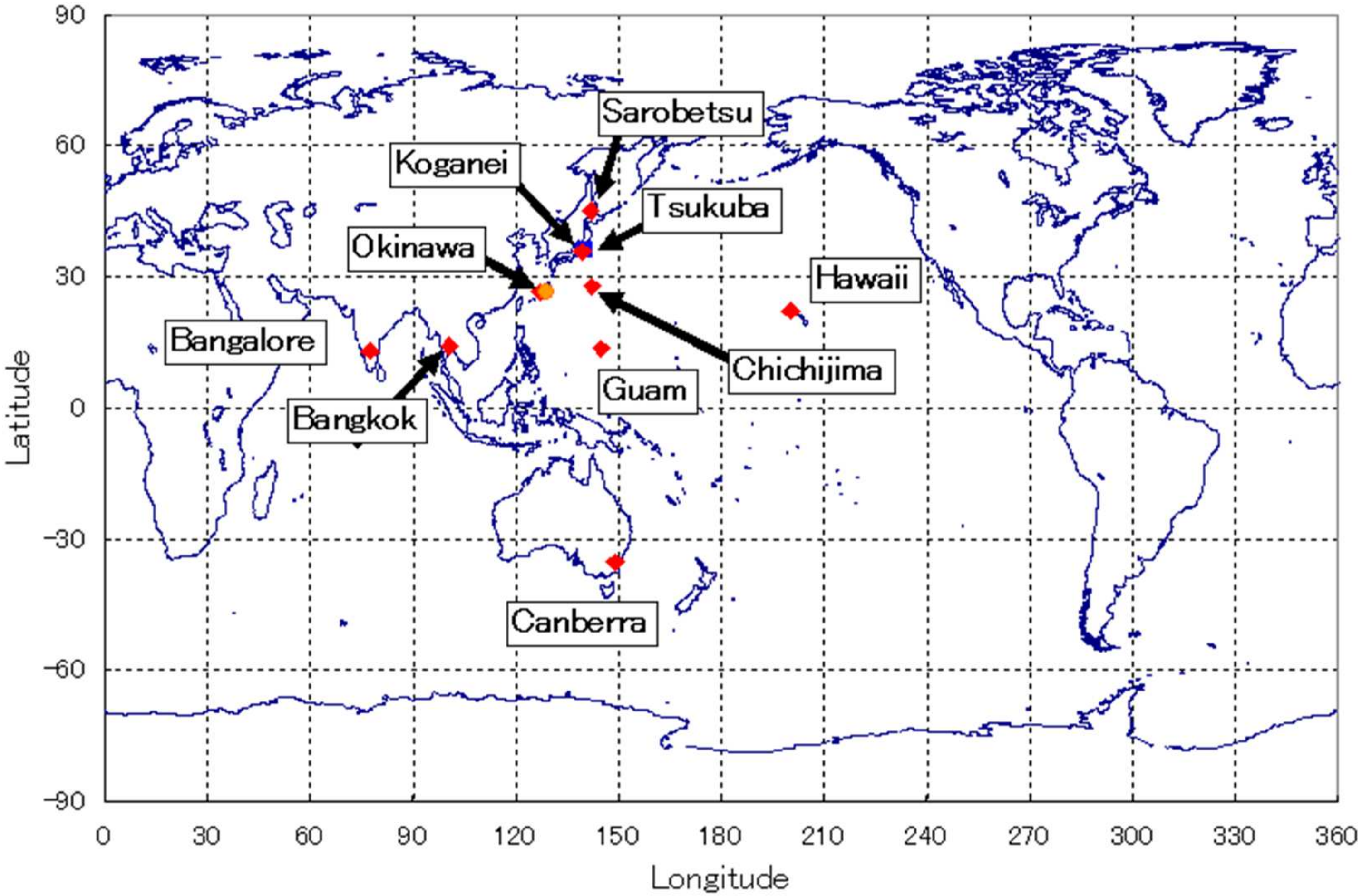
Ground trace from QZS-1 orbit

QZS-1 orbit parameters

| | |
|---|---|
| Semi-major Axis | 42,164 km (average) |
| Eccentricity | 0.075 ± 0.015 |
| Orbital Inclination | 43°± 4° |
| Argument of Perigee | 270°± 2° |
| Central Longitude of Ground Track | 135°± 5° East |

# QZSS monitoring stations

A QZSS tracking network of 9 monitoring stations are currently operated.



# Precise Point Positioning using LEX signal channel of QZS and application

**LEX: L-band experiment signal**

- **Carrier-phase-based Single Positioning**
  - No need of reference stations nearby
  - Global coverage world-wide
  - Accuracy: sub-dm ~ cm-level
  - Need precise satellite orbit/clock
- **Applications (Expected)**
  - Precision agriculture, machine control
  - Crustal deformation monitoring
  - Sea surface (Tsunami) monitoring
  - GNSS meteorology, LEO satellite POD

http://www.tsunamigps.com

Development Status of MADOCA, T. Takasu, 2012

# MADOCA Multi-GNSS Advanced Demonstration tool for Orbit and Clock Analysis

- Software for Precise Orbit/Clock estimation for Multiple GNSS
- For JAXA Precise Point Positioning (PPP) experiment via QZSS LEX channel
- Key-technology for precise positioning with GNSS

- Requirements
  - Satellites: GPS, GLONASS, QZSS and Galileo
  - Offline (in this study) and real-time functions

- Goal of Orbit/Clock Accuracy
  - Offline : 3 cm/0.1 ns (GPS), 7 cm/0.25 ns (Glonass/QZS)
  - Real-time: 4 cm/0.1 ns (GPS), 9 cm/0.25 ns (Glonass/QZS)

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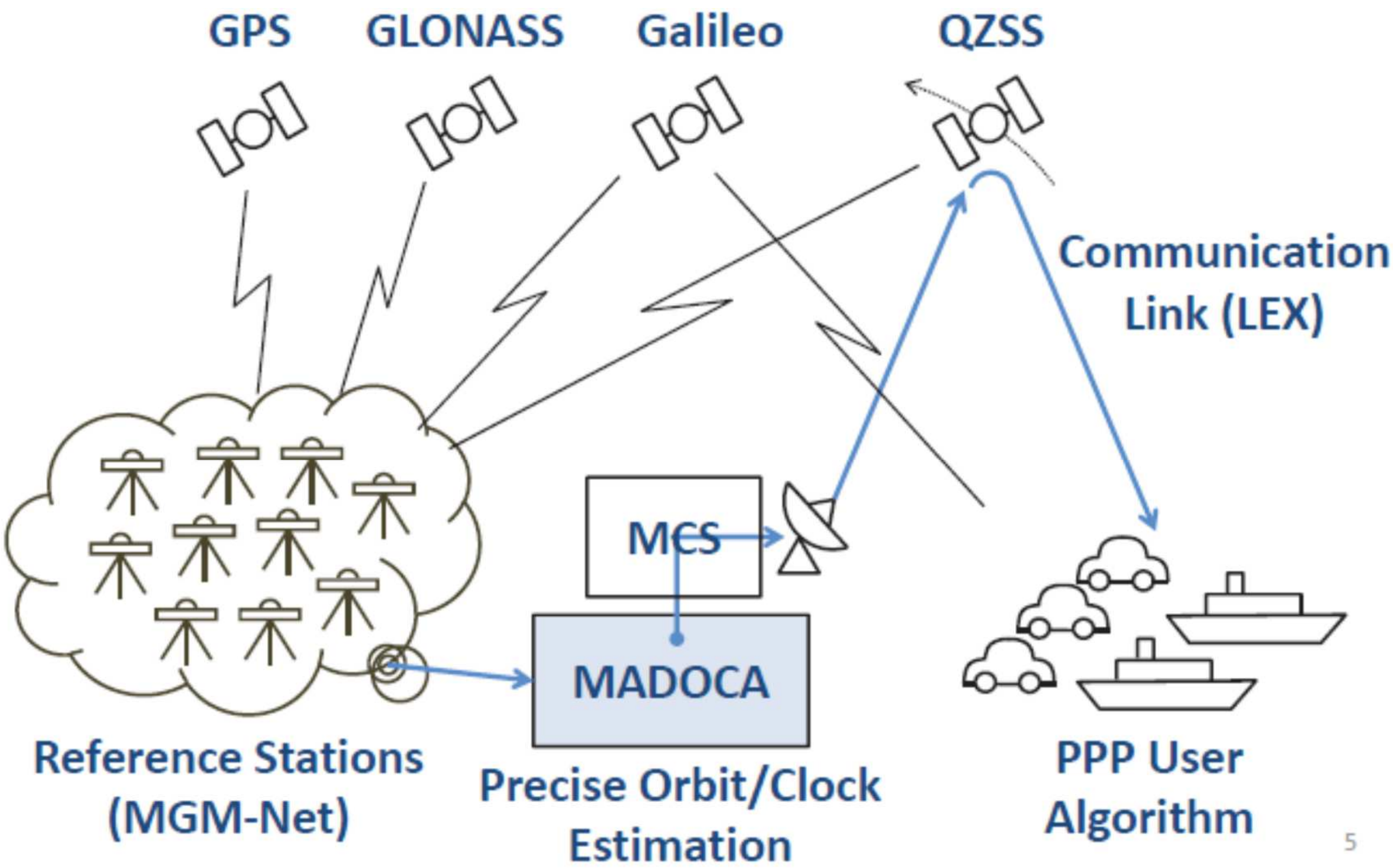
# Concept of real time PPP user using MADOCA

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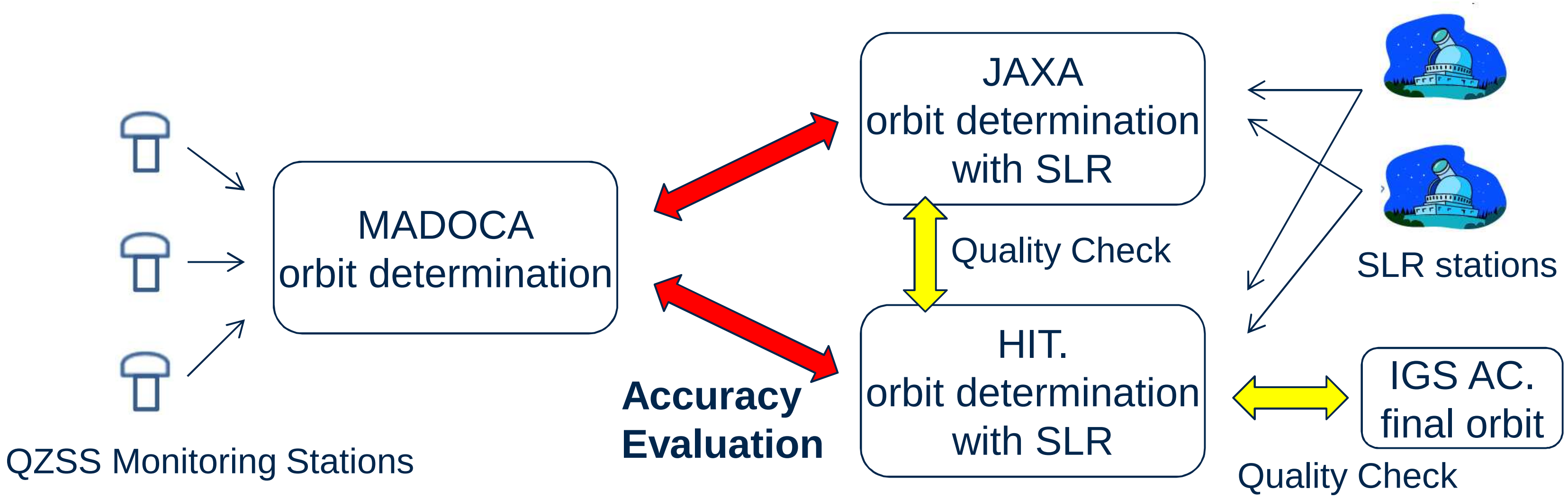
# Accuracy evaluation of QZS-1 MADOCA solutions with SLR

This Study

- SLR residuals to the QZS-1 orbits processed with MADOCA.
- Differences between the MADOCA-orbits and those with SLR tracking data.
- The orbits with SLR tracking data are provided by JAXA and Hitotsubashi Univ. (HIT).



# Evaluation Procedure

**Step.1 Prior evaluation: GPS orbits using SLR bservations**

- GPS orbit determination using SLR observations. (JAXA/HIT)
- Differences between JAXA/HIT-orbits and IGS final orbits.
- Differences between JAXA-orbits and HIT-orbits.

**Step.2 Evaluation of the QZS-orbits using SLR observations**

- QZS-1 orbit determination using SLR observations. (JAXA/HIT)
- Differences between JAXA-orbits and HIT-orbits.

**Step.3 Evaluation of the orbits processed with MADOCA**

- SLR residuals to the orbits processed with MADOCA.
- Differences between the MADOCA-orbits and the JAXA/HIT-orbits using SLR observations.

# STEP1:
# GPS orbit estimation with SLR

## Evaluation

- Differences between JAXA/HIT-orbits and IGS final orbits.
- Differences between JAXA-orbits and HIT-orbits.

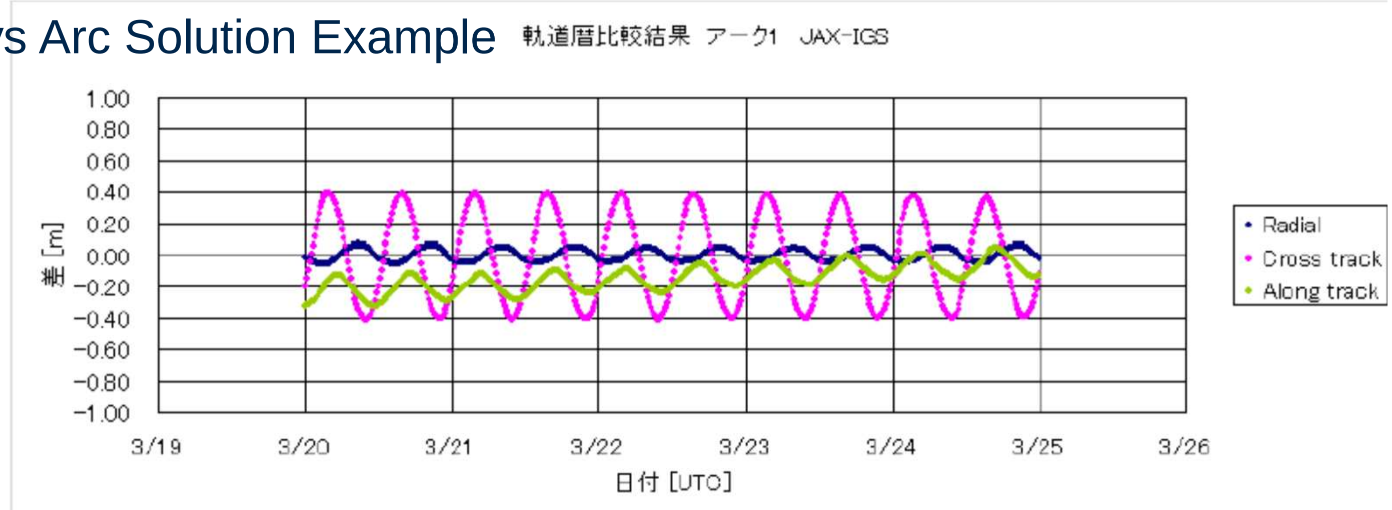
## GPS orbit determination using SLR observations

- Estimation periods are selected so that the SLR data at no less than 3 stations is provided at the same time.

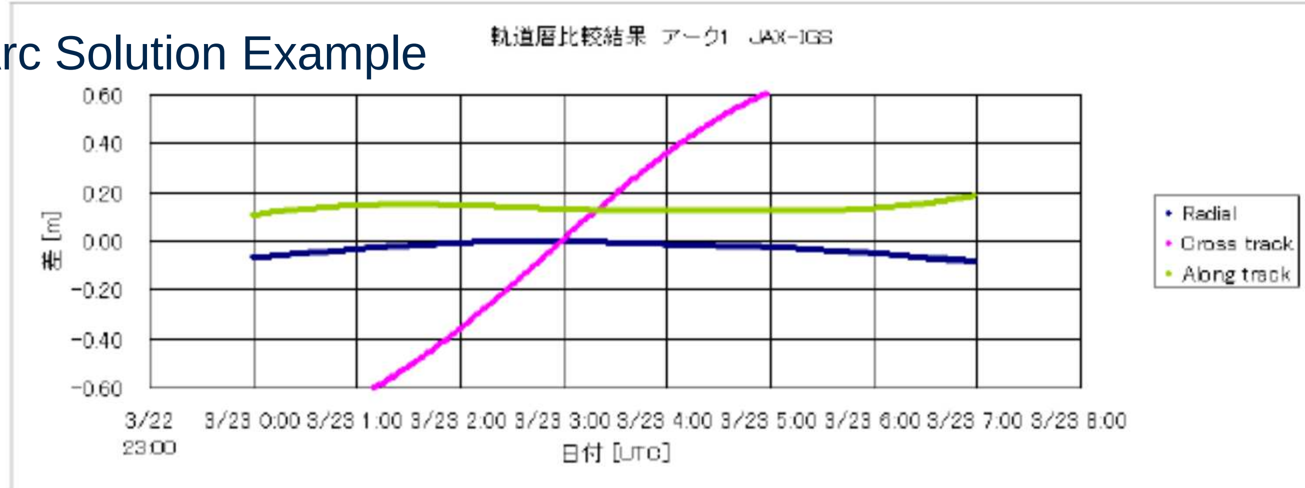
| Models/Parameters | JAXA | HIT |
|---|---|---|
| Site position | ilrsb | ITRF2008 |
| Satellite mass | 972.9 kg | 930.0 kg |
| Difference between CoM and optical center | [862.58, -524.51, 671.7] m (common) | |
| Troposphere delay model | Marini-Murray model | Mendes & Pavlis model |
| SRP model | CODE model | Canon ball |
| Estimation parameters | Orbit elements (6) | Orbit elements (6)<br>SRP correction coefficient (1)<br>Constant and 1/rev accelerations in the along-track direction (3) |

# GPS36: JAXA-IGS final orbit

5 Days Arc Solution Example



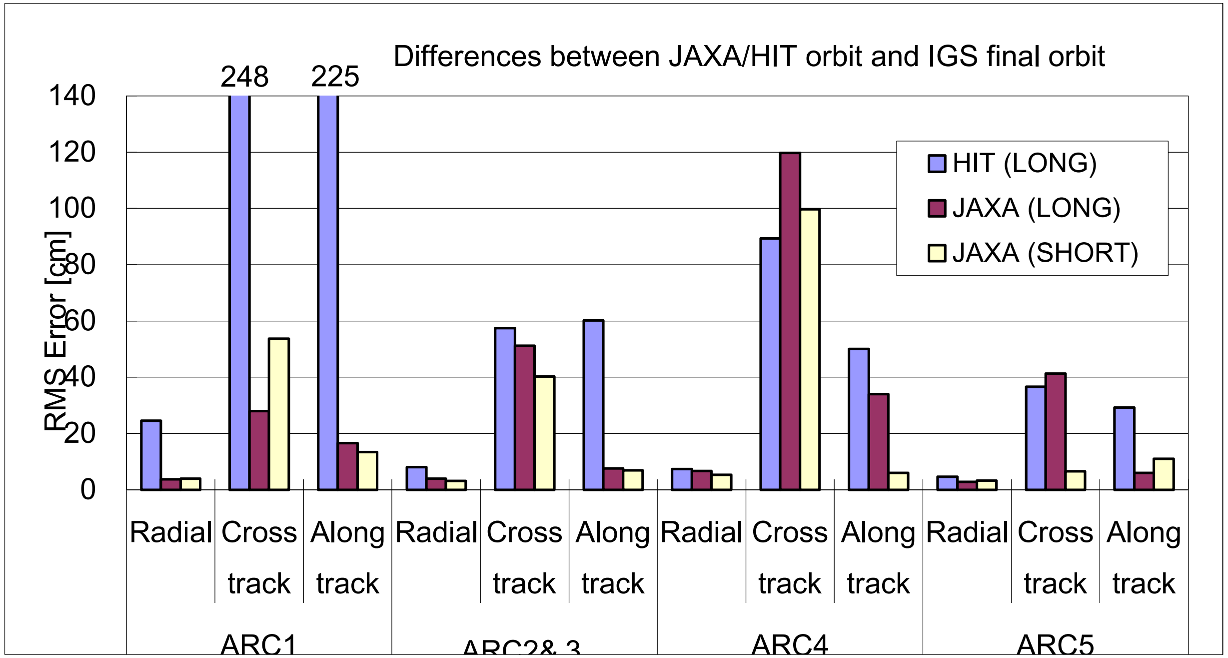

Short Arc Solution Example



# Step1: Results
# GPS orbit estimation with SLR

**Differences between JAXA/HIT-SLR orbits and IGS final orbits**

- JAXA vs. IGS final
  - Radial : ~ 5 cm
  - Along track : ~20 cm
- HIT vs. IGS final
  - Radial : ~ 10 cm (exc. arc1)




Arc Length
- Long (7~9 days)
- Short (4~7 hours)

# Step2:
# QZS-1 orbit estimation with SLR

**Evaluation**

- SLR residuals of the orbits determined by JAXA.
- Differences between JAXA-orbits and HIT-orbits.

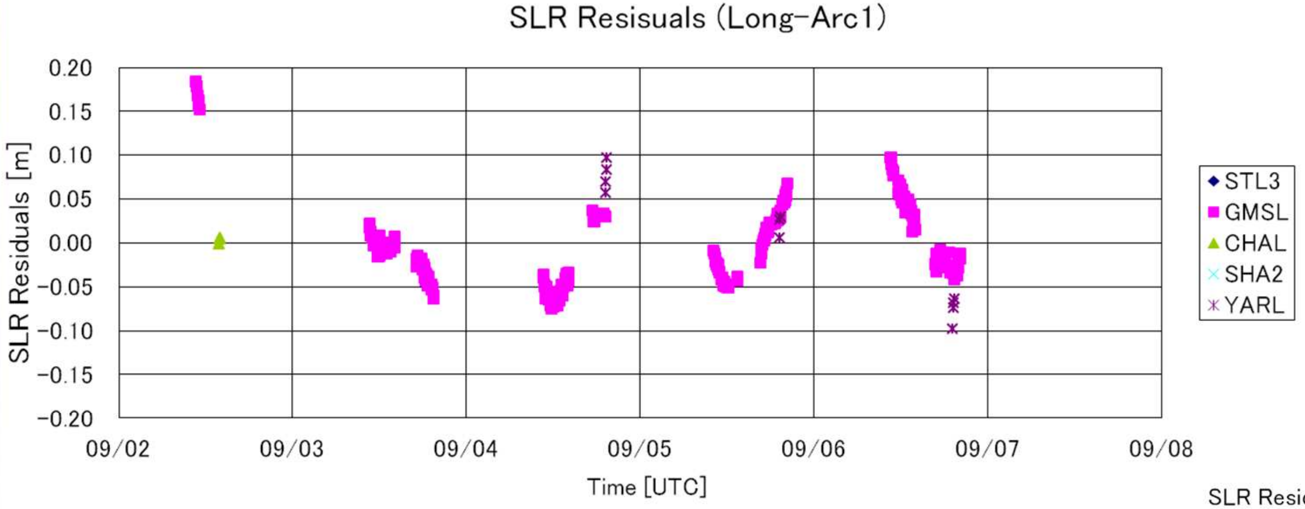
  - Estimation periods are selected so that the SLR data at no less than 3 stations is provided at the same time.

| Models / Parameters | JAXA | HIT |
|---|---|---|
| Site position | ilrsb | ITRF2008 |
| Satellite mass | 2280.7 [kg] (common) | |
| Center of mass | (Xs, Ys, Zs) = (-0.8, 2.9, 1819.3 ) [mm] (common) | |
| Optical reflection center | (Xs, Ys, Zs) = (-1150.0, -550.0, 4517.64 ) [mm] (common) | |
| Troposphere delay model | Marini-Murray model | Mendes & Pavlis model |
| SRP model | Canon ball | Canon ball |
| Cross-section area | 60.0 [$m^2$] | 52.0 [$m^2$] |
| SPR Coefficient (Cr) | 1.2 | |
| Estimation parameters | **Case-1**<br>Orbit elements (6)<br>SRP correction coefficient (1)<br>Constant accelerations in the along-track direction(1)<br>**Case-2**<br>1/rev accelerations in the along-track are estimated in addition to Case-1. | Orbit elements (6)<br>SRP correction coefficient (1)<br>Constant and 1/rev accelerations in the along-track direction (3) |

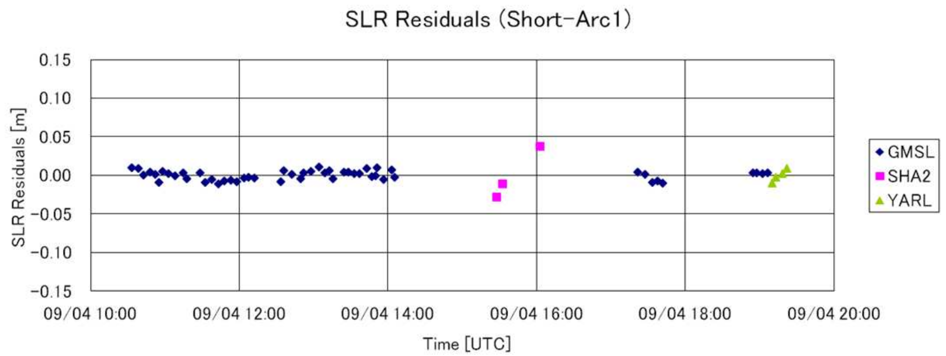
# Step2 Results:
# QZS-1 orbit estimation with SLR

**SLR residuals of the orbits determined by JAXA**

- Long arc (5~7 days)
  - SLR residuals: ~10 cm RMS
  - Periodic variation assumed to be due to the model error ware detected.



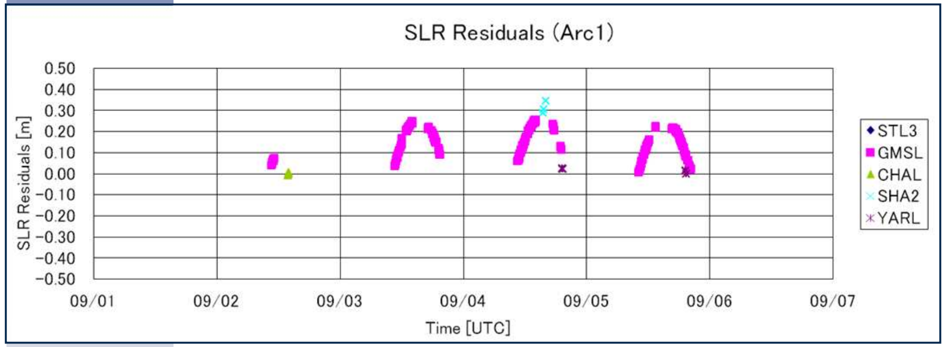

- Short arc (5~10 hours)
  - SLR residuals: ~1 cm RMS



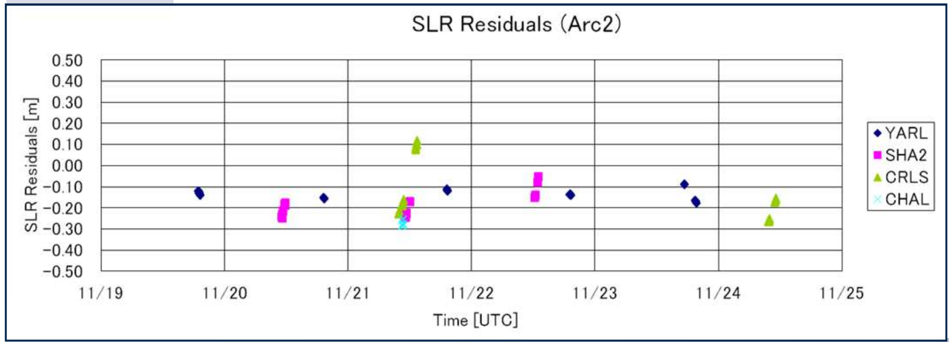
# Step3: QZS-1 orbit based on MADOCA

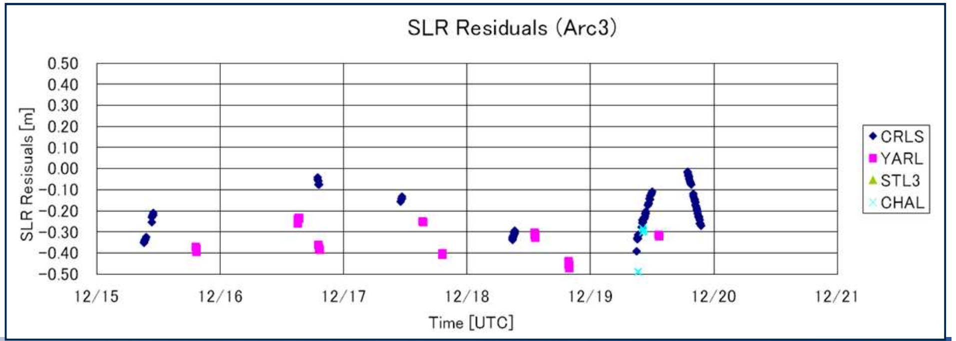
**SLR residuals to the orbits processed with MADOCA**

- U-shaped residuals that have a peak-to peak amplitude of 20 cm were detected in each arc.
- The average of SLR residuals in Arc1 were opposite in sign to those in Arc2 and 3.




| Evaluation period | SLR residuals (cm) | | |
|---|---|---|---|
| | AVE | STD | RMS |
| Arc1 : 2011/09/02 00:00 ~ 09/07 00:00 | 14.2 | 7.5 | 16.0 |
| Arc2 : 2011/11/19 00:00 ~ 11/24 00:00 | -15.3 | 9.4 | 17.9 |
| Arc3, 4 : 2011/12/15 00:00 ~ 12/22 00:00 | -24.1 | 11.0 | 26.5 |

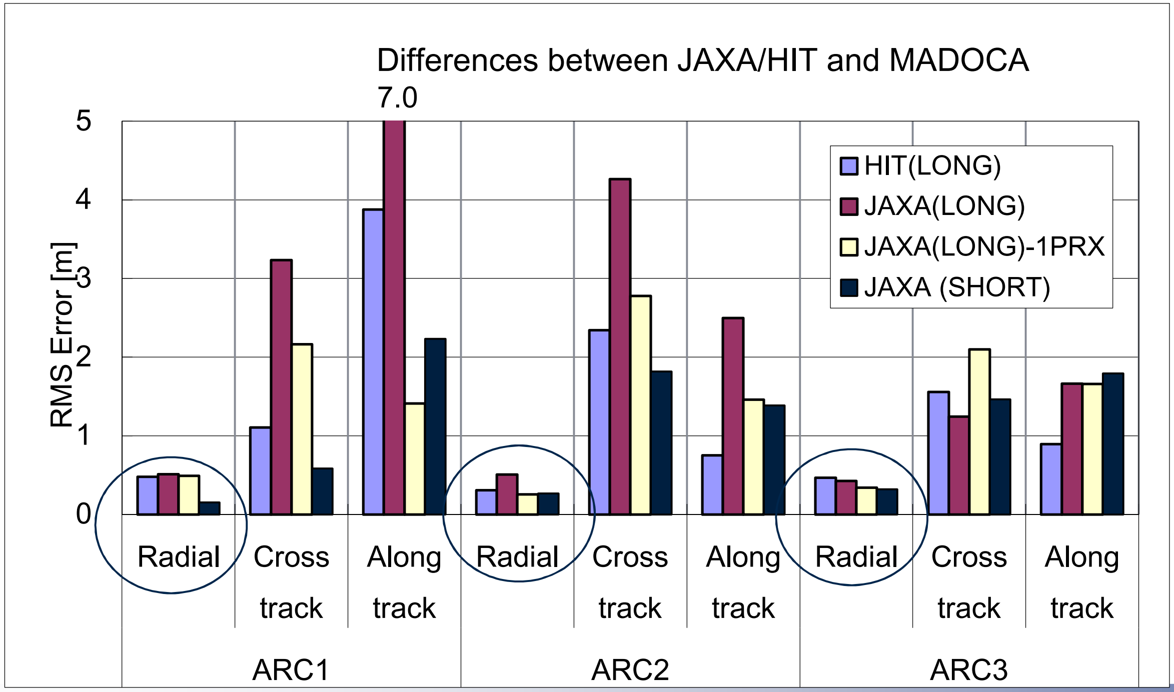


# Step3 results:QZS-1 orbit based on MADOCA and SLR orbits

**Differences between the MADOCA-orbits and JAXA/HIT-orbits**

- Radial biases that have an average of 20-30 cm from the orbits using SLR data were detected in each arc.
- It seems that the orbits processing with MADOCA obtain the accuracy of 20-30 cm in the radial direction.




Arc Length
- LONG (5~7 days)
- SHORT (5~10 hours)

-1PRX
- 1/rev accelerations in along-track is additionally estimated.

# Conclusion

- JAXA and HIT evaluate QZS-1 MADOCA using SLR data

<u>QZS-1 MADOCA periodic systematic error found by Residual Analysis</u>

- A U-curved P-P 20cm and bias mean difference by each arc in residual analysis were found.
- Periodic residual (comes from MADOCA analysis) should be studied.

<u>QZS-1 SLR only Orbit Determination</u>

- JAXA and HIT orbit matches by about 20cm level in the radial direction.

In which cross and Along direction orbit determination were not sensitive well.

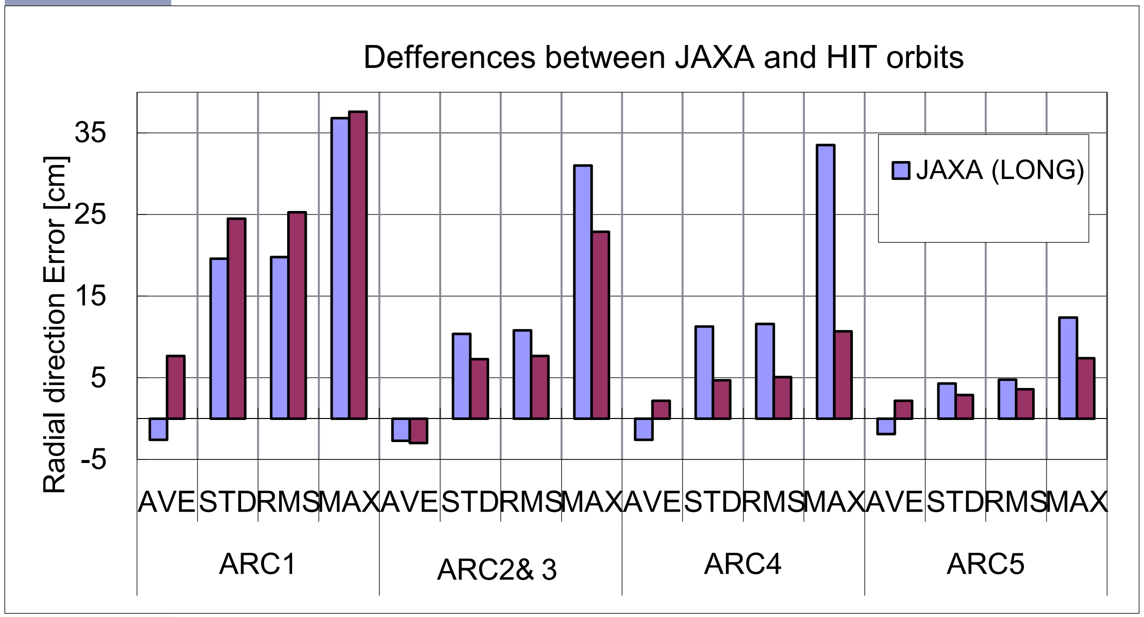
- More SLR data of QZS-1 is needed to evaluate QZS-1 MADOCA orbit.
- Even in a campaign basis SLR to get 3 or more stations participate at the same time for short arc solution to be important.

# Thank you for your attention.

# GPS orbit estimation with SLR

## Differences between JAXA-orbits and HIT-orbits

- JAXA vs. HIT
  - Radial track : ~ 5 cm
  - Along track : ~20 cm



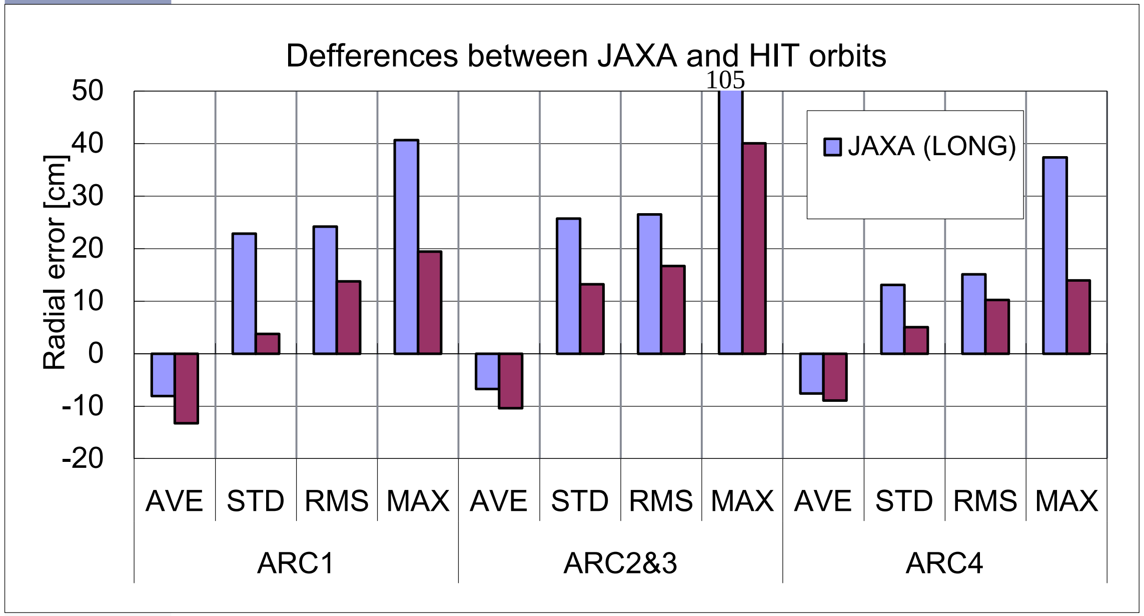

| Estimation period (Long) | Differences (cm) RMS | | |
|---|---|---|---|
| | Radial | Cross | Along |
| Arc1 ：2011/3/19 00:00 ~ 3/26 00:00 | 27.4 | 272.4 | 238.5 |
| Arc2, 3：2011/6/20 00:00 ~ 6/29 00:00 | 10.8 | 106.7 | 64.8 |
| Arc4 ：2011/7/08 00:00 ~ 7/15 00:00 | 11.6 | 76.7 | 75.1 |
| Arc5 ：2011/9/26 00:00 ~ 10/03 00:00 | 4.8 | 30.9 | 27.8 |

| Estimation period (Short) | Differences (cm) RMS | | |
|---|---|---|---|
| | Radial | Cross | Along |
| Arc1：2011/03/23 00:00 ~ 07:00 | 25.3 | 227.5 | 237.7 |
| Arc2：2011/06/21 20:00 ~ 24:00 | 13.0 | 89.3 | 69.5 |
| Arc3：2011/06/27 20:00 ~ 24:00 | 2.4 | 90.3 | 10.9 |
| Arc4：2011/07/11 19:00 ~ 23:00 | 5.1 | 169.6 | 10.7 |
| Arc5：2011/09/29 12:00 ~ 18:00 | 3.6 | 34.1 | 9.0 |

# Step2 results:
# QZS-1 orbit estimation with SLR

**Differences between JAXA-orbits and HIT-orbits**

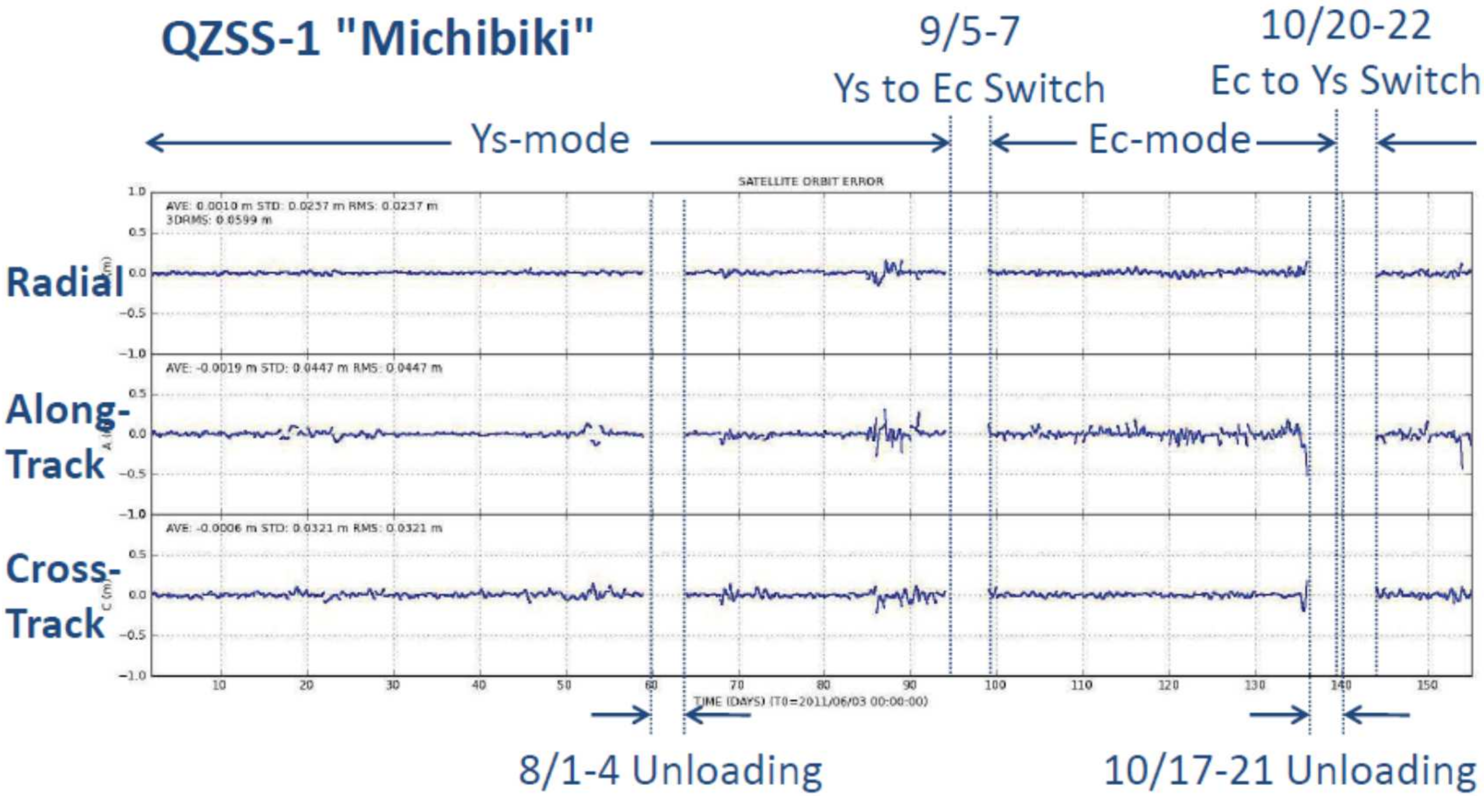
- Differences
  - Radial : ~30cm
  - Along/Cross track: several meters
- Biases that have an average of 10 cm in the radial direction exist in each arc.




| Estimation period (Long) | Differences (cm) RMS | | |
|---|---|---|---|
| | Radial | Cross | Along |
| Arc1 : 2011/09/02 00:00 ~ 09/07 00:00 | 24.2 | 335.3 | 853.4 |
| Arc2 : 2011/11/19 00:00 ~11/24 00:00 | 26.5 | 198.1 | 126.2 |
| Arc3, 4 : 2011/12/15 00:00 ~ 12/22 00:00 | 15.1 | 99.9 | 87.5 |

| Estimation period (Short) | RMS (cm) | | |
|---|---|---|---|
| | Radial | Cross | Along |
| Arc1 : 2011/03/23 00:00 ~ 07:00 | 13.8 | 100.7 | 156.5 |
| Arc2 : 2011/06/21 20:00 ~ 24:00 | 23.9 | 200.1 | 186.9 |
| Arc3 : 2011/06/27 20:00 ~ 24:00 | 4.6 | 257.5 | 8.8 |
| Arc4 : 2011/07/11 19:00 ~ 23:00 | 10.2 | 106.1 | 136.3 |

# MADOCA internal orbit accuracy by 24H-Overlap analysis




**R: 2.37 cm, A: 4.47 cm, C: 3.21 cm, 3DRMS: 5.99 cm**

2011/6/4 - 11/3 (153 days), 24 H-overlap

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