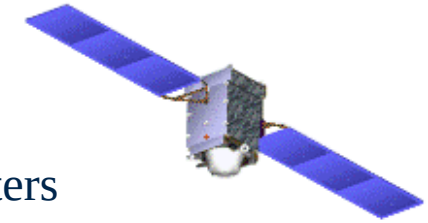
Accuracy evaluation of QZS-1 orbit solutions with Satellite Laser Ranging

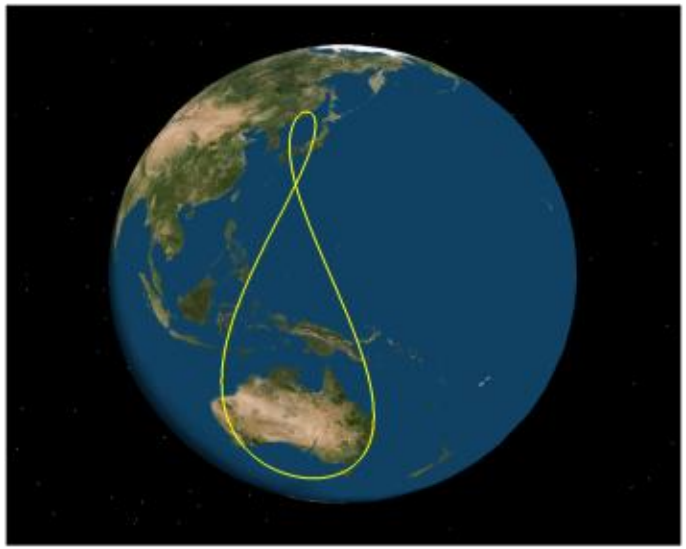
Kyohei Akiyama (Japan Aerospace Exploration Agency)
and
Toshimichi Otsubo (Hitotsubashi University)

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 L-band experiment signal(LEX) based on Multi-GNSS scheme.





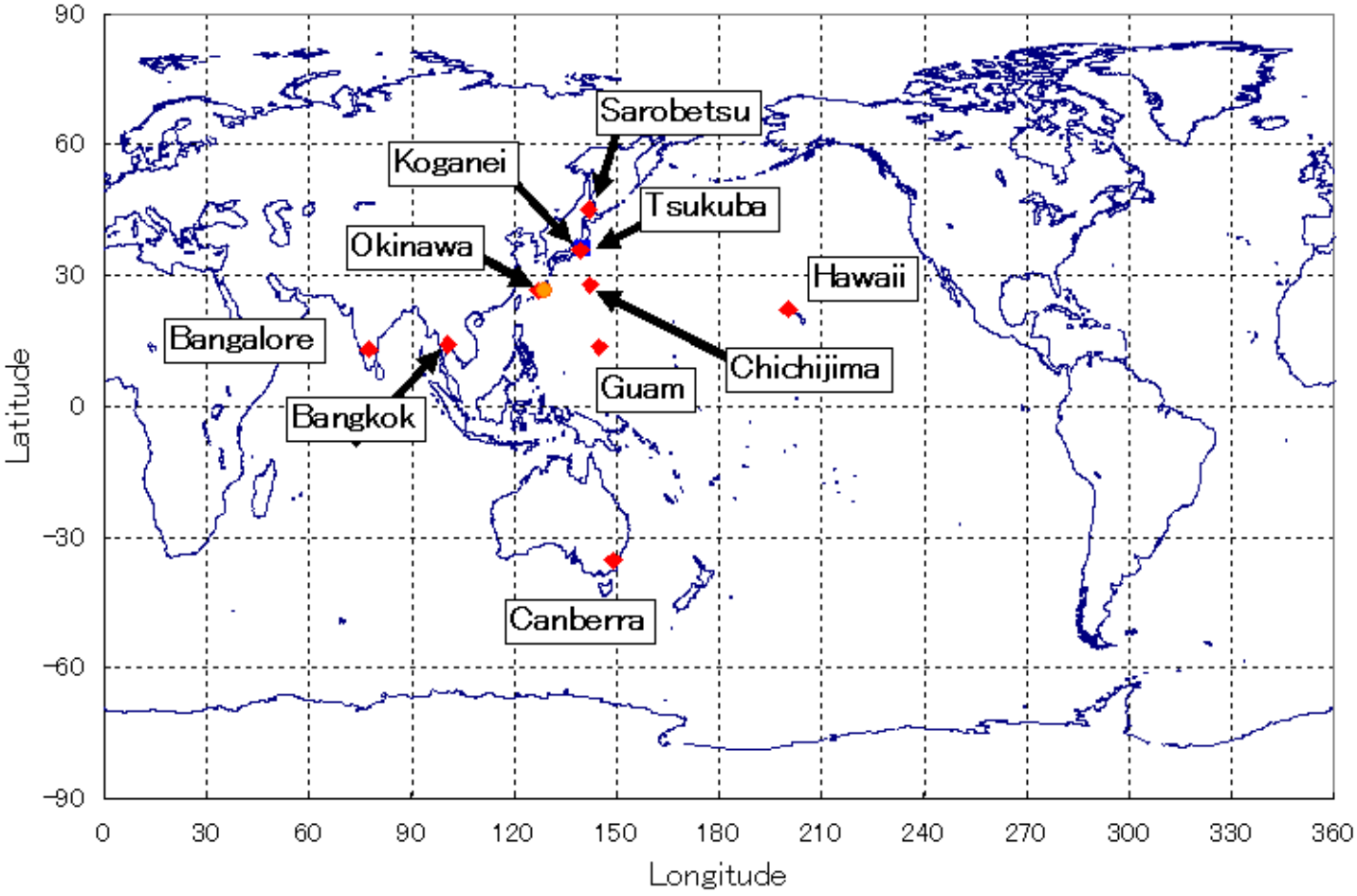
Ground trace from QZS-1 orbit

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 Orbit Determination tool for PPP experiment via QZSS LEX channel

MADOCA

Multi-GNSS **A**dvanced **D**emonstration tool for **O**rbit and **C**lock **A**nalysis

- Multi-GNSS precise orbit/clock estimation tool
- For JAXA PPP experiment via QZSS LEX channel
- Key-technology for precise positioning with GNSS

- Requirements
  - Satellites: GPS, GLONASS, QZSS and Galileo
  - Offline (FY23) and real-time (FY24) functions
- Goal of Orbit/Clock Accuracy
  - Offline : 3 cm/0.1 ns (GPS), 7 cm/0.25 ns (GLO/QZS)
  - Real-time: 4 cm/0.1 ns (GPS), 9 cm/0.25 ns (GLO/QZS)

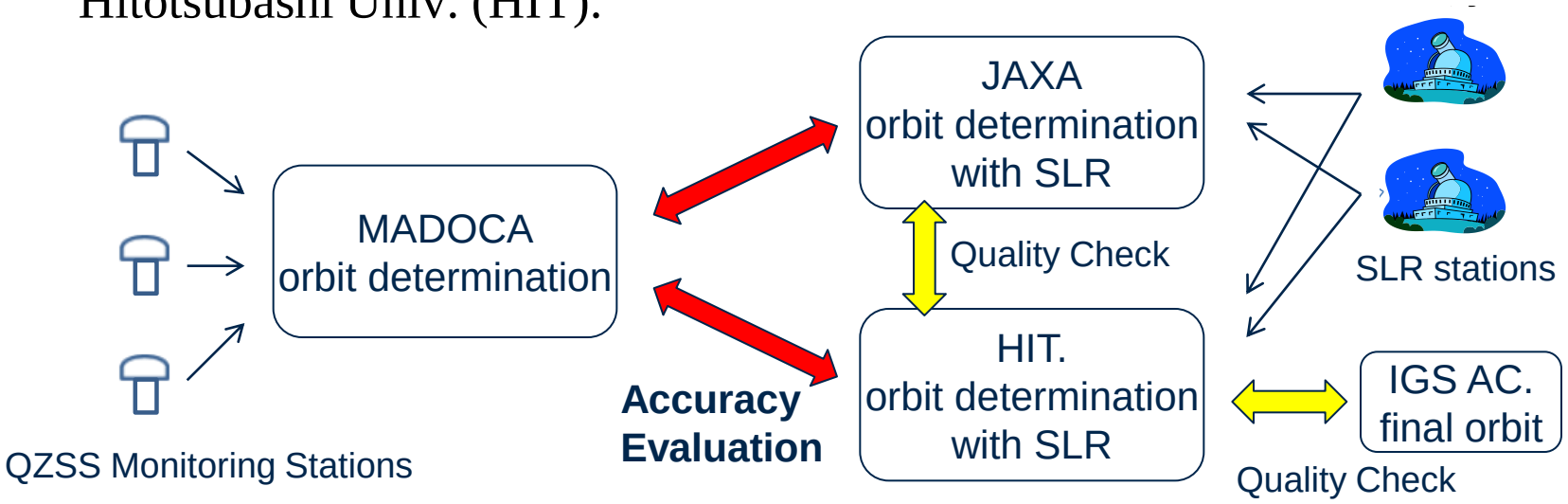
Development Status of MADOCA, T. Takasu, 2012

Accuracy evaluation of QZS-1 orbit

Accuracy evaluation of QZS-1 orbit solutions with SLR

- 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 of the orbits using SLR observations

- 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 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 obserbations.

Step.1:
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

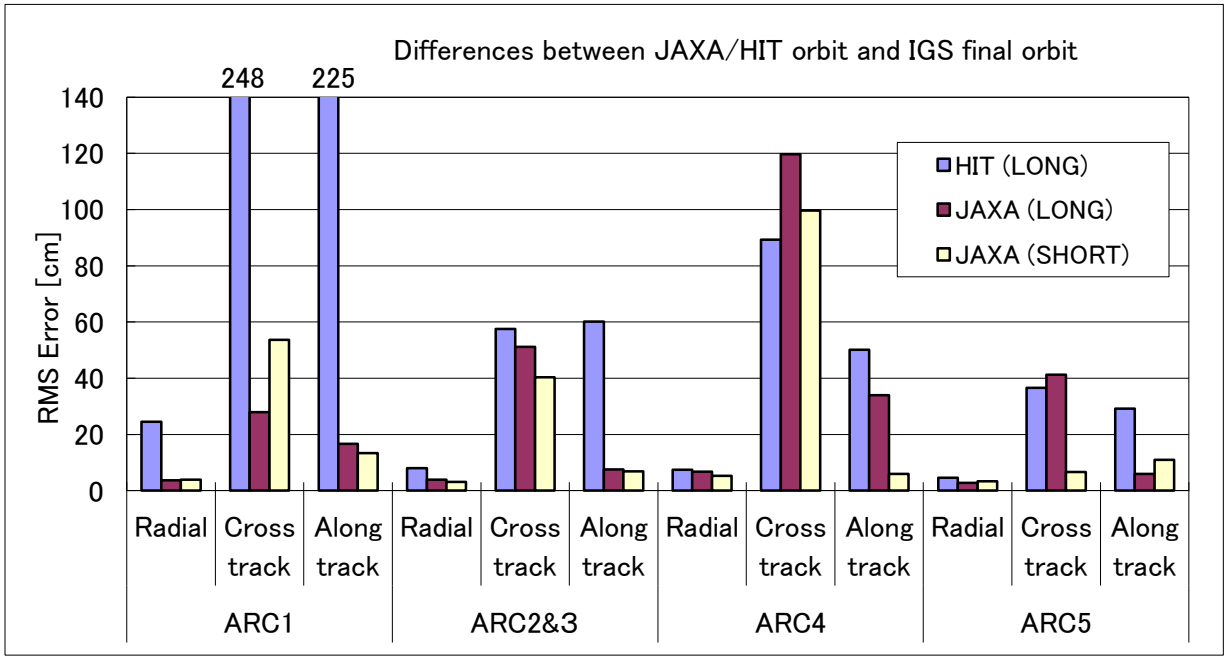
- Estimation periods are selected so that the SLR data at no less than 3 stations is provided at the same time.

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) SRP correction coefficient (1) Constant and 1/rev accelerations in the along-track direction (3)

Step.1: Result
GPS orbit estimation with SLR

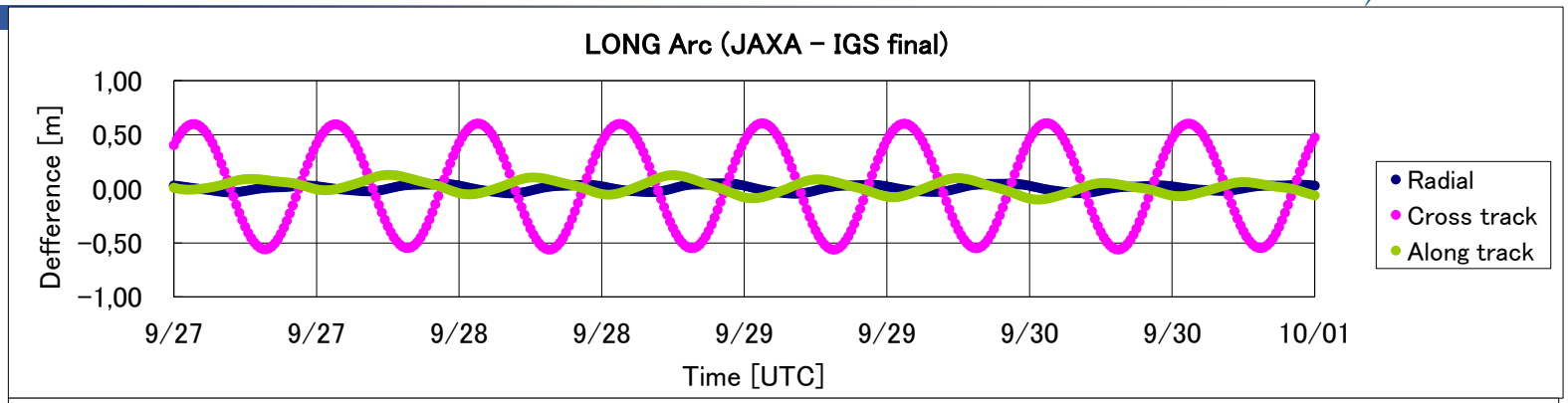
Differences between JAXA/HIT-orbits and IGS final orbits

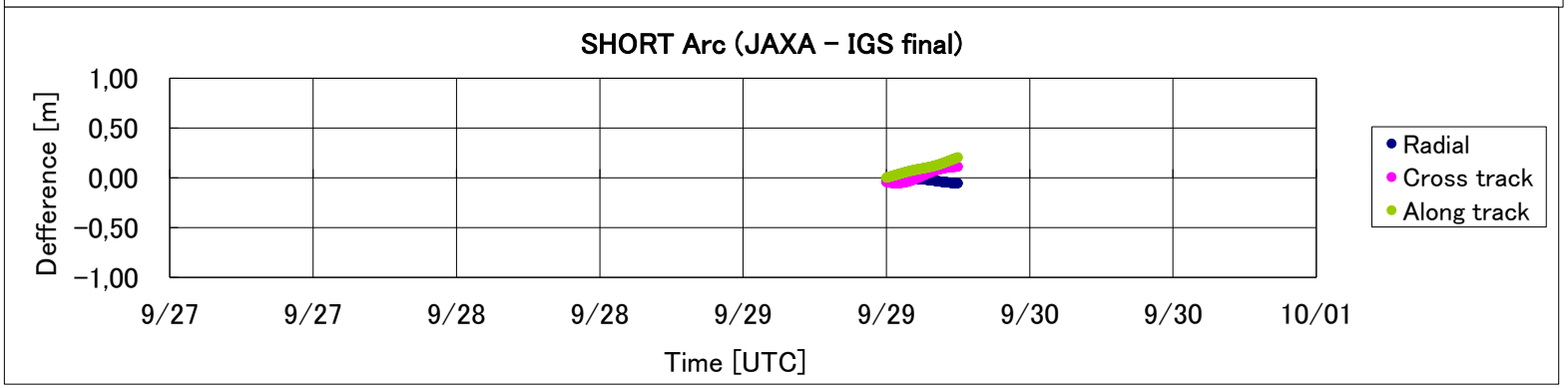
- JAXA vs. IGS final
  - Radial : ~ 5 cm
  - Along track : ~20 cm
- HIT vs. IGS final
  - Radial : ~ 10 cm (exc. arc1)

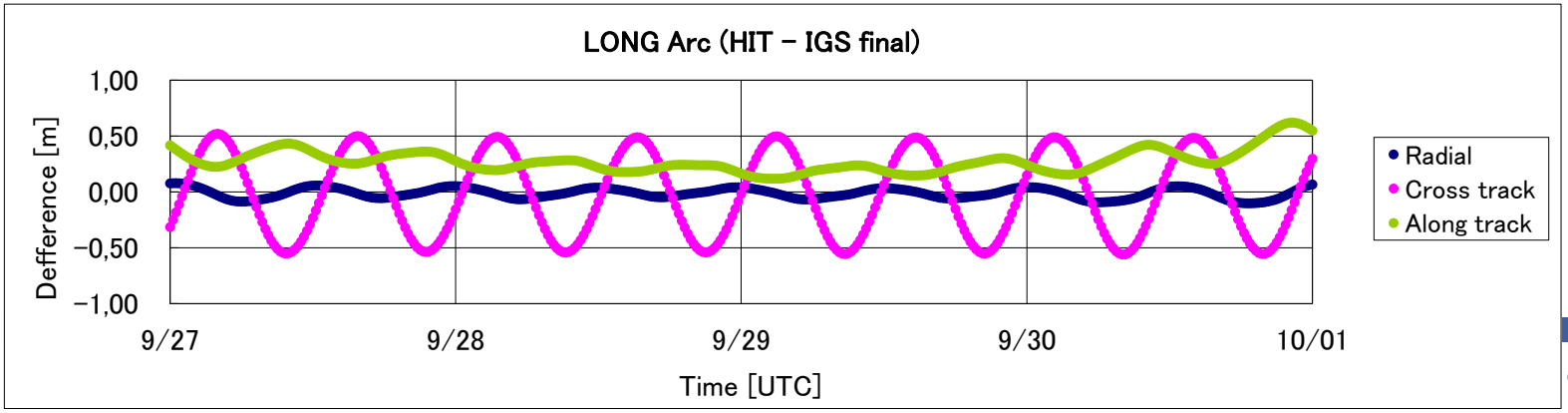


Arc Length
- Long (7~9 days)
- Short (4~7 hours)

Step.1: Result
GPS orbit estimation with SLR







Step.2 :
QZS-1 orbit estimation with SLR

Evaluation

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

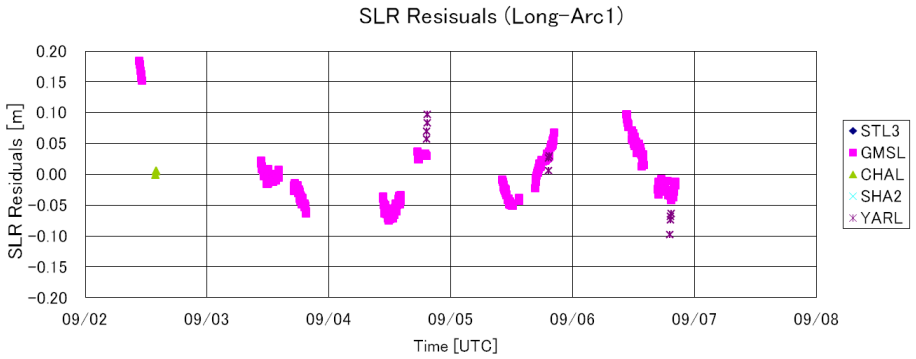
- Estimation periods are selected so that the SLR data at no less than 3 stations is provided at the same time.

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** Orbit elements (6) SRP correction coefficient (1) Constant accelerations in the along-track direction(1) **Case-2** 1/rev accelerations in the along-track are estimated in addition to Case-1.	Orbit elements (6) SRP correction coefficient (1) Constant and 1/rev accelerations in the along-track direction (3)

Step.2 : Result
QZS-1 orbit estimation with SLR

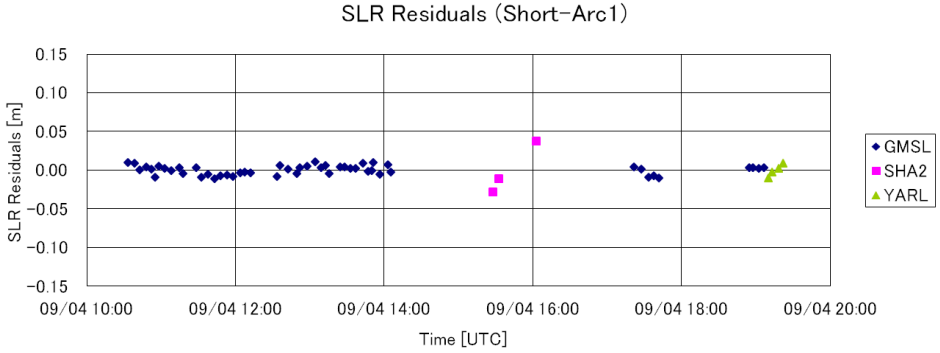
SLR residuals of the orbits determined by JAXA

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



Estimation period (Long)	SLR residuals (mm)		
	AVE	STD	RMS
Arc1 : 2011/09/02 00:00 ～09/07 00:00	-2.9	52.4	52.5
Arc2 : 2011/11/19 00:00 ～11/24 00:00	-11.7	35.9	37.7
Arc3&4 : 2011/12/15 00:00 ～12/22 00:00	9.8	72.1	72.5

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

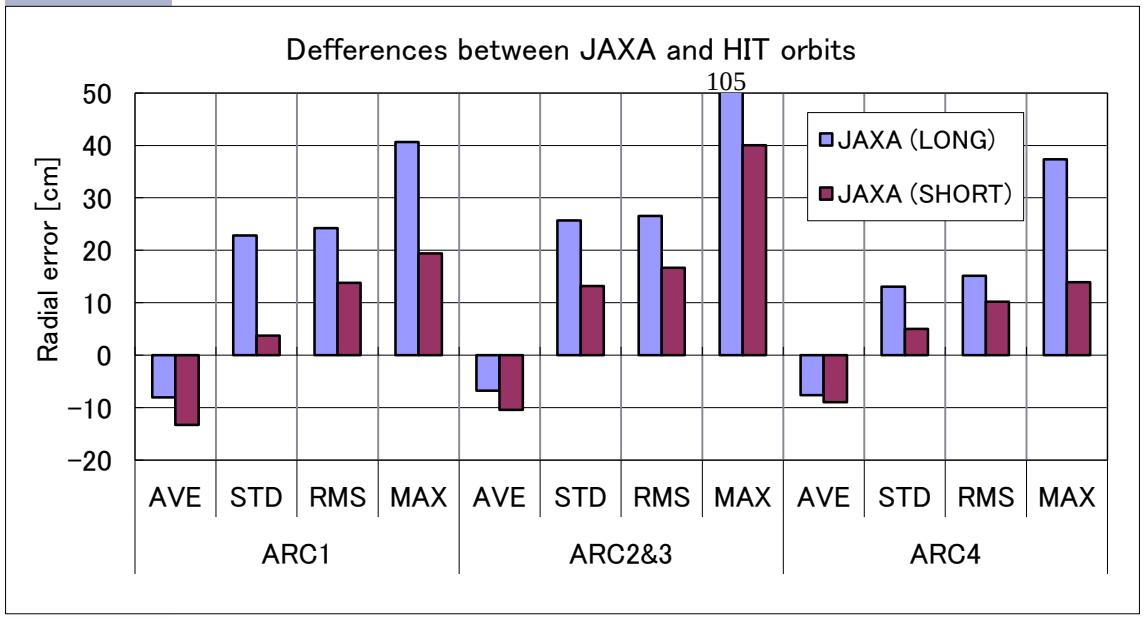


Estimation period (Short)	SLR residuals (mm)		
	AVE	STD	RMS
Arc1 : 2011/09/04 10:00 - 20:00	0.01	8.5	8.5
Arc2 : 2011/11/21 09:00 - 14:00	0.00	5.7	5.7
Arc3 : 2011/12/16 15:00 - 21:00	0.00	5.7	5.7
Arc4 : 2011/12/19 08:00 - 14:00	0.03	18.8	18.8

Step.2 : Result
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.



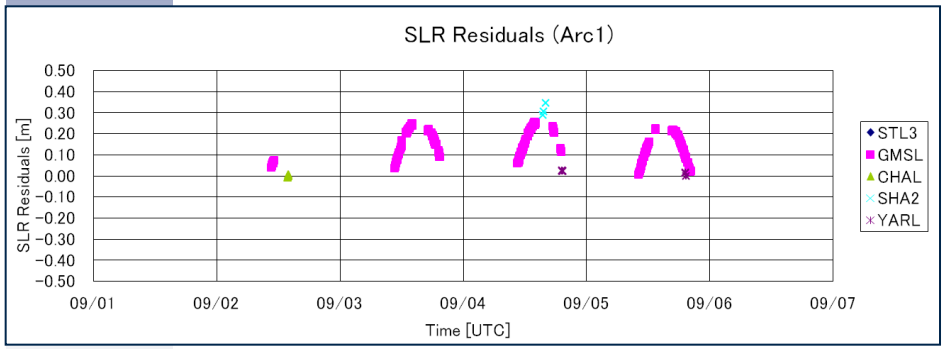
Estimation period (Long)	Differences (cm) RMS		
	Radial	Cross	Along
Arc1 : 2011/09/02 00:00 ~ 09/07 00:00	24.2	335.3	853.4
Arc2 : 2011/11/19 00:00 ~11/24 00:00	26.5	198.1	126.2
Arc3, 4 : 2011/12/15 00:00 ~ 12/22 00:00	15.1	99.9	87.5

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

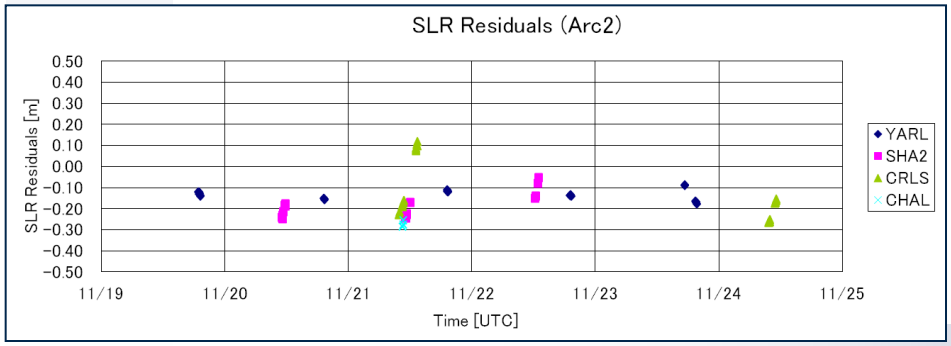
Step.3:Result
QZS-1 orbit based on MADOCA

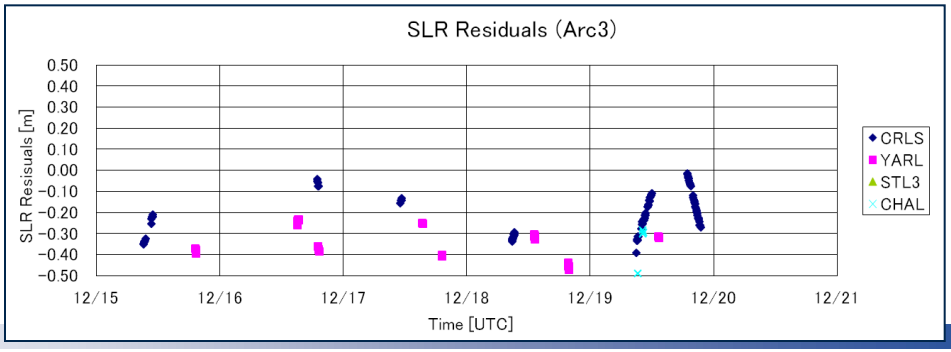
SLR residuals to the orbits processed with MADOCA

- 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

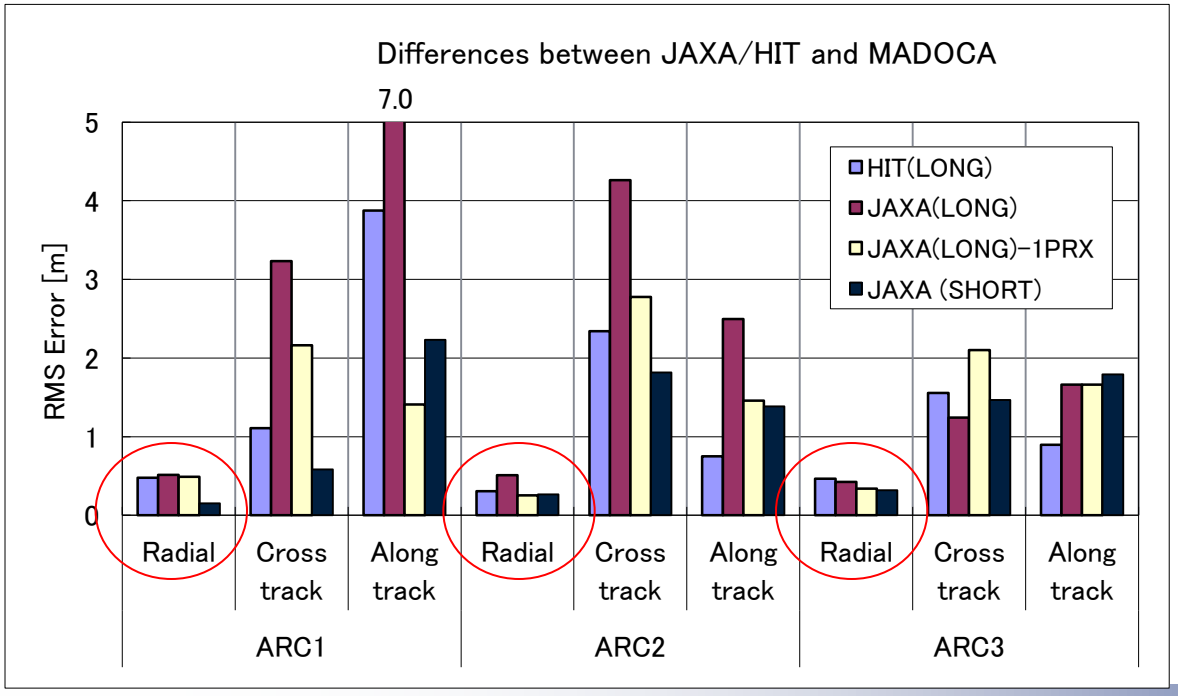




Step.3:Result
QZS-1 orbit based on MADOCA

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>

- U-shaped SLR residuals of P-P 25cm and bias mean difference by each arc were found.
- The reasons of periodic appearance of SLR residuals should be studied.

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

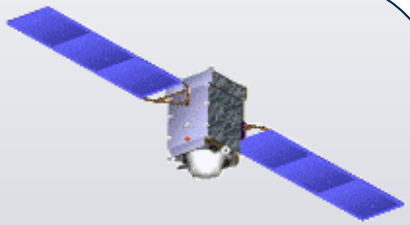
- JAXA and HIT orbits matched by about 20cm level in the radial direction.
- Orbit determination in the cross and along direction were not so sensitive.
- More SLR data of QZS-1 is required to evaluate QZS-1 MADOCA orbit.
- QZS-1 tracking campaign is desirable to get SLR observation at 3 or more SLR stations for short arc solution.

Promotion of QZSS Project

< Basic policy on the implementation of the operational QZSS project >

approved at the Cabinet meeting on September 30, 2011.

The QZSS will contribute to



- **Welfare of the Asia-Pacific region**
- **Broad range of security including the improvement the capacity to respond to natural disasters**

Promotion of QZSS Project

< Basic policy on the implementation of the operational QZSS project >

approved at the Cabinet meeting on September 30, 2011.

- **GOJ has decided to accelerate the deployment of the operational QZSS as expeditiously as possible.**
- **Four satellites constellation shall be established by the late 2010s.**
- **In the future, seven satellites constellation shall be completed to enable sustainable positioning.**

Thank you for your attention.