Accuracy Evaluation of QZS-1 Precise Ephemerides with Satellite Laser Ranging

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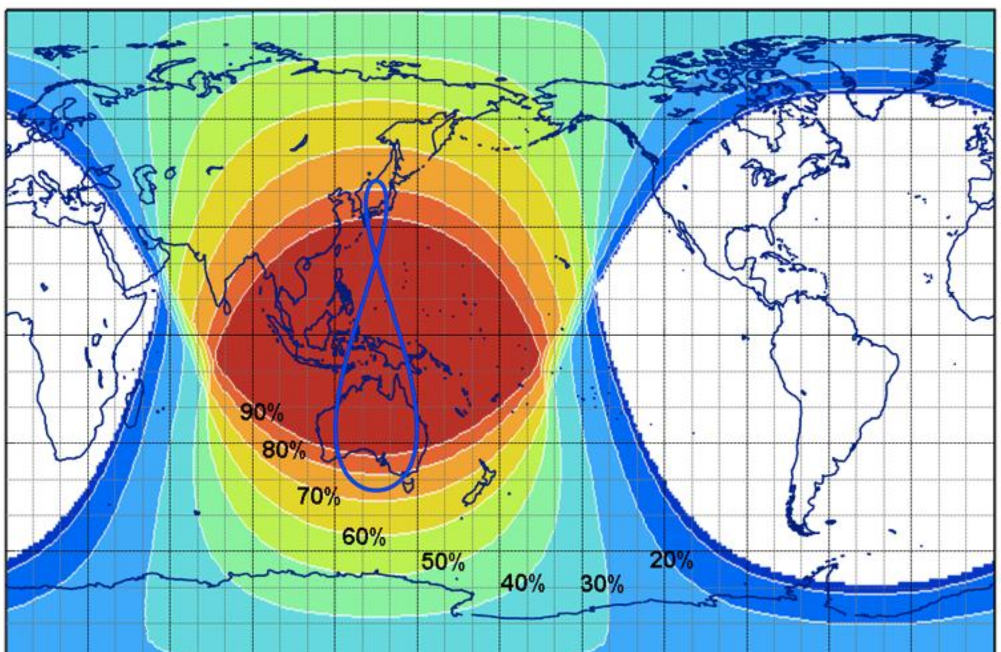
Introduction

Quasi-Zenith Satellite System (QZSS)

- QZSS is a Japanese navigation satellite system.
- QZSS improves positioning availability
  - GPS compatible signals from QZSS improve positioning availability in East Asia and Oceanian region.
- QZSS improves positioning accuracy
  - For the purpose of PPP (Precise Point Positioning) service provision, QZSS-LEX (L-Band Experiment) signals allow for precise orbits and clock data.



▼QZS-1 orbital elements

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

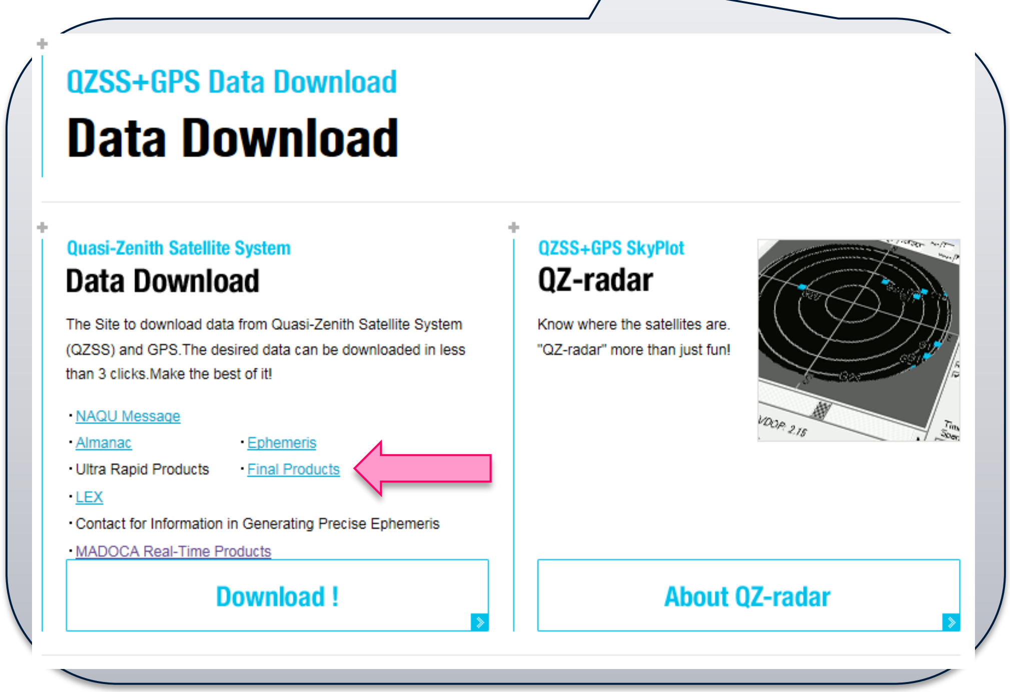
◂ Coverage of QZS-1

Visible rate of QZS-1 in 24 hours more than 10 degrees in elevation, indicated by percentage(%).

QZSS Final Products

- JAXA publishes precise ephemeris/clock of GPS/QZS-1. (since December 2012)
- The final products are to be released approximately 6 days later.
- Available in QZSS project site (http://qz-vision.jaxa.jp/USE/en/finalp).

- ➢ Enhanced the accuracy of QZS-1 final products (QZF) lead to high accuracy PPP even in region where GPS signals are insufficient.
- ➢ JAXA have been working on improving the accuracy of QZF.



MADOCA QZSS Orbit via LEX Signal

MADOCA : **M**ulti-GNSS **A**dvanced **D**emonstration tool for **O**rbit and **C**lock **A**nalysis

- Multi-GNSS precise orbit/clock estimation tool that JAXA developed at 2011~2012.
- From April of 2014, JAXA is promoting Precise Point Positioning (PPP) experiments using MADOCA orbit/clock products transmited via QZSS LEX channel.

Goal of orbit/clock accuracy :

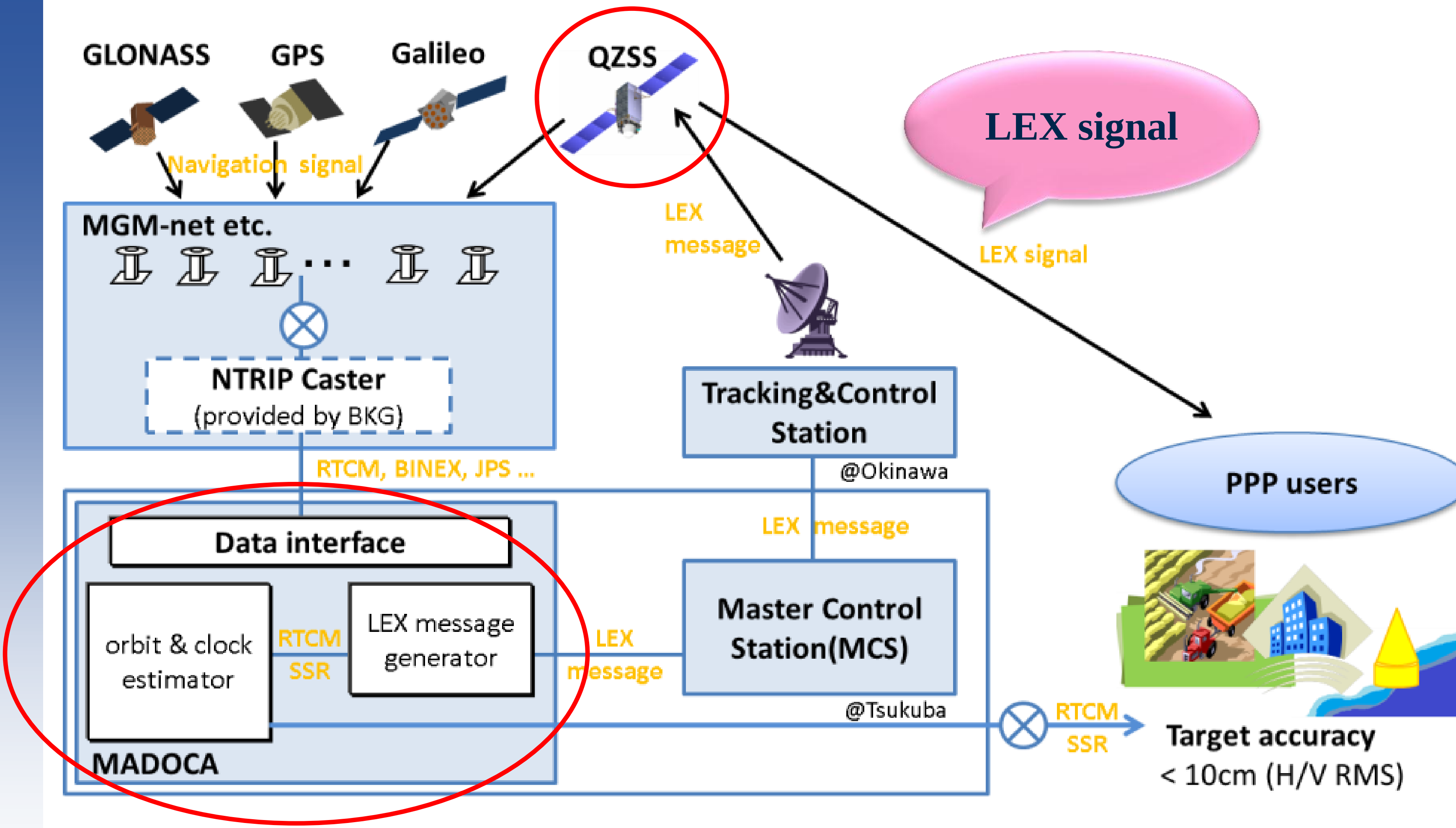
- Batch : 3 cm/0.1 ns (GPS), 7 cm/0.25 ns (GLO/QZS)
- Real-time: 6 cm/0.15 ns (GPS), 9 cm/0.25 ns (GLO/QZS)

Enhanced the accuracy of the MADOCA QZS-1 Orbit

- For Batch and Real-time processes, same parameters and models used.
- Improve the accuracy of Batch products
- Improve the accuracy of Real-time products

High accuracy of Real-time PPP !

Real-Time PPP Service



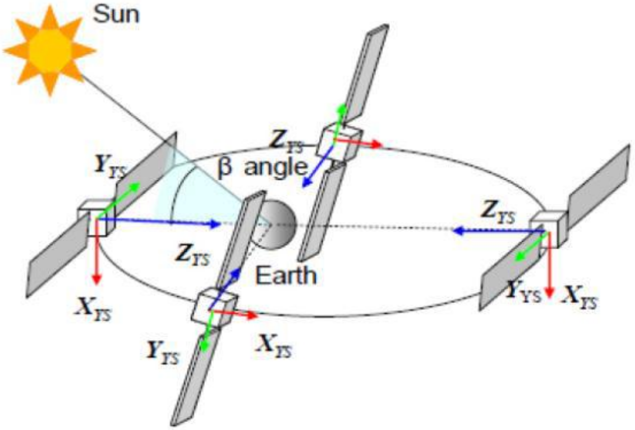
Accuracy evaluation of QZS-1 ephemerides

Accuracy evaluation of JAXA-processed QZS-1 ephemerides: MAD and QZF

① Cross validation with other QZS-1 orbits

name	reference
MAD	Orbit processed with MADOCA (Batch)
QZF	JAXA final products http://qz-vision.jaxa.jp/USE/archives/final
TUM	TUM Multi-GNSS EXperiment products ftp://cddis.gsfc.nasa.gov/pub/gps/products/mgex
ESOC	Orbit processed with ESOC software

② SLR residual to QZS-1 orbits



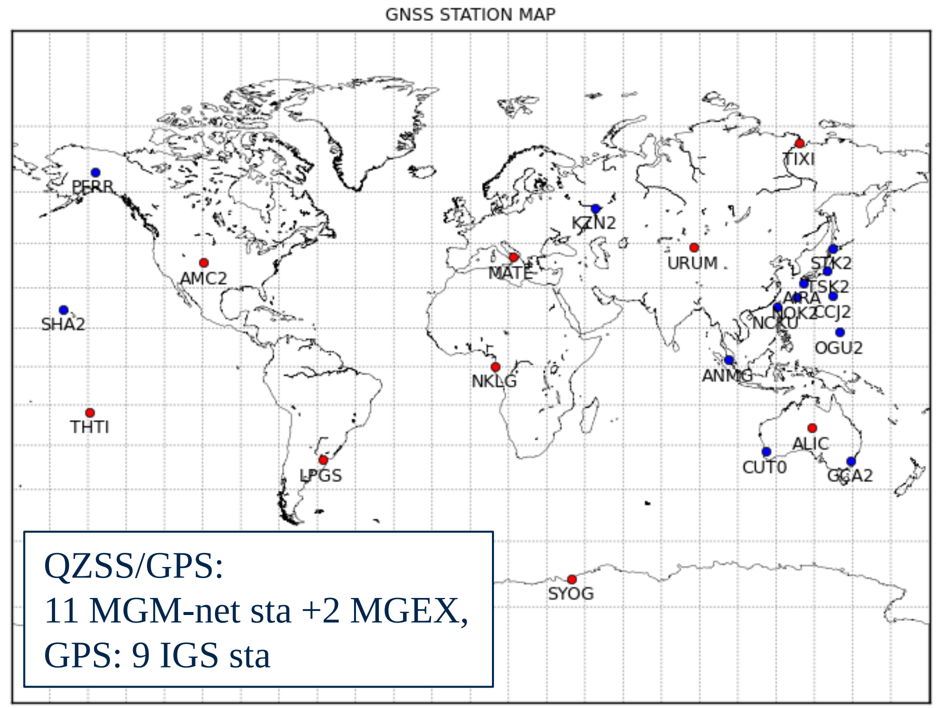
Evaluation period

- June 16 (0:00 a.m.) - July 12 (0:00 a.m.) in 2013（26 days）
- Attitude mode ：Yaw-Steering (YS) Mode

Accuracy evaluation of QZS-1 ephemerides

<u>Estimation Condition of MAD</u>

- Estimation Parameters
  - QZS-1 orbit/clock, GPS clock
  - Station position/clock
  - Tropospheric delay
  - Earth orientation parameter
  - Ambiguity



- Solar Radiation Pressure Model
  - QZS-1 :

    Modified-DBY (est 9 para. D,B,Y(const),D,B,Y(1/rev))

    +X,Y,Z (piece-wise const)

Accuracy evaluation of QZS-1 ephemerides

- Solar Radiation Pressure (SRP) model

<u>DBY model</u>

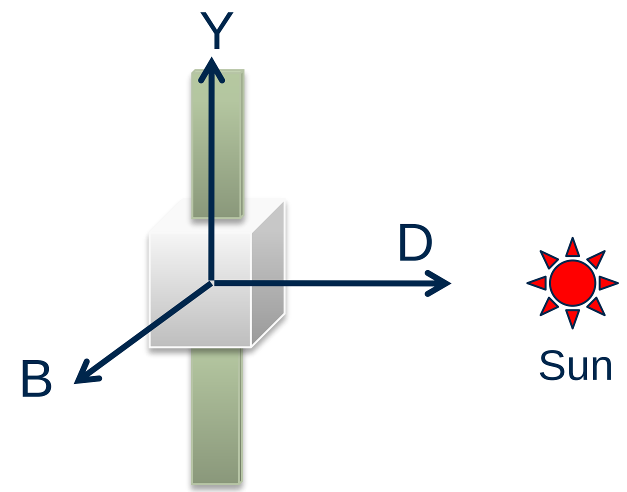
D : toward the Sun direction
Y : along the spacecraft's solar panel axis
B : D × Y direction

$$\mathbf{a}_{srp} = S\left(D\mathbf{e}_d + B\mathbf{e}_b + Y\mathbf{e}_y\right)\times 10^{-9}\ \left(m/s^2\right)$$

$$D = D_0 + D_c \cos f + D_s \sin f$$

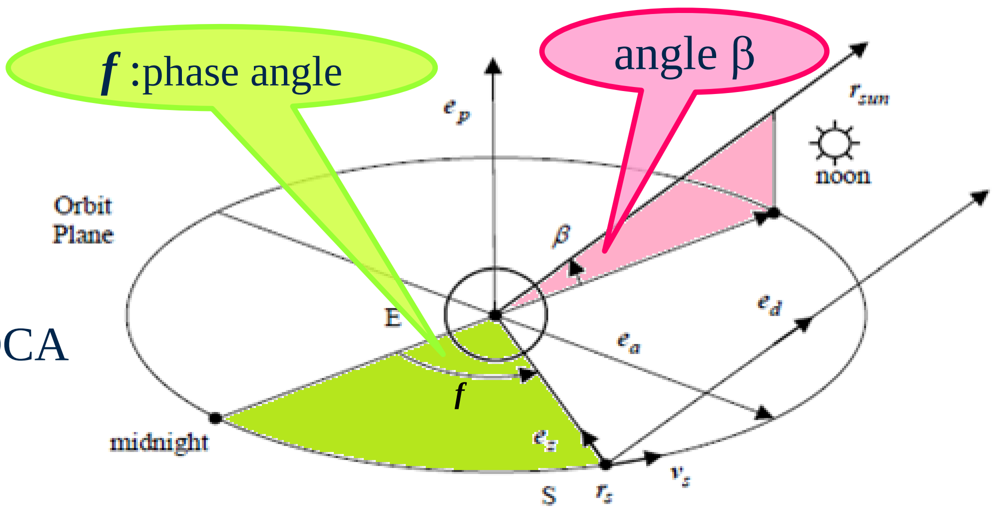
$$B = B_0 + B_c \cos f + B_s \sin f$$

$$Y = Y_0 + Y_c \cos f + Y_s \sin f$$



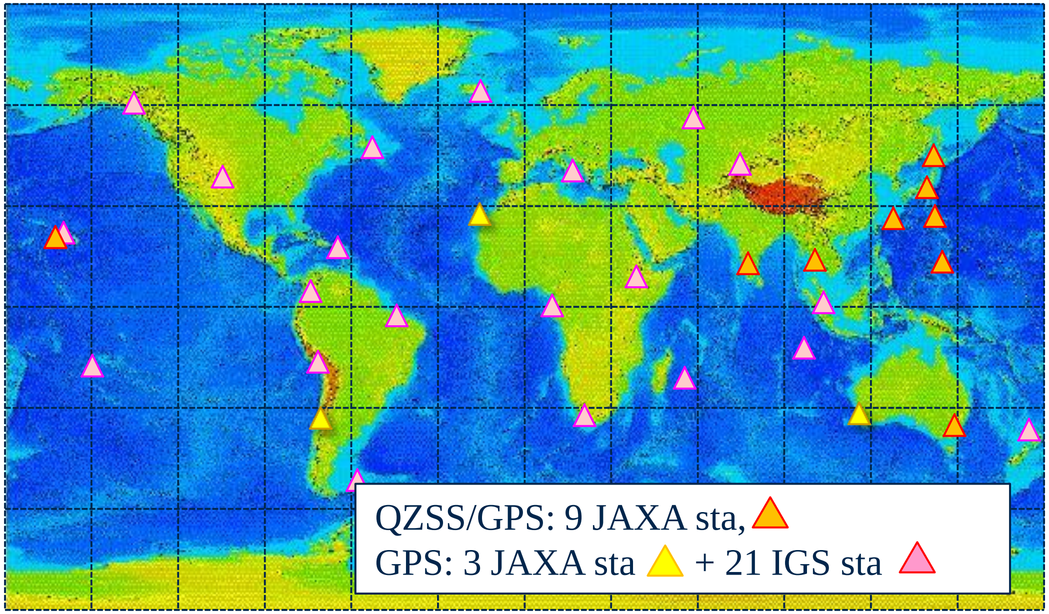
<u>Modified-DBY model</u>

- Enhanced DBY model in MADOCA
- A-priori SRP coefficients made dependent on angle β



Accuracy evaluation of QZS-1 ephemerides

<u>Estimation Condition of QZF</u>



- Estimation Parameters
  - GPS/QZS-1 orbit/clock
  - Station position/clock
  - Tropospheric delay
  - Ambiguity
- Solar Radiation Pressure Model
  - GPS: CODE model
  - QZS-1: est 13 Para. D,B,Y(const),D,B,Z(1/rev),D,X(2/rev)

Accuracy evaluation of QZS-1 ephemerides

Comparison of Estimation Conditions among Ephemerides

case name	MAD	QZF	TUM	ESOC
System	GPS + QZS	GPS + QZS	GPS + Galileo + QZS	GPS + QZS
QZSS/GPS stations	QZSS/GPS: 11 MGM-net sta +2 MGEX, GPS: 9 IGS sta	QZSS/GPS: 9 JAXA sta, GPS: 3 JAXA sta + 21 IGS sta	QZSS/Galileo/GPS: 6 CONGO sta + 3 MGEX sta, Galileo/GPS : 18 CONGO sta + 13 MGEX sta	QZSS/GPS: 20, GPS: 20
Frequencies	L1&L2	L1&L2	L1&L5	L1&L2
Arc	24H+48H+24H	7days	3days	2day
Est SRP para	QZS : Modified-DBY model (9 Para. : D, B, Y(const), D, B, Y(1/rev)) +X,Y,Z (piece-wise const)	GPS:CODE model QZS : 13 Para. : (D, Y, B(const), D, B, Z(1/rev), D, X(2/rev))	5 Para. :	QZS-1 : CODE model (5 Para. : D, Y, B(const), B(1/rev))

Result : Difference between ephemerides

Mean Differences in Radial Direction (m)

	MAD	QZF	TUM	ESOC
MAD	-	0.290	0.279	0.326
QZF	-	-	-0.010	0.027
TUM	-	-	-	0.046
ESOC	-	-	-	-

Mean Differences in Along Track (m)

	MAD	QZF	TUM	ESOC
MAD	-	0.020	-0.135	1.075
QZF	-	-	-0.172	0.870
TUM	-	-	-	1.209
ESOC	-	-	-	-

- MAD seems to have around 30 cm bias in radial.
- Other ephemerides (QZF, TUM, and ESOC) matched with each other in radial.
- ESOC had lager bias in along track than other ephemerides.

Result : Difference between ephemerides

RMS in Cross Track (m)

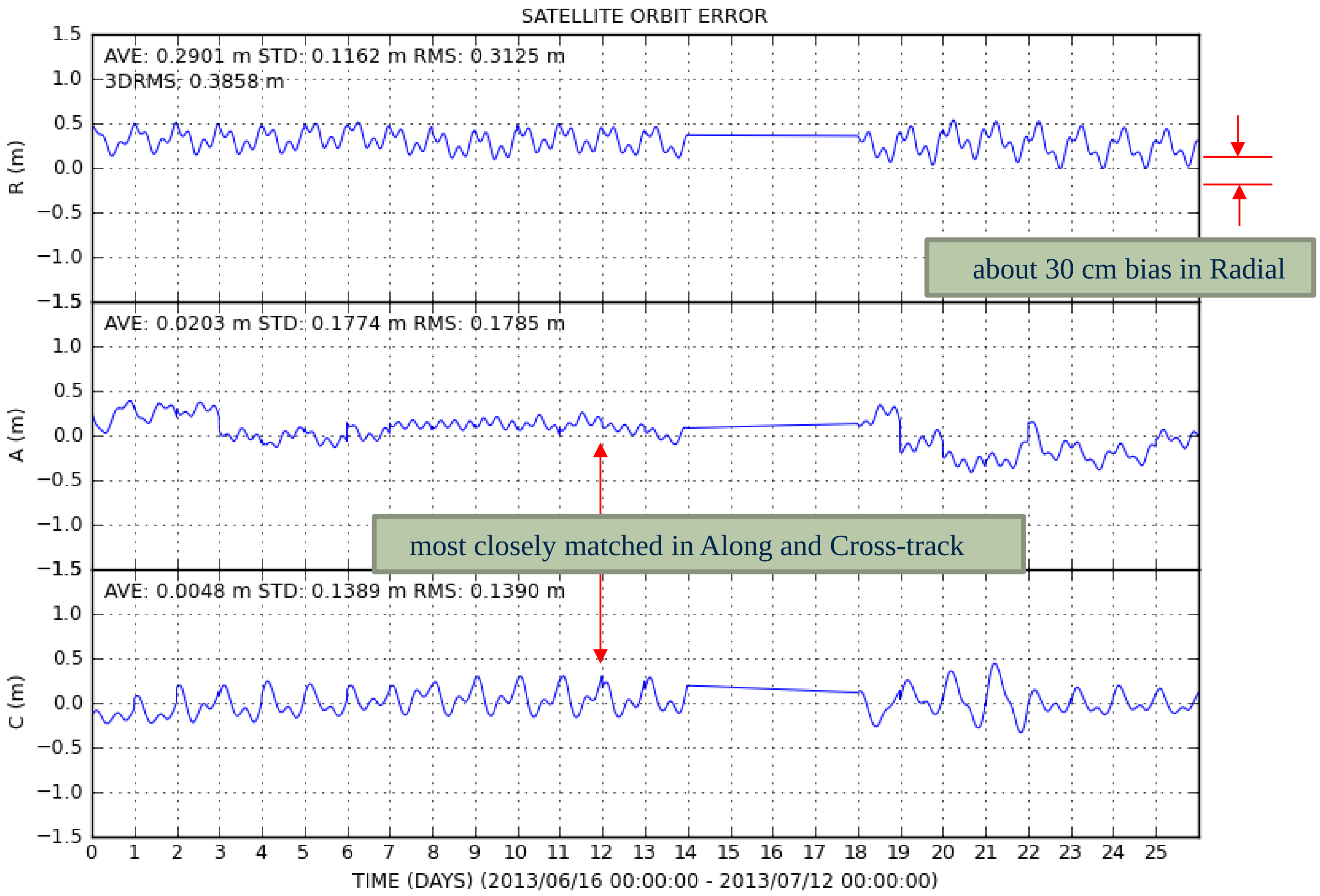
	MAD	QZF	TUM	ESOC
MAD	-	0.139	0.311	0.602
QZF	-	-	0.328	0.499
TUM	-	-	-	0.672
ESOC	-	-	-	-

Differences 3D-RMS (m)

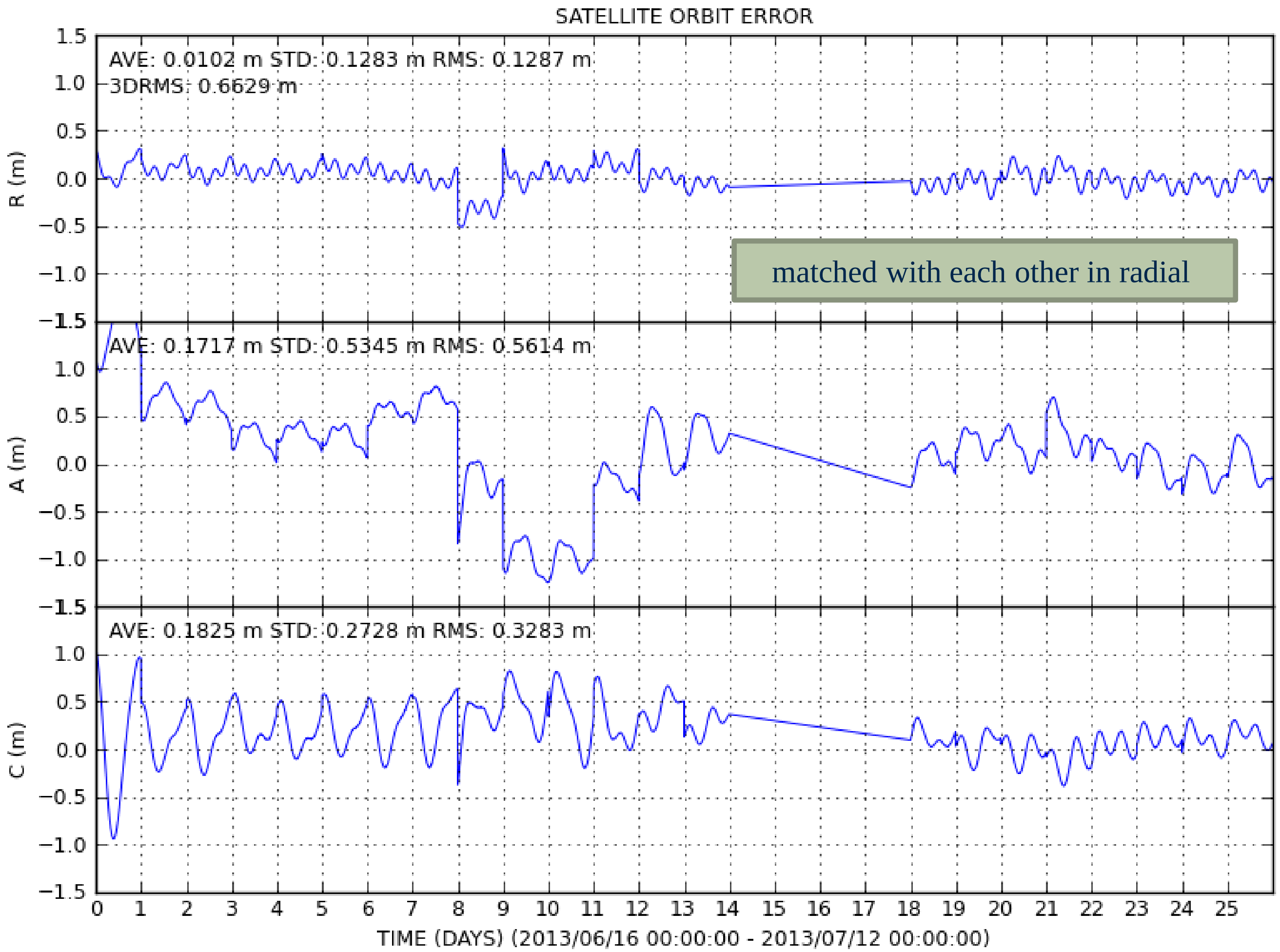
	MAD	QZF	TUM	ESOC
MAD	-	0.386	0.685	1.492
QZF	-	-	0.663	1.041
TUM	-	-	-	1.689
ESOC	-	-	-	-

- ESOC had periodic variations of one-day cycle in cross track (about 0.6m : 1σ).
  → Orbit determination in cross direction might have low accuracy.
- MAD most closely matched with QZF except for the bias in radial.
- QZF closely matched with TUM and ESOC in radial direction.
  - QZF evaluated to be a definitive ephemeris at present.

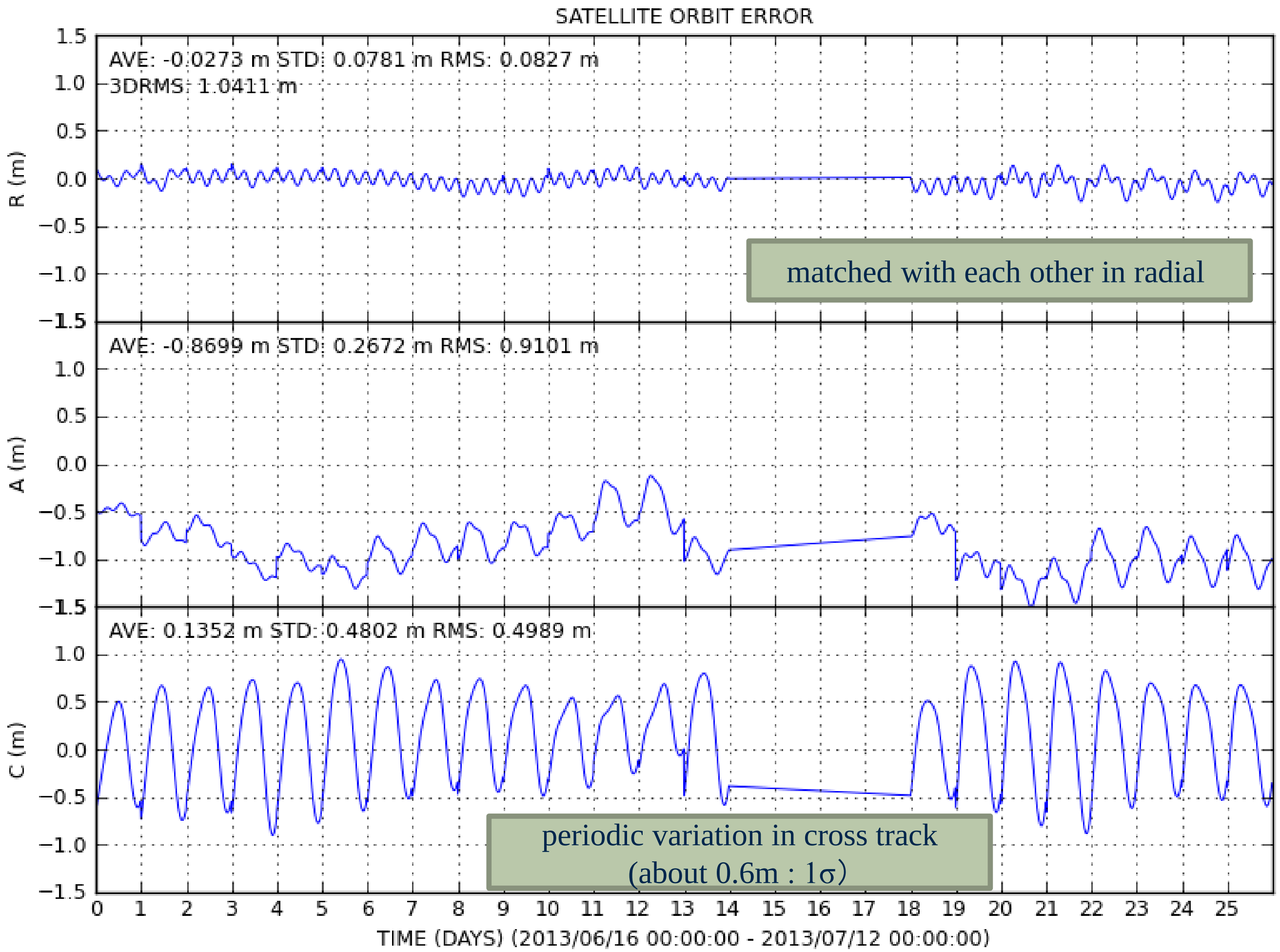
Result : MAD-QZF



Result : TUM-QZF



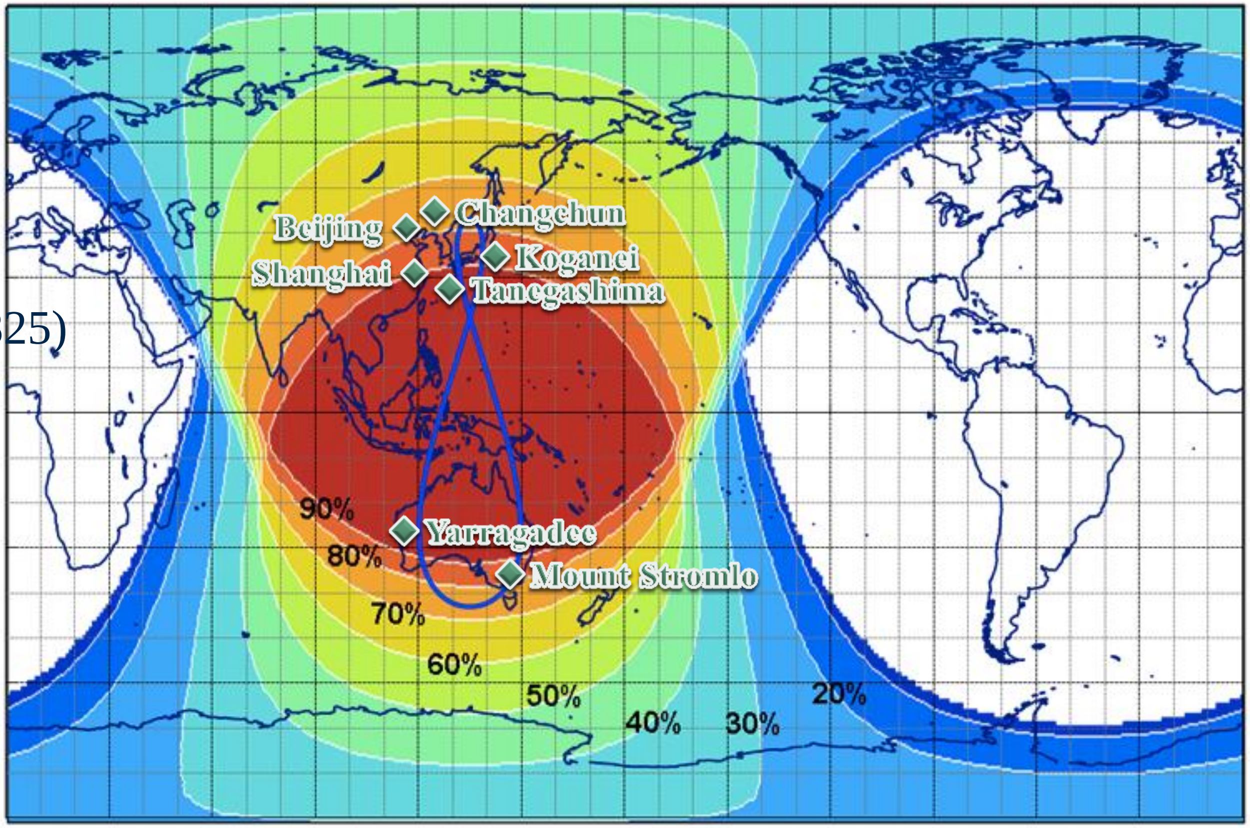
Result : ESOC-QZF



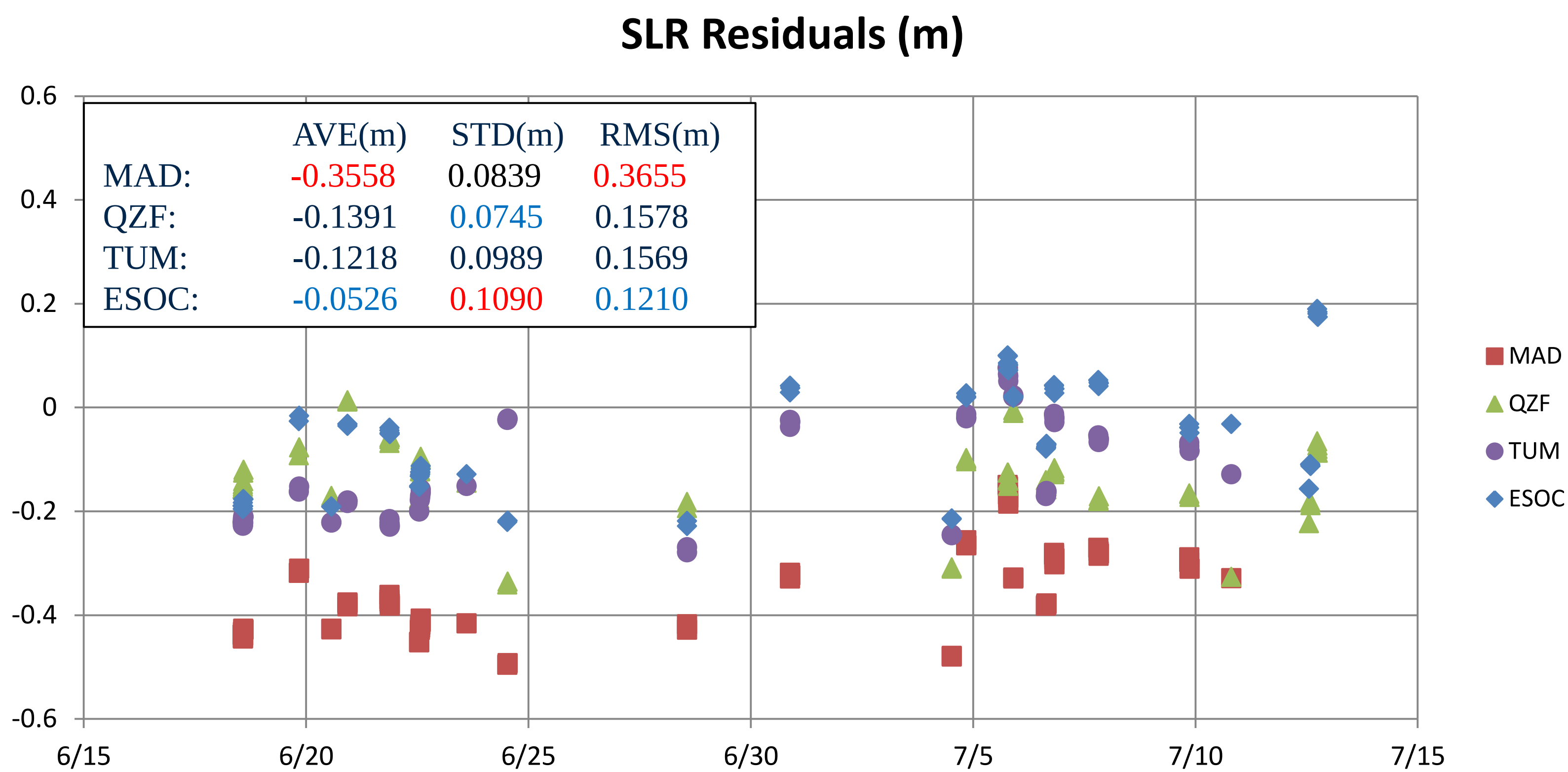
Analysis of SLR residuals

ILRS Tracking Stations

- Tanegashima (7358)
- Koganei (7308)
- Yarragadee (7090)
- Changchun (7237)
- Beijing (7249)
- Shanghai (7821)
- Mount Stromlo (7825)



Result : SLR residuals



	AVE(m)	STD(m)	RMS(m)
MAD:	-0.3558	0.0839	0.3655
QZF:	-0.1391	0.0745	0.1578
TUM:	-0.1218	0.0989	0.1569
ESOC:	-0.0526	0.1090	0.1210

- MAD showed a large bias (30~40cm) .
- Other ephemerides (QZF, TUM, and ESOC) also showed biases but their magnitudes were smaller than that of MAD.

Conclusion

- SLR data and ephemerides of other systems allow reliable accuracy evaluations of JAXA QZS-1 ephemerides.

  - QZF
    - SLR residuals: ~ 20 cm RMS

    - QZF evaluated to be a definitive ephemeris in our analysis

  - MAD processed with MADOCA
    - SLR residuals: ~ 40 cm RMS
    - Comparison with the other ephemerides shows 30~40 cm large bias in radial

    - Eliminating the bias in radial direction will lead to a further improvement in accuracy.

Thank you for your attention.