Orchestrating a brighter world NEC

21st International Workshop on Laser Ranging

Satellite Laser Ranging Evaluation to Quasi-Zenith Satellite System

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NEC Corporation
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Outline

1. Overview of the Quasi-Zenith Satellite System(QZSS)
2. Improve orbit determination accuracy by SLR data
3. Future plans of the QZSS & Summary

1. Overview of the Quasi-Zenith Satellite System(QZSS)

Quasi-Zenith Satellite System

- MICHIBIKI No.1 was launched on Sep. 11, 2010. Afterwards, Government of Japan decided to make QZSS into a 4-satellite.
- 4-satellite constellation was established in 2017, and the operational service was started in Nov. 1st, 2018.

Quasi-Zenith Satellite System (QZSS)

Space Segment 	3 Quasi-Zenith Orbit (QZO) Satellites 1 Geostationary (GEO) Satellites
Ground Segment 	2 Master Control Station (MCS) 7 Uplink Station 22 Monitor Station

QZSS Satellite(s) Overview

Block I-Q: MICHIBIKI No.1

- Lifetime: 10 years
- Orbit(QZO: Quasi-Zenith Orbit)

  Semi-major Axis (a): 42164[km]

  Eccentricity (e): 0.075/ Inclination (i): 41 deg

Block II-Q: MICHIBIKI No.2, 4

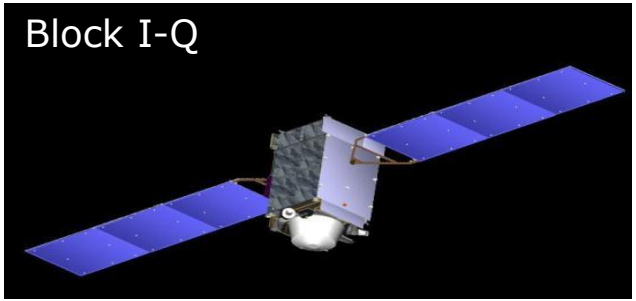
- Lifetime: 15 years+
- Orbit(QZO: Quasi-Zenith Orbit)

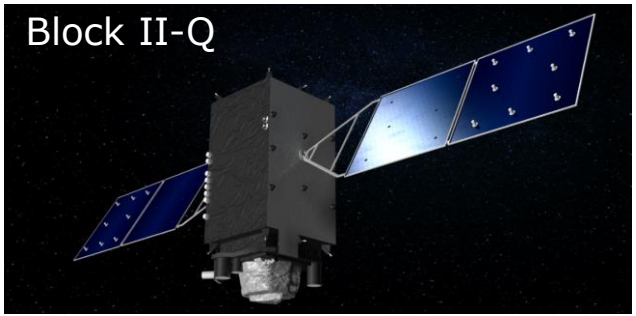
  a, e, i: same as Block I-Q

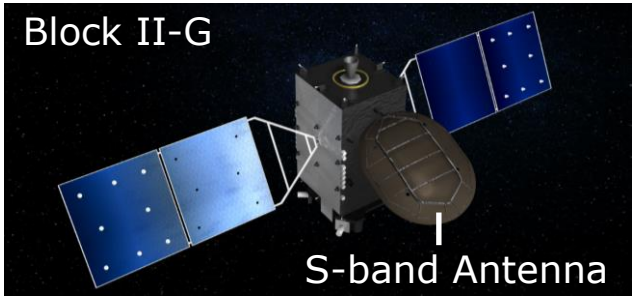
Block II-G: MICHIBIKI No.3

- Lifetime: 15 years+
- Orbit(GEO: GeoStationary Orbit)

  Longitude: E 127/ Latitude: 0





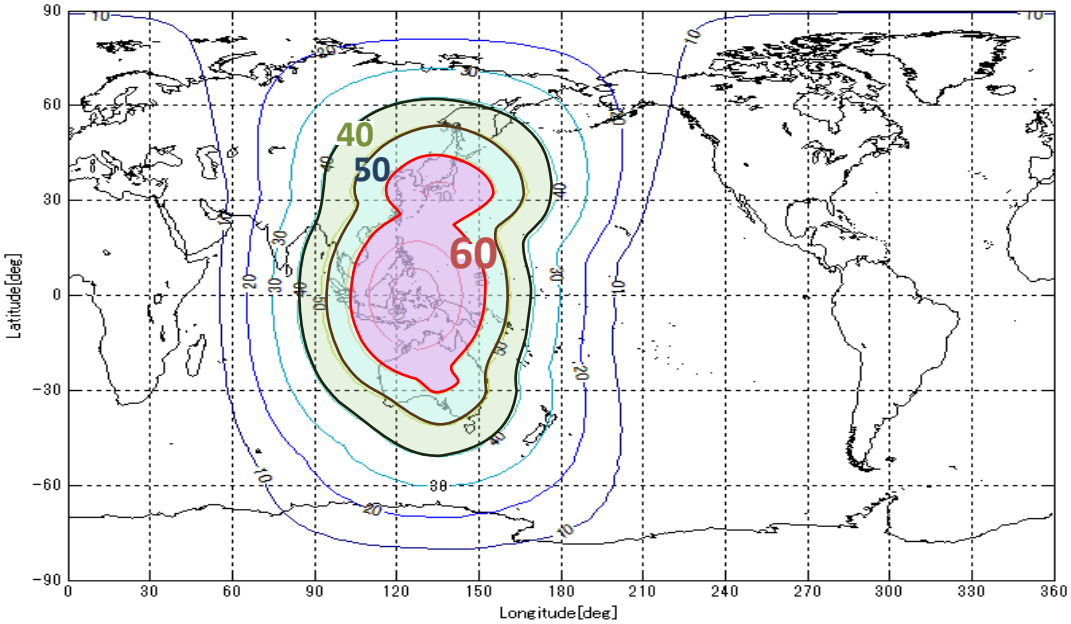


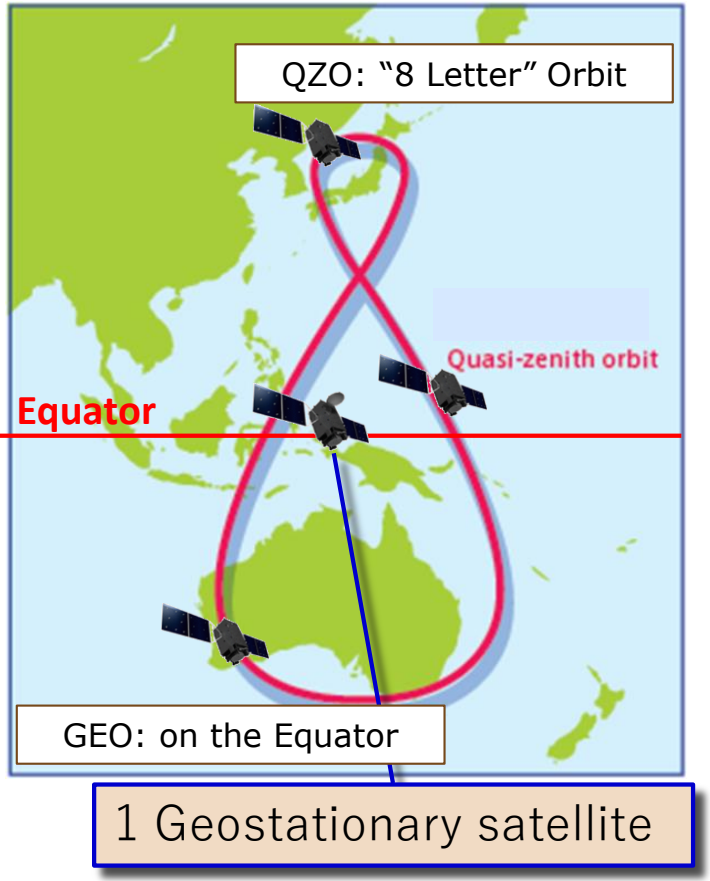
QZSS Orbit

Japan Region

- Over 20 degrees elevation (More than 2-QZS are available)
- Over 60 degrees elevation (1-QZS is available)

QZSS Coverage Area at least one QZS is visible





QZSS Satellite(s) Launch

MICHIBIKI Launched from Tanegashima space center.

	No.1*	No.2	No.3	No.4
launch	Sep.11, 2010	Jun.1, 2017	Aug.19, 2017	Oct.10, 2017
Alert off	Jun.21, 2011	Sep.15, 2017	Dec.18, 2017	Jan.12, 2018

* MICHIBIKI No.1 was transferred from JAXA to Cabinet Office on Mar. 2017.

[Block II-G: No.3]

[Block II-Q: No.4]

[No.3 launched]

Typical Mission of QZSS

- QZSS provides positioning-related service and messaging service.
- Positioning-related service
  - *Satellite Positioning, Navigation & Timing Service (PNT)*

    The service to provide satellite positioning as same as US-GPS.
  - *Sub-meter Level Augmentation Service (SLAS)*

    The service to provide accurate positioning around 1-2 meters*.
  - *Centimeter Level Augmentation Service (CLAS)*

    The service to provide highly accurate positioning around 10 centimeters*.

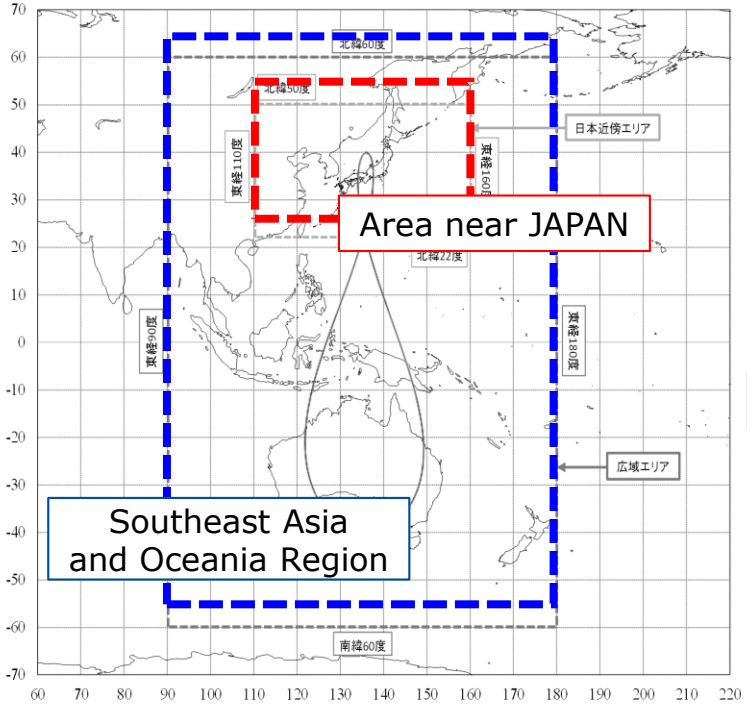
To evaluate and improve the positioning accuracy by SLR data.

* Ionosphere disturbance(fluctuations), multipath and others will affect the accuracy.

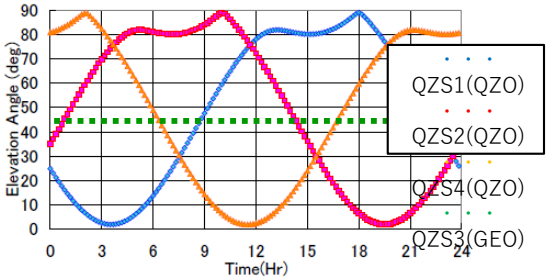
- Messaging Service
  - *Sattellite Report for Disaster and Crisis Management (DC Report)*
- Positioning-related service supported by JCAB
  - *SBAS Service*

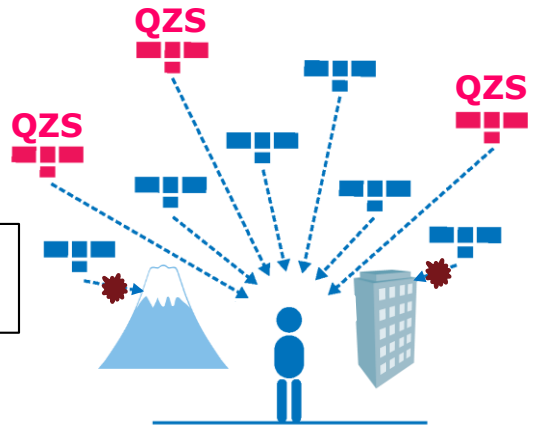
PNT Service (GPS Complementary)

- QZSS can be seen at high elevation angle and reduces the multipath effect.



QZSS visibility time (TOKYO)



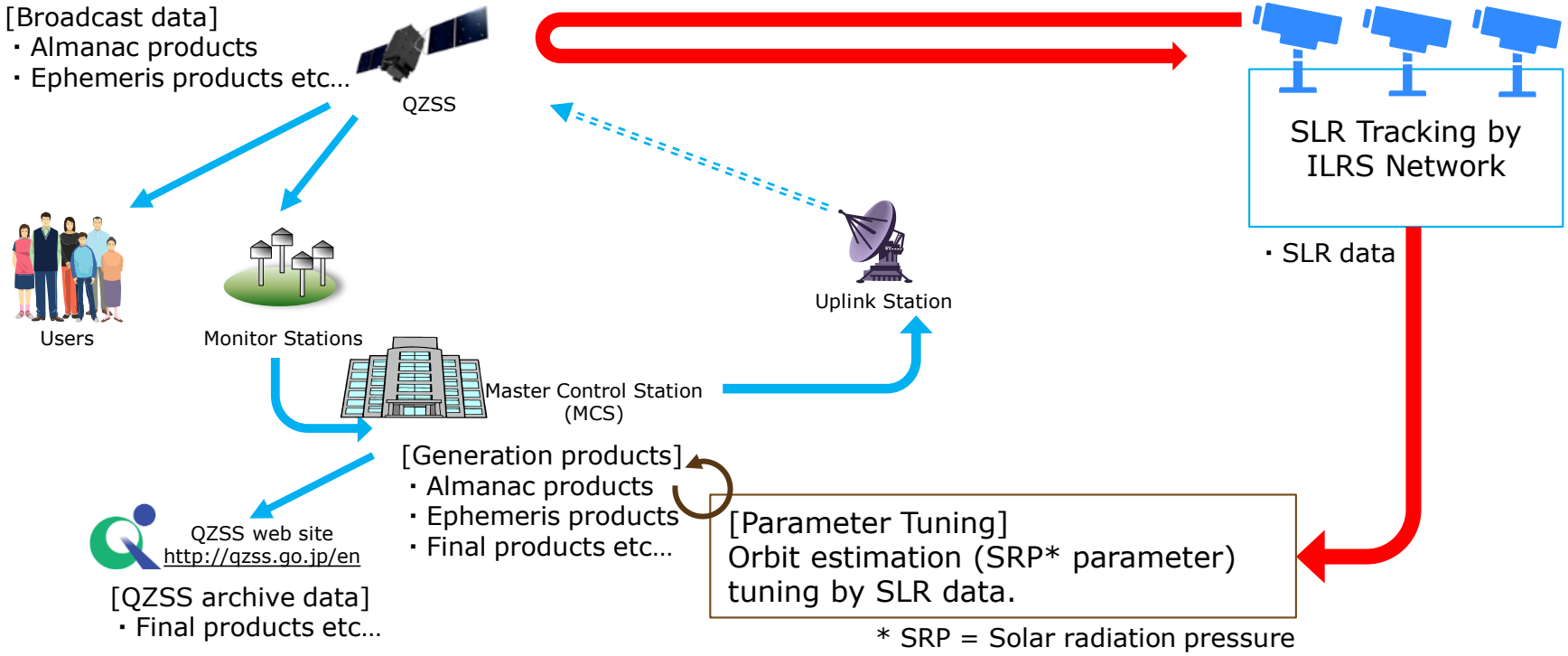


- QZSS transmits two types of the regional ionospheric parameters, i.e. parameters for the Southeast Asia and Oceania regions, and parameters for the area near Japan.

2. Improve orbit determination accuracy by SLR data

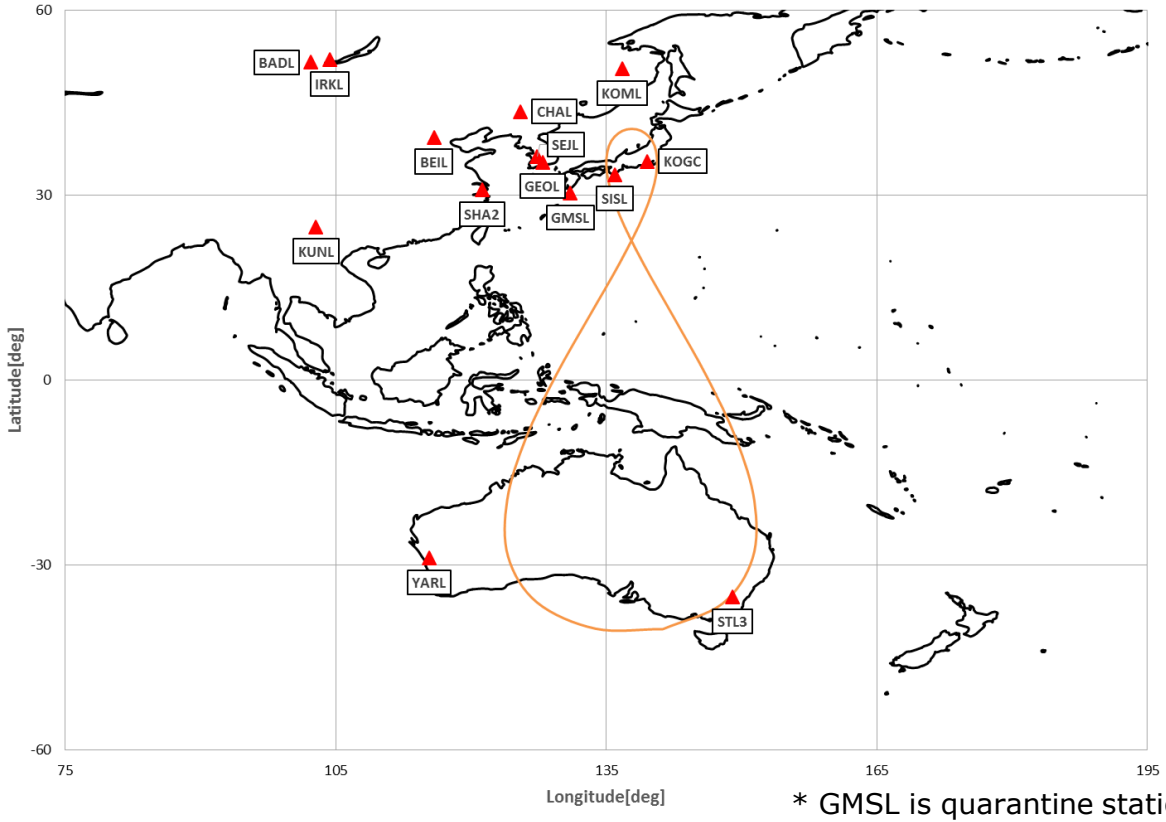
Tuning routine on QZSS operation

Accuracy evaluation using SLR data has helped modeling and parameter tuning of orbit determination.



SLR visible stations for MICHIBIKI

SLR visible station for QZO (over 20 degrees elevation)



Number of ranging data per SLR station

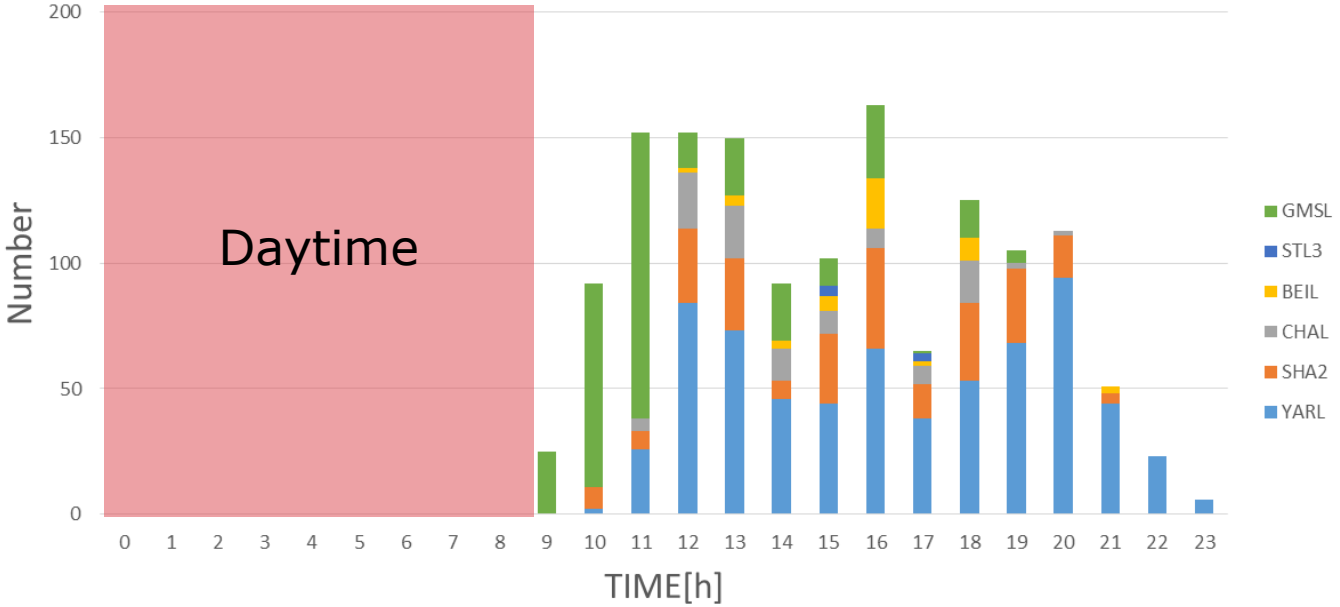
Name	Number
YARL	667
SHA2	246
CHAL	106
BEIL	49
STL3	7
GMSL*	341

From Jun.1, 2018. All QZS.

* GMSL is quarantine station (reference value). Data provided by JAXA.

SLR visible stations for MICHIBIKI

Time series graph of Number of SLR NPT data



We could obtain so many SLR data

- We thanks to the SRP parameter tunings by using these data, improve orbit estimation accuracy!! (detail is next slides)

Thank you for your cooperation!!

SRP parameter tunings for MICHIBIKI by SLR(1/4)

Solar radiation pressure (SRP)

- SRP, which is a kind of force models for satellites, is key factor for precise orbit determination and estimation.

Force models for satellite.

Gravity	Geopotential, Third-Body potentials, etc…	It is not necessary to estimate the models. Can be applied the same models for satellites. (For example, DE430).
Non-gravity	SRP, Atomospheric Drag, etc…	It is necessary to estimate the model for each satellite (especially SRP).

SRP models for orbit determination

- Analysis models
- Empirical models ✓: Adopted in MICHIBIKI

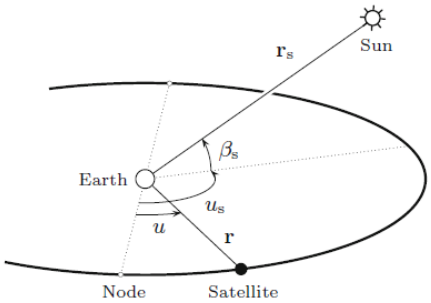
Depends on orbit position and β-angle. long-term fittings (parameter tuning) is required.

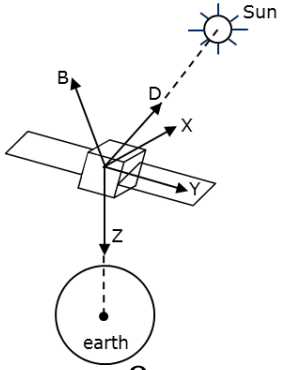
SRP parameter tunings for MICHIBIKI by SLR(2/4)

CODE model (A kind of SRP empirical models)

- Define of the DBY coordinate system

Coordinate System





Acceleration

$$a_{srp} = S \times (D(u)\boldsymbol{e}_D + Y(u)\boldsymbol{e}_Y + B(u)\boldsymbol{e}_B) \times 10^{-9}$$

$$D(u) = D_0 + D_c cosu + D_s sinu$$

$$\mathrm{Y}(u) = Y_0 + Y_c cosu + Y_s sinu$$

$$B(u) = B_0 + B_c cosu + B_s sinu$$

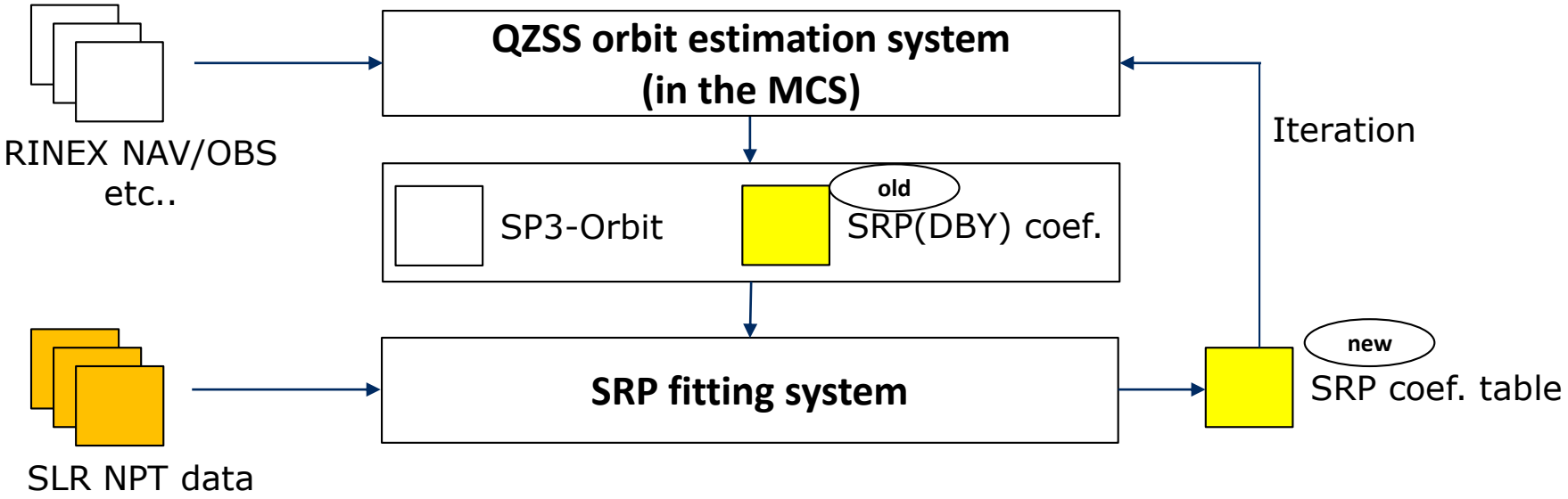
$$S = F_{shadow} \times AU^2/|r - r_s|^2$$

F_shadow = Penumbra/umbra of earth/moon
AU = Astronomical unit

⇒ We should optimize these 9 parameters (Dx, Bx, Yx) for each satellites.

SRP parameter tunings for MICHIBIKI by SLR(3/4)

Determination flow of SRP coefficients (Dx, Bx, Yx).



Find the SRP parameter which minimize the residual error:

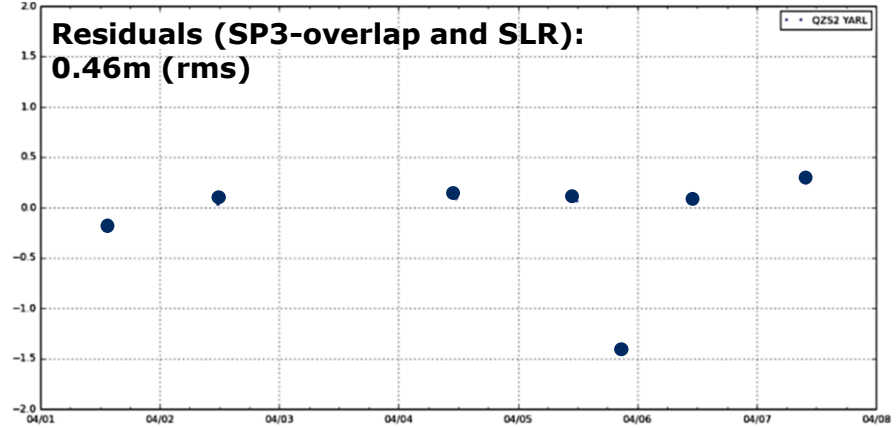
① The difference between the SP3-orbit and SLR.

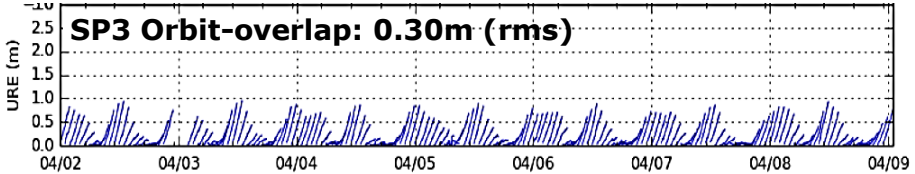
② The SP3-orbit overlap of successive generation.

Parameter tuning for MICHIBIKI by SLR(4/4)

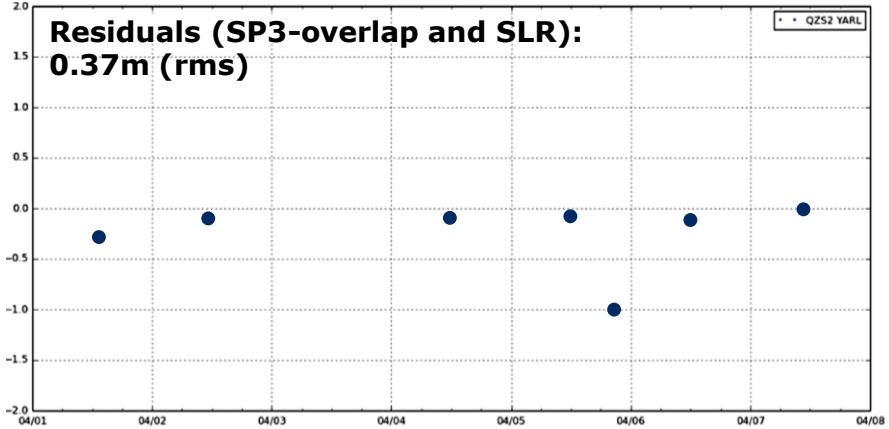
Result of SRP parameter fitting for MICHIBIKI No.2 (Offline).

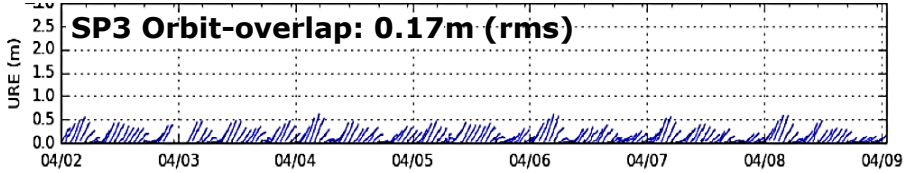
Before SRP fitting (old SRP coef.)





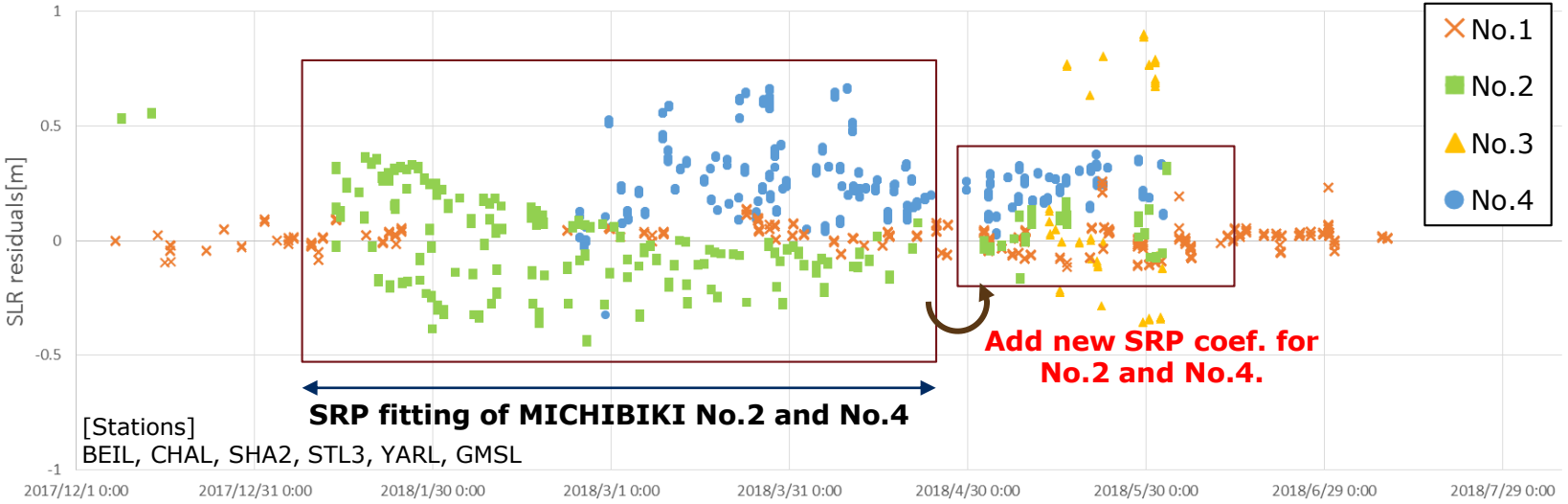
After SRP fitting (new SRP coef.)





Evaluation for MICHIBIKI

- Accuracy evaluation of all QZS products by SLR data.



- SLR residuals of No.2 and No.4 was improved by thanks to SRP fitting. We will carry out continuous tuning for Other QZS.
- We appreciate ILRS' laser ranging activities, and **need continuous support by ILRS** for QZS' accuracy improvement.

3. Future plans of the QZSS & Summary

Future plans of QZSS

- 4-satellite constellation of QZSS has just started on this November. It will be established 7-statellite constellation in 2023.

Summary

- The 4-satellites constellation was established by the end of 2017 and the full operational service has started on this Nov. 1st.
- QZSS achieved high-performance positioning results as GPS complemental system.
- The evaluated results of SRP fittings by SLR data is quite a good result. QZSS wants continuous cooperation by ILRS.
- We will start the development of 7-satellite constellation, and it will be established within 2023.

- Acknowledgements

  We would like to express the special thanks to ILRS' cooperation.

Thank you for your attention.

For more information, please visit our web site

http://qzss.go.jp/en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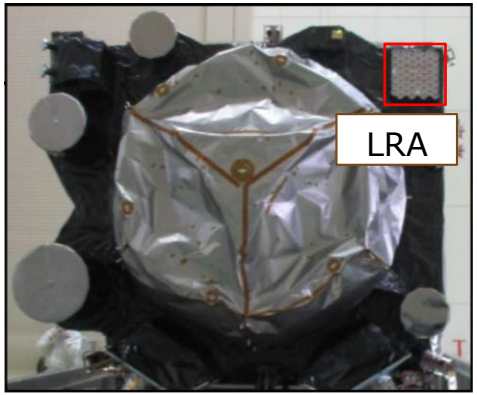
Laser ranging for QZS

- All QZS equipped the LRA for laser-ranging. Property information is below.
- Location of LRA optical center

	Coordinates (w.r.t origin of satellite reference frame) [mm]		
	X	Y	Z
Block I-Q	-1150.0	-550.0	+4505.3
Block II-Q	-988.2	-860.8	+4373.3
Block II-G	+1081.8	-460.8	+4373.3

Laser retro-reflector array (LRA)

- Envelope (same as all QZS)
  - 400[mm] x 400[mm]x100[mm]
- Number of corner cube reflector
  - 56 (7 rows x 8 lines)



Location of LRA (MICHIBIKI No.2)

Signal of QZSS

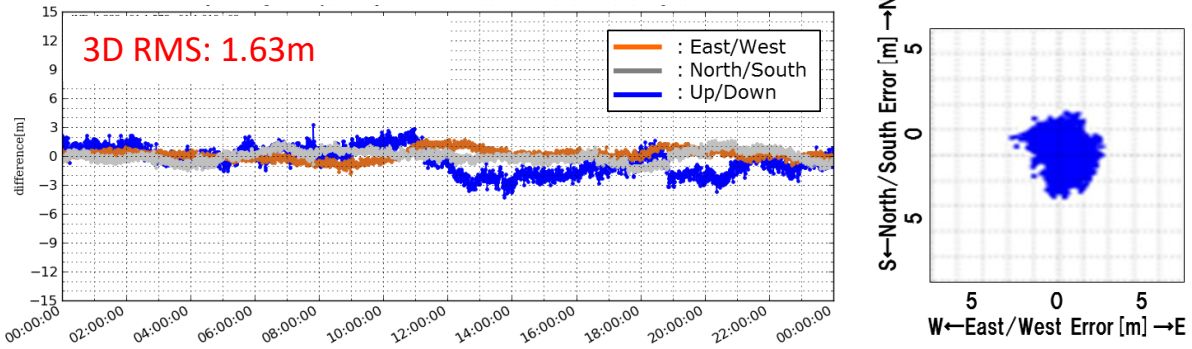
- In addition to the positioning signals (GPS complementation), QZSS transmits the augmentation signals and the message/experimental signals.

			1st Satellite	2nd-4th Satellite	
			Block I-Q	Block II-Q	Block II-G
L1C/A	1575.42MHz	Positioning(PNT)	✓	✓	✓
L1C		Positioning(PNT)	✓	✓	✓
L1S		Augmentation(SLAS)	✓	✓	✓
		Message Service	✓	✓	✓
L2C	1227.60MHz	Positioning(PNT)	✓	✓	✓
L5	1176.45MHz	Positioning(PNT)	✓	✓	✓
L5S		Augmentation Experimental	N/A	✓	✓
L6D	1278.75MHz	Augmentation(CLAS)	✓	✓	✓
L6E		Experimental	N/A	✓	✓
L1Sb	1575.42MHz	Augmentation	N/A	N/A	✓
S-band	2GHz band	Message Service	N/A	N/A	✓

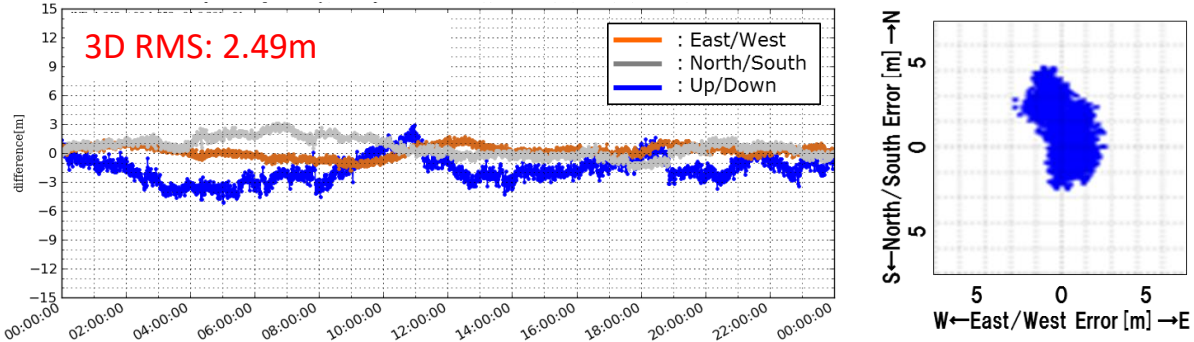
PNT Service (GPS Complementary)

- Thanks to the QZS added navigation, the residual error for user positioning accuracy was improved rather the GPS only.

GPS+QZS



GPS Only



2018/5/15 at Kobe, Hyogo Prefecture, Japan