

Interoperability Analysis of Open PPP/PPP-RTK Services

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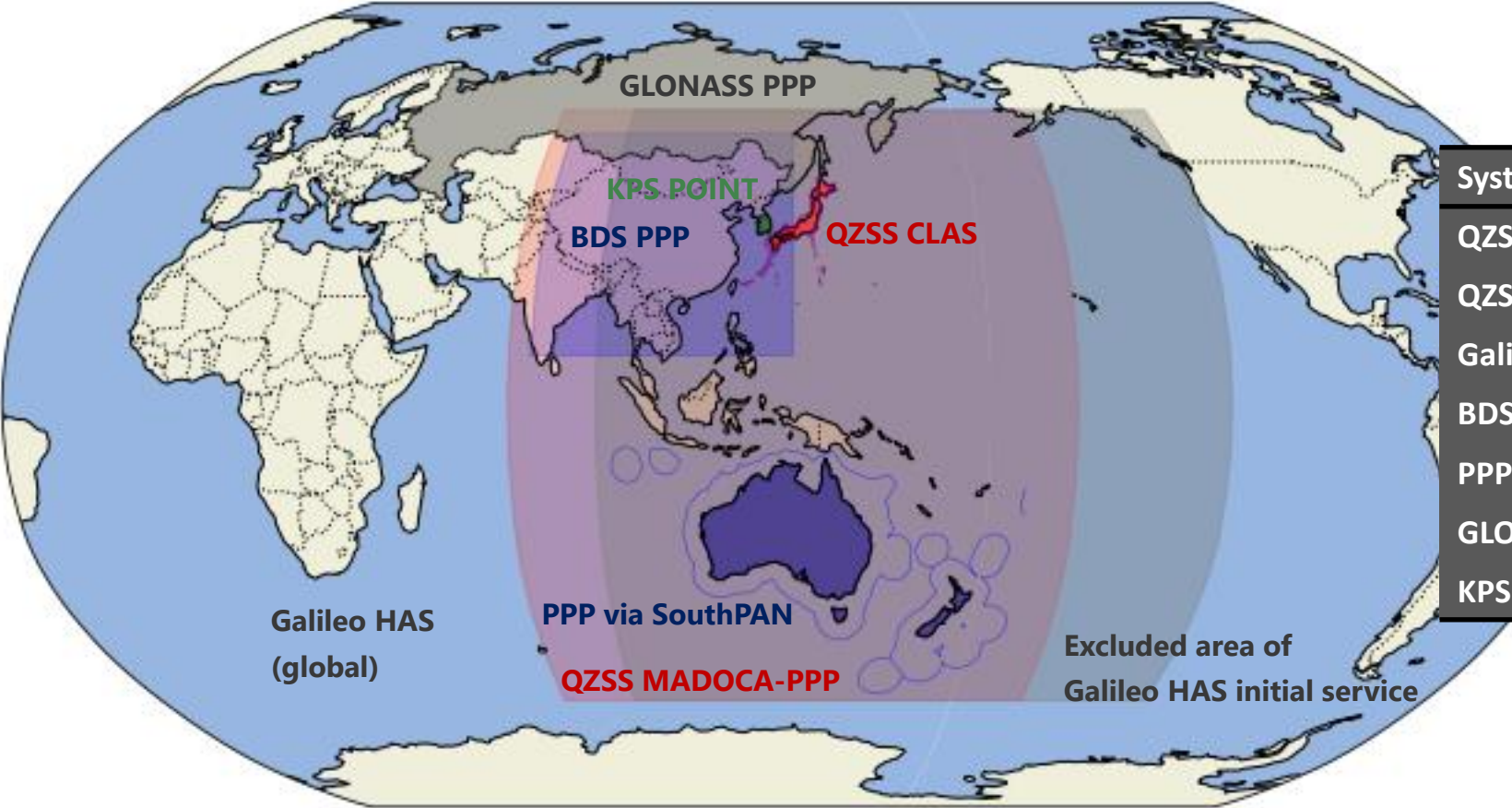
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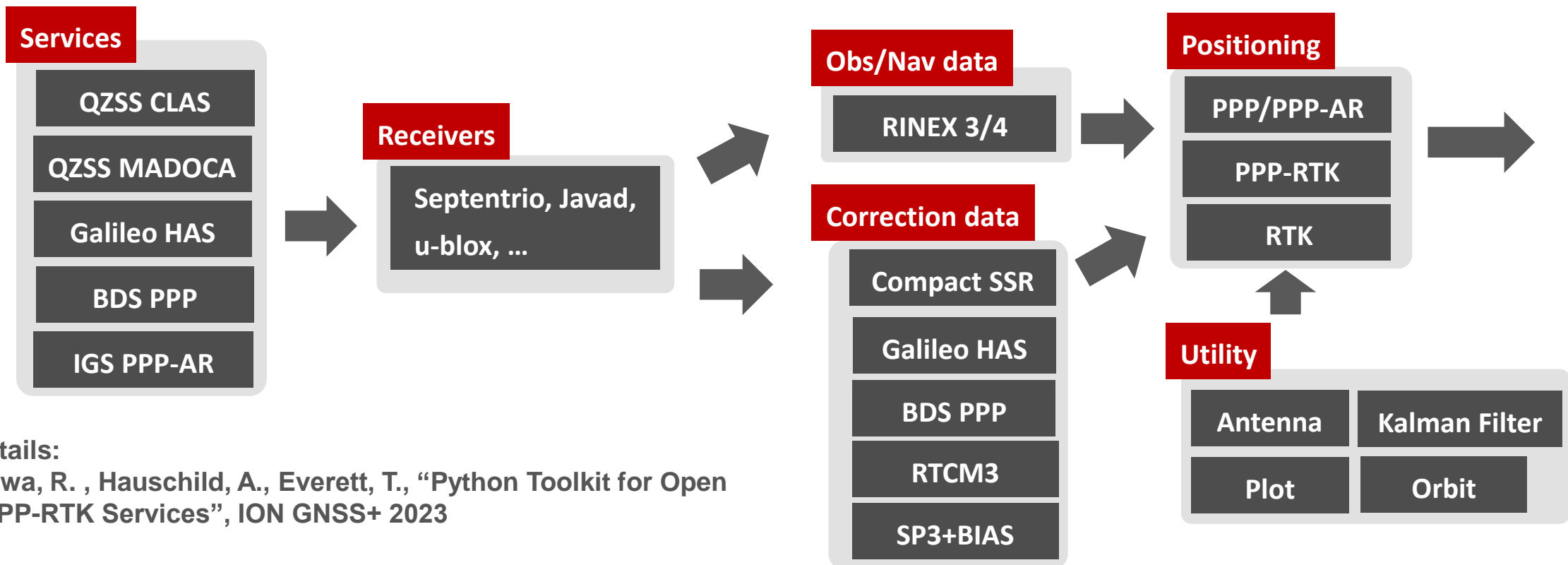
Age of Satellite Based Open PPP/PPP-RTK Services

Many open satellite-based PPP/PPP-RTK services are available.



System	Service	Status
QZSS CLAS	PPP-RTK	Operational
QZSS MADOCA-PPP	PPP	Trial Service
Galileo HAS	PPP	Initial Service
BDS PPP	PPP	Operational
PPP Via SouthPAN	PPP	Early Service
GLONASS PPP	PPP	Modernization
KPS POINT	PPP-RTK	Development

- ✓ Open source Toolkit for open PPP/PPP-RTK services by Python (available from pypi/github)
- ✓ Positioning techniques: RTK, PPP-RTK, PPP/PPP-AR
- ✓ Services: QZSS CLAS, QZSS MADOCA PPP, Galileo HAS, BDS PPP, IGS product
- ✓ Tutorials: Jupyter Notebook
- ✓ Utilities for visibility analysis, plotting



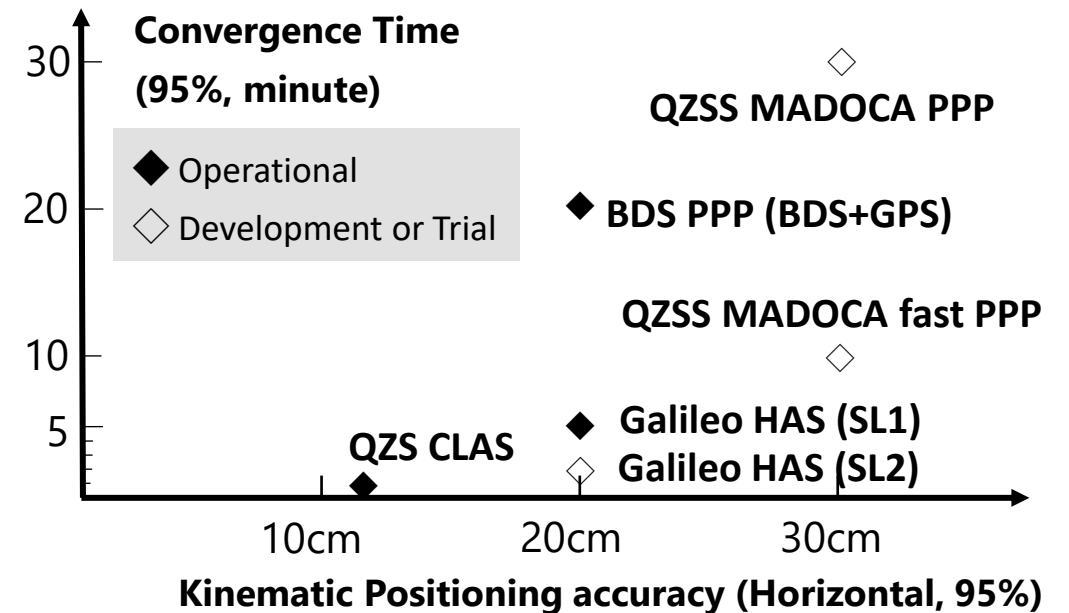
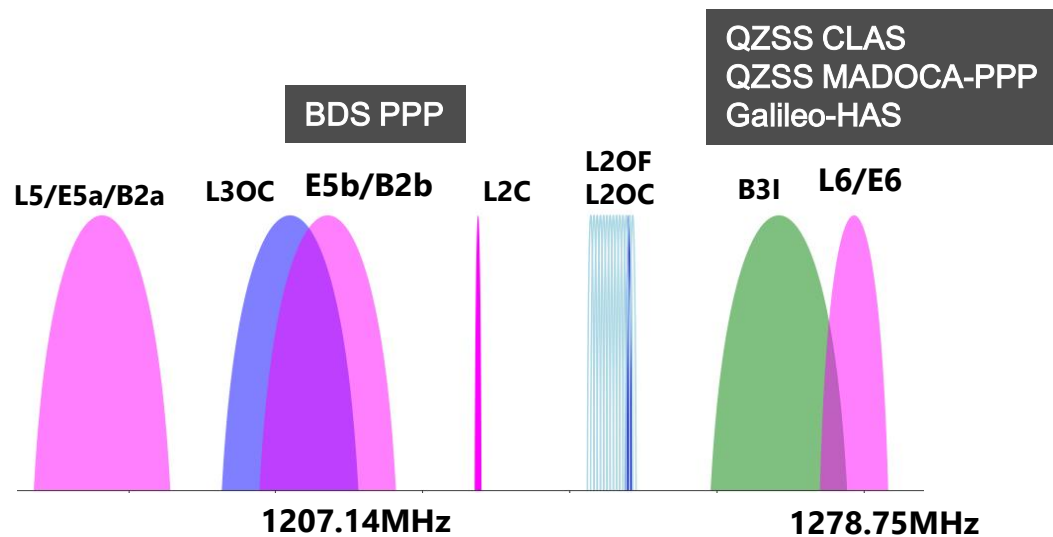
For details:

Hirokawa, R. , Hauschild, A., Everett, T., “Python Toolkit for Open PPP/PPP-RTK Services”, ION GNSS+ 2023

Open PPP/PPP-RTK services:

1. QZSS CLAS (PPP-RTK)
2. QZSS MADOCA PPP
3. Galileo HAS
4. BDS PPP
5. IGS product

	QZSS CLAS	QZSS MADOCA-PPP	Galileo HAS	BDS PPP
Techniques	PPP-RTK	PPP	PPP	PPP
Data rate	1,695 bps	1,695 bps	448 bps	462 bps
Service Area	Japan	Asia/Oceania	Global (SL1) / Regional (SL2)	China



	QZSS CLAS	QZSS MADOCA PPP	Galileo HAS	BDS PPP
Service	PPP-RTK	PPP	PPP	PPP
Format	CSSR	CSSR	Similar to CSSR	Customized CSSR
Supported GNSS	G+E+J	G+E+R+J	G+E	G+C
Orbit	✓ (30sec)	✓ (30sec)	✓ (50sec)	✓ (48sec)
Clock	✓ (5sec)	✓ (5sec)	✓ (10sec)	✓ (6sec)
Code Bias	✓ (30sec)	✓ (30sec)	✓ (50sec)	✓ (48sec)
Phase Bias	✓ (30sec)	✓ (30sec)		
Ionosphere	✓ (30sec)			
Troposphere	✓ (30sec)			
URA	✓ (30sec)			

RINEX signal code:

G: 1C, 2X, 2W, 5X
E: 1X, 5X
J: 1C, 2X, 5X

G: 1C, 1W, 1X, 2X, 2W, 5X
R: 1C, 1P, 2C, 2P
E: 1X, 5X
J: 1C, 1X, 2X, 5X

G: 1C, 2L, 2P
E: 1C, 5Q, 7Q, 6C

C: 2I, 1D, 1P, 5D, 5P, 7D, 7P, 6I

No code bias for GPS

'2P' (P (AS off)) should be '2W' (Z-tracking (AS on))?

RTCM SSR**IGS SSR** **RTCM 4076**

orbit $X_{orbit} = X_{broadcast} - \delta X$

$$\delta X = A\delta O = [e_r \quad e_a \quad e_c]\delta O$$

$$e_a = \frac{\dot{r}}{|\dot{r}|}, e_c = \frac{r \times \dot{r}}{|r \times \dot{r}|}, e_r = e_a \times e_c$$

$$\delta O = \begin{bmatrix} \delta O_{radial} \\ \delta O_{along} \\ \delta O_{cross} \end{bmatrix} + \begin{bmatrix} \delta \dot{O}_{radial} \\ \delta \dot{O}_{along} \\ \delta \dot{O}_{cross} \end{bmatrix} (t - t_0)$$

clock $t_{sat} = t_{broadcast} - \delta C/c$

$$\delta C = C_0 + C_1(t - t_0) + C_2(t - t_0)^2$$

code bias $\widetilde{PR}_{corrected} = PR_{observed} + cbias$

phase bias $\widetilde{CP}_{corrected} = CP_{observed} + pbias$

IGS product
SP3c/SP3d
Clock-RINEX
Bias-SINEX
orbit**SP3c/SP3d**

$$X_{ei} = \begin{bmatrix} \cos(\omega_{ie}\Delta t_i) & -\sin(\omega_{ie}\Delta t_i) & 0 \\ \sin(\omega_{ie}\Delta t_i) & \cos(\omega_{ie}\Delta t_i) & 0 \\ 0 & 0 & 1 \end{bmatrix} X_i, \Delta t_i = t_i - t$$

$$X_{orbit,cg} = interpolate(\Delta t_i, X_{ei})$$

$$e_z = \frac{-r}{|r|}, e_s = \frac{r_{sun} - r}{|r_{sun} - r|}, e_y = \frac{e_z \times e_s}{|e_z \times e_s|}, e_x = e_y \times e_z$$

$$X_{orbit} = X_{orbit,cg} + [e_x \quad e_y \quad e_z]d_{offset}$$

clock

$$t_{sat} = interpolate(\Delta t_i, t_i)$$

Clock-RINEX**code bias**

$$\widetilde{PR}_{corrected} = PR_{observed} - cbias$$

phase bias

$$\widetilde{CP}_{corrected} = CP_{observed} - pbias$$

Bias-SINEX

QZSS MADOCA PPP IS-QZSS-MDC-001

orbit $X_{orbit} = X_{broadcast} - \delta X$

$$\delta X = A\delta O = [e_r \quad e_a \quad e_c]\delta O$$

$$e_a = \frac{\dot{r}}{|\dot{r}|}, e_c = \frac{r \times \dot{r}}{|r \times \dot{r}|}, e_r = e_a \times e_c$$

$$\delta O = \begin{bmatrix} \delta O_{radial} \\ \delta O_{along} \\ \delta O_{cross} \end{bmatrix}$$

clock $t_{sat} = t_{broadcast} - \delta C/c$

$$\delta C = C_0$$

code bias $\widetilde{PR}_{corrected} = PR_{observed} + cbias$

phase bias $\widetilde{CP}_{corrected} = CP_{observed} + pbias$

QZSS CLAS IS-QZSS-L6-005

orbit $X_{orbit} = X_{broadcast} - \delta X$

$$\delta X = A\delta O = [e_r \quad e_a \quad e_c]\delta O$$

$$e_a = \frac{\dot{r}}{|\dot{r}|}, e_c = \frac{r \times \dot{r}}{|r \times \dot{r}|}, e_r = e_a \times e_c$$

$$\delta O = \begin{bmatrix} \delta O_{radial} \\ \delta O_{along} \\ \delta O_{cross} \end{bmatrix}$$

clock $t_{sat} = t_{broadcast} - \delta C/c$

$$\delta C = C_0$$

code bias $\widetilde{PR}_{corrected} = PR_{observed} - cbias$

phase bias $\widetilde{CP}_{corrected} = CP_{observed} - pbias$

Galileo HAS IDD **RTCM 1059/1060, 1242/1243**

orbit

$$X_{orbit} = X_{broadcast} - \delta X$$

$$\delta X = A\delta O = [e_r \quad e_a \quad e_c]\delta O$$

$$e_a = \frac{\dot{r}}{|\dot{r}|}, e_c = \frac{r \times \dot{r}}{|r \times \dot{r}|}, e_r = e_a \times e_c$$

$$\delta O = \begin{bmatrix} \delta O_{radial} \\ \delta O_{along} \\ \delta O_{cross} \end{bmatrix} + \begin{bmatrix} \delta \dot{O}_{radial} \\ \delta \dot{O}_{along} \\ \delta \dot{O}_{cross} \end{bmatrix} (t - t_0)$$

clock

$$t_{sat} = t_{broadcast} - \delta C/c$$

$$\delta C = C_0 + C_1(t - t_0) + C_2(t - t_0)^2$$

code bias

$$\widetilde{PR}_{corrected} = PR_{observed} + cbias$$

Galileo HAS SIS **HAS SIS ICD v1.0**

orbit

$$X_{orbit} = X_{broadcast} + \delta X$$

$$\delta X = A\delta O = [e_r \quad e_a \quad e_c]\delta O$$

$$e_a = \frac{\dot{r}}{|\dot{r}|}, e_c = \frac{r \times \dot{r}}{|r \times \dot{r}|}, e_r = e_a \times e_c$$

$$\delta O = \begin{bmatrix} \delta O_{radial} \\ \delta O_{along} \\ \delta O_{cross} \end{bmatrix}$$

clock

$$t_{sat} = t_{broadcast} - \delta C/c$$

$$\delta C = C_0$$

code bias

$$\widetilde{PR}_{corrected} = PR_{observed} + cbias$$

phase bias

$$\widetilde{CP}_{corrected} = CP_{observed} + pbias$$

BDS PPP

BDS-SIS-ICD-PPP-B2b-1.0

orbit

$$X_{orbit} = X_{broadcast} - \delta X$$

$$\delta X = A\delta O = [e_r \quad e_a \quad e_c]\delta O$$

$$e_r = \frac{\mathbf{r}}{|\mathbf{r}|}, e_c = \frac{\mathbf{r} \times \dot{\mathbf{r}}}{|\mathbf{r} \times \dot{\mathbf{r}}|}, e_a = e_c \times e_r$$

$$\delta O = \begin{bmatrix} \delta O_{radial} \\ \delta O_{along} \\ \delta O_{cross} \end{bmatrix}$$

Different definition

clock

$$t_{sat} = t_{broadcast} - \delta C/c$$

$$\delta C = C_0$$

Positive?

code bias

$$\widetilde{PR}_{corrected} = PR_{observed} - cbias$$

Commonly used (■) and un-commonly used (■) sign convention for SSR corrections

orbit $X_{orbit} = X_{broadcast} \text{+/-} \delta X$

code bias $\widetilde{PR}_{corrected} = PR_{observed} \text{+/-} cbias$

clock $t_{sat} = t_{broadcast} \text{+/-} \delta C/c$

phase bias $\widetilde{CP}_{corrected} = CP_{observed} \text{+/-} pbias$

	IGS product	RTCM SSR IGS SSR Compact SSR	Galileo HAS IDD	Galileo HAS SIS	BDS PPP	QZSS MADOC A PPP	QZSS CLAS
Orbit	*1	-	-	+	- *2	-	-
Clock	*1	-	-	-	+ *3	-	-
Code Bias	-	+	+	+	-	+	-
Phase Bias	-	+	/A	+		+	-

*1 Provided as satellite position and clock instead of correction

*2 Definition of coordinate transformation is different from RTCM SSR.

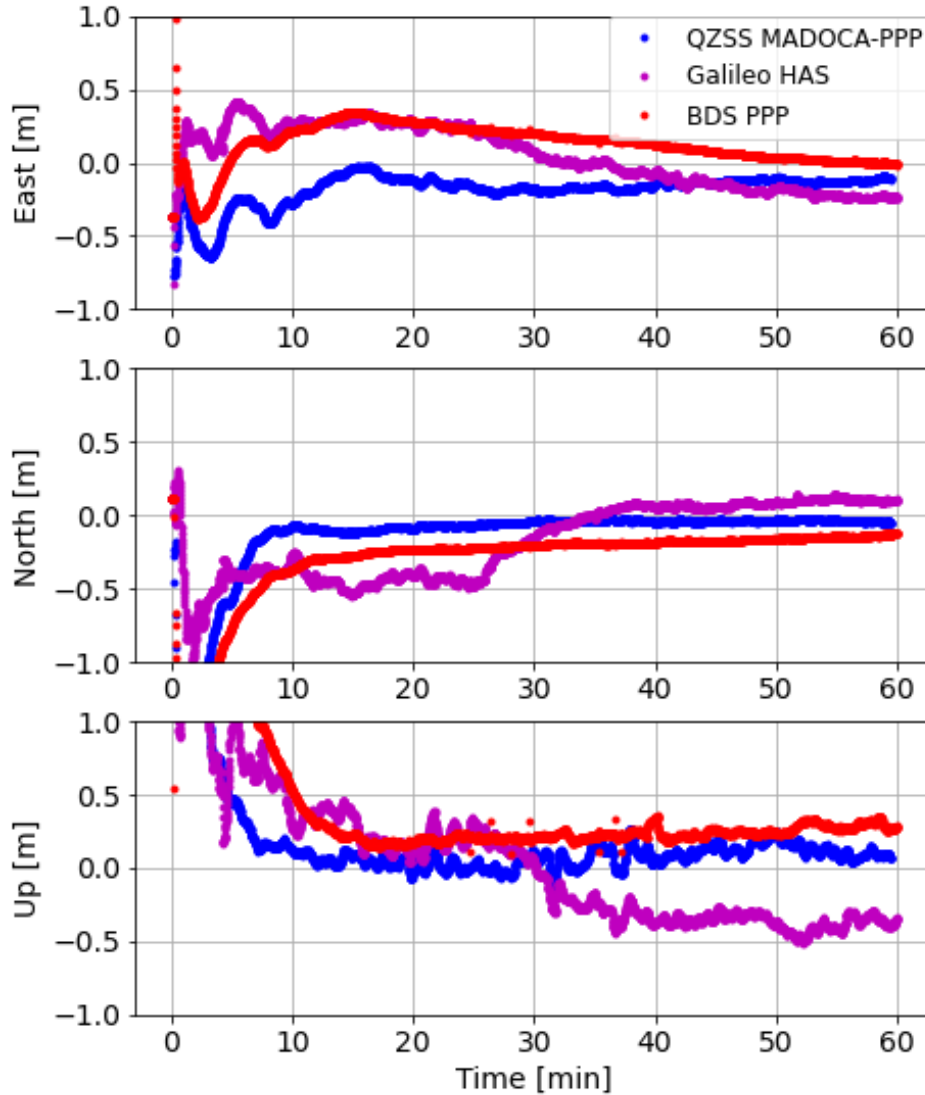
*3 Estimated the sign based on the analysis

- ✓ For the signed value (n-bit), some bit-patterns are defined as “not available” or DNU.
- ✓ For BDS PPP: “ $-2^{n-1}+1$ ” seems to be “not available” (undocumented)

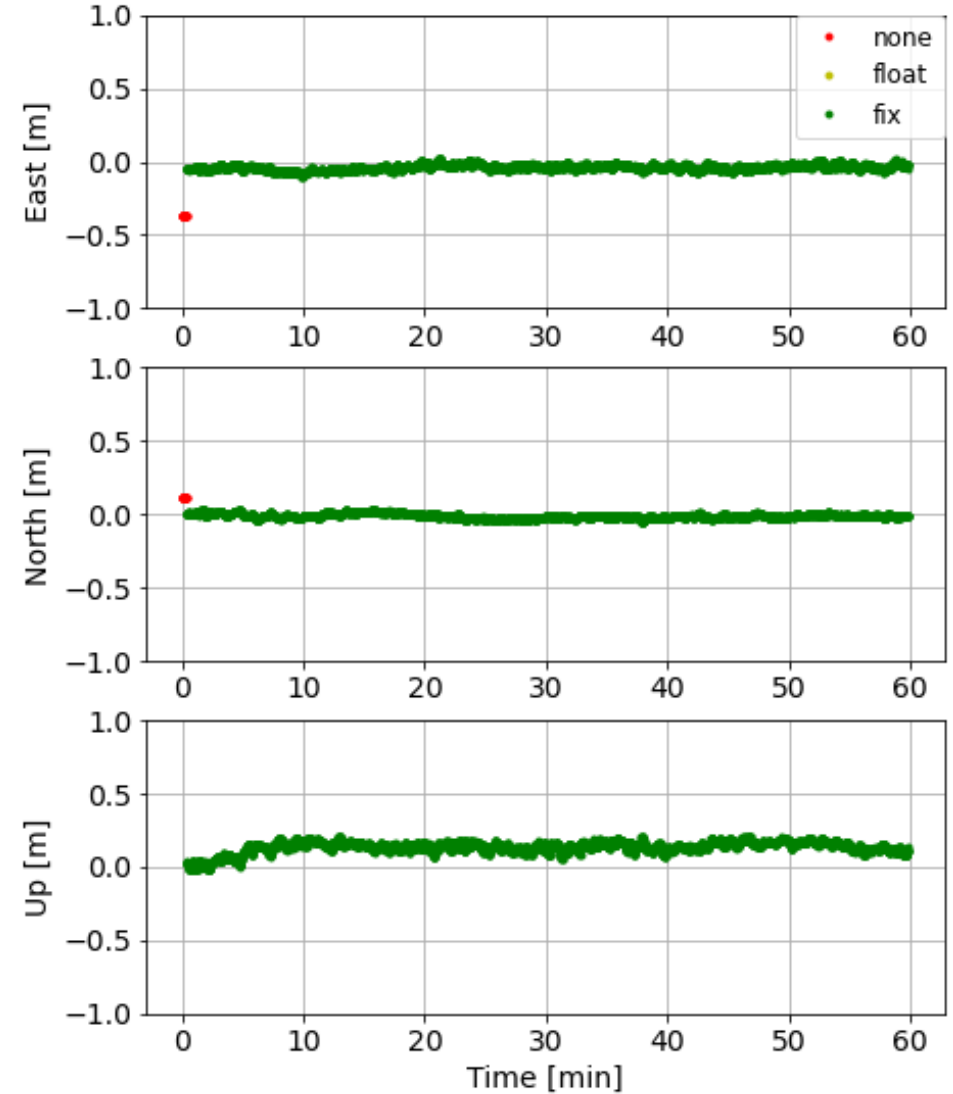
	RTCM SSR IGS SSR Compact SSR	Galileo HAS	BDS PPP
Data not available	-2^{n-1}	-2^{n-1}	$-2^{n-1} + 1$
Do-Not-Use (DNU)	n.a.	$2^{n-1} - 1$	n.a.

Estimated based on the analysis

PPP: QZSS MADOCA-PPP, Galileo HAS (SIS), BDS PPP



PPP-RTK: QZSS CLAS



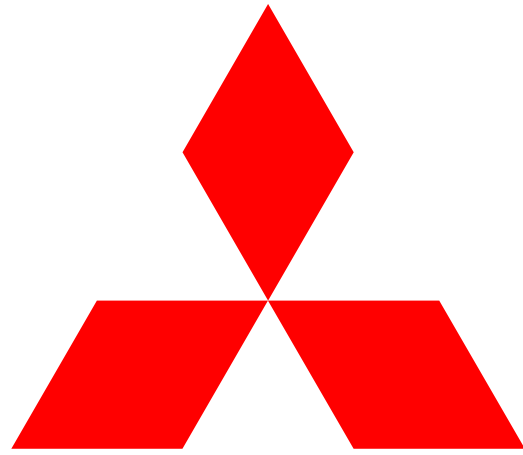
Note for Galileo HAS BDS PPP

Kamakura, Japan is currently outside of service area !

- An open-source toolkit for PPP/PPP-RTK, CSSRlib was introduced
- The inter-operability between four PPP/PPP-RTK services are analyzed:
 - ✓ The differences such as sign convention are found.
- The performance of open PPP/PPP-RTK services is evaluated.

[For future]

- Other Technical Items: Phasing, Coordinates, etc.
- How will the information be included in the provider's report?
- Do we need to define the recommendation for the convention?



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Changes for the Better