Opensource Toolkit for open PPP/PPP-RTK Services

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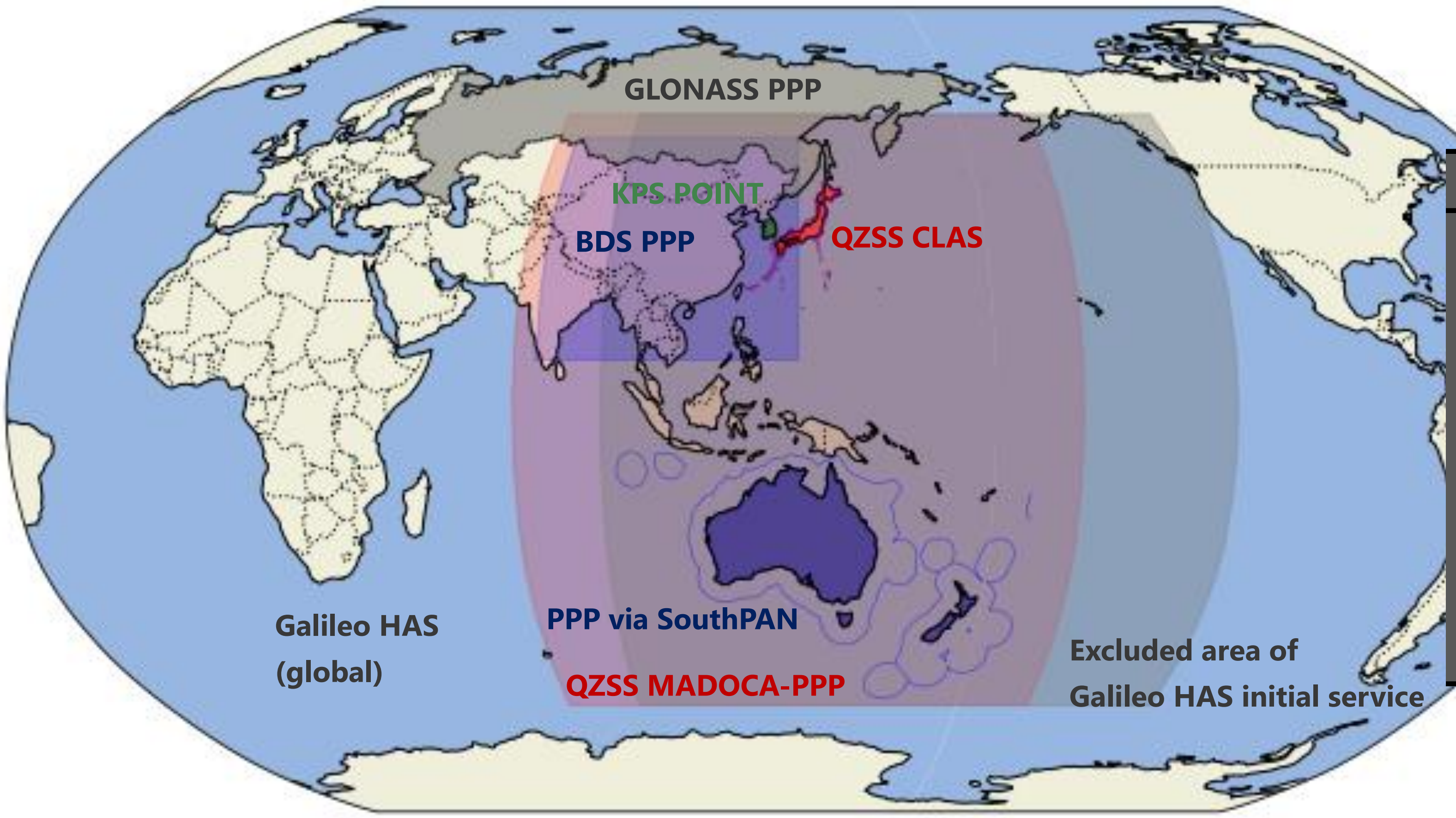
ICG 3rd PPP Interoperability Workshop, Chiang Rai, Thailand
January 30, 2024

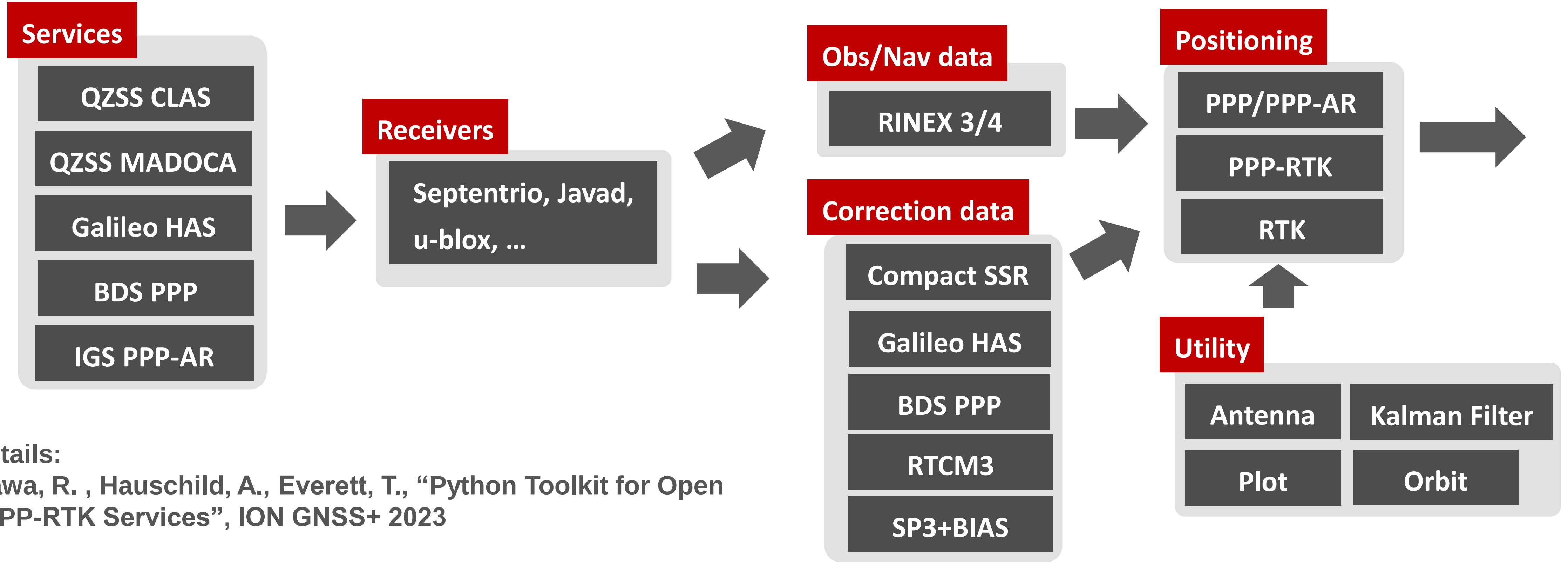
Many open satellite-based PPP/PPP-RTK services are available.



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
JPL GDGPS	PPP	Proposal

Introduction to CSSRlib

- ✓ Open source Toolkit for open PPP/PPP-RTK services by Python (available from pypi/github)
- ✓ Positioning techniques: RTK, PPP-RTK, PPP/PPP-AR, (SBAS)
- ✓ Services: QZSS CLAS, QZSS MADOCA PPP, Galileo HAS, BDS PPP, (PVS), 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

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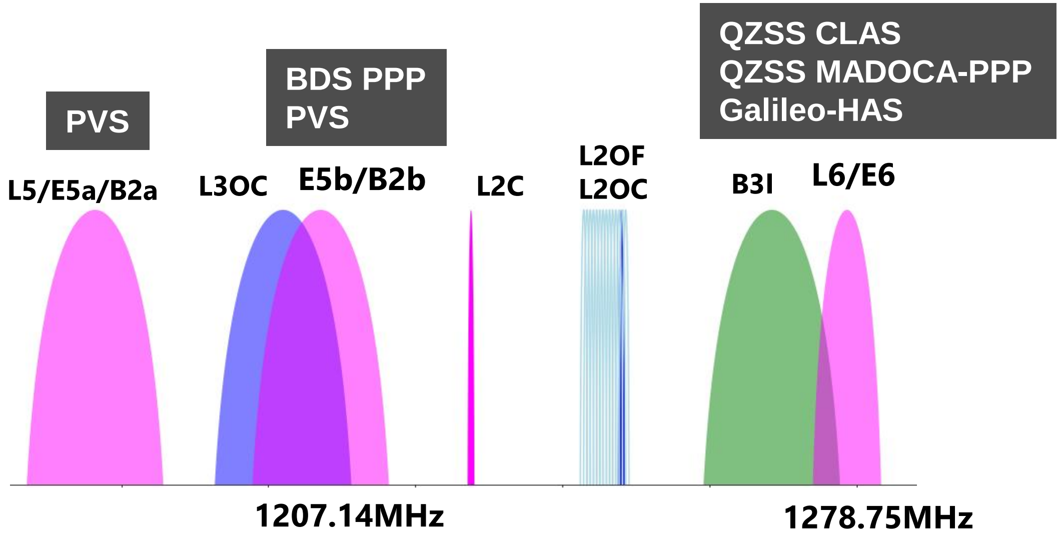
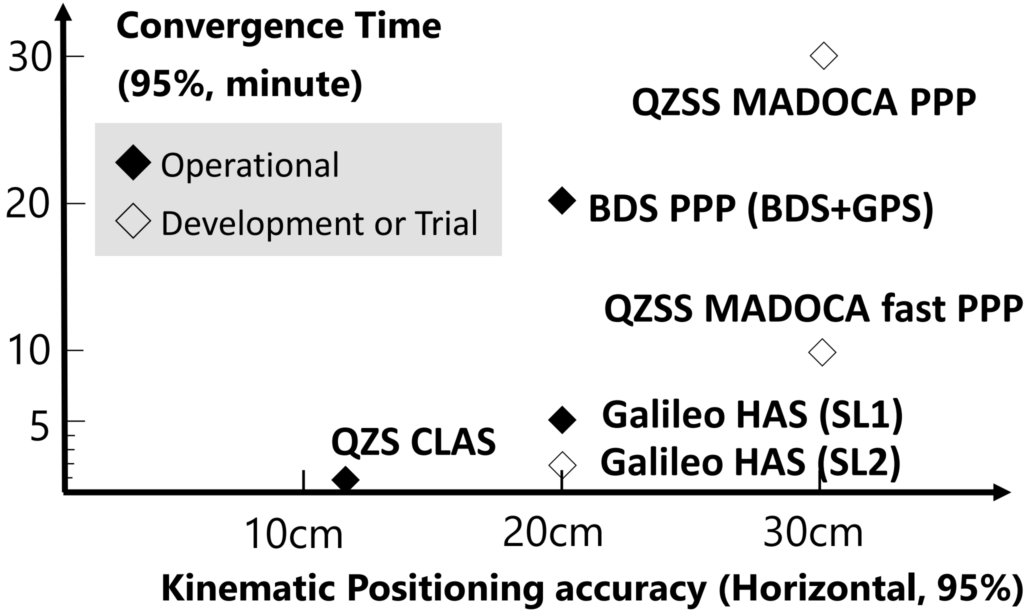
Changes for the Better

Open PPP/PPP-RTK services:

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

	QZSS CLAS	QZSS MADOCA-PPP	Galileo HAS	BDS PPP	PVS
Techniques	PPP-RTK	PPP	PPP	PPP	PPP
Data rate	1,695 bps	1,695 bps	448 bps	462 bps	500bps
Service Area	Japan	Asia/Oceania	Global (SL1) / Regional (SL2)	China	Australia/ NZ





Correction data provided by Open PPP/PPP-RTK services

	QZSS CLAS	QZSS MADOCA PPP	Galileo HAS	BDS PPP	PVS
Service	PPP-RTK	PPP	PPP	PPP	PPP
Format	CSSR	CSSR	Similar to CSSR	Customized CSSR	DFMC SBAS
Supported GNSS	G+E+J	G+E+R+J	G+E	G+C	G+E
Orbit	✓ (30sec)	✓ (30sec)	✓ (50sec)	✓ (48sec)	✓ (60sec)
Clock	✓ (5sec)	✓ (5sec)	✓ (10sec)	✓ (6sec)	✓ (60sec)
Code Bias	✓ (30sec)	✓ (30sec)	✓ (50sec)	✓ (48sec)	
Phase Bias	✓ (30sec)	✓ (30sec)			
Ionosphere	✓ (30sec)				
Troposphere	✓ (30sec)				
URA	✓ (30sec)				

RINEX signal code:

	QZSS CLAS	QZSS MADOCA PPP	Galileo HAS	BDS PPP
	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

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

No code bias for GPS

Sign convention in SSR correction

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

orbit

$$\boldsymbol{X}_{orbit} = \boldsymbol{X}_{broadcast} - \delta\boldsymbol{X}$$

$$\delta\boldsymbol{X} = \boldsymbol{A}\delta\boldsymbol{O} = [\boldsymbol{e}_r \quad \boldsymbol{e}_a \quad \boldsymbol{e}_c]\delta\boldsymbol{O}$$

$$\boldsymbol{e}_a = \frac{\dot{\boldsymbol{r}}}{|\dot{\boldsymbol{r}}|}, \boldsymbol{e}_c = \frac{\boldsymbol{r}\times\dot{\boldsymbol{r}}}{|\boldsymbol{r}\times\dot{\boldsymbol{r}}|}, \boldsymbol{e}_r = \boldsymbol{e}_a \times \boldsymbol{e}_c$$

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

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

$$\boldsymbol{X}_{ei} = \begin{bmatrix}cos(\omega_{ie}\Delta t_i) & -sin(\omega_{ie}\Delta t_i) & 0\\ sin(\omega_{ie}\Delta t_i) & cos(\omega_{ie}\Delta t_i) & 0\\ 0 & 0 & 1\end{bmatrix}\boldsymbol{X}_i \;, \Delta t_i = t_i - t$$

$$\boldsymbol{X}_{orbit,cg} = interpolate(\Delta t_i, \boldsymbol{X}_{ei})$$

$$\boldsymbol{e}_z = \frac{-\boldsymbol{r}}{|-\boldsymbol{r}|}, \boldsymbol{e}_s = \frac{\boldsymbol{r}_{sun} - \boldsymbol{r}}{|\boldsymbol{r}_{sun} - \boldsymbol{r}|}, \boldsymbol{e}_y = \frac{\boldsymbol{e}_z \times \boldsymbol{e}_s}{|\boldsymbol{e}_z \times \boldsymbol{e}_s|}, \boldsymbol{e}_x = \boldsymbol{e}_y \times \boldsymbol{e}_z$$

$$\boldsymbol{X}_{orbit} = \boldsymbol{X}_{orbit,cg} + [\boldsymbol{e}_x \quad \boldsymbol{e}_y \quad \boldsymbol{e}_z]\boldsymbol{d}_{offset}$$

clock

Clock-RINEX

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

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

$$\boldsymbol{X}_{orbit} = \boldsymbol{X}_{broadcast} - \delta\boldsymbol{X}$$

$$\delta\boldsymbol{X} = \boldsymbol{A}\delta\boldsymbol{O} = [\boldsymbol{e}_r \quad \boldsymbol{e}_a \quad \boldsymbol{e}_c]\delta\boldsymbol{O}$$

$$\boldsymbol{e}_a = \frac{\dot{\boldsymbol{r}}}{|\dot{\boldsymbol{r}}|}, \boldsymbol{e}_c = \frac{\boldsymbol{r} \times \dot{\boldsymbol{r}}}{|\boldsymbol{r} \times \dot{\boldsymbol{r}}|}, \boldsymbol{e}_r = \boldsymbol{e}_a \times \boldsymbol{e}_c$$

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

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

$$\boldsymbol{X}_{orbit} = \boldsymbol{X}_{broadcast} - \delta\boldsymbol{X}$$

$$\delta\boldsymbol{X} = \boldsymbol{A}\delta\boldsymbol{O} = [\boldsymbol{e}_r \quad \boldsymbol{e}_a \quad \boldsymbol{e}_c]\delta\boldsymbol{O}$$

$$\boldsymbol{e}_a = \frac{\dot{\boldsymbol{r}}}{|\dot{\boldsymbol{r}}|}, \boldsymbol{e}_c = \frac{\boldsymbol{r} \times \dot{\boldsymbol{r}}}{|\boldsymbol{r} \times \dot{\boldsymbol{r}}|}, \boldsymbol{e}_r = \boldsymbol{e}_a \times \boldsymbol{e}_c$$

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

clock

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

$$\delta C = C_0$$

code bias

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

phase bias

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

Sign convention in SSR correction

Galileo HAS IDD

RTCM 1059/1060, 1242/1243

orbit

$$\boldsymbol{X}_{orbit} = \boldsymbol{X}_{broadcast} - \delta\boldsymbol{X}$$

$$\delta\boldsymbol{X} = \boldsymbol{A}\delta\boldsymbol{O} = [\boldsymbol{e}_r \quad \boldsymbol{e}_a \quad \boldsymbol{e}_c]\delta\boldsymbol{O}$$

$$\boldsymbol{e}_a = \frac{\dot{\boldsymbol{r}}}{|\dot{\boldsymbol{r}}|}, \boldsymbol{e}_c = \frac{\boldsymbol{r}\times\dot{\boldsymbol{r}}}{|\boldsymbol{r}\times\dot{\boldsymbol{r}}|}, \boldsymbol{e}_r = \boldsymbol{e}_a \times \boldsymbol{e}_c$$

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

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

$$\boldsymbol{X}_{orbit} = \boldsymbol{X}_{broadcast} + \delta\boldsymbol{X}$$

$$\delta\boldsymbol{X} = \boldsymbol{A}\delta\boldsymbol{O} = [\boldsymbol{e}_r \quad \boldsymbol{e}_a \quad \boldsymbol{e}_c]\delta\boldsymbol{O}$$

$$\boldsymbol{e}_a = \frac{\dot{\boldsymbol{r}}}{|\dot{\boldsymbol{r}}|}, \boldsymbol{e}_c = \frac{\boldsymbol{r}\times\dot{\boldsymbol{r}}}{|\boldsymbol{r}\times\dot{\boldsymbol{r}}|}, \boldsymbol{e}_r = \boldsymbol{e}_a \times \boldsymbol{e}_c$$

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

clock

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

$$\delta C = C_0$$

code bias

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

phase bias

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

Sign convention in SSR correction

BDS PPP BDS-SIS-ICD-PPP-B2b-1.0

orbit $\boldsymbol{X}_{orbit} = \boldsymbol{X}_{broadcast} - \delta\boldsymbol{X}$

$$\delta\boldsymbol{X} = \boldsymbol{A}\delta\boldsymbol{O} = [\boldsymbol{e}_r \quad \boldsymbol{e}_a \quad \boldsymbol{e}_c]\delta\boldsymbol{O}$$

$$\boldsymbol{e}_r = \frac{\boldsymbol{r}}{|\boldsymbol{r}|}, \boldsymbol{e}_c = \frac{\boldsymbol{r}\times\dot{\boldsymbol{r}}}{|\boldsymbol{r}\times\dot{\boldsymbol{r}}|}, \boldsymbol{e}_a = \boldsymbol{e}_c \times \boldsymbol{e}_r$$

Different definition

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

clock $t_{sat} = t_{broadcast} - \delta C/c$ (Positive?)

$\delta C = C_0$

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

PVS SBAS-STN-0002

MT32 **orbit** $\boldsymbol{X}_{orbit} = \boldsymbol{X}_{broadcast} + \delta\boldsymbol{X}$

$$\delta\boldsymbol{X} = [\boldsymbol{e}_x \quad \boldsymbol{e}_y \quad \boldsymbol{e}_z]$$

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

$\delta C = C_0$

code bias (Group delay correction for GPS L1)

Analyzed the sign convention for Orbit/Clock/Bias correction

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

orbit	$\boldsymbol{X}_{orbit} = \boldsymbol{X}_{broadcast} +/- \delta\boldsymbol{X}$
clock	$t_{sat} = t_{broadcast} +/- \delta C/c$
code bias	$\widetilde{PR}_{corrected} = PR_{observed} +/- cbias$
phase bias	$\widetilde{CP}_{corrected} = CP_{observed} +/- pbias$

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

*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

Invalid and Do-Not-Use flag

- ✓ 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

Static Case on August 11, 2023 @ Kamakura, JAPAN (21:00-22:00 UTC)

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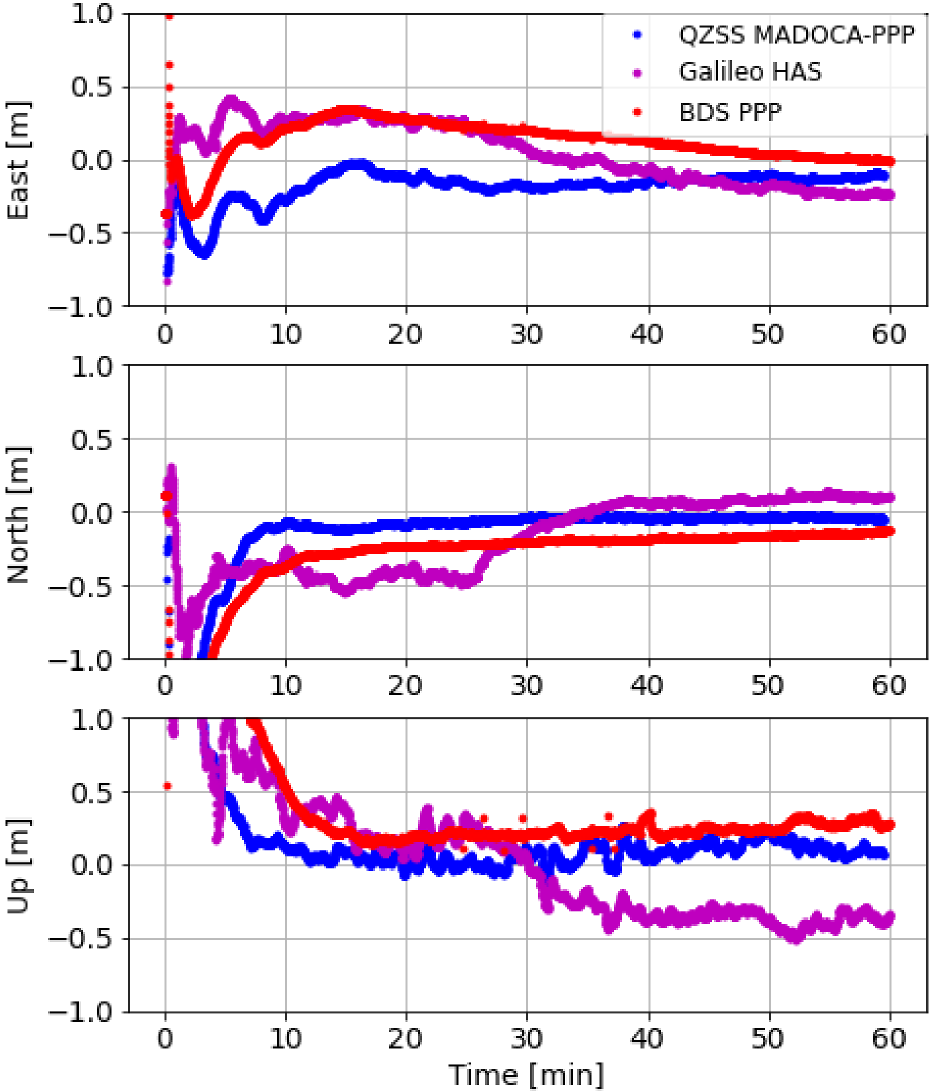
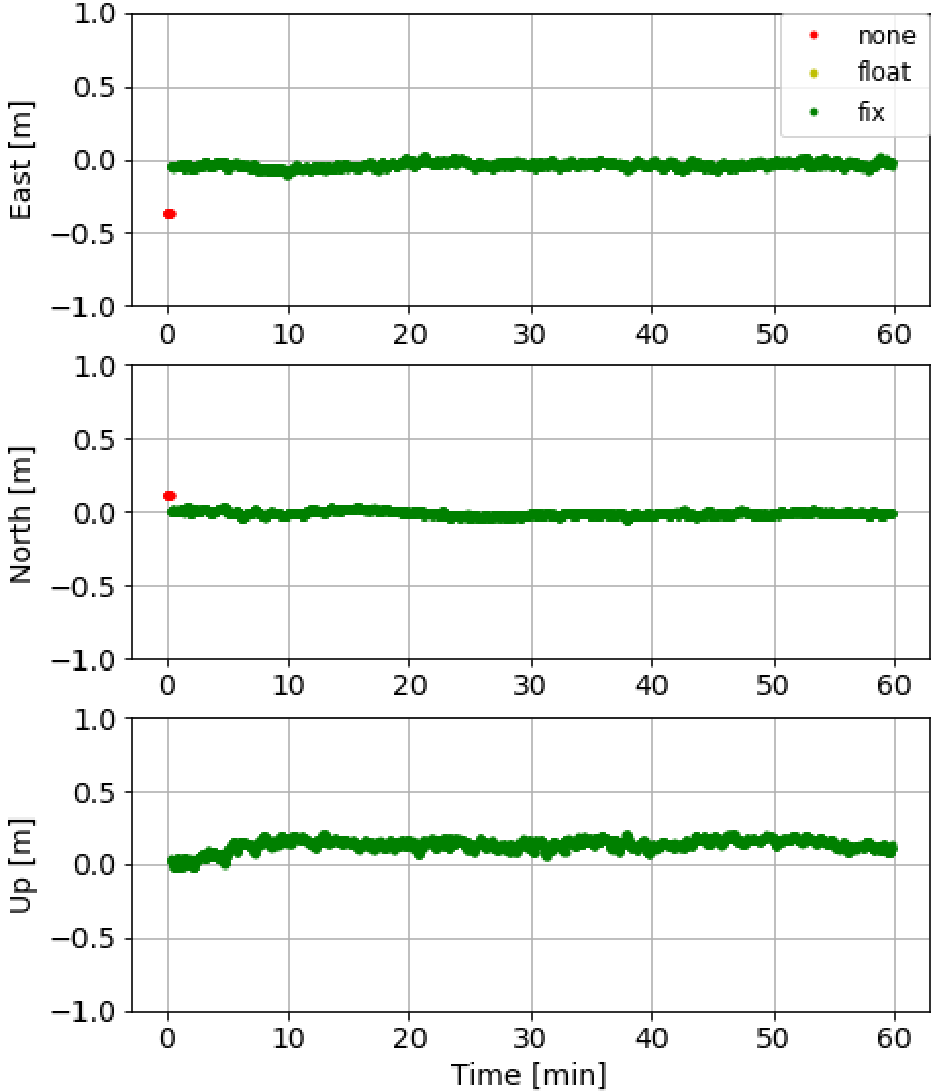
Note for Galileo HAS BDS PPP

Kamakura, Japan is currently outside of service area !

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



PPP-RTK: QZSS CLAS



Septentrio PolaRX5 + JAVAD RINGANT

10 Conclusion

- An open-source toolkit for PPP/PPP-RTK, CSSRlib was introduced.
  - ✓ Added experimental support for PVS/SBAS.
- 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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