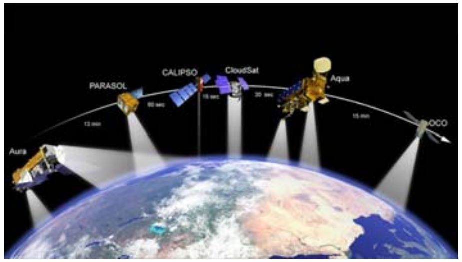

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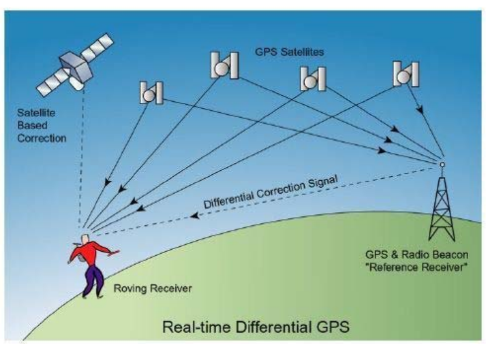
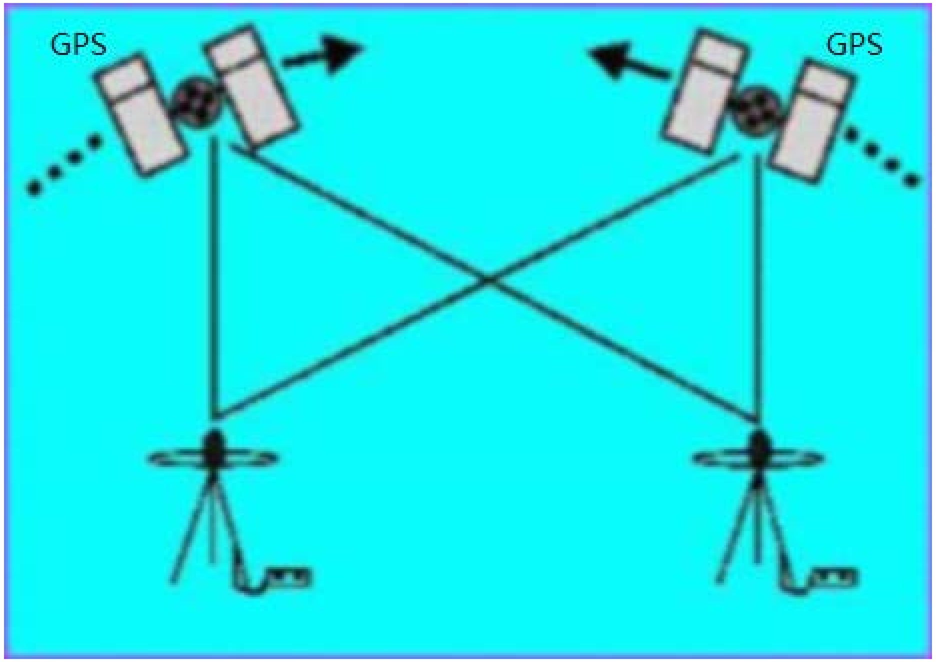
Analysis of Double-Differenced Multi-GNSS Inter-System Biases for Overlapping and Mixed Frequencies

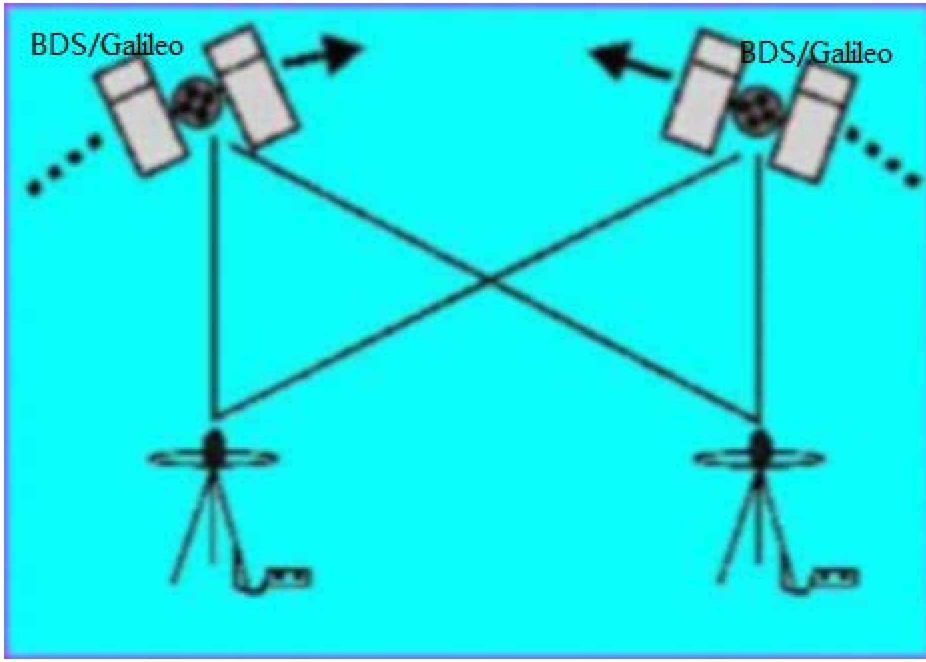
Never Stand Still

Shuyang Cheng, Wenhao Zhang and Jingling Wang



Double-difference measurement





Overlapping Frequency Scenario

$$P_{br,i}^{G0G} = \rho_{br}^{G0G} + \varepsilon_{br,pi}^{G0G}$$

$$L_{br,i}^{G0G} = \rho_{br}^{G0G} + \lambda_i N_{br,i}^{G0G} + \varepsilon_{br,Li}^{G0G}$$

$$P_{br,i}^{G0E} = \rho_{br}^{G0E} + D_{br,i}^{G0E} + \varepsilon_{br,pi}^{G0E}$$

$$L_{br,i}^{G0E} = \rho_{br}^{G0E} + \lambda_i (N_{br,i}^{G0E} + \varphi_{br,i}^{G0E}) + \varepsilon_{br,Li}^{G0E}$$

where G0 is the common GPS reference satellite

$$L_{br,i}^{G0E} = \rho_{br}^{G0E} + \lambda_i \left(N_{br,i}^{E0E} + N_{br,i}^{G0E0} + \varphi_{br,i}^{G0E}\right) + \varepsilon_{br,Li}^{G0E}$$

$$L_{br,i}^{G0E} = \rho_{br}^{G0E} + \lambda_i \left(N_{br,i}^{E0E} + \emptyset_{br,i}^{G0E}\right) + \varepsilon_{br,Li}^{G0E}$$

Odijk and Teunissen (2013)

Mixed Frequency Scenario

$$P_{br,i}^{G0G} = \rho_{br}^{G0G} + \varepsilon_{br,pi}^{G0G}$$

$$L_{br,i}^{G0G} = \rho_{br}^{G0G} + \lambda_i N_{br,i}^{G0G} + \varepsilon_{br,Li}^{G0G}$$

where G0 is the common GPS reference satellite

$$P_{br,i}^{G0C} = \rho_{br}^{G0C} + D_{br,i}^{G0C} + \varepsilon_{br,pi}^{G0C}$$

$$L_{br,i}^{G0C} = \rho_{br}^{G0C} + \lambda_i^C \varphi_{br,i}^{G0C} + \lambda_i^C N_{br,i}^{G0C} + \left(\lambda_i^C - \lambda_i^G\right) N_{br,i}^{G0} + \varepsilon_{br,Li}^{G0C}$$

$$L_{br,i}^{G0C} = \rho_{br}^{G0C} + \lambda_i^C \varphi_{br,i}^{G0C} + \lambda_i^C N_{br,i}^{G0C0} + \lambda_i^C N_{br,i}^{C0C} + \left(\lambda_i^C - \lambda_i^G\right) N_{br,i}^{G0} + \varepsilon_{br,Li}^{G0C}$$

$$L_{br,i}^{G0C} = \rho_{br}^{G0C} + \lambda_i^C (N_{br,i}^{C0C} + \emptyset_{br,i}^{G0C}) + \varepsilon_{br,Li}^{G0C}$$

Continuity of Estimable DD ISB

GPS pivot satellite changes from $G0$ to $G1$ between two consecutive epochs T_0 and T_1

$$\emptyset_{br,i}^{G0C}(T_0) = \varphi_{br,i}^{G0C} + N_{br,i}^{G0C0} + (1 - \lambda_i^G/\lambda_i^C)N_{br,i}^{G0}$$

$$\emptyset_{br,i}^{G0C}(T_1) = \varphi_{br,i}^{G0C} + N_{br,i}^{G1C0} + (1 - \lambda_i^G/\lambda_i^C)N_{br,i}^{G1}$$

$$\widetilde{\emptyset}_{br,i}^{G0C}(T_1) = \emptyset_{br,i}^{G0C}(T_1) - (1 - \lambda_i^G/\lambda_i^C)N_{br,i}^{G0G1}$$

$$= \varphi_{br,i}^{G0C} + N_{br,i}^{G1C0} + (1 - \lambda_i^G/\lambda_i^C)\left[\left(N_{br,i}^{G1} - \left(N_{br,i}^{G1} - N_{br,i}^{G0}\right)\right)\right]$$

$$= \varphi_{br,i}^{G0C} + N_{br,i}^{G1C0} + (1 - \lambda_i^G/\lambda_i^C)\, N_{br,i}^{G0}$$

(Gao et al. 2017)

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Multi-GNSS signals used in this study

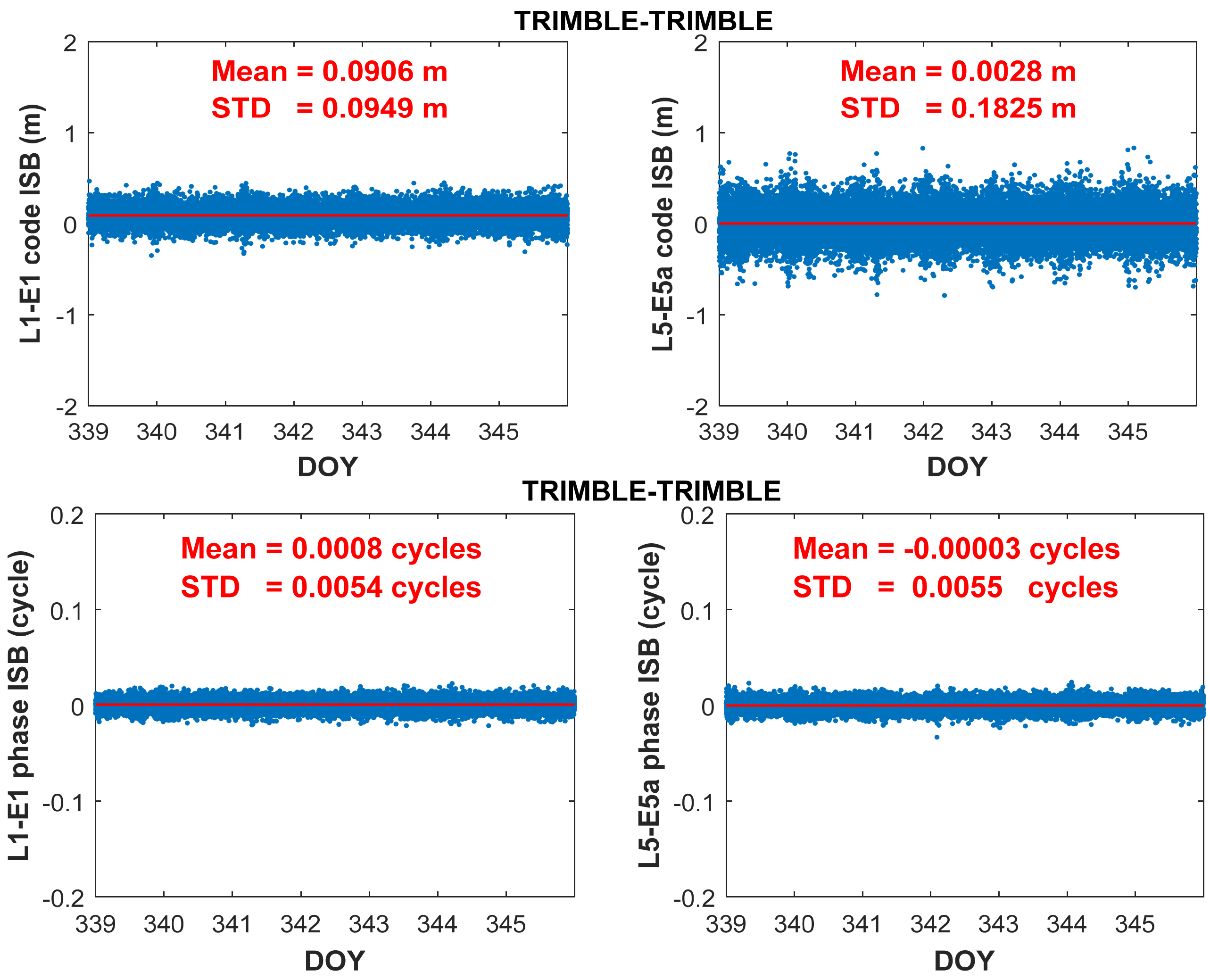
GNSS constellation	Band	Frequency (MHz)
GPS	L1	1575.420
	L2	1227.600
	L5	1176.450
Galileo	E1	1575.420
	E5a	1176.450
BDS	B1	1561.098
	B2	1207.140

Information of baselines used in the experiments

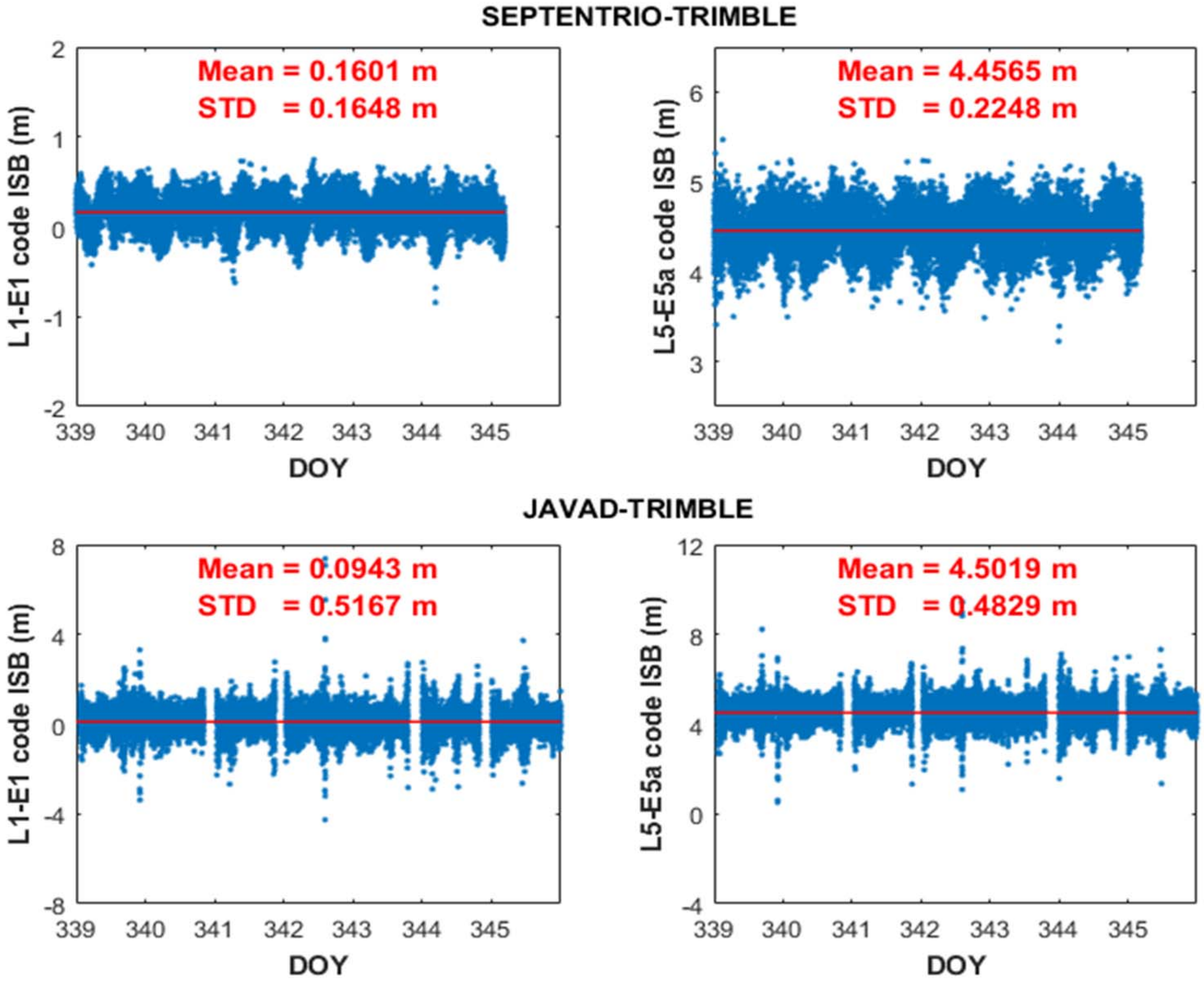
Baseline	Base Receiver Type	Rover Receiver Type	Baseline Length / m
CUT0-CUT2	TRIMBLE NETR9	TRIMBLE NETR9	0
CUT0-CUT1	TRIMBLE NETR9	SEPTENTRIO POLARX4	0
CUT0-CUAA	TRIMBLE NETR9	JAVAD TRE_G3TH_8	8.42

All the stations use the same type of antenna: 'TRM 59800.00 SCIS'.

Time series of GPS-Galileo (L1-E1 and L5-E5a) code/phase ISBs for the baseline with the same receiver type: ‘TRIMBLE



Time series of GPS-Galileo (L1-E1 and L5-E5a) code ISBs for the baselines with different receiver types: 'SEPTENTRIO-TRIMBLE' and 'JAVAD-TRIMBLE'



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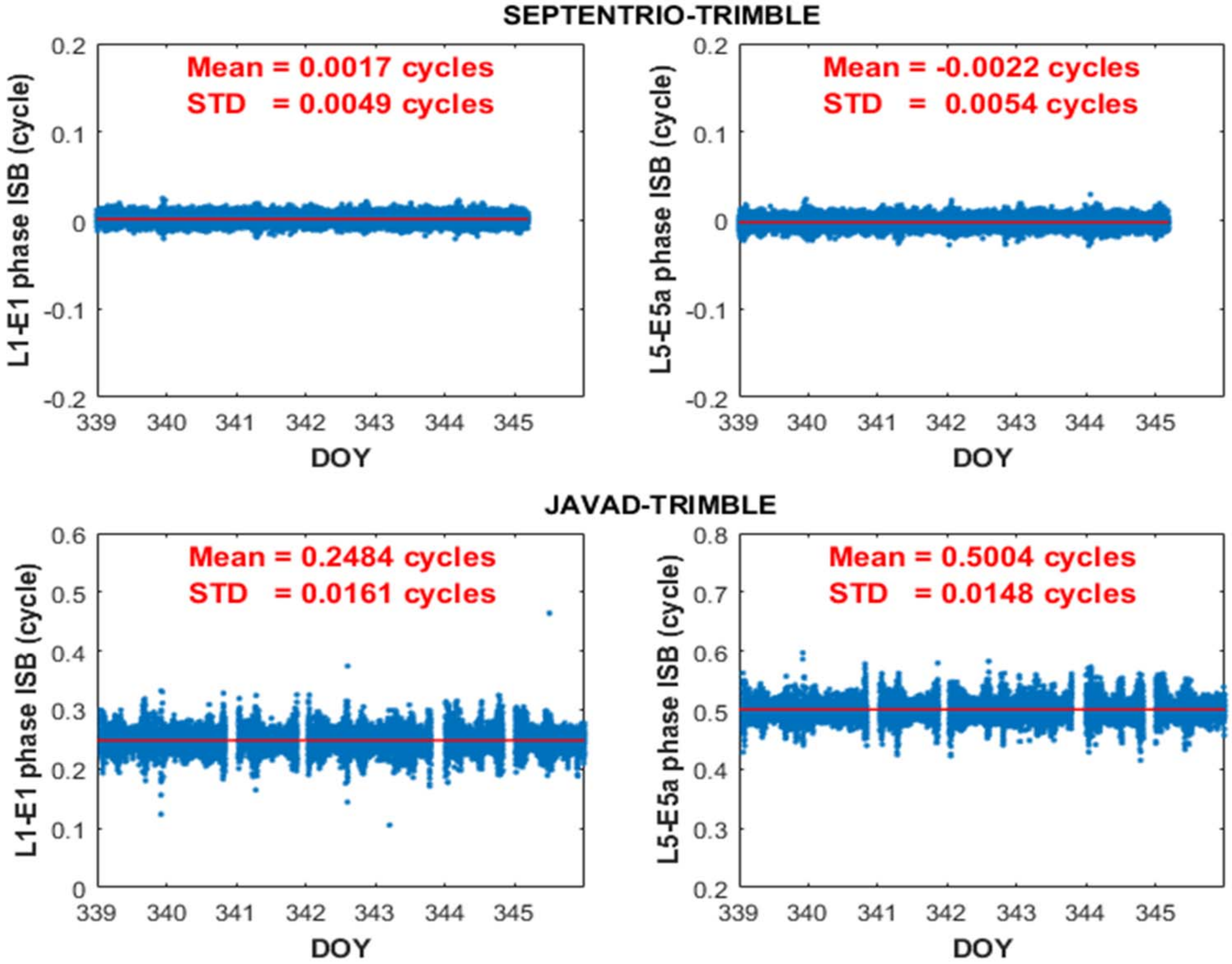
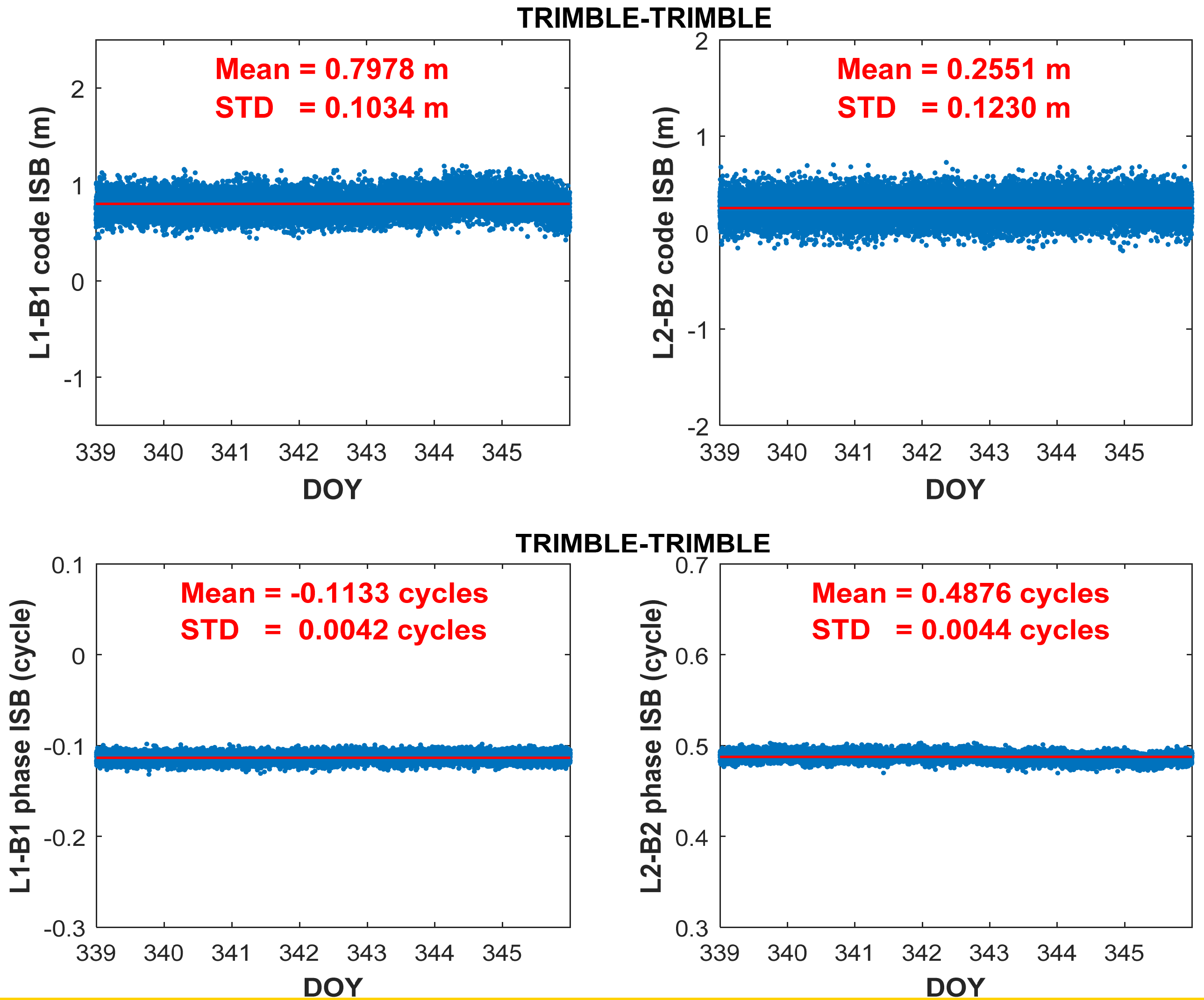
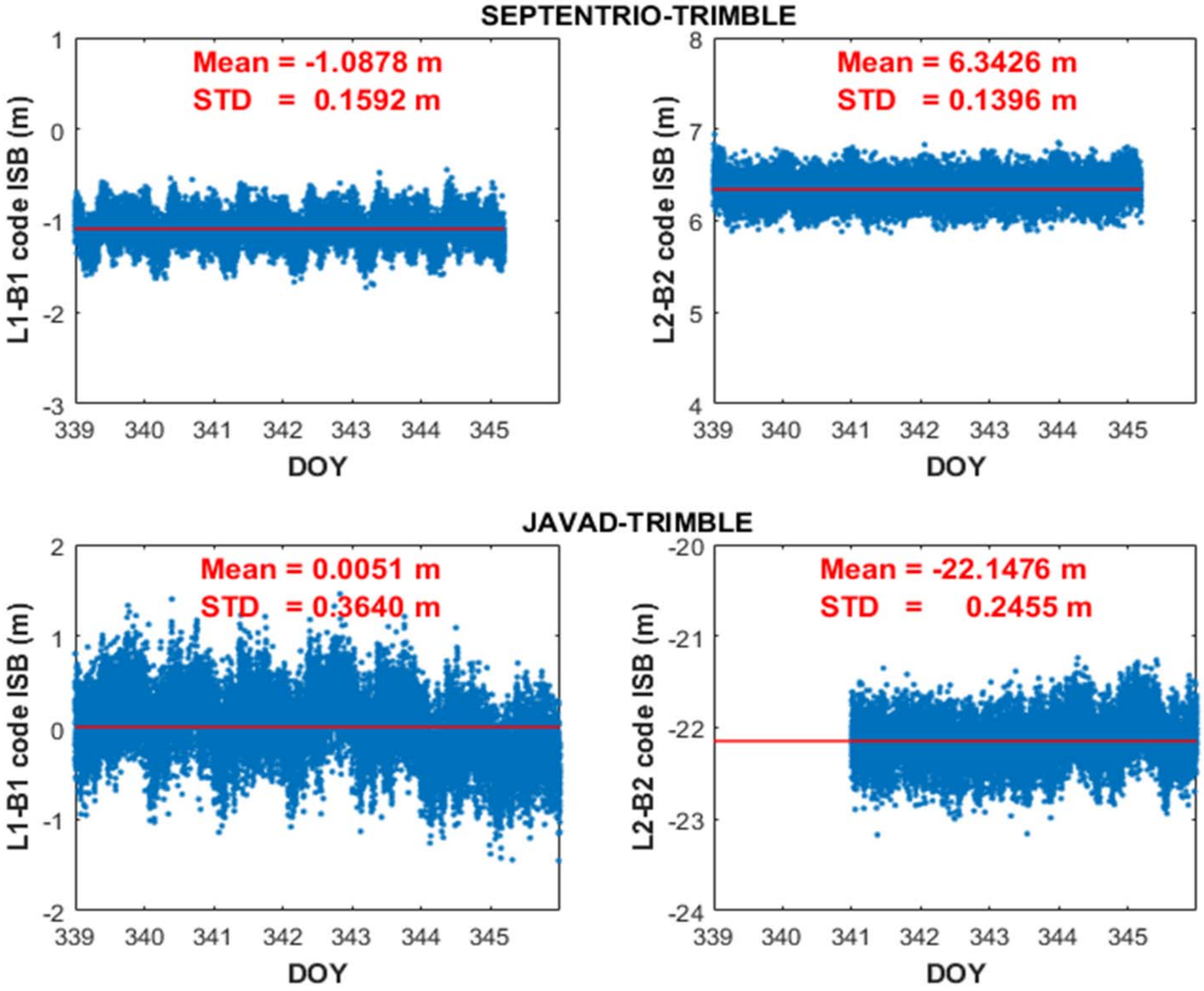
Time series of GPS-Galileo (L1-E1 and L5-E5a) phase ISBs for the baselines with different receiver types: ‘SEPTENTRIO-TRIMBLE’ and ‘JAVAD-TRIMBLE’



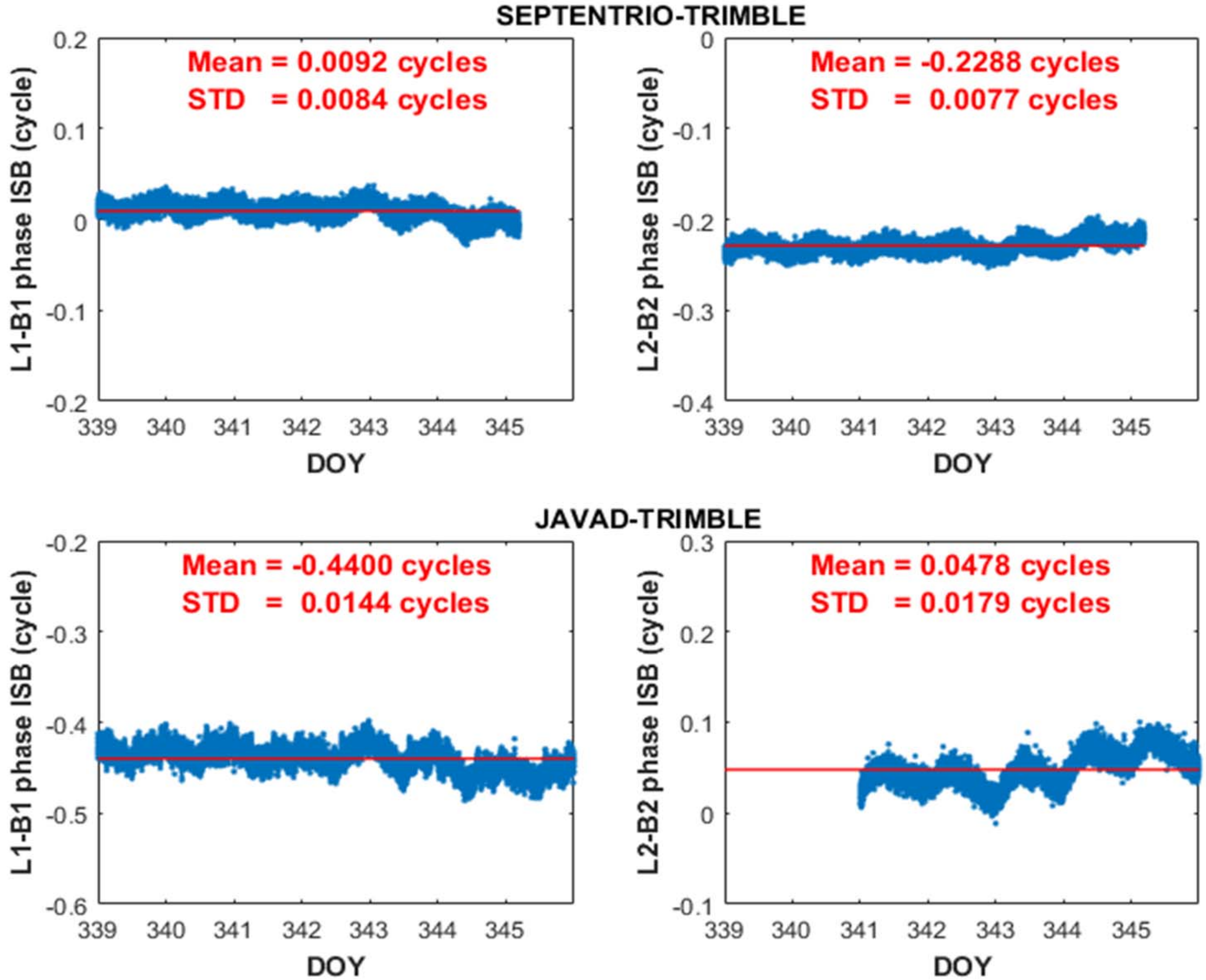
Time series of GPS-BDS (L1-B1 and L2-B2) code/phase ISBs for the baseline with the same receiver type: ‘TRIMBLE’



Time series of GPS-BDS (L1-B1 and L2-B2) code ISBs for the baselines with different receiver types: 'SEPTENTRIO-TRIMBLE' and 'JAVAD-TRIMBLE'



Time series of GPS-BDS (L1-B1 and L2-B2) phase ISBs for the baselines with different receiver types: ‘SEPTENTRIO-TRIMBLE’ and ‘JAVAD-TRIMBLE’



CONCLUSIONS

- In this study we have proposed the procedure to estimate multi-GNSS code and carrier phase ISBs
- We investigate the magnitude and stability of DD ISBs for both overlapping and mixed frequencies of different GNSS constellations using identical and different receiver types.
- For a baseline with same type receivers, ISBs have long-term stability for both overlapping and mixed frequencies.
- For a baseline with different receiver types, the GPS-BDS ISBs may have small variations which can be properly modelled in real-time estimation.

References

- Evans JD, Featherstone WE (2000) Improved convergence rates for the truncation error in geoid determination, *Journal of Geodesy* 74(5): 239-248
- Gao W, Gao C, Pan S, Meng X, Xia Y (2017) Inter-System Differencing between GPS and BDS for Medium-Baseline RTK Positioning, *Remote Sensing* 9(9), 948
- Gibbons G (2006) GNSS Interoperability: Achieving a Global System of Systems or "Does Everything Have to Be the Same?", *Inside GNSS* 1(1): 57-60
- Li X, Zhang X, Ren X, Fritsche M, Wickert J, Schuh H (2015) Precise positioning with current multi-constellation Global Navigation Satellite Systems: GPS, GLONASS, Galileo and BeiDou, *Scientific Reports* 5: 8328
- Liu H, Shu B, Xu L, Qian C, Zhang R, Zhang M (2017) Accounting for Inter-System Bias in DGNSS Positioning with GPS/GLONASS/BDS/Galileo, *The Journal of Navigation* 70(4): 686-698
- Nadarajah N, Teunissen PJG, Sleewaegen JM, Montenbruck O (2015) The mixed-receiver BeiDou inter-satellite-type bias and its impact on RTK positioning, *GPS Solutions* 19(3): 357–368
- Odijk D, Teunissen PJG (2013) Characterization of between receiver GPS-Galileo inter-system biases and their effect on mixed ambiguity resolution, *GPS Solutions* 17(4): 521–533
- Odolinski R, Teunissen PJG, Odijk D (2015) Combined BDS, Galileo, QZSS and GPS single-frequency RTK, *GPS Solutions* 19(1): 151–163
- Paziewski J, Wielgosz P (2015) Accounting for Galileo-GPS inter-system biases in precise satellite positioning, *Journal of Geodesy* 89(1): 81–93
- Wu M, Zhang X, Liu W, Ni S, Yu S (2017) Tightly Combined BeiDou B2 and Galileo E5b Signals for Precise Relative Positioning, *The Journal of Navigation* 70(6): 1253-1266