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GNSS Carrier Phase ISD time-frequency transfer accuracy evaluation

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Abstract

Due to the influence of pseudo-range noise, traditional GNSS common view method is difficult to improve the accuracy of time-frequency transfer. GNSS carrier phase precise point positioning (PPP) time-frequency transfer has become a research hotspot because of its high accuracy. In this paper, a time-frequency transfer model of GNSS carrier phase single difference (SD) and Integer Single Difference (ISD) between any two ground stations is studied. In order to solve the problem that the SD ambiguity cannot be fixed due to the influence of the phase biases at the receivers, a method of SD ambiguity fixing is proposed, that is the SD ambiguity is fixed with the constraint of the fixed double difference ambiguity among several stations and satellites. Here taking four time-frequency links between pairs of ground stations, BRUX-OPMT (262.3km), BRUX-PTBB (454.6km), BRUX-WTZR (637.7km) and BRUX-CEBR (1331.6km) as examples, the multi-GNSS time-frequency transfer experiment of SD, ISD and PPP method is carried out. The results show that the SD and PPP time-frequency transfer accuracy is equivalent, the stability of ISD is improved compared with SD, and the difference RMS between epochs is less than 10 ps. High precision carrier phase SD, ISD and PPP technology can be applied to the study of determining the gravity potential based on time-frequency measurements.

Methods

➤ GNSS Observation model

$$\begin{cases} P_{r,j}^{S,i} = \rho_r^{S,i} + cdt_r^S - cdt_j^{S,i} + MF_r^{S,i} ZWD_r + \gamma_j^S I_{r,j}^{S,i} + d_{r,j}^{S,i} - d_j^{S,i} + \varepsilon_{other} + \zeta_j^{S,i} \\ L_{r,j}^{S,i} = \rho_r^{S,i} + cdt_r^S - cdt_j^{S,i} + MF_r^{S,i} ZWD_r - \gamma_j^S I_{r,j}^{S,i} + \lambda_j^{S,i} (N_j^{S,i} + b_{r,j}^{S,i} - b_j^{S,i}) + \varepsilon_{other} + \xi_j^{S,i} \end{cases} \quad (1)$$

➤ Precise point positing (PPP) model

$$\begin{bmatrix} p_{r,IF}^{S,i} \\ l_{r,IF}^{S,i} \end{bmatrix} = \begin{bmatrix} \mathbf{g}_r^{S,i} & 1 & MF_r^{S,i} & 0 \\ \mathbf{g}_r^{S,i} & 1 & MF_r^{S,i} & \lambda_{IF}^{S,i} \end{bmatrix} \begin{bmatrix} \mathbf{x}_r \\ \tilde{cdt}_r^S \\ ZWD_r \\ \tilde{N}_{r,IF}^{S,i} \end{bmatrix} + \begin{bmatrix} \zeta_{IF}^{S,i} \\ \xi_{IF}^{S,i} \end{bmatrix} \quad (2)$$

➤ Single difference (SD) model

$$\begin{bmatrix} \Delta p_{rb,IF}^{S,i} \\ \Delta l_{rb,IF}^{S,i} \end{bmatrix} = \begin{bmatrix} -\mathbf{g}_r^{S,i} & 1 & MF_b^{S,i} & -MF_r^{S,i} & 0 \\ -\mathbf{g}_r^{S,i} & 1 & MF_b^{S,i} & -MF_r^{S,i} & \lambda_{IF}^{S,i} \end{bmatrix} \begin{bmatrix} \mathbf{x}_r \\ \tilde{dt}_{rb}^S \\ ZWD_b \\ ZWD_r \\ \Delta \tilde{N}_{rb,IF}^{S,i} \end{bmatrix} + \begin{bmatrix} \Delta \zeta_{IF}^{S,i} \\ \Delta \xi_{IF}^{S,i} \end{bmatrix} \quad (3)$$

➤

➤ Integer single difference (ISD) model

$$\begin{bmatrix} \Delta p_{rb,IF}^{S,i} \\ \Delta l_{rb,IF}^{S,i} \\ \Delta \nabla \tilde{N}_{rb,IF}^{S,ik} \end{bmatrix} = \begin{bmatrix} -\mathbf{g}_r^{S,i} & 1 & MF_b^{S,i} & -MF_r^{S,i} & 0 & 0 \\ -\mathbf{g}_r^{S,i} & 1 & MF_b^{S,i} & -MF_r^{S,i} & \lambda_{IF}^{S,i} & 0 \\ 0 & 0 & 0 & 0 & 1 & -1 \end{bmatrix} \begin{bmatrix} \mathbf{x}_r \\ \tilde{dt}_{rb}^S \\ ZWD_b \\ ZWD_r \\ \Delta \tilde{N}_{rb,IF}^{S,i} \\ \Delta \tilde{N}_{rb,IF}^{S,k} \end{bmatrix} + \begin{bmatrix} \Delta \zeta_{IF}^{S,i} \\ \Delta \xi_{IF}^{S,i} \\ 0 \end{bmatrix} \quad (4)$$

Experiment analysis

Table 1 List of selected MGEX stations.

Stations	Receiver type	Antenna type	Clock	Country	Distance (km)
BRUX	SEPT POLARX5TR	JAVRINGANT_DM	UTC (ORB)	Belgium	/
OPMT	ASHTECH Z-XII3T	3S-02-TSADM	UTC(OP)	France	262.3
PTBB	SEPT POLARX5TR	LEIAR25.R4	UTC (PTB)	Germany	454.6
WTZR	LEICA GR50	LEIAR25.R3	H-MASER	Germany	637.7
CEBR	SEPT POLARX5TR	SEPCHOKE_B3E6	H-MASER	Spain	1331.6

Table 2 Details of processing strategies.

Items	Strategies
Solutions	DF-IF PPP/SD/IPPP/ISD
Observations	GPS: L1/L2; Galileo: E1/E5a; BDS: B1I/B3I; GLONASS: L1/L2
Elevation cut-off	7-degrees
Satellite orbit & clock	GBM and GRG precise products
Satellite DCB	CAS BSX products (Zhang et al., 2018)
Earth rotation	Corrected (Petit et al., 2010)
Relativistic effect	Corrected (Kouba, 2009)
Phase windup effect	Corrected (Wu et al., 1992)
Tide effect	Solid Earth, pole and ocean tide (Petit & Luzum, 2010)
Satellite and receiver antenna	IGS14.atx
Station coordinates	Estimated as constants
Receiver clock	Estimated as white noises
	Dry component: Saastamoinen model (Saastamoinen, 1973)
Tropospheric delay	Wet component: estimated as random part. GMF mapping function (Böhm et al., 2006)
Ambiguities	Estimated as constant

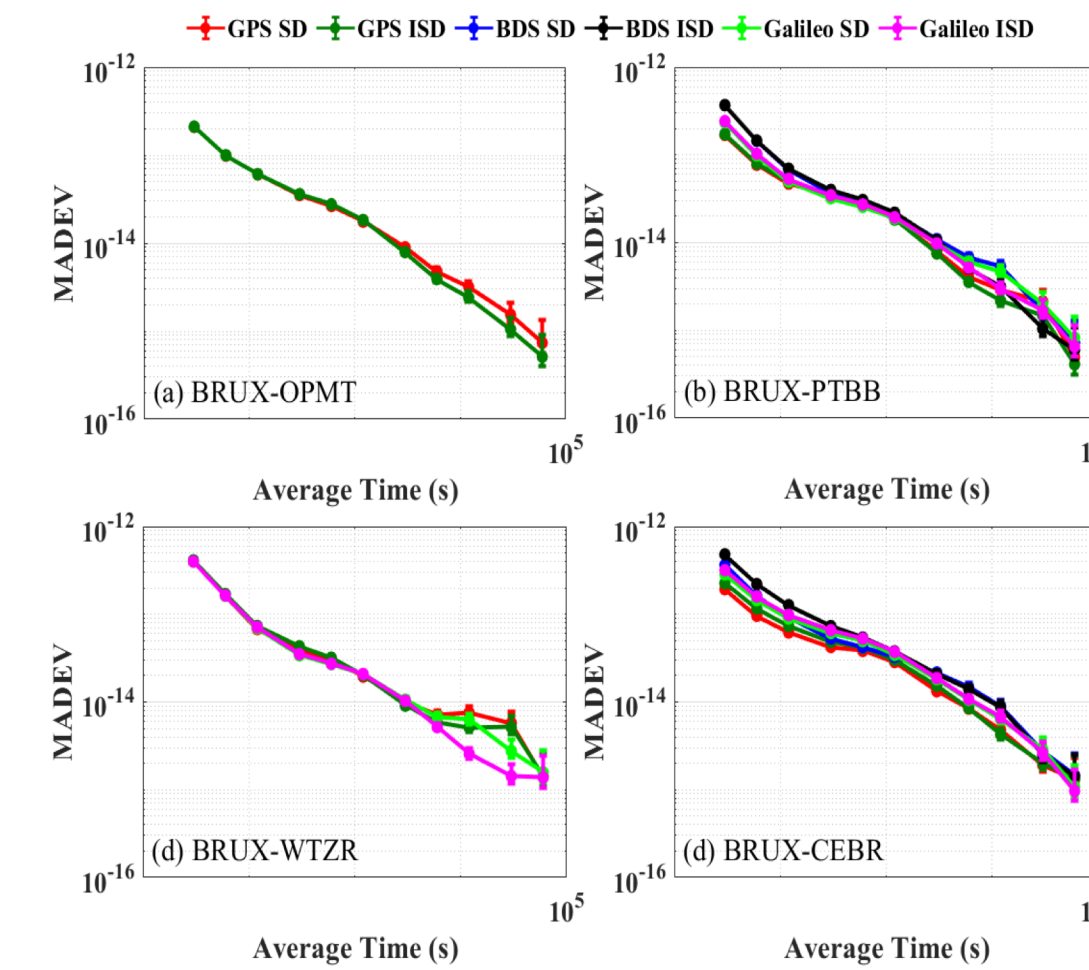


Fig. 1 MADEV of four time-frequency links for ISD and SD solution. (a) BRUX-OPMT k; (b) BRUX-PTBB; (c) BRUX-WTZR; (d) BRUX-CEBR.

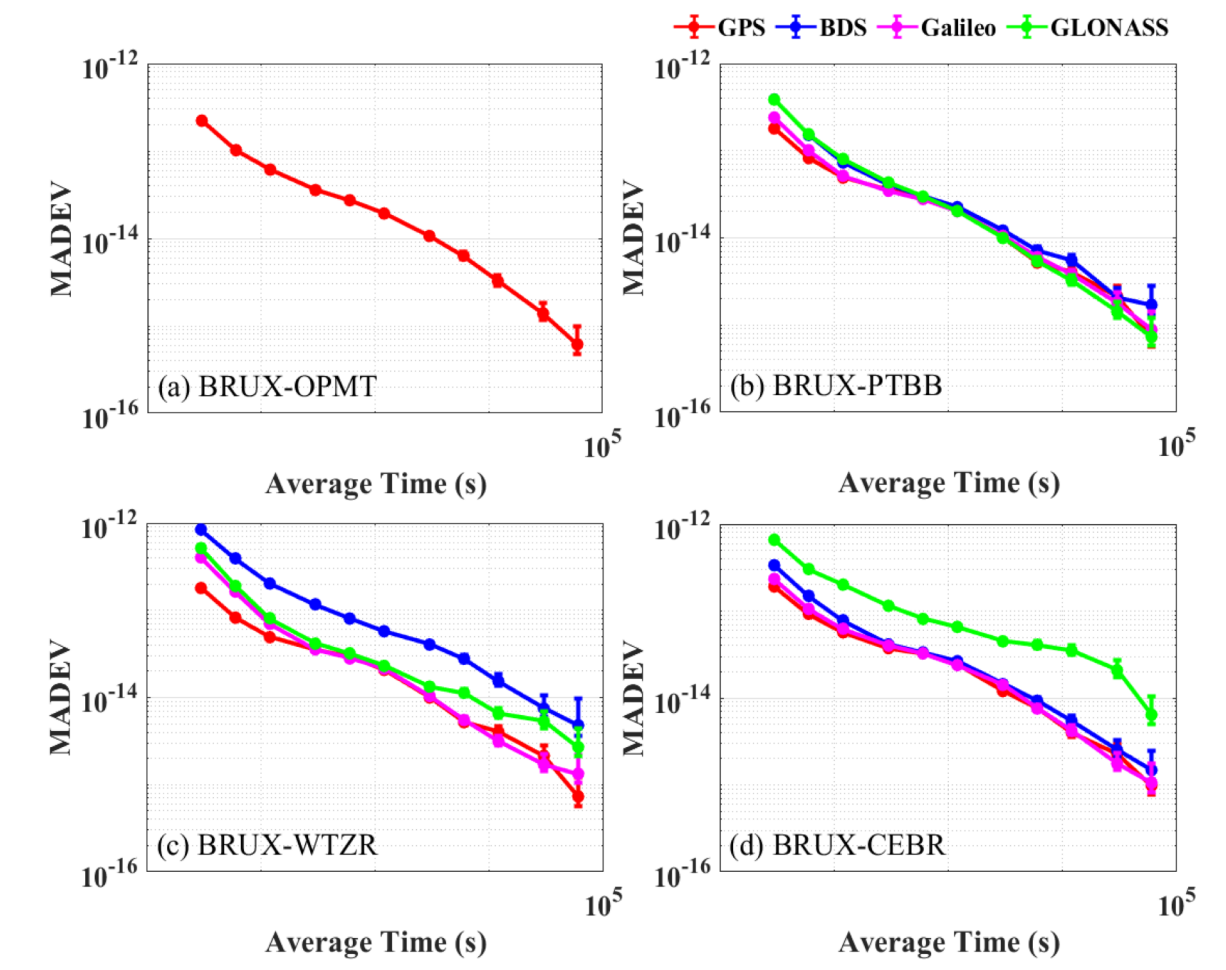


Fig. 2 MADEV of four time-frequency links for PPP solution. (a) BRUX-OPMT k; (b) BRUX-PTBB; (c) BRUX-WTZR; (d) BRUX-CEBR.

Table 3 Improvement percentage of GPS, BDS2/BDS3 and Galileo ISD compared with SD time-frequency transfer MADEV from DOY 189 to 193 in 2020 (%)

Tau	BRUX-OPMT			BRUX-PTBB			BRUX-WTZR			BRUX-CEBR		
	G	C	E	G	C	E	G	C	E	G	C	E
3,000	11.80	—	—	6.09	2.36	-0.03	10.05	—	2.90	13.85	3.52	3.15
6,000	18.45	—	—	12.23	24.76	14.46	18.69	—	24.07	1.35	5.52	4.86
12,000	23.95	—	—	25.46	40.87	36.20	32.10	—	59.43	3.67	2.55	4.45
30,000	31.41	—	—	30.36	37.05	17.34	10.24	—	48.34	5.38	9.11	7.13
60,000	30.55	—	—	16.71	16.54	20.54	-2.12	—	12.78	3.55	2.36	11.42

Table 4 Clock offset epoch difference at four time-frequency links for GPS, BDS2/BDS3, Galileo and GLONASS by SD solution from DOY 189 to 193 in 2020 (ps)

Time links	GPS	BDS2/BDS3	Galileo	GLONASS
BRUX-OPMT	0.02 ± 5.80	—	—	—
BRUX-PTBB	-0.01 ± 4.73	0.01 ± 9.81	-0.01 ± 6.21	-0.04 ± 10.01
BRUX-WTZR	0.94 ± 10.29	—	0.97 ± 10.20	0.93 ± 13.17
BRUX-CEBR	7.33 ± 9.23	7.27 ± 12.48	7.36 ± 9.81	7.66 ± 16.41

Conclusions

- With ambiguity-fixed solution, the frequency stability in time-frequency transfer can reach sub-10⁻¹⁶ level after five days of average.
- Compared with the results of the SD with ambiguity float solution, the short-term frequency stability in time-frequency transfer has no significant improvement, but the long-term frequency stability in time-frequency transfer based on ISD is increased by 15.90 % on average.

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