Enhancing Beidou PPP Ambiguity Resolution through Tight Integration between BDS-2 and BDS-3

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1. Motivation

Over the past two decades, precise point positioning (PPP) has gained widespread recognition for its remarkable ability to achieve centimeter-level accuracy. Assuredly, rapid convergence is still underexplored. Beidou has been complete for several years since 2020. The maximization of BDS utilization is a crucial aspect of establishing a comprehensive PNT system. However, the existing discrepancies between BDS-2 and BDS-3 are tricky obstacles that make the two generation constellations incompatible. GNSS users generally assign BDS satellites from different generations to separate systems in data processing, so that the positioning capabilities beyond those of BDS cannot be fully exploited. In order to facilitate PPP (especially BDS-only) convergence by enlarging the set of candidate ambiguities, the present contribution concentrates on the approach of tight integration (TI) between BDS-2 and BDS-3 constellations and explores how TI enhances the BDS-only positioning performance. Fig.1 delineates the overall algorithm architecture of phase bias estimation and ambiguity resolution under the TI strategy.

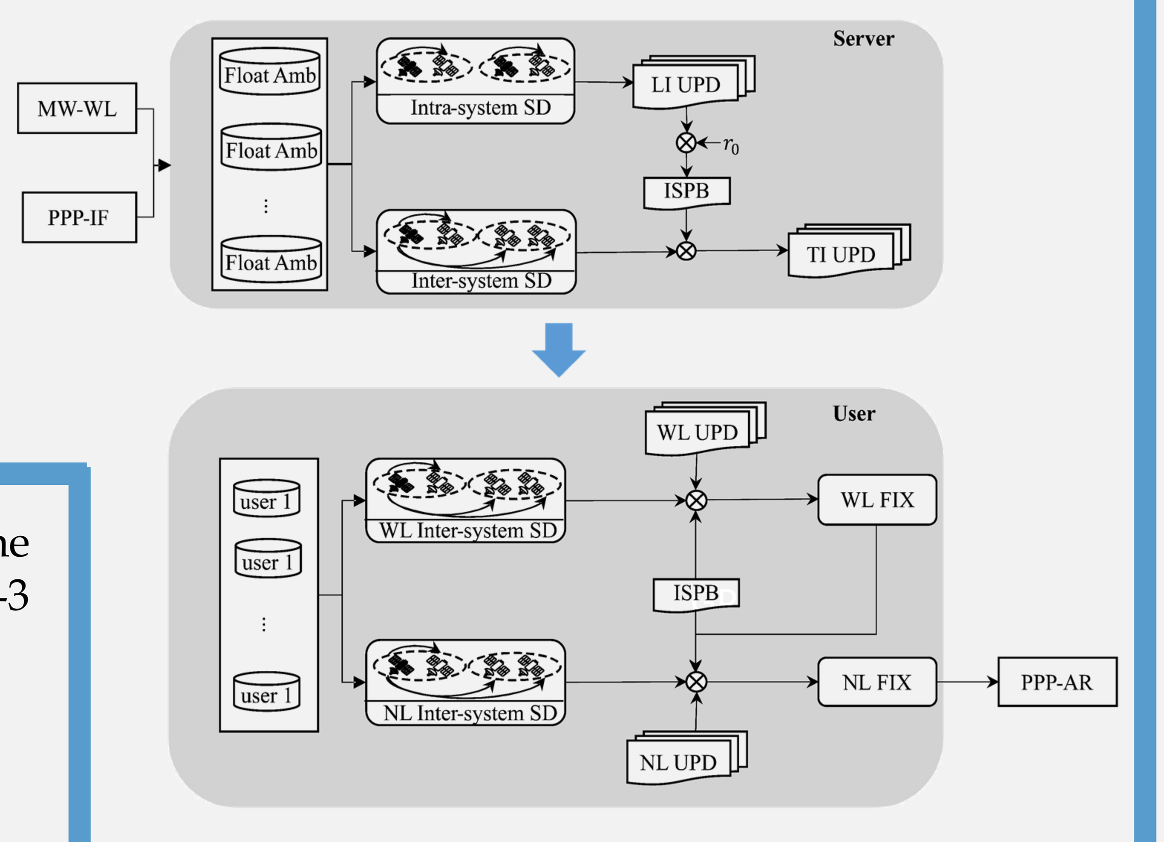

Fig. 1 The overall algorithm architecture of TI model

2. Tight Integration Model

Take WL as an illustrative instance, if we construct SD ambiguity within the BDS-2 and BDS-3 satellites like:

$$\Delta\mathcal{N}_{r,wl}^{ij,32} = \mathcal{N}_{r,wl}^{i,3} - \mathcal{N}_{r,wl}^{j,2} - (b_{wl}^{i,3} - b_{wl}^{j,2})$$
$$= \Delta\breve{\mathcal{N}}_{r,wl}^{ij,32} - (b_{wl}^{ij,32} + \vartheta_{r,iswb}^{32})$$

It is evident that, in addition to the UPD, the SD ambiguity also contains an extra fractional bias namely inter-system phase bias (ISPB), and therefore, it still lacks integer nature. Thanks to the consistency of ISPB intra the system, pure UPD can be extracted from the separate system first.

$$b_{r,wl}^{2} = \frac{1}{n2}\sum_{s=1}^{n2}[(\mathcal{N}_{r,wl}^{s,2} + b_{wl}^{s,2}) - [\![\mathcal{N}_{r,wl}^{s,2} + b_{wl}^{s,2}]\!]]$$

$$b_{r,wl}^{3} = \frac{1}{n3}\sum_{s=1}^{n3}[(\mathcal{N}_{r,wl}^{s,3} + b_{wl}^{s,3}) - [\![\mathcal{N}_{r,wl}^{s,3} + b_{wl}^{s,3}]\!]]$$

Specify a common reference station, ISPB can be obtained subsequently.

$$\vartheta_{r,iswb}^{32} = \Delta b_{rr_0,wl}^{2} - \Delta b_{rr_0,wl}^{3}$$

Once the ISWB corrections of all the stations are obtained, the tightly integrated WL UPD estimation model for BDS-2 and BDS-3 can be constructed as follows:

$$\begin{cases} \mathcal{N}_{r,wl}^{s,2} = \mathcal{N}_{r,wl}^{s,2} + b_{r,wl}^{3} - (b_{wl}^{s,2} + \vartheta_{r,iswb}^{32}) \\ \mathcal{N}_{r,wl}^{s,3} = \mathcal{N}_{r,wl}^{s,3} + b_{r,wl}^{3} - b_{wl}^{s,3} \end{cases}$$

The ISPB for NL can also be obtained in a similar manner; it will not be elaborated here.

3. Bias Evaluation

- The discrepancies do exist between BDS-2 and BDS-3 at the receiver end. Widelane and narrowlane ISPB std hovering around 0.05 cycles (shown in Fig.2 and Fig.3). Therefore, ISPB can be directly determined as a constant for each day.
- ISPB distinguishes among stations based on receiver type, firmware version, and antennas and domes. It is preferable to estimate ISPB station by station.
- Only after ISPB is precalibrated can UPD residuals in the manner of TI reach the level of the LI (loose integration).

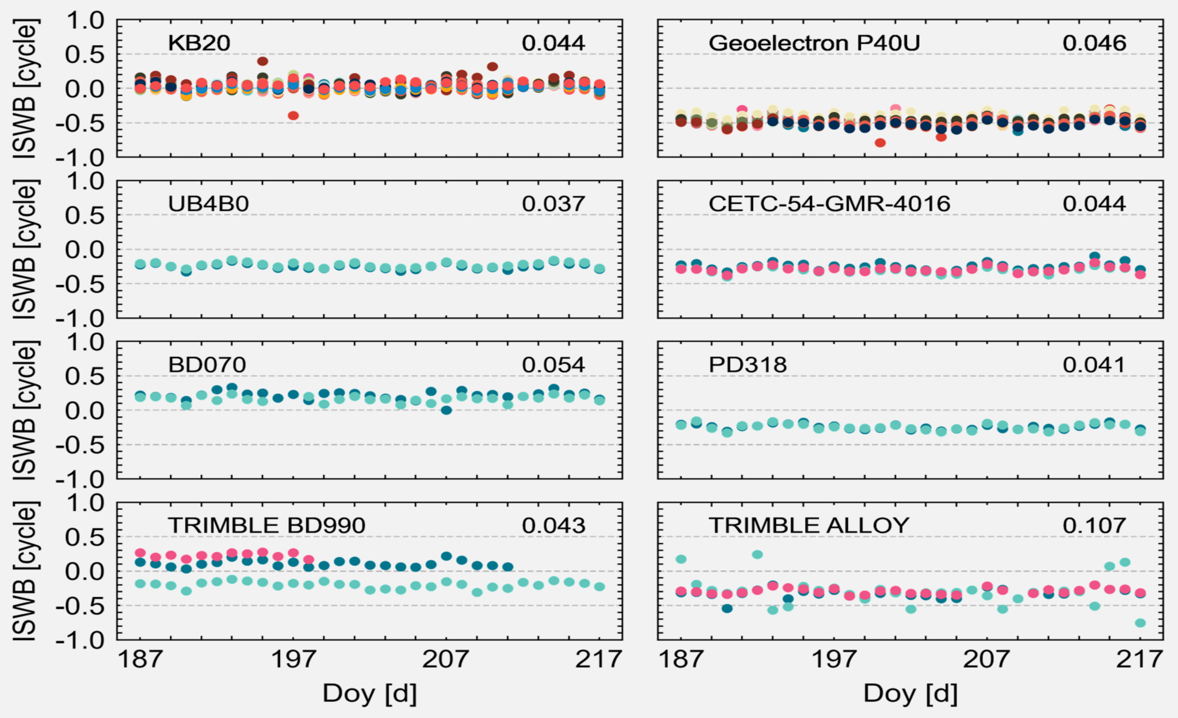

Fig. 2 Widelane ISPB series across a month. One station with a KB20 receiver was assigned as a reference station.

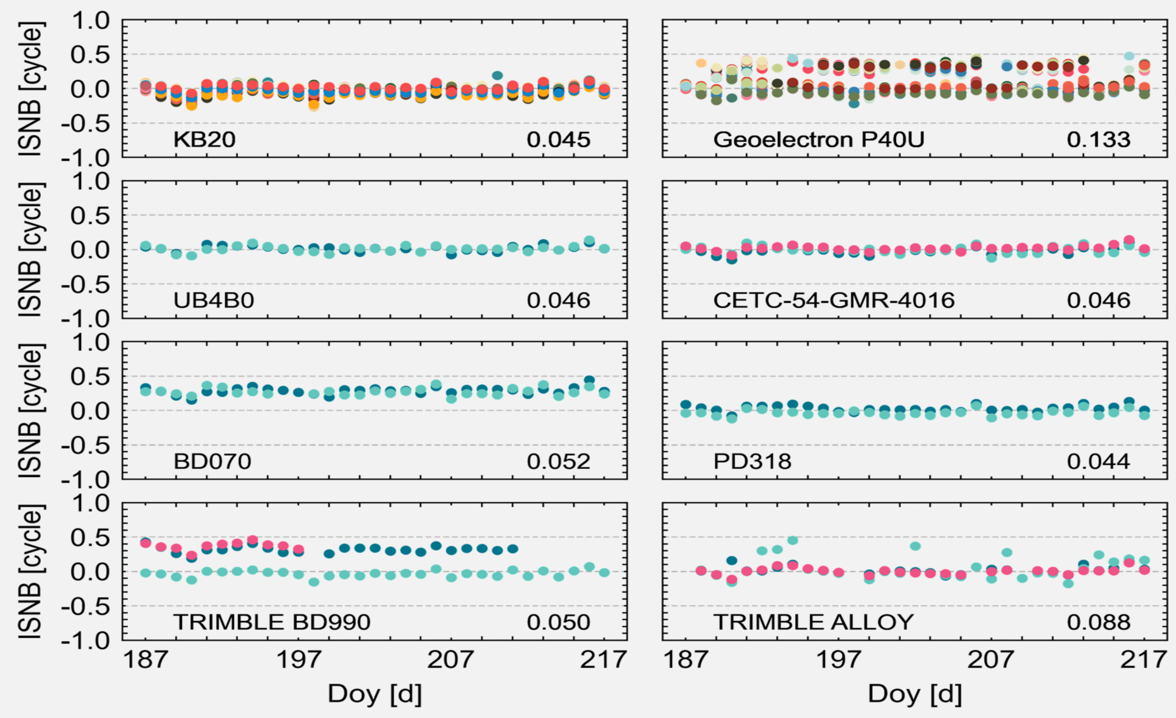

Fig. 3 Narrowlane ISPB series across a month. One station with a KB20 receiver was assigned as a reference station.

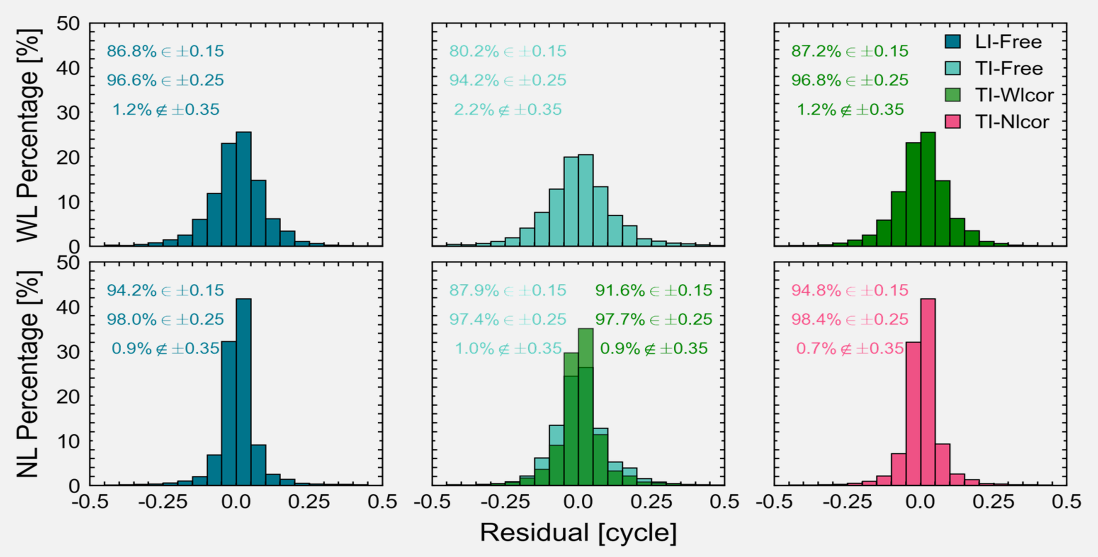

Fig.4 Distribution of widelane and narrowlane UPD residuals in the different schemes

4. Positioning Performance

- **In an open environment**,
  TI strategy needs 990/840/1170s for BDS-only convergence (5 cm of horizontal, 10 cm of vertical), which has certain advantages over LI in the early stage of convergence, being 13.2%, 9.7%, and 7.1% faster than LI-Free in the E/N/U directions and can speed up the convergence and positioning accuracy of user stations. After convergence, the positioning accuracy of all strategies is almost close to the same, with E/N/U being 0.8/0.6/1.6 cm respectively.
- **In the obstructed scenarios**,
  the advantages of the TI strategy are highlighted. While effectively ensuring positioning availability, TI approach can significantly improve positioning performance, which cannot be achieved via intra-system PPP-AR. This provides a reference for positioning in certain rejection areas.

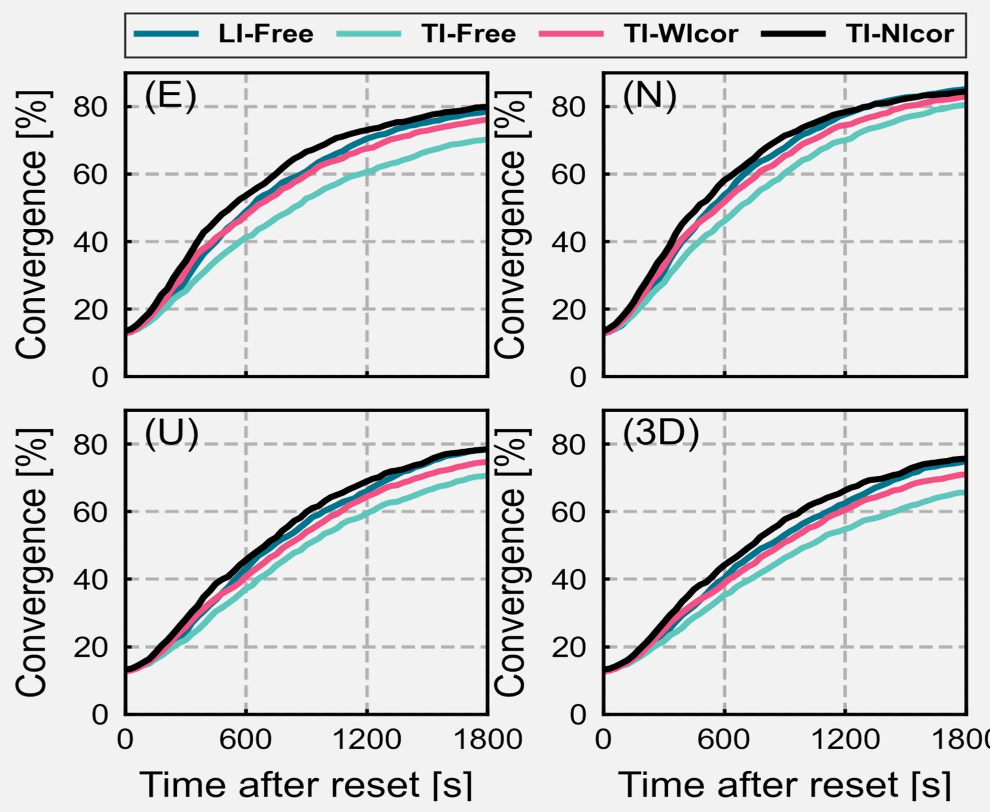

Fig.4 Convergence percentages and time after reset for arcs of 70 station across a month in open environment

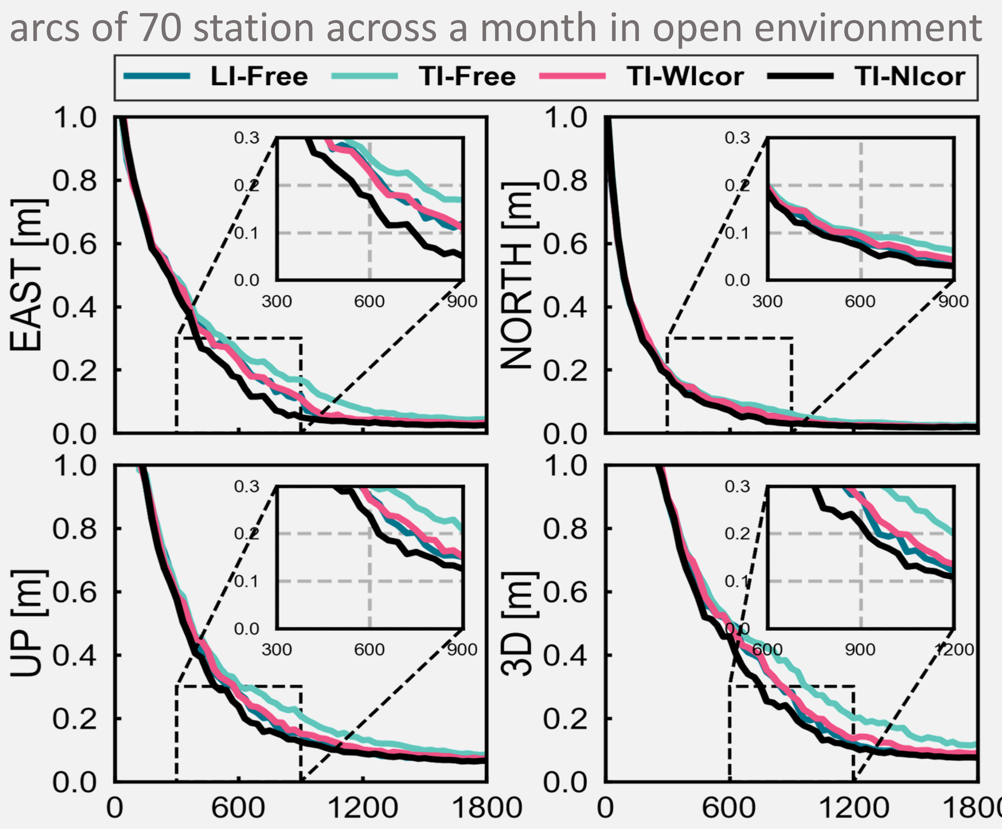

Fig.5 Positioning error and time after reset of the 68-percentile arcs 70 station across a month in open environment

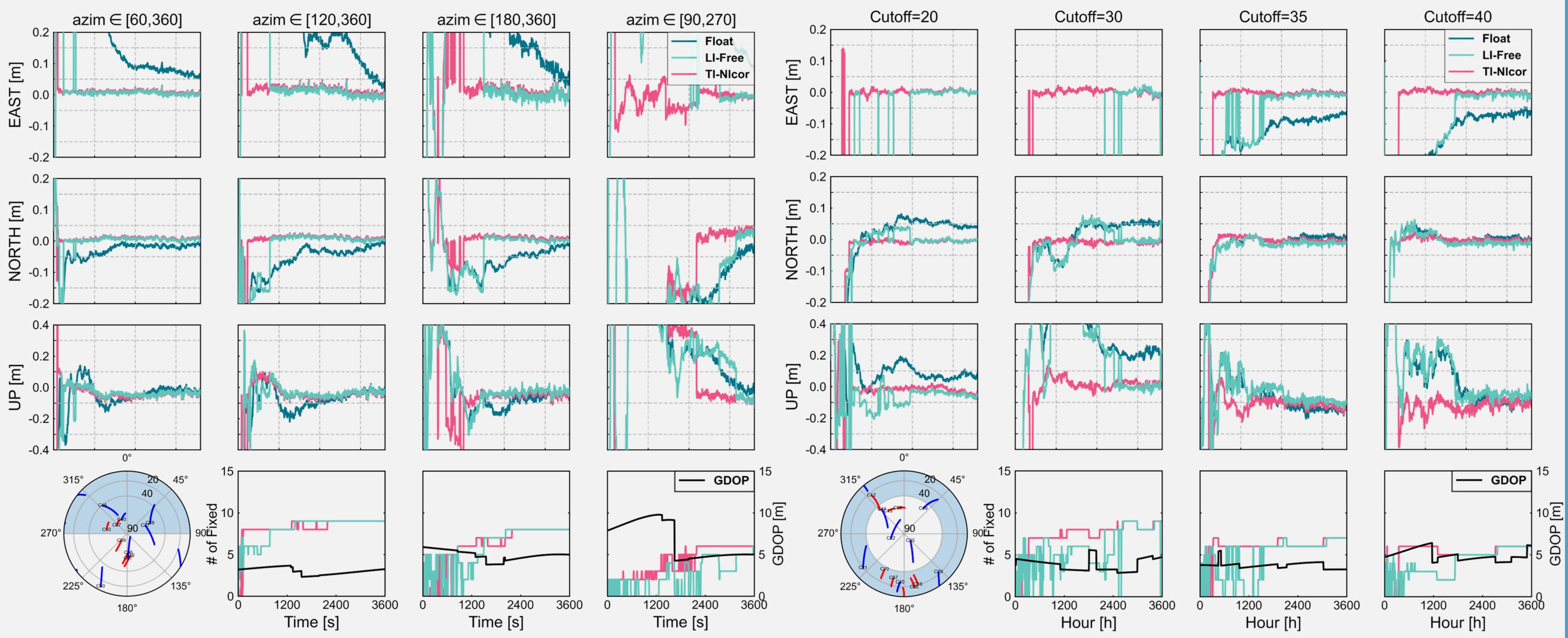

Fig.6 Typical 1-hour convergence series of PPP-AR in the monitoring scenario (left is elevation obstructed, right is azimuth obstructed). The first three rows display the positioning error series, while the last row records the fixed number of each AR strategy and the geometric dilution of precision (GDOP) series for the last three schemes. The most extreme skyplot is drawn in the lower left corner.

5. Conclusion

The tight integration strategy has the potential to yield at least one additional resolvable candidate ambiguity, theoretically enhancing the probability of successful PPP ambiguity resolution. With the correction of ISPB, the accuracy of the UPD under TI strategy is significantly improved in the server end. Regarding the PPPAR performance in an open area, the TI strategy has certain advantages over the LI strategy in the early stage of convergence. Moreover, the advantages of the TI strategy are highlighted in an extremely obstructed scenario. TI can significantly enhance positioning performance and ensure positioning availability, which cannot be achieved in the manner of LI PPP-AR. Overall, the TI strategy can facilitate the compatibility and integration between BDS-2 and BDS-3, leading to enhanced positioning performance.

6. Acknowledgement

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