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Differential inter-system biases estimation and performance assessment of tightly combined RTK with BDS-3, GPS, and Galileo

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By the end of 2018, China has successfully launched 19 new generation BDS-3 satellites, including 18 Medium Earth Orbit (MEO) satellites in operation and one Geostationary Earth Orbit (GEO) satellite under in-orbit test, to complete a primary system for providing global services. In addition to the backward BDS-2 compatible B1I (1561.098 MHz) and B3I (1269.520 MHz) signals, the new-generation BDS-3 satellites are also capable of broadcasting new B1C (1575.42 MHz) and B2a (1176.45 MHz) open service navigation signals that overlap with the GPS/Galileo L1-E1 and L5-E5a signals, which brings opportunity for the tightly combined processing or inter-system double-differencing of observations from BDS-3, GPS, and Galileo. In this presentation, for the first time we assess the interoperability of BDS-3 B1C/B2a signals with GPS/Galileo L1-E1/L5-E5a signals for tightly combined real-time kinematic (RTK) positioning using real data collected in Wuhan, China. First, the characteristics of BDS-3 B1C/B2a signals and its comparison with GPS/Galileo L1-E1/L5-E5a signals is evaluated in terms of observed carrier-to-noise density ratio, pseudorange multipath and noise, and double-differenced carrier phase and code residuals. It is demonstrated that the observational quality of BDS-3 B1C/B2a signals is comparable to that of GPS/Galileo L1-E1/L5-E5a signals. Then, we investigate the size and stability of phase and code differential inter-system bias (DISB) between BDS-3/GPS/Galileo B1C-L1-E1/B2a-L5-E5a signals using zero or short baseline data collected with receivers with both identical and different types. It is verified that the BDS-3/GPS/Galileo DISBs are indeed close to zero when identical types of receivers are used at both ends of a baseline. Moreover, they are generally present and stable in the time domain for baselines with different receiver types, which can be easily calibrated and corrected in advance. Finally, performance of single-epoch tightly combined BDS-3/GPS/Galileo RTK with single-frequency and dual-frequency observations was evaluated by a formal as well as an empirical analysis, consisting of ambiguity dilution of precision (ADOP), bootstrapped success rate (BSR), the empirical ambiguity resolution success rate, and the positioning accuracy. Experimental results from static and kinematic tests demonstrate that whether the combination is BDS-3/GPS, BDS-3/Galileo or BDS-3/GPS/Galileo, the tightly combined model (TCM) can deliver much higher BSR and lower ADOP with respect to the classical loosely combined model (LCM). Meanwhile, the empirical ambiguity resolution success rate and positioning accuracy were remarkably improved as well, especially under poor observational environments where the observed satellites for each system are limited and only single-frequency observations are available. In such cases, the improvement of the empirical ambiguity resolution success rate can reach up to approximately 10%∼50%.