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Editorial

Editorial for the Special Issue: “High-Precision GNSS: Methods, Open Problems and Geoscience Applications”

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In the past two decades, the high-precision Global Positioning System (GPS) has significantly increased the range of geoscience applications and their precision. Currently, it is one of two fully operational Global Navigation Satellite Systems (GNSS), and two more are in the implementation stage. The new European Galileo and Chinese BeiDou Navigation Satellite System (BDS) already provide usable signals, and both GPS and GLONASS are currently undergoing significant modernization, which adds more capacity, more signals, better accuracy, and interoperability, etc.

Meanwhile, there has been significant technological development in GNSS equipment (in some cases, even at low-cost), which is now able to collect measurements at much higher rates (up to 100 Hz), thus presenting new possibilities. On the one hand, the new developments in GNSS offer a broad range of new applications for solid and fluid Earth investigations, in both post-processing and real-time; on the other, this results in new problems and challenges in data processing that increase the need for GNSS research. Algorithmic advancements are needed to address the opportunities and challenges in enhancing the accuracy, availability, interoperability, and integrity of high-precision GNSS applications.

This special issue aims to provide an overview of the potential of high-precision GNSS for geoscience applications. Besides discussing the current developments in high-precision GNSS constellations, signals and algorithms devoted to Precise Point Positioning (PPP) and Precise Orbit Determination (POD), the special issue focuses on the use of high-precision GNSS in diverse geoscience applications, in terms of geodynamics, seismology, tsunamis, ionosphere, troposphere, etc. An overview of the contributions in this special issue is given in the following paragraphs.

Since December 2018, the third generation of BDS (BDS-3) started to provide global-coverage positioning, navigation and timing (PNT) services. The studies conducted on the new BDS satellites and redesigned signals have indicated that the signal in space range error (SISRE) of BDS-3 is superior to that of BDS-2 [1] and the atomic clock has better frequency stability than GPS BLOCK IIF satellites [2]. Among the four open service BDS signals B1I, B1C, B2a and B3I, the ionosphere-free (IF) combination of B1C-B2a was recommended for precise GNSS data processing in regard to the noise amplitude and compatibility with other GNSS. Further research demonstrated that 50%–60% improvements in position accuracy in the east component could be obtained by performing PPP ambiguity resolution (AR) with BDS and Galileo triple-frequency observations, with respect to those achievable with the float solution [3]. Besides the discussion of developments in the GNSS in this special issue, five currently available satellite-based augmentation systems (SBASs) were also evaluated in terms of their orbit, clock and ionosphere corrections [4].

Several studies included in this special issue are dedicated to the advancement of GNSS algorithms and models. Qu et al. [5] proposed a modified least-squares collocation algorithm (LSC) by combining the distance scale factor and adaptive adjustment. The new LSC algorithm better reflects the characteristics of GPS crustal movement and was thus valuable for analysis of regional tectonic dynamics. Wei et al. [6] presented a new cycle slip detection and repair approach for high-dynamic low-earth-orbit (LEO) satellites by making use of second-order time-difference geometry-free (STG) phase combinations. Understanding the characteristics of diverse biases in GNSS data processing is crucial for the refinement of current GNSS algorithms and models. Wu et al. [7] investigated, for the first time, the size and stability of phase and code differential inter-system bias (ISB) between BDS-3/GPS/Galileo for tightly combined real-time kinematics (RTK). The characteristics of atmosphere and broadcast ephemeris errors in short baseline RTK were also systematically analyzed in [8]. In regard to code bias, the time-varying characteristic of the GPS differential code bias (DCB) was investigated using triple-frequency observations in [9]. As for the phase bias, Wang et al. [10] constructed a new computationally efficient ambiguity acceptance test with a controllable success fix rate, namely, the fixed likelihood-ratio (FL) approach, which does not require Monte Carlo simulation. Focusing on the mathematical method of error modeling, Li et al. [11] employed independent component analysis (ICA) to remove the common mode error and select the optimal noise model for the GNSS coordinate time series by using observations from 79 GPS stations in Antarctica from 2010 to 2018.

Precise orbit information for GNSS satellites is the basis for high-precision GNSS applications. In this special issue, several studies were carried out to improve GNSS POD accuracy. Aiming to shorten the interruption period of BDS broadcast ephemerides after satellite maneuverings and improve the ephemeris accuracy, Qiao et al. [12] proposed a two-step orbit recovery strategy based on a piecewise linear thrust model. In another contribution from Ye et al. [13], the authors presented a three-step method for determining unhealthy time periods of GPS satellite orbit in broadcast ephemeris during POD to provide reliable information in near-real time. For the purpose of improving the ultra-rapid orbit accuracy for BDS-2/BDS-3, Wang et al. [14] linked the predicted clock offsets into the POD as constraints to strengthen the estimation. By making use of SLR Normal Points (NPs) data only, Yang et al. [15] performed the POD of BDS-2/BDS-3 and found 3D RMS values of 9-day overlaps of 0.49 and 1.89 m for BDS MEO and IGSO satellites, respectively. GNSS orbits are traditionally determined by observation data from ground stations, which usually need even global distribution to ensure adequate observation geometry strength. In order to overcome the weakness in the tracking geometry of ground stations, Li et al. [16] designed six different LEO constellations to enhance the GNSS POD and achieved a notable improvement in accuracy of over 70% compared with ground-based POD. As for the LEO POD, the potential of the use of inter-satellite link (ISL) was demonstrated in [17]. Gong et al. [18] focused on the onboard real-time POD for low-cost single-frequency GNSS receivers and developed a series POD strategy.

Along with up-to-date GNSS signals, equipment and precise orbit/clock products, the positioning accuracy of GNSS is undoubtedly a major concern. Relative positioning and PPP are two general positioning methods. Katsigianni et al. [19] demonstrated that the Galileo-only constellation is already able to achieve comparable PPP accuracy with GPS, and the accuracy can be further improved by combining GPS/Galileo observations or performed ambiguity resolution (AR). By making use of the fusion of three designed LEO constellation and GNSS, Li et al. [20] shortened the time to first fix (TTFF) of multi-frequency PPP AR to less than 5 minutes and over 60% accuracy improvement could be obtained with the LEO augmentation. As for relative positioning, Chen et al. [21] developed an inter-system phase ambiguity fixing method based on un-difference (UD) observations by calculating the inter-system phase bias. In addition, the performance of GPS/Galileo relative positioning for bridge dynamic monitoring was demonstrated [22].

In particular, the use of GNSS in specific geoscience applications is discussed in this special issue. As an important application of PPP, the current performance of multi-GNSS PPP time and frequency transfer was evaluated using different GNSS constellation and precise orbit/clock products in [23]. In regard to geodynamics, Zheng et al. [24] applied sidereal filtering in the GNSS observation domain to alleviate the centimeter-level PPP noise using multi-GNSS data during the 2017 Mw 6.5 Jiuzhaigou earthquake. The PPP method was also used to study the activity of the Long Point Fault in Houston, Texas with six-years of continuous GPS observations [25]. In this respect, a Stable Caribbean Reference Frame 2018 (CARIB18) using long-term continuous GPS observations was developed and introduced [26]. Research in this special issue is also concerned about glacier and climate change. Continuous GPS observations were employed for 14 years to investigate the ice flow velocity in [27]. By analyzing the vertical position time series from 469 European GPS stations, the post-glacial rebound (PGR) in Europe was comprehensively investigated in [28]. Moreover, Wu et al. [29] estimated the satellite accelerations directly from the onboard GPS data using the point-wise acceleration approach for the Gravity Field and Steady-State Ocean Circulation Explorer (GOCE) satellite, and achieved higher gravity field model accuracy than those derived from kinematic orbits.

Precise modeling of the refraction caused by the troposphere and ionosphere is also a topic of interest in this special issue. Sun et al. [30] proposed a new empirical model for estimating the tropospheric delay and atmospheric weight mean temperature by using ERA-interim reanalysis data. Zus et al. [31] improved the GNSS zenith wet delay (ZWD) interpolation by utilizing tropospheric gradients. In terms of ionospheric delays, Wang et al. [32] evaluated the performance of four ionospheric models in Multi-GNSS single-frequency positioning over China. Furthermore, with the rapid development of sensors in mobile phones, the most up-to-date phones were reported to be capable of real-time ionosphere monitoring [33].

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