# Multi-GNSS processing, positioning and applications

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PREFACE

# Multi-GNSS processing, positioning and applications

In the past few decades the Global Positioning System (GPS) has been the number one positioning tool in a range of Geodesy and Geophysics applications. The emerging Regional and Global Navigation Satellite Systems (RNSSs/GNSSs) can enhance positioning and non-positioning applications. GPS modernisation from dual-frequency to triple-frequency signals has lately also been complemented by global GLObal' naya NAvigatsionnaya Sputnikovaya Sistema (GLONASS), Galileo and BeiDou Navigation Satellite System (BDS), as well as the regional Quasi-Zenith Satellite system (QZSS) and Navigation with Indian Constellation (NavIC). By 2024 it is expected that we will have access to more than 110 satellites in a multi-GNSS model transmitting their signals on a range of different frequencies. This will significantly improve current dual-frequency GPS positioning as well as non-positioning applications, such as atmospheric modelling and timing applications. Rigorous models and algorithms are however needed so as to link and integrate such multi-frequency, multi-GNSS signals to the estimable parameters of interest.

Important topics in this field include single- and multi-frequency, multi-GNSS modelling, while making use of survey-grade and low-cost receiver and antenna equipment, including smartphones. With low-cost we refer to GNSS receivers and antennas having a cost of at most a few hundreds of dollars, whereas survey-grade receivers and antennas typically have a cost of several thousands of dollars. Other important topics include ionospheric and tropospheric delay estimation, and multi-GNSS Precise Point Positioning Real Time Kinematic (PPP-RTK). This Special Feature showcases the latest trends in multi-GNSS modelling. Five papers were accepted, based on their quality and significant contributions to the field. The topics covered are: multi-frequency and multi-GNSS for stochastic modelling, single-baseline RTK and PPP-RTK, respectively, ionospheric modelling, and a PPP performance analysis of dual-frequency, multi-GNSS data collected in smartphones.

## Stochastic modelling for multi-GNSS

Stochastic modelling involves determining the (co)variance information of the code and phase signals tracked from multi-GNSS receivers. This is important so as to derive precise estimates of the unknown parameters. For multi-epoch models, the observation time correlation will also have to be fully considered. Provided that the stochastic models are realistically determined, the uncertainty of the estimated parameters will be minimised. The special feature study (Miao et al.) looks at estimating the stochastic models for receivers able to track the second generation BDS-2, and the third generation BDS-3. This can provide for further insight into the stochastic properties of these new receivers and signals.

## Ionospheric modelling

When the satellite signals propagate through the atmosphere to the GNSS receivers, they will be affected by the tropospheric, and, more significantly, the ionospheric errors. Single-frequency receivers, in particular, need ionospheric models to be able to precisely determine positions, and by making use of ionospheric models one can also speed up the parameter convergence for dual- and multi-frequency GNSS applications. Through the development of PPP algorithms, the ionosphere can be precisely determined by the use of single-receivers. In this special feature the contribution by Fan et al. examines PPP-derived vertical total electron content (VTEC), which illustrates the potential for PPP-derived ionospheric delays.

## Multi-frequency, multi-GNSS long single-baseline RTK and PPP-RTK positioning

Through the many more signals obtained when combining GNSSs, the reliability and redundancy of the positioning models can be improved. Furthermore by using multiple-frequencies, more precise atmospheric delays and thus faster precise positioning can be obtained in comparison to single- and dual-frequency scenarios. In this special feature two articles look at combining GNSSs with multi-frequency signals (Zhang et al.; Duong et al.), to obtain fast and precise positioning. In these contributions the tropospheric and ionospheric delays need to be modelled, which here are referred to as long single-baseline RTK and PPP-RTK, respectively. It will be demonstrated by how much the combination of GNSSs and the use of multiple-frequencies can strengthen the models, especially when compared to the traditional dual-frequency GPS-only model.

## Dual-frequency multi-GNSS PPP in smartphones

In the past few years, low-cost multi-GNSS receiver development has taken a revolutionary role in precise positioning applications. These low-cost receiver chips are typically affected by the use of low-cost antennas that are very sensitive to multipath, which affects the performance. However by combining several GNSSs, it has been demonstrated that a competitive positioning performance can be obtained to that of using survey-grade GNSS receivers and antennas that are better at suppressing multipath. Smartphone manufacturers have started to take advantage of such low-cost GNSS chips, which has led to precise positioning applications in smartphones. In this special feature Aggrey et al. looks at the PPP performance when using dual-frequency and multi-GNSS measurements, collected from a range of different mass-market smartphones.

## Conclusions

The GPS has been the number one positioning tool in applications of Geodesy and Geophysics in the past few decades. The proliferation of the next-generation GNSSs enhances a wide range of positioning and non-positioning applications when they are integrated. This special feature is focused on this important subject. We sincerely thank all

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