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Array-based GNSS Ionospheric Sensing: Estimability and Precision Analyses

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Introduction: The Global Navigation Satellite Systems (GNSS) have proved to be an effective means of measuring the Earth's ionosphere. The well-known geometry-free linear combinations of the GNSS data serve as the input of an external ionospheric model to capture both the spatial and temporal characteristics of the ionosphere.
Next to the slant ionospheric delays experienced by the GNSS antennas, the geometry-free combinations also contain additional unknown delays that are caused by the presence of the carrier-phase ambiguous cycles and/or the code instrumental delays. That the geometry-free combinations, without an external ionospheric model, cannot unbiasedly determine the slant ionospheric delays reveals the lack of information content in the GNSS data.
Motivation and objectives: With the advent of modernized multi-frequency signals, one is confronted with many different combinations of the GNSS data that are capable of sensing the ionosphere. Owing to such diversity and the lack of information content in the GNSS data, various estimable ionospheric delays of different interpretations (and of different precision) can therefore be formed. How such estimable ionospheric delays should be interpreted and the extent to which they contribute to the precision of the unbiased slant ionosphere are the topics of this contribution.
Approach and results: In this contribution, we apply S-system theory to study the estimability and precision of the estimable slant ionospheric delays that are measured by the multi-frequency GNSS data. Two different S-systems are presented, leading to two different estimable parameters of different precision: 1) the phase-driven ionospheric delays and 2) the code-driven ionospheric delays. Presenting their closed-form analytical (co)variance matrices, we introduce a new concept in which the data of an array of nearby GNSS antennas are incorporated to improve the precision of the ionospheric delays.

Keywords: Global Navigation Satellite Systems (GNSS), Slant ionospheric delays, Phase- and Code-driven estimability, S-system theory