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Optimizing Multi-GNSS Orbit Combination: A Comprehensive Study on Weighting Strategies and Outlier Detection ;

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Combined precise satellite orbits and clocks stand as core contributions from the International GNSS Service (IGS), integrating the individual inputs of various Analysis Centers (AC). The availability and quality of multi-GNSS products developed by ACs within the IGS multi-GNSS Pilot Project propel IGS towards replacing combined GPS and GLONASS products with homogeneous combined products encompassing all GPS, GLONASS, Galileo, BeiDou, and QZSS systems. A primary challenge faced by the IGS lies in refining the combination algorithm for multi-GNSS orbits and clocks to provide users with the utmost quality products.

This study delves into concepts aimed at enhancing the orbit combination algorithm, with a specific focus on adjusting the weighting scheme and detecting outlier observations. The core of the combination methodology adheres to the concept proposed by GFZ, employing a least-squares framework wherein weights used for combining AC orbits are determined through least-squares variance component estimation (VCE).

Four distinct weighting strategies are introduced and compared in this study. These strategies involve utilizing either the constellation, satellite type, satellite type on the same orbital plane, or each satellite individually to form datasets used in determining weights for each AC. Furthermore, a novel approach is developed to correct the weights for individual ACs based on the results of Satellite Laser Ranging orbit validation. This serves as an additional factor in the combination, mitigating the impact of systematic AC-dependent orbit mismodeling issues. All proposed strategies underwent testing using multi-GNSS orbit solutions over a 10-month period in 2023.

Firstly, the combination results show an agreement between the different AC's input orbits around 15, 20, 30, 50, and 100 mm for GPS, GLONASS, Galileo, BeiDou, and QZSS, respectively. Regarding the AC weighting strategy, the constellation-specific weighting approach provides the most robust solution and allows for handling differences between AC-specific issues in the orbit modeling of individual constellations. The satellite-specific weighting approach offers better resilience against the adverse effects caused by the inhomogeneous quality of satellite blocks/types/generations within a constellation, especially for BeiDou. However, the satellite-specific weighting encounters problems related to the appearance of invalid negative variances/weights for individual satellites

as the output of VCE, mainly for BDS-3 and QZSS. The negative variance component can be an important indication of defects in our variance component model. Grouping satellites of similar characteristics in a satellite-type-specific weighting approach increases redundancy and reduces the issue but not entirely. Ultimately, we demonstrate potential solutions to address this issue. This involves simplifying the iterated VCE or resorting to the legacy inverse mean square differences between the mean orbit and the AC's orbits as weights, particularly in cases where the classic VCE proves ineffective.