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Galileo PPP rapid ambiguity resolution with multiple frequency combinations

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Multi-frequency signals bring a variety of combinations of different frequencies, which is potential to improve the performance of the precise point positioning (PPP) ambiguity resolution (AR). The current Galileo constellation transmitting signals on five frequencies including E1, E5a, E5b, E5 and E6 frequencies. In this contribution, we investigated the Galileo triple-frequency PPP AR based on different combinations: E1/E5a/E5b, E1/E5a/E6 and E1/E5/E6. Moreover, the quadruple-frequency PPP AR method was developed in order to utilize the observations from all available signals. Data recorded from 134 International GNSS Service (IGS) stations were used to validate the effectiveness of Galileo uncalibrated phase delay (UPD) products, and 41 stations that can observe E6 signals were selected to evaluate triple-frequency and quadruple-frequency PPP AR method. The multipath and signal noise ratio (SNR) of Galileo observations at each frequency was analyzed firstly, which shows that E5 signals have the highest quality. The code inter-frequency clock bias (CIFCB) was taken account of in the multi-frequency processing and it has been demonstrated that CIFCB corrections can significantly improve the convergence of different combinations of PPP solutions except for the E1/E5a/E5b combination. The UPD products were estimated based on multi-frequency observations with different combinations. It is interesting to find that the E5a-E5b extra-wide-lane (EWL) UPDs for all Galileo satellites are very close to zero. With the precise UPD products, the triple-frequency and quadruple-frequency PPP AR can be implemented. Numerous results show that the performance in terms of convergence and positioning accuracy can be obviously improved by ambiguity resolution. Moreover, the triple-frequency PPP AR also present better performance than dual-frequency PPP fixed solutions, a time to first fix (TTFF) can be improved by 13.0%, 7.7% and 20.0% for triple-frequency PPP AR based on E1/E5a/E5b, E1/E5a/E6 and E1/E5/E6 frequency, respectively. It is worth to be mentioned that triple-frequency PPP AR based on E1/E5/E6 frequency show the best positioning performance with the averaged TTFF of 37.05 min. Benefited by the abundant combinations, the quadruple-frequency PPP AR presented the best positioning performance with the shortest convergence and the highest positioning accuracy.