Some aspects of improving precision of ionospheric modeling

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Introduction
It is well known that ionospheric delay is one of the main error sources when positioning and navigating with GNSS. A high-precision ionospheric model is of great significance for GNSS based single-frequency navigation and positioning users. For the ionospheric related scientific researches of ionosphere (eg. ionospheric storm, ionospheric scintillation, anomalous variations of geomagnetic storms, earthquakes and tsunami), a precise and reliable ionospheric model is also required.

The International GNSS Service created the Ionosphere Working Group in 1998 with the goal of generating reliable VTEC maps (Hernández-Pajares et al. 2009). Since then, many scholars have done a lot of research in the field of ionosphere modeling. In this study, we analyze some aspects of improving the precision of ionospheric modeling in detail.

Outline
Ionospheric modeling using GPS (G) only, GPS+GLONASS (GR), GPS+BeiDou (GC), GPS+GLONASS+Galileo (GRE), and GPS+GLONASS+BeiDou+Galileo (GREC) observations have been performed to evaluate the contribution of Multi-GNSS
Phase-smoothing pseudorange, standard precise point positioning (PPP) and ambiguity fixed PPP methods are adopted to extract slant total electron content (STEC) measurement
The accuracy of the derived STEC is validated by co-located receivers
Global Ionospheric Map (GIM) have been derived based on ambiguity fixed PPP, and the accuracy of the derived GIM is assessed

Contribution of Multi-GNSS
Observations from over 400 IGS and MGEX stations for 366 days from January 1 to December 31, 2016, have been used to produce Global Ionospheric Map (GIM). The Phase-smoothing pseudorange method is used to derive STEC observations. The mean and standard deviation (STD) of bias between different observation combination are calculated to evaluate the contribution of Multi-GNSS. The mean and STD of the bias between some selected combinations are shown in Fig. 1. Fig. 1 shows that the mean and STD of bias between G and GR are within 0.5 and 0.8 TECU, respectively. The mean and STD of bias between G and GREC is slightly larger, but not larger than 1.2 and 0.8 TECU. Since the accuracy of traditional ionospheric modeling is in the range of 2 to 8 TECU, the contribution of Multi-GNSS is not obvious.

Validation of STEC
Since the ionospheric delay of a satellite is same for the co-located stations, differencing STEC derived by two stations cancels out the satellite biases as well as the ionospheric delays. The remaining receiver-dependent bias between stations is expected to be identical for all satellites. Fig. 2 show the time series of receiver-dependent bias between stations ZIM2 and ZIM3 using Phase-smoothing pseudorange and standard PPP for GPS system.

As shown in Fig. 3, the difference of STEC are mainly within 0.1 TECU for GPS, GLONASS, Galileo and BeiDou while using ambiguity fixed PPP, which is much smaller than the results shown in Fig. 2.

Validation of GIM

Conclusion
The mean and STD of bias between different observation combination are mainly within 1 TECU, which is smaller than the accuracy of traditional ionospheric modeling. The contribution of Multi-GNSS is not obvious.

The derived STEC is validated by co-located stations, the results show that STEC derived by ambiguity fixed PPP is more accurate than Phase-smoothing pseudorange and standard PPP

Estimated GIM agree well with the CODE product, with the differences being less than 2 TECU in most areas. Based on the results of single frequency kinematic PPP, CODE has the best performance in the three products. The GIM derived by ambiguity fixed PPP is better than Phase-smoothing pseudorange among most stations, but the advantage is not very obvious.

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