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Time-Lag Effects on GNSS Kinematic Precise Point Positioning of Ionospheric Response to Severe Geomagnetic Storms

Zhe Yang [(1)], Jade Morton [(2)]
(1) Tongji University, Shanghai, China; e-mail: zheyang@tongji.edu.cn
(2) University of Colorado, Boulder, CO, USA; e-mail: jade.morton@colorado.edu

As follow-up efforts in quantifying the sequence impacts of space weather (SWx) [1, 2, 3], this paper focuses on time-lag effects of ionospheric response to geomagnetic storms on the kinematic precise point positioning (PPP) using 5500+ GNSS stations installed worldwide. The time lag (T_{lag}) represents the time delay between a geomagnetic storm sudden commencement and kinematic PPP degradations due to storm-induced ionospheric disturbances. It is measured from the identification of sudden storm commencement (SSC) detected by magnetic ground stations and subsequent degraded PPP at the ground-based GNSS receivers for high precision applications.

$$T_{lag} = T_{PPP} - T_{SSC}$$

In this study, the PPP degradation is characterized by the most commonly used accuracy measures in the satellite position field, i.e., root mean squared (RMS) errors of resolved positioning solutions and theoretical equivalent measures in both two and three dimensions. The time when the degradation starts in positioning solutions (T_{PPP}) is determined by an alarm threshold of the used accuracy measures which is estimated based on a statistical distribution analysis of the position solutions, while T_{SSC} represents the onset time of SSC when the disturbance storm-time (Dst) index diminishes to a value of -50 nT at least. A simple approach concerning the difference between T_{PPP} and T_{SSC} is thus applied to derive the time lag T_{lag}. We consider two severe geomagnetic storms occurred in the 24th solar cycle and present an overview of the storm-time ionospheric response effects on the kinematic PPP solutions. The time lags in the PPP degradation are particularly analyzed for different latitudes.

Results suggest that the time lags (T_{PPP}) vary significantly at global scales with the decay of disturbed geomagnetic field. More specifically, at high latitudes, the PPP degradation mostly starts in the main phase of the storm, resulting in a time lag ranging from several minutes to 3 hours with respect to the sudden onset of the storm. At middle and low latitudes, a wide range of the time lag up to tens of hours is observed following the storm recover phase. The time lag effects are associated with varying ionospheric disturbances in response to the solar wind-magnetosphere-ionosphere coupling during the storms. As compared with existing studies of SWx impacts on GNSS applications, this contribution for the first time quantifies the time sequence between the SSC signatures in geospace coupled system and the PPP degradation in GNSS end-user service. The quantity information is anticipated to be utilized and incorporated into physical-based and machine learning models to advance SWx understanding and forecasting capabilities.

References

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