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GNSS observation of the solar wind – magnetosphere and ionosphere connection via penetration electric field

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The solar wind and magnetosphere can impose direct impacts on the upper atmosphere through various electromagnetic processes. These processes can result in either prompt or delayed ionospheric responses. Penetration electric fields, for example, can cause immediate ionospheric changes. In general, ionospheric electric fields are generated by the wind dynamo action during both quiet and disturbance conditions. Penetration electric fields (PEFs) is originated from the solar wind and magnetospheric disturbances (Kelley et al., 2010; Fejer et al., 1979; Mozer, 1973) and occur in the ionosphere during geospace disturbance periods, inducing ionospheric changes primarily at low and equatorial latitudes. These electric fields are typically observed in the magnetic field disturbances by magnetometers. In fact, in the 1960s (Nishida, 1968), magnetometers provide clear evidence of these prompt perturbations based on identification of sudden changes in observations from networks aligned in magnetic meridians at different longitudes. Currently there are approximately 600 sites of magnetometers around the world.

In this study, we report GNSS-based new observations of PEF effects developed simultaneously and globally on a regular basis during enhanced solar wind-geomagnetic activities with IMF Bz variations. These observations are characterized by the global extend and frequency of discernable ionospheric effects. The efficiency of the penetration as well as detectability of measurement techniques represent an important science question and also a technology challenge. Our study indicates that these effects can be easily seen in global GNSS differential TEC data (dTEC) (Zhang, Coster, et al., 2019; Zhang, Erickson, et al., 2017). This study employed 6000 ground receivers and in most of the regions, the receiver distribution is significantly much more dense than that in the prevailing global magnetometer networks. The spatial resolution of dTEC data implies the innovative potential for GNSS techniques to be applied for resolving high resolution EPF information in the ionosphere (Zhang, Nishimura, et al., 2023). Therefore one can study in great details the solar wind-magnetosphere and ionosphere condition, including temporal responses and spatial evolution, conductivity conditions of the ionosphere.

In this presentation, we provide GNSS evidence of PEF effects using several individual days of varying geomagnetic disturbances. We found a total of 10+ intervals of simultaneous global ionospheric disturbance events, each lasting for 30 min. These ionospheric disturbances occurred primarily on dayside at mid- and low latitudes and sometimes on the nightside (especially near the dawn sector) as well. There is a clear phase change (opposite effects in enhancing and reducing plasma density) between dayside and nightside.

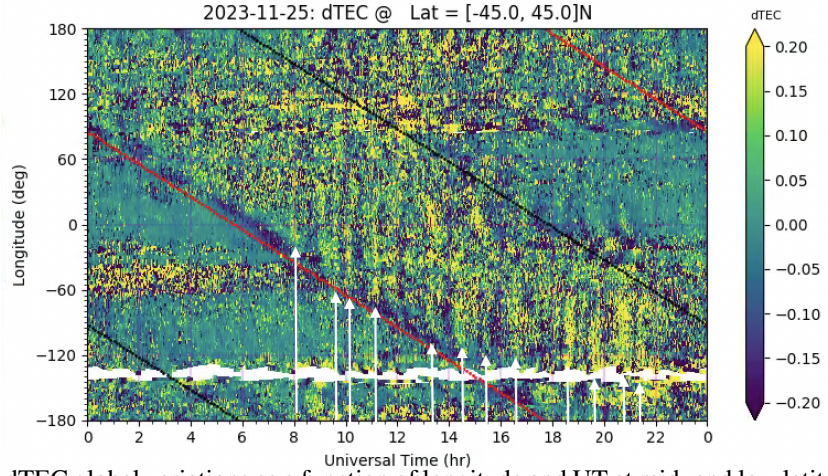

Figure 1. GNSS dTEC global variations as a function of longitude and UT at mid- and low latitudes in the latitudes -45 $\sim$ 45°N. Vertical stripes represent ionospheric sudden global disturbances (SGDs).