URSI AP-RASC, Sydney, Australia, 17-22 August 2025

Dynamic Properties of Travelling Ionospheric Disturbances deduced from Ionosonde and GNSS Measurements

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Travelling Ionospheric Disturbances (TIDs) are wave-like perturbations in the electron density that propagate through the ionosphere, often triggered by atmospheric gravity waves associated with geomagnetic storms and other geophysical processes. We present the dynamic propagation characteristics of the TIDs estimated from multi-site analysis of the critical frequency of F2 region, foF_2 and TEC derived from a Global Navigational Satellite System, GNSS measurements during selected geomagnetic storms of 2014 – 2017 over Australia. The HF Interferometry and the TEC perturbation techniques were applied to detect TIDs.

The TIDs detected using HF Interferometry coincided remarkably with the development phases (onset, main, and recovery) of geomagnetic storms lasting a few minutes to several hours in the Australian sector. The propagation parameters (period, velocity, azimuth, and SEC) dramatically changed with time over ionosonde sites throughout the storm phases. A wide range of propagation directions were detected during various stages of storm evolution. TIDs were detected with a wide spectral range with periods from ~50 – 170 min and propagation speeds from ~100 – 1800 m/s. Consistent events with coherent equatorward TIDs coincided with auroral activity for many of the case studies during certain phases of the storm e.g., 17 March 2015 (onset and recovery), 23 June 2015 (onset, main, and recovery), 20 December 2015 (onset phase), 8 September 2017 (onset phase), 12 April 2014 (recovery phase), 6 March 2016 (main and recovery phases), 19 February 2014 (double main phase events). In general, geomagnetic storms prominently characterized equatorward TIDs at middle and low latitude sites coinciding with *AE* enhancements indicating high latitude/auroral generation mechanisms. Coherent occurrences were mostly accompanied by weakly disturbed equatorial eastward electric fields, EEFs. Storms that produced highly disturbed EEFs produced poleward and stochastic TIDs, indicating localized irregularities and possible mixing effect of multiple disturbances from both low and high latitude origins.

The TEC perturbation method revealed large-scale TIDs during geomagnetic storms on a global scale. The dense spatial mapping of TEC perturbations showed widely structured zonal distribution of density enhancements and depletions that represented propagating large-scale TID wavefronts. Global maps showed that these wavefronts generated in the polar regions of both hemispheres simultaneously that generally propagated equatorward. However, variations in the TID characteristics at the different regions of the globe indicated an asymmetric energy deposition generating these disturbances. Equatorward propagating structured TID wavefronts in the Australian region were sheen during the super intense storms. The wavefronts were highly dissociative and spread over large latitudinal range. During moderate and less intense geomagnetic storms such enhancements were not visible. The study showed that TIDs generated during super intense storms propagated to large distances and reached middle and low latitude regions over Australia. On the other hand, auroral generations during moderate storms could not travel large distances. The propagation analysis of the large-scale TID structures over Australia revealed a high degree of propagational anisotropy, i.e., as the disturbance propagated equatorward the velocities varied significantly with different directions at various longitudes. The propagation characteristics estimated revealed a wide spectrum with periods that ranged from ~44 – 85 min and velocities from ~100 – 1000 m/s having both equatorward and poleward propagating events over the Australian sector. Results showed that although each storm was unique, its effects on the ionosphere often occurred with enhanced electron density disturbances such as TIDs and density instabilities over Australia that were associated with storm-induced activity at both auroral and equatorial regions.

The comparison of the TIDs characteristics from the two independent techniques (HF-Int and TEC perturbation) revealed significant differences in the TID characteristics that are attributed to the differences in detection techniques, geographic sensitivity, and system limitations. The TEC method analysis was limited by clear visuals of large-scale perturbation enhancements where weaker medium and small-scale structures remained undetected. The detections with HF-Int are sensitive to coherent disturbances at multiple sites but limited to the eastern side of Australia due to the localized ionosonde network of stations. Consequently, the parameters compared well when the TEC wavefront structures covered the eastern regions thereby, sensed by HF-Int in parallel.