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Modelling and Multi-Instrumented Observations of Traveling Ionospheric Disturbances

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ABSTRACT

Earth's space environment is a complex system of coupled processes involving neutral gas, electrically charged particles, and plasma waves occurring over a range of spatial and temporal scales. Signatures of atmospheric tides driven by tropospheric latent heat release have been shown to propagate well above 100 km and modify the ionosphere-thermosphere (IT) system. There has been a maturing realization that neutral atmosphere-ionosphere coupling via neutral waves plays a critical role in driving the dynamical behavior and day-to-day variability of the ionosphere. One of the important dynamical features of the atmosphere is atmospheric gravity waves (AGW). AGWs have been shown to directly impact ionospheric variability [1] and seed ionospheric irregularities which can interfere with the operation of satellite communication, *Global Navigation Satellite System* (GNSS), and surveillance systems. The phenomenon of Traveling Ionospheric Disturbance (TID) is an important manifestation of atmosphere-ionosphere coupling. TIDs are perturbations in ionospheric electron density caused by AGWs via ion-neutral collisions as they travel through the thermosphere/ionosphere from their source region. There is a great deal of interest in TIDs, from both an observational and modeling perspective, especially as they apply to operational systems that rely on nowcasting the ionospheric state.

Historically, TIDs have been classified as medium-scale or large-scale. Medium-Scale TIDs (MSTIDs) tend to have wave periods (τ_r) in the 10-30 min range, and propagate with horizontal phase speeds (c_H) less than 350 m/s. In contrast, large-scale TIDs (LSTIDs) tend to have periods larger than 30 minutes, and propagate with phase speeds exceeding ~300 m/s [2]. In addition, several studies have suggested that there is another class of TIDs which can occur at middle and low latitudes during the nighttime. They are electrobuoyancy waves, which tend to propagate westward and equatorward, and their source is commonly attributed to the Perkins instability [3].

In this paper, we review observational techniques for TIDs using an HF Doppler system and ground-based Global Positioning System (GPS) receivers. We describe an observational system to measure TID characteristics called TIDDBIT (TID Detector Built in Texas). TIDDBIT is a fully digital HF Doppler sounder that uses continuous wave (CW) signals across a spaced array. Over the last few years, several TIDDBIT systems were deployed in Texas, Virginia, Florida, Hawaii, and Peru. A significant advantage of the TIDDBIT system over passive techniques (e.g. airglow) is that it can provide critical information for the entire wave packet, including the horizontal and vertical phase propagation speeds as a function of TID period, ranging from the acoustic (1-min) to the gravity wave (10-90 min) part of the spectrum.

We also use Total Electron Content (TEC) measurements from various GPS receivers throughout the continental United States for TID observations. The network of GPS receivers used in the study in effect provides a 2D spatial map of TEC perturbations, which can be used to calculate TID parameters, including horizontal wavelength, speed, and period. We demonstrate the ability to derive a complete set of TID parameters (periods, amplitudes, horizontal phase speeds and wavelengths, and propagation direction) from a network of ground-based GPS receivers. For this study, we "image" TIDs from GPS data from over 4000 (receiver) sites in the US. Ground-based dual-frequency GPS receivers allow measurements of ionospheric TEC 24 hrs/day during any weather conditions worldwide, which makes this is an extremely versatile data set.

The focus of this study is on an LSTID event that occurred during a geomagnetically active period during October 7-8, 2015. This entire period was characterized by Kp > 5 with a maximum Kp of 7 occurring during 18-21 UT on October 7, 2015. We know that during geomagnetic storms the high-latitude atmosphere is stimulated by energy deposition from precipitating particles in the auroral zone, currents, and Joule heating. It is well accepted that enhanced Joule heating in the thermosphere during geomagnetically disturbed conditions can launch AGWs [3]. In this paper, we show results of the LSTID event on October 7, 2015 from the TIDDBIT radar system in Florida and GPS receivers. LSTID characteristics were successfully obtained from the *F*-region reflections. The radar provided a complete description of LSTID characteristics from Florida. We compare TIDDBIT-derived estimates of LSTIDs with those from the GPS TEC analysis. The GPS analysis provided an independent confirmation of the LSTID measurements from the TIDDBIT. Both systems indicated that the LSTID wave packet consisted of periods ranging from 30-minute to 50-minute, all propagating roughly Southward with horizontal phase speeds of ~400-500 m/s and horizontal wavelength of ~1300 km. Figure 1 shows a summary plot of azimuths, horizontal phase speeds, and periods of the TID wave packet measured by the Florida TIDDBIT system during 14-21 UT on October 7, 2015. The TIDDBIT data shows LSTIDs propagating at an azimuth of 180° (relative to geographic North) which is in good agreement with GPS TEC measurements shown in Figure 2.

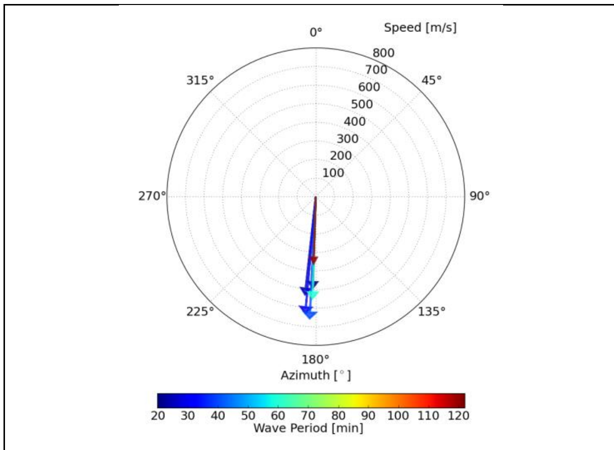

Figure 1. Periods, phase speeds, and azimuths of the LSTID wave packet derived from the TIDDBIT measurements on October 7, 2015. Different color vectors represent different periods.

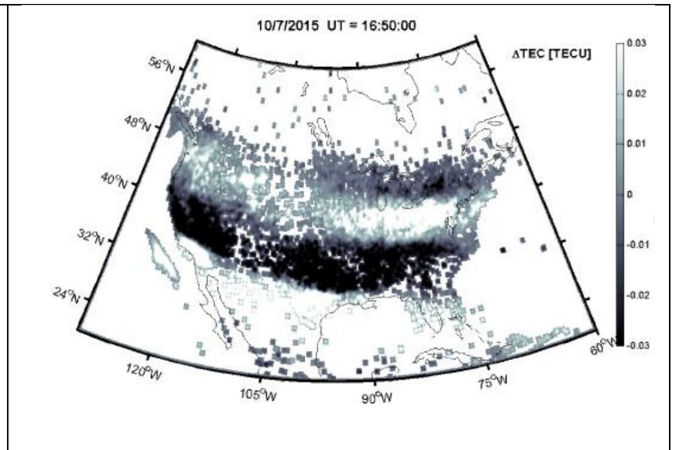

Figure 2. 2D 'image' of TEC perturbations derived from GPS receivers in the U.S. at 16:50 UT on October 7, 2015 showing the LSTID event.

It is also desirable to be able to use these data to specify the TID structure not only at the radar measurement altitude, but to extend it in 3D to greater and lower heights, and beyond the immediate vicinity of the measurement location. We present a simplified model to specify TIDs based on the ion continuity equation for plasma density [4]. Linearity of the neutral wind perturbations is assumed, and the different spectral components of the measured TID perturbations are added linearly. We use TID observations from the TIDDBIT sounder and GPS receivers as input into the model, and develop a 4D regional specification (spanning ~500 x 500 km in the horizontal direction, 90-1000 km altitude range, and ~2 hours in time) of both the perturbed electron density and the perturbed neutral wind from the corresponding atmospheric gravity wave (AGW). The model is also applied to the LSTID measurements during October 7, 2015.

Key words: Ionosphere, GPS, HF Sounder, Traveling Ionospheric Disturbance, TID Model

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