The Impact of Traveling Ionospheric Disturbances on Global Navigation Satellite System Services

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Abstract

Recently, total electron content (TEC) data from dense networks of GPS receivers have allowed for unprecedented observations of traveling ionospheric disturbances (TIDs). For the first time, the spatial structures and temporal evolution of medium- and large-scale TIDs can be measured. These recent observations of TIDs will be reviewed and the findings categorized. We will also discuss the implications of TIDs on field users of global navigation satellite system (GNSS) services. Finally, we will describe the proposed new measurements of TIDs using the new Murchinson Widefield Array (MWA) combined with GPS observations from a newly expanded network of GPS receivers in Australia.

1. Introduction

Traveling ionospheric disturbances are manifestations of middle-scale ionospheric irregularities arising as response to acoustic gravity waves. TIDs are frequently observed at high and middle latitudes ([1],[2],[3].[4],[5]). Their activity and amplitudes vary depending on latitude, longitude, local time, season, and solar cycle (i.e. [6],[7]). Large variations in TID characteristics and propagation directions are not surprising as they can be generated by very distinct classes of processes, from auroral sources at the high latitude thermosphere to the solar terminator and storms, hurricanes and tornados in the troposphere.

In broad terms, there are two main categories of TIDs, large-scale traveling ionospheric disturbances (LSTID) and medium-scale traveling ionospheric disturbances (MSTID). LSTIDs typically have an amplitude of about 20% of the TEC, wavelengths of 1000-3000 km, amd propagation velocities of 300-600 m/s equatorward. These disturbances appear to have a geomagnetic dependence and are of auroral origin. MSTIDs are characterized by an amplitude of 10% or less of the TEC. Their wavelengths are 100-500km, and propagation velocities are 50-200 m/s. These waves do not exhibit a geomagnetic dependence.

Topics that are currently being investigated by the scientific community include investigating the excitation mechanisms of gravity waves [8], studying the implications of the geographical and temporal variability of observed gravity waves [9], and defining the relationship of gravity waves to the observed TIDs These science topics address the broad general area of understanding the upward energy flow from the troposphere to the mesosphere to the thermosphere. Understanding the sources, energetics, and scale sizes of energy coupling from the lower atmosphere to the upper atmosphere, along with resulting ionospheric effects, is critical to a detailed knowledge of overall upper atmospheric energy balance.

2. Differential GPS Measurements of TIDs

A number of recent papers using differential GPS techniques ([7].,[10],[11].[12].[13],[14],[15]) have contributed to an increased understanding of traveling ionospheric disturbances (TIDs). Tsugawa et al., [11] recently showed that the daytime TIDs in the US propagate southeastward right after dawn until around mid-afternoon, and then propagate southwestward in the late afternoon. These TIDs had 10-60 min period and wavelengths of 300-1000km. The peak-to-peak amplitudes were larger than 0.5 TECU, and the amplitude of the daytime MSTIDs seemed to increase as they traveled equatorward as is shown in Figure 1.

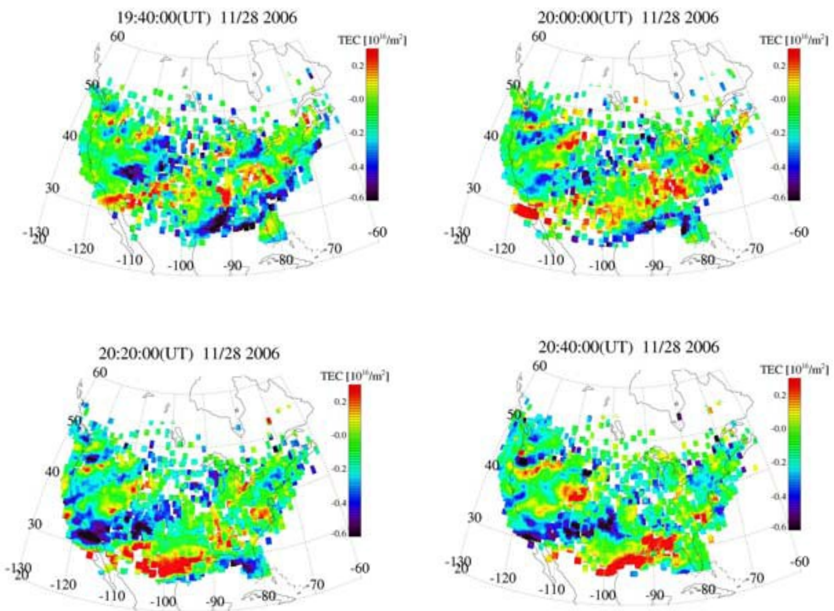

Figure 1. Maps of Differential TEC over North America during the daytime between 19:20 UT (13:20 CST) and 20:40 UT (16:00 CST) on November 28, 2006. (From Tsugawa et al., 2007) This product will be produced and correlated with fine-scale MWA observations of differential TEC.

3. Measuring TIDs with the Murchison Widefield Array

The MWA is a new low frequency array that is being built with funds from NSF and AFOSR to develop powerful new capabilities for radio astronomy and heliospheric science at frequencies from 80 to 300 MHz. This array has been designed to have extremely wide fields of view and unprecedented sensitivity at these frequencies. The MWA offers a tremendous new opportunity to study the development and propagation of TIDs.

The routine operations of the MWA will produce maps of the differential TEC to 10s of mTEC units on short temporal (~10 sec) and spatial (~ 1 km) scales over the array. This data is output by the "self-calibration" technique of the MWA astronomers, and is used by the astronomers to remove the ionospheric effects from their data. This reconstructed screen of differential TEC will be able to provide observations of MSTIDs with their 100-500 km wavelengths on an ongoing basis over the array.

Combining MWA and GPS observations of LSTIDs and MSTIDs will be able to provide better characterization of the geographic and temporal variability of TIDs in addition to providing additional insight into their excitation mechanisms, such as their excitation at dawn

4. Summary

For the first time, the spatial structures and temporal evolution of medium- and large-scale TIDs can be measured with differential GPS techniques over regional scales. We will review the new differential GPS observations of TIDs and categorize the recent findings. We will also discuss the implications of TIDs on field users of global navigation satellite system (GNSS) services. Finally, we will describe the proposed new measurements of TIDs using the new Murchinson Widefield Array (MWA) combined with GPS observations from a newly expanded network of GPS receivers in Australia.

5. References

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