INVESTIGATION OF TRAVELING IONOSPHERIC DISTURBANCES DURING A MIDLATITUDE SPREAD F EVENT

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Abstract: During a midlatitude spread F (MSF) event, data was collected to investigate the circumstances that may lead to MSF. Using the Total Electron Content (TEC) derived from the NCAT-SCINDA GPS station and the Continuous Operating Reference Stations (CORS) Traveling Ionospheric Disturbances (TID) were analyzed during a period of MSF over Wallops Island, Virginia. In addition to the TEC analysis, scintillation calculations have been made using the NCAT-SCINDA GPS receiver, USRP receiver and a Narrow Band (NB) receiver. Scintillation levels on the GPS, USRP and NB signals were very low throughout the period of MSF. Analysis of TEC data from multiple CORS sites has shown the presence of medium scale atmospheric gravity waves (AGW) within the MSF event region propagating towards low latitudes with a small eastward component. This is consistent with theories showing AGW may lead to MSF if an oppositely directed neutral wind is present. This study was performed in conjunction with a sounding rocket experiment investigating ionospheric disturbances at multiple scale sizes.

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I. INTRODUCTION

The University of Texas (UT) performed a study using ionogram data from Wallops Island, VA (WI). Their study concluded that irregular variations at midlatitudes occur several times throughout the year with increased frequency during the fall and winter seasons.[1] As a follow-up to the UT’s previous WI study, the UT proposed an experiment where a sounding rocket would be launched from WI into the F layer during a spread F event. The sounding rocket collected electric field, neutral wind, and ion density measurements. In conjunction with this experiment NCAT collected scintillation and total electron content data at GPS frequencies from its campus located in Greensboro, North Carolina. Scintillation data was also collected by the Air Force Research laboratory (AFRL) at VHF from Martha’s Vineyard (MV) (Figure 1). Midlatitude spread F was confirmed by digisonde measurements (Figure 2) and the sounding rocket was launched at 12:12 AM local time on October 30, 2007 from Wallops Island, Virginia (WI).

II. METHODOLOGY AND DATA ANALYSIS

GPS satellites are distributed throughout the sky giving each PRN a unique line of site to the receiver. This requires that PRNs be selected based on the path that they traverse; this included eliminating PRNs that were not within the WI area (space and time). The PRNs that were close to the WI area around the launch were PRNs 2, 4, 5, 10, 12, 17 and 23 (Figure 3).

The PRNs that were close to WI during the launch into the spread F event were 2, 4, 10, and 17, with PRN 2, 4, and 10 passing within one degree latitude and longitude of WI.

III. SCINTILLATION ANALYSIS RESULTS

The AFRL collected VHF scintillation data using a Universal Software Radio Peripheral (USRP) receiver operating on four frequencies, and a separate hardware based VHF receiver. NCAT collected L band scintillation data using its GPS based SCINDA receiver. VHF and L band scintillation is expressed as the S4 index following the relation:

$$S_4 = \frac{\sqrt{\langle I^2 \rangle} - \langle I \rangle^2}{\langle I \rangle}$$

Scintillation was observed for many days before the rocket launch from both NCAT and MV; S4 did not ex-
FIG. 2: Ionogram showing spread F and sporadic E at Wallops Island, VA just before launch

cceed 0.2 on either the USRP or VHF receiver and did not exceed 0.4 for elevations higher than 30 degrees on the SCINDA receiver. During the launch, scintillation observed at NCAT did not exceed 0.2 for PRNs 2, 4 and 10 during the flight of the rocket experiment (Figure 4). Scintillation measurements from MV during the rocket experiment were similar and did not exceed 0.2 for a period of eight hours centered on the launch time (Figure 5). The low levels of scintillation suggest that small-scale ionospheric irregularities played a limited role during this MSF event[2].

IV. TRAVELING IONOSPHERIC DISTURBANCE ANALYSIS

Total Electron Content (TEC) data was obtained from the SCINDA GPS receiver and the CORS network. Two groups of GPS receivers were used to analyze ionospheric disturbances; The Virginia group (VG) was centered on the rocket launch site at WI and the North Carolina Group (NCG) was centered on the NCAT campus.

V. TEC FROM THE CORS NETWORK

The CORS network is organized by NOAA which makes data available online in Receiver Independent Exchange (RINEX) format. This format stores the pseudoranges and carrier phases for each PRN. In order to calculate TEC from the pseudoranges and carrier phases, the azimuth and elevation of each satellite must be known. This was calculated with software provided by the Low Latitude Ionospheric Sensor Network (LISN) which made use of almanac data to calculate the GPS constellation orbital path. TEC was also calculated with software provided by the LISN which required the azimuth, elevation and either the DPR1-DCP1 or DPR1-DPR2 satellite bias information.

VI. FILTERING TEC

TEC data was filtered to remove ionospheric structures that were larger than mesoscale objects. This was accomplished by fitting a small term sine function of the form $\text{TEC}_f = A \sin(Bt + C) + D \sin(Et + F) + G$ and subtracting. $A$, $B$, $C$, $D$, $E$, $F$, and $G$ are constants. The small term sine function allowed for the removal of diurnal and tidal variations and geometrical aberrations. This method was highly successful when using TEC data that was calibrated using different methods (SCINDA and LISN). Figure 6 shows that this method allows mesoscale ionospheric structures to be compared.
FIG. 4: Scintillation index measurements from NCAT for PRNs 2, 4, and 10 (Vertical line represents the end of 29 Oct 2007)

FIG. 5: Scintillation index measured at four frequencies using the USRP from Martha’s Vineyard

VII. RESULTS OF TID ANALYSIS

TEC was filtered on PRNs where data was collected during the rocket launch; these were PRNs 2, 4, 5, 10, 12, and 17. The NCG PRNs that were within two degrees latitude and longitude (LL) during the launch were PRNs 2, 4, 10, and 17 with PRN 4 passing directly over the launch site. The VG PRNs that were within two degrees LL during the launch were 2, 4, 10, and 17 with PRN 10 passing directly over the launch site. As indicated in Figure 7, the TEC analysis showed the presence of an atmospheric gravity wave (AGW) with a period on the order of one and one half hours with peek to peek amplitude of three TECU occurring just before midnight on 29 October 2007.

VG and NCG comparison showed that the AGW was southward propagating with a small eastward component (Figure 8).

In Figure 2, sporadic E can be seen on the ionogram during the launch at approximately 120 Km. Sporadic E has been shown to be associated with AGW with periods from 10 to 70 minutes \[3\]. While the observed AGW has a period longer than 70 minutes; numerical studies have shown that spatial resonance is not required to modulate the height of sporadic E \[4\].

VIII. CONCLUSION AND DISCUSSION

We have shown scintillation levels were low throughout the MSF event both at VHF and l band frequencies, suggesting that small-scale ionospheric structures were minimal for the period of observation. Also presented is a method to compare mesoscale ionospheric structures between GPS-derived TEC data sets that have been calibrated using different methods. We have shown
the presence of an AGW with a period of approximately 90 minutes and amplitude of three TECU. Furthermore the AGW was seen to propagate towards low latitudes with as small eastward component. This small sine term method should be expanded to other MSF events to calculate correlation values between this method’s ability to show mesoscale ionospheric structures in relation to MSF and sporadic E. The selection of CORS sites should be expanded to give better estimations of AGW velocity.

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