Effects of Large Magnetic Storms on Communication and GPS Navigation Systems at Middle and Equatorial Latitudes

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ABSTRACT

Large magnetic storms with Dst exceeding 100 nanotesla cause a prompt penetration of electric fields into the mid-latitude and the equatorial ionosphere. The resulting steep spatial TEC gradients and scintillation in GPS receivers impact the Wide Area Augmentation System (WAAS), which is to provide GPS based navigation to aircraft. At the magnetic equator, the enhanced eastward electric field causes the crests of the equatorial anomaly to move to much higher latitudes and sets off plasma instabilities that cause intense UHF scintillation. It is shown that the temporal characteristics of SYM-H limit the equatorial activity to a narrow longitude sector.

INTRODUCTION

The effects of recent major magnetic storms (Dst > 100 nT) on the mid-latitude and equatorial ionosphere have engaged the attention of geophysicists and systems engineers. One of the reasons for this spurt of activity can be related to space weather initiatives of several agencies that required researchers to study the space weather events from their initiation on the sun to their impacts on the earth including their effects on space-based and ground-based technological systems. The Wide Area Augmentation System (WAAS) in the United States that will provide GPS based navigation to aircraft is one such system that is impacted by magnetic storm induced TEC variations and TEC fluctuations that are recorded with GPS receivers.

A recent comprehensive paper [1], showed that the penetration of magnetospheric electric field to mid-latitudes is well-correlated with rapid changes of the Dst index and the effects of the storm are most pronounced when such changes occur in the dusk sector. Large increases of TEC, TEC fluctuations and saturated 250 MHz scintillation were observed with consequent effects on systems like WAAS and satellite communication links. Based on incoherent scatter radar observations at Millstone Hill located at mid-latitudes, storm enhanced densities (SED) were observed in the ionosphere that convected westward at high speeds [3]. Reference [1] also showed that the eastward penetration electric field extends in about ten minutes into the equatorial ionosphere over limited longitudes to cause intense VHF and L-band scintillation of satellite signals. Such electric fields intensify over the South Atlantic region and are able to lift, transport and thereby deplete the equatorial ionosphere in this region [2].

We shall primarily discuss the ionospheric effects for the March 31, 2001 magnetic storm. The storm was unique because the decrease of high-resolution SYM-H index (equivalent to 1-minute Dst) first occurred during the post-midnight time period over the eastern coast of the United States and a decrease of SYM-H also occurred in the recovery phase of the storm during the dusk in the same region. We shall show that the ionospheric response, as measured by TEC variations and scintillation, was markedly different at these two different local times when SYM-H registered large changes with time.

RESULTS AND DISCUSSIONS

The top panel of Figure 1 shows the high-resolution (1-minute) values of SYM-H index which closely follows the hourly Dst index. The onset of the storm occurred shortly after 0400 UT on March 31, 2001, and the SYM-H index decreased sharply to attain a minimum value of –450 nT at 0812 UT. This main phase of the storm corresponded to the local midnight time frame over the eastern United States. The bottom panel shows the scintillation index S4, defined as the ratio of the standard deviation of signal fluctuations and the average signal intensity, recorded at 250 MHz from a geostationary satellite plotted as a function of UT from Hanscom AFB, Massachusetts. Scintillations commencing at 0443 UT exceeded the saturation level of unity and corresponded to a 350-km ionospheric intersection at 39^0 N lat, 74.7^0 W long. During the recovery phase of the storm, SYM-H again showed a minor decrease at 16 UT and a major decrease at 18 UT that corresponded to the local noon period at the ionospheric intersection of scintillation observations. Three bursts of associated scintillation exceeding 10 dB at 250 MHz were recorded.

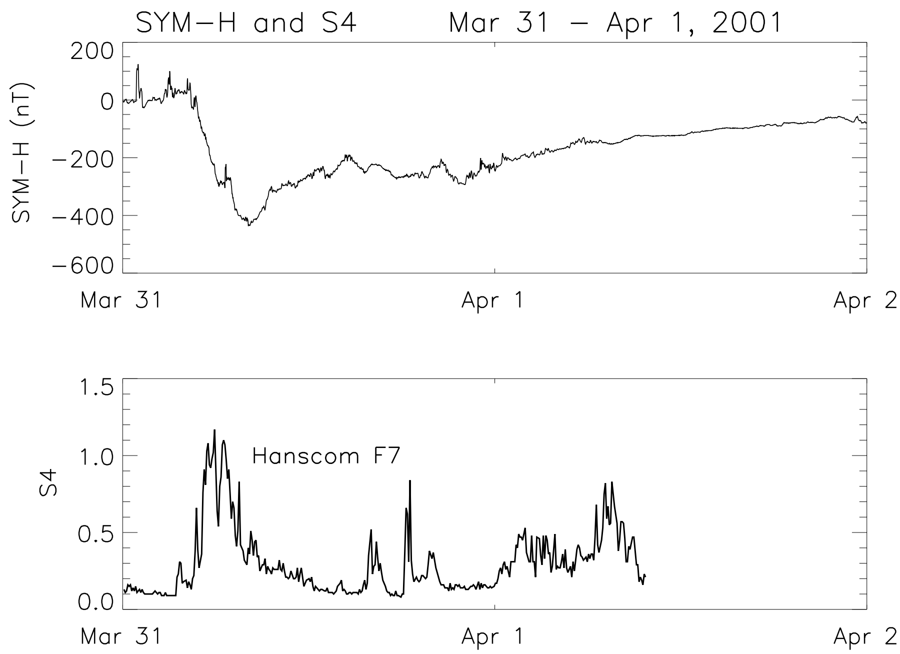

Figure 1. Scintillation index S4 at 250 MHz from a geostationary satellite received at Hanscom Air Force Base, Massachusetts, plotted against SYM-H index for March 31, 2001 storm.

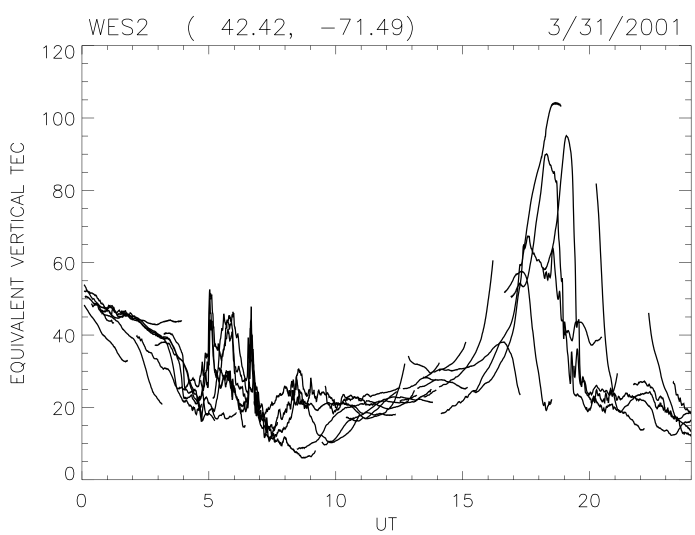

Figure 2. The equivalent vertical TEC measured using GPS satellites at Westford, Massachusetts (WES-2), on March 31, 2001.

Figure 2 shows the variation of the total electron content at Westford, MA (42.6^0 N, 71.5^0 E), recorded by the GPS receivers of the International Geodynamic Service (IGS). Associated with the main phase of the storm, relatively ordered increase and decrease of TEC between 20 to 40 TEC units (10^{16} el m^{-2}) were seen superimposed with large temporal variations. It probably indicates the intrusion of the auroral oval into the local ionosphere. Later, associated with SYM-H decreases in the recovery phase of the storm between 16-18 UT, that correspond to local noon period at Westford, MA, large TEC enhancements to 80 to 100 TEC units were recorded. These post-noon events are to be attributed to penetration electric fields and storm enhanced densities.

Figure 3 shows the time rate of change of TEC determined from 30 sec samples of TEC provided by the GPS receivers at Westford, MA. In the midnight time frame (around 0600 UT) the time rate of change as large as ±9 TEC units were observed. Such large magnitudes are probably due to the intrusion of the auroral oval around Westford, MA, that introduces large irregularity amplitude and ionospheric drifts. Such large TEC fluctuations are expected to impact the WAAS system. In the afternoon sector, the TEC was much larger than that in the midnight sector but TEC fluctuations amounted to ±3 TEC units perhaps because of a combination of smaller irregularity amplitudes and ionospheric drifts.

Figure 4 shows the onsets of scintillations at middle latitudes and in the equatorial anomaly region seen during the Bastille Day storm of July 15, 2000. The diagram shows that following the sharp decrease of SYM-H at 2000 UT on July 15, 2000, illustrated in the top panel, Hanscom AFB, MA, recorded the onset of 250 MHz scintillation at 2012 UT on a geostationary satellite link with 350-km intersection of 39^o N lat, 74.7^o W long. The bottom panel shows that Ascension Island (7.9^o S, 14.4^o W) observed the onset of 250 MHz scintillation at 2027 UT from a satellite parked overhead of the station. The onsets of scintillation at Hanscom AFB and Ascension Island within about ten minutes establish the prompt penetration of eastward electric field from mid-latitudes to the equatorial region. The spaced receiver 250 MHz scintillation drift measurements (not shown) made at Ascension Island showed westward drift of 400 ms^{-1} after the impulsive onset of scintillation. Near the magnetic equator during the post-sunset period, the drift is normally eastward. The large westward drift is attributed to the ionospheric disturbance dynamo induced by storm-time Joule heating at high latitudes. These drift results have been discussed in detail in [2] in the context of satellite in-situ measurements.

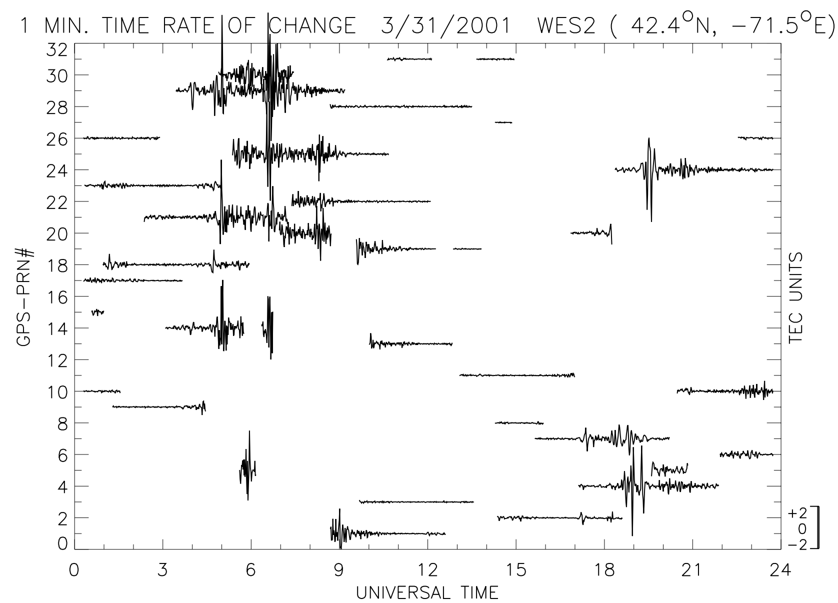

Figure 3. The time rate of change of TEC in TEC units (10^{16} el m^{-2}) min^{-1} using data shown in Figure 2.

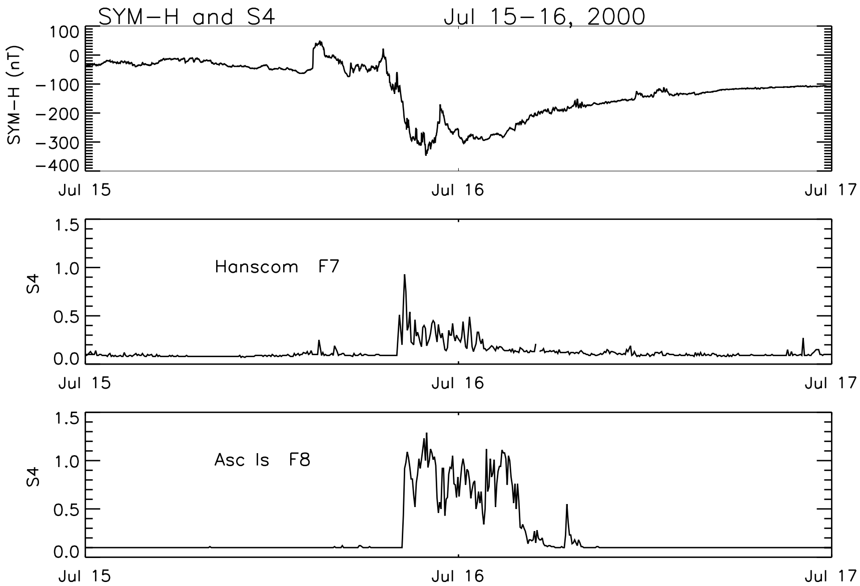

Figure 4. Scintillations at 250 MHz observed from geostationary satellites at Hanscom AFB, MA, and Ascension Island plotted against SYM-H for July 15-16, 2000.

REFERENCES

[1] Su. Basu, et al., "Ionospheric effects of major magnetic storms during the International Space Weather period of September and October 1999: GPS observations, VHF/UHF scintillations, and in-situ density structures at middle and equatorial latitudes", *J. Geophys. Res., 106*, pp. 30,389-30,413, 2001a.

[2] S. Basu, et al., "Response of the equatorial ionosphere in the South Atlantic region to the magnetic storm of July 15, 2000", *Geophys. Res. Lett., 28*, pp. 3577-3580, 2001b.

[3] J.C. Foster, "Storm time plasma transport at middle and high latitudes", *J. Geophys. Res., 98*, pp. 1675-1689, 1993.