Near-simultaneous plasma structuring in the midlatitude and equatorial ionosphere during magnetic superstorms


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Near simultaneous formation of ionospheric plasma density structures at middle and equatorial latitudes during the intense magnetic storms of October 29–31, 2003, July 15, 2000, and March 30–31, 2001 is investigated. The evolution of these structures is explored by measuring amplitude scintillation of satellite signals at 250 MHz, determining zonal irregularity drifts and by detecting equatorial plasma bubbles with DMSP satellites. During abrupt decreases of SYM-H (1-minute resolution Dst) that signify the penetration of high latitude electric fields, an impulsive onset of scintillation occurs at Hancom AFB (HAFB), a sub-auroal location, as well as in the equatorial region where the early evening period corresponds to the time of scintillation onset at midlatitudes. The onset of equatorial scintillation is delayed from that at midlatitudes by about 20 minutes which can be accounted for by considering instantaneous electric field penetration and plasma instability growth time of equatorial irregularities.

1. Introduction

During major magnetic storms the electric field imposed on the high latitude ionosphere almost instantaneously penetrates to middle and low latitudes on both the dayside and the nightside [Abdu et al., 1991; Fejer and Scherliess, 1997; Sastri et al., 2002] and is theoretically predicted to be damped on timescales of the order of tens of minutes due to an electrodynamic reaction of the magnetospheric plasma known as “shielding” [Southwood, 1977; Richmond and Lu, 2000]. Measurements of Wygant et al. [1998] on the CRRES satellite during the March 24, 1991 storm indicated that the large scale magnetospheric electric field penetrated into the inner magnetosphere between L = 2 and L = 4 when the rate of change of Dst was −50 nT/hr indicating fast ring current enhancement. The storm-time penetrating electric field can profoundly affect the distribution of plasma density in the ionosphere and can set-off or suppress plasma instabilities and create irregularities over a wide range of scale sizes ranging from tens of km to tens of m. Earlier work by Aarons [1991] showed the relationship between equatorial scintillation and the ring current during magnetic storms. More recently Basu et al. [2001a] found that when the rate of change of Dst exceeded −50 nT/hr during moderate storms, an abrupt onset of scintillation of 250 MHz signals from a geostationary satellite occurred at a midlatitude station with L = 2.8. The associated equatorial scintillation was observed in the longitude sector for which the early evening period corresponded to the time of rapid Dst variations and maximum Dst phase. In addition, during magnetic storms Joule heating at auroral latitudes causes a change in the global circulation pattern in the thermosphere and the ionosphere to give rise to an ionospheric disturbance dynamo [Blanc and Richmond, 1980; Fuller-Rowell et al., 2002; Fejer and Emmert, 2003]. The changes in the plasma density distribution and the formation of plasma density irregularities in the ionosphere during magnetic storms affect the propagation of transionospheric radio signals and can severely impact satellite communication and navigation systems.

2. Observations

the midlatitude and equatorial ionosphere were studied from both ground and space based measurements. The ground segment at midlatitudes comprised of 250 MHz scintillation measurements at HAFB (350-km ionospheric intersection at 39°N, 74.7°W, diplot 1.0°N) on the magnetic equator and at Ascension Island (7.9°S, 14.4°W, diplot 16.8°S) near the southern crest of the equatorial anomaly were used. At Ascension Island the spaced receiver scintillation measurements provided the zonal drift of plasma density irregularities and this result was used to determine the effects of the ionospheric disturbance dynamo on the zonal plasma drift in the equatorial region.

The continuous scintillation measurements made by the AFRL scintillation network were useful for tracking the onset of scintillation at middle and equatorial latitudes and determining its relationship to electric field penetration during ring current enhancements and fast decreases in SYM-H. In the absence of stations at particular longitudes, the ground segment was supplemented by the ion density data from the sun-synchronous polar orbiting DMSP satellites (at 840 km with an inclination of 97.8°) to determine the presence of equatorial plasma bubbles [Basu et al., 2001b].

3. Results and Discussions

Figure 1a shows the variation of SYM-H during the storm period of October 29–31, 2003 and Figure 1b shows the scintillation index S4 at 250 MHz recorded at HAFB from a geostationary satellite. The first impulsive onset of scintillation occurred at 0730 UT with a maximum value at 0940 UT in concert with a sharp decrease of SYM-H after 0700 UT that corresponds to a rate of change of Dst of −90 nT/hr. The other two scintillation onsets shown in Figure 1b at 1930 UT on October 29 and 1935 UT on October 30 occurred during sharp decreases in SYM-H. Thus the impulsive onsets of irregularity generation at sub-km scales, that cause 250 MHz scintillation, were observed at HAFB during rapid decreases of SYM-H signifying the penetration of high latitude electric fields. However, at this time the auroral oval also expanded equatorward and engulfed this sub-auroral station at L = 2.8 and hence the impulsive onset of scintillation at HAFB is attributed to auroral irregularities [Basu et al., 2005].

Figure 1c shows that Ancon located near the magnetic equator at 75°W did not observe any scintillation at the 350-km intersection point of 10.9°S, 78.7°W during the
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Electric fields
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Figure 3. Same as Figure 1 but for July 15–16, 2000.

Figure 4. Same as Figure 1 with only Hanscom scintillation data for March 31–April 1, 2001.
equatorial region at Ascension Island (14.4°W) and Figure 3c shows that the scintillation onset was indeed recorded there 15 minutes after the onset at HAFB. This delay is probably caused by the plasma instability growth time for equatorial irregularities as mentioned earlier. Figure 3e also shows that the irregularity drift was westward at the time of the onset of equatorial scintillation.

[11] Figure 4 shows (a) the variation of SYM-H during the March 31, 2001 storm and (b) the S4 index of 250 MHz scintillation recorded at HAFB. Two scintillation events occurred on March 31. The first event commenced at about 0500 UT during the main phase of the storm between 0400 UT and 0812 UT that encompassed the local midnight period. For the first event at about 0500 UT, the equatorial irregularities are expected at a longitude of about 225°E where at this time the post-sunset period of 2000 LT will prevail. Figure 2b shows that indeed as expected the DMSP F-15 satellite detected a deep plasma density depletion at 840 km around the magnetic equator at 197°E. On this day no bubbles were detected by the DMSP satellite at other longitudes. The second scintillation event at HAFB is comprised of three short bursts of scintillation, at about 1800 UT when SYM-H decreased during the recovery phase of the storm. Foster et al. [2002] have shown that during this local afternoon event a westward convecting plume of much enhanced total electron content (TEC) formed at middle latitudes and extended from the southeast to the northwest.

[12] It is significant to note that no irregularities were detected by Ancon at 79°W longitude sector during these three intense magnetic storms. The electric field penetration occurred at a time that did not correspond to the sunset period in this sector that provides steep longitudinal gradient in the ionospheric conductivity necessary for the irregularity generation. As such, models based only on observations at one particular longitude may not account for the global response of the equatorial ionosphere. Further, it is interesting to note that the onset of equatorial irregularities during the post-sunset period could occur when the disturbance dynamo conditions prevailed, contrary to model predictions [Fejer and Scherliess, 1997]. The Halloween storms have provided us with a unique opportunity to study the ionospheric plasma structuring and dynamics during distinct electric field penetration events. We hope that the results presented in the paper on the ionospheric response to the main phase of magnetic storms will provide the essential input to coupled ionosphere-magnetosphere models currently undergoing development.


References

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