AN INVESTIGATION INTO THE GEOMAGNETIC AND IONOSPHERIC RESPONSES DURING THE MAGNETIC ACTIVITY OF APRIL 6-7. 2000

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ABSTRACT

A study of geomagnetic storm of April 6-7, 2000 and its ionospheric response is presented. Investigation of the geomagnetic storm was made using measured parameters of the solar wind: plasma temperature, plasma speed, proton density and electric field; the B_z component of the embedded interplanetary magnetic field (IMF) and the corresponding D_{st} and A_p indexes during the period April 1-11, 2000. The ionospheric response to this storm was evaluated using the normalized deviation of the critical frequency of F2-layer, $\partial(foF2)$, for four ionosonde stations in the North American sector. The sudden and pronounced changes in the solar-wind parameters and the D_{st} plot which shows the absence of an initial phase after the SSC suggests that the probable cause of the storm was of CME origin. With a peak D_{st} index of -288nT and an A_p index of 300nT, the storm was single-step but intense. ∂foF2 plots indicate a predominantly negative storm with depletion occurring in all the selected stations. This indicates simultaneity in the F2-region response. Recovery was spontaneous across the stations.

Key words: Interplanetary Magnetic Field (IMF), solar wind, geomagnetic storm, storm-time disturbance index (D_{st}), planetary magnetic index (A_p)

Introduction

A geomagnetic storm is a temporary disturbance of the Earth's magnetosphere caused by a disturbance in the interplanetary medium due to a solar coronal mass ejection (CME) or a high speed stream of the solar wind originating from a region of weak magnetic field on the Sun's surface (Burlaga et al. 1982; Chen and Garren. 1993; Tsurutani et al. 1995; Chen et al. 1995. 1996; Chen, 1996; etc.). The dominant interplanetary phenomena causing intense magnetic storms are the interplanetary manifestations of fast coronal mass ejecta (CMEs). Two interplanetary structures are important for the development of such class of storms, involving an intense and long duration Bz component of the IMF: the sheath region just behind the forward shock, and the CME ejecta itself. The primary part of the dense gas might contain what can be called magnetic cloud structure (Klein and Burlaga, 1982). The magnetic cloud is a region of slowly varying and relatively strong magnetic fields with exceptionally low proton temperature and plasma beta (Tsurutani and Gonzalez, 1995; Chen et al, 1997; Farrugia et al, 1993). During solar maximum, the sun's activity is dominated by flares and erupting filaments and their associated coronal mass ejecta (Burlaga et al, 1982; Chen, 1996; Chen and Garren, 1993; Gonzalez et al, 2001; etc). Small-scale coronal holes are present at middle and low solar latitudes, and typically do not extend from the poles to the equator as often happens in the descending phase of the solar cycle. However, Gonzalez et al (2001), Srivastava et al, (2000), Blanco-Cano and Bravo (2001) have suggested possible roles of these small coronal holes in geo-effective solar activity. As fast-moving materials from a CME flows away from the Sun, it piles up against slower-moving gas that had been ejected earlier. This produces a sharp, dense shock front. The shock wave from the eruption on April 4, 2000 traveled two days through interplanetary space before reaching Earth. The IMF structures leading to intense magnetic storms have an intense and long duration southward component (Gonzalez and Tsurutani. 1987). Such a configuration tends to increase the coupling between the solar wind and the magnetosphere with the result that relatively more solar wind energy can enter the magnetosphere (Chaman-Lal., 2000).

On the night of April 6-7, 2000, one of the largest solar eruptions of the 21st century manifested on Earth, flooding its ionosphere with energetic particles and creating the widest sighting of aurora borealis for many years. The solar storm, caused by an enormous flare thrown out by the Sun as it approached its eleven-year peak of sunspot activity, measured G4 event on a scale of 1 to 5, threatening satellite communications and power grids.

Data and method

Figure1a(i-iii) and 1b(i-iv) shows measured parameters of solar wind: plasma temperature; plasma speed, electric field; the B_z component of the imbedded Interplanetary Magnetic Field (IMF), proton density, and the corresponding D_{st} and A_p indexes respectively for the period April 1-11, 2000. These data were obtained from the National Geophysical Data Center's SPIDR/OMNI websites (http//spidr.ngdc. noaa.gov and http//nssdc.gsfc.nasa.gov/ omniweb).

Ionospheric data used in this study were obtained from four National Geophysical Data Centers SPIDR global networks of ionosonde stations. These stations are located in the North American Sector. The ionospheric stations under analysis include three high latitude stations of Sondrestrom (66.9^{0}N), Gakona (62.4^{0}N), and Nassarssuaq (61.2^{0}N), and one mid-latitude station of Millstone Hill (42.6^{0}N). This classification is based on their latitudinal coordinates: high latitude stations are stations whose latitudinal coordinates are greater than or equal to 58.5^{0}N, while mid- latitudes are those with latitudinal coordinates of between 20.0^{0}N and 58.0^{0}N.

The criteria used in selecting the station a such that the storm variations represent re changes in electron density, not simp redistribution of the existing plasma, and th the storm sudden commencement did n coincide with sunrise at the statio (Chukwuma, 2003a). The second criterion necessary because the arrival of sunrise marked by a rapid increase in electr concentration and a less rapid increase in i concentration at all latitudes.

The data being analyzed consists hourly values of f_oF2 and spans seven day (April 2-8), inclusive of the storm day. Th stations are highlighted in Table 1.

The F2-region response to geomagnet storms is best described in terms of th normalized deviations of the critical frequenc foF2 (i.e. *∂(foF2)* from a referenc value(Chukwuma, 2003a) :

$$\partial(foF2) = [f_oF2 - (f_oF2)_{ave}] / (f_oF2)_a$$

The use of *∂(foF2)* rather than the criti frequency itself provides a first-order correcti for temporal, seasonal and solar cy variations.

Hence, *∂(f_oF2)* is calculated, from th respective hourly values of foF2, for Ap 6-8, 2000. The reference for each hour is t average value of foF2 for that hour calculat from the four quiet days preceding the S (i.e. April 2-5, 2000).

Previous studies have shown that so multiple-step storms did have their mai recovery phase lasting up to 48 hours or mo by determining *∂foF2* for a period of betwe 12 hours to 24 hours preceding the SSC and hours to 72 hours after SSC, the moment a the duration of depletion (or enhancement) foF2 could easily be observed on a *∂foF2* pl

Table 1: selected ionosonde stations in the North-American sector and their coordinates

STATIONS	GEOGRAPHIC CO-ORDINATES	DIFFERENCE BTW LST AND UT (Hours)	Local Time AT SSC (Hours)
SONDRESTROM	66.9^0N, 50.9^0W	-4	01:00
MILLSTONE HILL	42.6^0N, 71.5^{0W}	-5	00:00
GAKONA	62.4^0N, 145.2^0W	-10	20:00
NARSSARSSUAQ	61.2^0N, 45.4^0W	-3	02:00

esults and discussions

terpretation of Data Plots

eomagnetic Response

ıe flow speed plots show a slow speed stream around 400 km/s until around 16:00 UT of oril 6, 2000. The stream got to a peak value of ound 625 km/s at 09:00 UT on April 7, 2000. ıis high value of solar wind speed marks the rival of a shock at the interplanetary medium d the start of storm sudden commencement at ':00 UT on April 6, 2000 and it is accompanied ' a steep increase in plasma temperature from average of 85881K to 345986K. As expected, e orientation of the interplanetary magnetic eld, B_z, point southward, i.e. anti-parallel to the ırth's magnetic field, at the moment of the ock arrival. The D_{st} plot shows that the storm d not exhibit the ideal magnetic storm features which all the four phases are present. The SC which started at about 17:00 hrs on April 6, 00 is marked by a small, sudden but brief crease in D_{st} compared with the average for the eceding 5 days. The sudden and pronounced ıanges in the solar-wind parameters and the D_{st} ot which shows the absence of an initial phase ter the SSC suggests that the probable cause of e storm was of CME origin (Gonzalez and surutani, 1987; Srivatava and Venkatakrishnan, 998). The main phase began immediately after SC as result of the high ring-current-induced agnetic field compression. The D_{st} got to a eak value of -288 nT at 00:00 (UT) April 7 and opear to mark the end of the main phase. The covery phase which is due to the loss of ring-ırrent ions resulting from charge exchange with e neutral exosphere was immediate and adual, and continued for the next 36 hours.

The storm of April 6-7, 2000 has an IMF B_z component that swing southward at 17:00 UT on April 6 and stayed that way until 10:00 UT April 7 when it recovered slightly and swings northward but not really crossing the positive threshold. Almost immediately thereafter, it swings southward again and stayed that way for about 10 hours. According to Danilov (2001), a storm caused by the southward swing of B_z for more than 3 hours is an intense storm. Clearly, the storm of April 6-7, 2000 was a very intense storm.

The electric field, which before the storm sudden commencement, was alternating between positive and negative values of low magnitudes (<~5 mV/m), suddenly increased in amplitude in both directions a few hours before the storm but thereafter stabilizes at a low amplitude but stayed positive for a greater part of the storm. The sudden increase in the electric field coincides with an increase in proton density, which in turn marks the arrival of shock in the interplanetary medium.

The planetary geomagnetic index, A_p, peaked precisely at about the same time as the D_{st}, although, as expected, in the opposite direction. This is a further confirmation of the storm sudden commencement and of the severity of the storm.

Ionospheric Response

The arrival of the shock at 17:00 UT on April 6, 2000 corresponds to 01:00 hour, 00:00, 20:00 hour and 02:00 hour local times for Sondrestrom, Millstone Hill, Gakona and Narssarssuaq respectively. This means that the storm sudden commencement, as registered by the stations. did not coincide with sunrise (Chukwuma. 2003a. 2003b).

Figure 2(i-iv) shows the plots of $\partial foF2$ values for the four selected ionosonde stations under investigation and indicate the ionospheric responses at these stations. The $\partial foF2$ plot for the mid latitude station of Millstone Hill did not quite register the same level of depletion of the F2-layer compared with the three high latitude stations. The onset of SSC as indicated by ∂foF2 for Millstone Hill, Nassarssuaq and Gakona was well defined but this is not quite the case with Sondre strom.

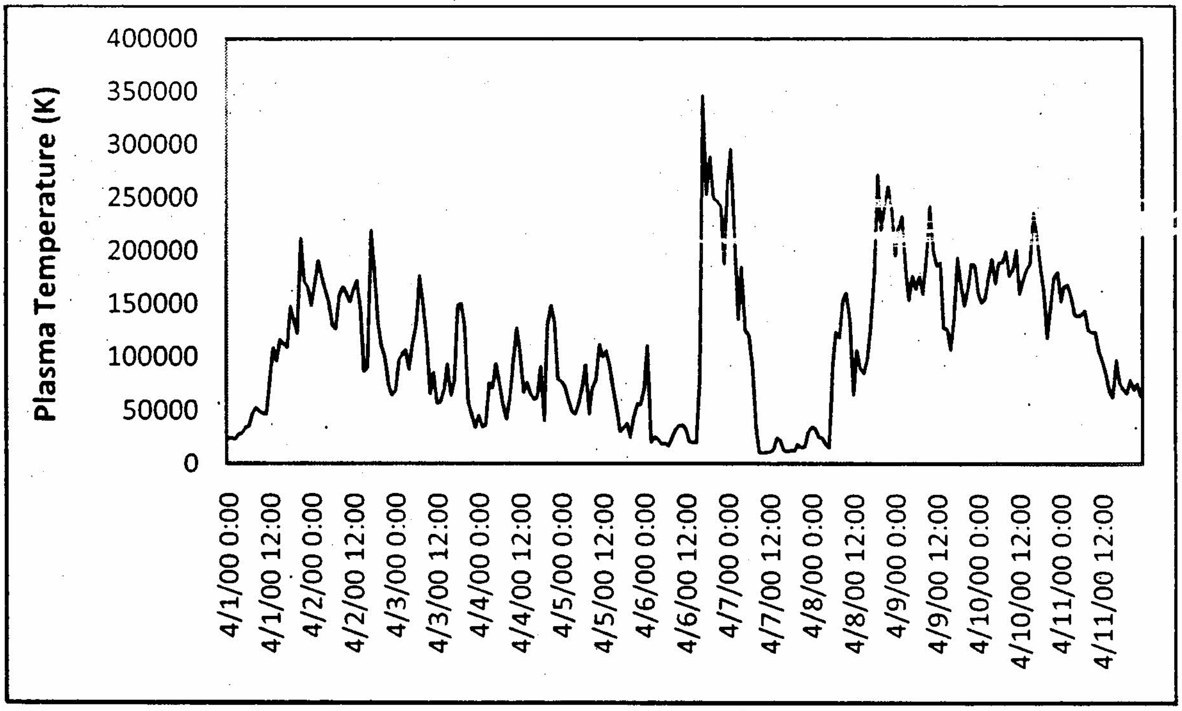
According to Danilov (2001), if there is more than 10% depletion or enhancement in the value of ∂foF2, then there is a storm. With a depletion percentage of more than 30%, i.e. a ∂foF2 value of <-30, for the high latitude stations, the storm was a predominantly negative storm. It is observed that the high latitude station of Sondrestrom, Gakona and Narssarssuaq recorded a high degree of depletion (~-40%) and the mid latitude station of Millstone Hill recorded a lower degree of depletion (~-10%) but of much longer duration than the other three. In the case of Gakona, the depletion peak was of a short duration but coincides precisely with the onset of the storm. For the other high latitude stations, the peak is of much longer duration.
The $\partial foF2$ plots show a very similar trend for all the selected stations. In particular, the storm sudden commencement is marked by a steep negative swing of $\partial foF2$ at about the same time and the depletion increases from mid to high latitude as expected (Chukwuma, 2007).

In summary, the ionospheric response wa spontaneous and pronounced. It is noted th prior to the arrival of the shock, the station particularly the low latitude ones, registered a enhancement of the *foF2* which abruptly turn depletion about 8 hours before SSC. The storm is single-phase but very intense and lasted abou 36 hours. Recovery was immediate ar spontaneous for all the stations. Clearly, there spontaneity and simultaneity in the ionospher response to this storm for all the selecte stations.

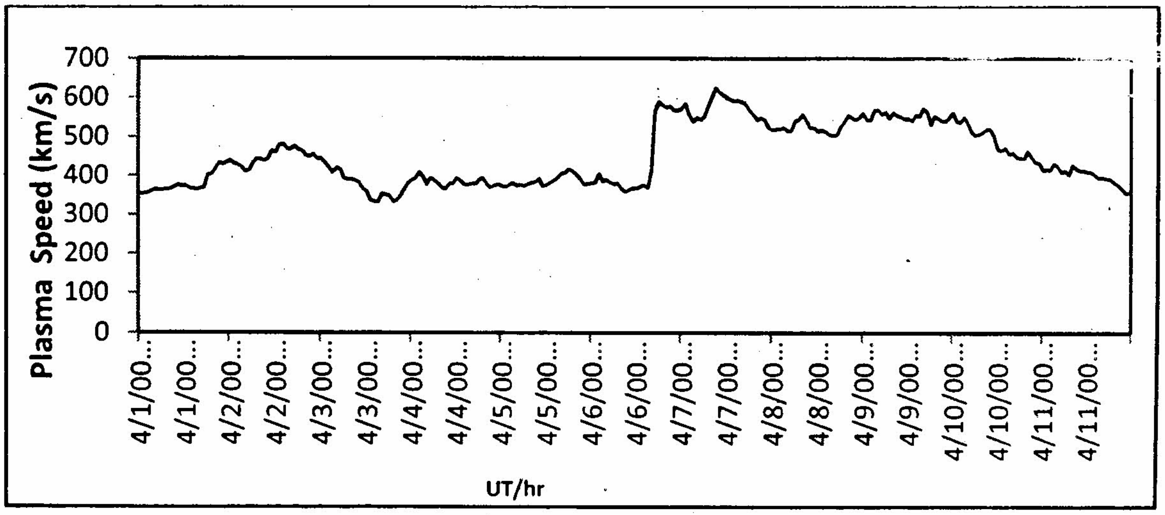
Conclusion

This study has presented a picture of tl interplanetary phenomenon, the geomagnet and ionospheric responses associated with tl storm of April 1-11, 2000. The study was bas on measured parameters of solar wind plasm the B_z component of the interplanetary magne field, IMF, and the corresponding D_{st} and . indexes for the period April 1-11, 2000. T main results of this study are summarized follows:

- The depletion of *foF2* occurred in all the stations. This indicates simultaneity in the F2 region response, which is in agreement with the suggestion of Chukwuma (2003b) of the storm of March 20-21, 1989.
- Recovery was spontaneous across the stations.
- It was an intense storm
- It was a single-step storm

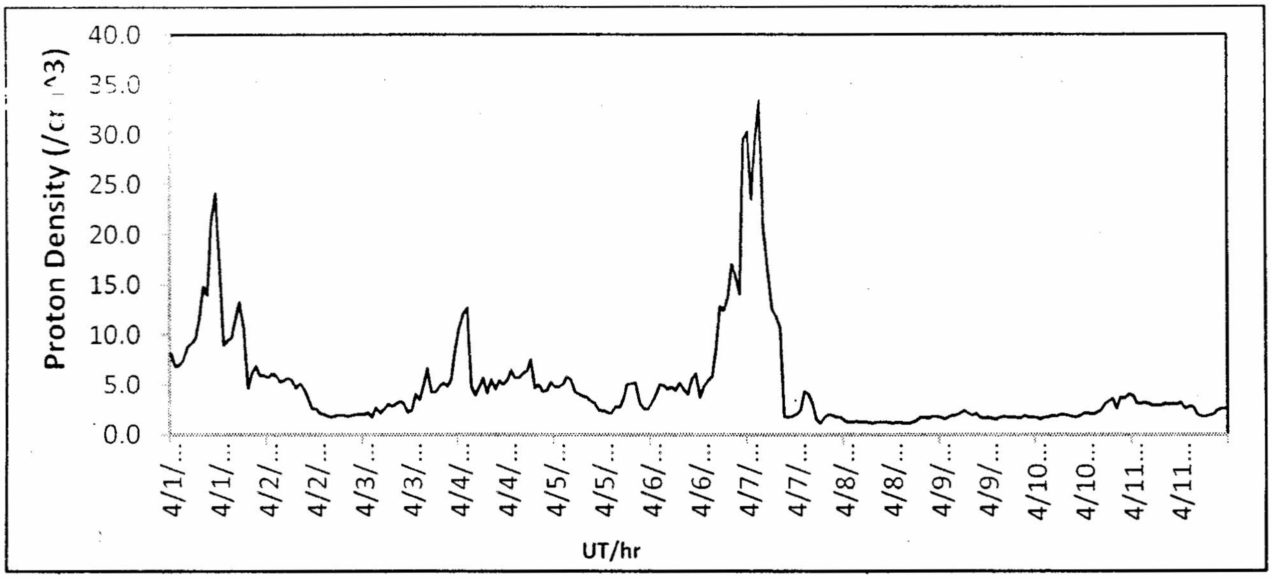

Plasma Temperature (K)
400000
350000
300000
250000
200000
150000
100000
50000
0
4/1/00 0:00
4/1/00 12:00
4/2/00 0:00
4/2/00 12:00
4/3/00 0:00
4/3/00 12:00
4/4/00 0:00
4/4/00 12:00
4/5/00 0:00
4/5/00 12:00
4/6/00 0:00
4/6/00 12:00
4/7/00 0:00
4/7/00 12:00
4/8/00 0:00
4/8/00 12:00
4/9/00 0:00
4/9/00 12:00
4/10/00 0:00
4/10/00 12:00
4/11/00 0:00
4/11/00 12:00

(i)


Plasma Speed (km/s)
700
600
500
400
300
200
100
0
4/1/00...
4/1/00...
4/2/00...
4/2/00...
4/3/00...
4/3/00...
4/4/00...
4/4/00...
4/5/00...
4/5/00...
4/6/00...
4/6/00...
4/7/00...
4/7/00...
4/8/00...
4/8/00...
4/9/00...
4/9/00...
4/10/00...
4/10/00...
4/11/00...
4/11/00...
UT/hr

(ii)

(iii)



(iv)

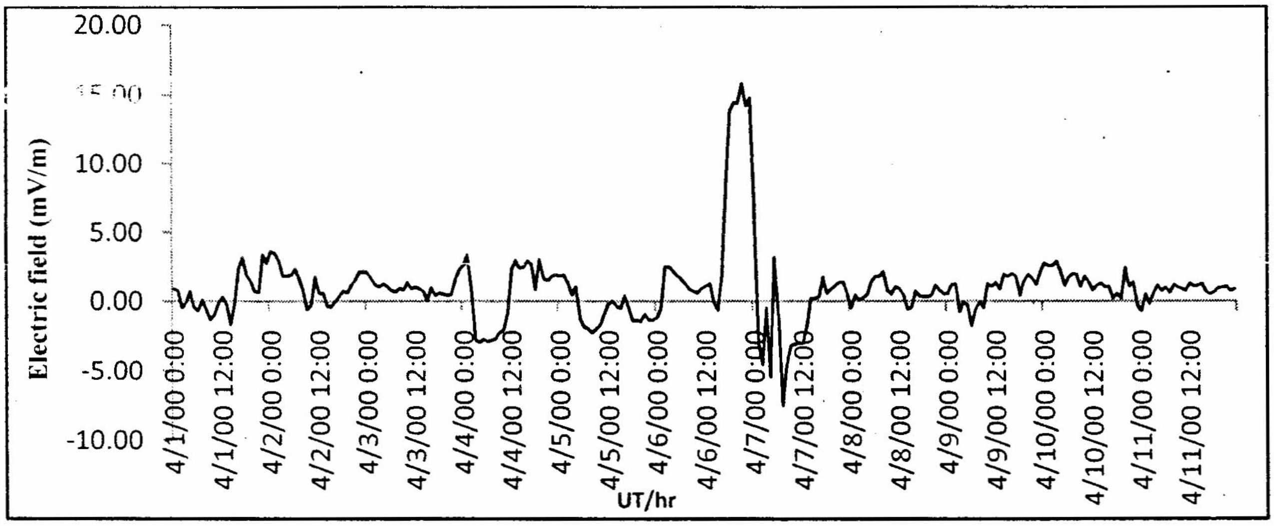


Fig. 1a(i-iv): Plots of Hourly Values of Plasma Temperature and Speed, Proton Density and Electric Field
During April 1-11, 2000 for the Storm of April 6-7, 2000.

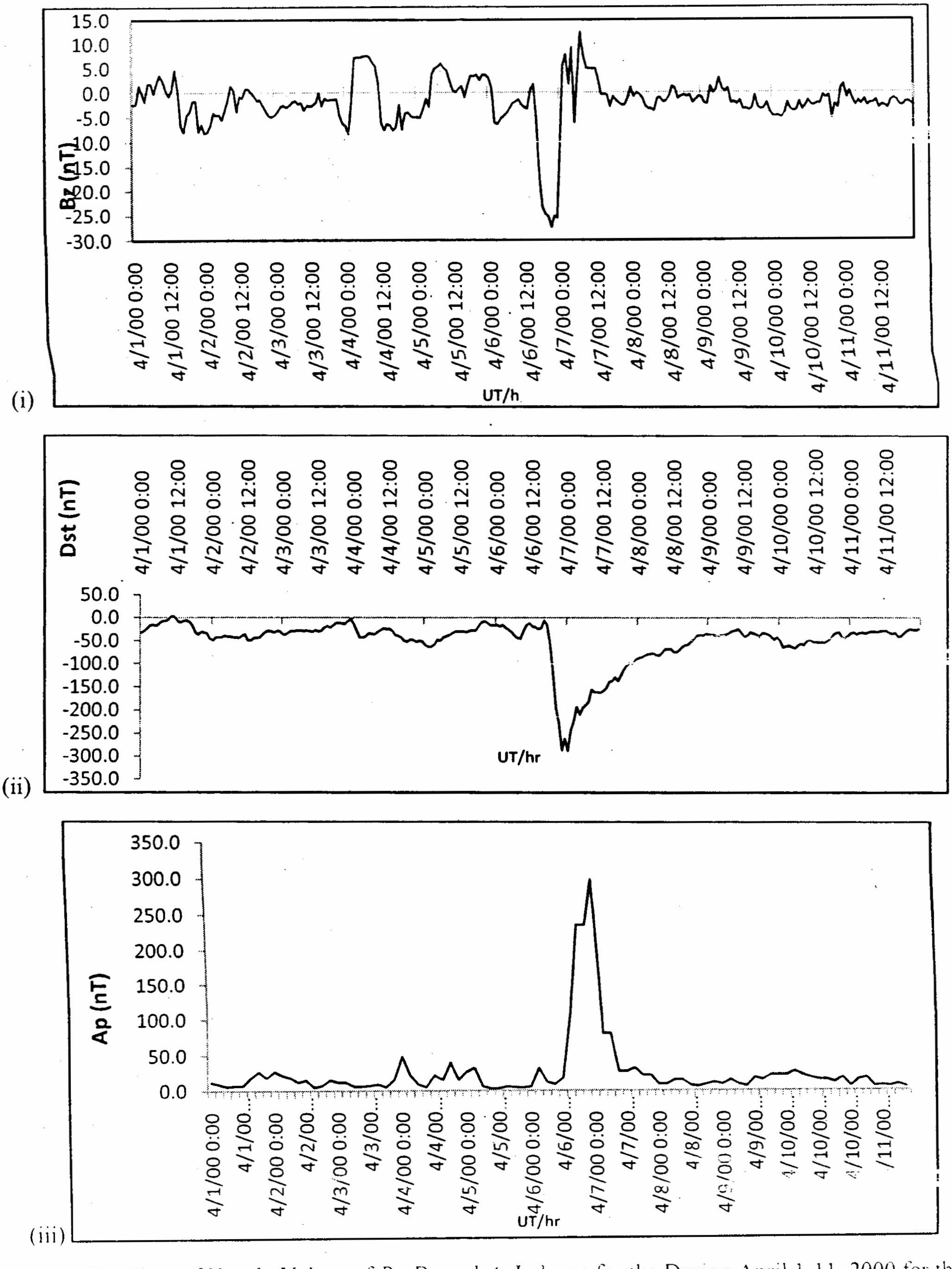
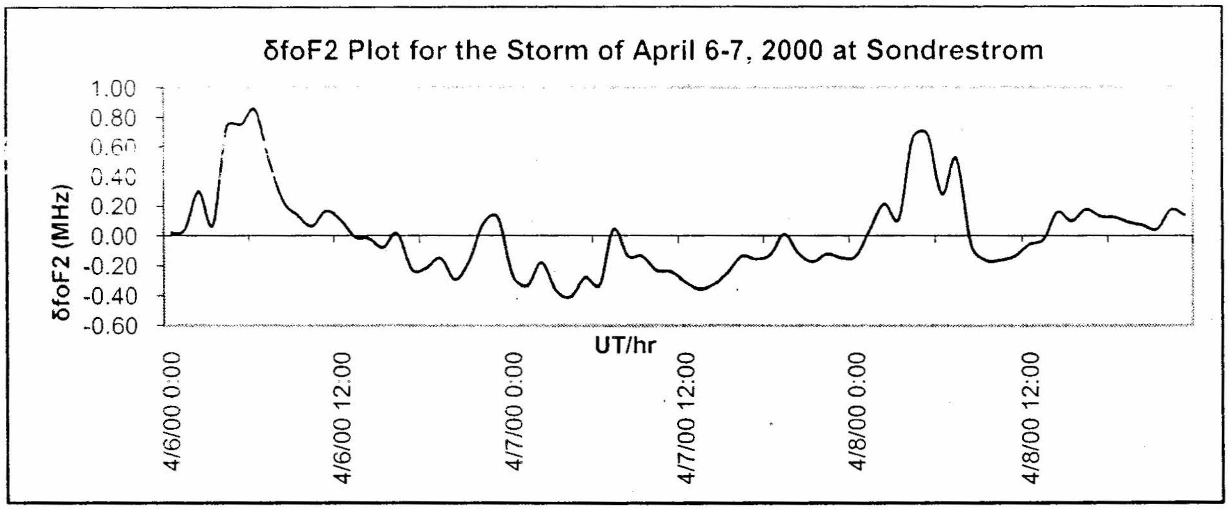
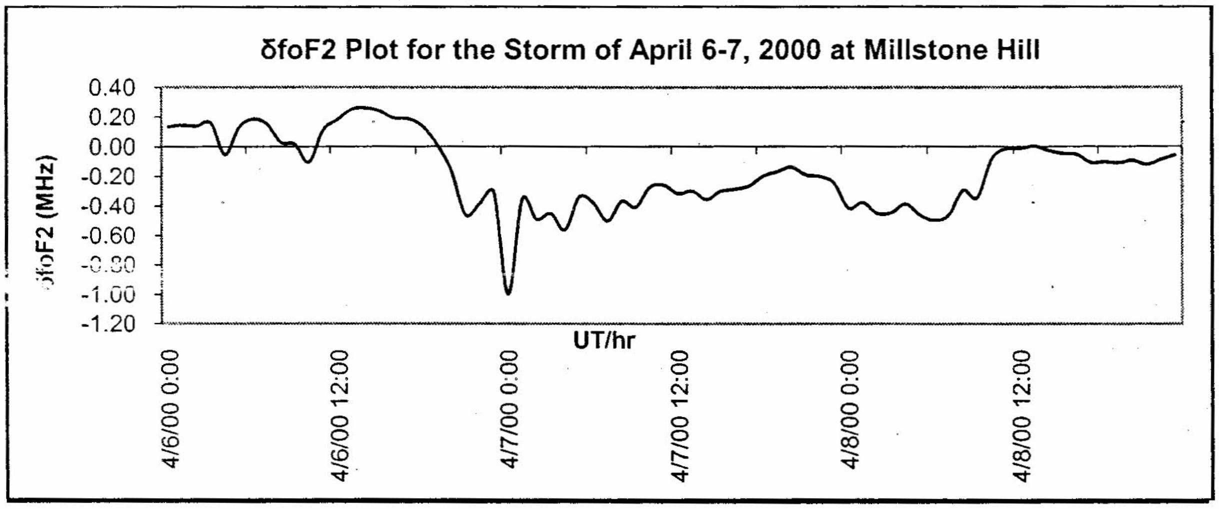


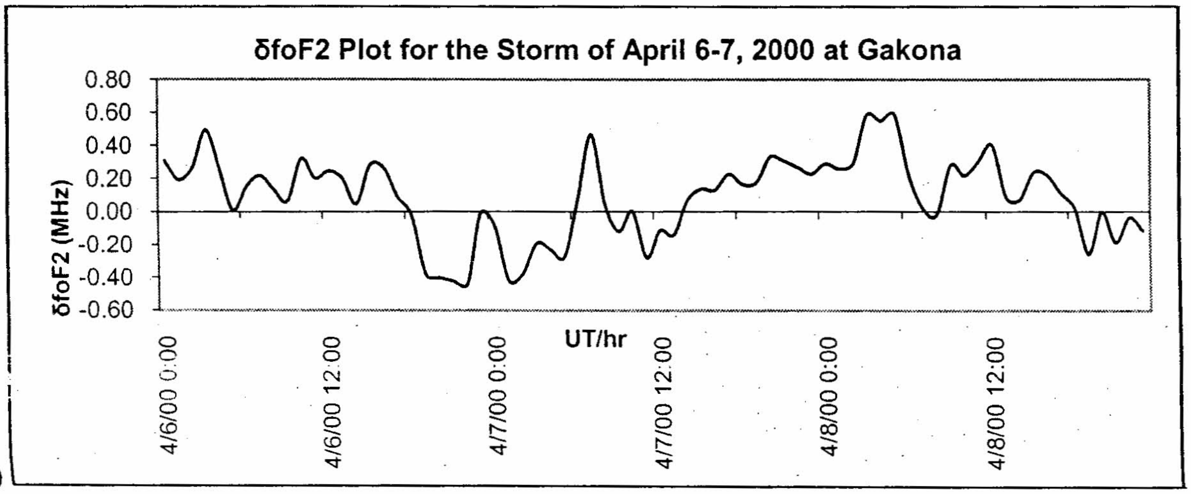
Fig. 1b(i-iii): Plots of Hourly Values of B_z, D_{st} and A_p Indexes for the During April 1-11, 2000 for the Storm of April 6-7, 2000.


δfoF2 Plot for the Storm of April 6-7, 2000 at Sondrestrom
1.00
0.80
0.60
0.40
0.20
0.00
-0.20
-0.40
-0.60
δfoF2 (MHz)
UT/hr
4/6/00 0:00
4/6/00 12:00
4/7/00 0:00
4/7/00 12:00
4/8/00 0:00
4/8/00 12:00

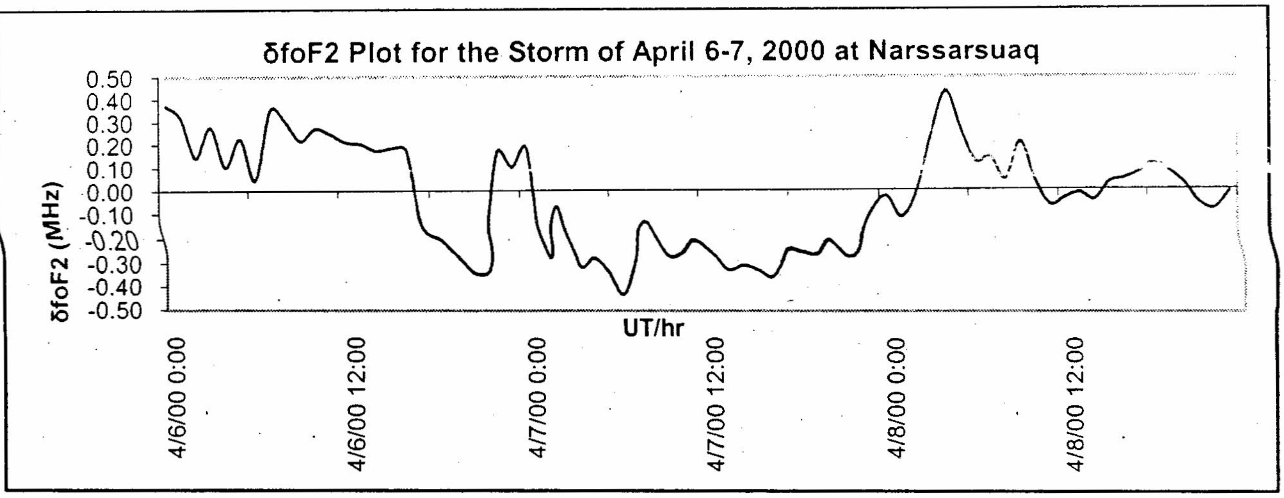
(i)


δfoF2 Plot for the Storm of April 6-7, 2000 at Millstone Hill
0.40
0.20
0.00
-0.20
-0.40
-0.60
-0.80
-1.00
-1.20
δfoF2 (MHz)
UT/hr
4/6/00 0:00
4/6/00 12:00
4/7/00 0:00
4/7/00 12:00
4/8/00 0:00
4/8/00 12:00

(ii)


δfoF2 Plot for the Storm of April 6-7, 2000 at Gakona
0.80
0.60
0.40
0.20
0.00
-0.20
-0.40
-0.60
δfoF2 (MHz)
UT/hr
4/6/00 0:00
4/6/00 12:00
4/7/00 0:00
4/7/00 12:00
4/8/00 0:00
4/8/00 12:00

(iii)



(iv)

Fig. 2(i-iv): Plots of Normalized Deviations of the Critical Frequency (∂foF2) for Four Stations in the North-American Sector

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