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RESPONSE OF THE IONOSPHERE TO INTENSE GEOMAGNETIC STORMS

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ABSTRACT

Recent results of the study of intense geomagnetic storms show that the depletion of f_0F2 was simultaneously worldwide and extended to very low latitudes. In this light, this work investigates the nature of ionospheric response associated with another intense geomagnetic storm of July 13-14, 1982. The investigation used measured parameters of solar wind plasma and imbedded IMF, and f_0F2 data obtained from a global network of ionosondes. The analyses of the results show that contrary to the opinion that intense storm causes depletion in the upper latitude, the upper latitude of Argentine Island showed an intense positive storm (enhancement). In addition, the depletion down the latitude is irregular and also lacked simultaneity

Keywords: Geomagnetic storms, solar wind plasma, magnetosphere, ionosphere

INTRODUCTION

Geomagnetic storms are major disturbances of the magnetosphere that occur when the interplanetary magnetic field turns southward and remain southward for a prolonged time. Storm time ring current is produced during a geomagnetic storm's main phase which can last as long as two or three days, charged particles in the near-earth plasma sheet are energized and injected deeper into the inner magnetosphere.

The extremely hot atmosphere of the sun is made of plasma; that is, it is a gas consisting of charged particles. Solar plasma streams radially into space at high speed and pulls the sun's magnetic field with it. This streaming plasma is the solar wind, which flows out past the earth and affects the earth's magnetic field, the magnetosphere and ionosphere. The solar wind is the supersonic outflow into interplanetary space of plasma from the sun's corona, the region of the solar atmosphere beginning about 4000 km above the sun's visible surface and extending several solar radii into space.

The solar wind is dominated by high speed flows emanating from coronal holes-regions of low coronal density and temperature, where the magnetic field is weak and the field lines are open to interplanetary magnetic space. Variations in the solar wind pressure and interplanetary magnetic field (IMF) can cause significant disturbances in the middle and low latitude ionosphere. Recent results of the study of intense geomagnetic storm show that the depletion of foF2 was simultaneously worldwide and extended to very low latitudes.

In this light, this work investigates the nature of ionospheric response associated with another intense geomagnetic storm of July 13-14, 1982.

MATERIALS AND METHODS

Geomagnetic observation: The interplanetary and geomagnetic parameters used in this study consisted of hourly values of imbedded interplanetary magnetic field (IMF) B_z (in GSM coordinates), the D_{st}, flow speed and the corresponding proton density. These hourly observations were obtained from the NSSDC's OMNI database (http: // nssdc.gsfc. nasa.gov/omniweb) for the storm event of July 13-14, 1982. The interplanetary and geomagnetic observation for this period spanned 13-15 July 1982.

The composition of interplanetary and geomagnetic observations for July 13-15 is shown in figure I. The areas where there is paucity on the plot indicated that no data was available for such periods. The D_{st} plot is the first panel of figure I. Its variation appeared to reveal a slow 12 hour build up that began with gradual commencement at 14: 00 UT on July 13.

Storms could be classified as follows: weak (D_{st}< -50nT), moderate (-50nT< D_{st} < -100nT) and intense (D_{st} < -100nT) (Vieira *et al.,* 2001). According to this classification, the D_{st} plot indicated that around 19:00 UT on July 13, the D_{st} had decreased to a value of -160nT indicating the commencement of an intense storm. However, D_{st} recovered rather abruptly to -130nT at 22:00 UT and thereafter decreased to its minimum peak value of -325nT at 1:00UT on July 14 signifying a very intense storm. D_{st} then began to recover again through July 14 and 15. However, the D_{st} recovery beginning at 3:00UT on July14 was indicative of northward turning B_z, as could be seen on the B_z plot. Geomagnetic activity is known to decrease precipitously whenever IMF is directed northward (Chaman-Lal, 2000).

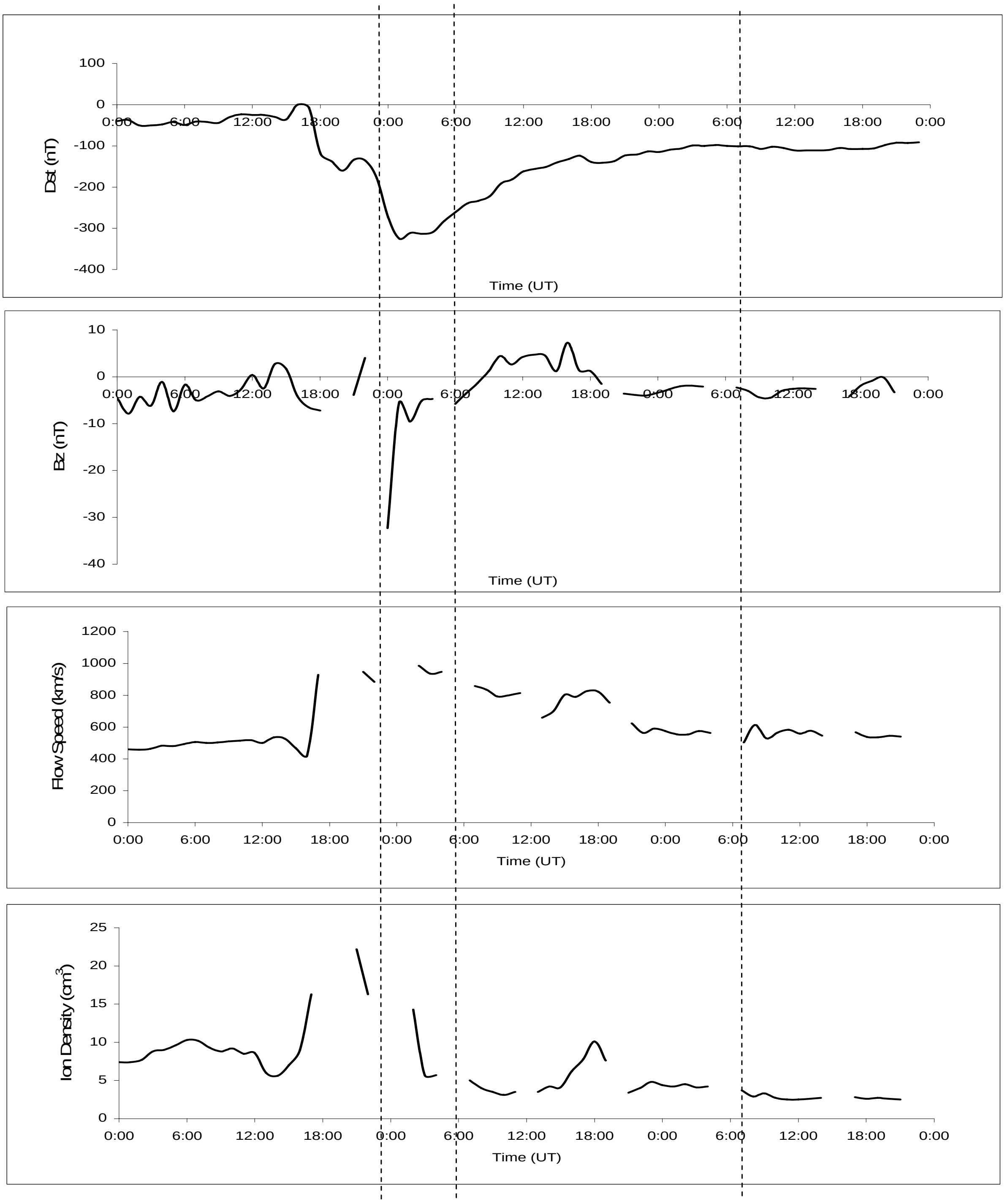

Fig. I: One-hour averages of the solar wind plasma parameter versus Time (in UT) for July 13-15, 1982.

The B_z plot is shown in the second panel of figure I. From the plot, it was observed that there was a southward turning of B_z before 12:00UT on July 13. The minimum peak value of~-33nT observed on the B_z around 0:00UT on July 14 corresponded to the minimum peak value experience on the D_{st} plot. It thereafter rotated northward and finally returned southward around 19:00UT of July 14 and throughout the rest of July 15. According to Gonzalez and Tsurutani (1987), the IMF structures leading to intense magnetic storms have an intense and long duration southward component. Moreover, this B_z value of -33nT experienced is an indication that there is going to be a dramatic enhancement in the geomagnetic activity. According to Chaman-Lal (2000), 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 then enter the magnetosphere.

Shown on the third panel is the plasma flow speed. The plot revealed a low speed stream between 0:00UT and 16:00UT on July 13 and thereafter increased precipitously to a value of 928 km/s around 17:00UT on July 13. It continued in this mode till around 04:00UT on July 14, and thereafter started decreasing. The sudden enhancement in the flow speed rate is an indication of the arrival of a shock in the interplanetary medium. Thus, when the magnetic cloud has a very high speed, that is, if the speed differential between the CME and the slow upstream solar wind is greater than the magnetosonic wave speed (50-70 km/s), it compresses the plasma ahead of it and forms a collisionless shock. Meanwhile, if both the sheath field and the cloud field have the proper orientation, there will be magnetic reconnection from both phenomenon and a 'double storm' will result (Kamide *et al.,* 1998).

The ion density plot in the fourth panel of figure I showed density increasing steadily from 03:00UT July 13 to a value $16.3/cm^3$. Note that the peak value of $22.2/cm^3$ was reached at the instance the plasma speed was about its peak value. The large increase in the proton number density during this period signaled the arrival of a shock in the interactive medium. As a result, the enhanced solar wind flow draws the plasma sheet density leading to the injection of the ring current and this caused the sharp depression in D_{st} within this interval on the D_{st} plot.

RESULTS AND DISCUSSION

The data used in this study consisted of hourly values of foF2 obtained from some of the National Geophysical Data Center's Space Physic Interactive Data Resource (SPIDR) global network of ionosonde stations. These stations are located in the American sector of the world, and they include Argentine Island (64, 4°N), Kiev (50,5°N), Ottawa (45,4°N), Tbilisi (41,7°N), Boulder (40.0°N) and Hoancayo (12.0°N). Tables 1 listed the stations.

Table 1: Ionosonde stations

Stations	Geographic co-ordinates		Difference between Lst and UT (in hours)
	ϕ	λ	
Argentine Island	65.2 °N	295.7 °E	-4
Churchill	58.8 °N	265.8 °E	-6
Winnipeg	49.8 °N	269.6 °E	-6
Ottawa	45.4 °N	284.1 °E	-5
Boulder	40.0 °N	254.7 °E	-7
Huancayo	12.0 °N	284.4 °E	-5

However, the data that was analyzed consisted of D (foF2) of respective hourly values of foF2 on July 13, 14, and 15. The reference for each hour was the average value of foF2 for that hour calculated from the four quiet days, July 8-11, 1982, preceding the storm. The use of D (foF2) rather than foF2 provided a first- order correction for temporal, seasonal and solar cycle variations so that Geomagnetic storm effects were better identified.

From the first panel of figure II, the plot of Argentine Island (64.4°N), which was a high latitude station in the northern hemisphere, an enhancement of the foF2 was observed on the average, but more pronounced around 23:00UT on July 13 to over 200%, before it began to decline gradually and then sharply to a value of ~-0.30 around 13:00UT on July 14 indicating a negative phase storm and returned to positive phase around 13:00UT next day and throughout.

From the plots of second, third and fourth panel of figure II, showing the ionospheric response at the three middle latitude stations of Tbilisi (41.7°N), Kiev (50.5°N) and Ottawa (45.4°N), it was observed that there was an appearance of negative phase storm throughout at these three stations. The paucity on the plot at Ottawa was as a result of absence of data for that time interval.

The response at Boulder (40.0°N), a mid-latitude station and Huancayo (12.0°N), a low latitude station (the fifth and sixth panel respectively), showed an entire positive phase storm (i.e. enhancement in the F2 region).

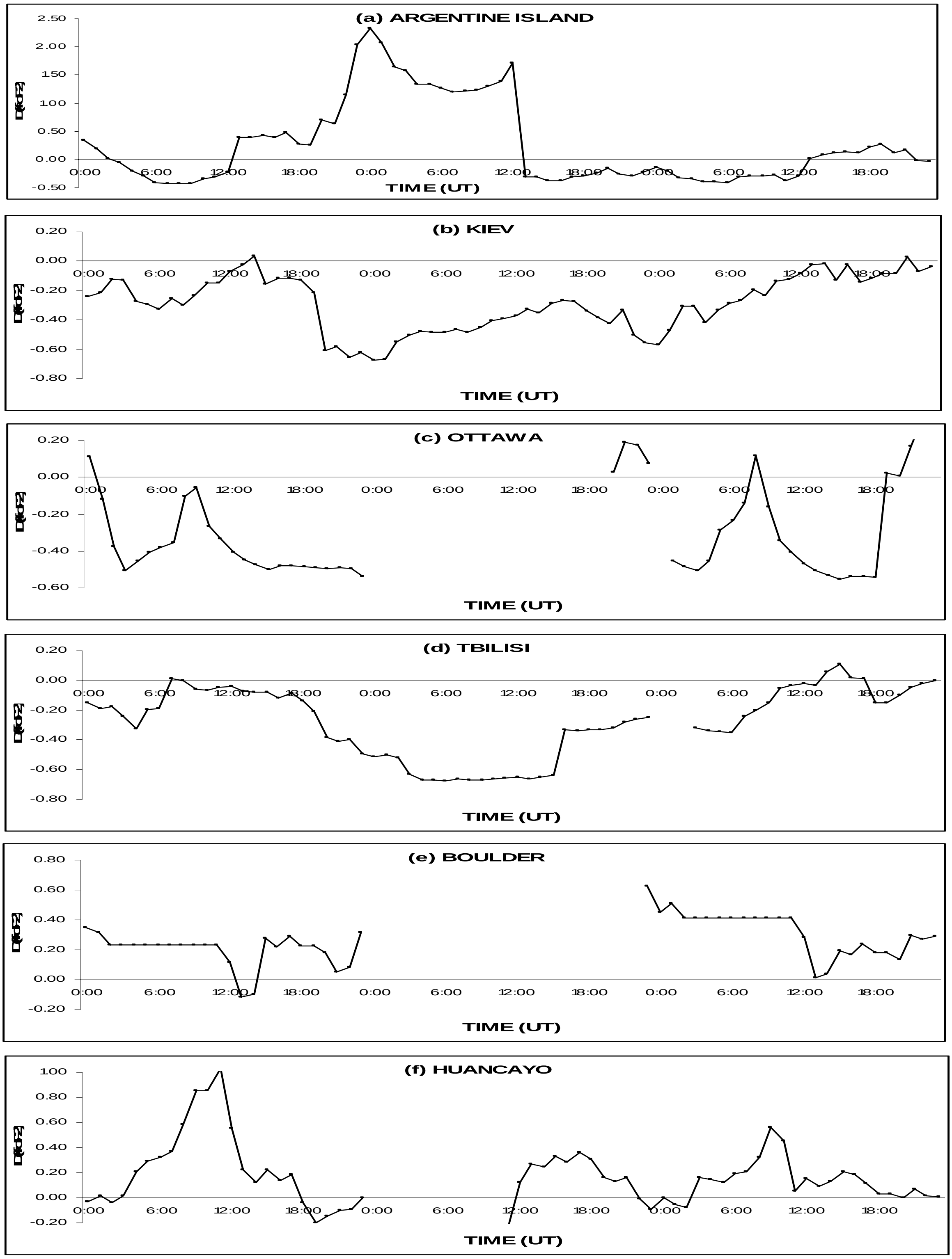

Fig. II: Variation in D (foF2) at American sector at all latitudes during July 13-15, 1982.

The enhancement of foF2 at Argentine Island did not come as a surprise because, according to Chandra and Spencer (1976), at high latitudes, it is very difficult to establish a definite pattern because of increased aurora activity during geomagnetic storm. However, the trends were clearer at middle latitude. Moreover, the enhancement observed at Boulder (in mid-latitude station) could have been produced by world as suggested by Jones and Risbeth (1971). The equator-ward winds lift the ionospheric plasma to high heights at which the electron loss rate is decreased and produces a positive storm.

According to Chukwuma (2003 and the reference therein), positive storm as observed at the low latitude station of Huancayo are most likely caused by equator-ward winds resulting from traveling ionospheric disturbances. The observed decrease in foF2 during this storm events could be related to the decreased in [O] / [N2] at F2 region altitude.

Assuming the thermospheric dynamic regime stayed unchanged during geomagnetic storms, the zone of depleted [O] / [N2] and so electron concentration would be limited by the polar ionosphere. However the heating induces its own circulation, which at F2 height tends to bring the air equator-ward to lower latitudes (Danilov, 2001).

It is important to note that the heated gas with depleted [O] / [N2] ratio in the lower atmospheric triggers a complex chain of reactions in the ionospheric and thermospheric system. This results in the re-distribution of heating and cooling rate, an increase in electron ion and neutral temperature, and a decrease in electron density near F2 peak (Chandra and Spencer, 1976; Danilov, 2001). Nevertheless an equator-ward wind resulting from the heating in the polar region tends to drive the plasma up the field lines were electron loss is decreased process competes with the increased in the loss rate caused by an enrichment of molecular nitrogen and increased temperature. Thus, the increase or decrease of foF2 depends upon the relative effectiveness of the two processes (Chandra and Spencer, 1976).

CONCLUSION

In this work, we have presented an interplanetary phenomenon, a geomagnetic and ionospheric response associated with the storm of July 13-15, 1982. From the study, the following were deduced:

That the storm of July 13-15, 1982 is a single step intense storm (D_{st}= -330nT), whose shock arrival in the interplanetary medium is indicated by the large southward turning of B_z, which in turn leads to increase geomagnetic activity.

In American sector positive ionospheric storm at the upper latitude station of Argentine Island, appearance of the positive storm and in the mid-latitude of boulder in the time of storm.

An intense positive sudden storm enhancement at the low-latitude of Huancayo.

Deletion of fof2 at all latitude lacked simultaneity.

From the above it is concluded that contrary to the opinion that intense storm causes depletion in the upper latitude, the upper latitude of Argentine Island showed an intense positive storm. This may agree with Kelley *et al.* (1979) and Spiro *et al.* (1988) that uplift in the ionospheric layer to higher latitude, where the recombination rate is small is an important mechanism responsible for the positive storm. The driving mechanisms of this uplift are the ion drag effect of the equator ward neutral wind and *ExB* plasma drift due to eastward electric field.

Also, contrary to the general opinion that a very intense storm causes a simultaneous depletion across all latitude with reduction from pole to equator ward. The observation here shows that the depletion lacks simultaneity and irregularity (i.e. undefined magnitude of depletion from pole towards equator).

The general conclusion thus, should follow with Danilov (2001) that the morphology of ionospheric storms is rather complicated. The reaction of the ionosphere as seen at different ionospheric stations may be quite different during the same storm depending on the station coordinates, local time of the magnetic disturbance beginning and some other parameters. The global distribution of ionospheric storm effects is also rather complicated and differs considerably from one storm to another.

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