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# GEOMAGNETIC STORM AND ITS EFFECTS ON THE IONOSPHERIC ENVIRONMENT: A CASE STUDY

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## ABSTRACT

Study and prediction of magnetic storms are becoming increasingly important as they have profound influence on human and societal life. Intense solar flares release very high energy particles that can be as injurious to human as the low energy radiation from nuclear blasts. Ionospheric storms can affect radio communications at all latitudes – some radio frequencies are absorbed and others are reflected, leading to rapidly fluctuating signals and unexpected propagation paths.

Other areas affected by geomagnetic storm include:

- Disruption of defense communication such as early warning radio system
- Erratic behaviour of air and marine navigation instrument
- Current surges in power lines, causing flickering lights and blackouts that result in damage that attracts colossal amount of money.

Seeing that our environment is vulnerable to magnetic storm this paper presents the interplanetary origin of an intense storm and the response of our ionosphere to it.

**Key words**: magnetic storms, solar flares, current surges, ionosphere

## INTRODUCTION

The earth's magnetic environment is rarely quiet, now and then it experiences magnetic storms, a disturbance of the magnetic field observable all around the globe, lasting a few days and adding appreciable to the earth's rapped plasmas. Our environment is seen to be vulnerable to this magnetic storm in the following ways:

### Radiation hazard to humans

Intense solar flares release very-high energy particles that can be as injurious to human as the low-energy radiation from nuclear blasts. Earth's atmosphere and magnetosphere allow adequate protection at ground level, but astronauts in space are subject to potentially lethal doses of radiation. The penetration of high-energy particles into living cells can cause chromosome damage, cancer, and a host of other health problems. Large doses can be fatal on the instant. According to Campbell, (2001), solar protons with energies greater than 30 mega electron volts (MeV) are particularly hazardous. In October 1989, the sun produced enough energetic particles that an astronaut in the moon wearing only space suit and caught out in the brunt of the storm, would probably have died.

### Biological effect

There is a growing body of evidence that changes in the geomagnetic field affect biological systems. Studies indicate that physically stressed human biological systems may respond to fluctuations in the geomagnetic field. Interest and concern in this subject have led the international union of Radio science to create a new commission entitled commission K- electromagnetic in biology and medicine (Davies, 1990).

Possibly the most closely studied of the variable sun's biological effects has been the degradation of homing pigeon's navigational abilities during geomagnetic storms. Pigeons and other migratory animals, such as dolphins and whales, have internal biological compasses composed of the mineral magnetite wrapped in bundles of nerve cells. While this probably is not their primary method of navigation, there have been many pigeon race smashes, a term used when only a small percentage of birds return home from a release site. Because these losses have occurred during geomagnetic storms, pigeons' handlers have learned to ask for geomagnetic alerts and warnings as an aid to scheduling races (Gauthreaux, 1980).

### Disrupted systems in communications

Many communication systems use the ionosphere to reflect radio signals over long distances. Ionosphere storms can effect radio communication at all latitudes. Some radio frequencies are absorbed and others are reflected, leading to rapidly fluctuating signals and unexpected propagation paths. TV and commercial radio stations ate little affected by solar activity, but ground-to-air, ship-to-shore, shortwave broadcast, and amateur radio (mostly the bands below 30 MHz) are frequently disrupted. Radio operators using high frequencies rely upon solar and geomagnetic alerts to keep their communication circuits up and running.

Some military detection or early warning systems are also affected by solar activity. The over-the-horizon radar bounces signals off the ionosphere in order to monitor the launch of aircraft and missiles from long distances. During geomagnetic storms, this system can be severely hampered by radio cluster. Some submarine detection systems use the magnetic signatures of submarines as one input to their locating schemes (Eather, 1980). Geomagnetic storms can mask and distort these signals.

## Geomagnetic observation

The interplanetary and geomagnetic parameters used in this study consist 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 are 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 spans 13-15 July 1982.

It is generally known that geomagnetic storms are the result of the interaction between solar wind and magnetosphere. One striking feature about the solar wind is its organization into high and low speed streams. The main source of geomagnetic activity is not the sunspot activity, but the flow of solar wind past the planet. For intense magnetic storm ( $D_{st} < -100nT$), the solar wind must be substantially higher than the average speed of ≈ 400km/s (Gonzalez et al., 2001).

The composition of interplanetary and geomagnetic observations for July 13-15 is shown in figure 1. The areas where there are paucity on the plot indicate that no data was available for such periods. The $D_{st}$ plot is the first panel of figure 1, its variation appears to reveal a slow 12 hour build up that began with gradual commencement at 14: 00 UT on July 13. Storms can 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 indicates 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, $D_{st}$ recovers 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 begins to recover again through July 14 and 15. However, the $D_{st}$ recovery beginning at 3:00UT on July14 is 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). The $B_z$ plot is shown in the second panel of figure 4.1. 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 corresponds to the minimum peak value experience on the $D_{st}$ plot. It thereafter rotates northward and finally returns southward around 19:00UT on 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 increases precipitously to a value of 928km/s around 17:00UT on July 13. It continues 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 (50-70km/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 1 shows density increasing steadily from 03:00UT July 13 to a value 16.3/cm.$^3$ Note that the peak value of 22.2/cm$^3$ is reached at the instance the plasma speed is about its peak value. The large increase in the proton number density during this period signals 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.

## IONOSPHERIC RESULTS AND DISCUSSION

Regarding terrestrial effects including damages during intense storms, communication systems including those in airplanes can go haywire, and power grids can go down. The most outstanding example is the 13 March 1989 event when the Hydro-Quebec (Canada) power grid went down for more than 9 hours, and the seaboard power grid was almost put down (Allen et al., 1989; Tsurutani et al., 2003). For the October-November 2003 Halloween events, NASA mentioned that the effects on Earth were severe enough to cause the rerouting of aircraft, affect satellite operations, and precipitate a power failure in Malmoe, Sweden. Long-distance radio communications were disrupted because of the effects on the ionosphere (Kane, 2005).

The data used in this study consists of hourly values of foF2 obtain from some of the National Geophysical Data Center's SPIDR (space physic interactive data resource). In order to look critically at the problem of geomagnetic effect on our environment, we have chosen to study the ionospheric response to July 13&14, 1982 storm by some selected stations across the globe instead of concentrating on just a sector. These stations are located in the American, Asian and European sectors of the world, and they include Argentine Island (64.4ºN), Kodaikanal (10.2ºN), Townsville (19.3ºS) and Hobart (42.9ºS) Table 1 list the stations.

However, the data that was analyzed consists of D($f_0F2$) of respective hourly values of $f_0F2$ on July 13, 14, and 15. The reference for each hour is the average value of $f_0F2$ for that hour calculated from the four quiet days, July 8- 11, 1982, preceding the storm. The use of D($f_0F2$) rather than $f_0F2$ provides a first-order correction for temporal, seasonal and solar cycle variations so that geomagnetic storm effects are better identified.

From the first panel of figure 2, the plot of Argentine Island (64.4ºN) which is a high latitude station in the northern hemisphere, an enhancement of the foF2 is observed on the average, but more pronounced around 23:00UT on July 13 to over 200%, before it begins to decline gradually and then sharply to a value of ~-0.30 around 13:00UT on July 14 indicating a negative phase storm and returns to positive phase around 13:00UT next day and throughout.

The second panel provides the plot of Townsville which is a low latitude station at the southern hemisphere, there is a positive ionospheric storm preceding the storm commencement. During the time of storm, an alternating positive and negative ionospheric storm was observed but more predominant is the positive storm. Nevertheless, starting from about 12:00UT on the 14, there was a depletion that lasted till 19:00UT. Thereafter, there was an upward turning which lasted throughout the rest of the period.

The response at Kodaikanal, a low latitude station in the northern hemisphere, shows a predominantly positive ionospheric storm which reached its first peak of 100% at around 22:00UT on July 13. The paucity on the plot is as a result of unavailability of data for that time interval.

The fouth panel shows the mid latitude station of Hobart which is also in the southern hemisphere. The $D_{f0F2}$ plot shows predominantly an enhancement before the time of storm. After $D_{f0F2}$ reached its maximum value of ~70% around 19:00UT on July 13, there was a rapid depletion that follows till around 23:00UT on the following day. Thereafter, another phase of positive ionospheric storm follows till about 8:00UT on July 15.

## CONCLUSION

The main results of the study are summarized in the following:

- The arrival of the storm brought about predominantly positive ionospheric storm.
- The enhancement (positive storm) is felt at both hemisphere (northern and southern)
- The enhancement is simultaneous across all latitudes (low, mid and upper)
- The effect could be felt across the globe (the stations under study were selected from different sectors of the globe)
- The enhancement varied in amplitude from one station to the other

The present work seems to suggest that the vulnerability of our environment to geomagnetic storms may be global (for instance, the resulting blackout and disruption of communication system), but the percentage felt may be different from one station to the other. The enhancement at Argentine Island is about 250% at 23:00UT on July 13, at Townsville is about 20% at 22:00UT, Kodaikanal is about 100% at 22:00UT while at Hobart is about 70% at 19:00UT on the same day. In addition, according to Kelly et al. (1979) and Spiro et al. (1988), the enhancement observed in this study is brought about by the lifting of the ionosphere which may lead to failure of radio frequencies from reaching the new virtual height, thereby, causing signals failure.

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**Table 1:** Ionosonde stations

| Stations | Geographic co-ordinates | | Difference between Lst and UT (in hours) |
|---|---|---|---|
| | $\phi$ | $\lambda$ | |
| Argentine Island | $64.40^0$N | $295.70^0$E | -4 |
| Townsville | $19.30^0$S | $146.70^0$E | +10 |
| Kodaikanal | $10.20^0$N | $77.50^0$E | +5 |
| Hobart | $49.50^0$S | $147.30^0$E | +10 |

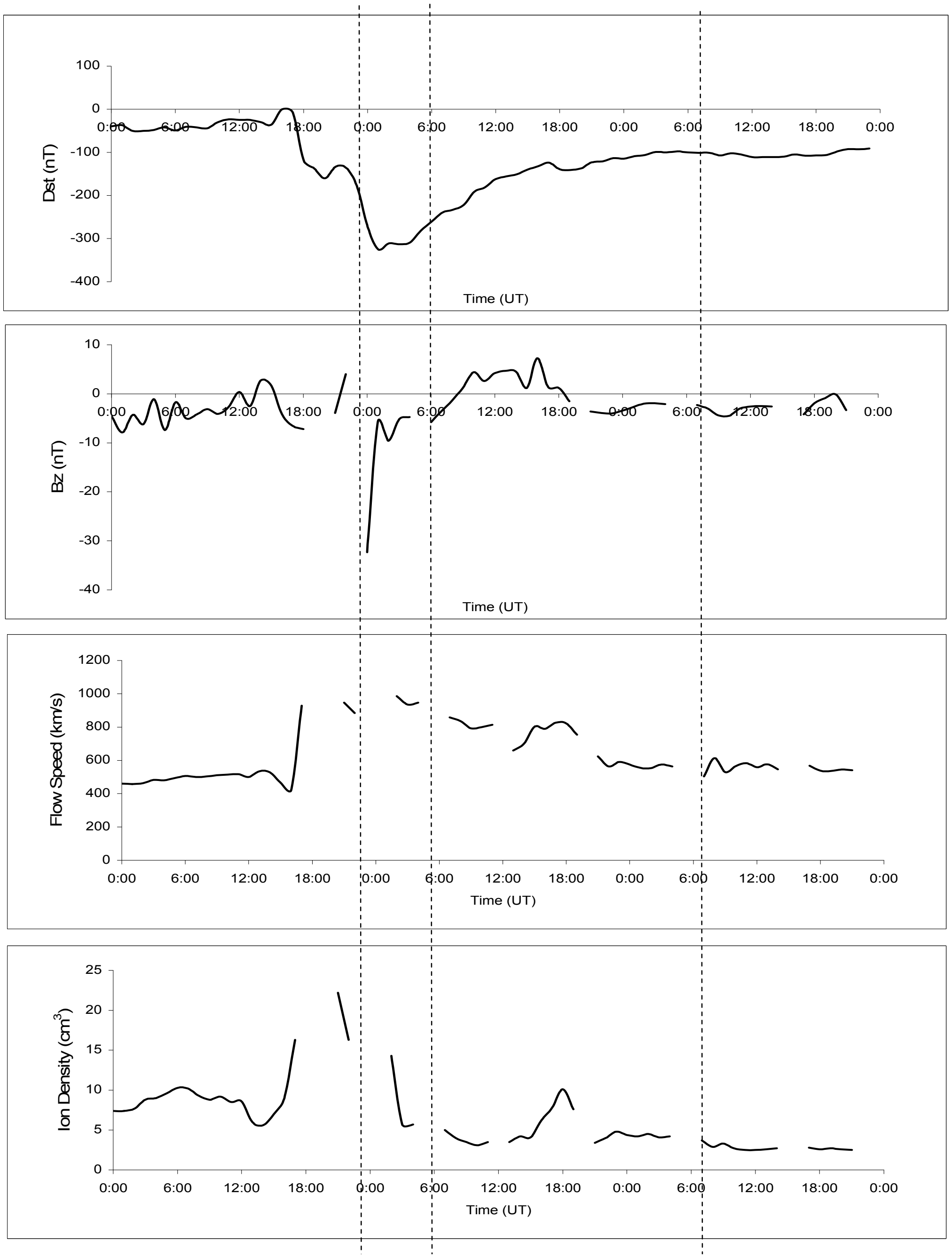

**Figure 1** One-hour averages of the solar wind plasma parameter versus Time (in UT) for July 13-15, 1982

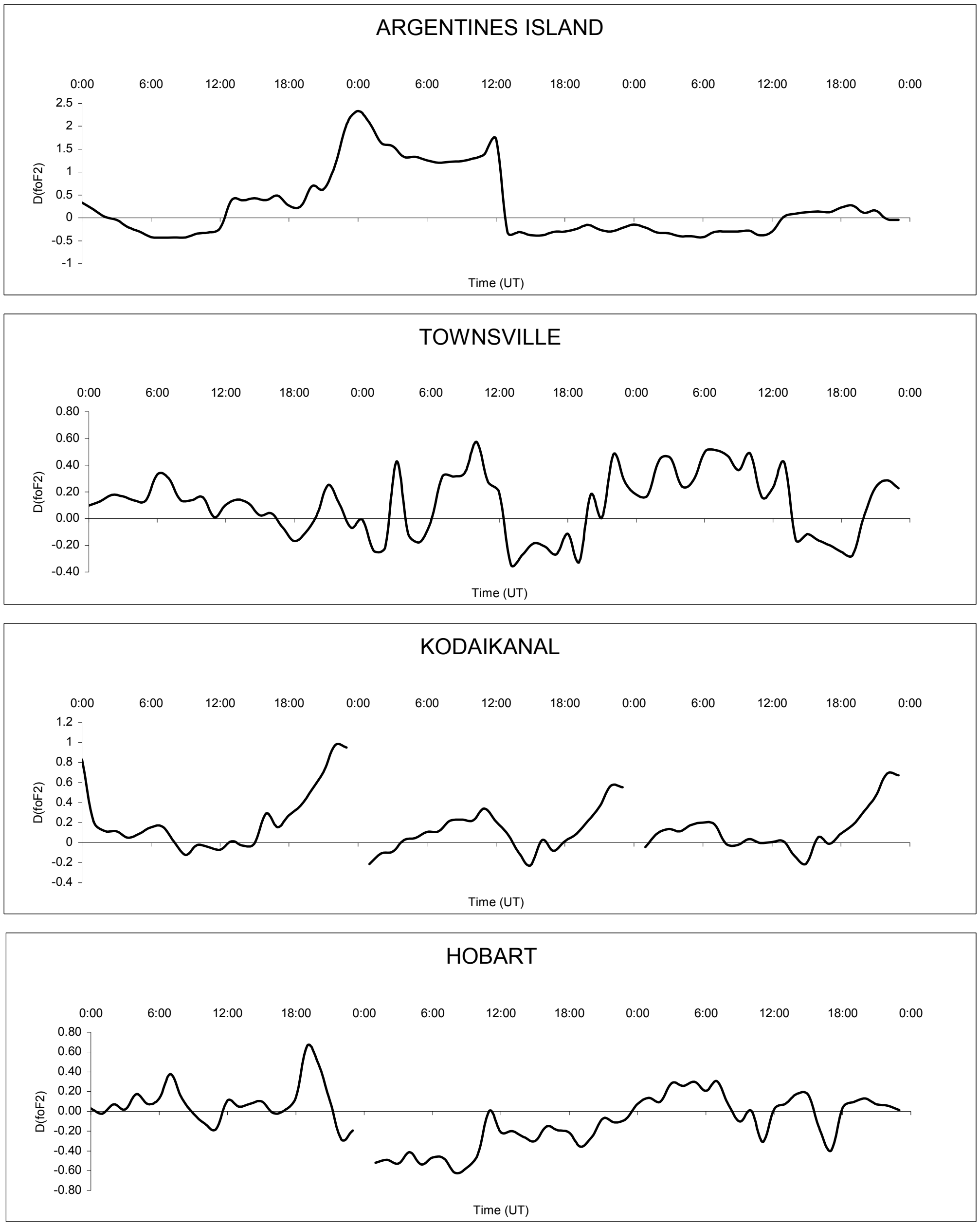

**Figure 2** Variation in $D_{foF2}$ during July 13-15, 1982