Morphological Investigation of Disturbed Ionosphere during Intense Geomagnetic Storms

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Abstract. Geomagnetic Storms are the disturbed magnetic conditions, influenced and induced by Interplanetary Magnetic Field and the Charged Particle's motion around the Earth, respectively, in Geospace. As the ionosphere is woven by the earth's magnetic field it responds to the change in that. During the geomagnetic storms the filled-in plasma between the magnetic field lines, geomagnetic flux tubes, redistributes itself in effect of the magnetic field forcing. In the present study we have done the investigation of the morphology of the ionosphere over the mid and high latitude regions during intense Geomagnetic Storms. We got fairly convincing results; in three cases decrease of the critical frequency of F2 layer (foF2) and in one case enhancement of the critical frequency of F2 layer (foF2) at mid and high latitudes.

1. Introduction

Solar transients; Solar Flares, Coronal Mass Ejections (CMEs), Solar Energetic Particles (SEPs) are the drivers of the Space Weather Effect in Geo-Space. When the gigantic cloud of plasma released through solar transient phenomena interacts with the Earth's magnetic environment it leads to the geomagnetic storms [1, 2]. Geomagnetic storms can be characterized by a depression in the H component of geomagnetic field for tens of hours. This depression in H component of earth's magnetic field is caused by the Ring Current encircling the Earth in a westward direction [3, 4]. Earth's ionosphere responds to varying solar and magnetospheric conditions. The ionospheric electron density over an altitude and location depends variably on the solar EUV Flux, X-ray Flux and the dynamic effects of neutral winds and electric fields. During geomagnetic storm due to the compression of earth's magnetosphere by solar wind electric fields have been observed along the geomagnetic field lines to the high latitude ionosphere. Sometimes this electric field penetrates to low latitudes and at high latitudes they lead to the rapid convection of plasma which may drive even the neutral winds via collisions and energetic particles precipitate into the lower thermosphere and below, increasing ionospheric conductivity and expanding the auroral zone. These intense electric currents are responsible for the coupling of high latitude ionosphere with magnetosphere and the enhanced energy input leads to considerable heating of the ionized and neutral gases. In this way the uneven expansion of the thermosphere generates pressure gradients which drive strong neutral winds. This disturbed thermospheric circulation changes the neutral composition and moves the plasma up and down along magnetic field lines, changing rates of production and recombination of ionized gas. During this phenomenon disturbed neutral winds generate polarization electric fields by dynamo effect by the collision with the plasma in the presence of Earth's magnetic field. There are two types of effects, in time scale, on the Earth produced by solar transients; prompt and delayed. Geomagnetic Storm effects are delayed effects due to cloud of particles ejected from Sun. Geomagnetic storm effect on the earth's atmosphere in the E region has widely been studied at high latitudes [5]. In the high latitude E region where particle precipitation in cusp and aurora are a source of substantial ionization gets affected by geomagnetic storms. Most of the ionospheric electron content is found in the F2 layer of ionosphere which tends to lie near a constant pressure level in the thermosphere [6]. Solar winds can raise or lower hmF2, characteristic height of F2 layer, above or below this level. Equator ward winds can lead to a rise in the F2 peak height up to regions of reduced loss which also produce increase in electron density of F2 region (NmF2). A drop in hmF2 due to pole ward winds decreases NmF2. Due to local time variation of winds and changes in neutral composition at middle latitudes, negative ionospheric storm effects are found to be observed very often in morning and positive storm effects in the afternoon and evening.

2. Event Selection Criterion

To Investigate the variability of ionosphere during Intense Geomagnetic Storms we have used the digital ionosonde observations carried out at two latitude station of northern hemisphere viz. mid latitude station Sofia, SQ143 (42.7° N, 23.4° E) and high latitude station College, CO764 (64.9° N, 147.8° W). For this study we have selected the four geomagnetic storms that occurred during 1999 to 2001. Only the four most intense (Dst ≤ -200 nT) geomagnetic storms were considered for the present study. The availability of various data sets was also checked and events with bad or missing data were removed from the analysis.

3. Data Sets and Sources

To accomplish this study we have we have used two sets of data: (1) Storm Intensity Index (Dst) and (2) critical frequency of F2 layer (foF2) of ionosphere measured by means of ground based radio sounding system, Ionosonde.

The data of Dst Index is available at various sites for downloading. However, for our study we have downloaded the data of Dst index from Space Physics Data Facility OMNI website (http://omniweb.gsfc.nasa.gov/). We have used the hourly values of Dst for the investigation.

For the present investigation we have used the manually scaled hourly averaged values of foF2 (critical frequency of F2 layer) over mid latitude station Sofia, SQ143 (42.7° N, 23.4° E) and high latitude station College, CO764 (64.9° N, 147.8° W) from (http://spidr.ngdc.noaa.gov/spidr/) SPIDR data services.

4. Results and Discussion

The disturbed and adverse geomagnetic conditions have a significant impact on the ionosphere. To investigate the variability of ionospheric foF2 during disturbed geomagnetic conditions we have selected four intense geomagnetic storms occurred during the year 1999 to 2001. The geomagnetic storms of 22 October 1999, 17 September 2000, 31 March 2001, and 11 April 2001 were selected to study the behavior of ionospheric delay foF2 during these geomagnetic storms. All the four cases are discussed serially as follows;

4.1. Case 1: 22 October 1999

One of the intense geomagnetic storms was observed on 22 October 1999. The storm had a sudden commencement phase followed by the initial and main phase. The storm intensity index-Dst had the minimum or peak value of -237 nT. The behavior of ionospheric foF2 over mid latitude station, Sofia and high latitude station, College before, after and on the storm day along with Dst index are shown in figure 1. From the Figure we find that the value of foF2 is decreased significantly over mid latitude as well as high latitude during the geomagnetic storm main phase i.e. 22 October 1999. However the effect of geomagnetic storm over high latitude is more. Thus the impact of geomagnetic storm is clearly seen on the mid and high latitude ionospheric foF2 as a negative effect.

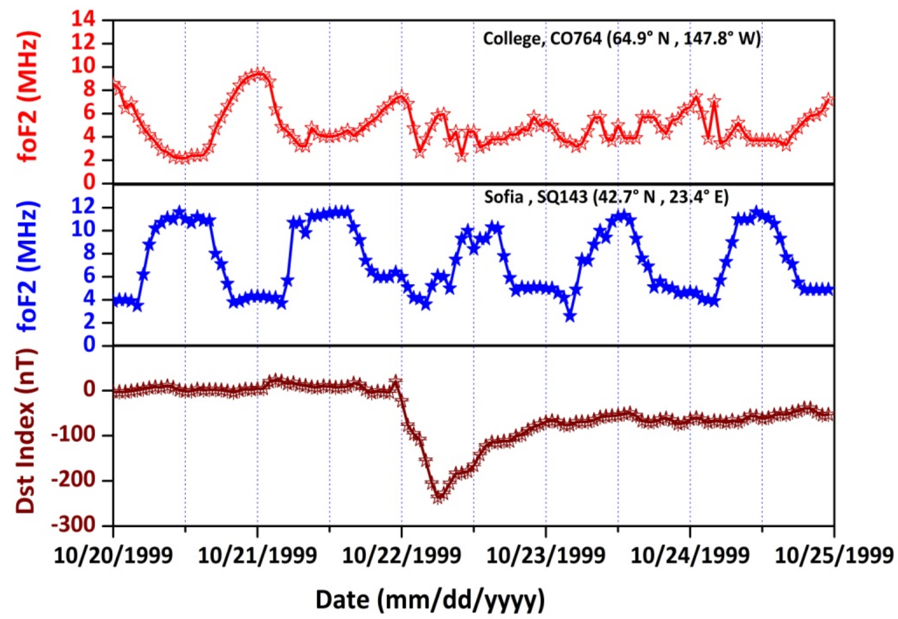

Figure 1. The temporal evolution of foF2 over mid latitude station, Sofia and high latitude station, College with Dst during the geomagnetic storm of 22 October 1999.

4.2. Case 2: 17 September 2000

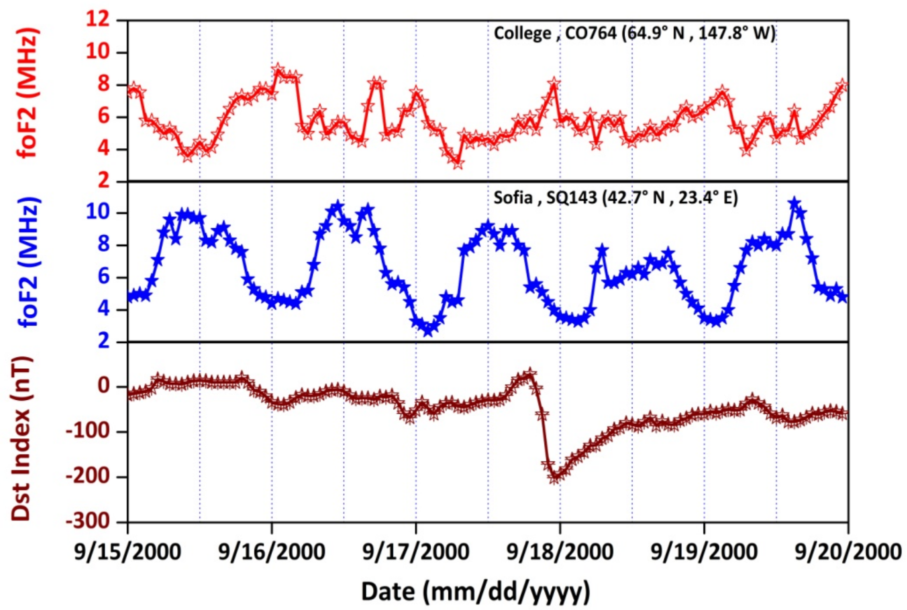

Figure 2. The temporal evolution of foF2 over mid latitude station, Sofia and high latitude station, College with Dst during the geomagnetic storm of 17 September 2000.

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Another intense storm was observed on 17 September 2000. The minimum Dst recorded during this storm was -201 nT. The effect of this geomagnetic storm on the ionospheric foF2 is shown in figure 2 along with changes in storm intensity index Dst. The main phase of the geomagnetic storm was observed on 17 September 2000. From the figure we find that during the main phase of geomagnetic storm the value of foF2 decreased over mid latitude as well as high latitude. However the effect of geomagnetic storm over mid latitude is more significant. Hence during this storm also we observed a negative effect over both latitude stations, mid and high.

4.3. Case 3: 31 March 2001

The effect of geomagnetic storm of 31 March 2001 on the ionospheric foF2 is shown in figure 3. The geomagnetic storm that occurred on 31 March 2001 was an intense geomagnetic storm with peak or minimum Dst -387 nT. From the figure we clearly see the decrease in Ionospheric foF2 over both mid and high latitude stations during the day of storm. However the effect of geomagnetic storm over high latitude is clearer than mid latitude. Hence this storm also shows a negative effect over mid latitude station as well as high latitude station.

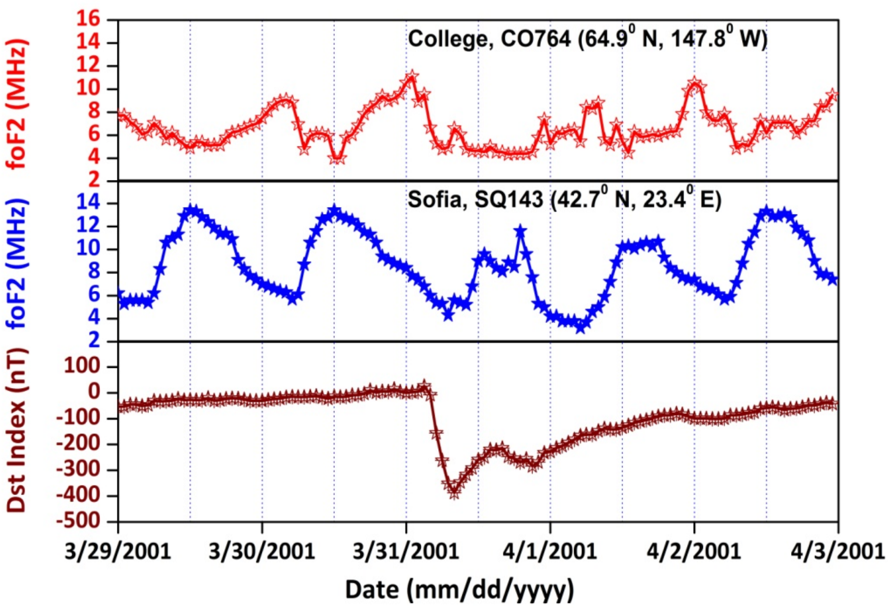

Figure 3. The temporal evolution of foF2 over mid latitude station, Sofia and high latitude station, College with Dst during the geomagnetic storm of 31 March 2001.

4.4. Case 4: 11 April 2001

The effect of geomagnetic storm of 11 April 2001 on the ionospheric foF2 along with changes in storm intensity index Dst is shown in figure 4. The minimum Dst observed for this geomagnetic storm was -271 nT. From the figure we find that Ionospheric foF2 shows a clear enhancement over mid and high latitude stations. Thus the impact of geomagnetic storm is clearly seen on the mid and high latitude ionospheric foF2 as a positive effect.

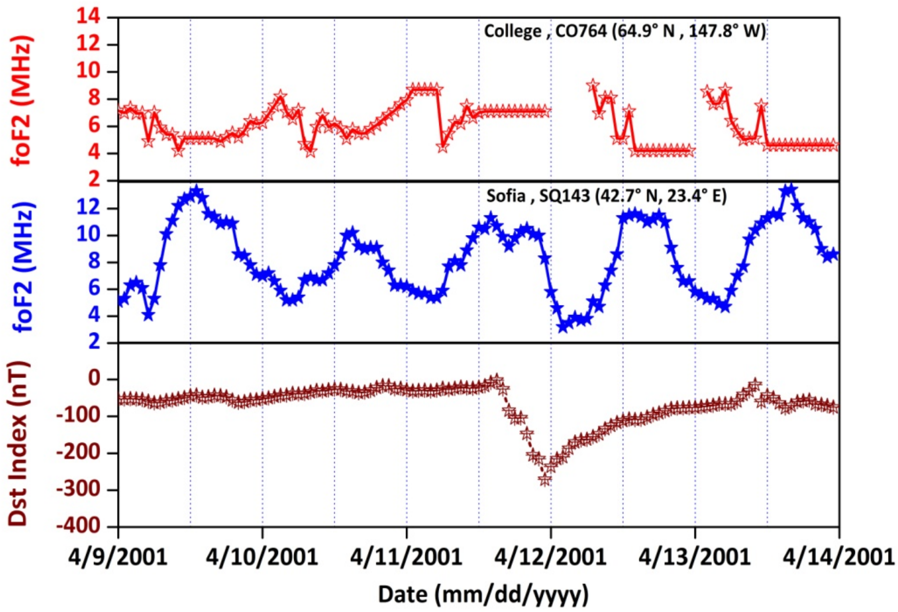

Figure 4. The temporal evolution of foF2 over mid latitude station, Sofia and high latitude station, College with Dst during the geomagnetic storm of 11 April 2001.

After compiling the above results we see that most of the times intense geomagnetic storm produce negative effect on ionospheric foF2 at mid latitudes as well as at high latitudes in northern hemisphere. The cause of simultaneous decrease of foF2 at high and middle latitudes as a revelation of depletion in F2 region plasma density are thought to be due to the changes in the neutral wind produced predominantly be the Joule heating in the auroral zone. In the cases where we observed the positive effect in midlatitude station is due to the magnetospheric electric field finding a way into the midlatitude has been found playing a major role in the ion density hence the foF2 during the main phase of the storm. East ward component of this magnetospheric electric field increase the local production on the dayside which reflects in the storm time density increase. Midlatitude F-region is has seasonal dependence as well as the neutral wind at F-region heights have so.

5. Conclusions

We summarize our main findings as follows;

- Most of the times intense geomagnetic storm produce negative effect on ionospheric foF2 at mid latitudes as well as at high latitudes in northern hemisphere. We have taken four intense geomagnetic storms for investigating the effect of intense geomagnetic storms on ionosphere and we get negative effect on mid and high latitude ionosphere of northern hemisphere during three cases out of four cases. However in one case out of four we got positive effect also.
- We also find that a particular geomagnetic storm produces same effect at all latitudes of a particular hemisphere. As in our study we got same effect on mid and high latitude ionosphere of northern hemisphere during each case.

- We also find that most of the times high latitude ionosphere shows more significant effect to the adverse geomagnetic conditions compare to mid latitude ionosphere in northern hemisphere, whatever the effect is negative or positive.

6. References

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