

Solar Transients Disturbing the Mid Latitude Ionosphere during the High Solar Activity

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Abstract. We investigate the effect of solar transients on the mid latitude ionosphere during the high solar activity period of solar cycle 23 i.e 2003 and 2004. A mid latitude station, Guangzhou (23.1N, 113.4E) was selected to carry out the investigation. The ionospheric behaviour at the selected station is characterized by considering the critical frequency of F2 layer (foF2) obtained by using the ground based Ionosonde observations. Then we selected two types of solar transients viz. solar flares and Coronal Mass Ejections (CMEs). To quantify the effect of solar flares we have considered the X-ray flux (1–8Å) and EUV flux (26–34nm). Similarly to quantify the effect of CMEs, we have considered the geomagnetic storms, because during high solar activity the geomagnetic storms are caused by CMEs. From our analysis we conclude that during the geomagnetic storms the value of foF2 decreases as compared to quiet days thereby showing a negative effect. On the contrary we found that during solar flares there is sudden and intense increase in foF2. We also performed a correlation analysis to access the magnitude of association between changes in flux values and peak values of Dst during flares and storms with the corresponding changes and peak values of foF2. We found that a strong correlation exists between the enhancements/decrements in foF2 and enhancements in flux values and Dst. We conclude, while geomagnetic activity suppresses ionospheric activity the flares enhance the same.

1. Introduction

Ionosphere, the upper part of earth's atmosphere, is highly vulnerable to solar disturbances. During solar disturbance like solar flares and Coronal Mass Ejections huge amount of energy is released from the sun in very short duration of time. This energy eventually reaches the geospace and is transferred to the magnetosphere where it causes several changes in the magnetosphere. Since the magnetosphere and ionosphere of earth form a coupled system therefore the state of ionosphere also gets disturbed largely due to such disturbances. The solar flares and CMEs affect the ionosphere differently.

During solar flares the release of energy occurs in the form of radiations. The increase in the radiation flux at specific wavelengths like X-ray and EUV is considerably large. Consequently, as the amount of X-ray and EUV flux impinging on the ionosphere increases, the ionization process in the ionosphere shoots up leading to sudden and intense increase in the electron density of ionosphere.



Therefore, flares abruptly change the structure and state of the ionosphere in the sunlit hemisphere, causing several types of disturbances commonly known as sudden ionospheric disturbances [1]. The ionospheric response to solar flares has been studied widely [2, 3, 4, 5]. It has been found that solar flares affect the ionosphere in many ways like increase of critical frequency of the F2 region [2], increase in electron density in the E and F1 region [6], sudden increase of the Total Electron Content (SISTEC) in the upper ionosphere.

Although, the solar flares influences of ionosphere are quite straight forward the geomagnetic influences of ionosphere are highly complex. The most important and prominent feature that has been observed during geomagnetic storms is the depression in foF2 and the Total Electron Content (TEC) [7, 8, 9]. The significant changes have also been reported in other ionospheric parameters, such as the virtual height of the F-layer (h'F), the peak height of the F2-layer (hpF2), the maximum electron density of the F2-layer (NmF2) [9, 10, 11]. The negative storm effects are thought to be caused due to the alteration in the global thermospheric winds and neutral composition. The change in neutral composition (increase in N₂/O) is responsible for the dramatic reduction in electron density [12, 13, 14]. These changes are transported to mid-latitudes by the storm-time global circulation. However, the positive F2-region effects at mid-latitudes are believed to be produced by travelling atmospheric disturbances (TADs).

2. Event Selection

In order to study the response of ionosphere to the two types of solar transients viz solar flares and Coronal Mass Ejections, we have selected the high activity phase of solar cycle 23 i.e. year 2003 and 2004. In order to study their effect on ionosphere we have selected a mid latitude station, Guangzhou (23.1N, 113.4E). After selecting the station and period of study we then proceed to the selection of solar flare and CME events. We have selected eight X-class solar flares on the basis of their visibility at the selected station and the full availability of data sets. The selection of CMEs was made by selecting geomagnetic storms produced by CMEs. The complete list of selected flares and storms is provided in table 1 and table 2.

Table 1. The complete catalog of all the selected solar flare events along with ionospheric parameters.

S. No	Event Date	Start Time	Peak Time	End Time	GOES Class	Active Region	Location	Δ foF2	Δ X-ray	Δ EUV
1	27-May-03	22:56	23:07	23:17	X1.3	10365	S06W20	4.15	8.67E-05	3.39E+09
2	28-May-03	00:17	00:27	00:39	X3.6			4.55	1.33E-04	3.23E+09
3	29-May-03	00:51	01:05	01:12	X1.2	10365	S07W46	4.45	1.32E-04	3.59E+09
4	10-Jun-03	23:19	00:02	00:12	X1.3	10375	N12W60	4.9	2.23E-04	5.48E+09
5	23-Oct-03	08:19	08:35	08:49	X5.4	486	S16E67	4.35	8.23E-05	2.17E+09
6	26-Oct-03	05:57	06:54	07:33	X1.2	486	S15E32	3.9	3.64E-05	3.11E+09
7	26-Feb-04	01:50	02:03	02:10	X1.1	564	N14,W28	7.4	4.98E-04	2.13E+10
8	16-Jul-04	01:43	02:06	02:12	X1.3	649	S10,E26	3.6	7.98E-05	3.98E+09

3. Data and method of analysis

In order to study and compare the effect of solar flares and geomagnetic storms on mid latitude ionosphere, we used several parameters describing these phenomena. We know flares are characterized by a dramatic increase in X-ray and EUV flux. The solar X-ray flux is monitored by GOES Satellite series. For our study we have taken the solar X-ray flux data from the National Geophysical Data Center (NGDC) server at <http://www.ngdc.noaa.gov/stp/GOES/>. We have taken the X-ray flux in the range 1Å to 8Å with 5 min resolution. Similarly, the EUV flux is monitored by an EUV spectrometer onboard Solar and Heliophysical Observatory (SOHO) spacecraft. The SEM experiment measures EUV flux, integrated in the two wavelength bands 26-34nm and 0.1-50nm and can be accessed at http://www.usc.edu/dept/space_science/semdatafolder/. In our analysis we have used the SEM EUV flux in the wavelength range 26-34nm band with 5 min temporal resolution.

Table 2. The complete catalog of all the selected geomagnetic storms.

S.No	Event Date	Peak Dst	Peak foF2	Δ foF
1	29 May 2003	-144	9.5	-3.87
2	20 November 2003	-422	14	-1.30
3	11 February 2004	-93	14	-1.11
4	30 August 2004	-129	9.1	-2.38
5	08 November 2004	-373	12.8	-1.64
6	10 March 2004	-78	14.2	-3.36
7	17 July 2004	-76	11.8	-0.63
8	04 April 2004	-117	14.1	-1.11
9	30 October 2003	-383	14.5	-0.49
10	12 July 2003	-105	13.9	0.60

The intensity and occurrence of geomagnetic storms is monitored by defining a storm intensity index commonly known as Disturbed Storm Time (Dst) index which is defined as an average of horizontal components of the ground magnetic field from selected observatories located around equator. The data for Dst indices with 1h resolution for each storm were obtained from the web server <http://wdc.kugi.kyoto-u.ac.jp/>.

In our present investigation we have used the ground based ionosonde observation to characterize the changes in the ionosphere as result of flares and storms. We have used the critical frequency of F2 layer, symbolized as foF2. The data of foF2 was taken from the database of NGDC. The NGDC maintains a huge database of more than 250 stations and can downloaded from its server at <http://spidr.ngdc.noaa.gov/spidr/>. We have used the 15 min values of foF2 over the Guangzhou station.

We took the peak values of X-ray flux, EUV flux, Dst index and foF2 to investigate the relation between the peak values. We also calculated the enhancement/decrements in the foF2 as well X-ray flux, EUV flux and Dst index to quantify the amount of changes. The enhancements in the flux values were calculated from the background flux and are designated as Δ X-ray and Δ EUV flux. However, the change in the foF2 was calculated in two ways separately for flares and storms. To investigate the flare effect the change was calculated from the median of the day. While for storm effects the change was calculated from the quietest day of the month and represented as Δ foF2.

4. Results and discussion

After obtaining the required data sets and doing the all the processing and analysis the final data sheets were prepared and graphs were constructed to obtain the results and finally arrive at general conclusions. The study was conducted in two parts. In the first part the effect of solar flares on the ionosphere was studied and in the second part the effect of geomagnetic storms was studied.

4.1. Effect of solar flares on the ionospheric foF2

We know during solar flares a dramatic increase occurs in the solar X-ray flux and EUV flux. Consequently, the ionization process in the ionosphere will be increased significantly which will be reflected in the foF2 parameter. First, we constructed the time profile foF2 and the X-ray flux. The time profile X-ray flux with the corresponding profile of foF2 for four of the selected flares is shown in figure 1. In each panel of the figure 1 we can clearly notice a sharp peak in the X-ray flux curve which corresponds to a solar flare. However, the foF2 follows a diurnal pattern i.e. increasing from morning achieving a normal diurnal peak in the afternoon and then decreasing back to minimum in the evening. Such type of behavior is characteristic of mid latitude ionosphere. But whence the X-ray flux peaks the foF2 curve undergoes a sudden and sharp jump instantaneously and then follows the normal diurnal pattern. In otherwords, during the time of solar flare the value of foF2 rises over the normal background value indicating an increase in foF2. This feature can be observed in all the four panels of the figure 1 with magnitude of increase being different for different flares. Therefore, we conclude

from figure 1 that during solar flares the value of foF2 is increased due to increase in the X-ray flux. The increase is almost instantaneous, intense and short lived.

Along with increase in X-ray flux, the flares are also characterized by significant increase in the EUV flux. The figure 2 show the temporal changes in the EUV flux along with corresponding changes in the foF2 during four of the selected solar flare events. Here we find a sharp peak in the wine colored curve indicating a solar flare. So we find during flare the flux of EUV radiation is significantly increased. The effect of this increase in EUV flux on the foF2 can be observed as a sudden increase in the foF2 over the normal diurnal pattern. Similar behaviour was observed for the other six flare events also. Figure 1 and 2 also shows a very good agreement between the radiation flux enhancements and the positive changes in ionospheric foF2. As the flux start increasing from their background levels due to a solar flare corresponding to it the foF2 also increases.

To access the magnitude of association between the solar radiations and the foF2 we took the peak values of both types of parameters and constructed the scatter plots and derived the corresponding correlation coefficients. We found that peak values of foF2 do not follow a very good correlation with the peak values of X-ray flux ($R=0.17$) and EUV flux ($R=0.33$). But on the otherhand when we examined the correlation of ΔfoF2 with $\Delta\text{X-ray}$ flux and ΔEUV flux, we found a very strong correlation between the two. The correlation coefficients were 0.97 and 0.93 respectively with $\Delta\text{X-ray}$ flux and ΔEUV flux as depicted in figure 3.

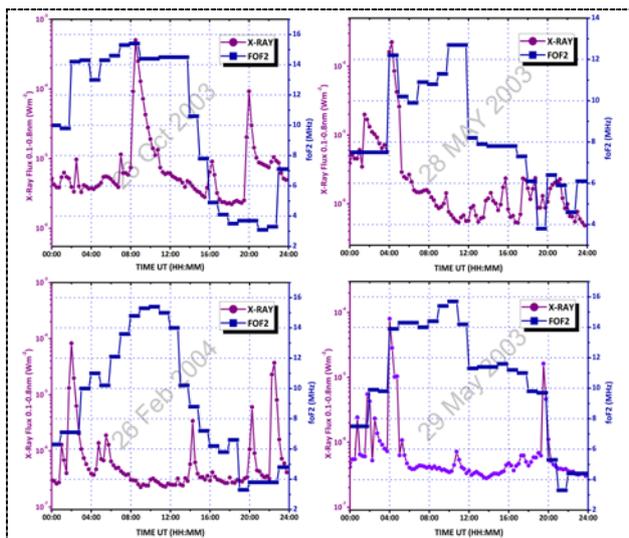


Figure 1. The time profile of foF2 along with the X-ray flux (1-8Å) profile during four of the selected flare events.

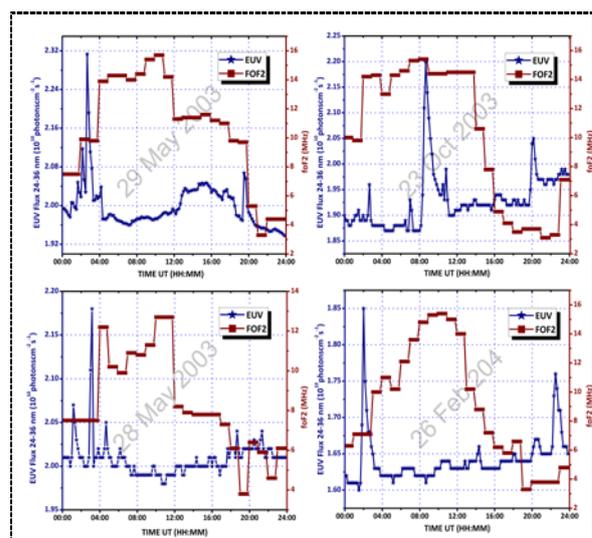
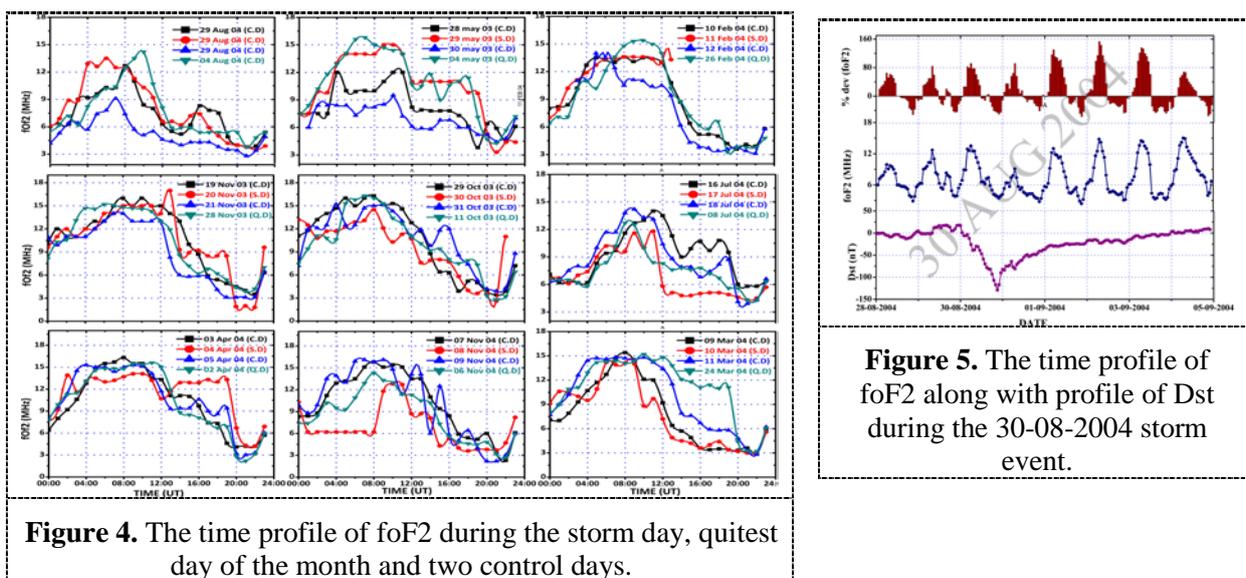
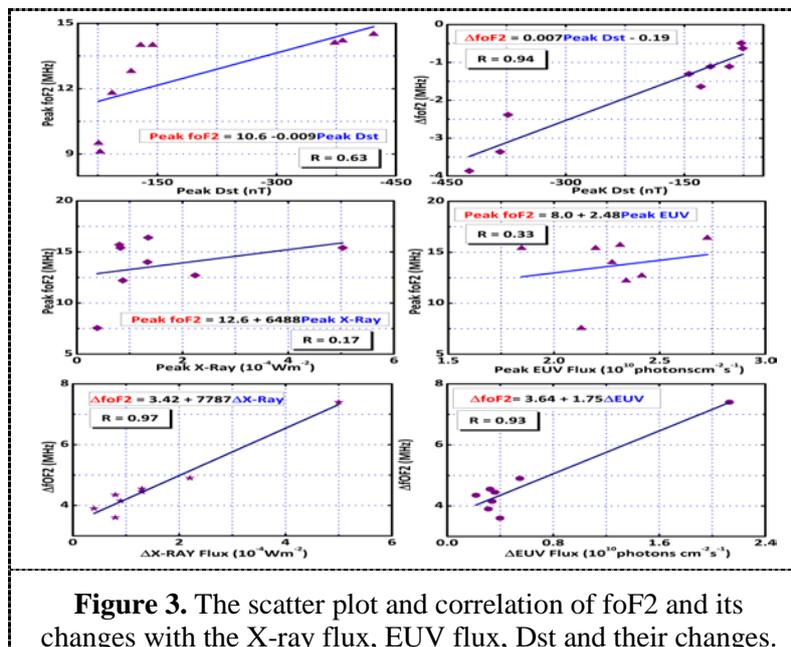


Figure 2. The time profile of foF2 along with the EUV flux (26-34nm) profile during four of the selected flare events.

4.2. Effect of geomagnetic storms on the ionospheric foF2

We now present the results describing the effect of geomagnetic storms on the foF2. The figure 4 shows the temporal variation of foF2 on the storm day, quietest day of the month and two control days. The nine panels represent the nine events. In all of events we find that the values of foF2 on the storm day are smaller than the values of foF2 on the quietest day of month. In some event the value of foF2 on the storm day is also smaller than the values on the two control days. However, in two cases (29 Aug. 2004 and 29 May 2003) the value of foF2 on the storm day is higher than the corresponding values on the control days. Therefore, it can be easily observed from the figure 4 that the value of foF2 is decreased due to a geomagnetic storm. Hence, it can be concluded that the geomagnetic storms produce a negative effect on the ionosphere. The negative effect of storms can be much clearly noticed in figure 5 where we have plotted the foF2 along with Dst index during one of the selected events.

From this figure we notice that the Dst index achieves the peak on the 30-08-2004, indicating the main phase of geomagnetic storm. In the second panel of figure 5 we can clearly notice that on that day the values of foF2 is significantly lower than the corresponding values on the other days. The peak of foF2 is significantly lower than the peak values on the other days. Therefore, figure 5 clearly depicts that geomagnetic storms have a negative effect on the ionospheric foF2 at mid latitudes. In order to quantify the magnitude of association between the two, we derived the correlation between the peak values of foF2 and the peak values of Dst, which is shown in top panels of figure 3. From the figure we notice a strong correlation between peak values of foF2 and Dst as well as between Δ foF2 and Dst. The corresponding correlation coefficients are 0.63 and 0.94 showing that Δ foF2 exhibits a very strong correlation with Dst than does peak foF2.



5. Conclusions

We studied and compared the response of ionosphere to solar flares and geomagnetic storms. From our analysis we draw the following conclusions:

- The value of foF2 undergoes an enhancement during the solar flares while during geomagnetic storms the value of foF2 suffers a decrease.
- The peak values of foF2 do not follow a very good correlation with the corresponding peak values of X-ray flux, EUV flux and Dst. However, the enhancements/decrements of the foF2 follow a very strong correlation with the enhancements of X-ray flux, EUV flux and Dst.

6. Acknowledgements

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7. References

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