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A STUDY ON THE IONOSPHERIC RESPONSE TO GEOMAGNETIC STORMS USING WAVELET ANALYSIS

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ABSTRACT

In the present study, we have investigated the effects of geomagnetic storm on the ionospheric parameter such as critical frequency of the F_2 layer, foF_2. The time periods considered are 10^{th}- 20^{th} July 1991, and 5^{th} -14^{th} November 1991 during which intense storms were occurred with D_{stmax}< -300 nT. It is found that the time series of foF_2 exhibits depressions during the storm dates, which indicate the occurrence of negative storms during the period 10^{th}- 20^{th} July 1991.We have used continuous wavelet transform (CWT) method for the analysis of the data. The abrupt changes in a signal produce relatively large wavelet coefficients (in absolute values) centered on the discontinuity at all scales, which have been effectively utilized to analyze foF_2 fluctuations associated with geomagnetic storms.In addition to this, the values of foF_2were generated for the above periods for the station Delebre (40.8 ^{0} N) using FLIP model. It is observed that a good correlation exists between the observed foF_2 and FLIP modelled foF_2, during quiet cum intense geomagnetic storm periods considered here.

KEYWORDS: Geomagnetic Storms, foF_2, Wavelet Analysis

Geomagnetic storms are major disturbances in the Earth's magnetosphere when the interplanetary magnetic field turns southward and remains so for a prolonged period of time (Russel et al., 1974; Rostoker and Falthammar, 1967; Tsurutani et al., 1992). Reconnection between the southward-directed(relative to the ecliptic plane) component of the solar wind-carried magnetic field, B_z, and northward-directed geomagnetic field can occur at the dayside magnetopause, resulting in the transfer of significant amounts of energy from the solar wind in to the Earth's magnetosphere (Buonsanto ,1999). All regions of geospace are affected by geomagnetic disturbances, and the operations of various technological systems can be impaired or even totally disrupted. A geomagnetic storm is defined by changes in the D_{st}(disturbance – storm time) index. The D_{st} index estimates the globally averaged change of the horizontal component of the Earth's magnetic field at the magnetic equator based on measurements from a few magnetometer stations. D_{st} is computed once per hour and reported in near-real-time. During quiet times, D_{st} is between +20 and -20 nano-Tesla (nT).The ionospheric storm effect to the geomagnetic storm can be classified in to five different categories of maximum electron density. The storms are classified as positive storms (p-storm) or negative storm (N-storm) depending on whether maximum electron density is positive or negative following the onset of geomagnetic storm. If ionospheric storms show initial positive electron density (> 20 % for more than three hours) followed by negative electron density, it is classified as PN-storms. If initially electron density is negative followed by positive density, they are classified as NP-storms (Pietrella et al., 2012).

MATERIALS AND METHODS

We considered two geomagnetic storm periods, 10^{th} – 20^{th} July 1991, and 5^{th} – 14^{th} November 1991. The corresponding SSC Date and UT are given in the table 1. The particular cases are intense storm periods, in which D_{stmax} is less than -300 nT. The data for the study is provided by the SPIDR (Space Physics Interactive Data Resource).SPIDR was a standard data source for solar-terrestrial physics. The wavelet analysis method is used for the analysis of the data.

CWT (Continuous Wavelet Transform) Coefficients

A continuous wavelet transform (CWT) is used to divide a continuous-time function in to wavelets. In the CWT, the analyzing function is a wavelet. By continuously varying the values of scale parametera and the position parameter b, we obtain the CWT coefficients C (a, b). Wavelets are functions, which have zero mean and are localized in both time and frequency space. The continuous wavelet transform of a discrete time series is defined as the convolution of the time series with a scaled and translated wavelet function. By varying the wavelet scale and translating along the time, one can construct a picture showing both the amplitude of any features versus the scale and how this amplitude varies with time (Kozelov et al, 2008; Berthelier et al, 1988; Eastman and Hones, 1979; Farthing et al, 1981; Forget et al, 1991; Gilman et al, 1963). To produce a plot of the CWT coefficients, plot position along the X-axis, and scale

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along the Y-axis, and encode the magnitude, or size of the CWT coefficients as color at each point in the X-Y, or time-scale plane. Abrupt changes in a signal produce relatively large wavelet coefficients (in absolute values) centered on the discontinuity at all scales, which have been effectively utilized to analyze foF_2 fluctuations associated with geomagnetic storms.

FLIP Model (Field Line Interhemispheric Plasma Model)

The FLIP model has been developed over a period of more than 20 years. The FLIP model is a one-dimensional (1-D) model that calculates the plasma densities and temperatures along entire magnetic flux tube from 80 km in the Northern hemisphere through the plasma sphere to 80 km in Southern hemisphere. The model uses a tilted dipole approximation to the Earth's magnetic field.

Cross Correlation Between Observed foF_2 and FLIP Modelled foF_2

We have done the cross correlation study of observed foF_2 (downloaded from SPIDR website) Vs modelled foF_2 (from FLIP model). In signal processing, cross correlation is a measure of similarity of two time series as a function of the lag of one relative to the other. The cross-correlation is similar in nature to the convolution of two functions. In fact, cross-correlation analysis is the tool most commonly used in the analysis of multiple time series.

RESULTS AND DISCUSSION

In the present study, we focused on the geomagnetic storms and its effects on the ionospheric parameter such as critical frequency of the F_2 layer (foF_2). We considered the geomagnetic storm periods – 10^{th} – 20^{th} July 1991 and 5^{th} -14^{th} November1991. We have used continuous wavelet transform (CWT) method for the analysis of the data.

Event I: 10^{th}-20^{th}July, 1991

During the period of study, 10^{th} -20^{th} July 1991, an SSC occurred on 12^{th} July at 0923 UT, whereas the $A_p$values of 10^{th} and 11^{th} July are less than 10 and hence can be considered as geomagnetically quiet days. Fig. 1 represents the K_p index value for the storm period 10^{th} -20^{th} July 1991 showing increase in K_p index value during the storm days July 13, 14 and 15, 1991. Fig. 2 represents foF_2Vs local Time showing depression in foF_2 during storm day July 13, 1991 for the mid latitude station Delebre (40.8 ^{0} N, 0.3 ^{0} E).Fig. 3 represents the plot of CWT coefficients during the storm period 10^{th} -20^{th} July 1991 showing small patterns at the right bottom at the scale below 20 around the time points 80 and 96 for the mid latitude station Delebre. Also some large predominant patterns are also found around the time points 144 and 192 at a higher scale of about 80. Fig. 4 depicts the combined plots of observed foF_2 and FLIPS modelledfoF_2 for the storm period 10^{th} -20^{th} July 1991 for Delebre. The FLIP modelled values are generally matching well with the observed values of foF_2 during the days from 15^{th} July at 12:00 UT up to 16^{th} July 20:00 UT.

Event II: 5^{th}-14^{th} November 1991

During the period of study, 5^{th} -14^{th} November 1991, an SSC occurred on 8^{th}November at 0647 UT, and therefore 5^{th}-7^{th} are considered as geomagnetically quiet days. Fig. 5 represents foF_2Vs local time showing depression in foF_2 during storm day November 8, 1991 for the mid latitude station Delebre (40.8 ^{0} N, 0.3 ^{0} E).Fig. 6 represents the plot of CWT coefficients during the storm period 5^{th} -14^{th} November 1991 showing small patterns at the right bottom at the scale below 20 around the time point 96, 168 and 192 for the mid latitude station Delebre. Another large pattern is also observed around the scale at the time points 84, 96, 120, 144 and 168. Fig. 7 depicts the combined plots of observed foF_2 and FLIPS modelled foF_2 for the storm period 5^{th} -14^{th} November 1991 for the station Delebre. The FLIP modelled values are matching from the respective observed values of foF_2 during the days from 5^{th} November at 12:00 UT up to 10^{th} November 18:00 UT.

Crosscorrelation Between Observed foF_2 and FLIP Modelled foF_2

During the period of study, 10^{th}-20^{th} July 1991, an SSC occurred on 12^{th} July at 0923 UT, and based on A_p values, 10^{th}-11^{th} are considered as geomagnetically quiet days. For the station Delebre (40.8 ^{0} N), a very good correlation exists between the observed foF_2 and FLIP modelled foF_2 during a band of period 16-32 (Fig 8). Similarly, the cross correlation between them is highest for the second event (5^{th} -14^{th} November 1991) especially between 48h and 120h which includes the storm days 9^{th}& 10^{th}November 1991.

Table 1: List of events considered

Serial No:	Events (period of study)	Name of station (Geographic latitude and longitude)	Date and UT of SSC	D_{stmax}(nT)
1	10^{th}-20^{th} July 1991	Delebre(40.8^{0}N,0.3^{0}E)	12.07.1991(09:23)	-285
2	05^{th}-14^{th}November 1991	Delebre(40.8^{0}N, 0.3^{0}E)	08.11.1991(06:47)	-354

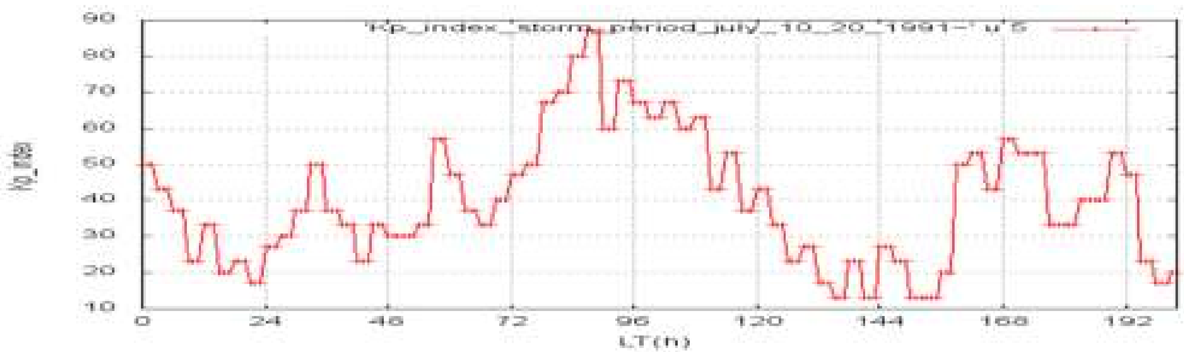

Figure 1: Represents the K_p index value for the storm period 10^{th} -20^{th} July 1991 showing increase in K_p index values during the disturbed period 13^{th} -15^{th} July 1991.

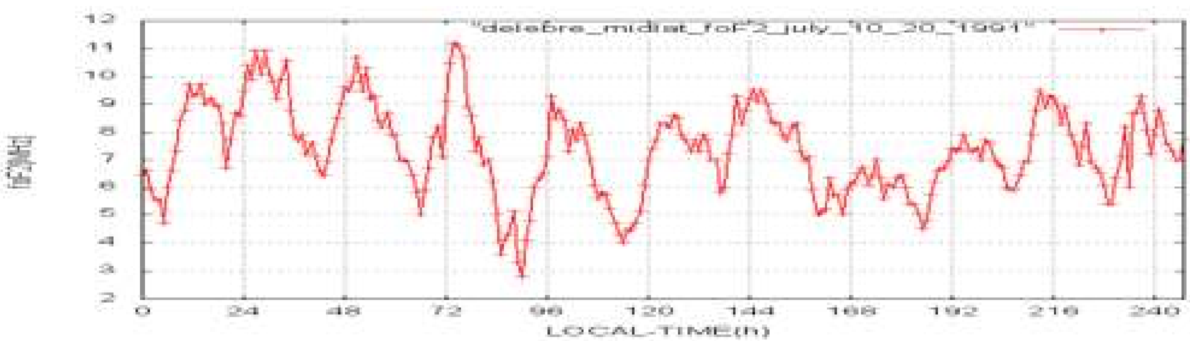

Figure 2: Represents foF_2Vs local time showing depression in foF_2 during storm day July 13 , 1991 for the mid latitude station Delebre(40.8 ^{0} N, 0.3 ^{0} E).

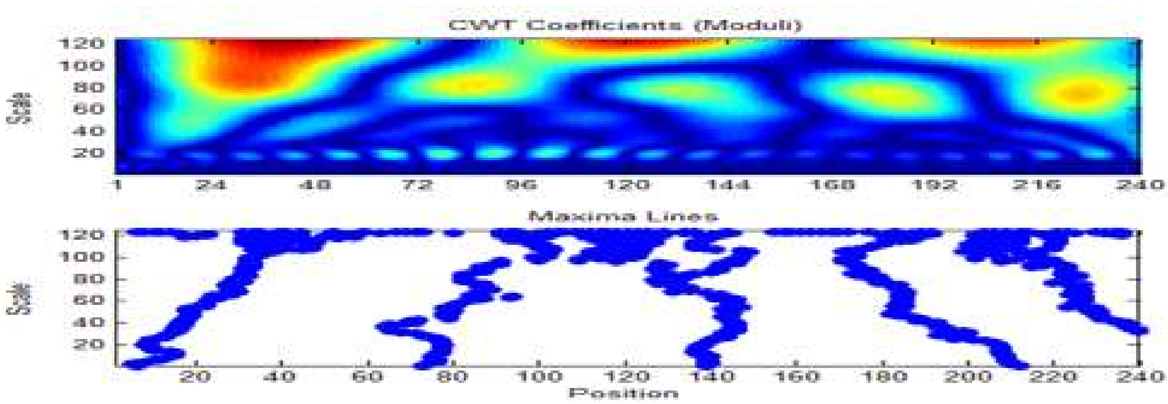

Figure 3: Represents the plot of CWT coefficients during the storm period 10^{th} -20^{th} July 1991 showing small patterns at the right bottom at the scale below 20 around the time points 80 and 96 for the mid latitude station Delebre. Also some large predominant patterns are found around the time points 144 and 192 at a higher scale of about 80.

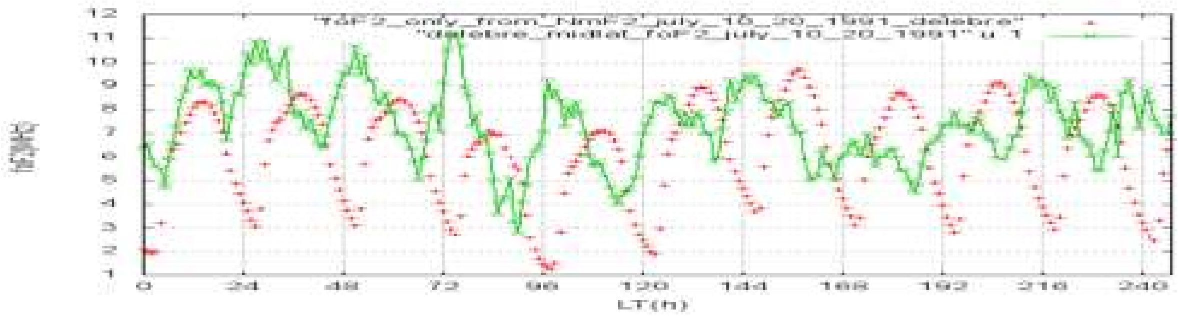

Figure 4: Depicts the combined plots of observed foF_2 and FLIPS modelled foF_2 for the storm period 10th -20th July 1991 for the station Delebre. The FLIP modelled values are matching from the respective observed values of foF_2 during the days from 15th July at 12:00 UT up to 16th July 20:00 UT.

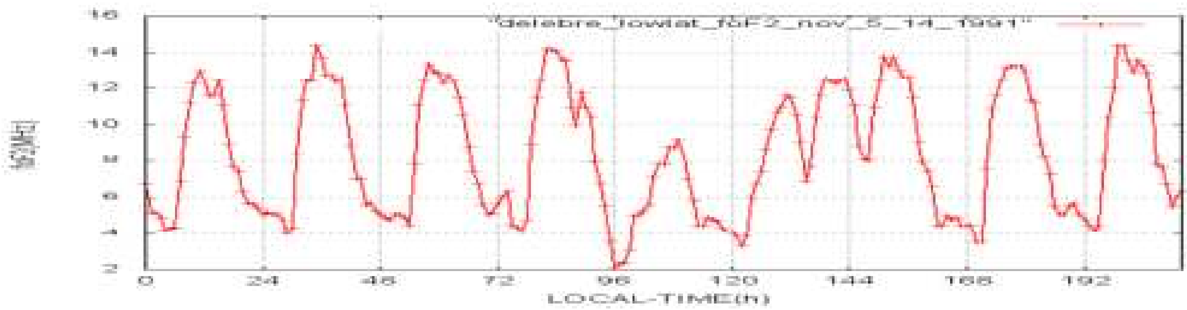

Figure 5: Represents foF_2Vs local Time showing depression in foF_2 during storm day November 8, 1991 for the mid latitude station Delebre(40.8 ^{0} N, 0.3 ^{0} E).

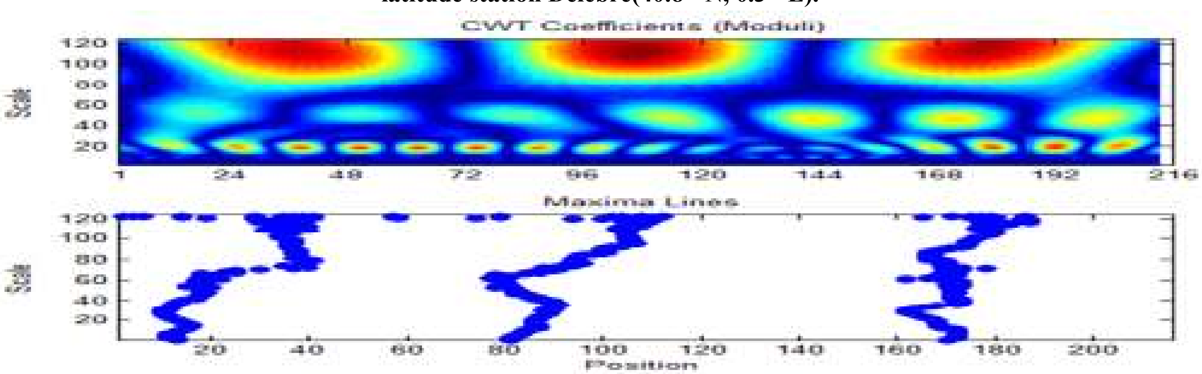

Figure 6: Represents the plot of CWT coefficients during the storm period 5th -14th November 1991 showing small patterns at the right bottom at the scale below 20 around the time point 96, 168 and 192 for the mid latitude station Delebre. Another large pattern is also observed around the scale at the time points 84, 96, 120, 144 and 168.

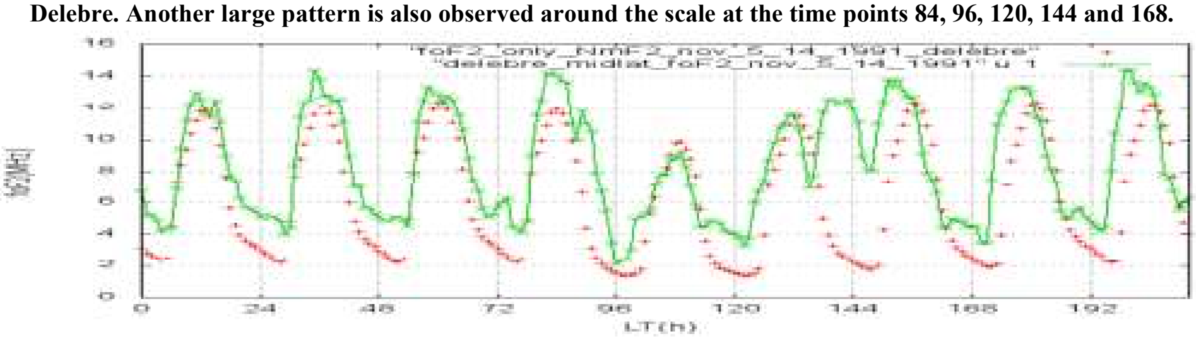

Figure 7: Depicts the combined plots of observed foF_2 and FLIPS modelled foF_2 for the storm period 5th -14th November 1991 for the station Delebre. The FLIP modelled values are matching from the respective observed values of foF_2 during the days from 5th November at 12:00 UT up to 10th November 18:00 UT.

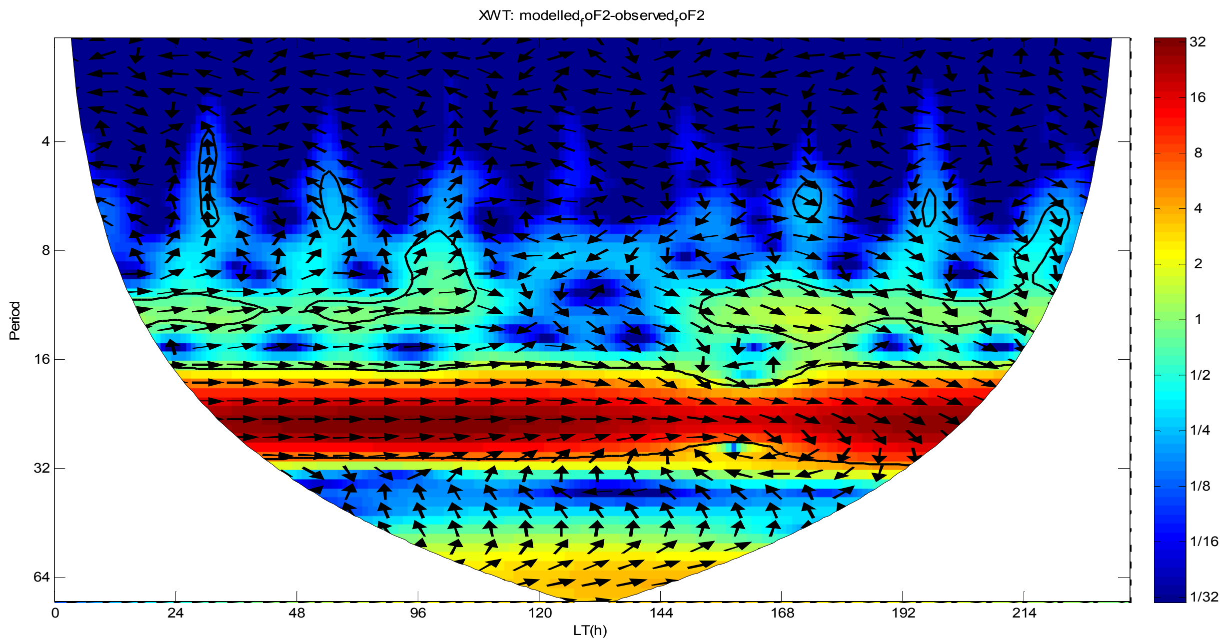

Figure 8: Representscross correlation between observed foF$_2$Vs modelled foF$_2$ during the storm period 5th -14th November, 1991 for the mid latitude station Delebre.

CONCLUSION

In the present study, we have investigated the effects of geomagnetic storm on the ionospheric parameters such as foF$_2$at different latitudes. We plotted the CWT coefficients of the ionospheric data of foF$_2$ during the geomagnetic storm periods 10th -20th July 1991and 5th – 14th November 1991. The abrupt changes (rapid magnetic field variation) in the data are displayed as small patterns in the plot of CWT coefficients. It is found that in the time series of foF2, there is depression in foF$_2$ during the storm dates which indicates that negative storms are responsible for it. Appreciable correlation between the measured and modelled values is noted for both the events during the quiet cum intense geomagnetic storm periods.

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