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Storm Effects on F-region Critical Frequency foF_2 and Propagation Parameter M(3000)F2 over Equatorial (Jicamarca) and Low (Madimbo) Latitude Stations - A Comparative Study

Anju Nagar

Department of Physics, S M S Govt Model Science College, Gwalior, Madhya Pradesh, India

ABSTRACT: Using the simultaneous data from an equatorial station, Jicamarca (12^0S, 283^0E) and low latitude station Madimbo (22^0S, 031^0E) during the low solar activity period from January 2006 to December 2010, a comparative study of the average and seasonal effects of storms on the ionospheric parameters, such as critical frequency of F2- layer and the Propagation parameters M(3000)F2 are presented. The results show that during summer the response of foF2 are quite opposite for the two locations after 36 hrs of the commencement of the storm while propagation parameter behaves differently after the SSC for two locations during summer as well as in equinox. During winter the response of foF2 and M(3000)F2 are almost same but reduced on scale in case of M(3000)F2.The effects of magnetic storm on both parameters are complex and deviate greatly from average behaviour for two locations.

KEYWORDS:F-region, Critical frequency, propagation parameter, Ionospheric disturbances**.**

I. INTRODUCTION

A geomagnetic storm is a marked temporary disturbance of the earth's magnetic field caused by space weather. During geomagnetic storms the magnetospheric energy input into the polar upper atmosphere can significantly modify the chemical and dynamics/electrodynamics processes of the ionosphere-thermosphere (I-T) system. The ionospheric activity is not always related to geomagnetic storms. Especially in the low and lower mid-latitude region, ionospheric variability occurs without geomagnetic storms. The ionosphere displays large day to day variability even on magnetically quiet periods and not always easy to define a storm. A geomagnetic storm is closely related to ionospheric activity and the effects of geomagnetic storm on the ionosphere are different for different latitudes even in the low latitude region the effects are very different. During the magnetic storms, eastward electric field is sometimes enhanced in dayside and transport ionospheric plasma to poleward. This cause decrease in the ionospheric density inside the Equatorial Ionization Anomaly (EIA) crests and enhancement outside the EIA crests.

Ionospheric storms are important for two reasons. First they constitute an important link in the complex chain of solar-terrestrial relations. Second it occurrence strongly and severely affects the ground based communication systems, rapid variations in the magnetic field can affect high frequency ionspheric propagation and related military and commercial operations and cause radio blackout. The effects of magnetic storm on the ionosphere are complex and deviate greatly from average behaviour. There are some common elements of behaviour for most storms, but it has been recognized that in the low latitude regions the ionospheric response to particulars geomagnetic storm manifests some irregularities. The statistics of the ionospheric storms are reported by several authors[1-6]. Using the critical frequency of the F2-layer (foF2) the types and onsets time of ionospheric storm related to each geomagnetic storm were statistically analyzed[7]. The results show that, the negative responses prevail at mild latitudes, whereas the positive responses prevail at low latitudes. At low latitude, positive phases commence most frequently in the daytime sector as well as night-time[8](18~21 LT).

Recently, Simi et al.[9] studied the ionospheric response of a geomagnetic storm (8-10 November, 2004) over the equatorial, and near equatorial latitude and revealed the important role of storm-induced O/N_2 changes, along with prompt penetration electric fields and disturbance dynamo electric fields in modulating the ionization distribution in the equatorial ionoization anomaly (EIA) region during this period.

Accoding to Abdu et al.[10] under the effects of the prompt penetration electric fields and the wind disturbance dynamo electric fields, equatorial ionization anomaly (EIA) can undergo a drastic modification resulting in large ionospheric disturbances at low latitude. In a number of works[11-13] authors revealed that upward motion of the ionosphere can also be caused by an enhanced penetration eastward electric field. Furthermore, the increase in peak electron density (NmF2) following an increase in height of maximum plasma density (hmF2) and its time delay at lower latitudes was provided as evidence of travelling atmospheric disturbances (TADs) that drive positive ionospheric storms in the low and middle latitudes[14]. Sobralet al.[15] presented some cases of foF2 increases over low latitudes to be related to an enhanced plasma fountain. During magnetically-disturbed conditions the low-latitude electric fields and currents change substantially from their quiet time pattern. The relative roles of different mechanism responsible for the suppression of the equatorial anomaly were studied by Pavlov et al.[16].

It has been recognized that geomagnetic storm manifests some irregularties more likely over equatorial and low latitude region owing to the presence of equatorial ionization anomaly phenomenon. Therefore, using the critical frequency foF2 and propagation parameter M(3000)F2 the effects of geomagnetic storm on the F2 region ionosphere over an equatorial station, Jicamarca (12^0S, 283^0E) and a low latitude station, Madimbo (22^0S, 031^0E) are presented in this paper.

II. MATERIALS AND METHODS

We have selected only 45 storms for this study that occurred during January 2006 to December 2010 due to non-availability of data. The maximum negative excursion of Dst for these storms generally varied between -5nT and – 85nT. To examine the seasonal effects we grouped all storms into three seasons winter, summer and equinox using the four months of data for each season [i.e. winter (November, December, January, February), summer (May, June, July, August) and Equinox (March, April, September, October)], changing summer for winter months for southern hemisphere stations .

We have also selected a typical storm occurred on 19 November 2007 which treated as individual storm for the study. The data of ionospheric parameters foF2 and M(3000)F2 have been obtained from space physics Interactive Data Resource (SPIDR) network (http://spidr.ngdc.noaa.gov) for two locations namely, Jicamarca (12^0S, 283^0E) and Madimbo (22^0S, 031^0E). The F2-region response to geomagnetic storms were described in terms of D(foF2) rather than foF2 and D[M(3000)F2] rather than M(3000)F2. The term is the normalized deviations of the critical frequency foF2 from the reference i.e.

$$D(foF2) = \frac{foF2 - (foF2)_{ave}}{(foF2)_{ave}} \tag{1}$$

Similarly,

$$D[M(3000)F2] = \frac{[M(3000)F2]_{ave}}{[M(3000)F2]_{ave}} \tag{2}$$

Where the reference for each hour is the average value of foF2 [or M (3000)F2] for the hour calculated from the five quiet days of the month (i.e. the month in which magnetic storm occurred) . We have considered the storm time, sudden storm commencement (SSC) as 0 hour and 72 hours after the SSC were analyzed for foF_2 and as well as for M(3000)F2. The value of Ap and Kp index for this period were also obtained from SPIDR while Dst values were downloaded from the website: http://wdckugi.kyoto-u.ac.jp/. The interplanetary magnetic field (IMF) B_z component have been downloaded from NSSDC's OMNI database.

III. RESULTS

Average effects on foF2 and M(3000)F2

The average behaviour of several indices that describe the interplanetary and geomagnetic conditions for all the storms analyzed for 72 hours after the commencement of the storm are depicted in Fig. 1 while Fig. 2 shows the average value of the deviation of the critical frequency foF2 and the propagation parameter M(3000)F2 separately during the 45 storms for two stations.

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In fig. 2, D(foF2) plot shows that there is general increase in the electron density at a maximum of the ionospheric F2 layer, then by resulting in a positive phase storm at both location. At Jicamarca after a negative phase a positive phase is being observed. The lack of negative phase in the overall mean variation is seen at Madimbo. In case of M(3000)F2**,** it is observed that Jicamarca shows mixed behaviour while the lack of positive phase seems at Madimbo. It is also noted that the D[M(3000)F2] variation were reduced on scale than D(foF2).

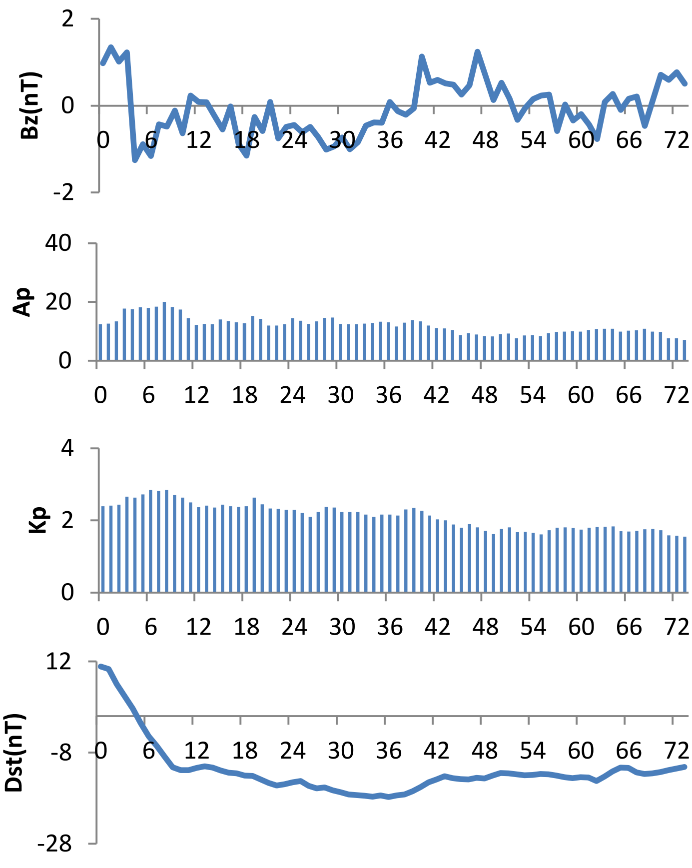
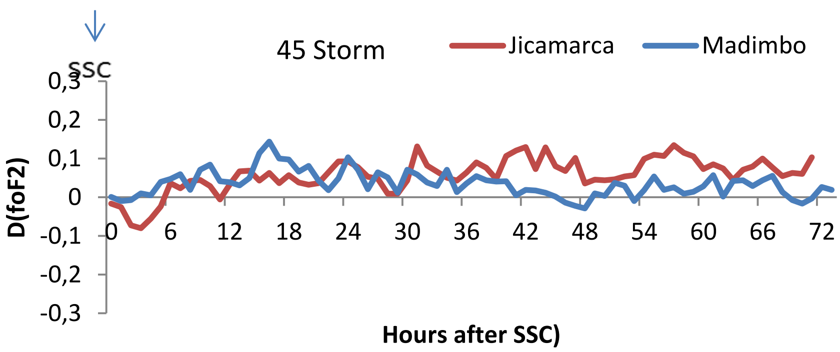


Fig.1. Average storm time variation in IMF component Bz ,Ap,Kp and Dst(nT) from top to bottom for 45 storms during the period from January 2006 to December 2010.



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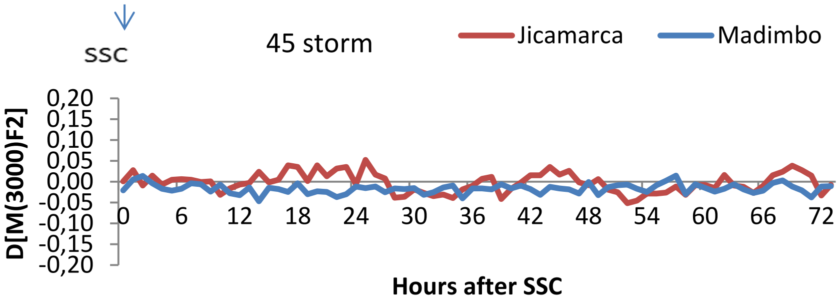

Fig. 2. Average variation in D(foF2) (upper panel) and D[M(3000)F2] (lower panel) for 45 storms during the period from January 2006 to December 2010.

Average seasonal effects on foF2 and M(300)F2

To investigate the ionospheric behaviour in different seasons, 45 storms have been divided into three season winter, summer and equinox during the period January 2006 to December 2010. However, a similar classification of the storms was not possible as a sufficient number of storms were not available during each season. In this, connection fig. 3 to 4 shows the seasonal variation of average deviation of foF2 and M(3000)F2respectively. From fig.3, it is found that during winter and equinox both locations follows an averaged pattern as discussed earlier. However, Madimbo deviates from average pattern after 42 hrs from SSC during summer. Further from fig. 4, it can be seen that during winter both locations show simultaneous depletion in M(3000)F2 but behaves differently and somewhat oppositely during summer as well as in equinox.

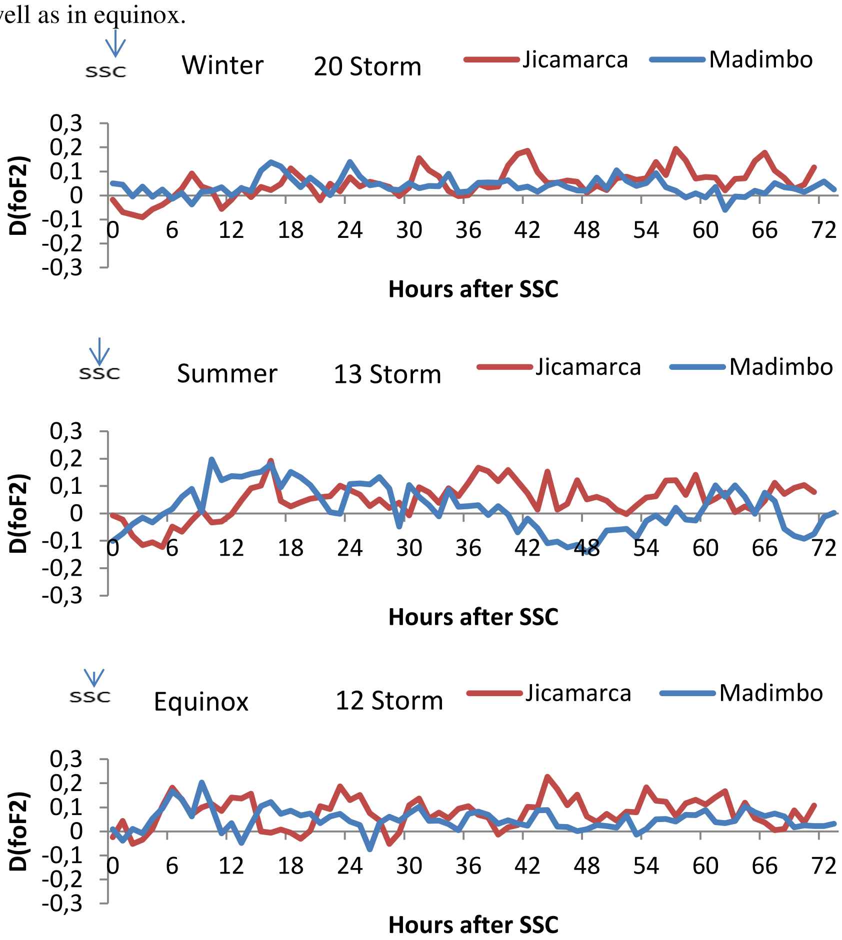

Fig. 3. Seasonal average variation in D(foF2) for storms occurred during January 2006 to December 2010.

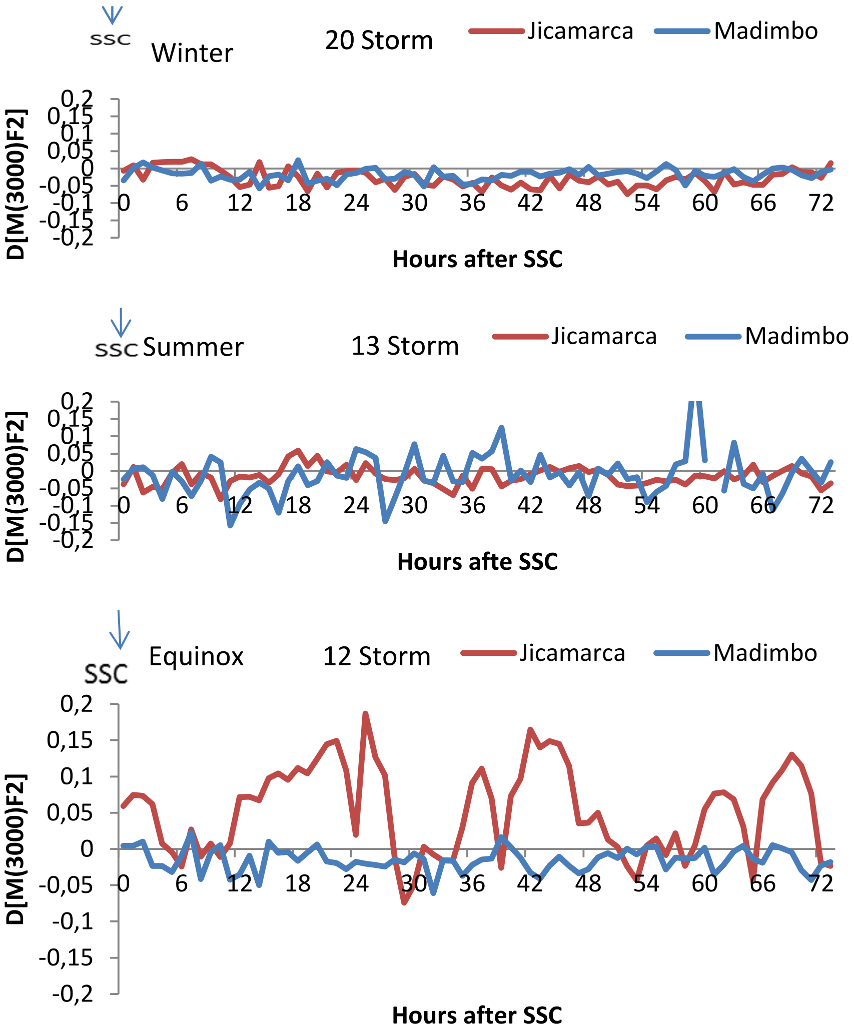

Fig. 4. Seasonal average variation in D[M(3000)F2] for storms occurred during January 2006 to December 2010.

An individual storm occurred on 19 november 2007

In fig.5 we have plotted the variation of B_z(nT), A_p, K_p and D_{st} (nT) indices during the considered storm while fig.6 represents the variation in D(foF2) and D [M (3000)F2] for 72 hours after time of SSC (consider the time of SSC as 0 hrs). The SSC is occurred at 1811 hrs (UT) on 19 November 2007.

The first Panel in fig. 5 shows that from the beginning 00 hrs, the IMF B_Z was northward till 10 hrs, after which it was turned southward and reached the maximum value -16nT at 16 hrs and remained negative up to 20 hrs. After that it experienced a sinusoidal wave like pattern (reduced on scale) until around 66 hrs and then again turned southward. The second and third panel of the same figure depicts that more southward turning of B_z coincides with the maximum value of Kp and A_p index. The D_{st} Plot shows two maximum negative excursion -57 and -61nT at 20 at 25 hrs after SSC (Panel four). This storm was followed by a slow recovery thereafter at 68 hrs Dst value again started to drop.From theplot of deviation of the critical frequency (foF2) shows that at Jicamarca a positive storm effect from commencement of the storm throughout the rest of hours with maximum deviation 80% at 38 hrs. Although a short lived negative phase is observed around 5 to14 hrs. The foF2 values for Madimbo do not respond during first 10 hrs and then a small negative phase at 12 hrs is observed after that it shows the considerable enhancement (positive storm effect) up to 36 hrs and a negative storm effect throughout the remaining hours.

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The response of M(3000)F2 values at Jicamarca is rather complex, constitute both phase alternatively after SSC, the maximum positive phase is observed at 39 hrs and maximum negative phase at 69 hrs after SSC. On the other hand, Madimbo is mostly characterized by negative phase with a 30% depletion level at 48 hrs after SSC.

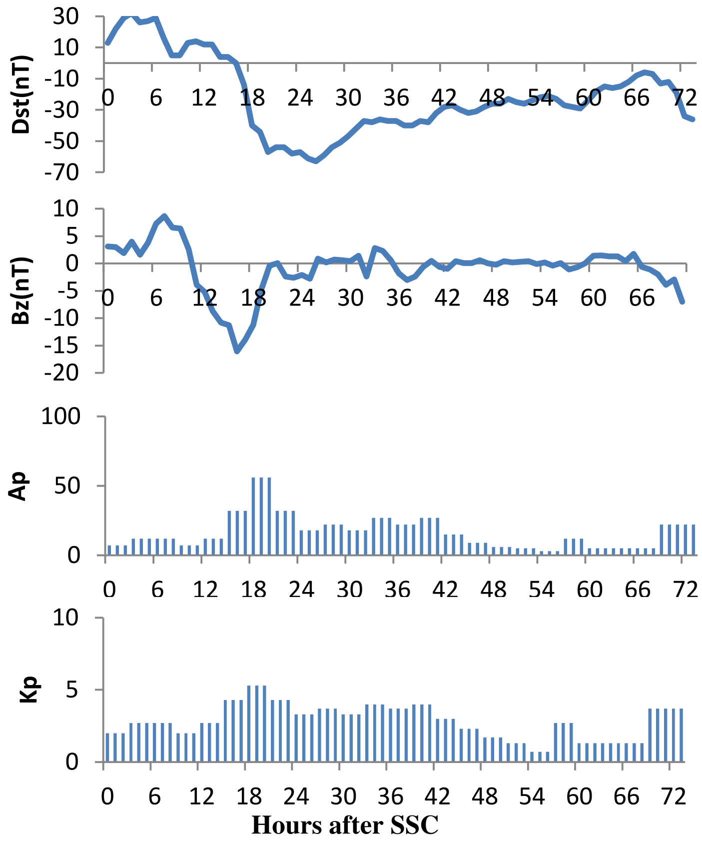

Fig. 5. Average storm time variation in IMF component Bz, Ap,Kp and Dst(nT) from top to bottom for 72 hours after SSC occurred on 19 November 2007.

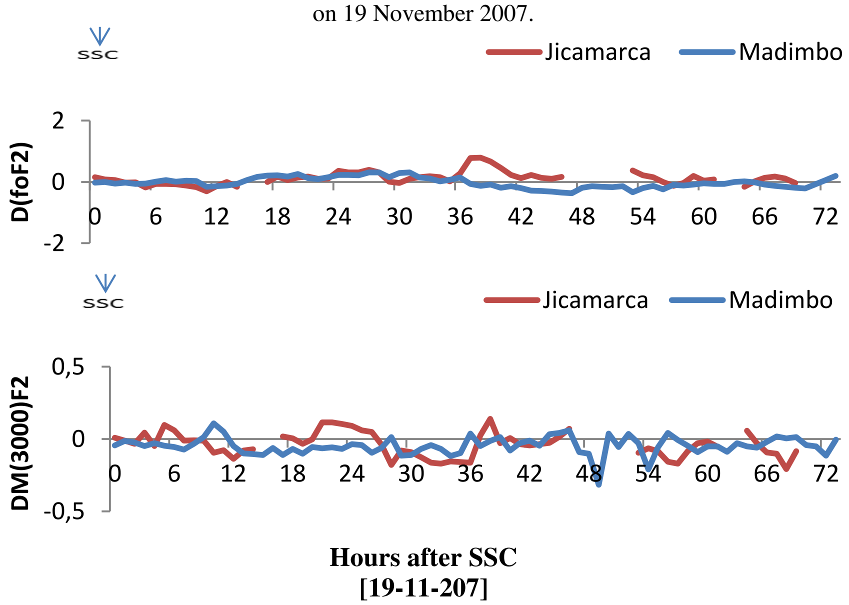

Fig. 6. Variation in D(foF2) (upper panel) and D[M(3000)F2] (lower panel) for 72 hours after SSC on 19 November 2007.

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IV. DISCUSSION

Since the beginning of the space age the cause of geomagnetic activity has been sought in spite of this there are no consistent explanations obtained on the mechanisms of ionospheric storms till now[17-24].
Recently, Adekoyaet al.[25] observed the simultaneous intense depletion of foF_2 at all latitudes during the intense geomagnetic storm of August 12, 2000. They suggested that it may not be mainly due to changes in neutral composition. According to them particle precipitation known to occur at both higher and lower latitudes during very intense geomagnetic disturbances may be account for the simultaneous depletion in foF2.

Thermospheric neutral composition changes with molecular nitrogen N_2 to atomic oxygen O(N_2/O) ratio, increase are believed to be responsible for the negative disturbances observed at mid latitudes. The same has been confirmed by measurements and model calculations[26-31]. The storm positive phase, more significantly at low latitudes in equinox and winter, is probably due to the downwelling of thermospheric gas. The downwelling of thermospheric gas mainly caused by storm induced thermospheric winds, may cause the increase of ionization at low-latitudes without any significant change in atom-to-molecule ratio[30]. It is believed that the storm negative disturbance is caused by the change in the thermospheric composition because of the heating of the thermosphere during magnetic storms. The occurrence of storm negative phase at mid and low-latitudes was due to equator-ward shift of the molecularly enriched air to lower latitudes by storm induced equator-ward directed circulation[32,33]. The equator-ward penetration of negative phases displayed a seasonal behaviour in summer the negative phase was better developed at lower latitudes than in the winter and equinox. Because in summer both dynamic background thermospheric circulation and storm induced circulations reinforce each other and are directed equator-ward throughout the day[22]. These results are quite agreement with our findings.

The quiet time summer to winter thermospheric circulation makes the background (O/N_2) ratio smaller in summer than in winter (and equinox) at all pressure (and height) levels. The chemical effects of storm time neutral winds can therefore produce negative ionospheric storms easily in summer. Model simulations[34] shows that combined effects of upward ExB drift and meridonal winds produce the most significant plasma enhancement at low latitude if meridional winds blow equator-ward, the ion drag along magnetic field line will oppose the downward diffusion and keep the plasma at altitudes where the recombination rate is lower. As a result the peak density will increase significantly and also its position will shift to higher latitudes.

Zhao et al.[35] concluded that long duration positive storm effect at middle-low latitudes attributed to several mechanisms. According to them periodic wave structures of foF2 at middle-low latitudes in the morning sector on 14 April should be caused by TADs with phase propagation velocities ranging 400-800 m/s, while in the afternoon and night-time, the positive phase would be most probably caused by both the enhanced equator-ward winds and disturbed eastward electric fields. During the recovery phase, negative storm effect was shown to permeate to the middle-low latitudes and persisted for 2-3 days, which was due to the reduced O/N_2 according to the observation as GUVI. It is well known that the ring current becomes significantly more intense during geomagnetic storm. The energy protons present in the ring current undergo a charge exchange reaction with the ambient hydrogen atom. These energetic neutralized hydrogen atoms are no longer in a constraint to follow the magnetic field and can directly precipate into the Earth's denser atmosphere[36] which is in turn is responsible for producing heating in the upper atmosphere[37,38]. The direct insertion of energy from the ring current in the form of particle precipitation into the upper thermosphere is also believed to play a crucial role over the equatorial and low-latitude region[39].

The storm-induced effect over equatorial and low latitude region is very complicated owing to the presence of equatorial ionization anomaly phenomenon and many other factors. The storm induced changes in ratio (O/N_2) also play a significant role in conjunction with the storm time electric fields in modulating the spatial distribution of ionization in the EIA at a given time[9].

Early studies showed that the formation of positive phase can be explained with the mechanism that at the time of geomagnetic storm during the sunlit hours the eastward electric field at the equatorial belt is suppressed. Due to this, the upward lift of plasma is reduced and positive phase developed at equator during main phase of storm[11,40-41]. Also, as previous studies have shown, middle and low latitudes ionosphere can be affected with an Equatorial Anomaly (EA) expanded pole-ward and become more produced during an important storm event[42,43]. An additional source of ionization arises from equatorial latitudes the enhancement of the zonal electric field during perturbed periods increases the upward drift and the subsequent drainage from equatorial region followed by the ambipolar diffusion down the magnetic field lines toward low latitudes. This effect could be also responsible for the delay and maintenance of positive effects at the crests[44]. Delayed positive ionospheric storms have been attributed to changes in neutral gas composition[45]. The storm induced circulations transports air rich in atomic oxygen from higher latitudes toward lower latitudes. The enhanced oxygen density will affect the ionization production thus producing the positive effects.

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