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Investigation into quiet and magnetic storms periods above Magadan during October - December 2003

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The present work investigated the ionospheric response of the latitude above Magadan to the geomagnetic storms during October - December 2003. The study was based on storm time disturbance index, Dst, and the corresponding foF2 data above the ionosphere of Magadan in the East Asian sector. The response was investigated at all classes of storm and the quiet period inclusive. The analysis of the foF2 data during October - December 2003 shows that Dst of low magnitude can cause intense ionospheric storm. Dst values > -30 nT, which has been generally accepted to be quiet period caused major ionospheric storms of the order of 65% depletion and 59% enhancement in October. Also, two weeks before the commencement of the very intense geomagnetic storm on 20 November 2003 (Dst < -422 nT), quiet period (Dst > -30 nT) caused major ionospheric storms of the order of 70% enhancement and 45% depletion. December that was predominantly quiet, the weak Dst produced intense ionospheric storms of the order of 76% enhancement and 70% depletion. It is worthy to note that the peak positive Dst on 20 December 2003 between 06:00 and 09:00 hrs UT caused an intense ionospheric depletion above the ionosphere of Magadan with a peak value of ~70%.

Keywords: Geomagnetic storm, Ionospheric storm, F2 layer critical frequency, Storm time disturbance index (Dst), Ionospheric depletion / enhancement

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1 Introduction

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[1]. Significant impact of space weather on human activity includes sudden satellite failures as well as their gradual degradation due to the earth's radiation belts. Other consequences include the disruption of high latitude HF radio communications, interference in military radars, and even occasional utility power outages as far South as New Jersey[2]. Also, Kane[3] stated that even moderate storms affect terrestrial power grid, and more intense storms can have disastrous effects. For these effects on the earth and its ionosphere, the continuous patrolling of solar flares and coronal mass ejections (CMEs) can be very useful for safe prediction.

Several reports show details of the variation of electron density at the F2 layer peak. These variations are involved with enhancement or reduction during the positive and negative storm phases. Danilov & Morozova[4] suggested that the characteristics of ionospheric storms should be studied in terms of deviations of the F-layer critical frequency, foF2, for positive and negative phases from the median value and changes in the minimum virtual height and the peak height. Sahai *et al.*[5] reported the occurrence of large scale equatorial F-region plasma depletions during geomagnetic storms. Walker & Wong[6] reported for the ionospheric effects in East Asia of the large magnetic storm of 13-15 March 1989, and the response of equatorial and low latitude F-region to the same storm of 13 March 1989, has been investigated by Lakshmi *et al.*[7] Ionospheric disturbances around East Asia region to severe geomagnetic storm were studied by Huang & Cheng[8] and Lakshmi *et al.*[9] Recent studies by de Abreu *et al.*[10] and de Jesus *et al.*[11] have reported the response of the ionospheric F-region during super storms in the Brazilian and South American sectors, respectively. Response of the equatorial ionosphere in the Indian sector to the severe magnetic storm of 15 July 2000 has been investigated by Sastri *et al.*[12], and the response of the equatorial ionosphere in the South Atlantic region to the great magnetic storm of 15 July 2000 has been investigated by Basu *et al.*[13] Also, Sahai *et al.*[14] reported the effects observed in the F-region in two longitudinal sectors during the major geomagnetic storm in October 2003. Mannucci *et al.*[15] reported on the major interplanetary events (Halloween storms) of 29–30 October 2003, while Abdu *et al.*[16] worked on the ionospheric responses to the October 2003 super storm. In the work of Turunen & Rao[17] on the influence of strong magnetic storms on the equatorial F-layer, the studies of magnetic storm effects on the ionosphere usually concentrate on the deviation of the F-layer parameters during storm periods from monthly averages.

Several studies have focused on the response of the ionosphere to great geomagnetic storms. However, it is important to investigate the hourly effects of super storm in detail. This paper presents the hourly investigation of the Halloween event of 2003 geomagnetic storm in order to determine the overall predominant physical mechanism taking place in the ionosphere during geomagnetic storms.

According to Kane[3], large Dst currents are known to cause severe perturbations in terrestrial environment. It is important to know the severity with which a storm may occur, so that possible preventive or remedial measures could be taken. Satellite observations of flow speed (*V*) and magnetic field component directed towards the south (B_s), as at present from the Advanced Composition Explorers (ACE) satellite near L1, are of limited utility for predictions, as these are available only with an antecedence of less than one hour. To predict with more antecedence, relationship must be established with directly observed solar features, as these are often seen tens of hours earlier. Since many storms are related to coronal mass ejections (CMEs), relationship of Dst with some key observational parameter of CME could lead to a prediction scheme.

Kane[3] stated that all the storms considered (Dst > -160 nT) probably had at least small damaging effects but probably did not make news, whereas storms with Dst < -300 nT can certainly be noticed prominently, and the remarkable events would attract worldwide attention. The stronger Dst events are believed to be the most damaging. In the last 47 years, the largest Dst event was on 13 March 1989 and is reported to have caused considerable damage[18]. However, the next two largest Dst events occurred very recently and in quick succession, i.e. 30 October 2003 and 20 November 2003, at an interval of only ~20 days) (Ref. 3). These offer a good opportunity to test, for these giant events, the previous relationships obtained for less intense storm. It is in this light that the present work investigates the depletions and enhancements of the ionosphere which can affect radio propagation as caused by the supposed quiet period as well as weak, moderate, intense and very intense geomagnetic storms during October - November 2003.

2 Data and Method of analysis

The data used in this study consists of hourly values of the storm time disturbance index, Dst, obtained from OMNIWEB (http://omniweb.gsfc.nasa.gov/) and hourly values of critical frequency of the F2 layer (foF2) obtained from Space Physics Interactive Data Resource (SPIDR) website (http://spidr.ngdc.noaa.gov).

In order to look at the problem of ionospheric storm as it affects the depletions and enhancements of the ionosphere, which in turn affect radio propagation caused by the supposed quiet period, weak, moderate, intense and very intense geomagnetic storms, the response of the ionosphere above the upper latitude station of Magadan in East Asian sector to the geomagnetic storms have been studied during October - December 2003. The geographic and geomagnetic co-ordinates of Magadan are (60°N, 51.9°E) and (51.9°N, 213.4°E), respectively.

The present study is concerned with variations in f_0F2 due to the geomagnetic storm during October - December 2003. However, the F2 region response to geomagnetic storms is most conveniently described in terms of D_{foF2}, that is, the normalized deviations of the critical frequency foF2 from Chukwuma[19] as:

$$\delta f_0 F2 = \frac{f_0 F2_{ave}}{f_0 F2_{ave}}$$

Hence, the data analyzed, in the present study, consists of respective hourly values of D_{foF2} during

October - December 2003. The reference for each hour is the average value of f_0F2 corresponding to absolute quietness (i.e. Dst = 0).

3 Results and Discussion

3.1 Geomagnetic and interplanetary observations

Figures 1-3 show the plot of the storm time disturbance index, Dst, for the period October - December 2003. Storms can be classified as: weak (-50 < Dst < -30 nT), moderate (Dst < -50 nT), intense (Dst < -100 nT), very intense (Dst < -250 nT) and otherwise quiet[20-22]. According to this classification, the Dst plot in Fig. 1 for October 2003 shows an alternating positive and negative Dst starting from a quiet period with a Dst of -11 nT at 00:00 hrs UT on 1 October. It reached its first weak value at 23:00 hrs UT on same day with a value of -36 nT. Thereafter, it alternated between positive and negative values until it attained its first moderate value of -52 nT at 11:00 hrs UT on 14 October. The first intense value for the month was recorded at 07:00 hrs UT on

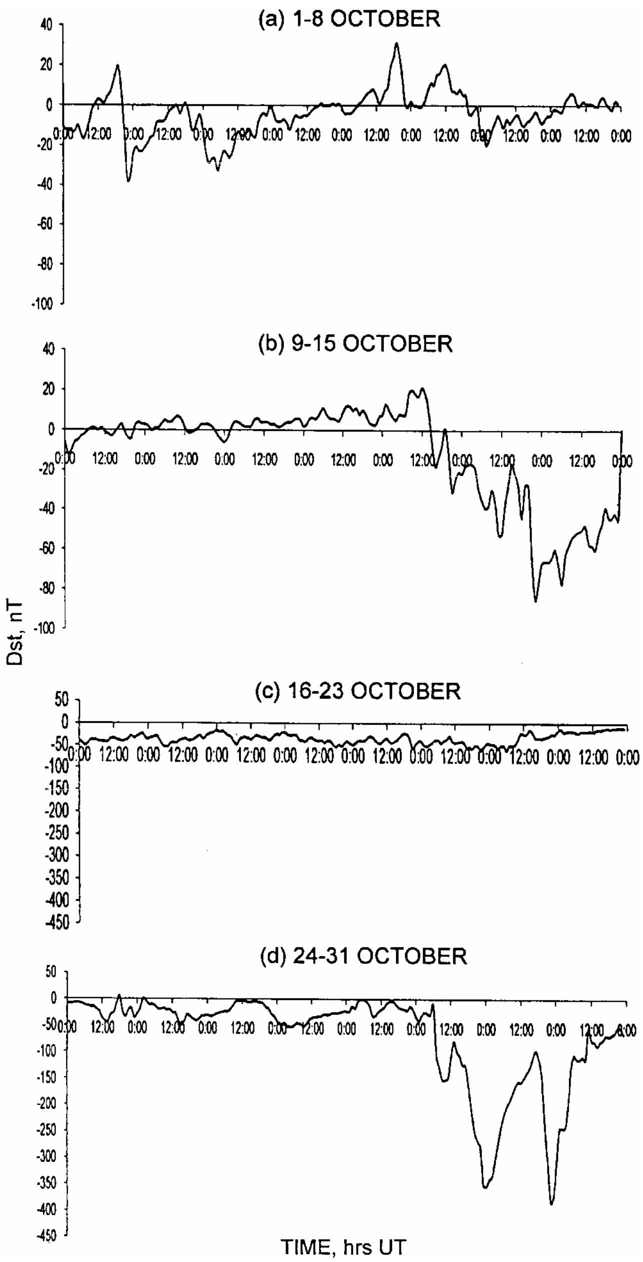

Fig. 1 — One-hour averages of Dst *vs* Time for October 2003

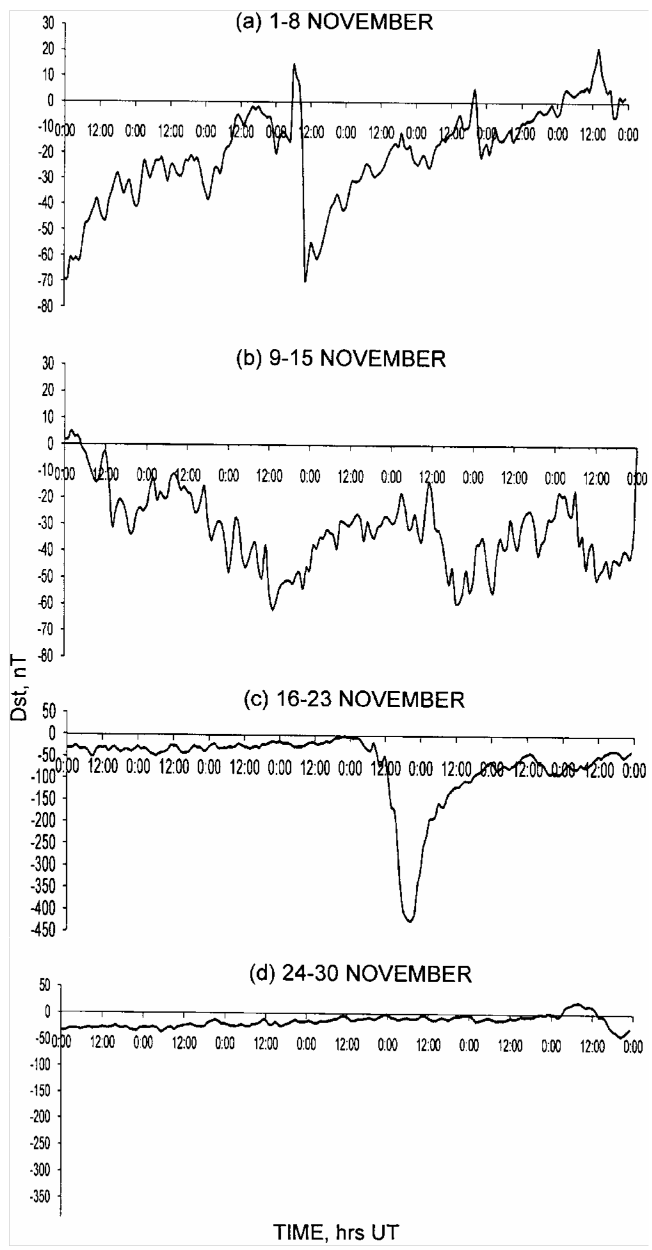

Fig. 2 — One-hour averages of Dst *vs* Time for November 2003

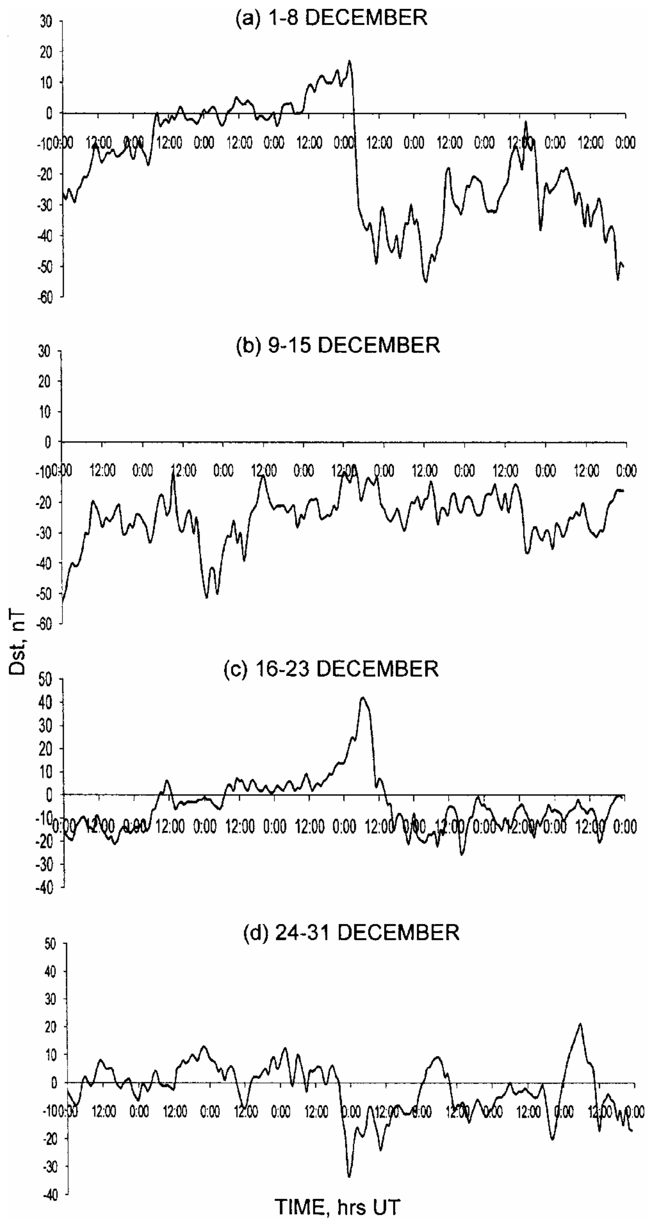

Fig. 3 — One-hour averages of Dst *vs* Time for December 2003

29 October with a value of -105 nT. It became very intense around 20:00 hrs UT on the same day with a value of -253 nT. The peak Dst minimum for the month was recorded on 30 October with a Dst value of -383 around 22:00 hrs UT.

Figure 2 shows the Dst plot for November 2003. The month began with a moderate storm of Dst value of ~ -70 nT at 00:00 hrs UT on 1 November. It recovered gradually to a weak storm around 07:00 hrs UT the same day with Dst index of -48 nT. The period 9 - 15 November was a mixture of quiet, weak and moderate storms period. However, starting from 16 November, a quiet and weak geomagnetic storm period lasting almost 4½ days preceded the notable storm of 20 November 2003, having a peak minimum Dst of -422 nT around 20:00 hrs UT. Thereafter, it recovered gradually, and throughout 24 – 30 November, it maintained a quiet and weak status.

Figure 3 began with a quiet period on 1 December and continued in this state till the early hour of 5 December. Thereafter, Dst remained negative till the dawn of 17 December. The peak positive value of Dst from October to December 2003 was recorded on 20 December around 07:00 hrs UT with a value of 42 nT. It is worthy to note that there were no intense and very intense geomagnetic storms in December 2003. The period was predominantly alternating between quiet and weak storms with only a handful of moderate Dst values.

3.2 Ionospheric response

The results of ionospheric study are shown in Figs 4 – 6. These show the D_{foF2} plots for the period October - December 2003 for the ionosonde station of Magadan. Tables 1-3 show the values of Dst, f_0F2 and the percentage depletion or enhancement caused by the ionospheric storm which is the response of the ionosphere to the quiet and troubled period of the geomagnetic storms.

A brief look at the analyses of the D_{foF2} plots for some significant days during October – December 2003 (Tables 1-3) reveal the following significant features:

(i) Dst values > -30 nT, which has generally been accepted to be quiet period caused major ionospheric storms of the order of 65% depletion and 59% enhancement at 11:00 hrs UT on 22 October and 06:00 hrs UT on 29 October, respectively.

(ii) Dst values of quiet and weak periods caused depletion of greater magnitude than that of notable very intense storm of 30 October 2003.

(iii) Two weeks before the commencement of the world notable very intense geomagnetic storm on 20 November 2003 (Dst < -422 nT), quiet period (Dst > -30 nT) caused major ionospheric storms of the order of 70% enhancement and 45% depletion at 01:00 and 15:00 hrs UT on 6 November, respectively.

(iv) Weak geomagnetic storm of Dst = -36 nT at 09:00 hrs UT on 13 November caused depletion

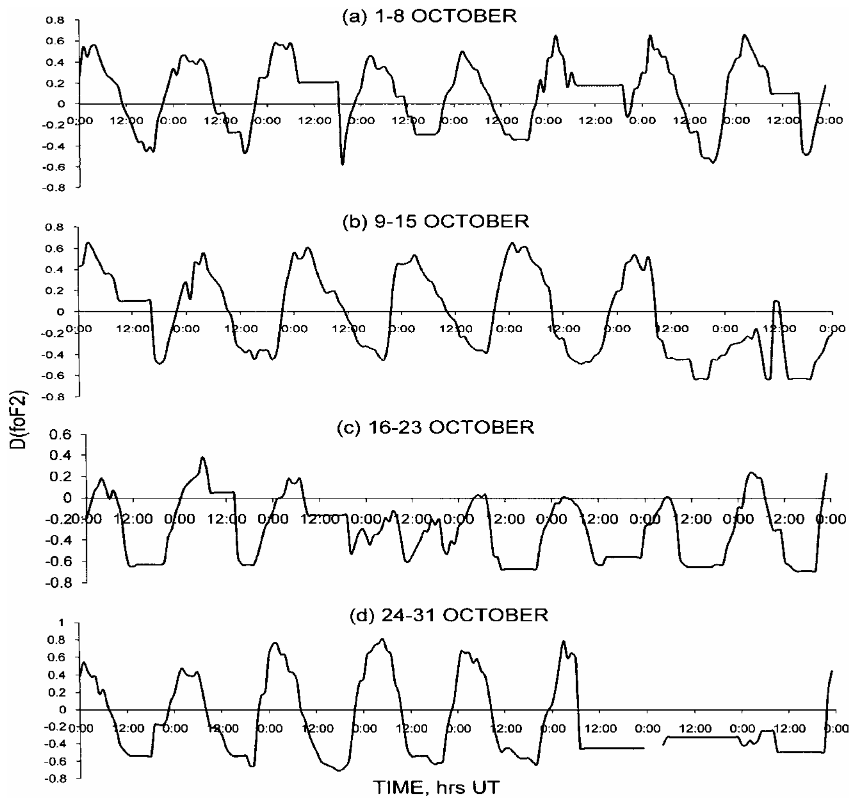

Fig. 4 — Variation in D_{foF2} at Magadan during October 2003

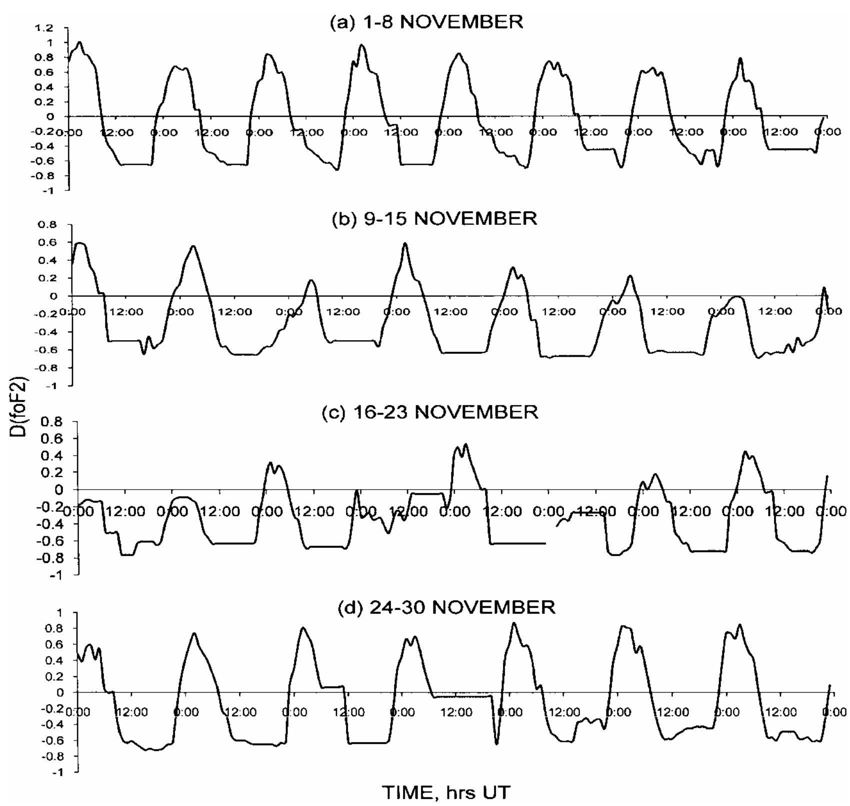

Fig. 5 — Variation in D_{foF2} at Magadan during November 2003

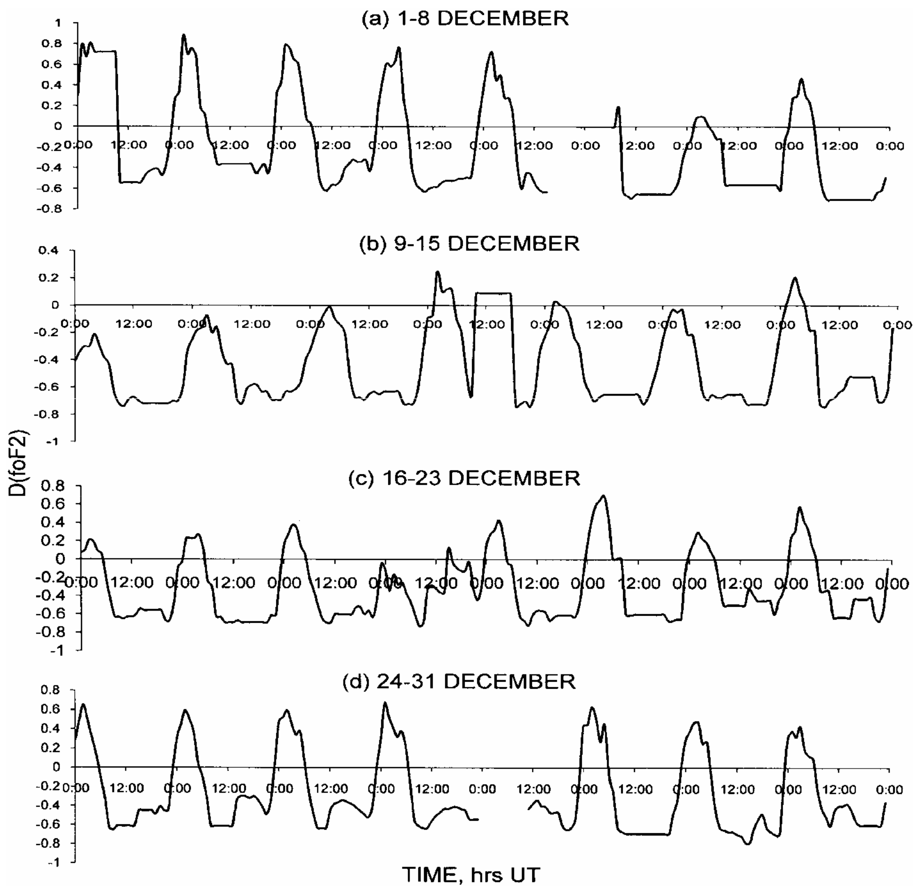

Fig. 6 — Variation in D_{foF2} at Magadan during December 2003

Table 1 — Day-to-day percentage depletion/enhancement for the month of October 2003

Date	Time, hrs UT	Dst, nT	Type of storm	Variation, %	Enhancement/ Depletion
1	02:00	-12	Quiet	45	E
	05:00	-10	Quiet	47	E
	09:00	-8	Quiet	21	E
	23:00	-36	Weak	21	E
22	11:00	-22	Quiet	65	D
	12:00	-24	Quiet	65	D
	13:00	-24	Quiet	65	D
27	13:00	-35	Weak	54	D
	14:00	-34	Weak	54	D
29	02:00	-32	Weak	56	E
	06:00	-10	Quiet	59	E
	11:00	-147	Intense	45	D
	07:00	-105	Intense	45	E
30	04:00	-273	Very intense	41	D
	08:00	-192	Intense	32	D
	23:00	-371	Very Intense	32	D

Table 2 — Day-to-day percentage depletion/enhancement for the month of November 2003

Date	Time, hrs UT	Dst, nT	Type of storm	Variation, %	Enhancement/ Depletion
1	01:00	-69	Moderate	88	E
	06:00	-56	Moderate	74	E
	11:00	-38	Weak	45	D
	18:00	-28	Quiet	65	D
6	01:00	-24	Quiet	70	E
	06:00	20	Quiet	56	E
	15:00	-5	Quiet	45	D
13	04:00	-23	Quiet	23	E
	09:00	-36	Weak	67	D
	10:00	-25	Quiet	69	D
20	00:00	-4	Quiet	41	E
	09:00	-38	Weak	63	D
	11:00	-58	Moderate	63	D
	13:00	-102	Intense	63	E
	15:00	-171	Intense	63	D
	17:00	-329	Very Intense	63	D
	21:00	-422	Very Intense	63	D
30	03:00	1	Quiet	85	E
	10:00	15	Quiet	56	D
	12:00	14	Quiet	50	D

Table 3 — Day-to-day percentage depletion/enhancement for the month of December 2003

Date	Time, hrs UT	Dst, nT	Type of storm	Variation, %	Enhancement/ Depletion
4	04:00	3	Quiet	76	E
	07:00	0	Quiet	41	D
	08:00	0	Quiet	56	D
	09:00	0	Quiet	60	D
	10:00	1	Quiet	63	D
6	01:00	-35	Weak	0	
	04:00	-55	Moderate	0	
	10:00	-34	Weak	67	D
	12:00	-18	Quiet	65	D
8	00:00	-24	Quiet	0	
	04:00	-18	Quiet	30	E
	10:00	-37	Weak	70	D
	13:00	-33	Weak	70	D
	21:00	-54	Moderate	63	D
	23:00	-50	Moderate	49	D
12	17:00	-19	Quiet	9	E
	18:00	-16	Quiet	74	D
	19:00	-12	Quiet	72	D
	20:00	-13	Quiet	70	D
	21:00	-14	Quiet	74	D
20	06:00	41	Quiet	7	D
	07:00	42	Quiet	40	D
	08:00	39	Quiet	63	D
	09:00	36	Quiet	67	D

of greater magnitude than that of intense and very intense storm on 20 November 2003.

(v) December that was predominantly quiet and weak Dst produced intense ionospheric storms of the order of 76% enhancement and 70% depletion at 04:00 hrs UT on 4 December and 08:00 hrs UT on 8 December, respectively.

(vi) Some of the few moderate storms scattered around the month of December produced no ionospheric storm at all, while absolute zero Dst produced intense ionospheric storm of the order of 60% depletion.

(vii) It is worthy to note that the peak positive Dst, between October and December, which happened on 20 December between 06:00 and 09:00 hrs UT, caused an intense ionospheric depletion above the ionosphere of Magadan with a peak value of ~70%.

4 Conclusion

This work presents a picture of the storm time disturbance index, Dst, and ionospheric response associated with the troubled and quiet period during October - December 2003. The study was based on storm time disturbance index, Dst and the corresponding foF2 data for Magadan station. The main results of this work are summarized as:

- Dst values > -30 nT, which has generally been accepted to be quiet period caused major ionospheric depletion and enhancement.
- Dst values of quiet and weak periods occasionally caused depletion of greater magnitude of the order of intense and very intense storm.
- Predominantly quiet months should not be ignored as can be seen from December 2003 data.
- Absolute zero Dst produced intense ionospheric storm.
- Positive Dst produced intense depletion and enhancement.

The principal features of the positive and negative phase distribution and variables have been explained on the basis of the principal concepts that during a geomagnetic disturbance, there is an input of energy into the polar ionosphere, which changes thermosphere parameters, such as composition, temperature and circulation. Composition changes directly influence the electron concentration in the F2 region.

Since a long time, with a large database, it is established that the geomagnetic storms after the sudden commencement can cause enhancements and depletions during the main phase and recovery phase of the storm. The effect of the geomagnetic storm is retained till two to three days and more after the sudden commencement. Also, in the present period of consideration, there is overlapping of storms and hence, the changes in density with less values of Dst.

The enhancements or depletions observed in the electron density during quite days may be due to some drivers other than the Dst, such as travelling ionospheric disturbances (TID's), solar flares and input of energy into the polar ionosphere.

From the aforementioned results, Dst of low magnitude should not be ignored. More research should be taken for the periods that are termed quiet in order to minimize the adverse effects of magnetic storm on our planet. Furthermore, positive Dst is another area that is left open for researchers to look more deeply into, since it can also cause depletions and enhancements in the electron densities of the ionosphere.

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