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Response of ionospheric foF2 over south east Asian sector to geomagnetic storm of 29 October 1973

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The auroral electrojet (AE) index was employed for the study of the ionospheric response to the geomagnetic storm of 29 October 1973. The interplanetary magnetic field (IMF) component, Bz, and the low latitude magnetic index, Dst, show that the event is a moderate (Dst = -64 nT, Bz = -5.8 nT) storm. The analysis from the disturbances in ionospheric foF2 during 29-31 October 1973 shows predominantly an enhancement (positive storm) at the mid and low latitude stations. In between the time of storm (14:00 hrs UT on 29 October and 05:00 hrs UT on 30 October), the upper latitudes also show some degree of enhancement. This paper concludes that the reason for the observed positive ionospheric storm over all latitudes under investigation could be due to injection of energy from the solar wind into the auroral region as a result of significant increase in the AE index which causes an uplift of the ionospheric layers to higher altitudes, where the recombination rate is small. Furthermore, this paper confirms the argument that moderate magnetic storms are capable of generating ionospheric storms which are of comparable magnitude with those resulting from intense geomagnetic storms.

Keywords: Geomagnetic storm, Moderate storm, Solar wind, Auroral electrojet index, Ionospheric storm response, Interplanetary magnetic field, Magnetic index (Dst)

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1 Introduction

The F2 region response to a geomagnetic storm, usually called an ionospheric storm, is a rather complicated event. It consists of the positive and negative phases, which have very complicated spatial and temporal behaviour. The principal features of the positive and negative phase distribution and variables have been explained on the basis of the principal concepts: during a geomagnetic disturbance there is an input of energy into the polar ionosphere, which changes thermosphere parameters, such as composition, temperature and circulation[1]. Composition changes directly influence the electron concentration in the F2 region and negative ionospheric storms are possibly caused by changes in the thermospheric composition due to the heating of the thermosphere during the geomagnetic storms[1,2]. One of the significant features of the negative phase is its equatorward propagation during the storm from auroral latitudes towards lower latitudes[2]. Several mechanisms have been considered as possible sources for the ionospheric positive phases[3,4], the F2 layer uplifting due to vertical drift, plasma fluxes from the plasmasphere and downwelling to the gas as a result of the storm induced thermospheric circulation[5]. The altered thermospheric circulation causes downwelling of the neutral species through constant pressure surfaces at low–middle latitudes equatorward of the composition disturbance zone, increasing the O density relative to N_2 and O_2. This produces increases in electron density concentration of the F2 region (NmF2) (Ref. 6).

Chaman Lal[7] reported that geomagnetic activity is a measure of the energy, which the magnetic field intercepts from the passing solar wind and funnels into the magnetosphere. The magnetic reconnection between southwardly directed IMF and northward magnetospheric fields proposed by Dungey[8] and the viscous mechanism proposed by Axford & Hines[9] are the two generally accepted principal modes of the entry of solar wind into magnetosphere. According to Tsurutani *et al.*[10] and Gonzalez *et al.*[11], coronal mass ejections (CMEs) are transient phenomena that involve the expulsion of significant amount of plasma and magnetic flux from the sun into interplanetary space on a time scale between a few minutes and several hours. It is generally accepted that the fast interplanetary manifestations of coronal mass ejections (ICMEs) are the major solar drivers of space weather, including large, non-recurrent geomagnetic storms and solar energetic particle events. The orientation of the IMF driven by the solar wind is also a very important factor. Gonzalez & Tsurutani[12] reported that the IMF structures leading to intense magnetic storms have an intense and long duration southward component. Such a configuration tends to increase the coupling between the solar wind and the magnetosphere with the result that relatively more solar wind energy can then enter the magnetosphere. Hence, geomagnetic storms and the associated ionospheric effects are the results of the interaction between solar wind and the magnetosphere through the coupling link, solar coronal hole-solar wind-magnetosphere-ionosphere.

According to Chukwuma (Ref. 13 and references therein), one way of getting large Dst events is to have two-step storm main phases, with the second enhancement of the Dst index closely following the first one. Such events are quite common and are caused by two IMF southward field of approximately equal strength. This could also be viewed as two moderate magnetic storms with the base of the second well below that of the first. The 29 October 1973 storm can be viewed as a two-step storm, because the main phase of the storm developed in two consecutive steps. In this work, the analysis of the foF2 data during the 29 October storm in the East Asian sector has been presented. Due to the absence of data for solar wind plasma parameters during the 29 October 1973 geomagnetic storm, the auroral electrojet (AE) index was employed to study the cause of the response of the ionosphere to this storm. Furthermore, the study looked into the possible outcomes of the injection of energy as measured by the AE index across all latitudes. The present paper attempts to verify the argument of Chukwuma & Lawal[14] that moderate magnetic storms are capable of generating ionospheric storms which are of comparable magnitude with those generated by intense geomagnetic storms.

2 Data and Method of Analysis

The data used in this study consists of 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 solve the problem on nature of ionospheric response to 29 October 1973 storm, the response in the East Asian sector has been chosen to study. The stations are: Yakutsk, Magadan, Khabarovsk, Wakkanai, Akita, Kokunbunji, Yamagawa, Okinawa and Manila. Table 1 lists the stations and their corresponding geographic coordinates. The stations were chosen with the criterion that storm sudden commencement did not coincide with sunrise at the stations. The criterion is important because the arrival of sunrise is manifested by rapid increase in electron temperatures and a less rapid increase in ion temperature at all altitudes. In a plasma that tends toward equilibrium, a sharp increase in particle temperatures results in a redistribution of the plasma[15].

The present study is concerned with variations in foF2 due to the geomagnetic storm of 29 October 1973. 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 the mean[13]:

$$D_{foF2} = [foF2 - (foF2)_{mean}]/(foF2)_{mean}$$

Hence, the data that was analysed consists of respective hourly values of D_{foF2} during 29-31 October. The reference for each hour is the average

Table 1 — Ionosonde stations

Stations	Geographic co-ordinates		Geomagnetic coordinates		Difference between LT and UT, h
	φ, °N	λ, °E	φ, °N	λ, °E	
Yakutsk	62.00	129.60	50.90	206.90	+ 9
Magadan	60.00	151.00	51.90	213.40	+10
Khabarovsk	48.50	135.10	37.80	200.00	+ 9
Wakkanai	45.40	141.70	35.30	206.00	+ 9
Akita	39.70	140.10	30.19	207.50	+ 9
Kokunbunji	35.70	139.50	26.17	207.50	+ 9
Yamagawa	31.20	130.60	22.30	208.70	+ 9
Okinawa	26.30	127.30	16.57	197.90	+ 8
Manila	14.70	121.10	4.05	191.90	+ 8

value of foF2 for that hour calculated from the five quiet days, 24–28 October 1973, preceding the storm.

3 Results and Discussion

The results of the present study are shown in Figs (1 and 2). Figure 1 shows the auroral electrojet (AE) index; the interplanetary magnetic field component, Bz; and the low latitude magnetic index, Dst for the period 27-31 October 1973.

Storms can be classified as: weak (Dst > - 50 nT), moderate (-50 nT < Dst < -100 nT) and intense (Dst < - 100 nT) (Ref. 16). According to this classification, the Dst plot for the period 29-31 October shows that the interval 00:00 – 07:00 hrs UT, 29 October was largely quiet with Dst fluctuating in the range -20 > Dst > -35 nT. However, at about 10:00 hrs UT, Dst began to depress steadily indicating a storm commencement, reaching a value of -64 nT at ~ 23:00 hrs UT. Thereafter, Dst recovered gradually reaching quiet values in the interval 03:00 – 18:00 hrs UT on 30 October.

The 29 October 1973 storm can be viewed as a two-step event. In the first step of the main phase, the Dst reache the peak value of -51 nT at 10:00 hrs UT on 29 October. With the sharp rotation of Bz to northward, there was a sharp partial Dst recovery to the level of -38 nT. The second step of the main phase has been associated with the sharp southward turning of Bz at 13:00 hrs UT. Thereafter, Dst and Bz reached peak values of -64 nT and -5.8 nT, respectively at 18:00 hrs UT on 29 October. This is in accordance with the argument of Kamide *et al.*[17] that two-step storm main phases, with the second enhancement of the Dst index closely following the first one, are quite common and are caused by two IMF southward field of approximately equal strength and that it could be

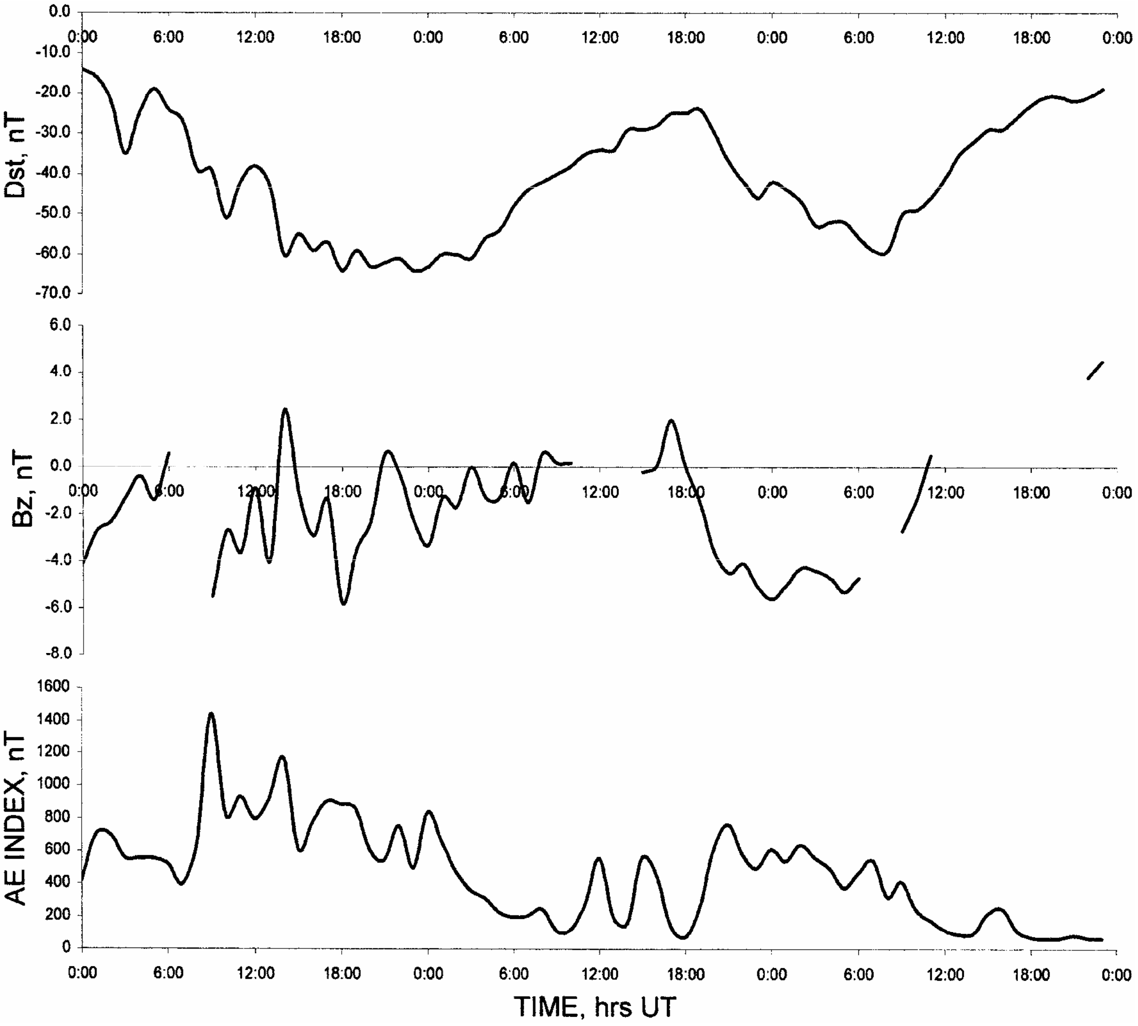

Fig. 1 — One-hour averages of the Dst, Bz and AE index *vs* Time during 29-31 October 1973

viewed as two moderate magnetic storms with the base of the second well below that of the first.

The third panel of Fig. 1 is the AE index for the period 29-31 October 1973. The plot shows a low energy input fluctuating in the range 400-700 nT in the interval 00:00 – 07:00 hrs UT on 29 October. However, the AE index increased sharply from ~ 400 nT at 07:00 hrs UT on 29 October until it finally reached the highest peak of 1450 nT at 09:00 hrs UT on the same day. Thereafter, it swang decreasingly to the steady level when the storm was over on 31 October around 18:00 hrs UT. It is important to note that the AE index reached its peak as at the time the Dst signals a moderate storm (i.e. the time the first Dst minimum reached -51 nT). Mikhalov & Perrone[18] had related the increases in electron density concentration of the F2 region to such auroral activity.

Figure 2 shows D_{foF2} *vs* time throughout 29–31 October 1973 for the ionosonde stations listed in Table 1. In Fig. 2(a), the high latitude stations of the East Asian sector, there is an alternating positive and negative ionospheric storm before storm commencement at Yakutsk (62.0°N) and Magadan (60.0°N). However, following the storm commencement at ~ 17:00 hrs UT on 29 October, a depletion of foF2 gradually developed at Magadan while there was an enhancement of foF2 at Yakutsk. Nevertheless, starting from about 21:00 hrs UT on this day, a rapid and definitive decrease in foF2 occured at these stations. Figure 2(a) also indicates that the two high latitude stations recorded predominantly a depletion of foF2 throughout 30 and 31 October. The peak depletion at Yakutsk are 38%, 39% and 27% at 13:00, 00:00 and 15:00 hrs UT, respectively for each of the three days (29-31 October), while at Magadan peak depletion are 40%, 48% and 36% at 23:00, 00:00 and 20:00 hrs UT, respectively.

Figure 2(b) shows the middle latitude stations of the East Asian sector. The D_{foF2} plots show an existing positive ionospheric storm preceding the storm commencement at Khabarovsk (48.5°N), Wakkanai (45.4°N), Akita (39.7°N), Kokubunji (35.7°N), and Yamagawa (31.2°N). Figure 2(b) also indicates that with the exception of the lowest of the mid-latitude stations (i.e. Yamagawa), which recorded positive ionospheric storm, all the other middle latitude stations recorded a sharp depletion of foF2 at 18:00 hrs UT and was coincident with the values of Dst and B_z. Note the alternating enhancement and depletion of fof2 throughout 30 and 31 October. However, this event was more of negative ionospheric storm for the first two stations nearest to the high latitude, while there was a positive predominance for the other three stations nearest to the lower latitude. Generally, Fig. 2(b) indicates that the middle latitude stations recorded predominantly an enhancement of foF2. The peak depletions recorded at these stations are tabulated in Table 2.

In Fig. 2(c), that is, the lower latitude stations of the East Asian sector, there was no immediate effect on foF2 in the ionosphere above Okinawa (26.3°N)

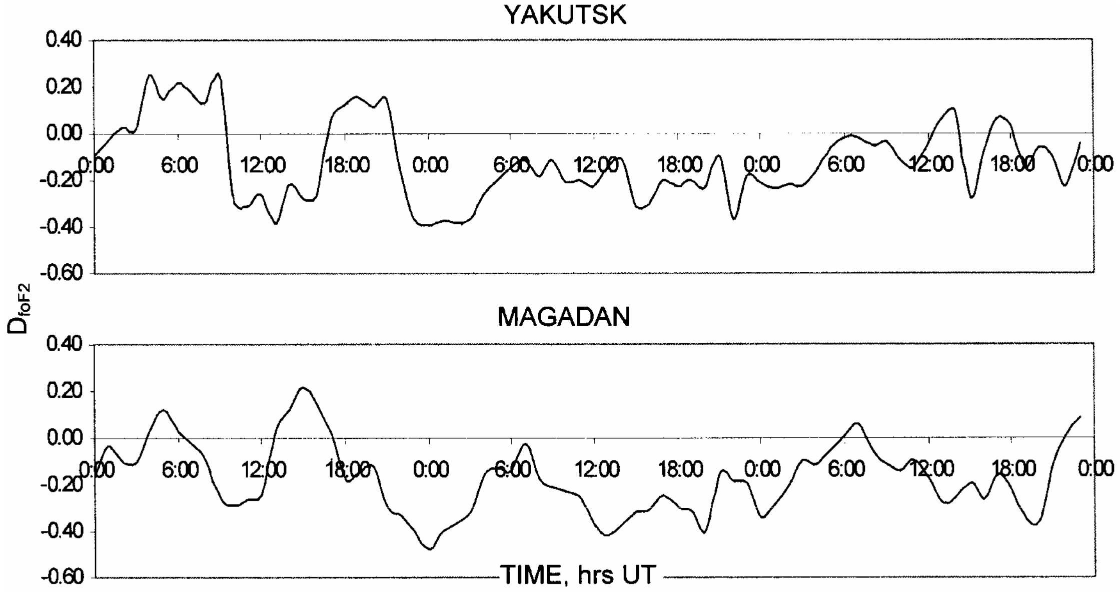

Fig. 2(a) — Variation in D_{foF2} at the upper latitude stations of East Asian sector during 29-31 October 1973 and Manila (14.7°N) following the arrival of the shock in the interplanetary medium. However, starting from 9:00 hrs UT and about 13:00 hrs UT on 29 October at Okinawa and Manila respectively, there was predominant positive ionospheric storm for most of the storm period at these stations. At Okinawa, an enhancement of 113% and a maximum depletion of 15% were recorded at the storm time. However, the ionospheres at these stations were characterized by intermittent negative storm. Surprisingly, of this intermittent negative storm, the lower latitude of Manila produced an ionospheric storm (44% at 03:00 hrs UT on 31 October), which was of the order of an intense ionospheric storm and also of about the magnitude produced by the upper latitude stations.

In the analysis of interplanetary phenomenon, geomagnetic and ionospheric response associated with the storm of 8 July 1975 in the East Asian sector,

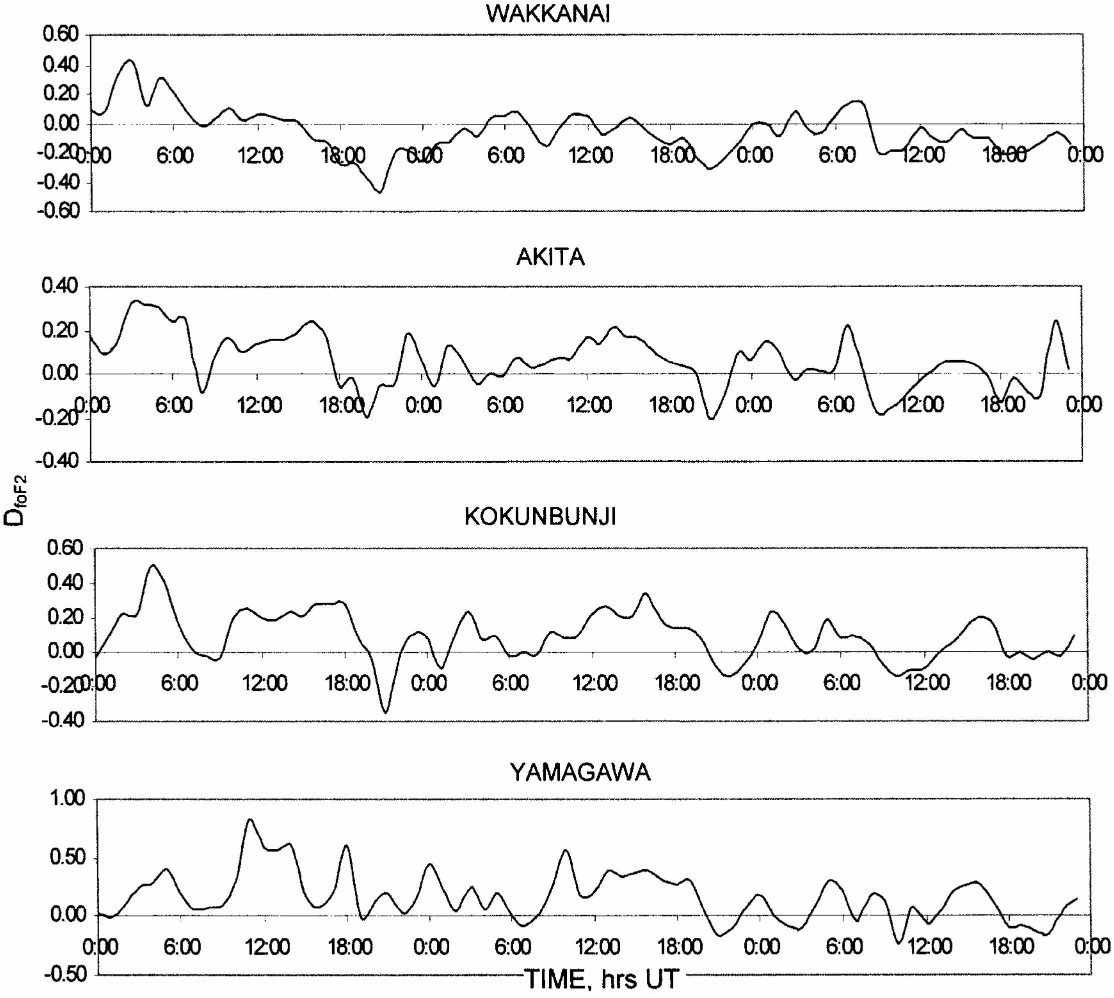

Fig. 2(b) — Variation in D_{foF2} at the middle latitude stations of East Asian sector during 29-31 October 1973

Table 2 — Peak depletions recorded at middle latitude stations

Station	29 October		30 October		31 October	
	Depletion, %	Time of occurrence, hrs UT	Depletion, %	Time of occurrence, hrs UT	Depletion, %	Time of occurrence, hrs UT
Khabarovsk	32	20:00	43	21:00	22	21:00
Wakannai	46	21:00	31	21:00	22	18:00
Akita	19	20:00	21	21:00	18	09:00
Kokubunji	35	21:00	14	22:00	14	10:00
Yamagawa	1	19:00	18	21:00	23	10:00

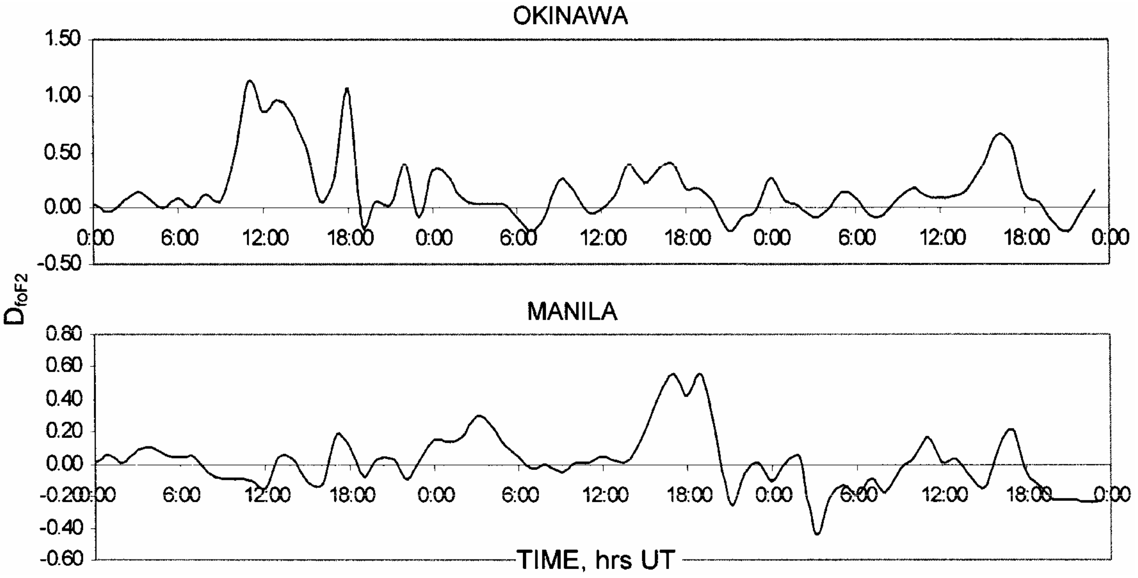

Fig. 2(c) — Variation in D_{foF2} at the lower latitude stations of East Asian sector during 29-31 October 1973

Table 3 — Stations with positive and negative storms

Station	Depletion, %	Enhancement, %
Wakannai	45	30
Akita	31	35
Kokubunji	59	35
Manila	30-100	5

Chukwuma & Lawal[14] showed that a moderate storm is capable of generating ionospheric storms which are of comparable magnitude with those resulting from intense geomagnetic storms. It is also important to note that during the intense storm of 1-2 April 1973, Chukwuma[19] showed that the stations have positive and negative storms (Table 3).

The D_{foF2} variations are described in terms of percentage of the critical frequency foF2 from the reference and following Liu *et al.*[20], positive and negative storms occur when the absolute maximum value of D_{foF2} exceeds 20%. According to Burešová & Laštovička[21], this limit is sufficiently large to prevent inclusion of random perturbations and disturbances of neutral atmospheric origin, thereby, making the indicated positive and negative storms represent real changes in electron density not simply redistribution of the existing plasma.

Figure 2 shows that during the 29 October storm, the depletion of foF2 was restricted to the high latitudes. It is important to note that the depletion (negative storm) diminished in amplitude towards the lower latitude[1]. Unlike the very intense storm of 13–14 March 1989 in which the depletion of foF2 was extended to latitude as low as 12.4°N, and at the same time globally[13], the F2 region global structure response of the present work lacked simultaneity just like the intense storm of 20–21 October 1989. This also shows the complexity of individual storm that the global distribution of ionospheric storm effects differ considerably from one storm to another.

4 Conclusions

In this work, some of the geomagnetic and ionospheric responses associated with the storm of 29 October 1973 have been presented. Due to the absence of data for solar wind plasma parameters, the present study employs the auroral electrojet (AE) index. The main results of this study are summarized as:

- The Dst, implicated moderate geomagnetic storm with its characteristic peak value of –64 nT occurred 1973 at 18:00 hrs UT on 29 October.
- Injection of energy into the ionosphere as indicated by the AE index
- Predominant positive ionospheric storm at the time of storm
- Intense ionospheric storm at the lower latitude of Manila

Having examined the ionospheric response in the main phase with regard to particle injection from solar wind to the magnetosphere, the study concludes that the joule heating of the auroral region as seen from the AE index would be the likely driver of some underlying mechanisms that are working together for the ionospheric phenomena causing an uplift of the ionospheric layers to higher altitudes, where the recombination rate is small. It is also important to note that the main phase was characterized by strong increase in AE in the interval 07:00 - 20:00 hrs UT on 29 October 1973, which probably set-off relative fast ionospheric disturbance dynamo electric fields[22] during the main phase. It also confirms the work of Chukwuma & Lawal[14] that there is need for more research focus on moderate storms as it can cause a great intense ionospheric storm comparable to that of intense geomagnetic storms.

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