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Time/level of ionospheric response to geomagnetic storm of 25-26 July 1981 at different latitudes

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The reaction of the ionosphere at different latitudes may be quite different during the same storm. In this light, this paper investigates time/level of response of the upper, mid and lower latitudes stations of two different regions to an intense geomagnetic storm. The parameters solar wind plasma and imbedded interplanetary magnetic field (IMF), and foF2 have been investigated. The data has been obtained from global network of ionosondes. The analysis of solar wind plasma show that the event on 25-26 July 1981 is a type 2 storm, i.e. the ratio of the magnitude of the second to first Dst (separated by at least 3 hours) decrease is less than 0.9. The analysis of the foF2 data shows that the depletion at the time of storm occurred at a greater percentage in the upper latitude than at the mid latitude, and very small at the lower latitudes. Furthermore, there was simultaneous depletion of foF2 at all latitudes.

Keywords: Solar wind plasma, Geomagnetic storm, foF2 depletion

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1 Introduction

A region's latitude has a great effect on its climate and weather. Latitude more loosely determines tendencies in polar auroras, prevailing winds, and other physical characteristic of geographic locations. When geomagnetic storm occurs, there is a tendency that the latitude or the location of a station determines when and how the disturbance affects the area. According to Danilov[1], the reaction of the ionosphere at different ionospheric stations may be quite different during the same storm depending on the station co-ordinates. According to Zhao *et al.*[2], the effect of geomagnetic storm in the equatorial and middle-low latitude F-region is positive in the Southern hemisphere during morning-noon and negative in lower magnetic latitudes in the Northern hemisphere. The magnitude of positive phase in total electron content (TEC) differ from one region to the other and also the super fountain effect, resulting in several times growth of TEC at low latitudes, occur frequently in some regions[3-6]. The ionospheric storm behaviour in the low latitude and equatorial region is also diversified depending on the equatorial ionization anomaly (EIA) response to different types of disturbance electric fields and disturbance winds[7]. The seasonal/latitudinal variations of the occurrence for positive and negative F2-layer quiet disturbances have been interpreted in the concept of the thermosphere-ionosphere interaction. The basic process is the solar-driven and storm induced thermospheric circulation's interaction, which varies with season and latitude[8-9], have shown that the ionospheric F-region disturbances observed in association with severe geomagnetic storms underwent major changes at all mid latitudes. However, the variations from storm to storm were much larger at lower mid latitudes. In this light, this paper investigates time/level of response of the upper, mid and lower latitudes stations of two different regions to an intense geomagnetic storm of 25-26 July 1981.

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) and other parameters such as proton density and flow speed obtained from OMNIWEB (http://omniweb.gsfc. nasa.gov/).

In order to solve the problem on latitudinal time variability response of 25-26 July 1981 storm, the response of two different regions, viz. East Asian and Euro-African, in their upper, mid and lower latitude have been studied. Tables 1 and 2 list the stations in East Asian and Euro-African regions and their corresponding geographic and geomagnetic coordinates.

The present study is concerned with variations in foF2 due to the geomagnetic storm of 25-26 July 1981. However, the F2 region response to geomagnetic storms is most conveniently described in terms of DfoF2, that is, the normalized deviations of the critical frequency foF2 (ref. 10):

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

Hence, the data consisted of respective hourly values of D_{foF2} on 25-27 July. The reference for each hour is the average value of foF2 for that hour calculated from the three quiet days, i.e. 20-22 July 1981, preceding the storm. An important characteristics used in the chosen reference period is that the days were devoid of any geomagnetic activities (i.e. Dst > -25nT). It may be noted that 23 and 24 July are not quiet due to the presence of a moderate storm during the period.

3 Results and Discussion

3.1 Geomagnetic and interplanetary observations

The results of the present study are shown in Figs 1-3. Figure 1 shows measured parameters of solar wind plasma for the period 23-27 July 1981, viz. the interplanetary magnetic field component (Bz), the proton density, proton velocity, and the low latitude magnetic index, Dst variations for the period.

Storms can be classified as: weak (Dst > - 50 nT), moderate (-50 nT > Dst > -100 nT) and intense (Dst < - 100nT) (ref. 11). According to this classification, the Dst plot for 23-27 July 1981 shows that the storm was weak (Dst > - 30nT) before mid day on 23 July. At 09:00 hrs UT, the Dst index increased to 4 nT, the positive change at this time is an indication of sudden storm commencement. Thereafter, Dst decreased sharply to -84 nT at 14:00 hrs UT on 23 July. It is reasonable to suggest that a moderate storm commenced at 12:00 hrs UT on 23 July with Dst = -68 nT. Dst reached the minimum value of -89 nT at 18:00 hrs UT and thereafter, started to recover gradually to -28 nT at 11:00 hrs UT on 25 July. Thereafter, Dst decreased to -120 nT at 14:00 hrs UT on 25 July. It is reasonable at this point to suggest from the value of Dst that an intense storm commenced at ≈14:00 hrs UT on 25 July. However, Dst decreased to a minimum peak of -226 nT at 20:00 hrs UT on the same day and to -l97 nT at 02:00 hrs UT on 26 July, and later recovered gradually to -l01 nT at 09:00 hrs UT marking the end of the intense storm.

Applying some calculations[12], Dst profile for the period 23-27 July 1981, appears to represent the second type with two steps of Dst depression, i.e. type 2 intense geomagnetic storm during 25-27 July 1981. According to Kamide *et al.*[13] and Kozyra *et al.*[14], two-step storms result from successive imparts of different regions of southward IMF Bz on the magnetosphere. The first impact triggers a magnetic storm, which does not have time to recover before

Table 1—Ionosonde stations of East Asian region

Station	Geographic co-ordinates		Geomagnetic co-ordinates		Difference between LT and UT, h
	Latitude	Longitude	Latitude	Longitude	
Yakutsk	62.00°N	129.60°E	50.90°N	206.90°E	+9
Magadan	60.00°N	151.00°E	51.90°N	213.40°E	+10
Wakkanai	45.40°N	141.70°E	35.30°N	206.00°E	+9
Akita	39.70°N	140.10°E	30.19°N	207.50°E	+9
Manila	14.70°N	121.10°E	4.05°N	191.90°E	+8

Table 2—Ionosonde stations of Euro-African region

Section	Geographic co-ordinates		Geomagnetic co-ordinates		Difference between LT and UT, h
	Latitude	Longitude	Latitude	Longitude	
Arkhangelsk	64.40°N	40.50°E	59.90°N	118.20°E	+3
Leningrad	60.00°N	30.70°E	56.11°N	118.4°E	+2
Moscow	55.50°N	37.30°E	50.72°N	121.50°E	+2
S1ouh	51.60° N	10.10°E	52.05°N	95.00°E	+1
Dakar	14. 80°N	17.40°W	21.70°N	54.10°E	-1
Johannesburg	26.10°S	28.10°E	27.00°S	91.80°E	+2

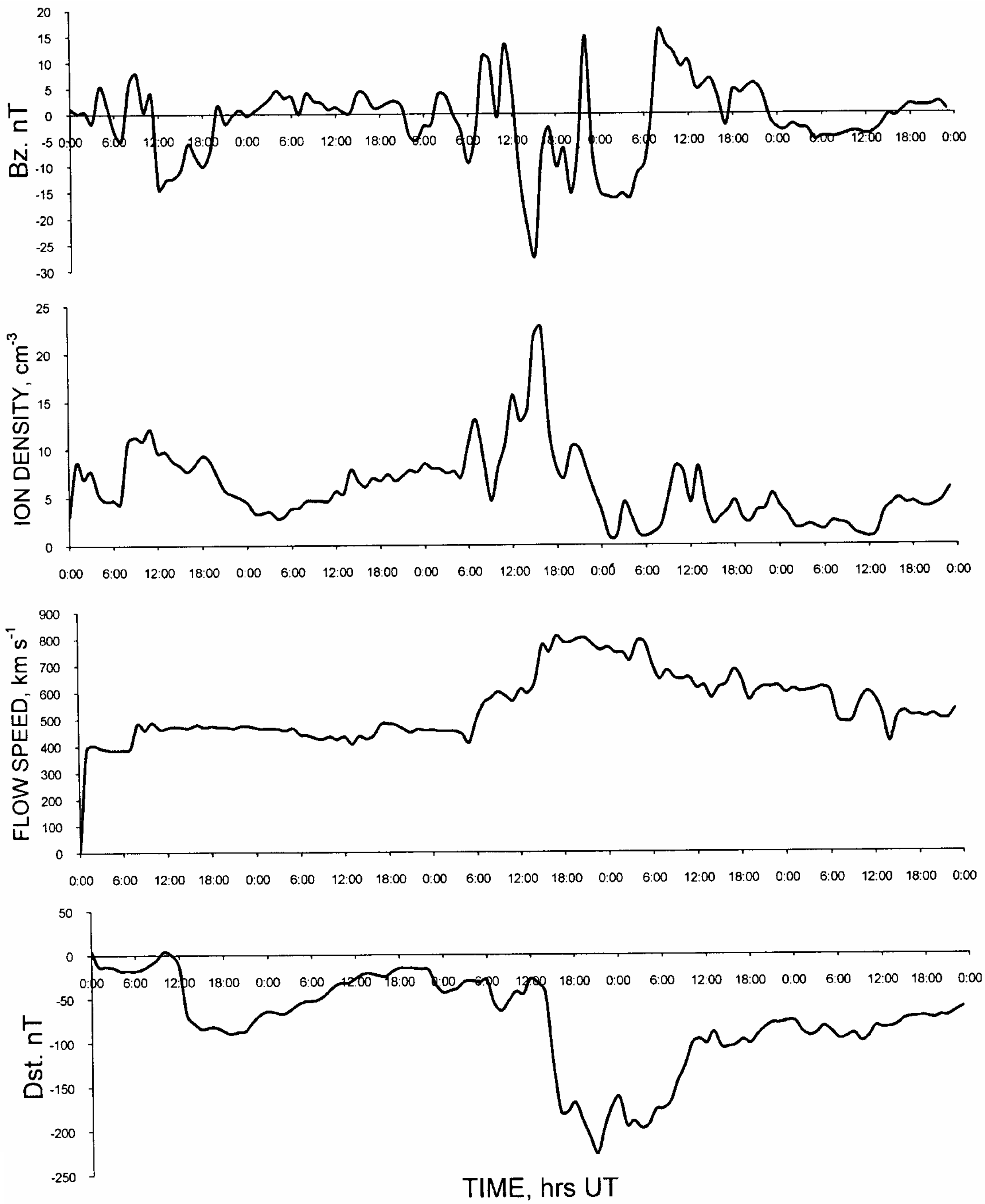

Fig. 1—One-hour averages of the solar wind plasma parameters versus time (hrs UT) during 23-27 July 1981

the second impact begins. The second decrease in Dst index is usually deeper than the first although the magnitude of the second interval of southward Bz is, in general, not significantly different from the first interval.

The second panel of Fig. 1 shows that solar wind proton density (N_{sw}) decrease steadily from 8.6 cm^{-3} at 00:00 hrs UT to 4.4 cm^{-3} at 06:00 hrs UT on 23 July. At 10:00 hrs UT, it increased abruptly to 12.1 cm^{-3}. Thereafter, it started to fluctuate within a range of 2.8 - 10.6 cm^{-3} between 11:00 hrs UT on 23 July and 10:00 hrs UT on 25 July. At 12:00 hrs UT, N_{sw} increased sharply from 12.9 cm^{-3} to 21.8 cm^{-3} at 14:00 hrs UT. The large increase in the proton number density at 10:00 hrs UT on 23 July and 14:00 hrs UT on 25 July, respectively signals the arrival of a shock in the interplanetary medium[15-16] at these times. It was observed that the increase in N_{sw}

at 10:00 hrs UT on 23 July resulted in Dst index registering a moderate storm with Dst = -68 nT at 12:00 hrs UT. It appears that the proton density enhancement and the consequent injection of the ring current at this particular time were insufficient to cause an intense magnetic storm compared to the N_{sw} of 13:00 hrs UT on 25 July.

The solar flow speed (V_{sw}) plot of Fig. 1 shows the existence of a slow stream during the period 00:00 - 06:00 hrs UT on 23 July with $V_{sw} < 400$ km s^{-1}. At 07:00 hrs UT with speed of 484 km s^{-1}, a high speed solar wind started to come on stream. The high speed continued its flow with V_{sw} = ~484±50 km s^{-1} until 14:00 hrs UT on 25 July when the speed increased to 775 km s^{-1}. According to Gonzalez *et al.*[17] and Gonzalez *et al.*[18], intense magnetic storms (Dst < -l00 nT) occur when the solar wind speed is substantially higher than the average speed of 400 km s^{-1}. The flow speed, V_{sw}, continued increasing till 20:00 hrs UT and decreased to 718 km s^{-1} at 02:00 hrs UT on 26 July. It may be noted that the coincidence increases in N_{sw} and V_{sw} indicate the arrival of shocks[16].

The magnetic field component plot shows Bz rotated slightly southward from 00:00 hrs UT to 02:00 hrs UT but oscillated weakly northward between 02:00 and 10:00 hrs UT on 23 July. Thereafter, Bz rotated southward at 11:00 hrs UT and remain southward till 18:00 hrs UT on 23 July. However, an intermittent northward and southward rotation of Bz preceded the strong southward Bz with peak value of 16.3 nT on 25 July that produced the intense geomagnetic storm of the period. It is well established that the Bz component of the IMF is the most important influence of the magnetosphere. When Bz is strongly negative, as presently the case, magnetic reconnection between IMF and the geomagnetic field produces open field lines which allow mass energy and momentum to be transferred from the solar wind to the Earth's magnetosphere[19]. Therefore, it is convenient to suggest that the Bz plot during the period under investigation, presented as essential interplanetary requirements, which is needed to activate the magnetosphere through reconnection.

3.2 Ionospheric response

The D_{foF2} variations vs time during 25-27 July 1981 at the East Asian ionosonde stations are shown in Fig. 2. The stations, as listed in Table 1, consist of the high latitude stations of Yakutsk and Magadan; the mid latitude stations of Wakkanai and Akita; and the low latitude station of Manila.

The D_{foF2} plot for Yakutsk shows that there was a negative storm in the period 00:00 - 11:00 hrs UT on 25 July. Thereafter, there was a sharp foF2 decrease that leads to an intense ionospheric storm with a peak depletion of 57% at 14:00 hrs UT the same day. The large depletion of foF2 at 14:00 hrs UT followed the large increase in proton number density at 13:00 hrs UT and preceded the present intense storm. It recovered to 31% depletion at 10:00 hrs UT on 26 July and again depleted to 53% at 18:00 hrs UT the same day, after which it recovered to 1% enhancement at 10:00 hrs UT on 27 July.

The D_{foF2} plot for Magadan shows that there was paucity of data until about 05:00 hrs UT on 25 July. The available data from 05:00 hrs UT indicates an emergence from intense negative ionospheric storm with a sharp recovery to a low negative storm of 4% at 08:00 hrs UT on 25 July. At 11:00 hrs UT on 25 July, foF2 decreased sharply to 21% and thereafter, reached a depletion of 48% at the time of the storm, i.e. 14:00 hrs UT. It later reached a maximum depletion of 50% at 20:00 hrs UT. The 48% depletion that occurred at 14:00 hrs UT followed the large increase in the proton number density at 13:00 hrs UT and preceded the present intense storm. The maximum depletion at 20:00 hrs UT followed the increase in the proton number at 19:00 hrs UT. The ionosphere maintained the negative phase throughout the period under study.

The D_{foF2} plot for Wakkanai in Fig. 2 shows a very weak ionospheric storm till 03:00 hrs UT which was followed by a sharp decrease to 30% at 05:00 hrs UT on 25 July. At 08:00 hrs UT, there was an upward rotation that lasted till 10:00 hrs UT with 12% depletion on 25 July. However, foF2 built up gradually to record a depletion of 33% at 14:00 hrs UT same day. This depletion follows the large increase in the proton number density at 13:00 hrs UT and preceded the present intense storm. Thereafter, foF2 depleted to 58% at 21:00 hrs UT and recovered gradually with intermittent swings.

The D_{foF2} plot for Akita shows a negative build up before storm commencement on 25 July, which indicates storm precursor signature. Following the commencement of storm at 14:00 hrs UT, there was depletion to 26% and thereafter, reached maximum depletion of 67% at 19:00 hrs UT on 25 July. This peak depletion occurred coincidentally with the peak flow speed of the solar wind particles at 19:00 hrs UT on 25 July. Thereafter, foF2 recovered gradually to an enhancement of 9% at 10:00 hrs UT on 27 July.

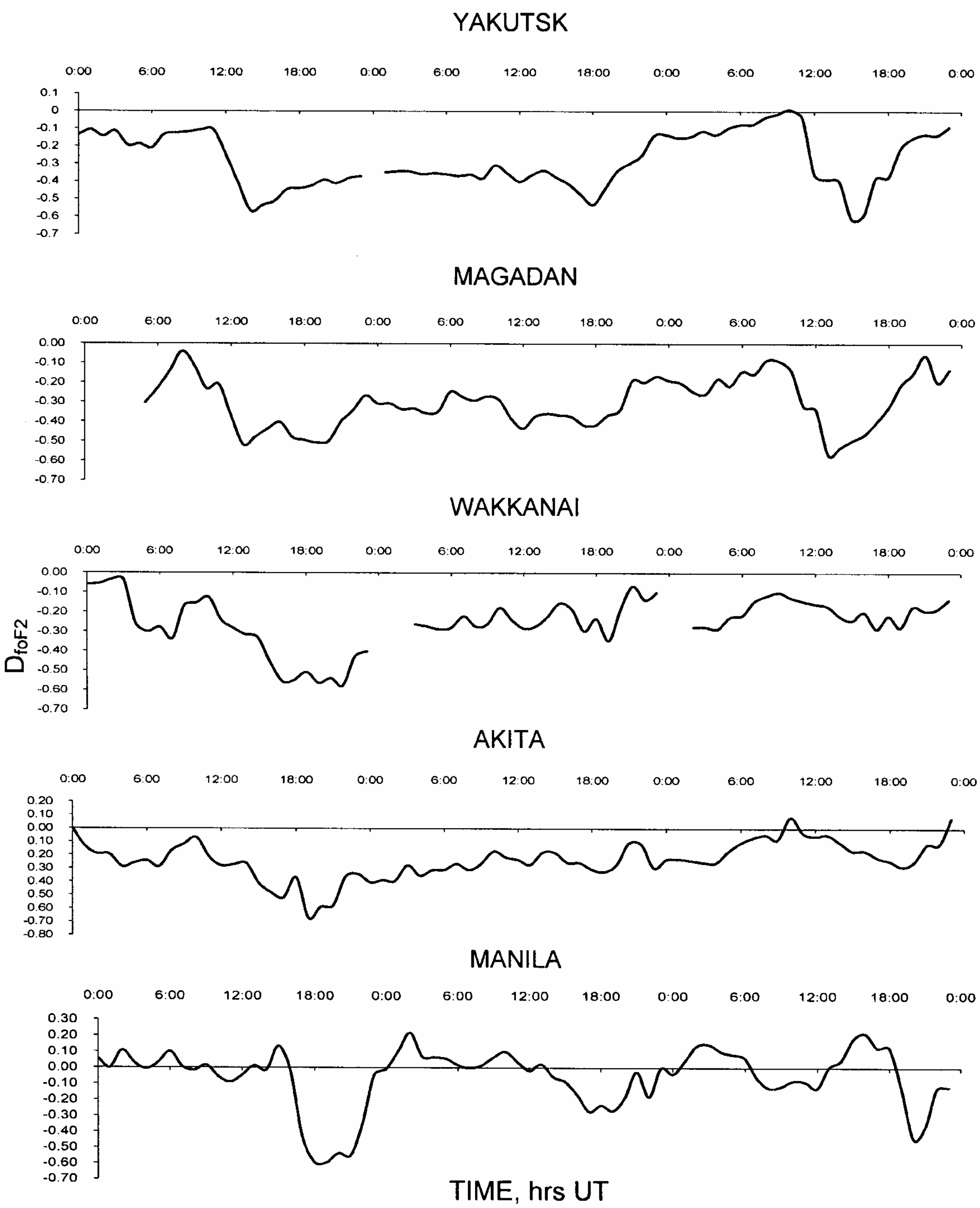

Fig. 2—Variation in D_{foF2} in the East Asian region during 25-27 July 1981

At Manila, between 00:00 and 15:00 hrs UT on 25 July, there was predominantly an enhancement all through the ionosphere above the lower latitude of Manila except the interval between 10:00 and 14:00 hrs UT, the interval at which the intense storm commenced. Following the storm at 14:00 hrs UT, the D_{foF2} plot of Manila showed 1% depletion but immediately increased and recorded 14% enhancement. However, a sharp decrease leading to 59% depletion followed at 19:00 hrs UT the same day, coinciding with the peak flow speed of the solar wind particles at that time. The ionosphere recovered with intermittent swing between positive and negative ionospheric storm for the rest of the period.

The D_{foF2} variations at the Euro-African region have been shown in Fig. 3. The stations, listed in Table 2, consisted of Arkhangelsk and Leningrad (high latitude stations); Moscow, Slough and Johannesburg (mid latitude stations); and Dakar (low latitude station).

The D_{foF2} plot of Arkhangelsk shows that from 00:00 to 11:00 hrs UT, there was a gradual recovery from a negative storm. At 12:00 hrs UT on 25 July, there was a sudden decrease of foF2 to 12% that lead to an intense storm at 14:00 hrs UT with a depletion of 20% and thereafter, recovered gradually to 4% at 23:00 hrs UT same day. Due to paucity of data, events before 08:00 hrs UT on 26 July could not be analysed. From 8.00 hrs UT on 26 July to 10:00 hrs UT on 27 July, there was an intense depletion ranging between 30 and 45%. Thereafter, a sharp recovery followed to 5% depletion at 11:00 hrs UT, and a quiet depletion as low as 2% continued throughout the rest of the period.

At Leningrad, there was also a recovery from negative storm from 29% depletion at 00:00 hrs UT to 1% enhancement at 11:00 hrs UT on 25 July. Thereafter, from 12:00 hrs UT, there was a sudden decrease of foF2 to 12% at 14:00 hrs UT on 25 July, which is the time of storm. Following this was another two successive sharp depletion that resulted in the intense ionospheric storm with a peak depletion of 49% at 22:00 hrs UT on the same day. However, the ionosphere recovered to 28% depletion at 14:00 hrs UT next day before it experienced another intense storm of 55% depletion at 21:00 hrs UT same day. It, thereafter, recovered gradually to 4% depletion on 27 July.

At Moscow, the D_{foF2} plot shows that there was a negative storm at 00:00 hrs UT which later recovered to an enhancement of 13% at 12:00 hrs UT on 25 July. Thereafter, a sharp depletion to 16% at 14:00 hrs UT occurred which was followed by a further decrease in foF2 that recorded 63% depletion at 20:00 hrs UT on 25 July. This depletion follows the large increase in proton number density at 19:00 hrs UT. Furthermore, the ionosphere above Moscow recorded a maximum depletion of 66% at 23:00 hrs UT the same day. However, the storm recovered gradually but remained intense throughout 26 July till 08:00 hrs UT the next day. Since 08:00 hrs UT on 27 July, there was a recovery to a level at which there were no ionospheric response to the magnetospheric processes.

The D_{foF2} plot for Slough shows that there was a gradual build up that resulted in a depletion of 28% at 07:00 hrs UT on 25 July and thereafter, recovered to an enhancement of 6% at 13:00 hrs UT on 25 July. Thereafter, there was a commencement of depletion to 9% at 14:00 hrs UT the same day. However, it recovered sharply to an enhancement of 3% at 16:00 hrs UT and again decreased sharply to 62% at 22:00 hrs UT. Beginning from 07:00 hrs UT on 25 July till 07:00 hrs UT on 26 July, the ionosphere recorded an intense ionospheric storm with a peak depletion of 62% at 22:00 hrs UT on 25 July. Thereafter, a swinging recovery resulted for the rest of the period.

The D_{foF2} plot For Dakar shows that there was paucity of data from 00:00 to 06:00 hrs UT, which made it impossible to analyse the events that happened in the period. Following this was a predominant enhancement till 14:00 hrs UT where the depletion started with 7% and reached maximum of 43% at 16:00 hrs UT on 25 July. The storm recovered gradually and reached a maximum enhancement of 89% at 00:00 hrs UT on 26 July. The storm remained predominantly positive for the rest of the period.

The D_{foF2} plot for Johannesburg shows that the ionosphere experienced an alternating positive and negative storm throughout the period under investigation. It experienced characteristic spikes with intense depletion values of 65, 45 and 45% at 07:00 hrs UT on 25 July, 19:00 hrs UT on July 25 and 19:00 hrs UT on 26 July, respectively. These characteristic spikes except the spike on 26 July occurred nearly coincidentally with the increase in proton number density at 06:00 and 19:00 hrs UT on 25 July. It is worthy to note that the ionosphere above Johannesburg experienced an enhancement of 3% at 14:00 hrs UT which is the time of storm.

The analyses of the D_{foF2} plots appear to reveal the following significant features:

- In the East Asian region, the upper latitude station respond to geomagnetic storm first, followed by the mid and the low latitudes.
- In the East Asian region, the depletion decreases from the high latitude to the low latitude. At the time of commencement of intense storm, 14:00 hrs UT on 25 July, the response of ionosphere of the East Asian region has been presented in Table 3.

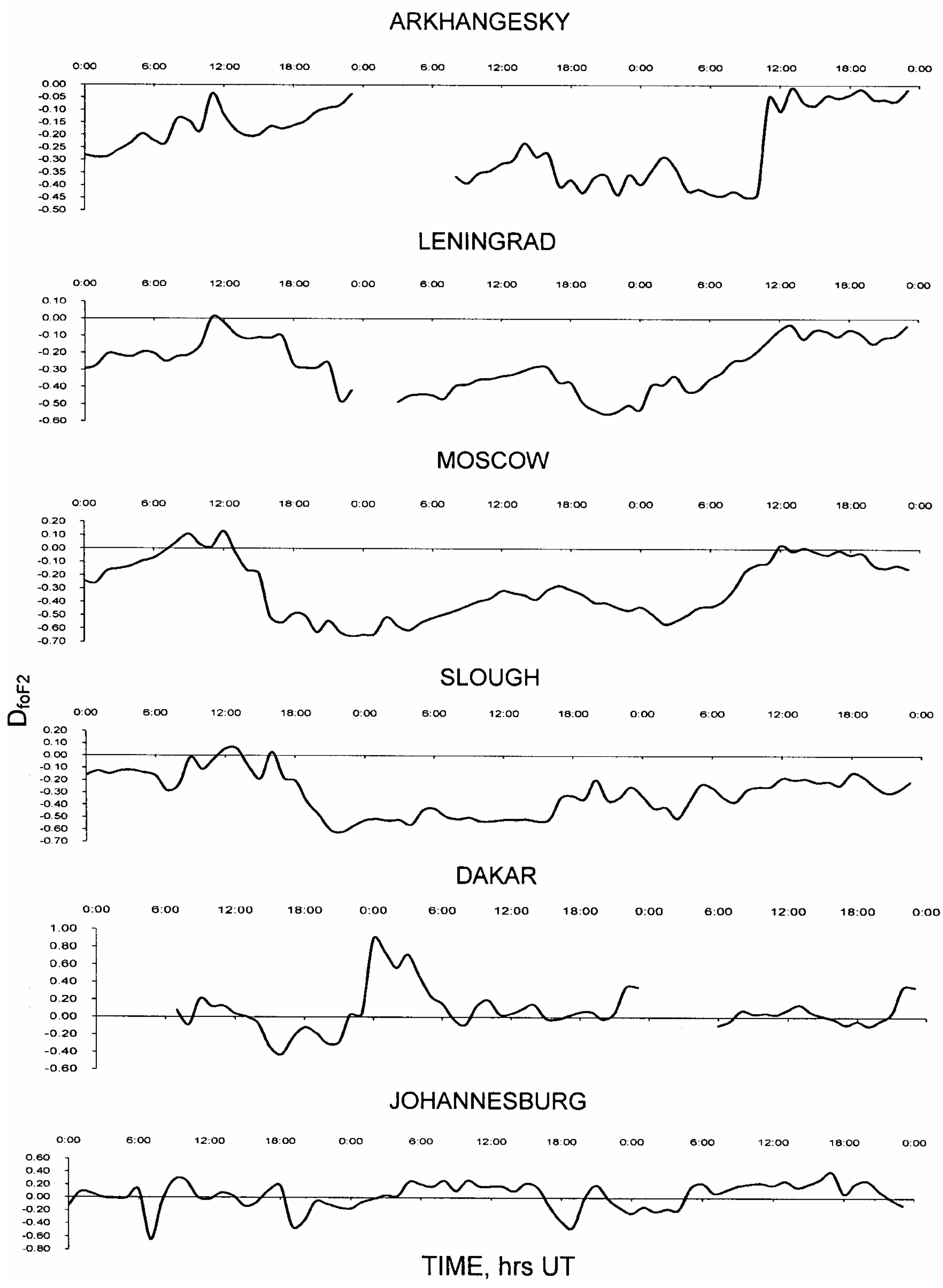

Fig. 3—Variation in D_{foF2} in the Euro-African region during 25-27 July 1981

Table 3—Response of ionosphere of the East Asian region at the time of commencement of intense storm on 25 July 1981

Station	Depletion
Yakutsk	57%
Magadan	48%
Wakkanai	33%
Akita	26%
Manila	1%

Table 4—Response of ionosphere of the Euro African region at the time of commencement of intense storm on 25 July 1981

Station	Depletion
Arkhangelsk	20%
Leningrad	12%
Moscow	16%
Slough	9%
Dakar	7%
Johannesburg	3% enhancement

- Also in the Euro-African region, the upper latitude stations respond to geomagnetic storm first, followed by the mid and the low latitudes.
- In the Euro-African region, the depletion decreases from the high latitude to the low latitude at the time of storm except for Moscow that sometimes behave as an upper latitude station.
- Occurrence of an enhancement in Johannesburg at 14:00 hrs UT on 25 July (Table 4).
- Occurrence of intense negative ionospheric storm (~59% peak) between 18:00 and 21:00 hrs UT on 25 July at the low latitude station of Manila which lasted for more than 3 hours.
- Appearance of intense negative storm (65%) before the commencement of intense geomagnetic storm at Johannesburg (26.10°S), which is very close to the low latitude stations.
- Simultaneous depletion of foF2 at all latitude, which seems to confirm the work of Chukwuma[10].

It is important to note that the heated gas with depleted $[O]/[N_2]$ ratio in the lower atmosphere triggers a complex chain of reactions in the ionospheric and thermospheric system. This results in the re-distribution of heating and cooling rate, an increase in electron ion and neutral temperature, and a decrease in electron density near F2 peak[1,20]. Nevertheless, an equator-ward wind resulting from the heating in the polar region tends to drive the plasma up the field lines where electron loss in decreased process competes with the increased in the loss rate caused by an enrichment of molecular nitrogen and increased temperature. Thus, the increase or decrease of foF2 depends upon the relative effectiveness of the two processes[20].

4 Conclusions

The double step geomagnetic storm of 25-26 July 1981 has been studied and the F2 region response using foF2 data obtained from ionosonde stations in East Asian and Euro-African longitudinal regions. The main results of this study show that the F2 region response is characterized by:

- The depletion at 14:00 hrs UT on 25 July suggests the response of the latitude to the storm at the time of intense storm commencement. It may be concluded that in both regions (East Asian and Euro-African), the upper latitudes first respond to the magnetic storm followed by the mid latitude stations. The response from both regions shows that the low latitudes stations were the last to respond. The only exception to this is the ionosphere above Moscow which may be due to travelling ionospheric disturbances (TID's).
- Occurrence of intense negative ionospheric storm (~59% peak) between l8:00 and 21:00 hrs UT on 25 July at the low latitude station of Manila which lasted for more than 3 hours.
- Appearance of intense negative storm (65%) before the commencement of intense geomagnetic storm at Johannesburg, which is close to the low latitudes.
- Simultaneous depletion of foF2 at all latitude, which seems to confirm the work of Chukwuma[10] during the study of 13-14 March 1989 very intense storm that the depletion of foF2 was simultaneous.

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