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RESEARCH ARTICLE

GEOMAGNETIC STORM EFFECTS ON F2-LAYER PECK ELECTRON DENSITY (N_mF_2)

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ABSTRACT

In this paper, we present a report of an investigation on the effect of geomagnetic storm on F_2 layer of equatorial ionosphere. Of particular interest is the impact on the peak electron density, N_mF_2 and the corresponding height, h_mF_2. The main focus is on the storms of March 12-15 and September 18-21, 1989; and those of March 6-9 and September 24-28, 1994. These were years of high and low solar activities respectively. The investigation was carried out by analyzing f_0 and Dst data mainly from the equatorial station of Ouagadougou, Burkina Faso. The former, f_0, yielded N_mF_2 and h_mF_2, while the latter, Dst gave the strength of the storms. The station has geographic latitude $12.4^o N$, longitude $1.5^o W$, and magnetic dip (geomagnetic coordinates; $8.78^o N, 248.48^o E$). However, in order to gain greater understanding of the impacts we expanded the investigation, for comparative purposes, to include similar data captured (i) at: the same the station on solar quite days before and after the storm events; (ii) at some non-equatorial stations, and (iii) at other equatorial station outside the Africa zone namely: Maui with geographic latitude $20.8^o N$ longitude $156.5^o W$ (geomagnetic coordinates; $19.52^o N, 99.03^o E$) and Canberra on geographic latitude $33.9^o S$, longitude $146.6^o E$ (geomagnetic coordinates; $25.66^o N$, $214.87^o E$). The investigation revealed that: (i) geomagnetic storm caused increase in N_mF_2 during daytime, and caused decrease in N_mF_2 during nighttimes; (ii) the storm effects are greater in March equinox than in September equinox for both periods of high and low solar activities, (iii) geomagnetic storms generally caused decreases in h_mF_2 at Canberra station (mid-latitude region) during both high and low solar activities; while increases in peak height were observed at Maui station (equatorial region]) during both solar activities.

INTRODUCTION

Geomagnetic storms, by their nature and dynamical processes are bound to affect and alter some of the ionospheric parameters, such as the layer's peak election density, N_m, and the corresponding layer height, h_m. The F_2 layer is the most affected by geomagnetic storm[1] .The disturbances, otherwise perturbations, of these parameters would affect, among other things, those applications that depend on the state of the ionosphere, vis-a viz, N_m and h_m, total electron content (TEC), etc. These applications include those of the Global Navigation Satellite System (GNSS), and long range High Frequency (HF) radio communication systems. The performance of GNSS, {for example Global Positioning System (GPS) satellite}, and HF radio communication system are adversely affected by geomagnetic storms. Geomagnetic storms have also been reported to cause havoc on electric power cables [2]. Thus, there is the need to investigate the effects of geomagnetic storms on N_mF_2 and h_mF_2 in particular. The knowledge gained would be of much help in planning the above systems applications. Geomagnetic storms are driven mainly by solar winds and corona mass ejection, both of which are solar activity dependent [3]. Thus, the magnitude and impact of geomagnetic storms are expected to be solar activity dependent. Thus, for better education and understanding of the effects of geomagnetic storms on ionospheric F_2 layer, there is need to carry out the investigation over years of high and low solar activities respectively. In this paper we present, in the main, the report of an investigation of the effect of geomagnetic storms on the F_2 layer peak election, N_mF_2, during years of high and low solar activities. The main focus

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is on the storms of March 12-15 and September 18-21, 1989; and those of March 6-9 and September 24-28, 1994. These were years of high and low solar activities respectively. The investigation was carried out by analyzing f_0 and Dst data mainly from the equatorial station of Ouagadougou, Burkina Faso. The former, f_0, yielded H_mF_2 and h_mF_2 while the latter, Dst gave the strength of the storms. The station has geographic latitude $12.4^o N$, longitude $1.5^o W$, and magnetic dip $5.9^o N$. The choice of equinoxial mouths was based on availability of data, and again the length of daytime and nighttime periods are almost the same, while the dynamics effects of ionization are greater at equatorial region [4]. A total of four storms monitored at three stations were investigated, giving twelve different analyses as shown in Table 1. The stations other than Ouagadougou, Burkina Faso are; Maui in America Sector and Canberra, Australia, with their geographic coordinates as mentioned above. Maui like Ouagadougou, is in the equatorial region, while Canberra is in the mid-latitude region. The two stations are almost equal interval from Ouagadougou. This was to allow for some comparative studies. The time evolution of storms occurs in three phase - the initial, (IP), main, (MP) and recovery phases (RP) [2]. Consequently, each storm was studied with respect to these three phases, and the storms' profiles in this respect are giving in Table 1. The initial phase is the onset of storm, while the main phase is the actual period of optimum storm effect, and the recovery phase is the period during which the storm is restoring it its initial phase.

METHODOLOGY

Data collection analysis

The data used for this study were: (i) critical/plasma frequencies of F_2 layer, f_0F_2, (ii) Dst values, (iii) IRI h_mF_2 model values. The critical frequencies enabled us to calculate N_mF_2. They were obtained online from space Physics Interaction Data Resources (SPIDR) Home page http://spidr.ngdc.noaa.gov/spidr/gurudataset.do . The Dst values were measures of the strength of the storms, and were obtained online from World Data Centre (WDC) for Geomagnetism, at: http://swdcwww.kugi.kyoto-u.ac.jp/dstdir., while the h_mF_2 values were obtained from International Reference Ionosphere (IRI) model, and were obtained online at: http://ccmc.gsfc.nasa.gov/models/iri.html, for those hours during which the storms occurred. The details of the storms are shown in Table 2. The peak electron density, N_mF_2, values were calculated using the relation:

$$N_mF_2 = \frac{\left(f_oF_2\right)^2}{80.6}$$

Where f_0F_2 is that frequency at which reflection of radio signal occurs in F_2 layer and it is called critical frequency. It is measured in megahertz (MHz). N_mF_2 is measured in electron density per cubic meter (el/m^3). The average value of f_0F_2 for five quietest days of the month during which the storm occurred was used as reference value. The derivative from the reference value during the storm day gave the effect of the storm on the ionosphereric parameter such as f_0F_2, N_mF_2 and h_mF_2.

Observations

Storm Effects During March Equinox of 1989 and 1994.

The storm evolutions in F2 layer during March 1989 and 1994 equinoxes showed no initial phase in all the three stations under study. These are illustrated in the Dst plots in figures 1a and 1b. At Ouagadougou, the storms caused a decrease in N_mF_2 during the onset of the main phase which occurred at about (0200LT) of 13th March, 1989, but with an increase in the peak height, h_mF_2, (Table1) compared with the quiet time value as shown in figure 1c. The increase in N_mF_2 began to show up during the daytime and later dropped at nighttime. These repeated events continued throughout the recovery phase. The same effects were observed during low solar activity where daytime increase and nighttime decrease in N_mF_2 take their course (fig1d). In fig.2a and 2b, the effects of storms during the main phase of high and low solar activities caused no significant change on N_mF_2 as observed at Maui station. However, during the recovery phase of March 1989 storm, a large drop in N_mF_2 was observed between 1700LT of 13th and 1300LT of 14th. In contrast, a large increase occurred during the recovery phase of March 1994. However Changes in N_mF_2 in the mid- latitude are contrary to what was observed in the equatorial region as can be seen in figure 3a and 3b. In particular, the storms occurrences in March equinox during 1989 and 1994 at Canberra station showed significant decrease in N_mF_2 values against the quiet time values for high and low solar activities irrespective of the time of the day during the main phase. While the decrease in N_mF_2 spanned to the recovery phase of March 1994, the storm effect during high solar activity of March 1989 in the recovery phase caused significant increase in N_mF_2 during day-time.

Storm Effects on N_mF_2 During 1989 and 1994 September Equinoxes

Ouagadougou: As can be seen from figures 4a and 4b, the disturbance storm time (Dst) for September equinox for both years showed the strength of the storms. The storms evolution in these cases showed initial phase with increase in N_mF_2 during high solar activity, and decrease in N_mF_2 during low solar activity. Records for the main phase were missing from the data during high and low solar activities. During the recovery phase of high solar activity two peaks between 1000LT and 1600LT of 19th September showing increase in N_mF_2 were observed, and a trough at noon-time, as shown in fig. 4c. Slight increase in N_mF_2 was also observed at daytime during recovery phase in the low solar activity, as depicted in fig.4d.

Maui: Figure 5 showed slight increases observed in N_mF_2 during the initial phase of 1989 storms, which occurred at 0100LT of September 18, while there was no significant change in N_mF_2 throughout the main phase. Increases in N_mF_2 started showing up at about 1800LT of 19th September till 21st September during the recovery phase. Storm records for September 1994 at Maui station were not readily available.

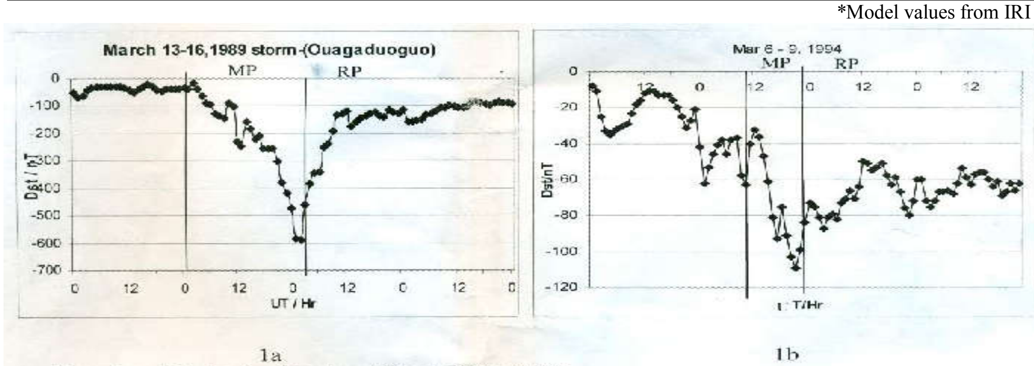
Table 1. List of storm' profile and analyses

Station	Storm Days	Max. Dst Value/ (nT)	Storm's Peak Day	Initial phase	Main phase	Recovery Phase
Ouagadougou	March 12-16, 1989	-589	14th	---------	0200(13th) to 0300(14th)	0300(14th) to 2300(16th)
Maui	Same as Above	-589	13th	---------	1600(12th) to 1700 (13th)	1700(13th) to 2200(16th)
Canberra	Same	-589	14th	---------	1200(13th) to 1300 (14th)	1300(14th) to 2300(16th)
Ouagaduogou	March 6 – 9, 1994	-115	7th	---------	1200 to 2200(7th)	2200(7th) to 2300(9th)
Maui	March 6 – 9, 1994	-115	7th	---------	1200 to 2200(7th)	1200(8th) to 2300(9th)
Canberra	March 6 – 9, 1994	-115	7th	---------	2200(7th) - 0800(8th)	0800(7th) to 2300(9th)
Ouagadougou	Sept 18 – 21, 1989	-255	19th	1100-2000 (18th)	2100(18th) to 0600 (19th)	0800(7th) to 2300(9th)
Maui	Sept 18 – 21, 1989	-255	18th	0100-1000 (18th)	1000 - 2000(18th)	0700(19th) to 2200(21st)
Canberra	Sept 18 – 21, 1989	-255 (1500)	19th	2100 (18th)-0600 (19th)	0600 - 1600(19th)	2100(18th) to 2300(21st)
Ouagadougou	Sept 24 – 28, 1989	-73 (2300)	25th	2100 (18th)-0600 (19th)	2000(25th)-0800(25th)	1700(19th) to 2300(21st)
Maui	Sept 24 – 28, 1989	No	Available	Data		
Canberra	Sept 24 – 28, 1989	-73 (0800)	26th	2100 (18th)-0600 (19th)	0600 - 0900(26th)	1200(26th) to 2300(28th)

Table 2. List of storms showing NmF2 and hmF2 values during high and low solar activities

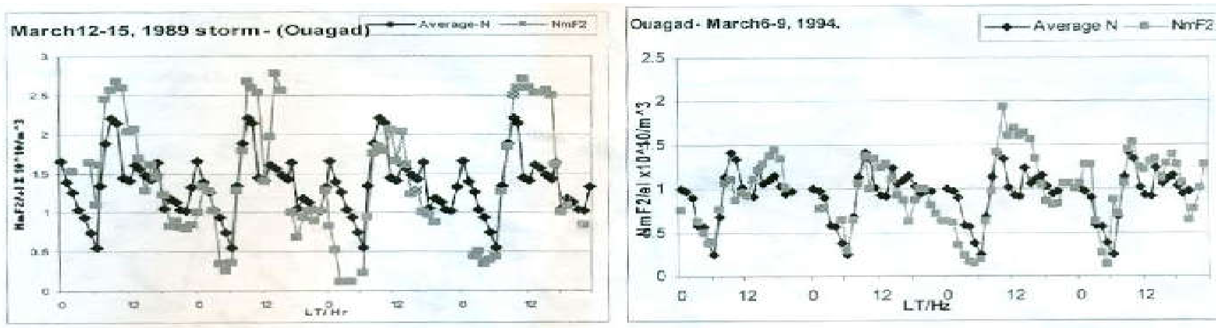
Station	Storm's peak Day	N_mF_2(Quiet) (el/m3)	N_mF_2(Storm) (el/m3)	h_mF_2(Quiet)* km	h_mF_2(Storm)* km
Ouagaduogou	March 14,1989.(0300)	1.00×10^{10}	0.10×10^{10}	309.63	313.61
Maui	March 13,1989.(1700)	0.40×10^{10}	1.20×10^{10}	345.14	348.28
Canberra	March 14,1989.(1300)	0.75×10^{10}	0.40×10^{10}	314.00	310.62
Ouagaduogou	March 7,1994.(2200)	1.00×10^{10}	0.70×10^{10}	368.40	332.04
Maui	March 7,1994.(1200)	0.25×10^{10}	0.25×10^{10}	285.62	286.93
Canberra	March 8,1994.(0800)	0.68×10^{10}	0.30×10^{10}	332.02	243.93
Ouagaduogou	Sept. 19,1989. (0600)	0.50×10^{10}	0.40×10^{10}	469.67	294.58
Maui	Sept. 18,1989. (2000)	1.75×10^{10}	2.20×10^{10}	317.83	353.60
canberra	Sept. 19,1989. (1600)	0.40×10^{10}	0.10×10^{10}	346.33	327.18
Ouagaduogou	Sept. 25,1989. (2300)	0.02×10^{10}	0.02×10^{10}	299.92	325.61
Maui	--------------	----------	---------	----------	----------
Canberra	Sept. 26,1989. (0900)	0.21×10^{10}	0.19×10^{10}	286.48	238.56

*Model values from IRI



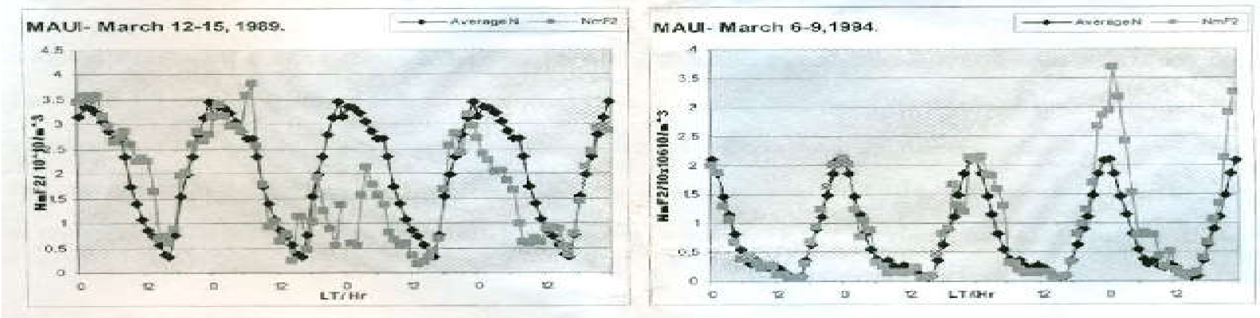
Figures 1a and 1b showing Dst values of March 1989 and 1994.

Canberra: Data from Canberra station showed significant decrease in N_mF_2 during initial and main phase of September 1989 storm, (figs.6a and 6b). This was immediately followed by an increase in N_mF_2 during the recovery phase between 2100LT of 19th March, 1989 and 0300LT the next day. During the low solar activity of September 1994, the initial phase of the storm which occurred at 1800LT on 24th till 0600LT on 26th showed slight increase in N_mF_2 at dusk sector. The usual



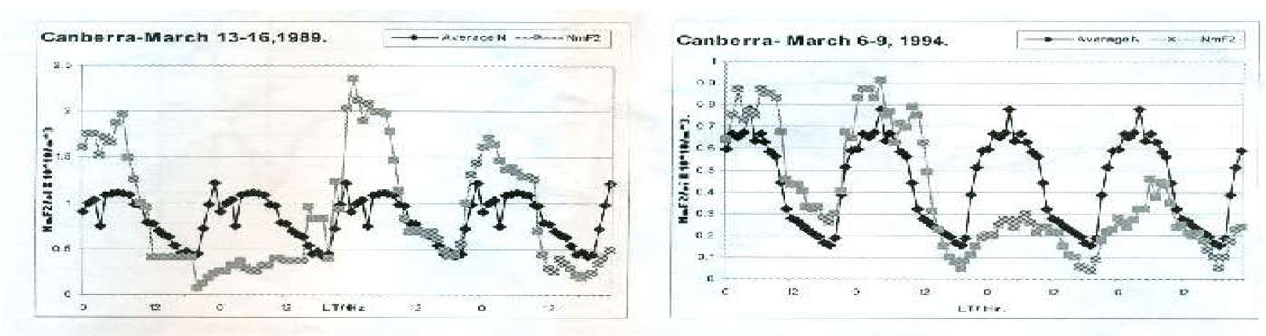
1c 1d

Figures 1c and 1d showing changes in N_mF_2 during March 1989 and 1994 equinoxes.



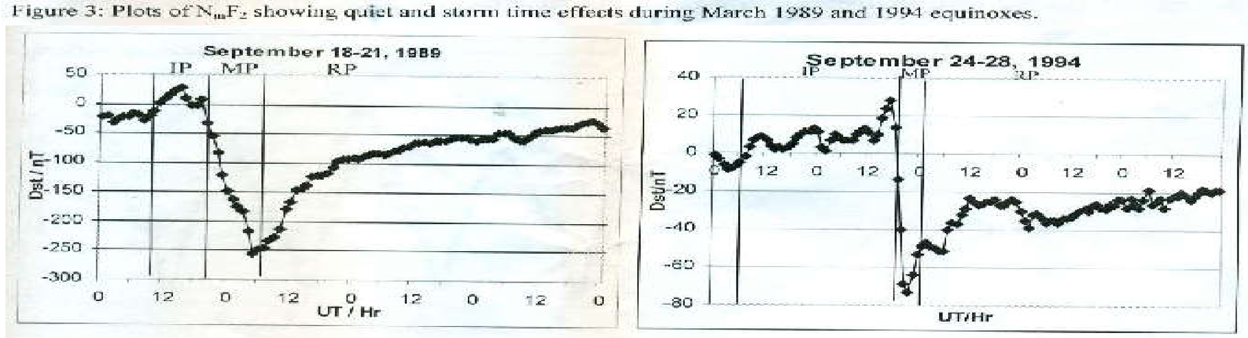
2a 2b

Figure2: Plots of N_mF_2 for High and Low solar activities during March equinox.



3a 3b

Figure 3: Plots of N_mF_2 showing quiet and storm time effects during March 1989 and 1994 equinoxes.



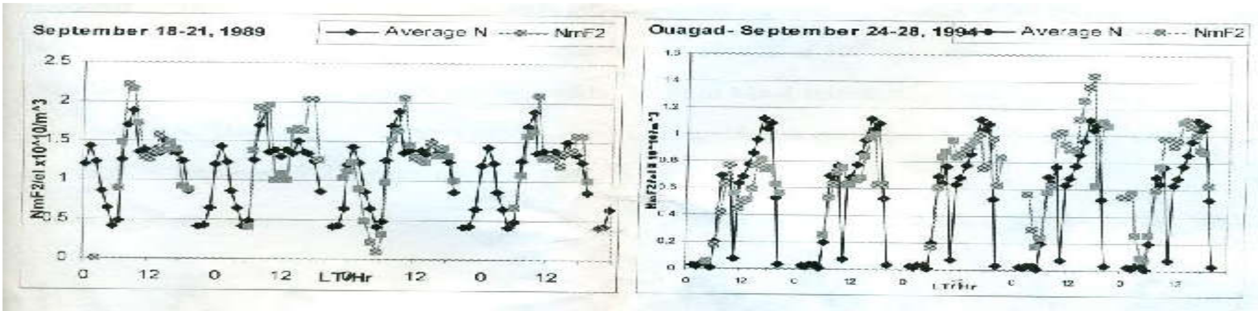
4a 4b

Figures 4a and 4b showing Dst index value for September equinox for high year and low year solar activities.

daytime increase was observed during the main phase. The onset of recovery phase between 1200LT and 1800LT of 26th also showed day-time increase in N_mF_2 and no significant change was recorded thereafter.

DISCUSSION

Ouagadougou: This slight decrease in N_mF_2 recorded at Ouagadougou station whose main occurred at nighttime during March, 1989 was probably due to the effect of westward movement of electric field in which ExB force caused downward movement of ionization. The increase in N_mF_2 that was observed thereafter during the day-time was as a result of the ExB forces that moved the ionization upward [3]. The recovery phase followed this trend of events between day-time and nighttime period. Again, the decrease in N_mF_2 can as well be explained in terms of large energy input



4c 4d

Figure 4c and 4d: showing changes in N_mF_2 for September equinox during high and low solar activities.

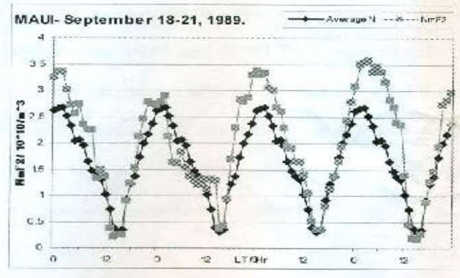
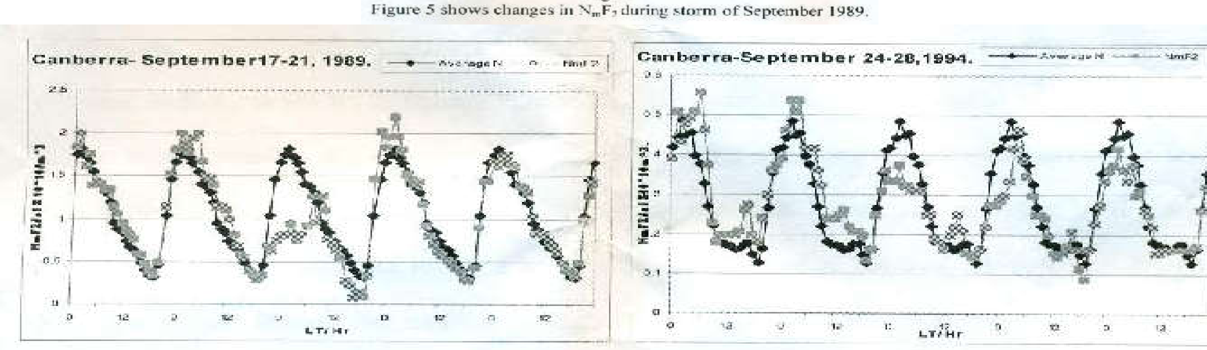


Fig. 5

Figure 5 shows changes in N_mF_2 during storm of September 1989.



6a 6b

Figures 6a and 6b showed changes in N_mF_2 for quiet and storm days during high and low solar activities respectively.

into the ionosphere that usually accompanied severe storm, which leads to increase in electron temperature [3, 4]. Such a raise in electron temperature leads to increase in the recombination rate and consequently increase loss rate, hence decrease in N_mF_2 as shown in figures 1c. The slight increase in h_mF_2 observed in March 1989, from Table 2, may be attributed to the fact that the effect of dynamics of ionization are much greater in the F region than at lower height[5]. As mentioned above from the ExB effect, the decrease in the depletion of ionization during the daytime resulted in the daytime increase in electron density. The decrease in the drift of electrons toward the equator at night during storm periods explains the decrease in electron density observed at night. The decrease in the downward drift of electrons at night during storm periods also indicates that the push of ionization downwards at night is reduced. This means that electrons can remain at higher altitudes at night during storm periods as observed in March 1989 storm [5].

Maui: No significant change in N_mF_2 at Maui station was observed during the main phase of the March 1989 Storm, as shown in Fig.2a. The large drop in N_mF_2 values during the early recovery phase, which occurred between 2100LT of 13th and 1200LT of 14th March, 1989, was as result of westward orientation of electric field E which caused ExB force to move ionization downward during the nighttime. In contrast, the increase in N_mF_2 values that occurred on the 8th March, 1994 at nighttime (0030LT) during the recovery phase (figure 2b), could probably due to the fact that the F_2-layer was being fed by the same downward movement of ionization from protonosphere region during the nighttime[4, 6]. The peak height of electron density h_mF_2 as illustrated in Table 2, showed slight increase as against the time quiet time values.

Canberra: Fig. 3a and 3b showed large drop in N_mF_2 at Canberra station which occurred between 2000LT of 13th and 1400LT of 14th during the main phase of March 1989 storm. This can be explained in terms of increase in electron temperature as a result of large solar energy input into the ionospheric F-region during magnetic storm. This increase in electron temperature may cause change in the neutral gas composition which would lead to increase loss rate, hence decrease in peak election density [4, 6, 7]. The recovery phase recorded positive storm effects with spiky daytime structure followed by nighttime spiky structures. The same could be said of the decrease in N_mF_2 value observed during the initial phase and also manifested in the main phase of storm of September 1989 but in smaller proportion with spiky structure that accompanied its recovery phase just at the onset.

The nighttime enhancement of electron density lasted mush longer than the daytime, and are generated in the dusk sector [5, 6]. One possible explanation for this was based on the assumption that positive storms are attributed to meridional winds. When solar wind dissipates energy into the upper atmosphere, it initiates what is called travelling atmospheric (TADs) that cause middle latitude daytime positive storm effects of short duration by an uplifting of the F2-layer. On the other hand, the dissipation of solar wind energy input generates a composition disturbance zone at polar latitude. During disturbed moderate magnitude, designated as midnight surge, and thus enhanced N_mF_2 value [6, 7, 8]. The same features were observed in the low solar activity of September 1994 but in a small magnitude. During low solar activity of March 1994, there significant decrease in N_mF_2 observed in the main the phase and the recovery phase.

Conclusion

Generally, the geomagnetic storms, especially when the main phase occurred during daytime, caused increases in the values of N_mF_2 at equatorial region, but decreases in N_mF_2 values when they occurred during nighttime. The increases are more consistent at higher equatorial region (as in Maui), while the decreases are major features in the lower equatorial region such as on Ouagadougou. These features were observable in both cases of high and low solar activities. However, in the mid-latitude, (Canberra), geomagnetic storms usually caused decreases in the value of N_mF_2, and corresponding decreases in the electronic peak height h_mF_2 during both high and low solar activities. The peak height, h_mF_2, increased consistently during daytime and nighttime in the high and low years of solar activities at Maui station.

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