Geomagnetic storm effects on the ionosphere over an equatorial station at low solar activity

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Abstract --- Ionospheric response to five geomagnetic storms at an equatorial station was studied. Ionograms recorded by the ionospheric prediction sounder (IPS 42) situated at Ouagadougou (12.4^{0}N, 1.5^{0}W, dip 5.9^{0}N), Burkina Faso, were used for this work. Ionograms for a year of low solar activity, 1995 (Rz = 18), were analysed. The peak electron density (NmF2), its height of occurrence (hmF2) and the slab thickness (TF2) are the ionospheric parameters considered. The percentage enhancement in NmF2 due to storm was generally above 50%. The magnitude of the increase in NmF2 does not appear to depend on storm strength. The increases in NmF2 were usually accompanied by decreases in the thickness of the F2 layer.

Index Terms -- Electron density, equatorial ionosphere, magnetic storms, slab thickness

1 INTRODUCTION

IT is well known that the geomagnetic field varies daily and remains fairly steady about an average value. However, there are moments when this field exhibits sudden and remarkable variations. The occurrence of the sudden departure of the geomagnetic field from the regular daily variation is termed geomagnetic storm.

Studies on the effect of geomagnetic storms on ionospheric parameters have been carried out at equatorial latitude. The common characteristics investigated are usually the peak parameters. The other parameters have also been studied ([1],[2],[3],[4],[5],[6] and [7]). Most studies of magnetic storm effects have been done using single ionospheric parameters. The parameter used most is either the peak electron density, NmF2, or in recent time, the total electron content, TEC. Fewer studies employ about two parameters simultaneously. The common one is NmF2 and hmF2 or NmF2 and TEC (e.g., [8]; [9]). The use of more than two parameters simultaneously is not common.

Ionosonde data, obtained at Ouagadougou (12.4^{0}N, 1.5^{0}W, dip 5.9^{0}N), Burkina Faso, an equatorial station in West Africa, using the ionospheric prediction sounder (IPS 42), were used for this work. The parameters used for this study are the peak electron density (NmF2), its height of occurrence (hmF2) and the slab thickness (TF2). The simultaneous effects of geomagnetic storms on these parameters were investigated. The entire storm events studied occurred at low solar activity. These consisted of three moderate and two strong storms.

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2 STORM CHARACTERIZATION

Geomagnetic storms are characterized by remarkable deviations in the variation of the earth's magnetic field from the quiet conditions. The Dst (disturbance storm time) index provides a measure of geomagnetic activity. It is based on the average value of the northward horizontal component of earth's magnetic field, recorded hourly at four low-latitude geomagnetic observatories, namely, Honolulu (Hawaii), San Juan (Puerto Rico), Hermanus (South Africa) and Kakioka (Japan). The Dst index is used to determine the occurrence, duration and magnitude of a storm. The minimum Dst value attained (in nanoteslas, nT) is used to define the severity of a magnetic storm. Employing the system of [10], storms are classified as follows: moderate storms (-100nT < Dst < -50nT); strong storms (-200 nT < Dst < -100nT); severe storms (-350nT < Dst < –200nT). Great storms are characterized by Dst value less than -350nT. A magnetic storm is characterized by an interval during which the Dst is less than – 20nT and drops below – 50nT. A storm event is identified as one for which one of the days has magnetic index Kp ≥ 5 and Ap > 26.

In this paper, five storm events were analyzed. The storm events studied are those of January 16-20, 1995 (moderate storm); January 28-31, 1995 (moderate storm); April 6-10, 1995 (strong storm); October 1-7, 1995 (moderate storm); and October 17-21, 1995 (strong storm). These five storms are the ones for which sufficient ionospheric data were available.

3 MATERIALS AND METHODS

The ionosonde data used are those recorded at Ouagadougou, Burkina Faso, an equatorial station in Africa (12.4^{0}N, 1.5^{0}W, dip 5.9^{0}N). The data were for the year 1995, a year of low solar activity with an average sunspot number (R_{12}) of 18. The hourly values of Dst were used for the storm description. The ionograms for this study were scaled manually using the computer and inverted by means of the NEW POLAN programme developed by [11]. Average values of the parameters were obtained from five magnetically quiet (Ap < 26) days' records, obtained during the month in which the magnetic storm occurred. The average was calculated on an hourly basis for the whole 24 hours of the days involved. The quiet day averages served as reference for comparison with corresponding hourly values of the parameters for the disturbed days. The storm days were chosen by considering consecutive days with Ap > 26. Pre-storm and post-storm days were considered. Table 1 summarizes the data for the storm events and the reference days used.

To quantify the peak electron density's response to storm, the quiet-time peak was used as the base. The storm effects are calculated as percentage increases or decreases over this base. Due to the nature of the variations in NmF2, either a pre-noon or a post-noon peak was picked as reference. The storm-time peak was then compared with this reference.

TABLE 1
GEOPHYSICAL CONTEXT DURING THE STORM EVENTS

Storm days (1995)	Ap index	Equatorial min	Dst extreme max	Quiet days	Ap index
Jan. 16-20					
16	17	-43	-1	8	8
17	37	-81	-29	9	7
18	37	-95	-43	24	4
19	05	-40	-20	26	3
20	06	-27	-5	27	4
Jan. 28-31					
28	03	-02	28	8	8
29	33	-56	22	9	7
30	39	-55	-27	24	4
31	29	-44	-24	26	3
April 6-10					
6	6	-17	9	3	2
7	100	-149	4	4	3
8	34	-102	-60	15	4
9	25	-68	-39	16	4
10	26	-56	-39	21	2
Oct. 1-7					
1	3	-27	-3	15	5
2	16	-52	1	25	4
3	21	-58	-27	26	3
4	57	-92	-29	28	2
5	24	-51	-38	29	3
6	25	-57	-34		
7	26	-54	-30		
Oct. 17-21					
17	8	-31	-11	15	5
18	32	-127	9	25	4
19	31	-124	18	26	3
20	34	-65	-7	28	2
21	13	-51	-26	29	3

The geomagnetic and the Ap indices were obtained from the National Geophysical Data Centre, Boulder, Colorado, U.S.A.

4 RESULTS

4.1 NmF2

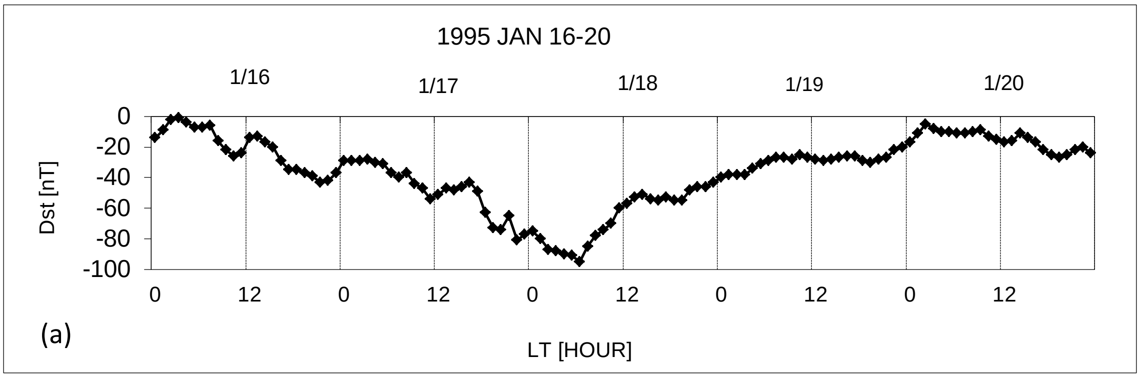
Figures 1(a)-5(a) depict the storm descriptions while figures 1(b), (c), (d)-5(b), (c), (d) show the storm effects on the parameters. As can be seen in figures 1(b)-5(b), the peak electron density, NmF2, responded to the storm with an increase. The increases in the peak electron density were more prominent on the major storm days than the other days. Remarkable effects on the peak electron density, NmF2, were observed on the storm days of October 19, 1995 (figure 5(b)), and October 3, 1995 (figure 4(b)). Similarly, the increase in NmF2 was greater on January 18 (figure 1(b)), January 29 and 30 (figure 2(b)) than on all other days. This daytime increase in NmF2 was observed in all the storms considered.

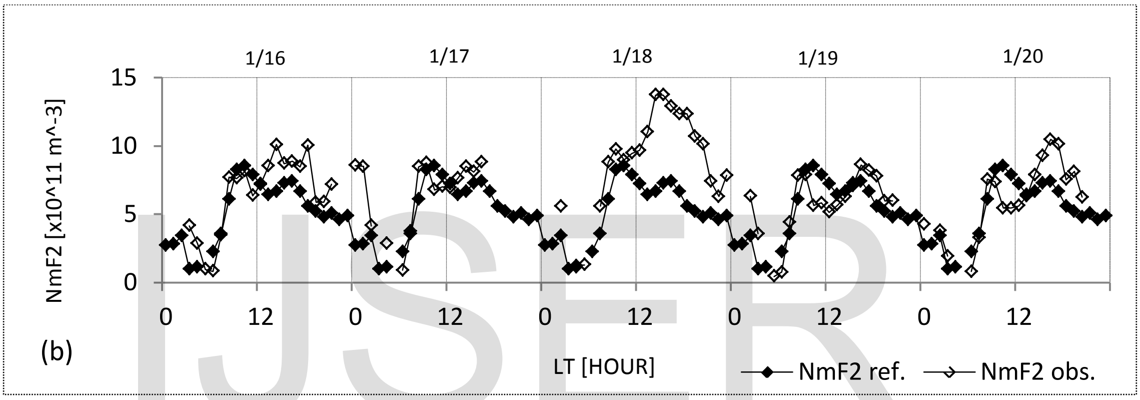
4.2 hmF2

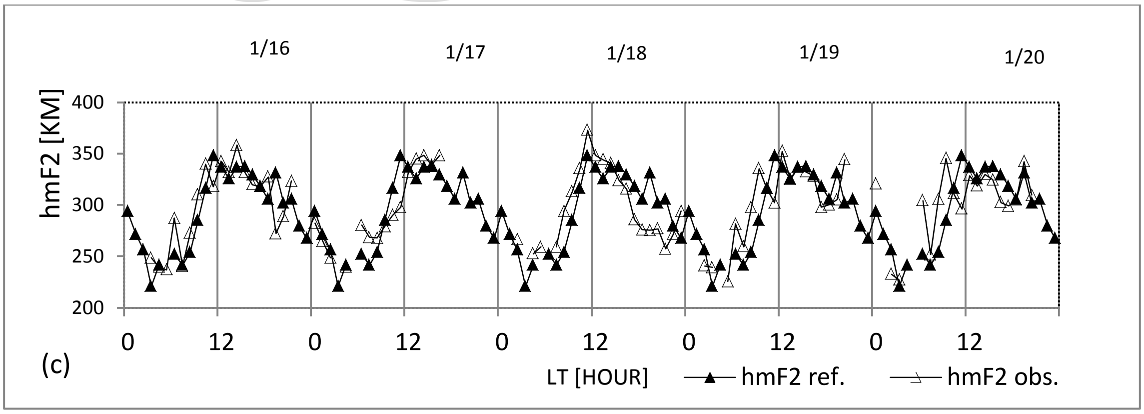
A nighttime increase in peak density height, hmF2, occurred on all the storm days. Figures 1(c)-5(c) depict the storm effects on hmF2. The greatest increase occurred on October 19, 1995 (figure (c)). The day after the storm also displays a nighttime increase in hmF2. A remarkable nighttime increase in hmF2 was observed on January 29, 1995 (figure 2(c)). This nighttime increase in hmF2 was observed in all the storms studied. No significant change in hmF2 was observed during the daytime.

4.3 TF2

A daytime decrease was observed in the slab thickness of the F2 layer, TF2.This effect was most noticeable on October 19, 1995(figure 5(d)) and on January 18,1995 (figure 1(d)) between 1000 and 1600LT. A nighttime increase in TF2 was also observed during the storm events. This can be seen clearly between January 29 and 30 (figure 2(d)). This pattern of daytime decrease and nighttime increase in the slab thickness of the F2 layer was observed in all the storms studied.


1995 JAN 16-20
1/16
1/17
1/18
1/19
1/20
Dst [nT]
0
-20
-40
-60
-80
-100
0
12
0
12
0
12
0
12
0
12
(a)
LT [HOUR]


1/16
1/17
1/18
1/19
1/20
NmF2 [x10^11 m^-3]
15
10
5
0
0
12
0
12
0
12
0
12
0
12
(b)
LT [HOUR]
NmF2 ref.
NmF2 obs.


1/16
1/17
1/18
1/19
1/20
hmF2 [KM]
400
350
300
250
200
0
12
0
12
0
12
0
12
0
12
(c)
LT [HOUR]
hmF2 ref.
hmF2 obs.

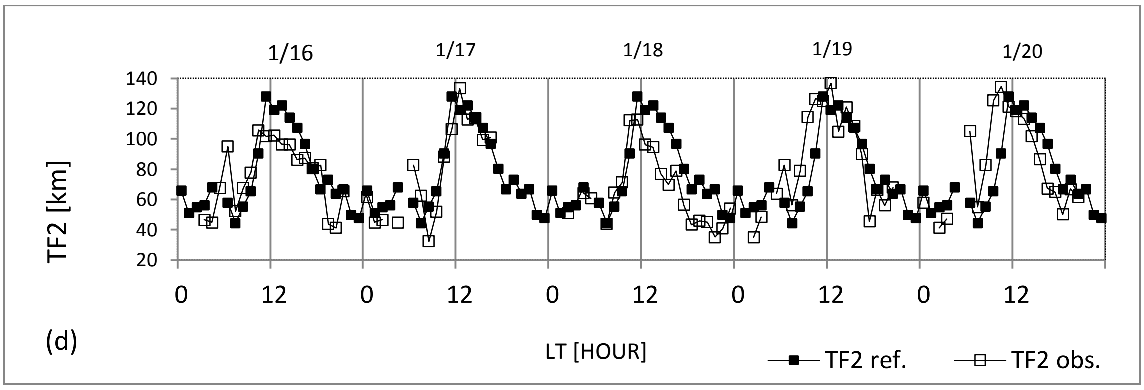

1/16
1/17
1/18
1/19
1/20
TF2 [km]
140
120
100
80
60
40
20
0
12
0
12
0
12
0
12
0
12
(d)
LT [HOUR]
TF2 ref.
TF2 obs.

Fig. 1. Storm of Jan. 16-20,1995: (a) storm description (b) response of NmF2 to storm, (c) effect of storm on hmF2 and (d) storm effect on TF2

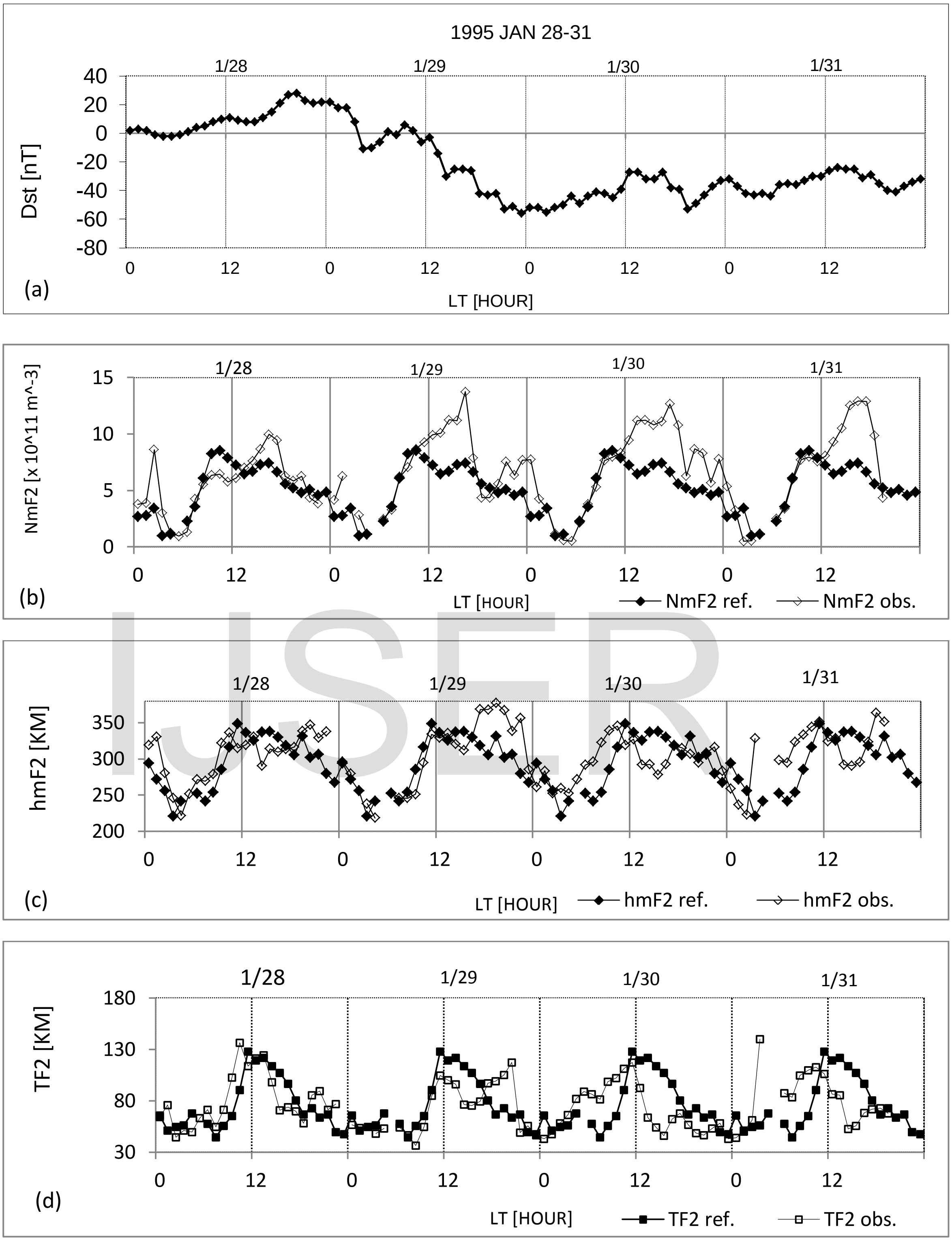


Fig. 2. Storm of Jan. 28-31,1995: (a) storm description, (b) response of NmF2 to storm, (c) effect of storm on hmF2 and (d) storm effect on TF2

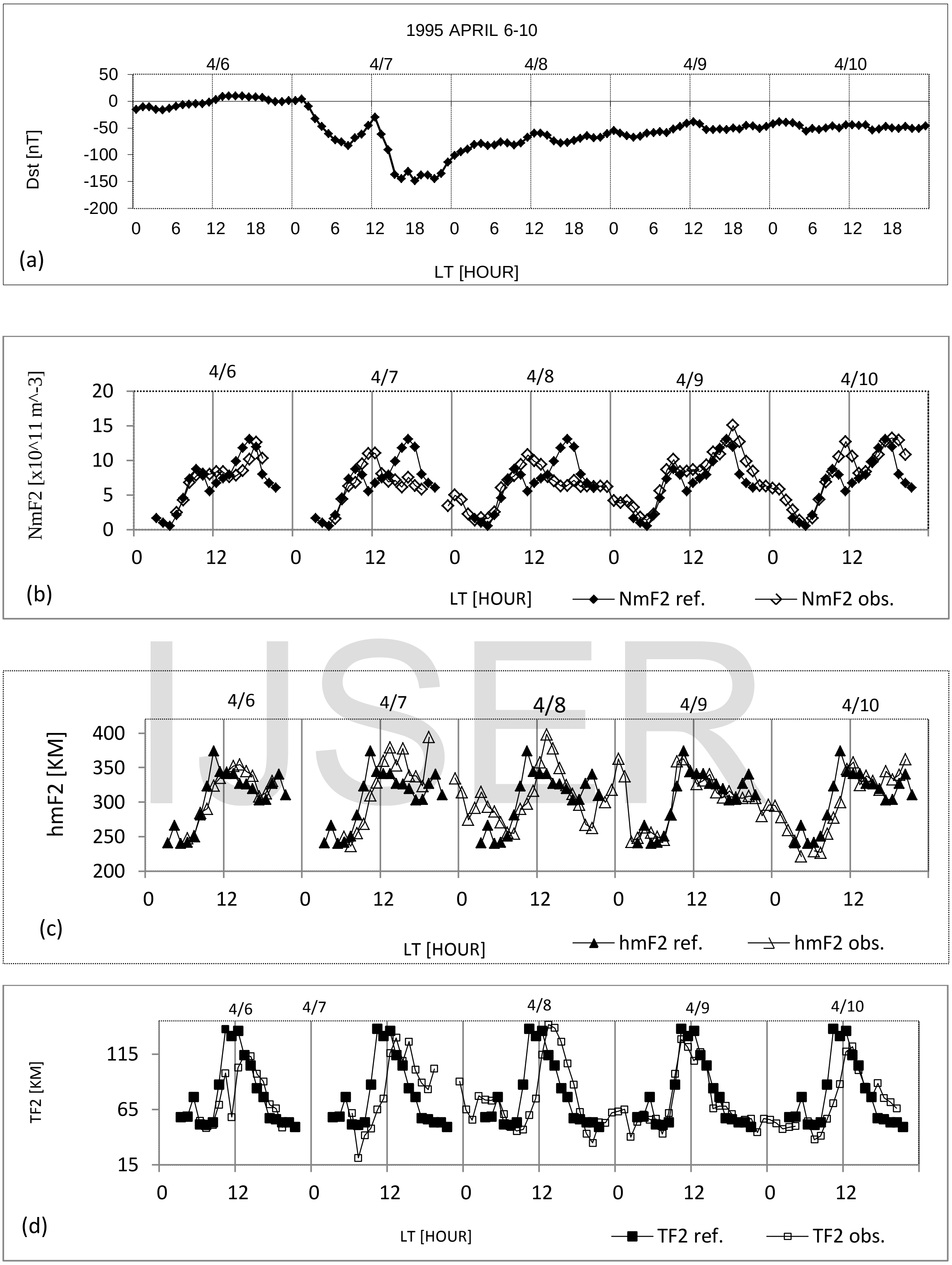


Fig. 3. Storm of April 6-10,1995: (a) storm description, (b) response of NmF2 to storm, (c) effect of storm on hmF2 and (d) storm effect on TF2

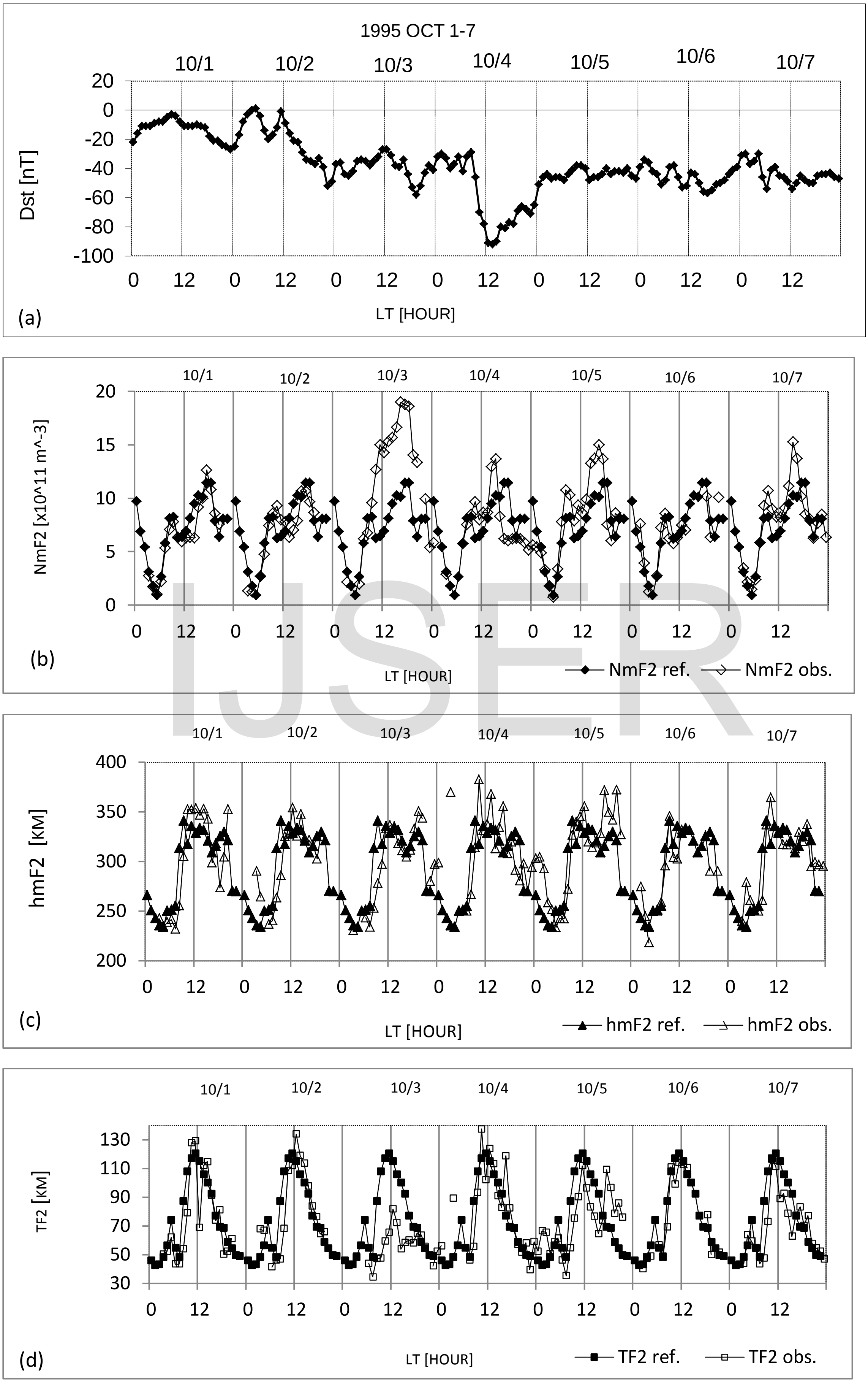

1995 OCT 1-7
10/1
10/2
10/3
10/4
10/5
10/6
10/7
Dst [nT]
20
0
-20
-40
-60
-80
-100
0
12
LT [HOUR]
(a)
NmF2 [x10^11 m^-3]
20
15
10
5
0
(b)
NmF2 ref.
NmF2 obs.
hmF2 [KM]
400
350
300
250
200
(c)
hmF2 ref.
hmF2 obs.
TF2 [KM]
130
110
90
70
50
30
(d)
TF2 ref.
TF2 obs.

Fig. 4. Storm of Oct. 1-7,1995: (a) storm description, (b) response of NmF2 to storm, (c) effect of storm on hmF2 and(d) storm effect on TF2

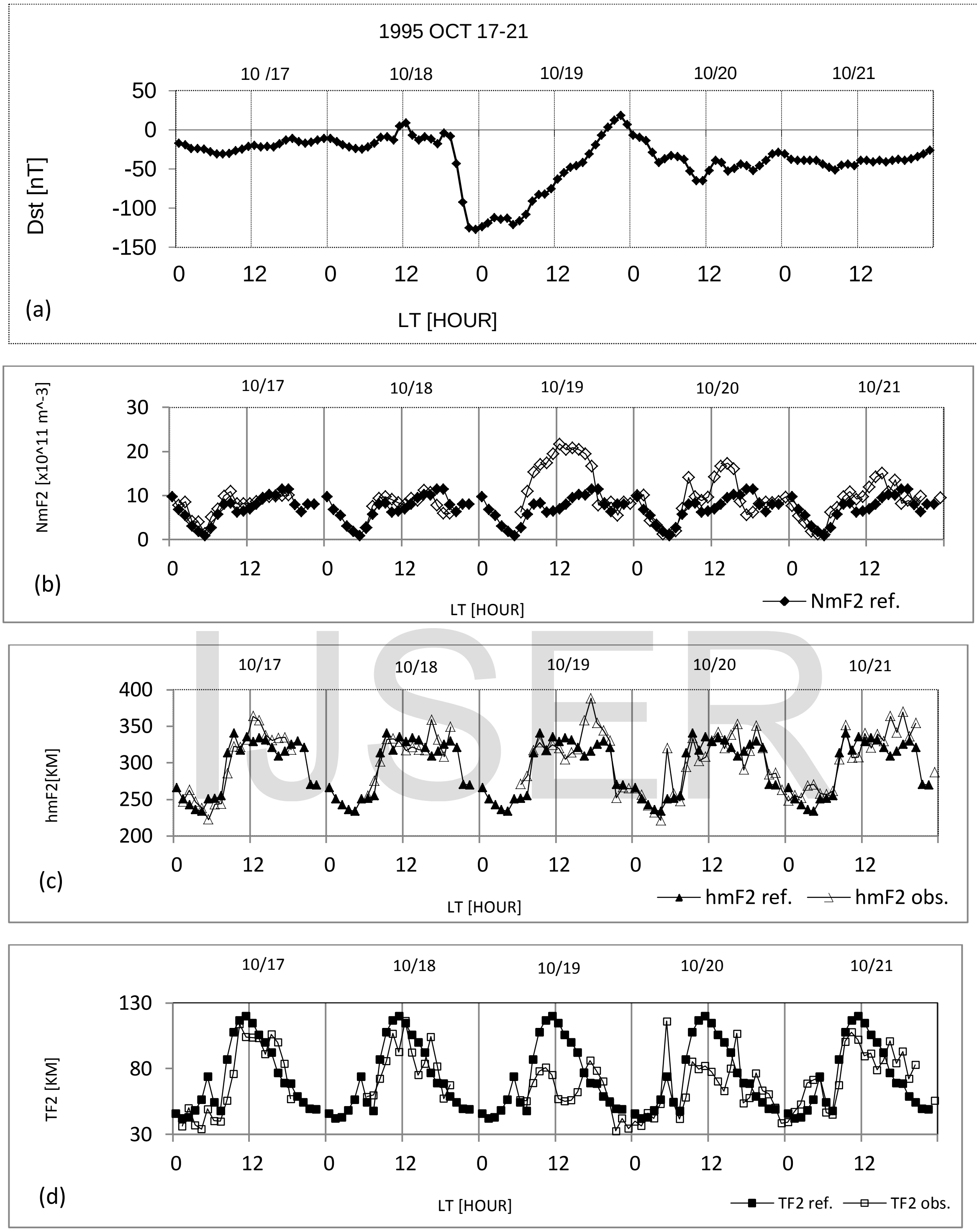


Figure 5. Storm of Oct. 17-21,1995: (a) storm description, (b) response of NmF2 to storm, (c) effect of storm on hmF2 and (d) storm effect on TF2

5 DISCUSSION

The following are the general observations made. NmF2 increased in response to geomagnetic storm, at low solar activity, for moderate and strong storms. The magnitude of the increase does not appear to be dependent on storm strength. The increases in NmF2 are usually accompanied by a decrease in the thickness of the F2 layer, TF2. The height corresponding to the peak electron density, hmF2, responded to the storm with an increase. This increase in hmF2 generally occurred concurrently with the increase in NmF2.

The current understanding of the dynamics of the E and F regions of the ionosphere depends largely on the interplay between the electric fields and plasma drifts. It is known that there exists a coupling between the electric field (**E**) and the earth's magnetic field (**B**), which is about horizontal at the equator, to produce the **E**×**B** force, at the low-latitude ionosphere ([12], [13], [14]). The quiet daytime movement of electrons away from the equator along magnetic field lines, on both sides of the equator, causes a depletion of electrons at the equatorial region. Thus, the F2 peak is moved to a higher altitude. This movement affects the thickness of the layer. This explains the equatorial anomaly on a global basis and also the trough in the daytime NmF2 observed locally at Ouagadougou.

It is well known that magnetic storm events are characterized by a decrease in the daytime eastward electric field ([15],[16]). This decrease in the daytime eastward electric field during a storm suggests an enhancement of the nighttime westward field. This leads to a reduction in the daytime drift of electrons away from the equator and an enhancement of the drift towards the equatorial F2 region at night. This accounts for the observed increases in NmF2 during the day when geomagnetic storms occur. This produces the reduction in prominence or the absence of noon bite-out. It also accounts for the decrease in the thickness of the layer.

6 CONCLUSION

Three moderate and two strong geomagnetic storms were studied. The effects of these storms on the ionosphere for a year of low solar activity were analysed. The ionosphere responded to the storms with an enhancement in the peak electron density, NmF2. The enhancement does not appear to depend on the strength of the storms.

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