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Ionospheric disturbances at the crests of the equatorial anomaly during geomagnetic storms

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RESUMEN

Se analizan las perturbaciones ionosféricas que se presentan en las crestas de la anomalía ecuatorial durante algunas tormentas geomagnéticas, con el objeto de verificar el patrón de comportamiento esperado. Se encuentra que la densidad electrónica máxima de la región F experimenta una gran variabilidad y puede diferir considerablemente del patrón promedio, principalmente en invierno. A pesar de este comportamiento irregular se reconocen, sin embargo, algunas características para diferentes tiempos locales de comienzo de las tormentas geomagnéticas. Los resultados que se obtienen son útiles ya que permiten mejorar el modelo cualitativo existente para predecir el comportamiento ionosférico en las crestas de la anomalía ecuatorial en los períodos perturbados.

PALABRAS CLAVE: Anomalía ecuatorial, tormenta geomagnética, perturbaciones ionosféricas.

ABSTRACT

Ionospheric disturbances at the crests of the equatorial anomaly during some geomagnetic storms were investigated. The peak electron density of the F region shows a great variability and may differ considerably from the average pattern, especially in winter. Some systematic trends may be recognized for different local times of sudden commencements of geomagnetic storms. The results are useful to improve the qualitative model to forecast ionospheric behavior at the crests during perturbed conditions.

KEY WORDS: Equatorial anomaly, geomagnetic storm, ionospheric disturbances.

INTRODUCTION

The ionospheric F2 region undergoes drastic changes during geomagnetic storms. Enhancements of peak electron density at middle latitudes (called positive ionospheric storms) are usually observed when the sudden commencement of the storms is produced at daytime, followed later by depressed peak electron density values (called negative ionospheric storms).

The initial effects are attributed to transport of ionization produced either by an intensified electric field (Tanaka and Hirao, 1973; Lanzerotti *et al*., 1975; Mendillo *et al*., 1987; Jakowsky *et al*., 1992) and/or by meridional thermospheric winds propagating equatorward (Jones and Rishbeth, 1973; Prölss,1993). Both effects lift the ionospheric layers into regions where fewer molecular species are present and the recombination is slower.

The negative effects are produced by increases of N_2/O density ratio, i.e., changes in neutral gas composition (Mayr and Volland, 1972; Prölss, 1980; Forbes and Harel, 1989). The composition disturbances are closely related with storm time thermospheric winds circulation.

At low latitudes the equatorial anomaly is less developed during storm time. The critical frequency of the F2 layer in the equatorial trough is larger than during undisturbed times and the crests are less pronounced (Rishbeth, 1975).

This paper discusses whether the described behavior of the critical frequency of the F2 layer, foF2, is observed at the crests of ionization of the equatorial anomaly during some geomagnetic storms. We use two ionospheric stations located at the crests of the equatorial anomaly in both hemispheres. The variations of foF2 with local time and season on the day of the storm, and on the two following days, are shown.

To obtain the perturbation degree during the storms, the differences dfoF2=foF2-foF2(q) where foF2(q) are the values corresponding to a quiet geomagnetic day of the month of the storm, are discussed.

OBSERVATIONS

The locations of the ionosonde stations and the storms used in this paper are listed in Tables 1 and 2. The fact that these stations have different longitudes permits an investigation of the ionospheric response to several storm sudden commencements. Figures 1 to 5 represent the hourly values dfoF2 during storm periods. The arrow indicates the UT time of the sudden commencements of storms (sc).

Table 1

Station	Geographic latitude	Geographic longitude	LT
Tucuman	26.9 S	64.4 W	UT - 4 h
Okinawa	26.3 N	127.8 E	UT + 9 h

Table 2

Geomagnetic storm	| Dst | max
10 January 1976	164 nT
27 August 1978	242 nT
26 July 1979	82 nT
13 July 1982	338 nT
21 September 1982	228 nT

Figure 1 illustrates the storm of 10 January 1976 (sc: 0620 UT). At Tucuman a negative effect is observed from a few hours after sc (0220 LT) until around 16 LT on storm day, followed by a positive ionospheric effect during the first hours of the next day. There follows new negative storm, which remains for around 24 hours. At Okinawa a fluctuating small positive storm effect is observed from before sc (1520 LT), which stays during the entire storm period. At both stations, foF2 increases in the local afternoon on the day of the storm. The initial response at Tucuman is in agreement with the average behaviour. Also, the negative effect observed after the positive storm at afternoon-early morning sector. However, the slightly enhanced foF2 values observed at Okinawa on the storm day and during the two following days disagree with the expected structure. Thus, a hemispheric asymmetry is observed.

Figure 2 shows the differences for the storm of 27 August 1978 (sc: 0246 UT). Enhanced values at Tucuman are seen from the sc (2246 LT on 26 August) and throughout the two following days. At Okinawa, dfoF2 data increase from negative values in response to sc (1146 LT) and a small positive effect is produced from around 18 LT on the storm

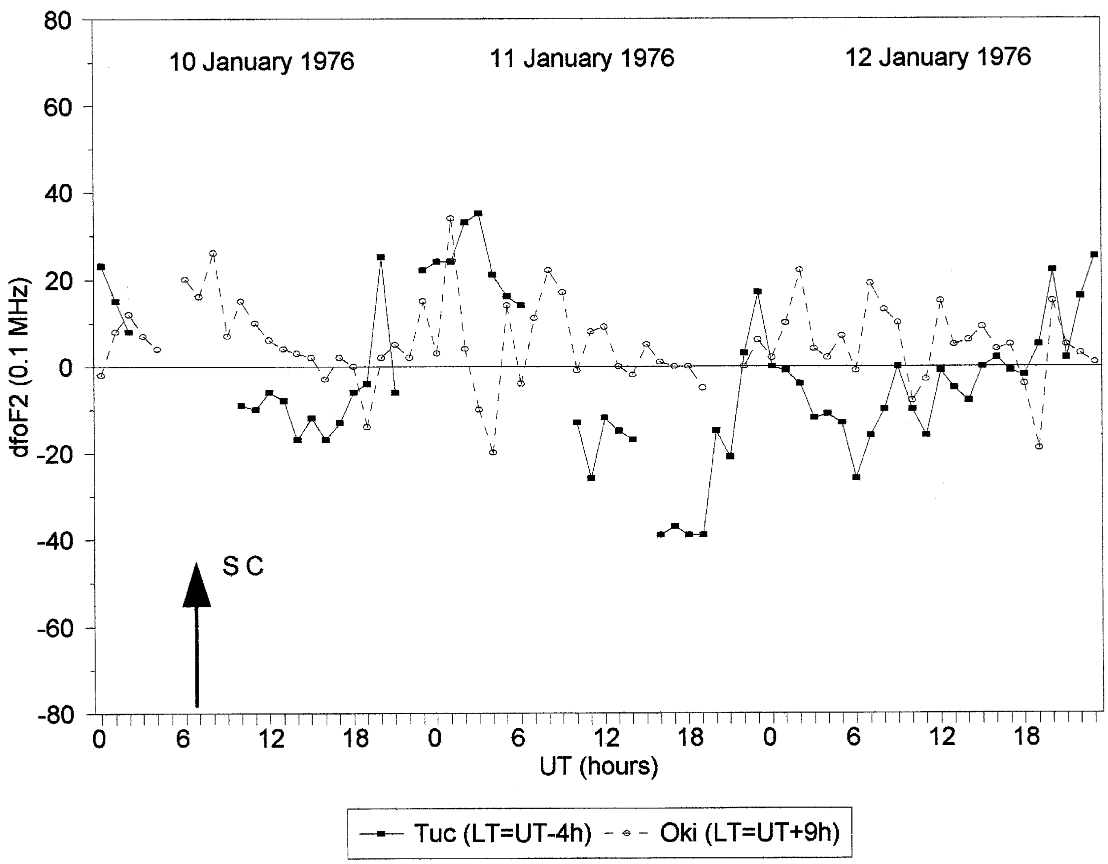

Fig. 1. Evolution of dfoF2 at Tucuman and Okinawa during the geomagnetic storm of 10 January 1976.

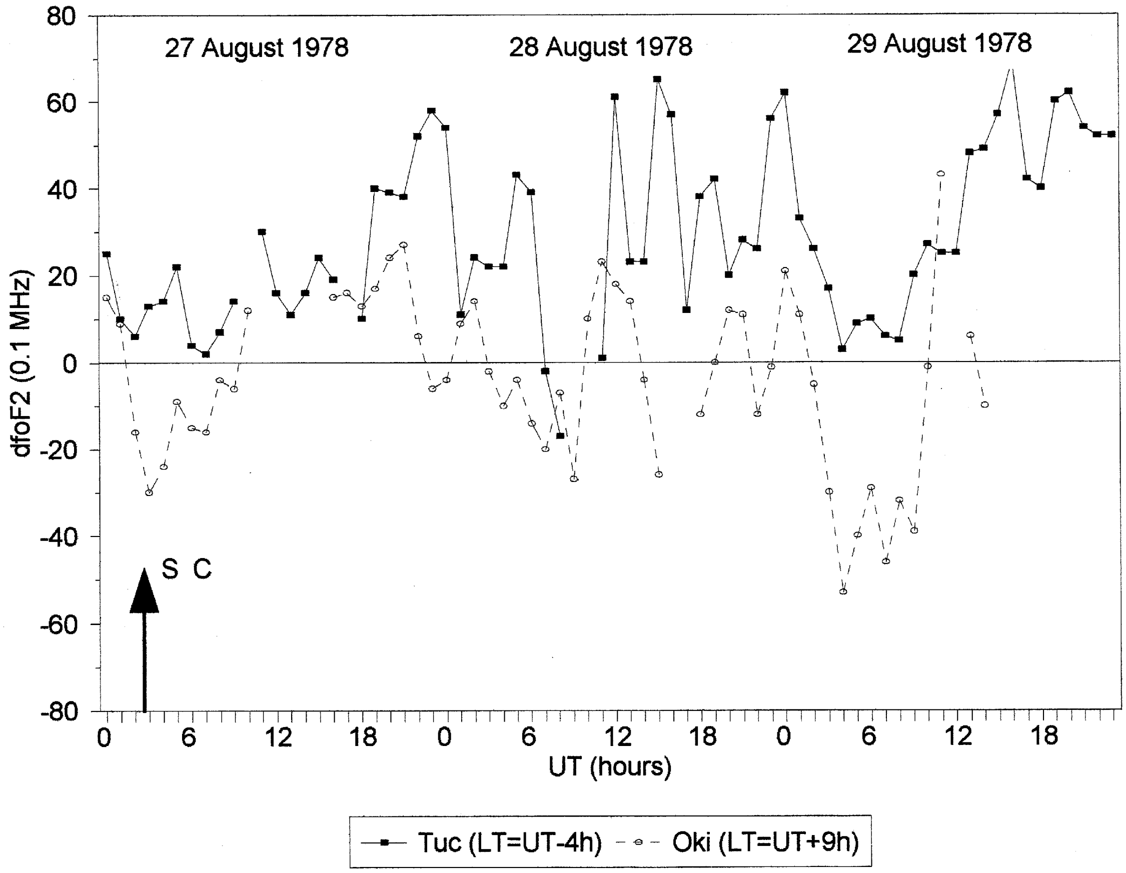

Fig. 2. The same as Figure 1 but for the storm of 27 August 1978.

day to noon on the next day. After that, an irregular behavior with prevalent small negative values until around afternoon on 29 August is observed. The increase of ionization density at the crests of the equatorial anomaly on the day of commencement of the storm is more conspicuous in the winter hemisphere, in opposition with average behavior. In the winter hemisphere, the deviations from the pattern are also observed on the two days after sc.

Figure 3 presents dfoF2 data at Okinawa only, during the storm period of 26-28 July 1979 (sc: 1833 UT). Increased values of foF2 are observed before sc (0333 LT on 27 July). A decrease begins around 1-1.5 hours after sc causing a small negative storm effect during 6 hours; at about 16 LT a considerable positive ionospheric effect begins, which remains with oscillations during the two following days. Globally, this behavior is in clear opposition with the normal pattern.

Data from the magnetic storm of 13 July 1982 (sc: 1617 UT) are shown in Figure 4. At Tucuman increased values of dfoF2 are seen almost for the entire storm period. There is no data from 20 LT on 13 July to 06 LT on 14 July. At Okinawa, also with missing data, negative values of dfoF2 are seen after sc (0117 LT on 14 July) until around 08 LT on 15 July when a fluctuating positive effect begins. This was the largest storm of solar cycle 21; however the ionospheric perturbation observed at Okinawa on 14 July coincides with the average. The pattern at Tucuman, in the winter hemisphere, differs from normal resulting in a hemispheric asymmetry of the crests of ionization.

Figure 5 shows dfoF2 data during the storm period of 21-23 September 1982 (sc: 0339 UT). Storm effects observed at Tucuman are presented separately. A positive fluctuation is produced in response to the onset of the storm, which lasts until local midnight on 21 September, followed by an irregular negative storm effect. From around local night on 22 September positive values are seen again.

DISCUSSION AND CONCLUSIONS

The ionospheric F2-layer at stations located at latitudes of the crests of the equatorial anomaly shows deviations and clear contradictions from the average pattern thus confirm the uncertainty of the model. The behavior observed at both stations in winter is in opposition with the established qualitative ionospheric structure.

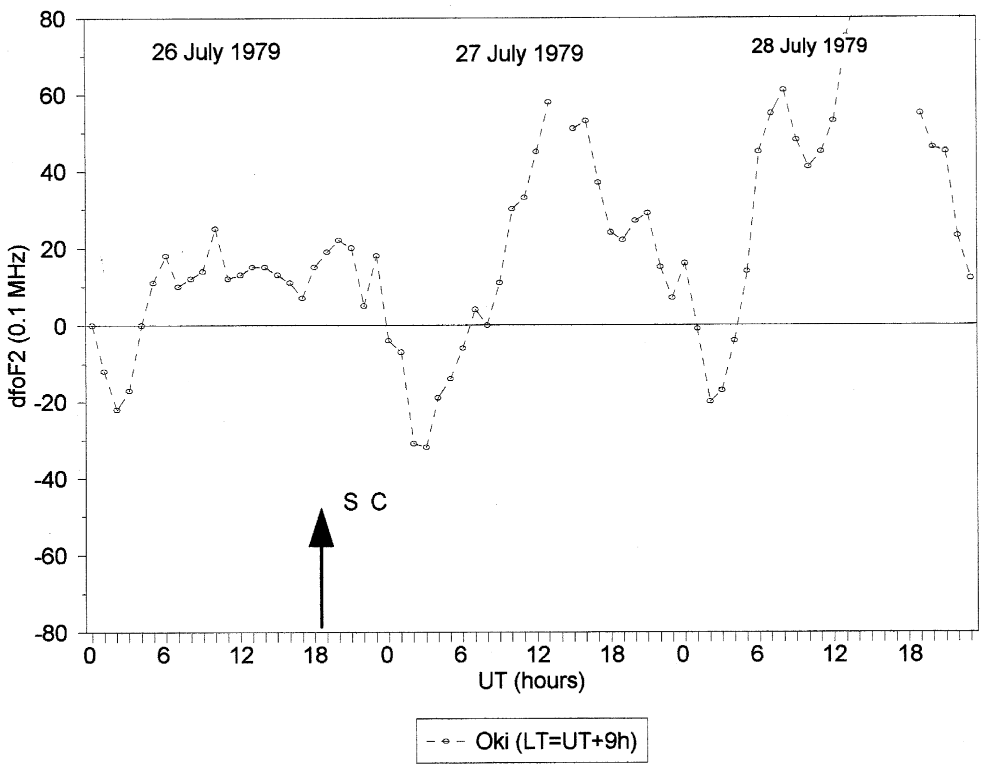

Fig. 3. The same as Figure 1 but for the storm of 26 July 1979.

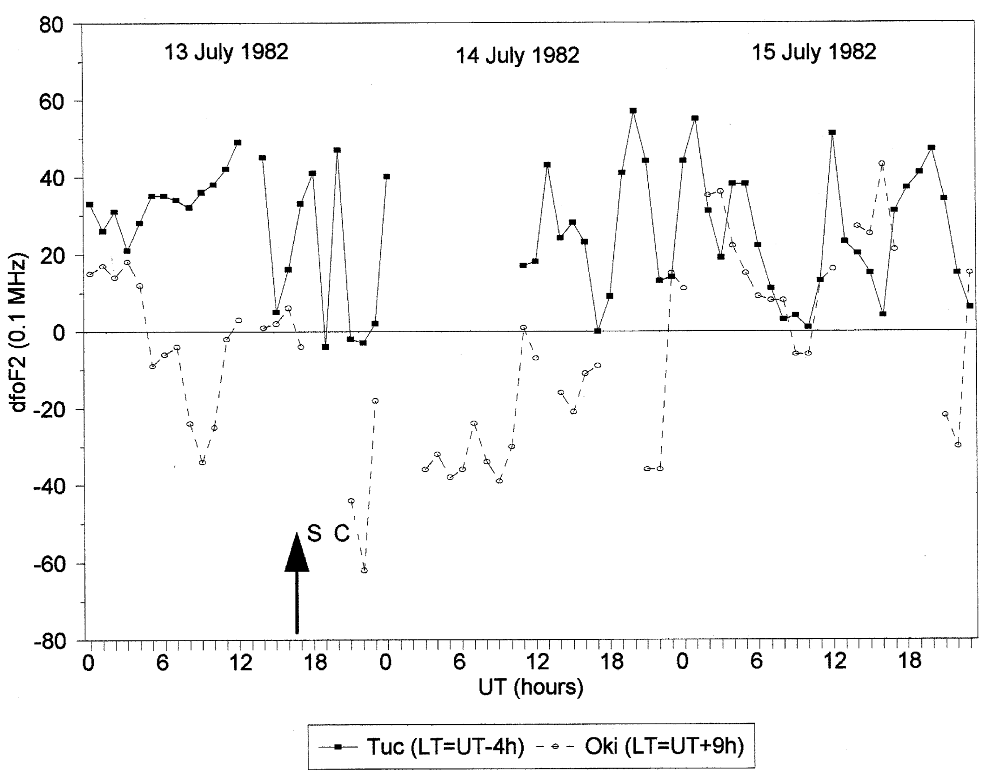

Fig. 4. The same as Figure 1 but for the storm of 13 July 1982.

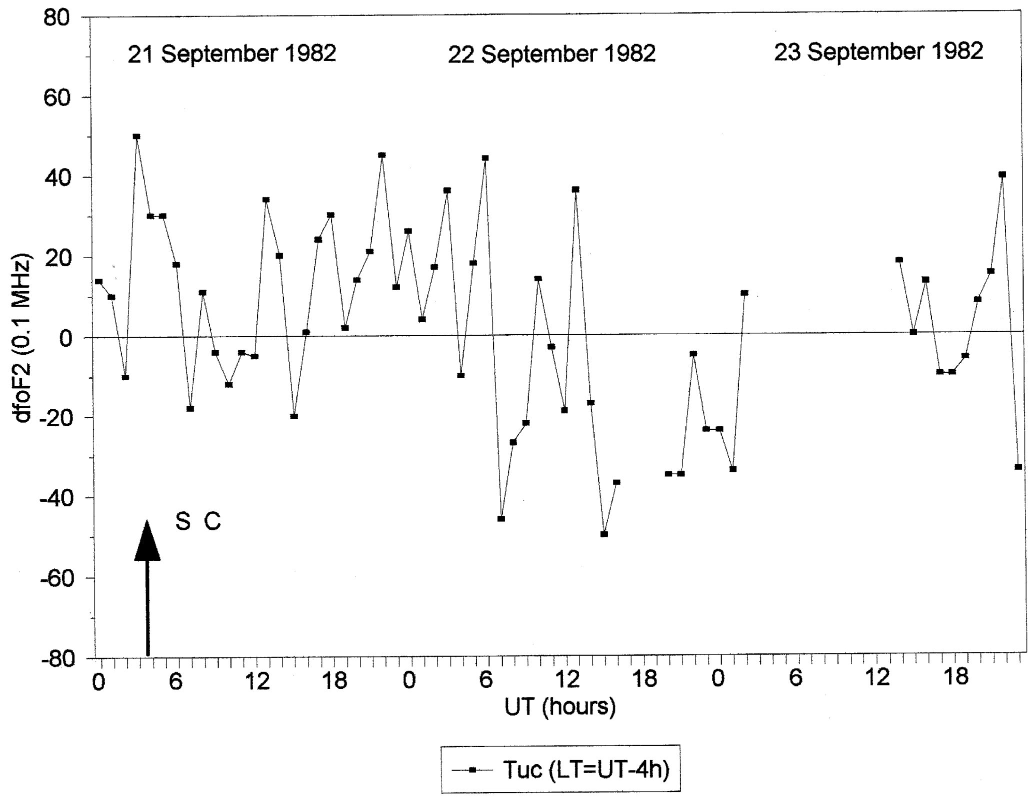

Fig. 5. The same as Figure 1 but for the storm of 21 September 1982.

The ionosphere shows an individual behavior during each geomagnetic storm, but some features in the ionospheric structure of the crests of the equatorial anomaly may be useful for the improvement of the qualitative mean model. These features may be summarized as follows.

(a) When the onset of the storm was around local noon, enhanced values of foF2 have been initially observed on the storm day until night, both in the summer and winter hemispheres, followed generally by a negative effect of variable duration.

(b) When the storm occurred near local midnight in the summer hemisphere, depressed values of foF2 have been firstly observed, remaining until noon. After that, positive storm effects were seen.

(c) Enhancement of ionization at the crests is recorded also when the onset of the storm was around midnight (Tucuman on 21 September 1982 and Okinawa on 26 July 1979). A behavior in accordance with the average is often delayed.

An electric field, and/or meridional winds, have been suggested to explain the initial ionospheric disturbances observed on the first stage of the geomagnetic storms. The latter one is also responsible for the appearance of delayed negative effects.

Ionospheric storm effects observed when the sudden commencement occurs around local noon require the existence of a fairly rapid mechanism such as an electric field (Okinawa on 10 January 1976 and 27 August 1978; Tucuman on 13 July 1982). Thus, the initial positive ionospheric effects may be explained in terms of movements of ionization produced by electric and magnetic fields. At daytime, a dawn-dusk electric field in conjunction with the geomagnetic field causes a drift of ionization from a region where the loss rate is greater into a region where the loss rate is lower. The rapid ionospheric response to cs of storms supports this assumption. An additional source of ionization arises from equatorial latitudes: the enhancement of the zonal electric field during perturbed periods increases the upward drift and the subsequent drainage from equatorial region followed by the ambipolar diffusion down the magnetic field lines toward low latitudes. This effect could be also responsible for the delay and the maintenance of positive effects at the crests.

The initial negative ionospheric variations observed when the onset of the storms is near local midnight (Tucuman on 10 January 1976; Okinawa on 27 July 1979 and 13 July

1982) may be due to an intensified dusk-dawn electric field in conjunction with the geomagnetic field, which reverses the ion drift to lower altitudes where increased molecular species hasten the ion decay.

Positive ionospheric storm effects have been observed when the sudden commencement is produced at night (Tucuman on 27 August 1978). This may be attributed to the plasmasphere. Under certain conditions an increase in the downward drift of ionization at night due to an electric field would imply an increase in the depletion of ionization from the plasmasphere to feed the F2 layer.

The initial positive effects are not likely to be due to winds flowing from high to low latitudes, because these winds prevent the transport of ionization along the magnetic field lines. They hinder the formation of the equatorial anomaly and generate negative storm effects at the crests. However, the negative effects seen in the first phase of storms are not produced by equatorward winds since these storm effects should be considerably delayed from the commencement of geomagnetic storms. It takes a few hours before the winds developed by the storms reach low latitudes.

Delayed positive ionospheric storms have been attributed to changes in neutral gas composition (Chandra and Stubbe, 1971; Mayr *et al*., 1978; Rishbeth, 1991). The storm-induced circulation transports air rich in atomic oxygen from higher latitudes toward lower latitudes. The enhanced oxygen density will affect the ionization production, thus producing the positive effects.

There is some agreement that the negative ionospheric storms are caused by an increase in the molecular gases and a decrease in the atomic oxygen density (increase in the N_2/O ratio). The compositional changes are associated with storm-induced winds. The negative effects are usually delayed, suggesting that they are produced by neutral winds since several hours are required between the generation and arrival at low latitudes of these winds. They promote or substitute the initial effect of an electric field.

In conclusion, our results support the need to improve the model of behavior of the ionospheric structure at the crests of the equatorial anomaly, and also at the trough because significant differences with the accepted qualitative model are observed.

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