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Behaviour of the ionospheric F2-layer during geomagnetic storms in southern middle latitudes

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RESUMEN

En este trabajo se estudia el comportamiento de la capa F2 durante dos tormentas geomagnéticas usándose valores horarios de NmF2 y h'F2 de cuatro estaciones del hemisferio sur. Los resultados muestran grandes incrementos en NmF2 y h'F2 durante días perturbados respecto a las medianas mensuales. Se sugiere que la deriva hacia arriba del plasma ionosférico es debida a un campo eléctrico de dirección este de origen magnetosférico, durante el primer día de la tormenta. En días subsiguientes, los vientos termosféricos juegan un papel importante durante la fase positiva de las tormentas.

PALABRAS CLAVE: Capa F2, tormenta geomagnética, campos eléctricos, vientos termosféricos.

ABSTRACT

Hourly values of NmF2 and h'F2 from South American stations were used to study the behavior of the ionosphere during geomagnetic storms. The results show a remarkable increase in NmF2 and h'F2 during perturbed days (by a factor of 2) with respect to the monthly median. It is suggested that the upward drift of plasma is produced by an eastward electric field of magnetospheric origin during the first day of the storm. Thermospheric winds play an important role during the positive phase of the storm.

KEY WORDS: F2-Layer, geomagnetic storm, electric fields, thermospheric winds.

INTRODUCTION

Ionospheric storms are usually related to geomagnetic storms, but may also be associated with large solar flares (Garriot *et al.*, 1967; Mendillo *et al.*, 1974), and with atmospheric gravity waves (Clark *et al.*, 1971; Davis, 1973).

The changes in ionospheric parameters during a storm have been studied using different techniques, with ionosondes and Faraday rotation. Most studies have been performed in the northern hemisphere and there is little information on the southern hemisphere, particularly for South America. The F-region in mid-latitudes in the northern hemisphere during typical summer storms often shows an increase in maximum electron density on the first day, followed by a sharp decrease with respect to quiet days on the following (Hibberd and Ross, 1967). In winter increases in maximum electron density are observed only.

We describe the behaviour of the maximum electron density in the F2-layer, NmF2, and the height h'F2 during the geomagnetic storms of July 13 and December 10, 1982 using data from four ionospheric stations in Argentina. The NmF2 and h'F2 values on the day of the storm and following days are compared to monthly medians at each station.

EXPERIMENTAL DATA

Hourly values of foF2 and h'F2 from ionosondes were obtained at four stations (see Table 1 for geographical locations).

Table 1

Ionospheric stations	latitude, degrees	longitude, degrees
Tucumán	-26.9	-65.4
San Juan	-31.5	-68.5
Buenos Aires	-34.5	-58.5
Ushuaia	-54.8	-68.3

The maximum electronic density values of NmF2 were calculated from foF2 values using:

$$NmF2=0.0124\ (foF2)^2 \cdot \qquad (1)$$

Both storms had a sudden onset (SC). The first storm began on July 13, 1982 at 1617 UT; its Kp addition reached 144 on the day of the storm and 153 on the following day. The second storm began on December 10, 1982 at 0722 UT; its Kp addition reached a value of 36. The ionospheric parameters were obtained on the day of the storm and two days after the SC.

These two storms had different times of sudden commencement: 1217 LT and the second at 0322 LT. We wish to determine whether the time of onset is relevant for a short range of geographical longitudes. The first storm began a few days after the beginning of winter and the second just before the southern summer.

OBSERVATIONS

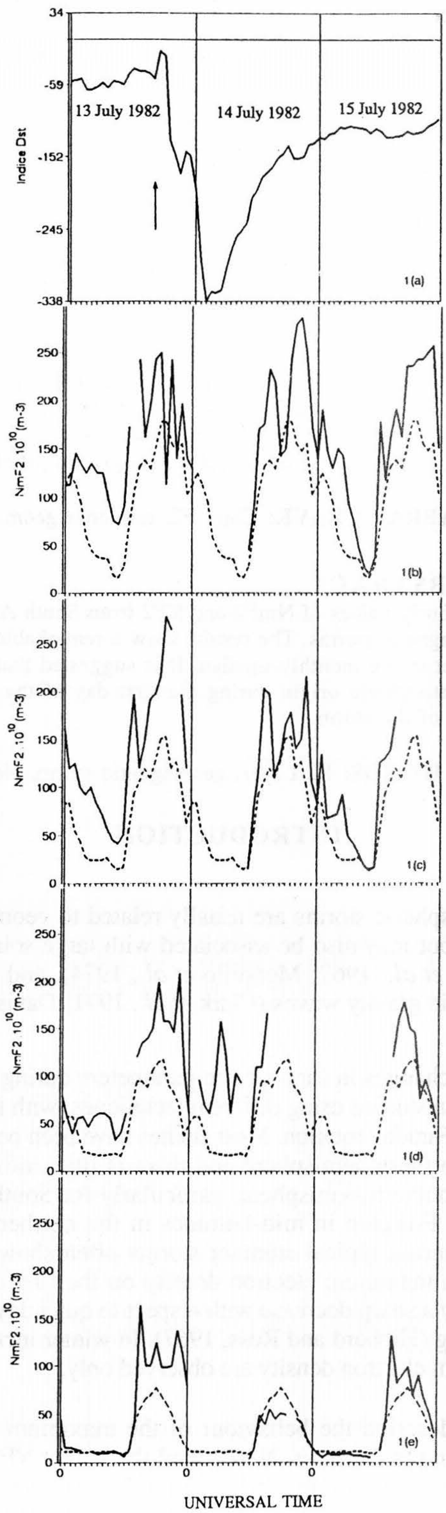
Figures 1(a-d) show the Dst and NmF2 values at Tucumán, San Juan, Buenos Aires and Ushuaia for the storm of July 13, 1982. The dotted line is the monthly median of NmF2 and the arrow shows the SC value. All four stations feature positive phases (NmF2 values higher than the monthly median) on the day of the storm. The NmF2 values are twice the monthly median. Only Ushuaia shows a negative phase (NmF2 values below the monthly median) of seven hours duration (1500 UT to 2200 UT) on the day following the onset of the storm (July 14th). All four stations show a maximum before the storm, between 1200 UT and 1500 UT. There is a gap in the data at Buenos Aires but the tendency up to 1200 UT suggests a maximum. The response to SC is delayed by about two hours with respect to the onset; at all stations the response is more or less simultaneous (at 1800 UT). There is a minimum at three stations between 1900 and 2100 UT, followed by a maximum at 2200 UT at Tucumán, Buenos Aires and Ushuaia. On the days following the SC the recovery of normal values is very slow.

Figures 2a, 2b and 2c show the heights of h'F2 at Tucumán, San Juan and Buenos Aires (there is no information for Ushuaia). The dotted line represents the monthly median and the arrow the sudden onset. Observe that all stations show an increase in h'F2 at approximately 1800 UT, with a fluctuation of more than 90 km from the monthly median in Tucumán, which agrees with the first NmF2 maximum. There is a rapid return of h'F2 to normal values which shows values below the average on the day after the SC especially at Tucumán and San Juan. The increase of h'F2 is due to a group delay of the wave below the reflection height. The actual rise of the F2-layer is smaller, as determined from Bradley and Dudeney (1973); it should be considered as a qualitative measure of the perturbation only.

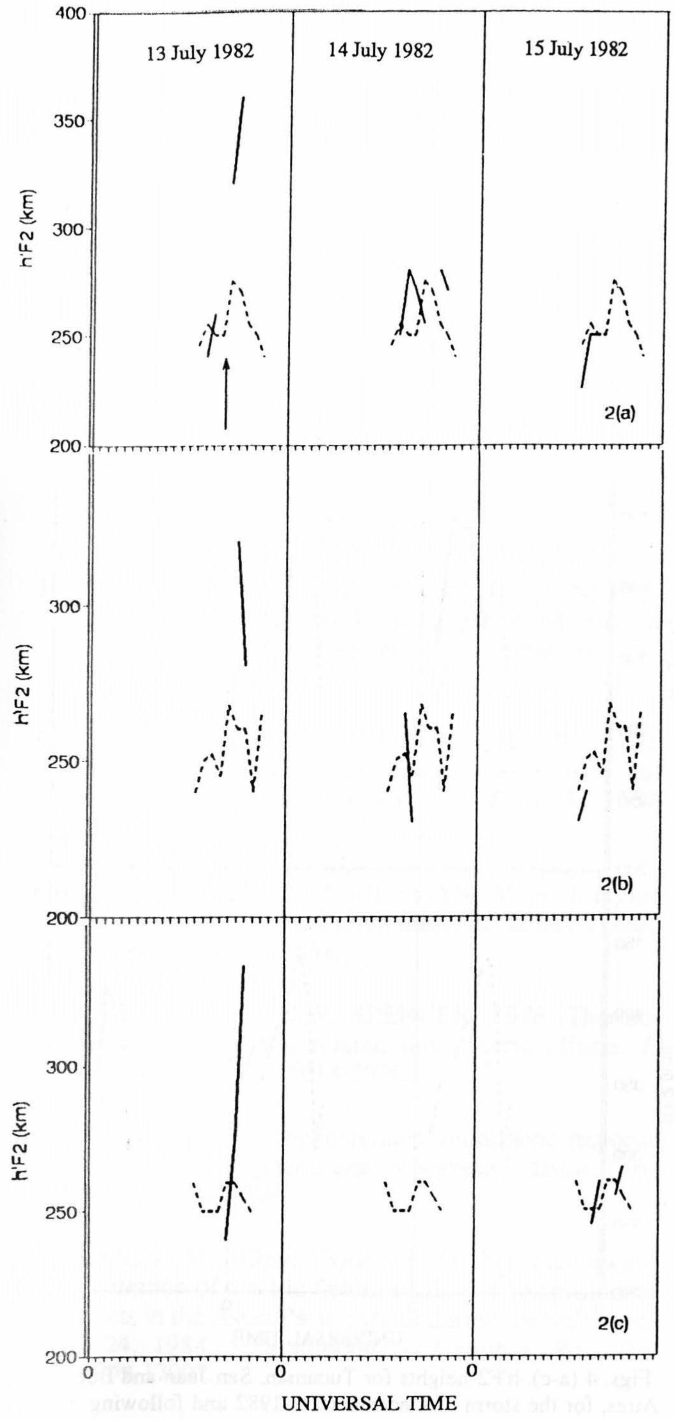
Figures 3 (a-d) show the Dst and NmF2 values at Tucumán, San Juan and Buenos Aires, for the storm of December 10, 1982 and following days. There is no information at Ushuaia for that period. In the night-time two of the stations (Tucumán and Buenos Aires) show a negative phase before the SC. Again, the response to the storm SC is delayed. As before, NmF2 decreases to a minimum value between 0900 and 1000 UT followed by two maxima more or less simultaneously between 1600 and 1700 UT, and at 2100 UT.

Figures 4 (a-c) show the h'F2 heights. There is no information for Buenos Aires on the day of the storm, but at Tucumán and San Juan the maximum occurs at 2000 UT and the preceding minimum, between 1600 and 1700 UT. This h'F2 minimum agrees with the first NmF2 maximum following the SC. The second NmF2 maximum agrees with the last minimum observed for h'F2.

During the first storm NmF2 values decay with increasing latitude to a minimum between 08000 and 1100 UT followed by a maximum between 1900 and 2300 UT. Peak NmF2 deviations from the monthly median occur during daytime. The positive phase of the storm tends to be longer and more prominent at lower latitudes. These results agree with those obtained by Matsushita (1959).



Figs. 1 (a-d). Dst index and NmF2 values for Tucumán, San Juan, Buenos Aires and Ushuaia, for the storm of July 13, 1982 and following days. Dotted line, monthly median of NmF2.



Figs. 2 (a-c). h'F2 heights for Tucumán, San Juan and Buenos Aires for the storm of July 13, 1982 and following days.

The second storm does not show these variations with latitude. Rather, NmF2 values are higher at San Juan where the peak deviations from monthly median are observed. The positive phase of this storm is less prominent than for the storm in July, perhaps because of its lower intensity.

Both storms have peak NmF2 values after local noon, especially on the day following the SC. However, positive phases do not always occur. They are found mainly during the winter in mid-latitudes.

DISCUSSION

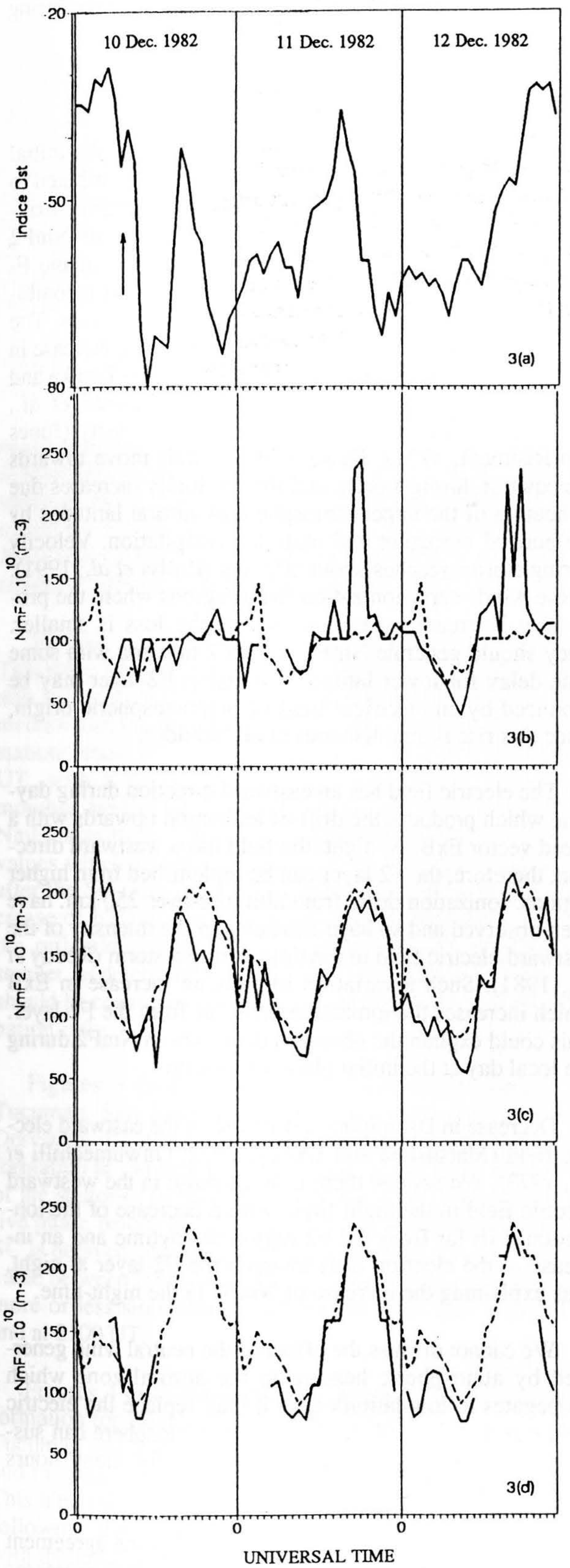
The steady increase in the Dst index during the initial phase of the storm (Figures 1a and 3a) may be attributed to compression of the magnetosphere by solar plasma arriving to the magnetopause. The positive phase of NmF2 (Figures 2 and 4) is produced by the uplifting of the F-layer. As the ionization reaches regions with less recombination (loss), there is an increase in electron density. The upward motion of the F2 layer and the resulting increase in ionization might be produced by electric fields (Tanaka and Hirao, 1973; Lanzerotti *et al.*, 1987; Jakowski *et al.*, 1992), or by southern winds of moderate intensity (Jones and Rishbeth, 1971). These neutral winds move towards the equator during storms and their velocity increases due to heating of the upper atmosphere at auroral latitudes by the auroral electrojet and particle precipitation. Velocity during storms reaches about 500 m/s (Prölss *et al.*, 1991). These winds carry ionization from regions where the production is greater to regions where the loss is smaller. They should generate NmF2 and h'F2 maxima with some time delay for lower latitudes. A rising F2-layer may be produced by an electrical field of magnetospheric origin, since this rise is simultaneous at all latitudes.

The electric field has an eastward direction during daytime which produces the drift of ionization upwards with a speed vector ExB. At night, the field has a westward direction; therefore, the F2-layer can be replenished from higher regions. Ionization drifts from altitudes over 250 km. have been observed and so have increases in the intensity of the eastward electric field in daytime during a storm (Reddy *et al.*, 1981). Such a variation implies an increase in ExB which increases the ionization drift, far from the F2-layer. This could explain the observed decreases in NmF2 during the local day at the initial phase of a storm.

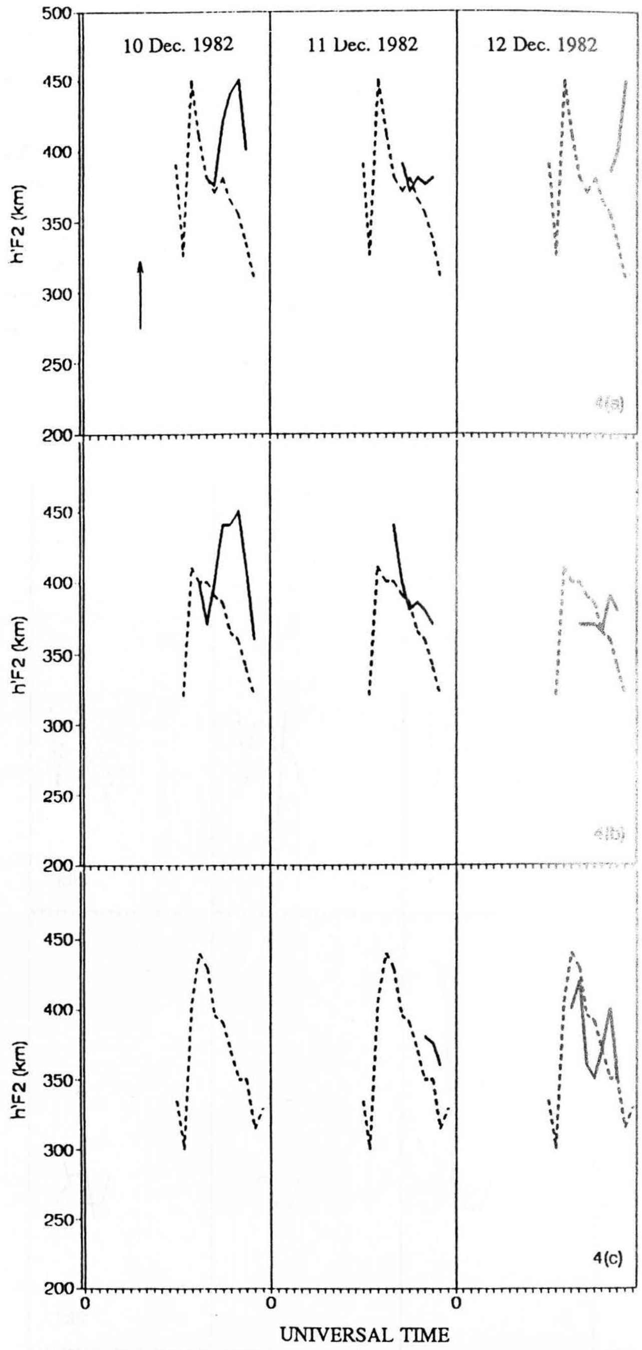
Decrease in Dst implies a decrease in the eastward electric field (Matsushita and Basley, 1972; Onwumechilli *et al.*, 1973). We assume there is an increase in the westward electric field in the night-time, with a decrease of the ionization drift far from the F2-region at daytime and an increase in the electron drift towards the F2-layer at night, thus explaining the increase of NmF2 in the night-time.

We cannot dismiss the effect of the neutral wind generated by atmospheric heating in the auroral zone which propagates to low latitudes, as it may replace the electric field effect. It is unlikely that the magnetosphere can sustain an electrical field on a large scale for many hours (Prölss *et al.*, 1991).

On negative phase, there seems to be some agreement that it is generated by a higher loss of O+ which increases N_2 and O_2 densities (Chandra and Herman, 1969; King, 1971; Mayr and Voland, 1972; Hays *et al.* 1973; Jaccia *et al.*, 1976; Hedin, 1988; Burns *et al.*, 1989). Both changes would lead to a decrease in the ionization density of the F–



Figs. 3 (a-d). Dst index and NmF2 values for Tucumán, San Juan and Buenos Aires, for the storm of December 10, 1982 and following days. Dotted line, monthly median.



Figs. 4 (a-c). h'F2 heights for Tucumán, San Juan and Buenos Aires, for the storm of December 10, 1982 and following days.

layer (Prölss and Von Zahn, 1974; Chandra and Spencer, 1976; Hedin *et al.*, 1977; Mayr *et al.*, 1978; Titheridge and Buonsanto, 1988; Forbes, 1989). There is direct evidence of changes in composition during storms: N_2 density may increase by a factor of 10 and O_2 by a factor of 5 with respect to quiet values in lower latitudes (Reber *et al.*, 1973).

CONCLUSIONS

The ionosphere disturbed by a geomagnetic storm has several features. During a winter storm (July) NmF2 maximum electronic density decreased as latitude increased. The respective monthly median showed a similar behaviour. In order to explain the positive phase on the day of the storm we assume the presence of an eastward electric field which caused the F2-layer to rise.

In the night following the SC the electrical field may change to westard, thus producing the decrease in NmF2 height. Neutral thermospheric winds in F2 cannot be excluded to account for the positive phases. However, such winds lack a rapid response as electric fields do.

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