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Negative phases at South-American stations during magnetic storms

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RESUMEN

Serán analizados datos ionosféricos de tres estaciones sudamericanas (en latitudes alta, media e baja) durante eventos de tormenta magnética en los cuales se observa la ocurrencia de fases negativas en foF2.

Es bien sabido que la causa de las fases negativas en altas latitudes está en la mudanza de la razón entre las concentraciones de los constituyentes atómicos y moleculares de la atmósfera neutra. En este trabajo vamos a estudiar qué ocurre en latitudes medias y bajas. Para esto, vamos a simular, usando el modelo ionosférico-termosférico FLIP (Field Line Interhemispheric Plasma), las mudanzas en la razón [O]/[N_2] que reproducen las observaciones en las tres localidades.

Se encuentra que, en altas latitudes, todas las fases negativas son bien explicadas por mudanzas en la razón [O]/[N_2]. Pero, si la latitud disminuye, comienzan a aparecer otras causas para las disminuciones de foF2: en medias latitudes, donde la influencia de los vientos sobre el pico de la capa F2 es predominante, el paso de ondas de gravedad explicarían fases negativas de corta duración, y en bajas latitudes, los vientos termosféricos perturbados causarían desvíos temporales de los padrones normales de foF2 provocando fases positivas y negativas alternadas.

PALABRAS CLAVE: Ionosfera, tormentas magnéticas, fases negativas.

ABSTRACT

Ionospheric data at three South-American stations (in low, mid and high latitudes) show negative phases in the high latitude location during magnetic storms. The negative phases in foF2 are caused by changes in the ratio between atomic and molecular concentrations of the neutral atmosphere.

We find that at high latitudes the negative phases are well explained by the [O]/[N_2] rate changes. As the latitude decreases, as the wind influence on the F2 layer peak is dominant, the propagation of gravity waves can explain short-lived negative phases. In low latitudes, disturbed thermospheric winds can cause time delays in the normal pattern of foF2, creating alternating positive and negative phases.

KEY WORDS: Ionosphere, magnetic storms, negative phases.

INTRODUCTION

Dynamical coupling of the ionosphere-thermosphere system during magnetic storms is a scientific problem because of intense perturbations in the system.

The vertical distribution of neutral constituents of the upper atmosphere in the polar region is affected by dissipation of energy from the solar wind. This energy may produce heating and atmosphere expansion, even in calm magnetic conditions. Thus, an atmospheric region presents an increase of molecular concentrations characteristic of low elevations, and a decrease of atomic concentrations characteristic of the ionospheric F region [Prölss, 1977].

When the conditions are perturbed, the region of compositional changes forms convection cells that reach, eventually, low and equatorial latitudes. Due to thermal expansion of the upper neutral atmosphere in high latitudes, the molecular species reach higher elevations and settle down as cells rich in N_2 in the ionospheric F region [Prölss, 1977]. These air cells move and expand in latitude and longitude due to the propagation of perturbed winds patterns, gravity waves and the Coriolis effect.

In terms of the photochemical balance, the F2 density peak depends on the ratio between the concentrations of atomic and molecular constituents [Prölss, 1995]:

$$\text{Nmax (foF2)}=[O]/[N_2] \ . \qquad (1)$$

In magnetic storm, the ratio [O]/[N_2] decreases and negative phases in the ionospheric density appear. We study the negative phases during storms in several latitudinals sectors on the South American continent. We use 7 events observed at a net of 4 stations located in high, middle, low and equatorial latitudes (Tables 1 and 2). Using ionospheric simulation, we obtain information on the changes in the neutral atmosphere at high latitudes and the displacement of such changes at lower latitudes during interference conditions.

Table 1

Ionospheric stations

Station	Code	Geographic Coordinates		Dip angle
Fortaleza	FZ	4° S	38° O	-8.3 °
Cachoeira Paulista	CP	23° S	45° O	-30.4 °
Concepción	CON	37° S	73° O	-37.1 °
King George Island	KGI	62° S	59° O	-56.5 °

Table 2

Storm events with ionosperic negative phases

Month/year	SSC(LT in IRJ)
09/86	1500
10/86	1300
11/86	2000
04/89	—
05/89	1100
09/89	0700
10/89	0500

METHODOLOGY

The ionosphere response will be initially obtained from changes in the neutral atmosphere. We use the FLIP (Field Line Interhemispheric Plasma) model; this 1-D inter-hemispheric model simulates the ionospheric-thermospheric dynamics by solving the conservation equations (energy, momentum and electron flux) along the magnetic field lines. FLIP gives main neutral and ionic constituents and uses the method of Richards [1991] to obtain meridional magnetic thermospheric winds. With FLIP outputs, we obtain Nmax, and the foF2 ionospheric parameter.

FLIP incorporates the MSIS model in order to describe the neutral atmosphere. We modify the output values of MSIS during execution of FLIP, by multiplying for several values of the R factor,

$$R = ([O]/[N_2])_{storm} / ([O]/[N_2])_{calm} \quad . \qquad (2)$$

The R factor depends on the relative variations of [O] and [N_2] in storms and calm periods. First, we modify [O] and [N_2]. Later, we simulate the neutral atmosphere for every storm day. MSIS is coupled to FLIP and, if we use the perturbed daily magnetic activity indexes, the neutral atmosphere will already be perturbed by the increase of energy in the atmosphere. In order to obtain the change from calm conditions, we begin by modeling the neutral atmosphere and use the indexes of magnetic activity of calm days to find the new configuration of the ratio [O]/[N_2] that describes foF2 changes.

Tests were done with the FLIP model, by assuming independent variations of the concentration of the neutral constituent. Concentrations of O and N_2 were perturbed in relation to the MSIS values. Next, the FLIP model was executed in CON and IRJ using the hmax data for storms and calm days. We found that the simulations produced quite similar effects in foF2: the negative phases in foF2 could be reproduced by either diminishing [O] or increasing [N_2] by a reciprocal factor. However, the effect of increasing [O] is different from that of diminishing [N_2]. The value of foF2 is more sensitive to [O] increase, because of differences in the reaction times. There is a more sensitive chemistry to [O] changes.

As [O], foF2 and hmax increase or decrease, the thermospheric winds blow toward, pole or the equator. Conversely, as [N_2] decreases or increases the winds blow toward the pole or the equator. The hmax changes are, in general, small. A similar effect occurs with wind perturbation.

The response to the ionospheric parameters foF2 and hmax is proportional to the concentration changes of the neutral atmosphere components. CON deviations in foF2 are more important that IRJ for the same changes in concentration. If the concentrations diminish, the effects are noticed during the day-time (between 0600 and 1800 UT) and if they increase, the changes are noticed at all times.

MODELING OF THE NEGATIVE PHASES

In order to determine the negative phases, we compare foF2 in storm days with the mean of the five calm days of every month (see Figures 1 and 2). When the ratio between the perturbed values and the calm values of foF2 is negative, we have a ionospheric negative phase.

From the events of Table 2, we find negative phases at IRJ, a station at high latitude. Depending on the event, a negative phase is observed also at lower latitudes, such as to CON and/or CP.

The features of the negative phases in each latitude region are different (see Figures 1 and 2). At IRJ, foF2 remains below the mean values all day and over several perturbed days. At CON and CP, the negative phases are usually short. They occur at the end of the day, and they show oscillatory

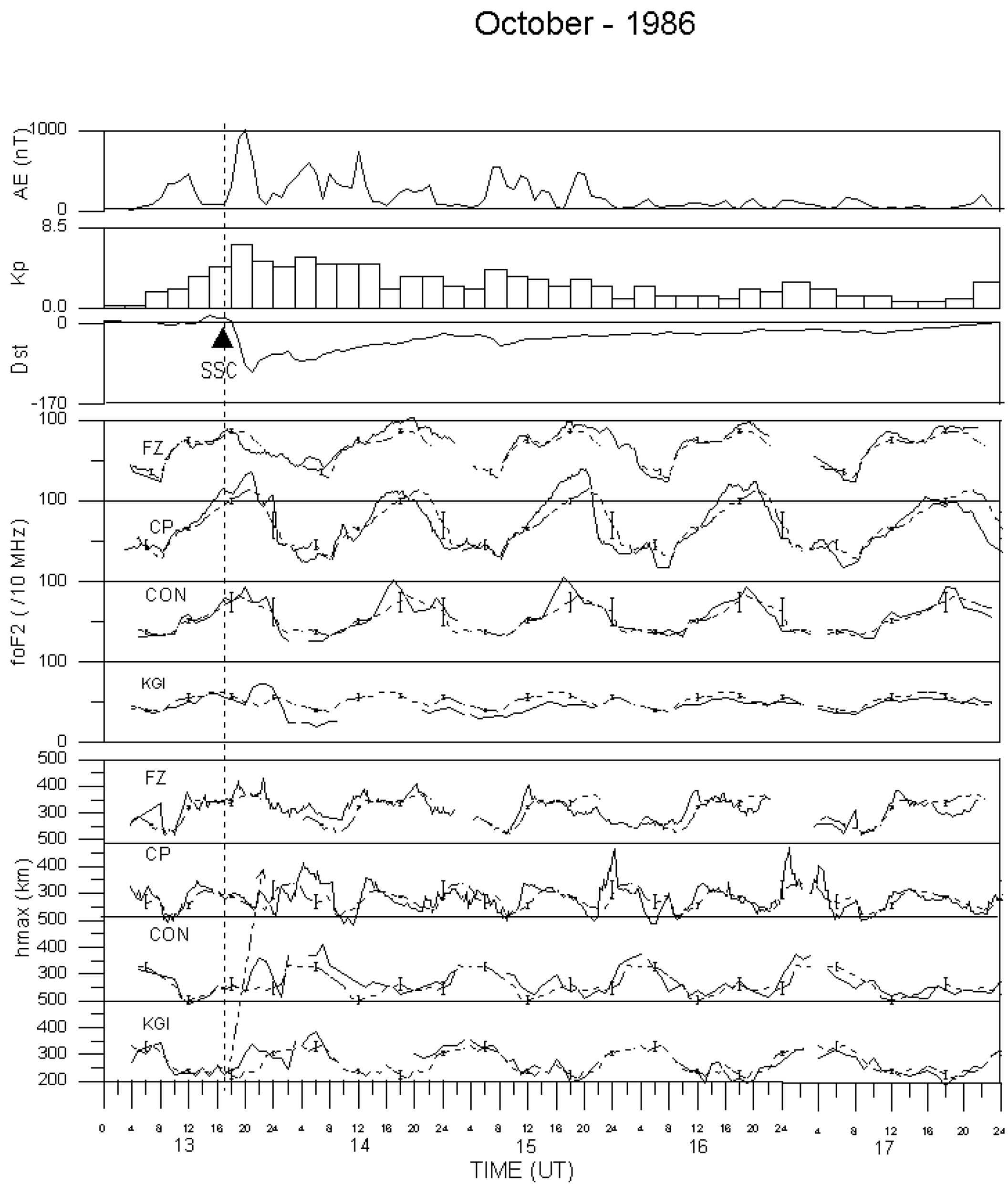

Fig. 1. Storm event of October 1986: hmax and foF2 ionospheric parameters for the four South-American stations. Dashed line shows calm data, continuous line shows storm data.

behavior preceded by positive phases. At CP the behavior of foF2 resembles a temporary deviation of the normal pattern of daily variations with alternating negative and positive phases.

RESULTS

In order to reproduce the observed negative phases, let us change the ratio $[O]/[N_2]$ by modifying [O] and keeping $[N_2]$ unchanged. This was done because few physical approaches exist for the control of simultaneous modifications of the two concentrations, as the R ratio has multiple and complex dependencies. Figures 3 and 4 show the results of negative phase simulations done with FLIP for the two storms described.

In the October 1986 event (Figure 3), CON shows negative phases of some hours duration at night. CON also shows positive phases in earlier hours. This is a TID (traveling ionospheric disturbance) propagation behavior, due to gravity wave displacement [Borba, 1993]. The FLIP simulation succeeds in reproducing the observed foF2 values but it is less successful in reproducing the shape of the curve. The daily pattern of foF2 at CP seems to have suffered a

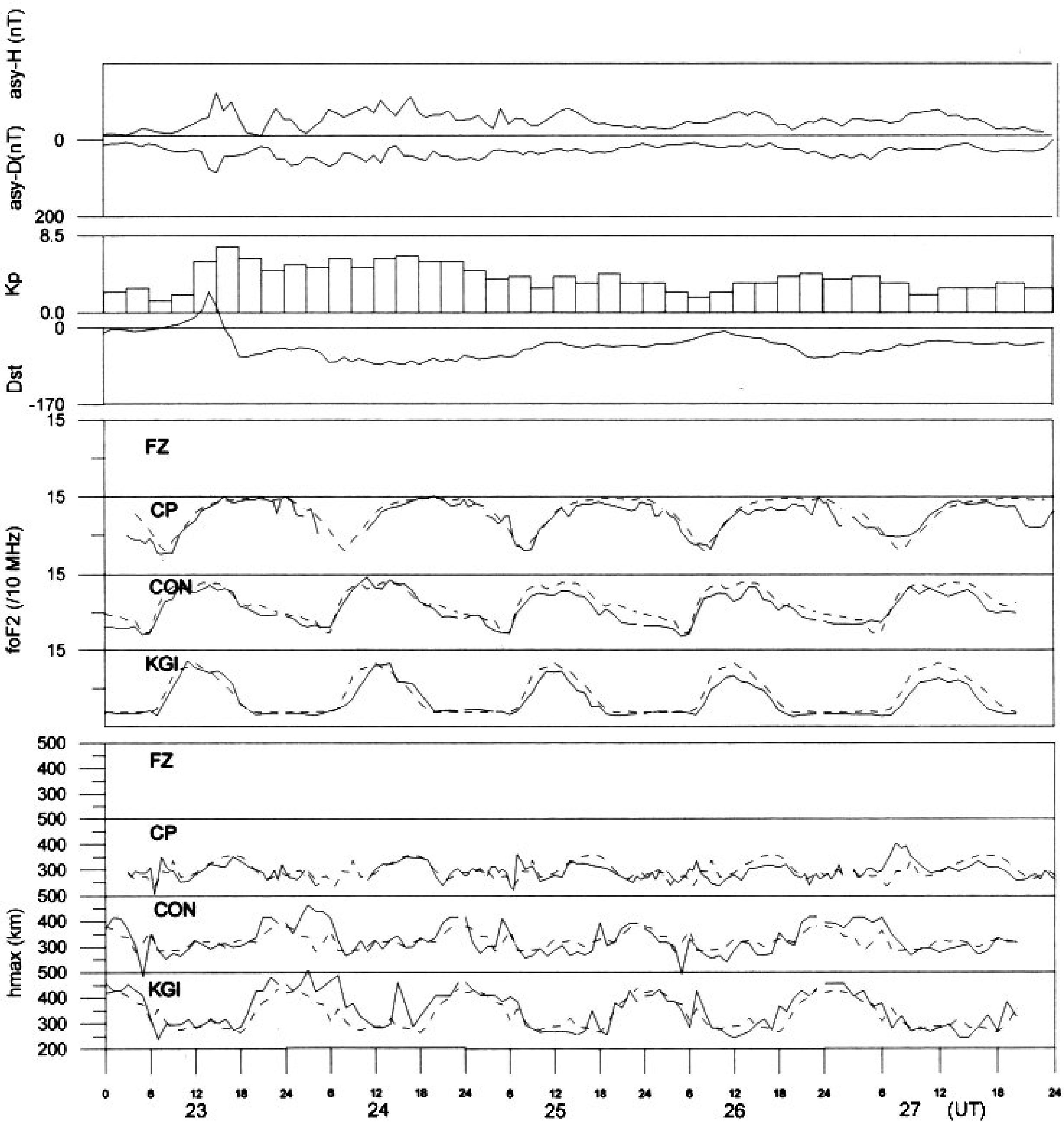

Fig. 2. The same of Fig. 1, but for the May 1989 storm.

displacement in earlier hours, when a strong wind is observed blowing toward the equator, possibly increased by zonal geographical wind. This elevates the layer and inhibits the Aeq formation. This wind does not appear at FZ and is small at CON. On the 17^{th} day a strong negative phase is observed at CP and a weak negative phase at CON and IRJ. In the model results we observe that the R value increases with local time. This is not observed during the last day of this storm at CP. But we may verify the electric field action on the hmax values.

For the May 1989 event (Figure 4), we find good agreement between FLIP and observations at all three locations. Only at CP, after the evening, there is some difference. The simulation gives values of foF2 but cannot reproduce the peak of the equatorial anomaly. Data at FZ for this event does not exist. Composition changes at CP and the negative phases at the three stations are due exclusively to changes in the neutral atmosphere.

The R values at CON and IRJ present few variations

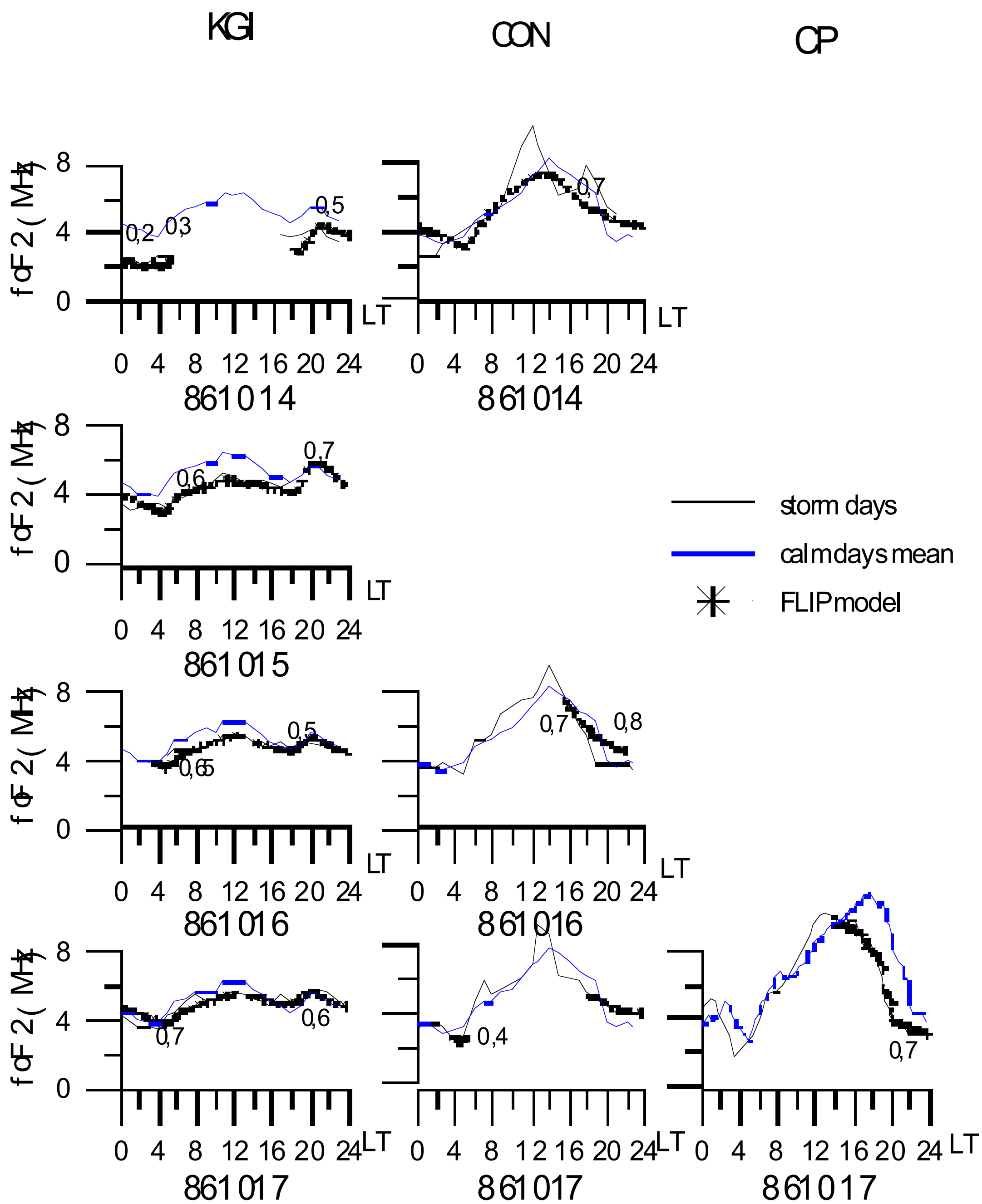

Fig. 3. Negative phase modeling results for October 1986.

from day to day and the negative phases are present at all hours of the day, as one might expect when the interference settles down in a region. When the simulation results are compared with the experimental data of foF2, the agreement is better for IRJ that for CON and CP. In the case of CP, for several days it was impossible to find R values that described the negative phase. In some cases, the decrease in foF2 is correlated with the factors that affected hmax, and not with composition changes. Only for 5 days, the composition changes explained the negative phase at CP, and then, at night, the model predicted foF2 values below the observed values. This may be due to electric field action raising the amount of ionization. The dates on which composition changes explain the negative phase at CP are: 17/10/86, 29/04/89 25-27/05/89. The dates of 17/10/86 and 29/04/89 correspond to the last perturbed day of the storm; and 25-27. May 1989 are the last three days of the storm.

In general, the agreement is good for high latitudes. This makes sense because the simulation was done

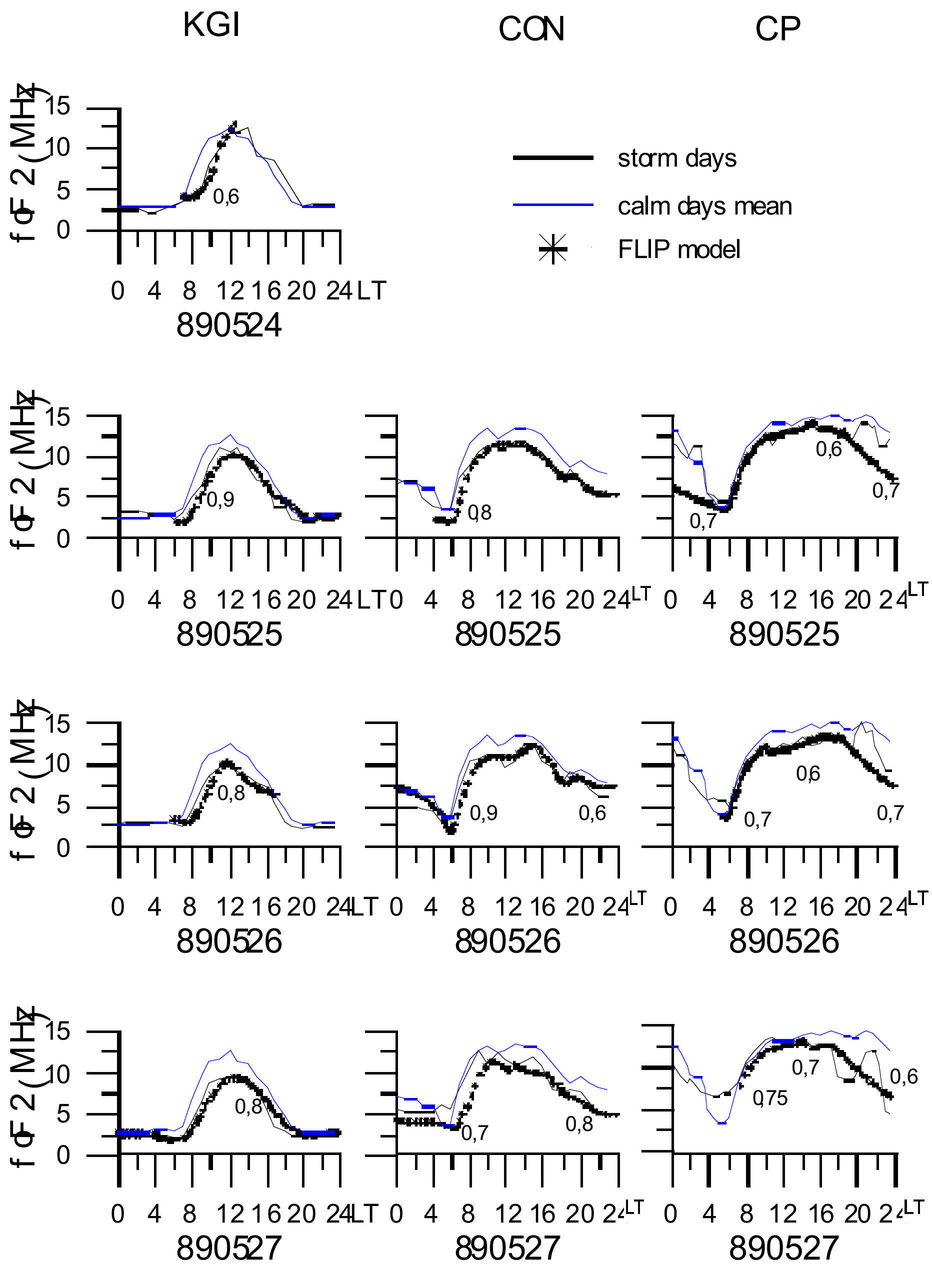

Fig. 4. Negative phase modeling results for May 1989.

considering only changes in the neutral atmosphere as the cause of the decrease in foF2. This factor becomes less important in mid-and lower latitudes.

From Prölss (1995), we know that R values can present wide variability, depending on latitude, longitude, local time, season, solar and magnetic activity, hour of storm commencement, and other factors. We know that high values of Kp are associated with more drastic decreases of R. At CON, the conditions for observing values of R less than 1 are quite limited, as the observations indicate negative phases more commonly at night. Even at CP the conditions of occurrence of $R < 1$ are limited to levels of magnetic activity, that should be very high in order to reach minor latitude regions; but other factors, including time of storm commencement and season are also involved. Simulations of the neutral atmosphere changes with FLIP provide limits of the R rate, as other factors could also contribute to the formation of the negative phases. Hence the model yields approximate values of R, characteristic of the maximum interference in the neutral atmosphere.

The R value may vary along the day. In general, R grows with time of day and with the time of the storm. This is to be expected if the perturbed conditions of the neutral atmosphere diminish. But for some high solar activity storms, R rises and falls several times during the event. For some days R remains constant. This indicates a complex dynamics in the region of composition changes, producing temporary complex variations in the negative phase intensity.

CONCLUSIONS

We use a numerical model for the analysis of the negative phases in several latitudes. The model is used with good results for high and low latitudes and it can also be used to study the neutral atmosphere changes during a magnetic storm.

Some causes of the possible effects on the ionosphere during the negative phases in foF2 formation are:

- changes in neutral atmosphere composition, especially in high latitudes and eventually also in mid-and low latitudes.

- Neutral perturbed winds: when the interference is directed toward the pole and more often when the resulting wind is blowing toward the pole, we observe negative phases at CON and CP.

- Zonal geographical wind: at CP, the magnetic declination angle is large, thus causing significant differences between the geographical equator and the magnetic equator. The zonal wind has a component along the magnetic meridian. Thus, if the zonal wind is perturbed, the magnetic wind is also perturbed, and this displaces the ionized layer vertically. A disturbance toward the west/east in the zonal wind causes a disturbance toward the equator/pole in the southern magnetic wind, and the ionosphere rises/descends. The zonal winds at CP are toward the west during the day and to the east at night. When the zonal wind blows westward and is perturbed to the west, the layer F2 rises early, accelerating the growth of the daily ionosphere and producing a deviation of the daily pattern of foF2 for earlier times. A zonal wind blowing to the east and perturbed to the east causes a deviation of foF2 to earlier times. On the contrary when the effect of the disturbance on the zonal wind is opposite to the normal behavior, the effect of the ionosphere is to delay the day pattern. This factor only acts at CP, because CON and IRJ have smaller dip angles. Yet in some days a deviation in the days pattern of foF2 is observed.

- TIDs produces negative phases in the night at CON and CP.

Finally, we conclude that all negative phases observed at IRJ are produced mainly by composition changes. At CON, the action of poleward perturbed winds, TIDs and changes in the neutral atmosphere are the most common causes. Changes in composition are the main cause for all days of the storm of May 89. At CP, the main causes of the negative phases are zonal geographic perturbed winds and thermospheric perturbed winds toward the pole. The changes in composition of the neutral atmosphere are a probable cause of the negative phase only for the event of May 89 and in the days 17/10/86 and 29/04/89, the final days of the interference.

It is interesting to notice that the large air cell rich in N_2 that penetrates strongly to low latitudes, produces an intense negative phase in May of 89, a weak storm in which the propagation of interferences originated in the auroral region is not the strongest.

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