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Long term trends in sporadic E layers and electric fields over Fortaleza, Brazil

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Abstract. Long term trends in the sporadic E-layer occurrences and associated electric fields over the equatorial station, Fortaleza are analysed using 16 years (1975-1990) of ionosonde data. The secular drift of the magnetic equator and hence that of the equatorial electrojet current (EEJ) to northward of Fortaleza has resulted in marked long term changes in the occurrence characteristics of the different types of Es layers: the q-type (arising from electrojet instability processes) and the l, f, c and h types (resulting from wind/wind shear mechanisms). Systematic decrease in the occurrence rates of the q-type Es, accompanied with increases in the remaining types of Es, was registered from 1975 to 1990, during which period the magnetic equator drifted to north of Fortaleza by ~400km. The long term trend manifests competing roles of the equatorial electric field and wind systems, in the generation of the different types of Es layers as a function of the distance from the electrojet center. The F-layer dynamo electric field is seen to exercise strong control of Es layer formation near sunset. Solar cycle variations, represented by the F10.7cm flux, seems to be present in elctrojet intensity and the lower thermospheric wind system.

Introduction

Long term trends in the ionospheric characteristics could arise from anthropogenic sources (Rishbeth and Roble, 1992) or from natural changes taking place within the solar-geophysical system. The results to be discussed in this paper belong to the latter class and concern the changes taking place in the ionospheric conditions that control the formation of sporadic E (Es) layers and the generation of the associated electric fields over the Brazilian equatorial site, Fortaleza. The Es-layer formation at equatorial latitudes is known to be quite different from those at middle and high latitudes. The q-type Es echoes observed in the height region of 105-110km in the daytime equatorial ionograms is a manifestation of the type II irregularities of the equatorial electrojet (EEJ) produced by the well known gradient ExB drift instability mechanism (Reid, 1968) that is primarily driven by the eastward global E region dynamo electric field, whereas other different types of Es-layers, such as the l,f,c and h types, (see URSI Handbook of Ionogram Interpretation and Reduction, Second Edition, 1972, Report UAG-23) that occur outside the EEJ over low latitudes, and midlatitudes, are known to be produced by wind/wind-shear mechanisms (Axford, 1963; Whitehead 1961; Abdu and Batista, 1977). The latter types of Es, contrary to the q-type, could often blanket echoes from the F-region. Sometimes they occur also under conditions of EEJ reversal, such as when a westward electric field produces a counter electrojet event (see, for example, Rastogi, 1974; Mayaud, 1977). The l and f types, (hereafter referred to as l/f type) occur during the day and night, respectively. The h-type Es develops around 180km and, descending in sequential ionograms (MacDougall, 1974; Wilkinson et al., 1992), becomes c-type Es. We shall from here on consider them as h/c-type Es. We have carried out an extensive analysis on the hourly occurrence statistics of these different types of Es layers over Fortaleza for the month of September from 1975 to 1990.

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Results

The hourly percentage occurrences of the different types of Es layers with respect to the total number of soundings carried out for the month of September of each year are plotted in Fig.1 as a function of local time for the years,1975-1977,1979,1980, 1982-1984,1986,1987,1989 and 1990. The following interesting features may be noted: 1) The q-type Es occurrence is restricted to daytime only, which is expected on the basis of its well known source in the EEJ instability processes. Its occurrence rises sharply after sunrise, and reaches the highest rates, approaching ~100%, before noon in approximate concurrence with the EEJ intensity. During the solar minimum years of 1975-1976, the occurrence rate starts to decrease soon after midday to reach zero value around sunset. There is an afternoon enhancement in the Es occurrence which becomes dominant during the years 1977, 1979-1980 and 1982 around the solar maximum. (2) The q-type Es occurrence rate starts a steady decline from 1982 (with ~90 percent) to 1989-90 (with 5-20 percent) making difficult an evaluation of the solar cycle trend in the afternoon peak mentioned above. (3) The h/c type events occur only during the sunlit hours, with two maxima, one in the morning and the other in the afternoon hours. The amplitudes of these maxima show significant increase from 1975 (with ~15%) to 1990 (with up to ~60%). This diurnal double peak characteristics is similar to the Es local time distribution pattern over Cachoeira Paulista reported earlier (Abdu and Batista, 1977). This type of Es-layers can be shown to be produced by vertical ion velocity convergence arising from zonal winds and vertical shears in them (Abdu and Batista, 1977). Their occurrence rates increasing from 1975 to 1990 show therefore a correspondingly increasing role of winds and wind shears in the Es layer formation over Fortaleza during this period. (4) The l/f-type Es that occurs generally in the 100-105km region has higher occurrence rate during the night than during the day. This feature is persistent in all the years (with the only exception of 1989). (5) The most striking aspect of the l/f type Es is its almost negligible daytime occurrence in 1975 and a steady increase to about 50 percent in 1990. This feature as well as similar feature of c-/h-types are in exactly opposite phase to the trend in the q-type Es occurrence during the same period. It may be pointed out that the association between the decrease of q-type Es occurrence and the increases in other types of Es, such

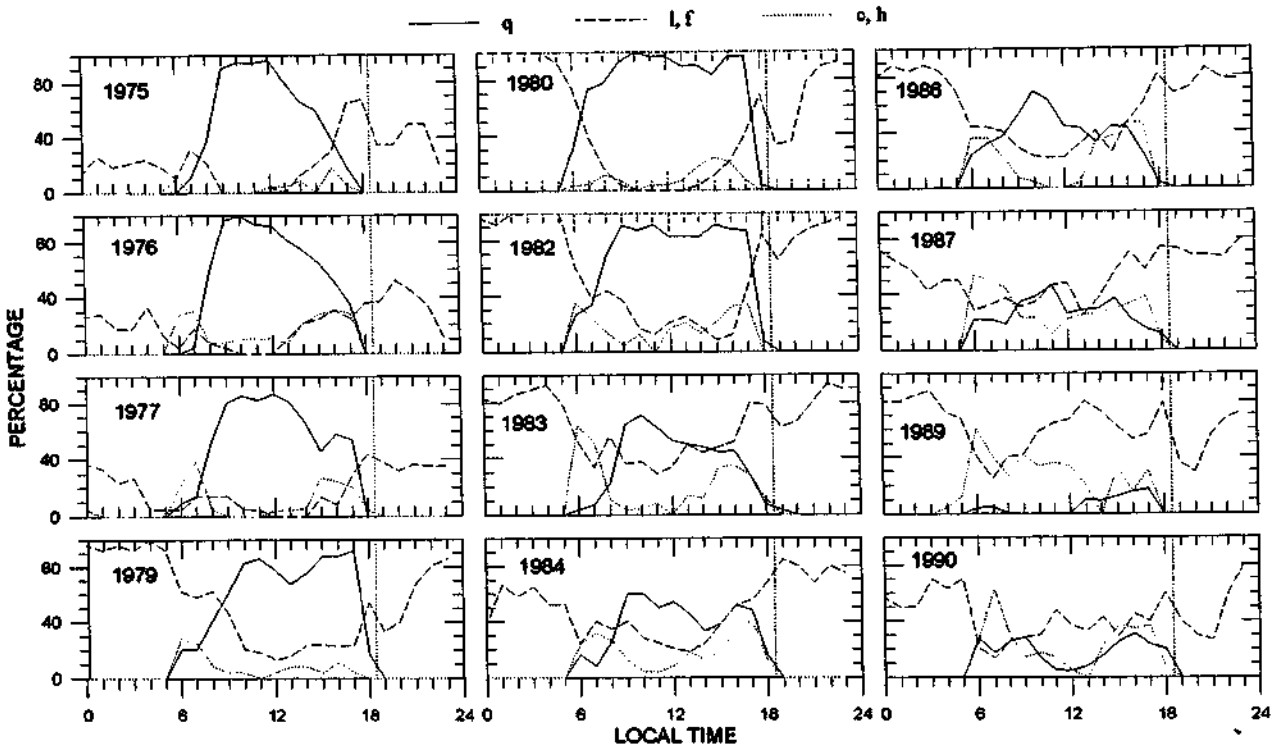

Figure 1. Diurnal patterns of the q, l/f and h/c types of Es hourly percentage occurrences for the September months of years from 1975 to 1990, over Fortaleza.

as is present just befor 18 LT, is not caused by possible masking of the latter types by the q-type Es which is known to be a "transparent" layer.

Fig. 2 presents the long term trends in the occurrence rates of the three types of Es from 1975 to 1990 at fixed local times from 08LT to 15LT. Clear trend of q-type Es occurrence decreasing from 1975 to 1990 is evident, especially from 10LT to 15LT. The l/f and c/h types of Es present an exactly opposite trend, that is, the occurrence rate increases from 1975 to 1990. The Es occurrence rates averaged for the hours 10-14 LT are presented in Fig.3 (middle panel) together with the yearly average solar F10.7 flux (bottom panel) and the variation of the distance of Fortaleza station from the magnetic equator (top panel) as per the International Geomagnetic Reference Field (IGRF) model, as a function of years from 1975 to 1990. This figure permits us to analyse the long term changes in the different types of Es layers as a function of the increasing distance of the station from the center of the EEJ during the 16-year period, as well as in function of the solar activity cycle. We may note the following important characteristics: (a) the q-type Es decreases from 90% occurrence in 1975 to almost insignificant values in 1990, as the EEJ drifted to further northward of Fortaleza. In other words the control of the EEJ associated E-field on the q-type Es layer formation decreased drastically from 1975 to almost negligible values in 1990. The other types of Es layers showed significant enhancement towards 1990, suggesting that their occurrences increased with increasing distance of Fortaleza from the EEJ center. (b) there are modulation cycles, superimposed over the long term trend, that are often in opposite phases in the q-type on one hand and in the l/f and c/h types on the other. These modulations seem to have a contribution from the solar activity cycle. For example, the broad maximum centered around 1980 with respect to an otherwise decreasing trend, in the q-type Es,

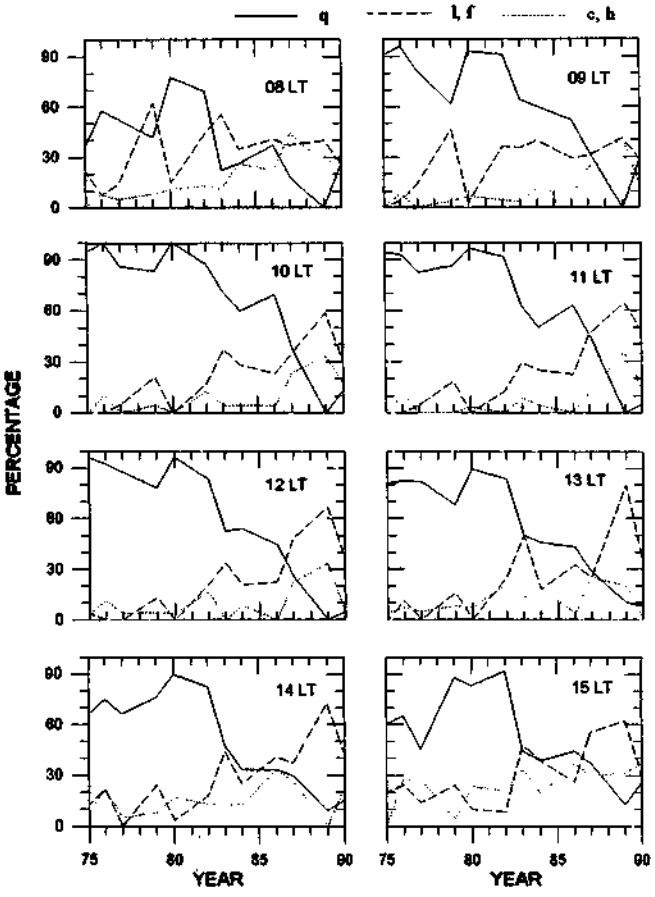

Fig.2-The percentage occurrences, as in Fig. 1, plotted versus year for different local times.

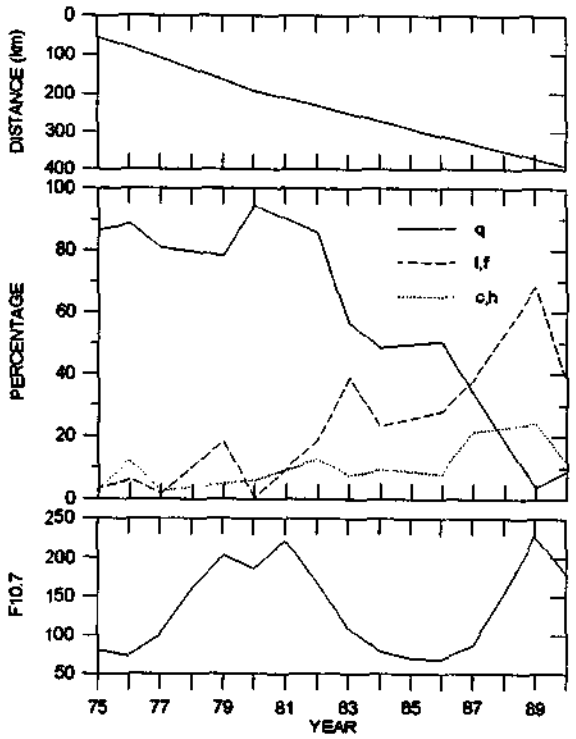

Figure 3. Top panel: The distance of Fortaleza station from the magnetic equator (in km) from 1975 to 1990, determined using the IGRF model; Middle panel: Percentage occurrences of the q, l/f and c/h types of Es layers over Fortaleza as a function of the years from 1975 to 1990;
Bottom panel: The F10.7cm solar radio flux for the period 1975-1990.

appears to be produced by processes associated with the solar cycle maximum in the F10.7cm flux. However, the F10.7 maximum of 1989 did not cause any enhancement in the q-type E_s, which may be explained by the fact that its formation is mainly controlled by the electric field of the EEJ which has moved away from Fortaleza. In contrast, l/f and h/c types of Es seem to show maxima corresponding to the 1989 solar flux maximum. Over all, while Fig. 3 presents long term trends in different Es phenomena, it seems to present also solar cycle effects on their driving foreces, that is, electric fields and winds.

Discussion

The long term trends in the occurrences of the different types of Es layers over Fortaleza are, in fact, manifestations of the variations, from the center to the periphery of the EEJ, of the competing roles of electric fields and neutral winds in the formation of these Es layers. At the EEJ center the vertical polarization Hall electric field driven by the primary E-layer dynamo electric field, is responsible for the gradient ExB drift (type II) irregularities that manifest as q-type Es in the ionograms. The Hall field gets weakened with increasing distance from the EEJ center. Thus the observed decrease in the q-type Es formation over Fortaleza from 1975 to 1990 can be attributed to the fact that during this period the Fortaleza station steadily receded from the EEJ center as shown in Fig. 3. On the other hand the l/f and c/h types of Es layers are known to be produced by winds that are expected to be the same in the rather restricted latitude range covered by the EEJ. Considerations on the ion and electron momentum equations show that horizontal winds (zonal and meridional), cannot produce any vertical ion motion right at the magnetic equator (at zero dip angle). This is corroborated by the present observation of almost negligible occurrence of l/f and h/c types of Es-layers over Fortaleza around 1975 when q-type showed almost 100 percent occurrence. At the periphery of the EEJ, that is, over Fortaleza towards the end of the analysis period, winds are very efficient in producing the l/f and h/c type Es. However, the formation of such wind induced layers seem to be opposed by the eastward electric field that is uniformly present in the EEJ and its periphery (nearby low latitude) regions. This can be verified from the fact that the decay of q-type Es occurrence, that marks the decrease of eastward electric field, just before 18 LT, is always accompanied by rapid rise in the wind induced Es layers, in Fig.1. This seems to be an evidence that an eastward electric field opposes the action of the wind to produce the vertical ion convergence needed to form the Es layers. This is evident also in the subsequent decrease in l/f type Es occurrence centered around 1830LT (indicated by vertical line in Fig.1) observed in almost all years which coincides exactly with the peak time of the F-layer dynamo induced prereversal eastward electric field enhancement (Woodman, 1970; Rishbeth, 1971; Heelis et al., 1974; Abdu et al., 1981; Batista et al.,1986; Farley et al., 1986; Fejer et al., 1991). Some specific examples of such Es layer interruptions caused by the prereversal eastward electric field enhancement are presented in Fig.4. Of the 10 days of observations during one of the SUNDIAL campaigns, 8 days showed Es layer interruptions just around 18LT, whereas on 3 and 5 December 1988 such interruptions occurred in a way to suggest longer persistence of the Es layer for the weaker prereversal electric field of the former day compared to the latter day as can be judged from the h'F slope around 18-19LT. (But this needs to be demonstrated better by analysing more data.) Such analysis using larger data sets showed 95% probability for Es-layer inhibition associated with prereversal electric field enhancements. The opposing influences of the eastward electric

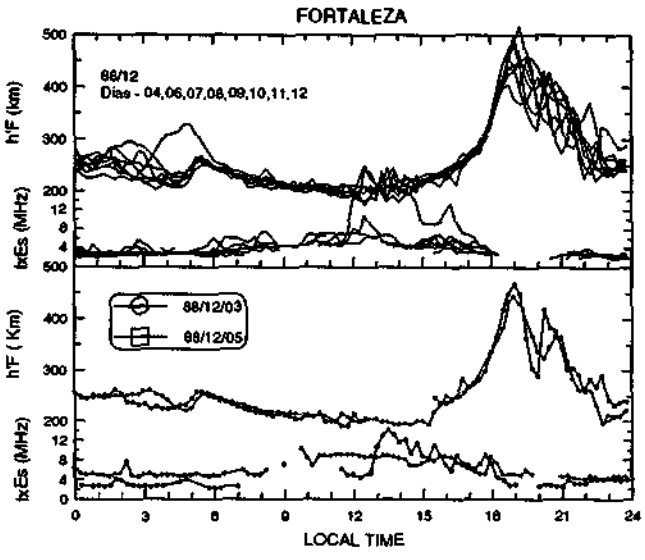

Figure 4. The diurnal variation of the h'F and fxEs (the highest frequency reflected by the Es layer) over Fortaleza during a 10-day interval (3-12 December 1988), showing that Es layer interruptions around 18LT occurred on 8 of these days (upper panel) whereas on two days, 3 and 5 December (lower panel), they persisted for longer time before total disappearences (see the text).

field and the wind/ wind shear mechanisms for Es-layer formation can be quantitatively verified also using the ion vertical velocity height derivative obtained from ion and electron momentum equations. Thus the increasing trend in the occurrences of l/f and h/c types of Es-layers from 1975 to 1990 seen in Fig.3 is, in fact, a net trend resulting from the opposing influence of an ambient eastward electric field in the formation of these layers by winds.

The present results seem to suggest also a solar F10.7 cm flux control of the different types of Es layers (Fig.3). A notable increase (with respect to an otherwise decreasing trend) in the q-type Es is observed around 1980 which seems to be associated with the solar flux maximum around the same period, and maxima in the l/f and h/c types of Es seem to be associated with the peak in the solar flux around 1989. The equatorial daytime electric field has been shown to have little dependence on solar activity cycle (Fejer et al., 1991). Therefore the q-type Es dependence on the F10.7 flux in Fig.3 could signify a solar cycle control on the EEJ intensity through electron density and collision frequencies of the E region. This latter aspect of the solar activity control of the lower thermosphere is evident also in the occurrence of what appear to be maxima in the wind induced Es layers associated with the solar maximum around 1989. This might suggest further that the E-layer/ lower thermosphere winds could have higher intensities during solar maximum than during solar minimum. We may caution however, that the Es occurrencee maxima around 1989 might warrent further confirmation from analysis of more recent data.

Conclusions

The present study leads to the following conclusions:1) Equatorial sporadic E layer (type-q) occurrence over Fortaleza underwent drastic decrease from 1975 to 1990. This decrease arises from the displacement to further northward of Fortaleza of the EEJ center where the q-type Es occurs with maximum efficiency. 2) During the same period the wind driven Es layers (that is, type l/f and h/c) showed significant increase in their occurrence rates over Fortaleza, thus demonstrating the increasing efficiency of wind mechanism for the Es layer formation at the flanks of the EEJ. 3) There is evidence that an eastward electric field originating from E- or F-layer dynamo can act to oppose the ion convergence mechanism responsible for the non q-type Es formation in the equatorial region, thus offering a competing role with winds in the formation/dissipation of such Es layers. 4) Solar cycle could modulate the lower thermospheric parameters, such as collision frequencies, electron density and wind velocities and shears, as suggested from the present results.

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