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LONG TERM CHANGES IN THE SPORADIC E-LAYER PHENOMENA OVER FORTALEZA, BRAZIL

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Sporadic E layer occurrences over the equatorial station Fortaleza are analysed for a 15-year period, from 1975 to 1990. The secular drift of the magnetic equator and hence that of the equatorial electrojet current (EEJ) northward of Fortaleza has resulted in marked long term changes in the occurrence characteristics of the different types of E_s layers: q, l, f, c and h types. Systematic decrease in the occurrence rates of the q-type E_s, accompanied with increases in the remaining types of E_s, was registered from 1975 to 1990, during which period the magnetic equator drifted northward of Fortaleza by 400km. The overall results show competing roles of the equatorial zonal electric field and wind systems, as well as their long term changes, in the generation of the different types of Es layers at the central region and at the flanks of the EEJ. The F10.7cm radio flux variation during the solar cycle seems to control both the electric field and E region winds of the equatorial region.

MUDANÇAS DE LONGO PRAZO NO FENÔMENO DA CAMADA E ESPORÁDICA SOBRE FORTALEZA, BRAZIL *Realiza-se neste trabalho uma análise da ocorrência das camadas E-esporádicas sobre Fortaleza durante 15 anos, de 1975 a 1990. A deriva secular do equador magnético,e portanto da corrente do eletrojato equatorial, (EJE), ao norte de Fortaleza durante estes anos resultou em mudanças de longo prazo nas características de ocorrência das camadas-E_s de diferentes tipos: q, l, f, c e h. Decréscimo sistemático na ocorrência de $E_s$tipo q, acompanhado de aumento nas ocorrências dos demais tipos de E_s, foi registrado de 1975 a 1990. Durante esse mesmo período o equador magnético se deslocou por 400km ao norte de Fortaleza. Os resultados mostram o papel relativo do campo elétrico e do sistema de ventos, tanto como as suas mudanças de longo prazo, nos mecanismos de geração das camadas $E_s$na região central e na periferia do eletrojato. A variação do fluxo solar em 10.7cm (F 10.7cm) durante o ciclo solar tem controle tanto no campo elétrico como no vento da região E equatorial.*

INTRODUCTION

The sporadic E layer (E_s layer) generation mechanism operating at equatorial latitudes is known to be quite different from those for the middle and high latitudes. The well-known gradient drift (that is, ExB drift) mechanism is known to be responsible for the equatorial type (widely known as the q-type) Es that occurs inside the equatorial electrojet (EEJ), whereas other different types of E_s (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 at low latitudes, in the vicinity of the EEJ, are known to be produced by wind/windshear mechanism (Axford, 1963; Whitehead 1961; Abdu and Batista, 1977). The latter types of Es, that often blanket echoes from the F-region, could occur in the electrojet region under conditions of EEJ reversal such as when a westward electric field produces a counter electrojet event (see, for example, Mayaud, 1977; Rastogi, 1974). A comparative study on the occurrence features of the different types of E_s layers with due considerations on their generation mechanism, therefore, could lead to a better understanding of the competing roles of the equatorial electric fields and winds in the control of the low latitude aeronomical processes.

At Fortaleza (38°W, 4°S, 7°dip) an ionosonde (type C4) has been in operation since 1975 when that station was under the direct influence of the EEJ, that is, within about 100km from the center of the EEJ belt (magnetic equator). The secular variation of the geomagnetic field which attains a globally maximum rate in the Brazilian region has resulted in an apparent northward drift of the magnetic equator, a feature that is continuing at a rather rapid rate. According to the IGRF (International Geomagnetic Reference Field) representation this drift corresponds to approximately 2 degree increase in geomagnetic latitude per year. The consequent displacement of the EEJ center to northward of Fortaleza has produced systematic long term changes in the sporadic E-layer features over that station, which is the subject matter of the present paper. The role of neutral winds (presumably zonal wind) in the generation of the E_s gaining importance with increasing distance of Fortaleza from the EEJ center is clearly evident from the present results. The results seem to show also that the dynamo eastward electric field intensity, basically responsible for the q-type Es layer formation, decreases with increasing distance from the EEJ center.

RESULTS

Type II irregularities of the EEJ, produced by the well known gradient ExB drift instability mechanism (see for example Reid, 1968) that is primarily driven by the eastward global dynamo electric field is believed to be responsible for the q-type E_s echoes observed in the height region of 105-110km in the equatorial ionograms. The l and f types that occur during the day and night respectively, represent the same Es layer phenomenon. From here on we shall denote this as l/f type Es. The h-type E_s is that which first occurs as high as 180km and descending in sequential ionograms, to lower heights, just above the E-layer peak of 120km becomes denoted as c-type E_s. We shall from here on consider them as one type denoted as c/h type E_s. The hourly percentage occurrences of these different types, that is, q, l/f and c/h types, with respect to the total number of sounding carried out during a year are plotted in Fig. 1 as a function of local time. Results for the years, 1975- 1977, 1979, 1980, 1982-1984, 1987, 1989 and 1990 are presented in this figure. The following interesting features of this figure may be noted:

1) The q-type E_s occurrence is restricted to daytime only, which is expected on the basis of its well known source in the EEJ instability processes. The occurrence rate rises sharply after the sunrise, reaching the highest values approaching 100%, around 9-10LT.

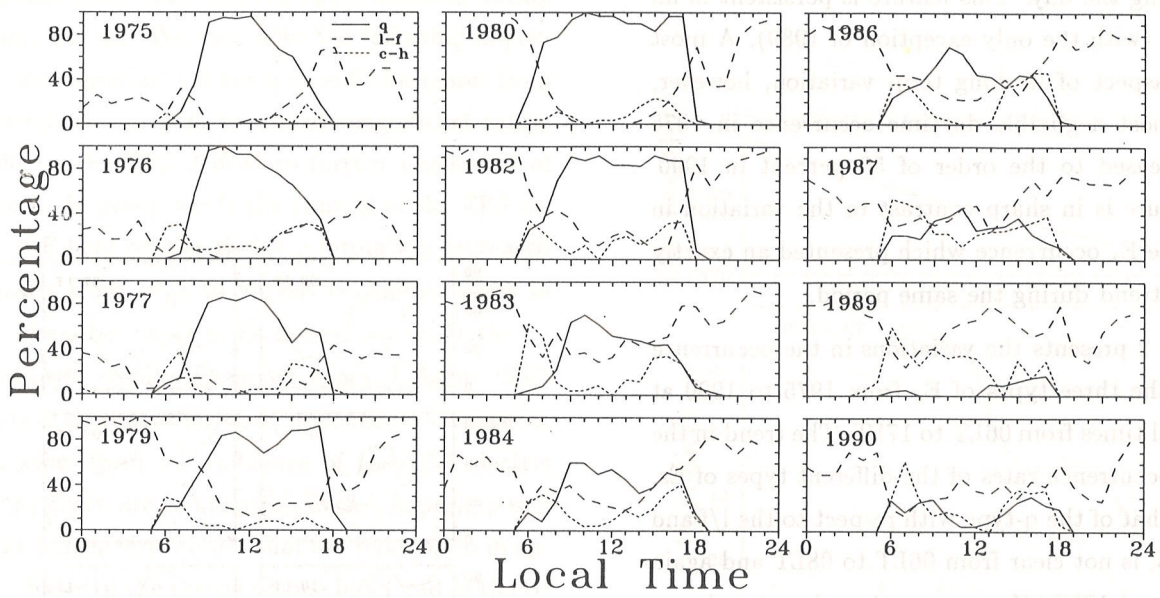

Figure 1. Diurnal patterms of the q, l/f and c/h types E_s percentage occurrences for various years from 1975 to 1990, over Fortaleza. The percentage occurrence of each of these E_s types, at a given hour, was calculated with respect to the total number of soundings carried at that hour during an year.

Padrão diurno da ocorrência percentual da camada E_s dos tipos q, l/f e c/h para vários anos entre 1975 e 1990. A ocorrência percentual de cada tipo de E_s, em uma dada hora, foi calculada com respeito ao número total de sondagens naquela hora durante o ano.

During the low solar activity years of 1975-1976, the occurrence rate starts to decrease soon after midday to reach nighttime zero values. It is interesting to note further that there is a secondary (pre sunset) enhancement in the occurrence which appears to be related to the increasing solar activity of the years 1977, 1979- 1980 and 1982. However, a detailed characterization of this feature as a function of the solar activity cycle is made difficult due to the increasing distance of Fortaleza station from the EEJ center to be discussed shortly. The q- type E_s occurrence is observed to decrease monotonically, and at a rapid rate, starting from 1982, to reach a very low value of 5-20% in 1990.

2) The c/h 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 (when the evening peak occurrence was of the order of 15%) to 1990 (when the morning maximum registered 60%). The diurnal double peak characteristics in the occurrence distribution of this type of E_s resembles very much the E_s local time distribution pattern over Cachoeira Paulista observed in one of our previous studies (Abdu and Batista, 1977). This type of E_s can be shown to be produced by wind shear mechanism. The vertical ion velocity convergence needed to produce this type of E_s layers could be shown to be produced predominantly by vertical shears in zonal winds (Abdu and Batista, 1977). The occurrence rates of this type of E_s increasing from 1975 to 1990 clearly shows a correspondingly increasing role of wind shear in the Es layer formation over Fortaleza during this period. Possible significance of this fact as well as that of the morning and afternoon peaks in the occurrence rates will be discussed later.

3) The l/f-type E_s that occurs generally in the 100-105km has a larger occurrence rate during the night

than during the day. This feature is persistent in all the years (with the only exception of 1989). A most striking aspect of its long term variation, however, is its almost negligible daytime occurrence in 1975 that increased to the order of 50 percent in 1990. This feature is in sharp contrast to the variation in the q-type E_s occurrence which presented an exactly opposite trend during the same period.

Fig. 2 presents the variations in the occurrence rates of the three types of E_s from 1975 to 1990 at fixed local times from 06LT to 17LT. The trend in the relative occurrence rates of the different types of Es, namely, that of the q-type with respect to the l/f and c/h types, is not clear from 06LT to 08LT and again at 16LT and 17LT. However, rather clear trends are evident at other hours. Especially, from 10LT to 15LT the q- type E_s shows steady decrease from 1975 till 1990 (with the exception of a peak centered around 1981, year of solar activity maximum), whereas the l/f and c/h types of E_s present an exactly opposite trend, that is, the occurrence rate increases from 1975 to 1990. It is interesting to note that there are modulation cycles, superimposed on these trends, that are in opposite phases for the q-type E_s on the one hand and for the l/f and c/h types on the other, clearly noticeable from 10LT to 14LT. Possible implications of this feature will be mentioned later.

In Fig. 3 we have presented in the middle panel yearly mean occurrence rates of the three types of E_s averaged for 10- 14LT, as a function of the years from 1975 to 1990, and in the bottom panel, the corresponding yearly average values of the solar F10.7cm flux. The top panel shows the distance, in km, of the Fortaleza station from the magnetic equator according to the IGRF (International Geomagnetic Reference Field) model.

This figure permits us to analyse the long term changes in the different types of E_s layers as a function of the increasing distance of the station from the center of the EEJ during the 15-year period, as well as

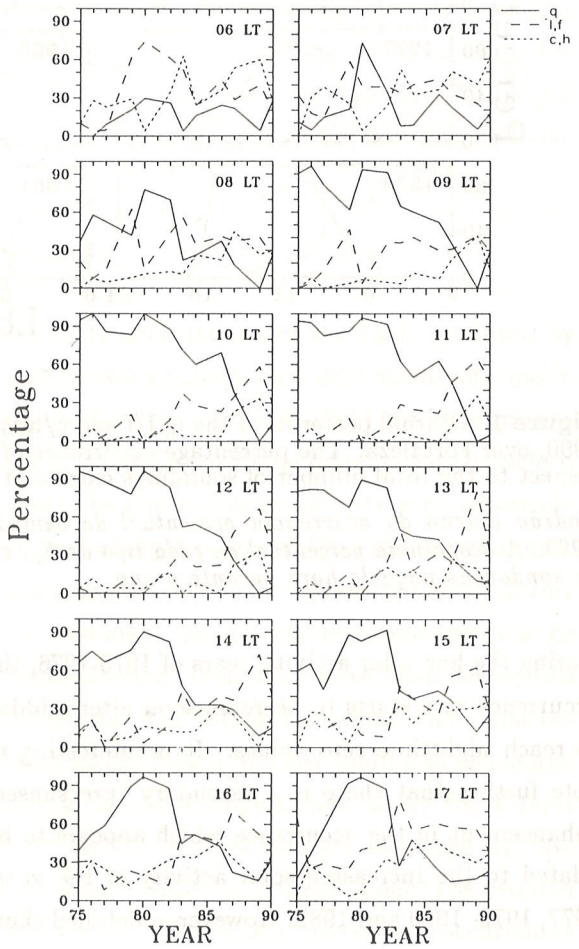

Figure 2. The percentage occurrences, as in Fig. 1, plotted versus the years at different local times.

Ocorrência percentual similar à da Fig. 1 versus o ano, para diferentes horas locais.

in function of the solar activity cycle variation during the same period. 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 Es layer formation decreased drastically from 1975 to almost negligible values in 1990. The other types of Es layers, especially the l/f type, showed significant enhancement towards 1990, suggesting thereby, that their occurrences increase as we go away from the influence of the EEJ electric field; (b) there are modulation cycles, superimposed over the longer term trend, that are more often in opposite phases in the q-type on one hand and in the l/f and c/h types on the other. The indications are that these modulations are produced by the solar activity cycle. For example, the broad maximum in the q-type Es centered around 1981 appears to be produced by processes associated with the solar activity maximum in the F10.7cm flux. However, the solar flux maximum of 1989 did not cause any enhancement in the q-type Es, which is understandable since its formation is mainly controlled by the electric field of the EEJ which has moved away from Fortaleza. This association between the solar flux and the q-type E_s layer formation provides an evidence on the EEJ electric field control of this E_s layer phenomenon. There is a pronounced peak in the l/f and c/h types of Es corresponding to the 1989 solar flux enhancement. Overall solar cycle effects on two distinctly different types of driving forces of the Es phenomena are represented in this figure.

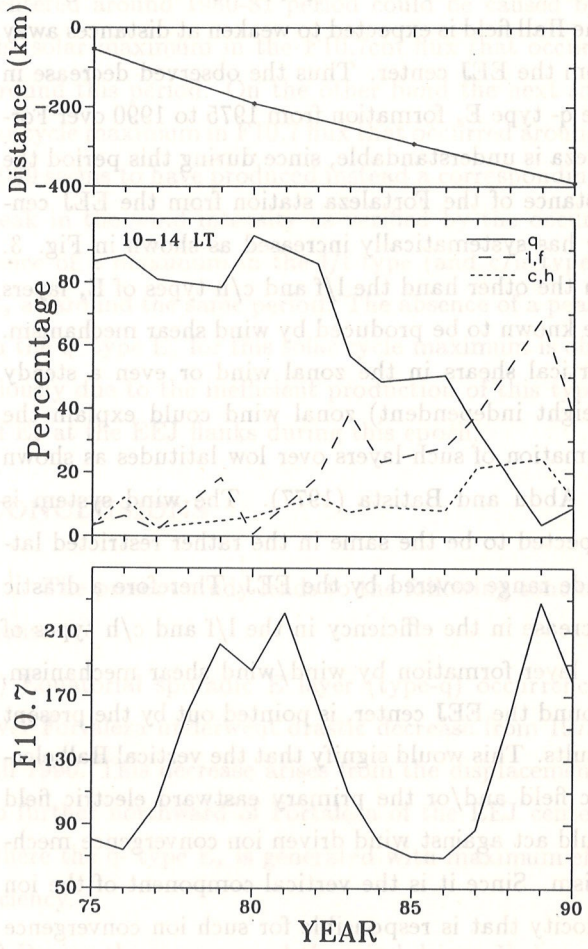

Figure 3. Top panel:the variation in the distance of Fortaleza station from the magnetic equator (in km) from 1975 to 1990, determined using the IGRF model. Middle panel: Percentage occurrences of the q, l/f and c/h types of E_s layers over Fortaleza as a function of the years from 1975 to 1990. Bottom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

Painel superior: distância (em km) entre o equador magnético e a estação de Fortaleza entre 1975 e 1990, determinada usando o modelo IGRF. Painel central: ocorrência percentual das camadas E_s dos tipos q, l/f e c/h sobre Fortaleza em função do ano, entre 1975 e 1990. Painel inferior: fluxo solar F10.7 para o período de 1975 a 1990.

DISCUSSION

Competing roles of the electric field and wind in the E_s layer formation and its long term changes as a function of distance from the EEJ center is the main point that comes out of the present analysis. 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 instability process that manifests as q-type E_s in the ionograms. The Hall field is expected to weaken at distances away from the EEJ center. Thus the observed decrease in the q- type E_s formation from 1975 to 1990 over Fortaleza is understandable, since during this period the distance of the Fortaleza station from the EEJ center has systematically increased as shown in Fig. 3. On the other hand the l/f and c/h types of E_s layers are known to be produced by wind shear mechanism. Vertical shears in the zonal wind or even a steady (height independent) zonal wind could explain the formation of such layers over low latitudes as shown by Abdu and Batista (1977). The wind system is expected to be the same in the rather restricted latitude range covered by the EEJ. Therefore a drastic decrease in the efficiency in the l/f and c/h types of E_s layer formation by wind/wind shear mechanism, around the EEJ center, is pointed out by the present results. This would signify that the vertical Hall electric field and/or the primary eastward electric field could act against wind driven ion convergence mechanism. Since it is the vertical component of the ion velocity that is responsible for such ion convergence processes, a vertical (Hall) electric field is unlikely to contribute to oppose (or favour) the E_s formation. The eastward electric field could, on the other hand, influence negatively the vertical component of the ion convergence required to produce these E_s layers. Therefore, the increase in the l/f - type E_s layers exactly at the time of the evening rapid decrease of the q-type E_s (that is, the decay in the eastward electric field) just before 18LT, (Fig. 1) seen very markedly in the years 1977, 1979, 1980, 1982, 1983 and less so in other years, is a rather clear evidence of the effect of an eastward electric field in opposing the ion convergence required for the E_s layer formation. Such an electric field influence could be inferred also from the occurrence of the conspicuous decrease in the l/f type E_s starting at 18LT which appears in all the years, with the exception of 1976 and 1987 (Fig. 1). This decrease occurs exactly at the time of the F-layer dynamo induced evening (prereversal) enhancement in the eastward electric field (Woodman, 1970; Rishbeth, 1971; Fejer et al., 1979; Abdu et al., 1981, 1992; Batista et al., 1986). Especially, recent results from Abdu (1991) show very systematic interruption of the E_s layer development coincident with the rapid rise of the evening F-layer over Fortaleza that arise from the development of the F-layer dynamo (see also, Heelis et al., 1974; Farley et al., 1986). Some examples of this effect, that is, the interruption of the E_s layer formation due to the development of the evening F-layer dynamo electric field, are presented in Fig. 4. This result was obtained from the ionospheric sounding over São Luiz do Maranhão (1^o dip) conducted during a recent IEEY (International Equatorial Electrojet year) EITS (Equatorial Ionosphere - Thermosphere System) global campaign.

All the E_s characteristics just discussed above show that an eastward electric field could act to retard, or even totally inhibit, the formation of wind induced E_s layers in the central region as well as at the flanks of the electrojet. Thus it follows that the daytime increased occurrences of the wind driven E_s layers at the perifery of the EEJ (during the period from 1987 till 1990 over Fortaleza) could point to a significant degree of weakening of the eastward electric field at the flanks of the EEJ. It is interesting to note that this region in the EEJ can be identified to belong to where Onwumechili (1992) has found the need for the existence of a westward EEJ return current. If a return current could indeed be present at these latitudes then it is necessary that the corresponding zonal electric field should either be westward or very weak if eastward.

Another important point that has emerged from the present analysis is a clear solar cycle control of both E-field and winds as explained below. The eastward electric field that produces the q-type E_s layer

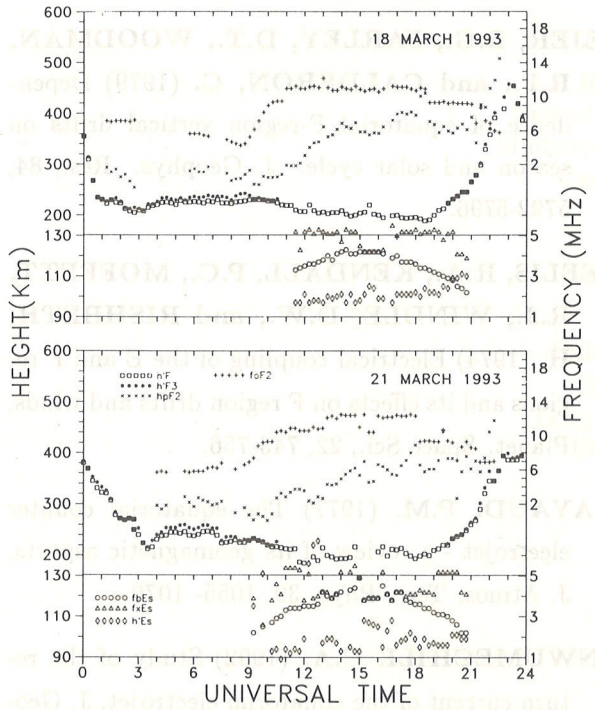

Figure 4. The diurnal variation of the E and F-layer parameters, over São Luiz do Maranhão observed on 18 and 21 March 1993 during the IEEY/EITS campaign period. With increasing heights (h'F/h'3F and hpF2) of the F-layer produced by the development of the dynamo eastward electric field, the E_s layer occurrences (represented by fbE_s, ftE_s and $h'E_s$) shown in the lower section, are totally inhibited around 18LT (21UT).

Variação diurna dos parâmetros das camadas E e F sobre São Luiz, Maranhão, observados em 18 e 21 de março de 1993, durante a campanha IEEY/EITS. O aumento nas alturas da camada F (h'F, h'3F e hpF2) produzido pelo desenvolvimento do campo elétrico de dínamo,para leste, provoca uma inibição da ocorrência das camadas E_s (representadas por fbE_s, ftE_s, $h'E_s$) conforme mostra a parte inferior da figura.

seems to be controlled by the solar cycle variation in the F10.7cm flux. The broad peak in the occurrence centered around 1980-81 period could be caused by the solar maximum in the F10.7cm flux that occurs around this period. On the other hand the next solar cycle maximum in F10.7 flux that occurred around 1989 seems to have produced instead a corresponding peak in the wind intensity as verified by the occurrence of a maximum in the l/f type (and c/h type) E_s at around the same period. The absence of a peak in the q- type E_s for this solar cycle maximum is obviously due to the inefficient production of this type of E_s at the EEJ flanks during this epoch.

CONCLUSIONS

The present study leads to the following conclusions:

1) Equatorial sporadic E layer (type-q) occurrence over Fortaleza underwent drastic decrease from 1975 till 1990. This decrease arises from the displacement to further northward of Fortaleza of the EEJ center where the q- type E_s is generated with maximum efficiency.

2) During the same period the wind driven E_s layers (that is, type l/f and c/h) showed significant increase in their occurrence rates, thus demonstrating the increasing efficiency of wind mechanism for the E_s layer formation at the flanks of the EEJ with increasing distance from the EEJ center.

3) An eastward electric field can act to oppose the ion convergence mechanism responsible for the non q-type E_s formation in the equatorial region, thus showing the competing roles of the electric field and wind in the occurrence of such E_s layers.

4) Solar cycle effects in the dynamo electric field and wind intensity are observed as significant increases in both the parameters with increase in the F10.7cm flux.

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