JOURNAL OF GEOPHYSICAL RESEARCH, VOL. 88, NO. A1, PAGES 399-402, JANUARY 1, 1983

VERTICAL IONIZATION DRIFT VELOCITIES AND RANGE TYPE SPREAD F IN THE EVENING EQUATORIAL IONOSPHERE

M. A. Abdu, R. T. de Medeiros[1], J. A. Bittencourt, and I. S. Batista

Instituto de Pesquisas Espaciais - INPE
Conselho Nacional de Desenvolvimento Científico e Tecnológico - CNPq
12200 São José dos Campos, São Paulo, Brazil

Abstract. Range type spread F indices in the post sunset hours, determined from ionograms, are compared with F layer vertical velocities, also deduced from ionograms, for a period of one year, over the magnetic equatorial station Fortaleza (geographic coordinates: 4°S, 38°W; dip latitude: 1.8°S), Brazil. Besides good correlation between the two parameters, the results suggest the presence of a certain threshold value for the vertical ionization velocity and a corresponding threshold height for the base of the evening F layer, as one of the necessary conditions for the occurrence of spread F irregularities valid for southern solstice (summer) and equinoctial months. The nature of the possible variabilities in the amplitude of the initial perturbation in the ionization (seeding mechanism), which is another prerequisite for the generation of irregularities, is discussed briefly.

1. Introduction

From the early investigation of the equatorial spread F by Booker and Wells [1938] it has been known that this phenomenon is closely associated with the large heights of the F layer in the evening equatorial ionosphere (see, also Lyon et al. [1961] and Farley et al. [1970]). The F layer ionization drifts upward during the day and downward during the night due to the eastward and westward electric fields, respectively produced by the E region dynamo. Prior to the reversal to downward, the vertical drift undergoes an enhancemente, in the evening hours, due to the build up of polarization electric field in the F region and its zonal component caused by the east-west gradient in the E region conductivities that occurs at sunset hours [Rishbeth, 1971, 1981]. The resulting pre-reversal maximum in the F layer drift velocity has been measured by Jicamarca VHF radar [Woodman 1970; Fejer et al., 1979] and theoretically simulated by Heelis et al. [1974].

The associated large height of the base of the F region is believed to be a necessary precedence to the occurrence of the spread F irregularities. Farley et al. [1970] presented some evidence, from the Jicamarca radar results, favoring the postulate that the F region should perhaps attain a threshold height before the meter scale irregularities are generated. They also presented some evidence in conflict with this postulate and concluded that no sweeping generalization was possible regarding a threshold altitude for radar backscatter spread F echoes. Our analysis of one year of ionograms over Fortaleza (geographic coordinate: 4°S, 38°W; dip latitude: 1.8°S) [Abdu et al., 1981a] showed that the F region heights attain equally large values in the northern solstice months (J months) as in southern solstice (D months) and equinoctial months, but the range type spread F (associated with VHF backscatter echoes) is observed very often (more than 90% of the days) in the latter two seasons, while very rare occurrence was registered in J months. These observations, therefore, pose an important question as to the nature of the relative importance of the height of the evening F layer and its time derivative, namely, the vertical drift velocity (V_z), with respect to other possible factors, in the circumstances leading to the formation of the irregularities.

Results of vertical velocities over Jicamarca published by Woodman [1970] suggested a certain relationship between the occurrence, or otherwise, of the V_z prereversal peak (V_{zp}) over Jicamarca with those of spread F over Huancayo. Seasonal variations in the V_z prereversal peak, as published by Fejer et al. [1979], also showed large values of V_{zp} in D months and equinoctial months, when spread F occurrence over Huancayo is generally large, as compared to J months.

The purpose of this paper is to present and discuss some statistical relationship of a more direct nature between the amplitude of the V_z prereversal peak and the indices of range type spread F over the magnetic equatorial station Fortaleza for a period of one year.

2. Data Analysis and Results

The vertical ionization drift velocity (V_z) was determined as d(h'F)/dt (where h'F is the virtual height of the bottomside of the F layer, read from ionograms taken at 15-min intervals), which is a valid representation of the vertical ionization velocity of the equatorial ionosphere during evening hours [see Bittencourt and Abdu, 1981; Abdu et al., 1981a]. The error in the determination of V_z depends on the precision with which Δh' (corresponding to a Δt of 15 minutes between the consecutive observations) could be read from the ionogram, which is of the order of 1 km. This will introduce an error of ±10% in the V_z values. The degree of range spreading in the ionogram is represented by index numbers, 0, 1, 2, and 3, with zero signifying absence of spread F and 3 representing severe spreading to the extent of making the

[1] Permanent address: Universidade Federal do Rio Grande do Norte, Natal, Brazil.

Paper number 2A1271.
0148-0227/83/002A-1271$05.00

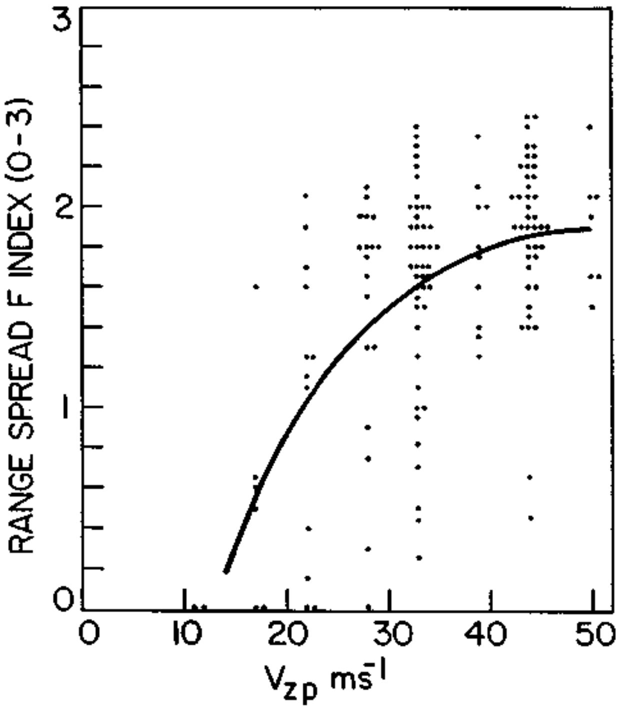

Fig. 1. Scatter plot of range type spread F index, taken as mean of the values, read at 15-min intervals, during the four hours following the onset of spread F on a given night, against the pre-reversal maximum in the F layer drift velocity (V_{zp}) deduced from the evening ionograms for the same night. There are many cases of occurrences of a number of equal spread F index value for a given V_{zp} value. In such cases the equal index values are plotted horizontally with one of the points (usually the middle point) plotted at given V_{zp} value.

virtual height reading impossible. The numbers 1 and 2 represent weak and moderate degrees of range spreading, respectively. The indices read at 15-min intervals during four consecutive hours after the initiation of a spread F event were averaged and plotted against the value of the V_{zp} associated with that event. The 4-hour interval used here, to obtain the mean spread F index, is chosen based on the consideration that many of the range spread events do not persist beyond 2300-0000 LT after their onset usually between 1830-1930 LT. The results for 140 days selected during the months of regular spread F occurrence, namely, January to April and September to December in 1978, are presented in Figure 1. Even though there is large scatter in the index values for a given V_{zp}, a positive relationship between the two parameters is clearly brought about in the figure by the solid line that represents the mean values of the spread F indices. It is important to note that for V_{zp} values less than around 15 m s^{-1} spread F events do not occur over Fortaleza. We may consider this as a threshold velocity for the F region vertical movement in order that spread F irregularity may be generated. The tendency for the indices to saturate is due to the maximum value of the index used being 3. A similar inference on the threshold V_{zp}, could not be established for winter months (J months) since the range type spread F rarely occurs in these months.

In order to examine the behavior of the F layer height in relation to the spread F occurrence, we have selected the days of spread F occurrence immediately following (or preceding) the days of nonoccurrences. There were only 6 such cases available in the entire period considered in Figure 1. The average height variations for the 6 days with and without spread F events are plotted in Figure 2a, which shows significant height differences between the two groups of days during the pre-midnight hours. The largest difference, of the order of 70 km, occurs near the peak value of the h'F around 1900 LT. It seems clear, therefore, that during the regular spread F occurrence season, the spread F irregularities would appear to occur on a given night only if the height of the base of the F layer attains a certain value similar to the threshold height observed on some occasions by Farley et al. [1970] as one of the conditions for the generation of the meter scale irregularities, especially, when they occur in the early hours of the night. It seems, also, that this threshold height is attained if the V_{zp} exceeds a certain threshold value, which is approximately 15 m s^{-1} in the results presented in Figure 1.

On the other hand, range type spread F does not occur in northern solstice months, even when the heights of the F layer base attain values as high as (or even higher than) those on the spread F nights of southern solstice months, as can be verified by comparing the curves marked 2 in Figure 2a and 2b. This would seem to be attributable to the fact that the large heights in the J months are attained much later after the sunset times over the conjugate E regions of Fortaleza (also marked in Figure 2; see also Abdu et al. [1981b]) in comparison with D and E months. On the few nights when range type spread F is observed in J months, the heights of the F layer are significantly higher than on other days, peaking at the same local time as on other days. The V_{zp} on both the groups of days (not shown here) were found to be of the order of 40 - 50 m s^{-1}, which is well within the ranges of V_{zp} in Figure 1, corresponding to spread F occurrences in southern solstice months. The times of the V_{zp} was, however, much later than in the D and E months. These results would suggest that, although the higher heights of h'F favor spread F occurrence in J months, the pre-reversal velocity peak does not seem to influence the generation of spread F irregularities, as it is doing in the other months as seen clearly in Figure 1.

3. Discussion

The present understanding on the generation of equatorial spread F irregularities, based largely on the VHF radar results [Woodman and La Hoz, 1976; Tsunoda, 1980] is that they occur at regions of steep electron density gradients associated with plasma depletions, or bubbles, in the equatorial ionosphere [McClure et al., 1977]. The primary mechanism of generation of the plasma bubble is believed to be the

Rayleigh-Taylor mechanism (and, perhaps, also the gradient drift mechanism) operating on an initial perturbation in the ionization at the ion density gradient of the bottomside F region of the equatorial ionosphere [Dungey, 1956; G. Haerendel, unpublished manuscripty 1973; Chaturvedi and Kaw, 1975; Scannapieco and Ossakow, 1976; Ossakow et al., 1979; Anderson and Haerendel, 1979]. On the basis of the theory and the present results, it appears that spread F irregularities could be generated only if the vertical ionization drift velocity and the height of the bottomside F layer are appropriate in the presence of an initial perturbation source. Since the V_z peak is a measure of the ambient F region east west electric field, the wide scatter of the individual spread F index values for a given V_{zp} in Figure 1, might perhaps be caused by certain day to day variabilities in the initial perturbation amplitudes.

From the results presented in Figures 1 and 2 it is conceivable, therefore, that an initial perturbation source was usually present near sunset hours, in the presence of sufficient vertical ionization drift velocities and corresponding large h'F values, in the D and E months, whereas these three prerequisites do not seem to be present near the sunset hours on an average day in J months. This point seems to be illustrated in Figure 2 that shows that the h'F values at the sunset hours (marked in the figure) are significantly smaller in J months than in the months of regular spread F occurrences. The vertical velocities and h'F values in the post sunset period are, however, as large, but considerably delayed in J months, in comparison with D and E months, so that any initial perturbation source, if regularly present at sunset hours in J months, does not seem to persist long enough to cause the generation of the irregularities in these months. However, on the exceptional nights (that are few) when they do occur in the J months, the differences in V_{zp} and h'F values with respect to the days of nonoccurrences seem to be present as in the D and E months. Therefore, we may point out that the general absence of spread F events in J months does not seem to be explainable only on the basis of a hypothesis of a general absence of the seeding mechanism from sources such a TIDs and thunderstorm activities, (see, for example, Röttger [1981]), in these months, since as Figure 2b shows there is significant increase in the F layer base height (as also in the V_{zp} though not shown here) on the days of spread F occurrences as compared do the days of nonoccurrences.

4. Conclusions

The main conclusions from the present study are the following. The range spread F indices from ionograms, during the four hours following the onset of spread F in the equatorial ionosphere over Fortaleza, during the D and E months, is directly correlated with the prereversal peak in the F region ionization drift velocity, as deduced from the ionograms. The substantial scatter in the index values for a given V_{zp} could be arising, at least partly,

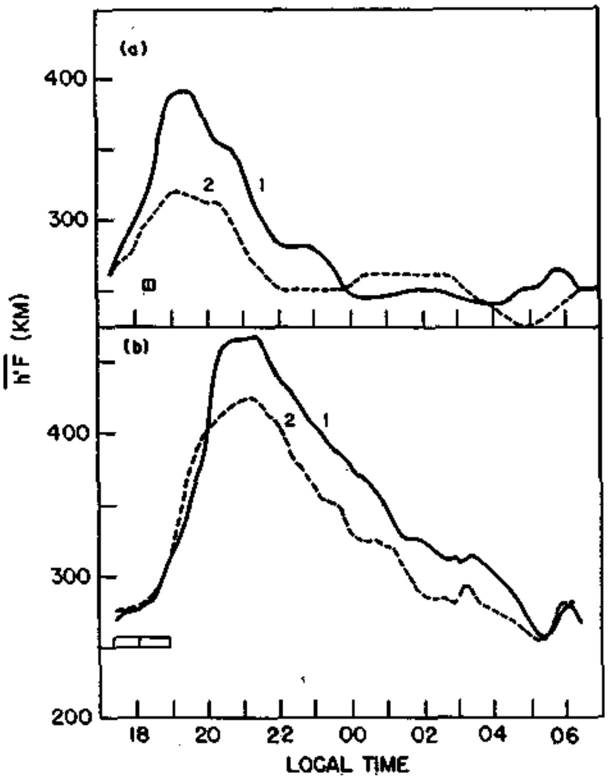

Fig. 2. (a) Heights of F layer base, read as h'F from ionograms, plotted as mean for 6 days of spread F occurrences (solid line) corresponding to the 6 days of nonoccurrences (dashed line) observed during the spread F season, namely, D and E months, in 1978. (b) Similar curves as in (a) prepared for northern solstice months. Here, only four nights of range type spread F events, observed in these months, are included. The rectangles marked at the evening hours are the durations of sunset between the conjugate E layers, for Fortaleza, taken at ±12° from magnetic equator [see Abdu et al., 1981b]. The middle line that divides the rectangles into two represents the time of local E layer sunset over Fortaleza. The rectangles in the part(a) is representative of December, while that in part(b) is representative of June.

from day to day variabilities in the initial perturbation source (or the seeding mechanism) which is a prerequisite for the generation of the irregularities by the well-known plasma instability processes. Other sources of the scatter of indices could possibly be variations in the exospheric temperature and densities that determine the ion-neutral collision frequency, and possible variabilities in the ion density gradient scale length at the F layer base. The relationship between the spread F index and V_{zp} is studied here only for the southern solstice (D) and equinoctial (E) months, as during the northern solstice (J) months the occurrence of the range type spread F is very rare. During the months of regular spread F occurrence, (namely, D and E months) there seems to be a threshold value for the V_{zp} (around 15 m s^{-1}), above which only range type spread F events occur. They do not generally occur even when the V_{zp} values reach above this threshold value in northern solstice (J) months. A comparison of the h'F variations for groups of days representing, separately, the spread F occurrences and nonoccurrences during the D and E months and J months, showed that the highest value of h'F (and V_{zp}) on both the groups of days occurs in the postsunset hours, but significantly later in J months than in D and E months (see also Abdu et al. [1981b]). But the maxima of h'F and V_z values on the days of spread F nonoccurrences in J months are as large as on days of spread F occurrence in other months. These observations seem to suggest that any initial perturbation mechanism for the irregularity generation, that might be present in J months, (as it seems to be the case in the other months), does not seem to persist, in general, with significant amplitude for more than about 2 hours, which is the observed delay between the local sunset and the time of the V_{zp} (as determined from the curves of Figure 2b). This delay is of the order of only a few minutes in the D and E months, as can be verified from Figure 2a.

Acknowledgements. This work was partially supported by the Fundo Nacional de Desenvolvimento Científico e Tecnológico under contract FINEP-130/CT.

The editor thanks J. P. McClure and another referee for their assistance in evaluating this paper.

References

Abdu, M. A., I. S. Batista, and J. A. Bittencourt, Some characteristics of spread F at magnetic equatorial station Fortaleza, J. Geophys. Res., 86, 6836-6842, 1981a.

Abdu, M. A., J. A. Bittencourt, and I. S. Batista, Magnetic declination control of the equatorial F region dynamo electric field development and spread F, J. Geophys. Res., 86, 11443-11446, 1981b.

Anderson, D. N., and G. Haerendel, The motion of depleted plasma regions in the equatorial ionosphere, J. Geophys. Res., 84, 4251-4256, 1979.

Bittencourt, J. A., and M. A. Abdu, A theoretical comparison between apparent and real vertical ionization drift velocities in the equatorial F region, J. Geophys. Res., 86, 2451-2454, 1981.

Booker, H. G., and H. W. Wells, Scattering of radio waves in the F region of the ionosphere, Terr. Magn. Atmos. Electr., 43, 249-256, 1938.

Chaturvedi, P. K., and P. K. Kaw, Steady state finite amplitude Rayleigh-Taylor modes in spread F, Geophys. Res. Lett., 2, 1975.

Dungey, J. W., Convective diffusion in the equatorial F region, J. Atmos. Terr. Phys., 9, 304-310, 1956.

Farley, D. T., B. B. Balsley, R. F. Woodman, and J. P. McClure, Equatorial spread F: Implications of VHF radar observations, J. Geophys. Res., 75, 7199-7210, 1970.

Fejer, B. G., D. T. Farley, R. F. Woodman, and C. Calderon, Dependence of equatorial F region vertical drifts on season and solar cycle, J. Geophys. Res., 84, 5792-5796, 1979.

Heelis, R. A., P. C. Kendall, R. J. Moffett, D. W. Windle, and H. Rishbeth, Electrical coupling of the E and F regions and its effects on F region drifts and winds, Planet. Space Sci., 22, 743-756, 1974.

Lyon, A. J., N. J. Skinner, and R. W. Wright, Equatorial spread F at Ibadan, Nigeria, J. Atmos. Terr. Phys., 21, 100-119, 1961.

McClure, J. P., W. B. Hanson, and J. F. Hoffman, Plasma bubbles and irregularities in the equatorial ionosphere, J. Geophys. Res., 82, 2650-2656, 1977.

Ossakow, S. L., S. T. Zalesak, B. E. McDonald, and P. K. Chaturvedi, Nonlinear equatorial spread F: Dependence on altitude of the peak and bottomside electron density gradient scale lenght, J. Geophys. Res., 84, 17-29, 1979.

Rishbeth, H., Polarization fields produced by winds in the equatorial F region, Planet. Space Sci., 19, 357-369, 1971.

Rishbeth, H., The F region dynamo, J. Atmos. Terr. Phys., 43, 387-392, 1981.

Röttger, J., Equatorial spread F by electric fields and atmospheric gravity waves generated by thunder storm, J. Atmos. Terr. Phys., 43, 453-462, 1981.

Scannapieco, A. J., and S. L. Ossakow, Nonlinear equatorial spread F, Geophys. Res. Lett., 3, 351-454, 1976.

Tsunoda, R. T., Magnetic field-aligned characteristics of plasma bubbles in the nighttime equatorial ionosphere, J. Atmos. Terr. Phys., 42, 743-752, 1980.

Woodman, R. F., Vertical drift velocities and east-west electric fields at the magnetic equator, J. Geophys. Res., 75, 6249-6259, 1970.

Woodman, R. F., and C. LaHoz, Radar observations of F region equatorial irregularities, J. Geophys. Res., 81, 5447-5466, 1976.

(Received March 12, 1982;
revised June 21, 1982;
accepted August 19, 1982.)