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Y. Nakamura

9. Authorship *M.A. Abdu*
O.R. Nelson
I.S. Batista
J.H.A. Sobral

Responsible author

13. Authorized by

Nelson de Jesus Parada
Director General

14. Abstract/Notes

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DEPENDENCE OF EQUATORIAL F-REGION PLASMA BUBBLE RISE VELOCITY AND DYNAMO ELECTRIC FIELD ON SOLAR CYCLE

M.A. Abdu, O.R. Nelson, I.S. Batista and J.H.A. Sobral

Instituto de Pesquisas Espaciais - INPE
Conselho Nacional de Desenvolvimento Científico e Tecnológico - CNPq
12200 São José dos Campos, S.P., Brasil

ABSTRACT

Latitudinally spaced ionosonde observations of spread F events in a restricted longitude sector of the Brazilian equatorial region has enabled determinations of statistically reliable values for the transequatorial plasma bubble vertical rise velocity (as described by Abdu et al., 1983). Measurements carried out of this parameter and of the F-region ambient ionization vertical drift prereversal enhancement during the past few years, 1975-1976, 1978-79 and 1980-81, show their significant dependence on sunspot cycle. Further, the spread F onset local times at the equatorial as well as at the low latitude locations are found to be delayed during low sunspot years as compared to high activity years. Implications of these results are discussed in the light of possible solar cycle changes in the F-region dynamo field intensity.

INTRODUCTION

Equatorial F-region plasma vertical drift prereversal enhancement in the evening hours, arising mainly from the F-region dynamo induced polarization electric field development at these hours, is now widely accepted as a basic criterion for the generation and growth of transequatorial plasma bubbles under magnetically quiescent conditions. The dynamics and morphology of equatorial plasma bubbles and their associated irregularities have been the subject of rather extensive investigation in recent years using VHF radars, satellite and rocket in situ measurments, radio and photometric diagnostics and theoretical model studies (see for example, Woodman and La Hoz, 1976; Tsunoda et al., 1982; McClure et al., 1977; Szuszczewicz et al., 1981; Weber et al., 1980; Sobral et al., 1980; Abdu et al., 1983; Anderson and Haerendel, 1979; Zalesak et al., 1982). On the other hand, different aspects of the ambient ionospheric dynamic conditions have been investigated using the incoherent scatter radar measurements over Jicamarca (Woodman, 1970; Woodman et al., 1977; Fejer et al., 1979). Also, some specific studies on the prereversal enhancement in the F-region vertical ionization drift have been carried out from ionosonde observations in Brazil (Abdu et al., 1981). Simultaneous information on the plasma bubble and the ambient ionosphere dynamics are useful for gaining important insight into the basic electrodynamic processes that are at work in the equatorial plasma bubble phenomena. Such simultaneous information are, however, sparsely available because of some inherent limitations on the relevant measurement techniques. Recent studies using latitudinally spaced ionosonde observations in the Brazilian longitude sector by Abdu et al. (1983) have shown the possibility, in principle, to measure simultaneous plasma bubble rise velocity as well as the F-layer vertical drift in the evening hours. However, the available ionosonde location geometry coupled with the observational schedule did not permit determination of individual bubble velocities but provided reliable statistical mean value, representing a few days, of this parameter. The F-layer rise velocities, on the other hand, could be determined over the equator with adequate precision on individual evenings, since the layer heights are near or above 300 km at these hours (Bittencourt and Abdu, 1981). In the present paper we have extended the analysis method described by Abdu et al. (1983) to examine possible dependence of these two important parameters on solar activity cycle.

DATA ANALYSIS AND RESULTS

The evening range spread F onset local times and F-layer height (h'F) data over Fortaleza (4^{o}S, 38^{o}W, dip latitude 1.8^{o}S), an equatorial station, and over Cachoeira Paulista (23^{o}S, 45^{o}W, dip latitude 14^{o}S), a low latitude station, have been analysed for October, November, December and January months of the irregularity producing seasons of 1975-76, 1978-79 and 1980-81, the mean sunspot numbers for these epochs being 16, 116 and 146, respectively. The plasma bubble rise velocities were calculated using the evening first onset times of range spread F events over Fortaleza and Cachoeira Paulista based on a procedure described by Abdu et al. (1983).

Figure 1 shows the spread F onset local times over the equatorial and low latitude locations (in the two upper frames) plotted as 9-day running means for October, November, December and January months of 1975-76 representing low sunspot years and of 1978-79 and 1980-81 representing high sunspot years. Over the equator the spread F onset local times during the low sunspot years are found to be significantly later than during high activity epochs. Same trend is seen, more enhanced, over the low latitude location Cachoeira Paulista. For a given epoch the spread F onset times at the low latitude location are later than over the equator. The differences between these onset times, Δt, are shown in the lower frame of the Figure 1. This time difference is interpreted as caused by the finite time that a flux tube aligned plasma bubble irregularity structure takes to propagate upward from the field line of its generation over the equator to the apex of the field line that meets the low latitude bottomside F-region. Therefore, from simple geometrical considerations, and knowing the magnetic field line distribution in the equatorial ionosphere, it is possible to deduce the plasma bubble rise velocities from the measurements of Δt's. Although the bubble eastward velocity could reach on the order of 200 ms^{-1} (Abdu et al., 1985a),and it is not measured simultaneously,the variations in this value will have only small effect on the deduced bubble rise velocity as explained by Abdu et al. (1983). We have further assumed that the local onset times of the bubbles and their conditions of generation are practically the same along a restricted longitude sector of the magnetic equator as it applies to our present study.

In the upper frame of Figure 2 we have presented 9-day running means of the plasma bubble rise velocity, $\overline{V}_B$, deduced as described above, for the three epochs of the present study. The velocities are, in general, lower during the low sunspot years and higher during the high sunspot years. We should caution the reader about the poor statistics of the available data during some parts of these curves; in particular the statistics is poor during the prominent peaks in $\overline{V}_B$ centered around December 15, 1978 and in the later part of January 1979. Further, the 1978-79 curve presents some differences from our previous published values for the same period (Abdu et al., 1983) due to the fact that some data points have been reconsidered and included in the new analysis. The sunspot cycle variation in the mean velocities is found to be significant, the ratio of the monthly average $\overline{V}_B$ values for the high to low activity periods ranging from approximately 1.5 to 3.

The F-layer vertical drift evening prereversal enhancement peak amplitude (V_{zp}), namely, the F-layer dynamo induced eastward electric field at sunset hours, is plotted, in the form of 9-day running mean values, $\overline{V}_{zp}$, in the lower frame of Figure 2 for the three epochs. Here again a clear dependence of $\overline{V}_{zp}$ on sunspot number is evident. The factor of increase from low to high activity epochs is ~2.5. In some part of the curve, namely, during part of October, in November, and again in parts of December and January, the

$\overline{V}_{zp}$ values seem to assume intermediate values corresponding to the intermediate sunspot number values lying between the lowest and highest limits attained in the three epochs. However, in major parts of these curves a sunspot saturation in both $\overline{V}_B$ and $\overline{V}_{zp}$ seems to be the rule. Another important feature of the results in Figure 2 is that the correlation between $\overline{V}_B$ and $\overline{V}_{zp}$ is generally poor on short-term scale (days to weeks), (although many exceptions are evident as also shown in Abdu et al., 1983), but important on the scale of solar activity cycle, namely, both $\overline{V}_B$ and $\overline{V}_{zp}$ increase significantly from low to high activity period.

DISCUSSION AND CONCLUSIONS

Significant solar activity dependence of the F-region ionization vertical drift (V_z) prereversal enhancement, namely, the eastward ambient electric field, as well as the plasma bubble rise velocity, are evident in the results presented here. The solar cycle dependence of the V_{zp} as measured by Jicamarca radar has been discussed by Fejer et al. (1979). The V_{zp} values over Jicamarca are found to be, in general, lower than those over Fortaleza for both the solar activity maximum and minimum epochs. The ratio of V_{zp} from one epoch to the other seems to be, however, comparable, if we consider the equinoctial values of Fejer et al. For other epochs this ratio is undeterminable since the prereversal enhancement in V_z is almost absent during those epochs of low sunspot years over Jicamarca.

It might be worthwhile to discuss here briefly the existing ideas on the mechanism and parameters possibly responsible for the observed solar cycle effects on the V_z prereversal enhancement. Importance of F-region dynamo in producing the prereversal V_z enhancement has been discussed by Rishbeth (1971), Heelis et al. (1974) and Matuura (1974) (see also Abdu et al., 1981 for magnetic declination angle effect on the F-region dynamo field development). The combined effects of E and F-region tidal winds have been considered by Heelis et al. (1974) in their numerical model for explaining the

F-region plasma motion. Under the daytime conditions the equatorial F-region plasma is driven mainly by the E-region dynamo-induced electric field coupled along the perfectly conducting magnetic field lines, while the F-region field line perpendicular current produced by thermospheric pressure gradient winds (namely, the F-region dynamo current) causes field aligned current to flow that has its path completed via the highly conducting daytime E-region. Under the post sunset condition the extremely poor conductivity of the E-region disrupts the flows of the field aligned current, thus causing the development of F-region polarization electric field which then dominates the F-region plasma flow (Rishbeth, 1971). Therefore, under the day to night transition period, characterized by the presence of a longitudinal gradient in the conjugate E-layer conductivities, having corresponding gradients also in the dynamo and field aligned currents as well, there would result an enhancement in the eastward ambient electric field which in turn could cause the V_z prereversal enhancement. The two important factors basically responsible for the V_z enhancement could therefore be the thermospheric wind amplitude and the E-region conductivity longitudinal gradient scale length. Thus if long-term variations in the E-layer conductivity gradient is assumed to be small, then a solar cycle variation in the thermospheric wind strength could produce the type of solar cycle changes in $\overline{V}_{zp}$ observed from our present analysis.

The effect of the ambient electric field on the plasma bubble process has in fact two aspects namely, in determining the bubble generation (plasma instability) condition and then in the subsequent bubble vertical growth rate (V_B). The first aspect can be verified from the fact that spread F onsets are, in general, later in local time during low sunspot years when the $\overline{V}_{zp}$ amplitudes are lower. This could indeed be so if a threshold height criterion is a necessary condition for the spread F producing generalized gradient drift instability mechanism to be operative (see for example, Farley et al., 1970; Abdu et al., 1983) so that in a rising evening F-layer the local time of attaining such threshold heights would depend upon the layer vertical drift velocity. The later onset local times under the lower $\overline{V}_{zp}$ values of the low sunspot years and the earlier onset times under the higher $\overline{V}_{zp}$ values of high sunspot years seen in Figures 1 and 2 are consistent with this picture. It might be noted further that in the higher ranges of $\overline{V}_{zp}$ values (those of 1978-79 and 1980-81) the trend of the onset time getting earlier (later) with increasing (decreasing) $\overline{V}_{zp}$ values is often violated. This might point out the importance of additional conditions for the irregularity generation. One such additional requirement should be the presence of an initiating perturbation source in the form of, for example, a gravity wave giving rise to altitude modulation in the F-layer ionization distribution and its phase relationship with the vertical ionization drift (see for example, Booker, 1979; Tsunoda and White, 1981; Klostermeyer, 1978).

The influence of the V_{zp} (i.e. ambient electric field) on the bubble growth (vertical rise) velocity has been investigated by Anderson and Haerendel (1979) using magnetic flux tube integrated parameters. For the bubble generation at a given height, and under a given integrated electron density gradient scale length, the rise velocity starting from the initial stage itself is higher for higher ambient electric field (E_0). In fact the bubble polarization field (E_1) responsible for the rise velocity depends also on bubble depletion magnitude, besides the ambient field. The numerical results of Anderson and Haerendel show also that the ambient electric field positively influences the rapid growth of the bubble depletion magnitude, so that typically some 20 minutes from the bubble development initiation this parameter completely rules the vertical rise velocity. Thus depending upon the height and electron density gradient scale length at which the bubble development is initiated the ambient electric field could have varying positive influence on the bubble rise velocity. The solar cycle variation in the bubble rise velocity obtained from our analysis would therefore be consistent with a corresponding variation in the F-region dynamo field which in turn could be produced mainly from a solar cycle dependent thermospheric wind pattern of appropriate magnitude. The implications of these solar cycle dependent ambient F-region, and plasma bubble, dynamics on the equatorial spread F morphology have been discussed very briefly by Abdu et al. (1985b).

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FIGURE CAPTIONS

FIGURE 1 - Local times of range spread F onsets during the October, November, December and January months of 1975-76 (full line), 1978-79 (dotted line) and 1980-81 (dashed line) plotted for the equatorial station, Fortaleza, and low latitude station, Cachoeira Paulista. The time differences in the local time of spread onsets at the two stations are plotted in the lowest frame for the three epochs respectively.

FIGURE 2 - Nine-day running means of plasma bubble vertical rise velocities ($\overline{V}_B$) for the October-January period of the low sunspot epoch 1975-76 and high sunspot epochs 1978-79 and 1980-81 in the same format as that of Figure 1. Lower half of the figure presents the nine-day running means of the amplitude of the vertical ionization velocity evening prereversal enhancement ($\overline{V}_{zp}$) plotted for the corresponding months and sunspot epochs as those of the $\overline{V}_B$ values.

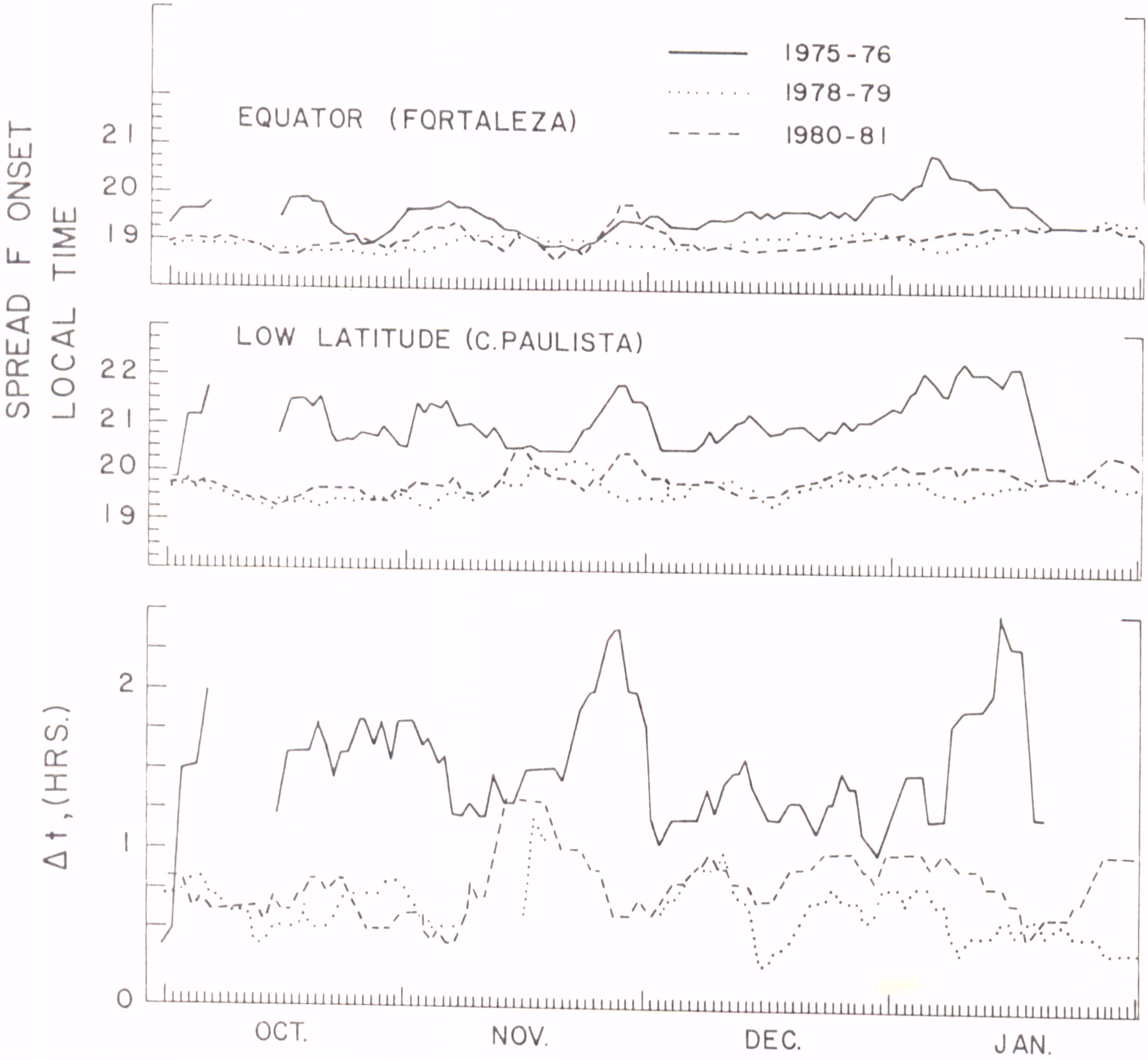
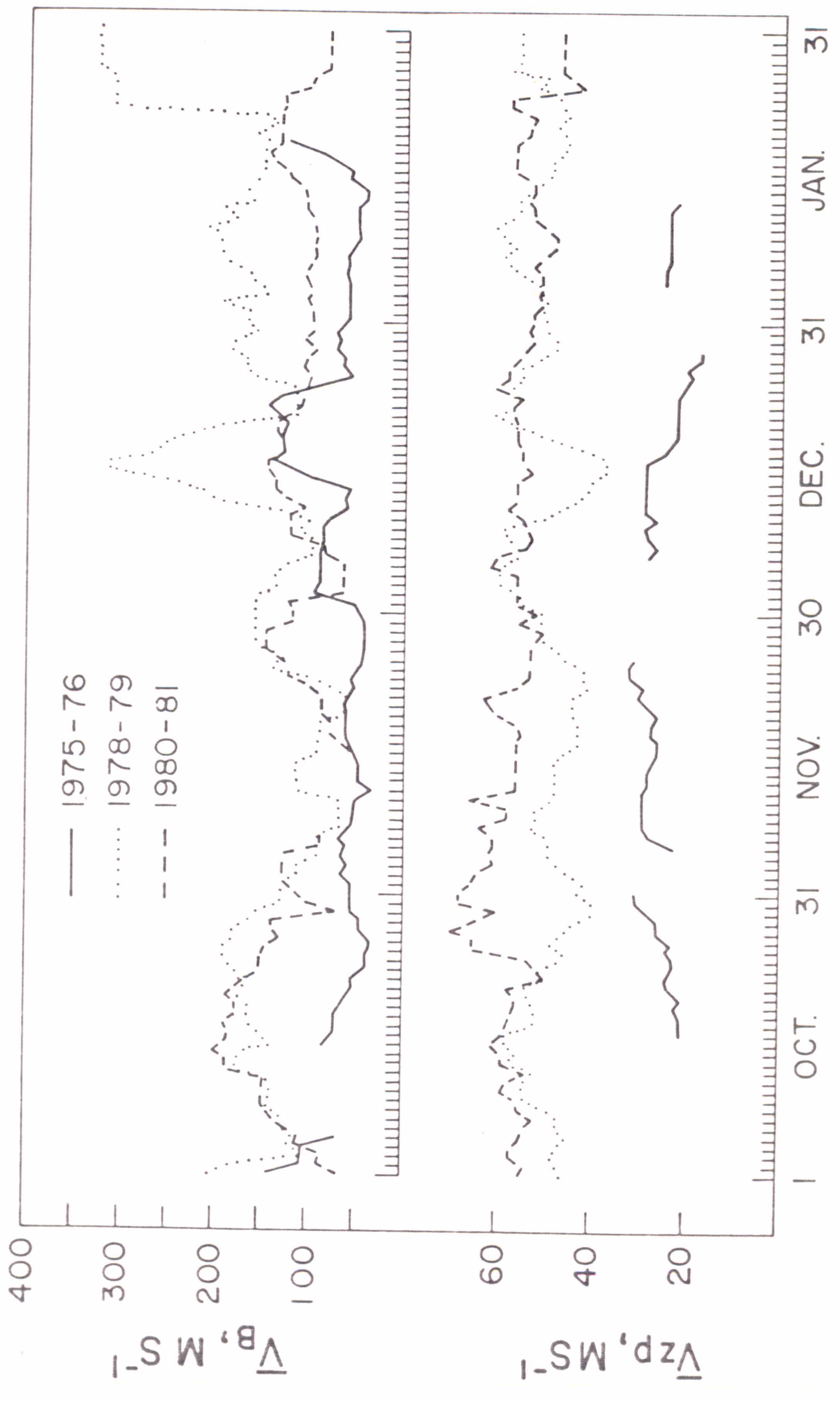

1975-76
1978-79
1980-81
EQUATOR (FORTALEZA)
LOW LATITUDE (C.PAULISTA)
SPREAD F ONSET
LOCAL TIME
21
20
19
22
21
20
19
Δt, (HRS.)
2
1
0
OCT.
NOV.
DEC.
JAN.

Fig. 1



1975-76
1978-79
1980-81
400
300
200
100
60
40
20
V_B, M S^-1
Vzp, MS^-1
1
OCT.
31
NOV.
30
DEC.
31
JAN.
31

Fig. 2