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ABSTRACT

A comparative study is carried out of the spread F occurrence rates at Fortaleza (4^{O}S, 38^{O}W) and Huancayo (12^{O}S, 75^{O}W), two stations located along the magnetic equator in the American zone. While there are similarities in the gross features of the range type spread F occurrences, profound differences, on a seasonal basis, are present in the case of the frequency type spread F at the two stations. Profound dissimilarities are observed also in the evening enhancement in the F-region vertical drift velocity (V_Z) measured over Jicamarca (and the F-region height changes observed over Hancayo), with respect to that observed over Fortaleza, in that the seasonal trends in the local times of prereversal V_Z peak occurrences are in exactly opposite sense at the two stations. An attempt is made to interpret these results in terms of the differences in the magnetic field declinations at the two stations that cause significant differences in the conjugate E-region sunset durations and, hence, in differing rates of F-region polarization electric field developments at these stations. Influence of the F-region dynamo on the gross features of the prereversal V_Z peak and spread F characteristics seems to be born out in the present results.

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1. INTRODUCTION

One of the important morphological aspects of equatorial ionospheric irregularities is the longitudinal difference in their occurrence rates revealed from satellite measurements (Hanson and Sanatani[1],1971; Basu and Basu[2],1976). This difference is characterized, in particular, by a global maximum of occurrence over the Brazilian longitude in the Atlantic zone in such a way that there is a rapid increase in the occurrence rate within a few degrees eastward of Huancayo. Extensive studies on the morphology of these irregularities have been carried out based on the spread F echoes in vertical incidence ionograms, ever since the early investigation on the subject, by Booker and Wells[3](1938). However, this particular aspect of the longitudinal variation of the irregularity occurrence has not received adequate attention so far. On the other hand, the rapid change in the magnetic field configuration, especially that of the declination angle along the magnetic equator in South America, could be an important factor in shaping the longitudinal variations of the spread F occurrences and related parameters over this region (see Hanson et al.[4], 1973).

In the present paper we have undertaken a comparative study of the spread F occurrence rates and related F-region parameters for two magnetic equatorial stations in the American zone, namely, Huancayo, Peru (geographic 12^{o}S,75^{o}W, dip lat. 0.6^{o}) and Fortaleza, Brazil (geographic 4^{o}S, 38^{o}W, dip lat. -1.7^{o}). From the early works of Booker and Wells[3](1938) and from many later works based on ionosonde, as well as coherent and incoherent radar investigations, it has become an established fact that the evening rapid rise of the F-layer, produced by a prereversal enhancement in the F-region ionization drift velocity, is closely linked in some way with the development of the equatorial spread F (Woodman[5],1970; Farley et al.[6], 1970; Skinner and Kelleher[7],1971). Hence, a comparative study is carried out also of the radar measurement of the vertical drift velocity over Jicamarca, with vertical drift velocity deduced from ionograms over Fortaleza. Remarkable dissimilarities in the vertical velocity characteristics are observed, which seems to be an important factor in the observed differences in the spread F occurrence rates at the two stations. The results on the vertical drift velocities seem to have interesting implications also on the theoretical predictions of the role of F-region dynamo in causing the rapid rise of the post sunset F-region.

2. SPREAD F OCCURRENCE AT FORTALEZA AND HUANCAYO

In a recent paper (Abdu et al.[8],1981) we have presented and discussed some characteristics of spread F over Fortaleza. In Figure 1 we present a summary of the spread F occurrence rates over Fortaleza of both the range type and frequency type for the one year period from September 1978 till August 1979. The range spread occurrence is higher during the eight-month period from September till April, which is in agreement with the yearly distribution of the 137 MHz scintillation index over Huancayo during low and high sunspot years presented by Aarons[9](1977). Over Fortaleza, the period from October to January, in particular, has the highest percentage of long lasting spread F, whereas the scintillation occurrence over Huancayo shows maxima in November and February (Aarons[9],1977). On the other hand, the frequency type spread F occurs over Fortaleza most frequently during the northern solstice (winter) months of May, June and July, with almost negligible occurrence during the southern solstice months.

In Figure 2 we have compared the mean nighttime variations, for the three seasons (southern solstice, equinoxes and northern solstice) of range type and frequency type spread F for Huancayo and Fortaleza. The curves for Huancayo were taken from Rastogi[10](1978) and correspond to the year 1961 (the sunspot numbers for 1961 and 1978-79 being 70 and 85 respectively, the small difference in these numbers might not cause any significant change in the spread F occurrence rates, as the results of Chandra and Rastogi[11],1970, indicate). The following contrasts, in the spread F occurrence features at the two stations, may be noted: (a) the range type spread F occurrence is higher during summer and equinoxes over Fortaleza, than over Huancayo, especially during the premidnight hours ; (b) during a few hours immediately following the local sunset, the spread F occurrence (which is mainly that of range type) is significantly higher over Fortaleza throughout the year; (c) perhaps the most outstanding difference is in the seasonal variation in the occurrence rates of the frequency spread type irregularities that show a summer maximum over Huancayo, whereas Fortaleza presents a winter maximum. While the summer maximum over Huancayo could be considered as part of the overall spread F enhancement over this station, the winter enhancement over Fortaleza, which is confined to the frequency type spread F only, seems to be an abnormal feature.

3. F-LAYER HEIGHT AND VERTICAL VELOCITY AND SPREAD F

Close connection between the spread F occurrence and vertical movements of the F-layer has been known since the early work over Huancayo by Booker and Wells[3](1938). Farley et al.[6](1970) observed that the onset of spread F, as seen in the VHF backscatter radar results over Jicamarca, was associated, in many cases, whith upward motion of the F-layer. They suggested also that the bottomside of the layer must be above some threshold altitude if the instability causing the spread F is to occur. Rastogi[10](1978) summarised that the onset of range spread F occurs when the F region drifts are upwards, but the peak occurrence takes place about an hour later, by which time the drifts get reversed downward, a feature that has been observed also in the earlier backscatter results of Clemesha[12](1964) over Ghana. Monthly mean relationships of the spread F occurrences and F-layer height variations over Fortaleza are presented in Figure 3 for different seasons. Plotted in the same figure are the vertical ionization drift velocities, derived as $d(\overline{h'F})/dt$, which could give essentially the same results as from a Doppler measurement of the true velocity when the low lying ionization is small and the layer is sufficiently high (Farley et al.[6],1970). Bittencourt and Abdu[13](1981) have shown theoretically that the threshold height, above which the true velocity and that deduced from the movements of the iso-electron density contours of the F-layer are equal, is in the vicinity of 300 km. Our discussion in this paper will be based on the V_z values in the evening and premidnight hours when the F-layer heights over Fortaleza are usually above 300 km.

Figure 3 shows that the range type spread F has its onset very close to (in fact a few minutes earlier than) the prereversal peak in the vertical drift velocity during equinoxes and summer months, when the amplitudes of these peaks are also higher. In these months the probability of the spread F occurrences increases sharply within an hour of their onset and, in fact, reaches their maxima even when the F layer drifts were upward. This feature is slightly different over Huancayo where, as Rastogi[10](1978) reported, the F-layer drift gets reversed downward by the time spread F occurrence rate reaches its maximum. The month of December presents largest number of long lasting events of range spread, the occurrence rate being around 90% for most part of the night. This may be attributed to the fact that one of the largest amplitudes of the V_z prereversal peak occurred in association with highest h'F values during this month. Also, the V_z peak seems to be followed by significant fluctuations in its value, present even in the monthly mean values, which could, perhaps, be caused by regular TID activity or by fluctuating east-west electric field (see Somayajulu et al.[14],1975). Part of the structures in the V_z curve could be attributed to the fact that it has been deduced from $\overline{h'F}$ values read at 15 minute intervals.

In winter (June) range type spread F has a minimum occurrence rate at both Fortaleza and Huancayo, as mentioned before, and the amplitudes of the prereversal maximum of the drift velocity are correspondingly weaker, compared to other months (in the case of Huancayo, this point can be verified from Figure 4 indirectly, or directly from Figure 5 that presents V_z values for Jicamarca). We may note, in particular, that for Fortaleza the prereversal maximum occurs later and has larger width giving rise to the post sunset $\overline{h'F}$ maximum which is later than, but as high as, in the other months. It is interesting to note that frequency type spread F occurrence has the highest rate in this month, having their onset times around 1940 LT, apparently coincident with a second peak in the prereversal V_z enhancement. The last point can be confirmed, however, only from a statistical study of individual events which we do not attempt in this paper.

Figure 4 presents a comparison of the monthly mean local time variations of F-layer heights during the three seasons, for Fortaleza and Huancayo. In the case of Huancayo, we have plotted $\overline{h'F}$ values for 1961, for which spread F occurrences were presented in Figure 2, and for 1978 corresponding to the simultaneous Fortaleza values. The Huancayo $\overline{h'F}$ values are very similar during 1961 and 1978 in the case of equinoctial and winter months. Summer values around midnight are, however, very different in the two years. The F-layer heights are found to be higher (except around midnight in summer) over Fortaleza, which might be responsible for the generally higher incidence rate of the spread F over this station compared to Huancayo, as was seen in Figure 2. An important point of contrast in the $\overline{h'F}$ variations over the two stations, presented in Figure 4, is that the times of the post sunset h'F maxima over Huancayo progress towards later hours, proceeding from winter to summer as expected roughly from the sunset times during the respective seasons, whereas for Fortaleza this trend is exactly reversed. This point merits special significance when we note that Fortaleza is located south of (though only 4^{o}S) the geographic equator as is Huancayo (12^{o}S). The monthly mean local time variations of the vertical drift velocities, measured by the Jicamarca radar, for the period 1968-71 (Fejer et al.[15], 1979), is presented together with the $d(\overline{h'F})/dt$ values deduced for Fortaleza, for the three seasons in Figure 5 (we may point out that the two periods considered for the two stations represent very similar phases of the solar activity cycle). The large difference in the amplitudes of the two sets of the vertical velocities present during the later hours of the night (after 22-23 LT), could be mainly due to the recombination process gaining importance when $\overline{h'F}$ values get below the threshold altitude of 300 km, as pointed out earlier (Bittencourt and Abdu[13],1981).

Figure 5 shows that the seasonal trend in the times of the prereversal peak of the drift velocities over Fortaleza is exactly opposite to that over Jicamarca, in agreement with the trend in the times of the post sunset $\overline{h'F}$ maxima presented in Figure 4. This could have consequences on the seasonal trend in the spread F occurrence as well.

4. DISCUSSION

There have been increasing efforts in recent years to unravel the problems of the equatorial ionosphere irregularities, by refinements in experimental observations, both from ground and space, and by advancements in theory and computer modelling (Farley et al.[6], 1970; Woodman and LaHoz[16], 1976; McClure et al.[17],1977; Haerendel[18],1974; Scannapieco and Ossakow[19],1976; Kelley et al.[20],1976; and Ossakow[21], 1979). The present consensus, on the generation and morphology of these irregularities, seems to be that in most cases they originate from a gravitational Rayleigh-Taylor type instability that operates in the presence of sharp density gradient, such as that existing in the bottomside of the evening equatorial F-layer, when the height of the layer is sufficiently raised. This primary R-T instability gives rise to electron density depleted regions or "bubbles" that provide regions of further sharp density gradients, allowing other types of instability mechanisms, such as $\underset{\sim}{E}\times\underset{\sim}{B}$ and drift wave mechanisms, to operate, thus giving rise to smaller scale sizes of the irregularities (Haerendal, 1974). On the other hand, the generations of these irregularities, whether by R-T mechanism or otherwise, will be aided if the initial source of disturbance is an atmospheric wave of TID type and if the irregularities so produced have drift velocities comparable to, and in the direction of, the phase speed of the TID, as suggested by several authors in recent years (Booker[22],1979; Beer[23], 1974; Whitehea[24],1971; and Klostermeyer[25],1978).

We have pointed out in an earlier paper, (Abdu et al.[8], 1981), that the range type of spread F over Fortaleza is seen almost always preceded by satellite traces, which we suggested as indicating that some sort of wave distrubance was a necessary condition for the formation of the irregularities giving rise to the range spread type echoes. In the presence of this, or other type of disturbance, the condition for the instability growth is that $\frac{1}{n_0}(dn_0/dh)(g/\nu_{in}) > \nu_r$ (Ossakow et al.[26],1979), where the scale height of the bottomside ionization distribution, $n_0/(dn_0/dh)$, is taken as $f/2(df/dh')$ and is estimated from the ionograms, assuming negligible low lying ionization. Here, ν_{in} is the ion-neutral collision frequency and ν_r is the recombination rate. Estimation from ionograms shows that, in cases where the above inequality was satisfied, range type spread F did, in general, occur and vice versa. Further, a height change of 20-30 km does affect the inequality condition even for the same scale length of the electron density distribution. The heights of the F-layer during equinoxes and summer, at the start of the range type spread, in Figure 3, is close to or above 300 km, whereas in winter, when the sunset occurs slightly before 18 LT (see the following discussion regarding the sunset conditions), the h'F has values significantly less than 300 km ($\sim$ 270 km), a height low enough to affect the above inequality condition for the growth of the R-T instability. Therefore, the winter minimum in the range type spread F over Fortaleza might be, in part, caused by the lower heights at sunset of the F-layer over Fortaleza. The post sunset winter F-layer does go up over Fortaleza, but at a slower rate (as the relatively lower V_z amplitude indicates), and attains a maximum significantly later, and of somewhat higher values, than in other months. This point raises the question as to why the range type spread echoes do not occur in winter even when the h'F goes up to the summer and equinoctial levels in the post sunset period. We may speculate over the following possible answers: (a) the scale length of the bottomside electron density distribution might not be sufficiently small enough to aid the growth of the instabilities; (b) the amplitude of the atmospheric wave disturbances might decay at distances farther from the sunset terminator; and (c) less frequent occurrences of the source of the initial disturbances in winter months, in general. More detailed studies should be carried out to verify these or other possibilities.

On the other hand, frequency type spread F has a maximum in winter months, which might possibly be associated with the later occurrences of large h'F values in this month. If this association is indeed true, then it might suggest that the circumstances leading to the generation and maintainance of these irregularities could be different from those responsible for the irregularities of range type spread F as was implied also, from different considerations, in some previous works (Chandra and Rastogi[11],1970; and Rastogi and Woodman[27], 1978; see also Abdu et al.[8], 1981). From the present results, it is interesting to note that the months of largest frequency type spread F occurrence, at the two stations, are also the months when the prereversal enhancements of V_z had broader maxima, or later occurrences of the post sunset h'F maxima, as can be verified from Figures 2, 3, 4 and 5, even though these months are from winter and summer seasons at Fortaleza and Huancayo, respectively. The monthly mean characteristics at the two stations seem to show also that, while larger amplitudes of the prereversal V_z peak, in general, occur in association with larger spread F occurrence rates, as has already been suggested from previous works (see, for example, Woodman[5], 1970), it appears necessary that the maxima in V_z should be sharper (or faster rise of the layer) when the probability of the range type spread F is high, and it should be broader when the occurrence of the frequency type spread F is high. (This point should, however, be confirmed from more detailed study of individual events, which we are presently carrying out.) These observations do not necessarily support the idea (see, for example, Skinner and Kelleher[7], 1971) that it is the ascending or descending velocities of the evening F-layer that determine the range spread type irregularity development. On the other hand, it might suggest that the F-layer should ascend to a threshold height (Farley et al.[6], 1970) where additional conditions for the irregularity growth are present, so that if any of these additional conditions has fast enough local time variations in the post sunset period, then a rapid or slow rise of the layer will determine whether or not the irregularities will be generated.

There are two important aspects concerning the differences in the spread F and h'F characteristics over Fortaleza and Huancayo that merit further attention: (1) the post sunset heights of the F-layer (especially in the premidnight period) are in general higher, with larger V_z prereversal amplitudes and correspondingly higher incidence of spread F, over Fortaleza, as compared to Huancayo; (2) seasonal trends in the times of the prereversal V_z maxima (and those of the post sunset h'F maxima) are exactly opposite at the two stations. The second aspect manifests itself in the significantly later occurence of the times of these maxima in winter over Fortaleza, as compared to Huancayo where they seem to be normal, or at least in the proper sense, as expected from that of the sunset times. Associated with this aspect seems to be, as mentioned before, the winter maximum in the frequency spread over Fortaleza, as compared to its summer maximum over Huancayo.

The second aspect, in particular, seems to be very significant, as these pronounced differences are observed between two stations separated by only 38^o of longitude in the American zone. Important influential factors causing these differences might lie in the large differences in the magnetic declination angles (being 20^oW at Fortaleza and 4^o E at Huancayo) as the following considerations would show, and perhaps, also in the relative separation of the two stations from the geographic equator.

The daytime upward drift of the F-region ionization and its reversal after sunset (Woodman[5],1970); Fejer et al.[15],1979) are determined by appropriate eastward and westward electric fields respectively. These electric fields have two main sources, namely, an E-layer dynamo field that is mapped on to the F-region by the highly conducting field lines and an F-region polarization electric field, produced by thermospheric winds, that gets short circuited during daytime by the high conductivity of the E-region. By sunset, the decreasing E-layer conductivity causes a certain decoupling of the E and F-layers, with the result that the F-region polarization electric field dominates to control the F-region ionization drift (Rishbeth[28],1971, [29]1977). Theoretical study by Heelis et al.[30](1974) has demosntrated that the evening enhancements, or the prereversal maxima, in the upward drift velocity, such as that measured by the Jicamarca radar (Woodman[5],1970) could be satisfactorily explained by this decoupling process. Thus, we could see that the times of the prereversal maximum in V_z should be determined by sunset times at the conjugate E-layers over the low latitudes that are coupled to the equatorial F-region by magnetic field lines. We have calculated these sunset times for Fortaleza and Jicamarca, considering conjugate E-regions to be at $\pm 12^o$ magnetic latitudes for the two stations, and assuming that the solar radiation responsible for the E-layer ionization is completely absorbed above 80 km (namely, a screening altitude of 80 km).

The sunset times, so calculated, are marked in Figure 5 in the form of rectangles (marked F and J for Fortaleza and Jicamarca, respectively), whose lengths in time represent the duration of the sunset starting from one conjugate E-layer and ending at the other (the rectangles are divided into two at the points corresponding to the local E-region sunset times, at the respective stations). For summer conditions over Fortaleza, the sunset duration between the conjugate E-layers is very small, being only 11 minutes, due to the large declination angle of the field lines over Fortaleza, whereas for Jicamarca, the sunset duration is significantly longer, being 108 minutes. We way note that the width of the prereversal peak in V_z is correspondingly smaller over Fortaleza and larger over Jicamarca. This trend is exactly reversed in winter months, when the sunset duration is largest for Fortaleza (117 minutes) and significantly smaller (41 minutes) for Jicamarca, with corresponding differences in the widths of the prereversal V_z peaks also present at the two stations. In equinoctial months, the difference in the sunset duration does not appear to be significantly pronounced to reflect as differences in the V_z peak widths. The reversal, at the two stations, of the seasonal trend in the times of the V_z peaks, is also clearly present in the calculated sunset duration. Thus, we may observe that there does appear to be present a definite dependence of the width of the prereversal peak of F-region drift velocities on the duration of the sunset between the conjugate E-regions. We may point here that this relationship, in fact, seems to provide an experimental verification of the theoretical prediction of the role of F-region dynamo (Rishbeth, 1971; Heelis et al., 1974) on the evening V_z enhancements. Such a verification is possible because of the large difference in the magnetic declination angle between Jicamarca and Fortaleza. Thus, the gross features of the spread F occurrences, vis-a-vis F-region height variations, appear to be controlled to some extent by the thermospheric winds, through their role on the generation of the F-region dynamo.

The general tendency in the V_z curves in Figures 5 is that the evening enhancements of the drift velocities start a little before the onset of sunset at the first conjugate E region, and the post maximum decrease starts immediately following the termination of the sunset at the other conjugate E-region. However, we may notice that this pattern has a certain alteration in winter over Fortaleza, where the V_z enhancement starts somewhat later after the initiation of sunset and the maximum is reached well after the termination of sunset at the conjugate E-region. The reason for this delay, in the V_z enhancement features, is not clear to us. However, we speculate over possible presence, in this month, of sufficiently large conductivities at the northern conjugate E-region, even after the initiation of the sunset at the southern conjugate E-region, unlike in summer months when the sunset duration between the conjugate E-regions is very small. Further, we may point out that at the southern conjugate E-region itself, appreciable conductivity might be present even at sunset hours due possibly to particle produced ionization in the south Atlantic geomagnetic anomaly. In fact, secondary peaks, during evening hours in some winter months, in the occurrence of sporadic E layers of blanketing type presumably produced by charged particle precipitation in the anomaly region, have been reported over Cachoeira Paulista (22°S,45°W) (Abdu and Batista[31],1977). Another possible cause of the delay could be in the role of thermospheric zonal winds in driving interhemisphere ionization fluxes, which is strongly controlled by the magnetic declination angles, as the recent Atmosphere Explorer satellite results indicate (Heelis and Hanson[32],1980), and their seasonal dependence.

5. CONCLUSIONS

The present study of the spread F occurrences and F-layer height variations over Huancayo and Fortaleza shows that there are some similarities in their characteristics at the two stations, while profound dissimilarities are also present. The onset of range type spread F occurs at sunset with upward vertical movement of the F-layer, at both stations, although they seem to be taking place at a more rapid rate over Fortaleza than over Huancayo. Higher rates of range type spread F occurrence during summer and equinoctial months are observed at both places, although the rate is somewhat higher, especially during the premidnight hours, over Fortaleza. The spread F occurrence over Fortaleza is higher during a few hours immediately following the sunset, throughout the year.

Pronounced dissimilarity is evident in the occurrence rates of frequency type spread F, in that the yearly maximum occurs in summer over Huancayo, whereas Fortaleza presents a winter maximum. This dissimilarity seems to have its counterpart in the characteristics of the F-region height variations as well, as seen in the prereversal peak in the vertical ionization drift velocity, and the post sunset $\overline{h'F}$ maximum, occurring at local times that vary with season in exactly opposite directions at the two stations. This similarity in the opposite seasonal trend observed in the occurrence rates of frequency type spread F, and that of the times of V_z prereversal peak might suggest that the mechanism for generation of the irregularities of the frequency type spread F could be different from that responsible for the range type spread F, in agreement with some earlier observations.

An attempt is made to qualitatively explain the dissimilarities in the evening enhancements of V_z, at Fortaleza and Huancayo, as being caused by differences in the developments of the F-region polarization electric fields, at the two stations. The significant differences in the magnetic declination, present at the two stations, causes sunset durations between conjugate E-regions of the respective stations to be significantly different and to occur with exactly opposite seasonal trends in much the same way as the observed seasonal trend in the times of the V_z prereversal peak (and their durations) at these stations. Thus, the present results seem to provide an experimental verification of the theoretical predictions of the role of the F-region dynamo on the evening V_z enhancements and, hence, have implications on the possible role of the thermospheric winds in controlling the gross features of the spread F occurrences at Fortaleza and Huancayo. The undue delay observed in the prereversal V_z enhancements in winter months over Fortaleza merits detailed study. Further investigations are being carried out using data from Huancayo, Jicamarca and Fortaleza, to elucidate the different aspects of the longitudinal differences in the spread F phenomena and related F-region parameters in the American zone.

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FIGURE CAPTIONS

Figure 1 - Monthly mean rates of spread F occurrences, of both the range spread type and frequency spread type, for the one year period starting from September, 1978, till August, 1979.

Figure 2 - Comparison of the range type and frequency type spread F for summer, equinox and winter months for Fortaleza and Huancayo. The Fortaleza results were reduced from the ionograms, while Huancayo results were taken from Rastogi (1978).

Figure 3 - Plots of monthly mean characteristics of the $\overline{h'F}$, (thick full line) vertical drift velocity V_z (thin full line), obtained as $d(\overline{h'F})/dt$, and the range and frequency types of spread F occurrences (broken line and dots, respectively) over Fortaleza, representing the three seasons. The figure 100, written inside each frame represents 100 percent occurrence rate on a linear scale.

Figure 4 - A comparison of the $\overline{h'F}$ variations during the three seasons for Fortaleza and Huancayo. The $\overline{h'F}$ values for Huancayo, for the year 1961, were taken from Rastogi (1978), and for the year 1978 they were obtained from the World Data Center. The values for Fortaleza were read from Fortaleza ionograms.

Figure 5 - F region vertical drift velocities measured by Jicamarca radar (taken from Fejer et al., 1979) and those deduced from Fortaleza ionograms presented for the summer, equinoctial and winter months. The open rectangles near the evening hours represent sunset durations between conjugate E-regions (see the text for further details).

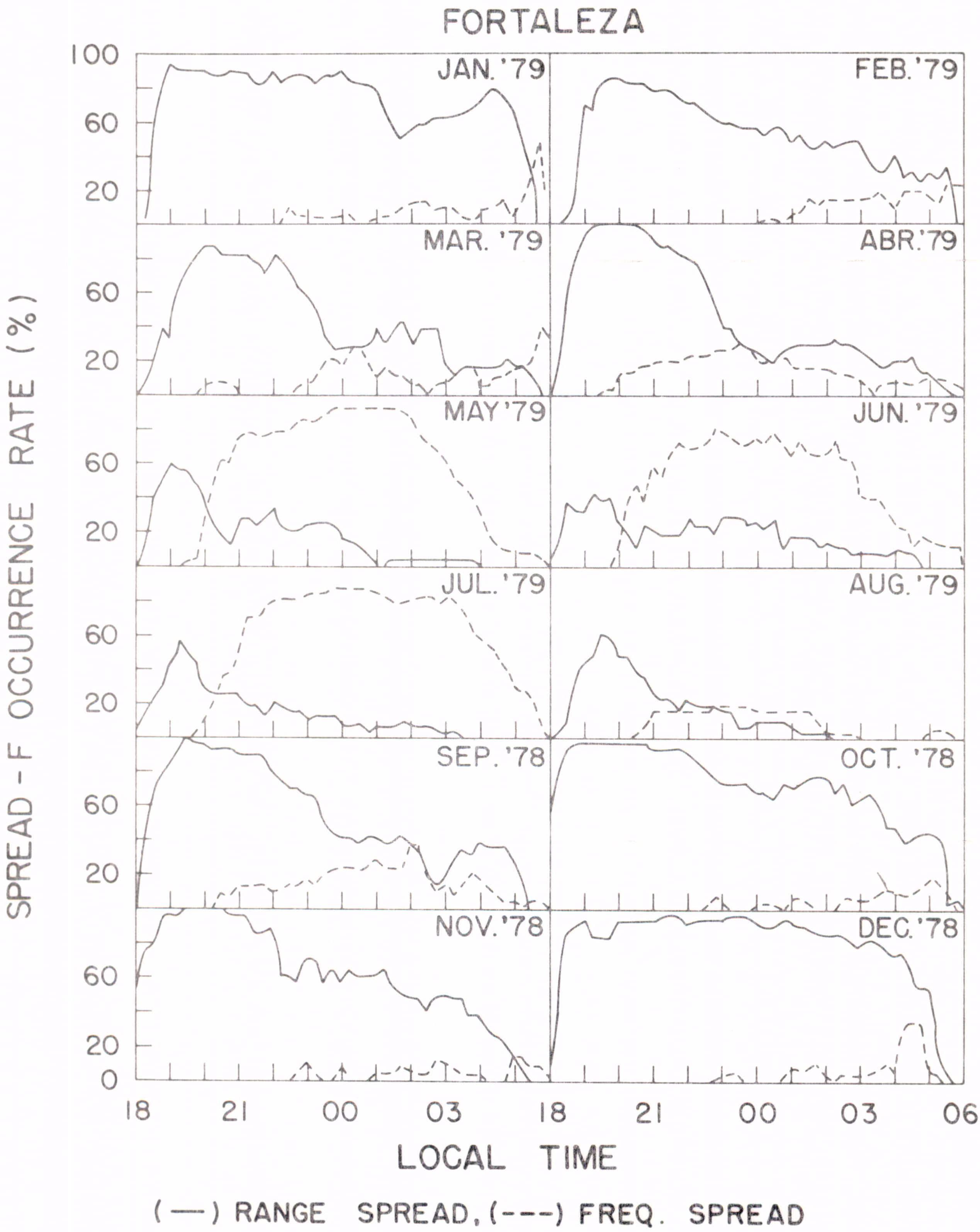
FORTALEZA
JAN.'79
FEB.'79
MAR.'79
ABR.'79
MAY'79
JUN.'79
JUL.'79
AUG.'79
SEP.'78
OCT.'78
NOV.'78
DEC.'78
100
60
20
0
SPREAD - F OCCURRENCE RATE (%)
18
21
00
03
06
LOCAL TIME
(—) RANGE SPREAD, (---) FREQ. SPREAD

Fig. 1

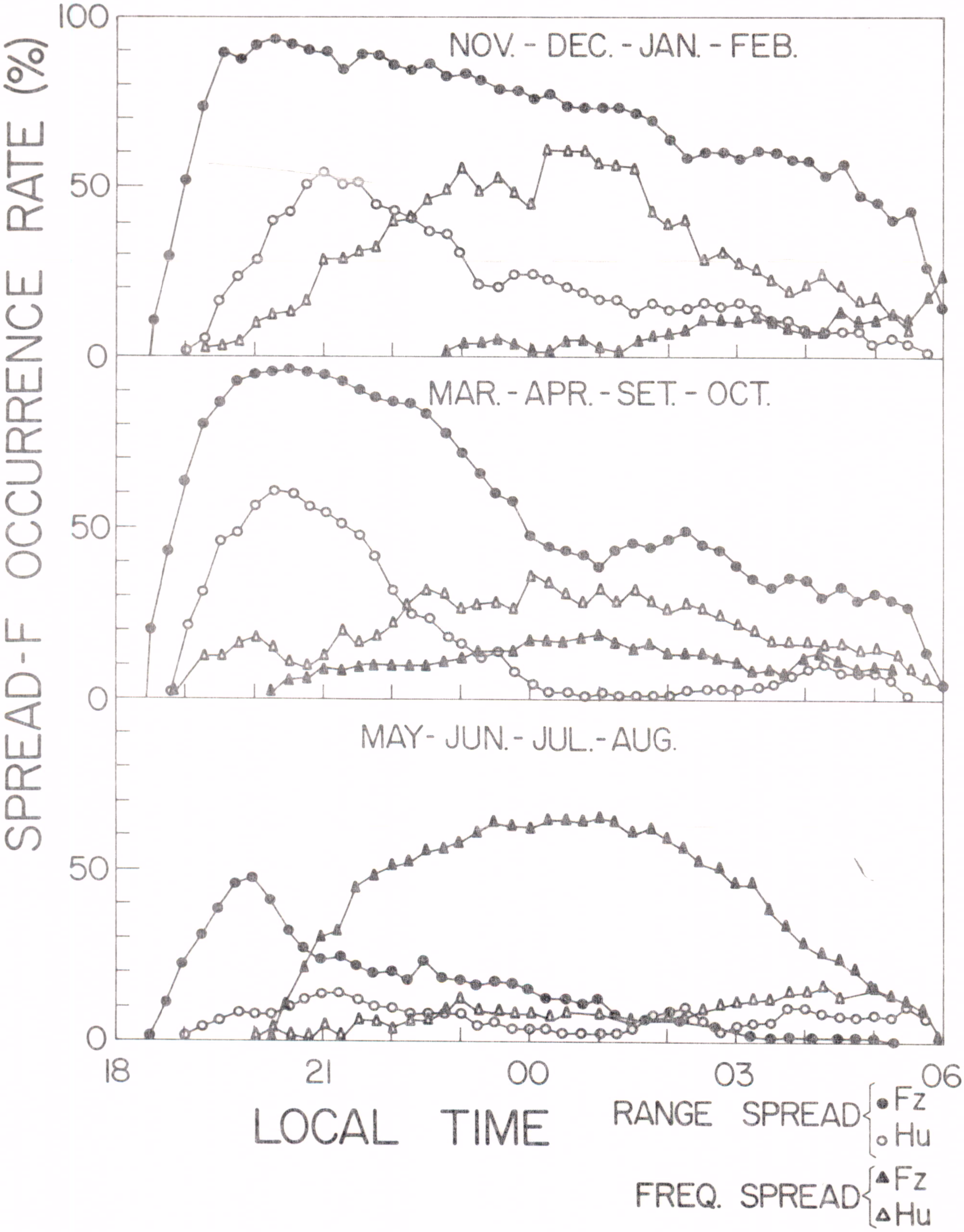
SPREAD-F OCCURRENCE RATE (%)
100
50
0
NOV. - DEC. - JAN. - FEB.
MAR. - APR. - SET. - OCT.
MAY- JUN.- JUL.-AUG.
18
21
00
03
06
LOCAL TIME
RANGE SPREAD
Fz
Hu
FREQ. SPREAD
Fz
Hu

Fig. 2

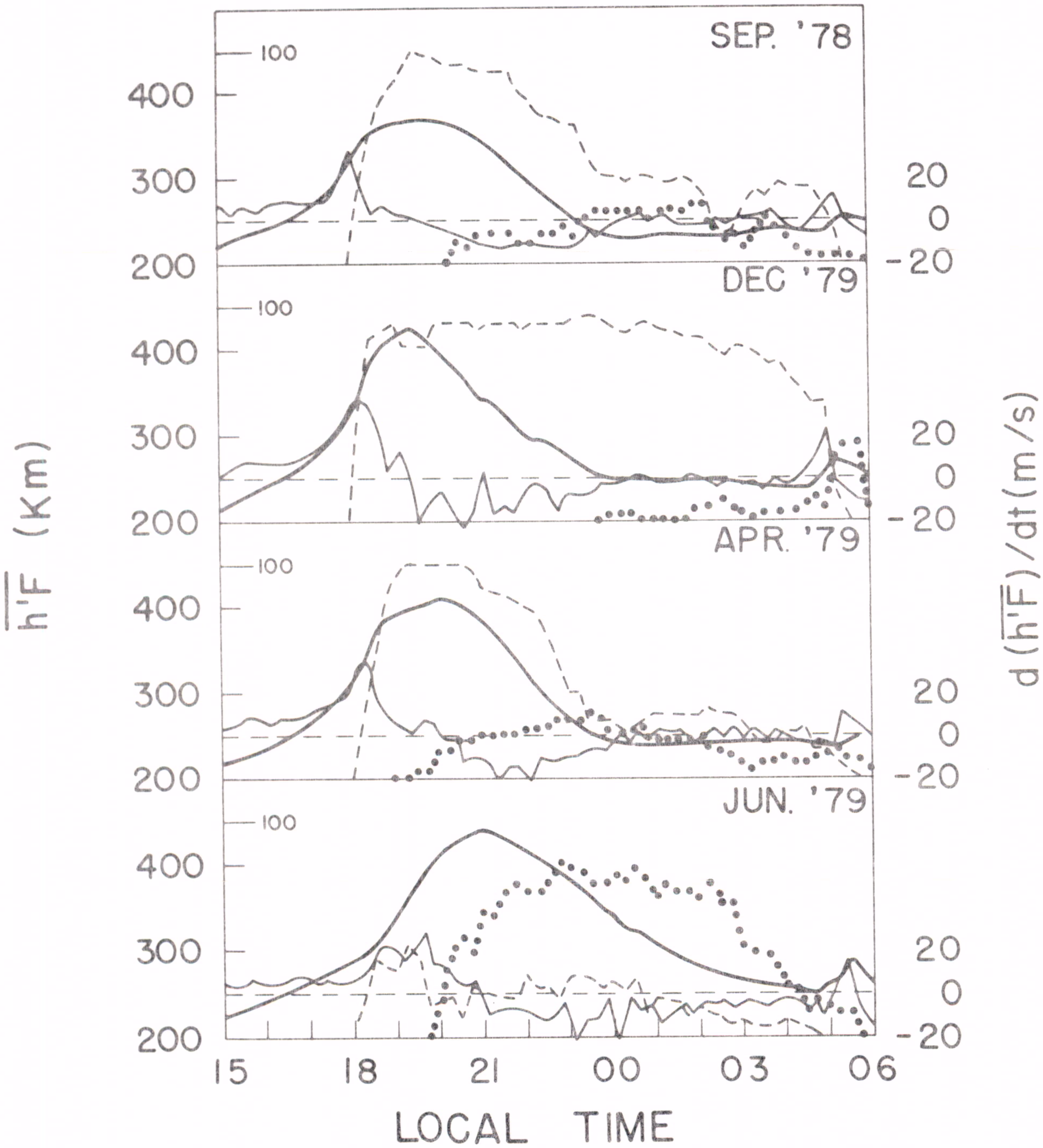
SEP. '78
DEC '79
APR. '79
JUN. '79
100
400
300
200
20
0
-20
$\overline{h'F}$ (Km)
d($\overline{h'F}$)/dt(m/s)
15
18
21
00
03
06
LOCAL TIME

Fig. 3

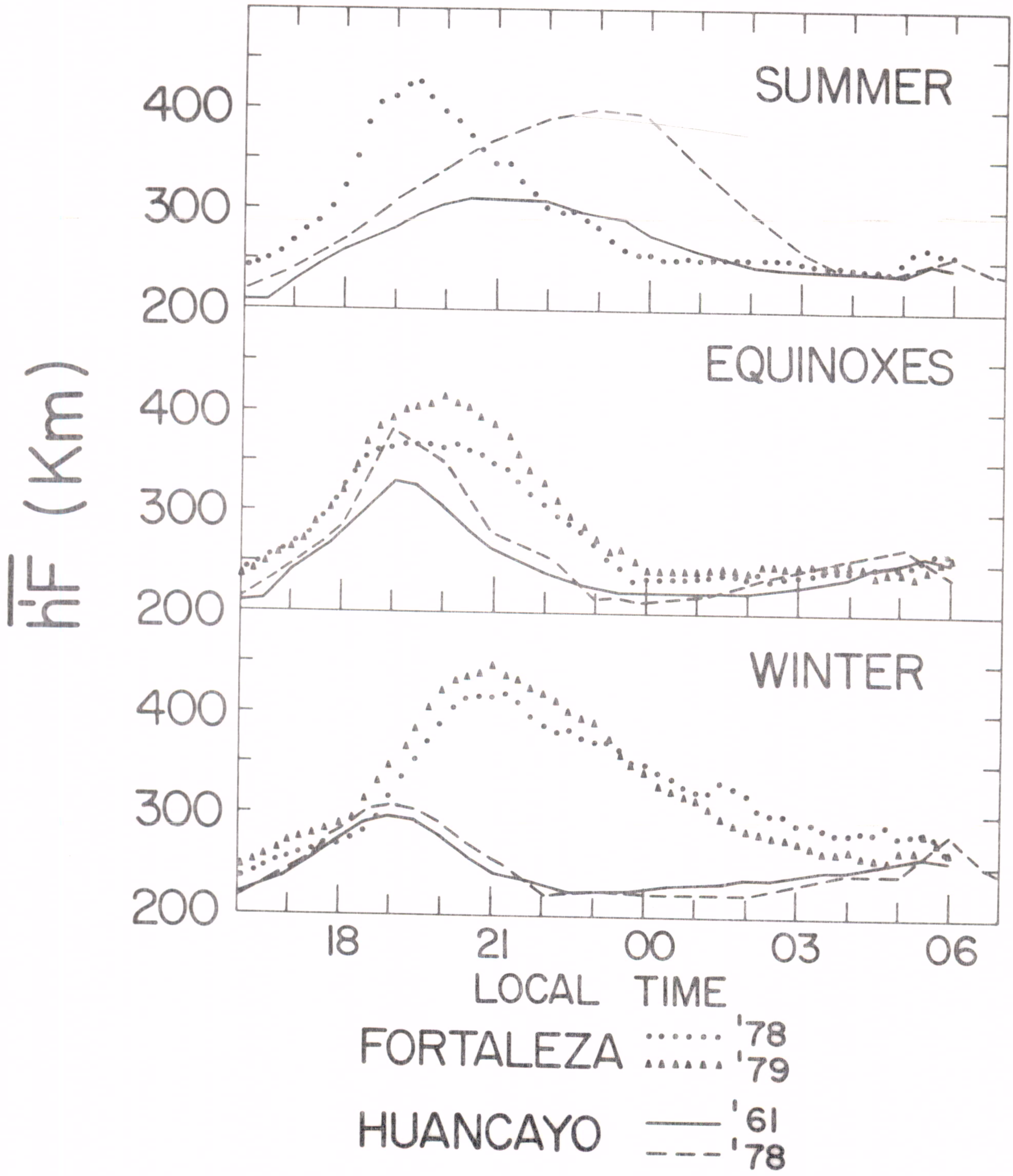
SUMMER
EQUINOXES
WINTER
400
300
200
hF (Km)
18
21
00
03
06
LOCAL TIME
FORTALEZA '78
'79
HUANCAYO '61
'78

Fig. 4

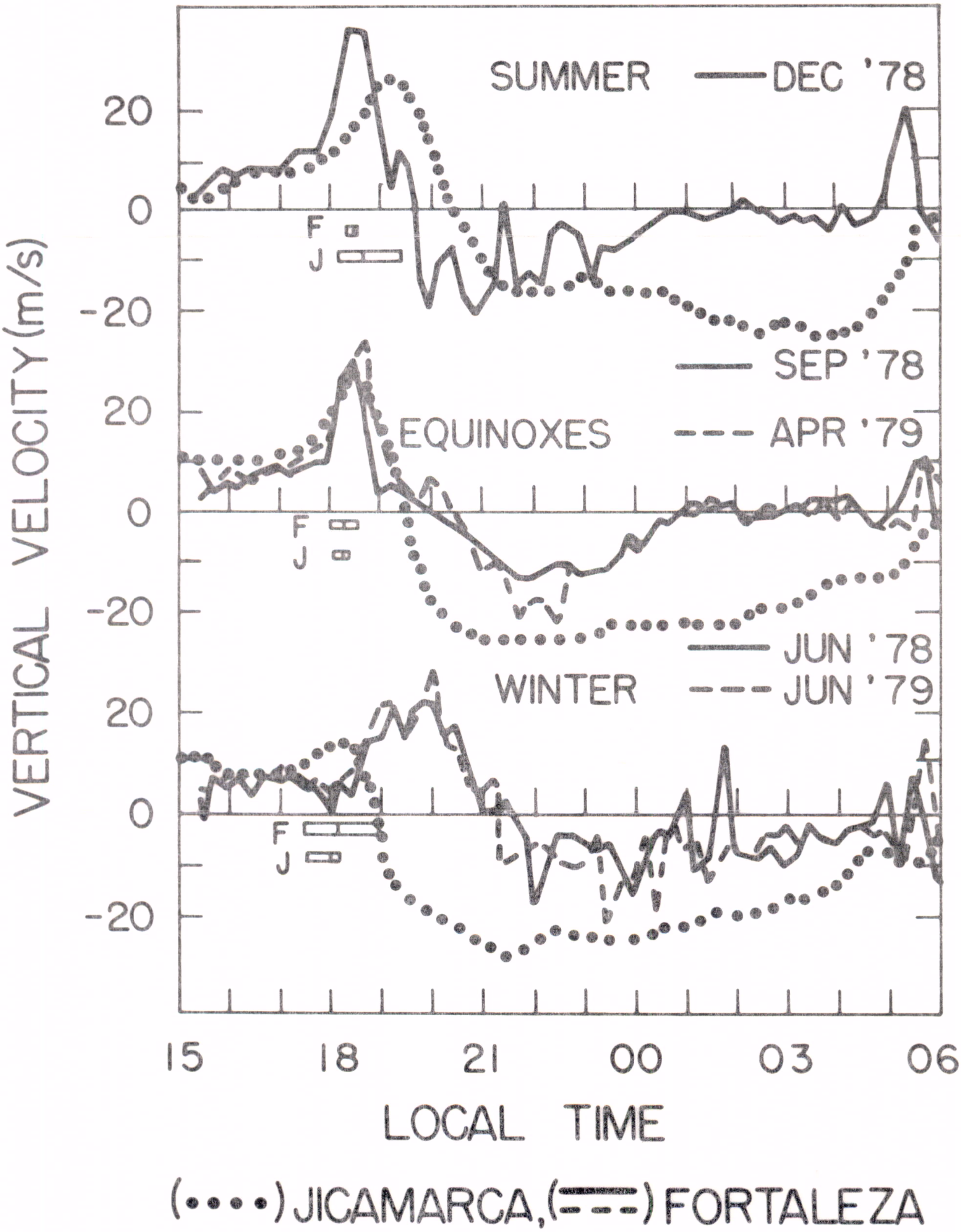
SUMMER
DEC '78
SEP '78
EQUINOXES
APR '79
JUN '78
WINTER
JUN '79
F
J
20
0
-20
VERTICAL VELOCITY (m/s)
15
18
21
00
03
06
LOCAL TIME
(••••) JICAMARCA, (▬ ‒ ‒) FORTALEZA

Fig. 5

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