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14. Abstract/Notes

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A COMPARATIVE STUDY OF VHF SCINTILLATION AND SPREAD F EVENTS OVER NATAL AND FORTALEZA IN BRAZIL

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Abstract

A comparative study is carried out of the equatorial ionospheric irregularity occurrences, as observed by range spread F events over Fortaleza (4^{o}S, 38^{o}W, dip latitude 1.8^{o}) and satellite vhf signal scintillation event over Natal (5.8^{o}S, 33.23^{o}W, dip latitude 4.8^{o}S) for a one-year period, 1978. Close association is observed in the occurrences and the durations of the irregularities at the two stations. Marked differences in the seasonal behaviour of the occurrences of the irregularity events over these two stations are noted with respect to that over Huancayo, most important of them being that while the latter station presents equinoctial maxima in the occurrence rates (as over some African stations), the Brazilian stations show an additional and pronounced peak in December. This result is explained as possible evidence of magnetic declination control of the spread F irregularity generation and its seasonal dependence. The present results have important implications also on the coexistence of different irregularity scale sizes during equatorial plasma bubble irregularity events.

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INTRODUCTION

In this paper we have carried out a comparative analysis of simultaneous observations of the equatorial ionospheric irregularities by ionosonde and satellite vhf signal scintillation techniques. These two techniques are sensitive to a spectrum of irregularity scale sizes ranging from decameter to kilometers. The morphology of these irregularities have been studied extensively, over different longitudinal zones of the magnetic equator, since the early investigation by Booker and Wells (1938) using ionograms over Huancayo (see, also, Osborne, 1952; Wright et al., 1956; Lyon et al., 1961; Aarons et al., 1971; Chandra and Rastogi, 1972; McClure and Hanson, 1973; Rastogi, 1980a; Abdu et al., 1981a). These different studies have revealed marked longitudinal differences in their occurrence characteristics. Extensive studies on the global morphology of the irregularities observed by satellite vhf signal scintillation and in situ measurements have revealed further longitudinal differences in the occurrence characteristics of the irregularities (Aarons, 1977; Aarons et al., 1980a; see also a recent review by Basu, 1981). The global scintillation occurrence model calculated from OGO-6 irregularity measurements by Basu et al. (1976), in particular, shows pronounced enhancements in the occurrence of scintillation, in November and December months, in the longitudinal zone over Brazil. From analysis of ionosonde data taken over Fortaleza, a station situated exactly in a region of high scintillation rate, as per the results of Basu et al. (1976), we have shown that the occurrence rate of spread F over this station is significantly higher than over Huancayo, situated only some 38^{0} westward (Abdu et al., 1981a). The spread F occurrence rates over Fortaleza is higher also compared to the rates over the African and Indian zones.

Association between the occurrences of scintillation and spread F events have been investigated for the low latitude station Taipei in the Asian zone by Huang (1970), and for Huancayo by Bandyopadhyaya and Aarons (1970) and Rastogi et al. (1981), who have shown good correlation in the gross features of the two phenomena. Coexistence of the irregularities observed by these two phenomena and those responsible for vhf backscatter radar echoes (namely the meter scale), however, depends upon the phase of an irregularity event. For example, during the development phase of a plasma bubble event all these spectral bands have been found to coexist (Basu et al., 1978; Aarons et al., 1980b). On the other hand, there exist differences in some detailed features of the seasonal and local time variations of the spread F and scintillation occurrences presented by Aarons (1977) and Rastogi (1980b) over Huancayo for similar phases of the solar activity cycles. Correlative studies of scintillation and spread F occurrences in longitudinal zone over Brazil, which appears to be a region of a global high in the occurrence of these irregularities are, therefore, thought to be useful for a better understanding of the global morphology of the equatorial ionospheric irregularities. One year of data (1978) on spread F occurrence observed by ionosonde over Fortaleza (4^oS, 38^oW, dip latitude 1.8^oS) and the data on scintillation of the signal at 275 MHz from the satellite MARISAT-1 received at Natal (sub-ionospheric intersection latitude and longitude at 350 km being 5.8^oS and 35.23^oW respectively) for the same period are analysed in this paper.

SPREAD F AND SCINTILLATION EVENTS OVER FORTALEZA AND NATAL

We should point out that there are difficulties in statistically comparing the results obtained from two techniques that are sensitive to different irregularity scale sizes. Further, while the sounding technique is sensitive to irregularities in the sub-peak electron densities of the F-layer over a wide horizontal area, the scintillation technique responds to vertically integrated effects around the satellite ray path. Nevertheless, questions on the nature of the coexistence of different irregularity sizes in the different phases of an irregularity event and the horizontal extensions of the irregularity regions and the plasma bubbles that could reach upto a few hundreds of kilometers in the east-west direction, (and many times as much in the magnetic north-south direction) would indeed argue for the usefulness of a comparative study.

A comparison of the evening onset times of the range type spread F and scintillation at the two stations, on a day-to-day basis, showed, on a few occasions, scintillation occurrences earlier, by 1 to 2 hours over Natal. Considering the east-west ionospheric separation between the two stations, of about 4.3^{o}, these onset sequences might suggest generation of the irregularities localized in space as observed by Aarons at al. (1978). However, on many occasions, in more than fifty percent of the cases, localized patches of irregularities were first observed over Fortaleza well before scintillation onsets over Natal. Seasonal versus local time behaviour of range type spread F events over Fortaleza and scintillation events over Natal can be obtained from the contours of monthly mean iso-occurrence rates presented in Figures 1 (a) and (b), respectively. All events of range type spread F and scintillation were considered irrespective of their magnitudes or intensities. For drawing these contours the monthly mean occurrences of the events, at a given hour, expressed as percentage of the number of observations for that hour, was put down against the markings of the corresponding months, and for local times from 1800 LT up to 0600 LT. The percentage occurrence distribution indicated in increments of ten are then obtained from linear interpolation along both the x and y axis. Figures 2(a) and (b) show that, in general, the occurrence rates are significantly higher over Fortaleza and Natal than those presented for Huancayo in the cases of scintillation by Aarons (1977) and in the case of spread F by Rastogi (1980b). The nighttime maxima of the spread F and scintillation are occuring at about the same time, namely, between 19 and 22 LT during most of the months. In December, however, the peak occurrence rate can be seen extending up to morning hours around 02 LT. The months of March, October and December present highest occurrence rates of both the spread F and scintillation in 1978 (December presenting an anual high in the long duration events), which contrasts somewhat with the results for Huancayo presented by Aarons (1977) showing maxima in around November and February on either side of a secondary minimum around December (or January), during high as well as low sunspot years. The statistical results of scintillation index SI having values greater than 60% presented by Yeh et al. (1981) for Natal, for 1976-77 period, shows yearly maximum occuring between October and December months. The primary yearly minimum of occurrences of the irregularities during the norhtern solstice months (centered around June) over Brazil agrees with the results of Aarons (1977) and Rastogi (1980b) for Huancayo. It is interesting to note, as a matter of details, that the contours of higher occurrences of scintillation over Huancayo (namely, those in November and February) in the results of Aarons (1977) is delayed by about 2 hours in local time (occuring around 23 LT) with respect to corresponding contours of spread F presented by Rastogi (1980b) (occurring around 21 LT), wiht the exception of a near-midnight peak in January (in Rastogi's results), during the solar minimum as well as maximum. A similar time difference dos not seem to be very evident in the results over Fortaleza, although some indication of this seems to be present in the months of August to November and in February. In these months, the percentage occurrences of scintillation in less before about 22 hr but higher at later hours, compared to the spread F occurrence rates. In March and April the percentage of spread F occurrence is generally higher throughout the night, compared to the scintillation occurrence.

A statistical representation of the nocturnal relative occurrences of the two phenomena at the two stations are presented in Figure 2. Data from simultaneous measurements available during 1978 are used, and four possibilities of the occurrences are considered as follows: percentages of the times when (a) the range type spread and scintillation were both present; (b) scintillation was present without spread F; (c) spread F was present without scintillation; and (d) both were absent. Close association is evident between the occurrences (or otherwise) of the two events in segments (a) and (d) of Figure 2 that also shows clearly a seasonal variation in the occurrence rate of the two phenomena. However, a few cases of independent occurrences were also present as suggested in segments (b) and (c) of Figure 2. These could be caused by short lived (less than about 1 1/2 hours) events, since the separation of the ionospheric regions observed by the two techniques is around 480 km and the irregularity patches could be assumed to have an eastward velocity of the order of 100 m s^{-1} (Aarons, 1978).

Another way of verifying the degree of possible association of the irregularity events over Fortaleza and Natal would be by studying the relative durations of the events at these stations. Such a comparison is presented in Figure 3. In preparing this figure, all the spread F events that have durations of n to n+1 hours (where n varies from 0 to 11 starting from 18 LT) were considered for Fortaleza for a given n at a time. Subsequently the average durations of all the corresponding scintillation events over Natal were determined. The figure shows the histograms representing these mean values as well as all the individual values used in obtaining the means. Though there is a large degree of spread in the relationship of the durations of individual events, the almost one to one relationship presented by the mean curve confirms the association of the irregularity events at the two stations separated by 480 km (exceptional cases of events that apparently to not obey this trend, either by short life time or generation far away from either stations, are marked by open circles in the figure).

Association between the range type spread F and scintillation is evident from the response of both these phenomena to magnetic disturbances as well, as shown in Figures 4(a) and (b) for scintillation and spread F events, respectively. For this analysis, 12 magnetically perturbed epochs were considered for which data were available during 1978. Each of these epochs covered a few disturbed (or stormy) days followed by a few "quiet" days, the transition form disturbed to "quiet" conditions being arbitrarily set at $k_p = 3^+$ during the recovery phase. During each of these epochs, a maximum number of 4 disturbed days and 4 "quiet" days were considered and the mean nocturnal variations of spread F indices and scintillation indices plotted in this figure contain all the disturbed and quiet days in these two groups. During the premidnight period magnetic disturbance inhibits significantly the generation of the spread F and scintillation irregularities, a result which is in good agreement with the recent results of Rastogi (1981) and Aarons et al. (1980a) for Huancayo for the summer and equinoctial months (see these two papers for further references on the magnetic activity influence on spread F). There does not seem to be present any significant effect in the post midnight period in our results, which contrasts with the results of the above authors for Huancayo, showing appreciable enhancements in the irregularity generation, in the post mignight period, on disturbed nights as compared to quiet nights, during all seasons as well as during the solar activity maximum and minimum phases.

Figure 5 presents three histograms of the statistics, for three different possibilities, of the relative occurrences of frequency type spread F and scintillation similar to the results for range type spread F shown in Figure 2. The almost complete lack of association between the two bands of irregularities responsible for these two phenomena is in agreement with the results of Huang (1970) for the low latitude station, Taipei, and that of Bandyopadhyaya and Aarons (1970) and Rastogi et al. (1981) for the equatorial station Huancayo. These results confirm our earlier conclusion (Abdu et al., 1981a) that the irregularities responsible for frequency type spread F, though of similar scale sizes as those responsible for range type spread F, are produced under conditions entirely different from those in which the irregularities producing vhf backscatter plumes, range type spread F and vhf-uhf scintillation are produced.

DISCUSSION

An interesting aspect of the seasonal variation in the irregularity occurrences as seen both in our spread F and scintillation results is a pronounced December enhancement. Such a trend was seen also in the results of Yeh et al. (1981). This December enhancement contrasts markedly with the secondary minimum (or a tendency towards that) in this month present in the results for other stations cited before. The difference with Huancayo, especially, is striking since this station is located in the American zone of the magnetic equator, and only 38^{0} westward of Fortaleza. A possible explanation for this different behaviour of the irregularity occurrences could be sought in the following reasoning.

Irregularity generation in the post-sunset equatorial ionosphere is very much dependent upon the vertical drift velocity (V_z) and height, of the F-layer in the evening hours (Farley at al., 1970; Woodman, 1970; Abdu et al., 1983). In particular, Abdu et al. (1983) have shown recently that good positive correlation is present between the amplitude of the evening prereversal enhancements in the vertical drift velocity (V_{zp}) and the indices of the range type spread F over Fortaleza. The evening enhancement in the V_z is believed to be occurring as a result of an enhancement in the eastward component of the F-layer dynamo electric field that builds up due to the rapid decrease in the E-layer conductivities at sunset hours, as described by Rishbeth (1981). Based on ionosonde and backscatter results, Abdu et al. (1981b) have shown that in December the prereversal peak in V_z is significantly larger over Fortaleza than over Huancayo (or Jicamarca), whereas in equinoctial months they have nearly the same values at the two stations. This large V_z enhancement in December over Fortaleza could be arising from the large westward magnetic declination angle (21°W) over Fortaleza, which causes movement of the sunset terminator to be almost parallel to the magnetic meridian (namely, making small angle with the magnetic meridian), thus causing relatively faster decrease in the conductivities of the conjugate E-layers, in this month. On the other hand, over Huancayo, the magnetic declination angle (4°E) does not offer conditions propitious for a decrease in the conjugate E-layer conductivities at a rate as rapid as that which applies to Fortaleza. Since identical V_{zp} values in equinoctial months over the two stations correspond to comparable equinoctial peaks in the irregularity occurrence rates at these stations, it is reasonable to expect that the enhanced V_{zp} in December over Fortaleza could be responsible for the enhanced occurrence of the irregularities in the same month over this station.

From simultaneous observations of irregularity events by backscatter radar and scintillation techniques in Peru, Aarons et al. (1978) determined that the east-west dimension of the irregularity structure could be of the order of 400 km and that the integrity of such a structure could be maintained for at least 3 hours. Our observation of the association of the irregularity event at Fortaleza and Natal is, in general, consistent with these values. In our one-year data, however, many of the events might be of shorter durations and with east-west dimensions significantly less than that found by Aarons et al. (1978). Thus the time difference in the onsets of the irregularity events observed in many of the events cannot be directly used to infer eastward velocities. Further, the separation of the observing regions in our case is greater than 400 km.

Table 1 presents monthly average onset times of spread F over Fortaleza and scintillation over Natal during the months of the usual irregularity occurrences. The onset times are given in local standard time (LST) (with reference to 45^{o}W longitude), which is used to record the data at both the stations, as well as in the local meridian times (LMT) at these stations. Based on the time differences in the onsets of the events at the two stations,when referred to a common standard time, it should be possible to infer eastward velocities of those irregularity patches that have shown clear time lags at Natal with respect to Fortaleza. However, there is an uncertainty in such determination owing to the absence of information on the direction from which the initial range spreading echoes appear in the ionogram. In fact, the initial echoes detected in the ionograms marking the onset of spread F could arise from regions horizontally separated by as much as 250-300 km from the vertical of the inosonde. We can, therefore, make, perhaps, only a lower limit for the eastward velocities corresponding to the lowest possible separation of the region sensitive to the ionosonde over Fortaleza and the subionospheric point over Natal, which is around 200 km. The corresponding minimum limit on the eastward velocity would be around 100-110 m s^{-1} in the months of March and April when time differences of 30 and 32 minutes are observed. These values are consistent with the results of Aarons et al. (1978) and Yeh et al. (1981). Since the time difference would depend very much upon the location of the irregularity generation between Natal and Fortaleza and also the sizes of the irregularity structure, besides the eastward velocity, it would not be possible to infer any useful information on the possible higher ranges of the eastward velocities from the data presented in Table 1.

Figures 2 and 3 show that only a few cases of uncorrelated irregularity events were observed at Fortaleza and Natal. These cases could be arising possibly from limited dimension and/or short life times of localized events. Another possible source would be spectral distribution of the scale sizes of the irregularities, which could be verified only from simultaneous observations of a common ionosphere region. Observations of meter scale irregularities sensitive to vhf radar and that of the hectometer to kilometer sizes producing vhf scintillation carried out in a common ionosphere volume by Basu et al. (1978) have shown that the former class of irregularities is not generally present when the latter is predominant in the late phase of an irregularity event. The lower wave lenght cut off in such cases is not known. The small percentage of the cases of independent occurrences of the two events shown in Figures 2 and 3 might suggest that the short wave lenght limit during the late phase of an irregularity does not exclude decameter sizes responsible for the range type spread F events.

CONCLUSIONS

We have analyzed one year of data (1978) on the occurrences of range type spread F over Fortaleza and those of the scintillations of the vhf signals from the satellite MARISAT-1 received at Natal, two stations located in a zone of globaly high irregularity occurrences rates over the magnetic equator. There is good association between the occurrences of the events and their duration at the two stations, suggesting that a great majority of the events represented motions of large scale irregularity structures having dimensions of a few hundreds of kilometers, in agreement with previous results. An important finding in our result is the presence of a pronounced December maximum in the occurrence rates of the irregularities responsible for both the spread F and scintillation events. This contrasts markedly with the reduced occurrences of these irregularities in the same month over Huancayo. We have explained this as evidence of a possible influence of magnetic declination angle on the generation of the spread F irregularities through the F-layer dynamo-induced vertical drift of the evening equatorial ionosphere, in agreement with our previous results (Abdu et al., 1981b). Equinoctial maxima over Fortaleza and Natal, on the other hand, resemble those observed over Huancayo. The relative occurrence statistics of the spread F and scintillation events suggest also that the short wavelength cut off in the late phase of a plasma bubble irregularity event does not exclude the decameter size irregularities.

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FIGURE CAPTIONS

Figure 1. (a) Iso-occurrence contours of the monthly mean distribution, in percentages, of range type spread F over Fortaleza, plotted as functions of local time and months of the year 1978. Maxima in the occurrence rates may be noted in March, December and October months. Data for July are missing completely.
(b) Similar contours, as in (a), plotted for the case of scintillation events over Natal.
(If should be born in mind that the sunspot number during January 1978 is less by 60 than that during December 1978. However, the figure is plotted to show the equinoctial and summer behaviour of the irregularity occurrences on an uninterrupted scale).

Figure 2. Relative occurrence statistics of range type spread F over Fortaleza and scintillation over Natal for four possible combinations described in the text, plotted for all the months of the year 1978 (Data for July are missing). The + and - signs are used to represent the presence or absence, respectively, of the phenomenon.

Figure 3. (a) Plots of durations of scintillation events over Natal versus durations of corresponding events of range type spread F over Fortaleza. The histogram representing the mean trend is plotted as per the procedure described in the text.
(b) Distribution of the number of events available in each one hour time interval considered in the analysis.

Figure 4. (a) Nocturnal variations of range type spread F index during magnetically disturbed days (----) as well during "quiet" days (——), determined from 12 events during 1978 according to the procedure described in the text.
(b) Nocturnal variations of the indices of scintillation, on the 275 MHz MARISAT-1 transmission, registered over Natal, plotted for magnetically disturbed (----) and "quiet" days (——) as in Figure 5.

Figure 5. Relative occurrence statistics of frequency type spread F over Fortaleza and scintillation over Natal for three cases, plotted for all the months during 1978. Data for July is missing. The + and - signs are used to represent the presence or absence, respectively, of the phenomenon.

Table 1. Table showing the monthly average onset times in LST and LMT of the onsets of spread F over Fortaleza and scintillation over Natal

1978	Onset times				Δ(LST) (minutes)
	Spread F		Scintillation		
Month	LST*	LMT	LST*	LMT	
January	19:00	19:28	19:18	20:03	18
February	18:56	19:24	18:57	19:42	1
March	18:58	19:26	19:30	20:15	32
April	18:45	19:13	19:15	20:00	30
September	18:50	19:18	19:00	19:45	10
October	18:23	18:51	18:25	19:10	02
November	18:35	19:03	18:30	19:15	-5
December	18:42	19:10	18:45	19:30	03

* LST referred to 45^{o}W longitude

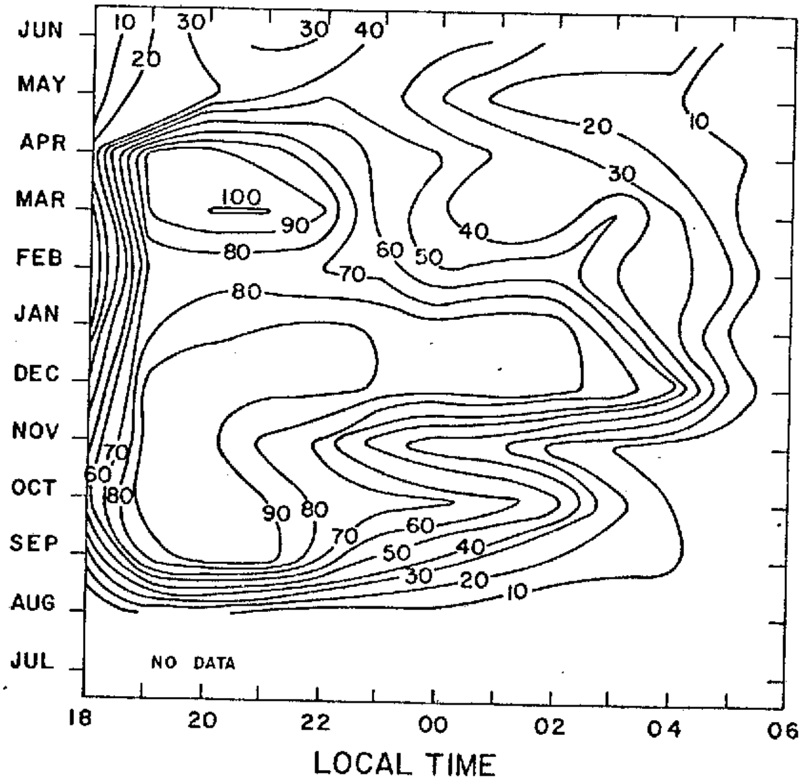
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Fig. 1a

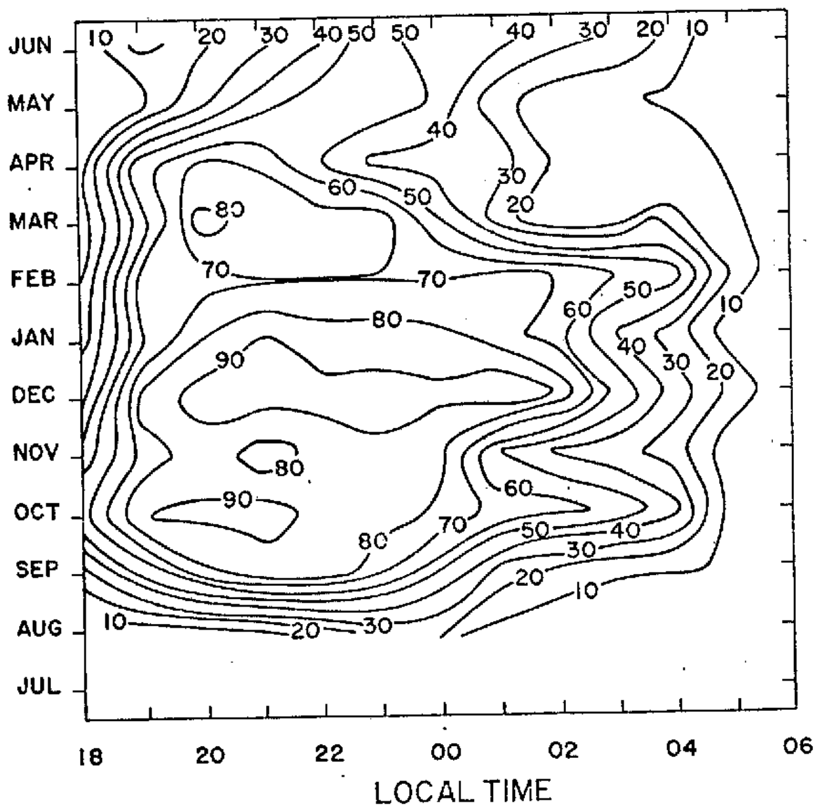
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Fig. 1b

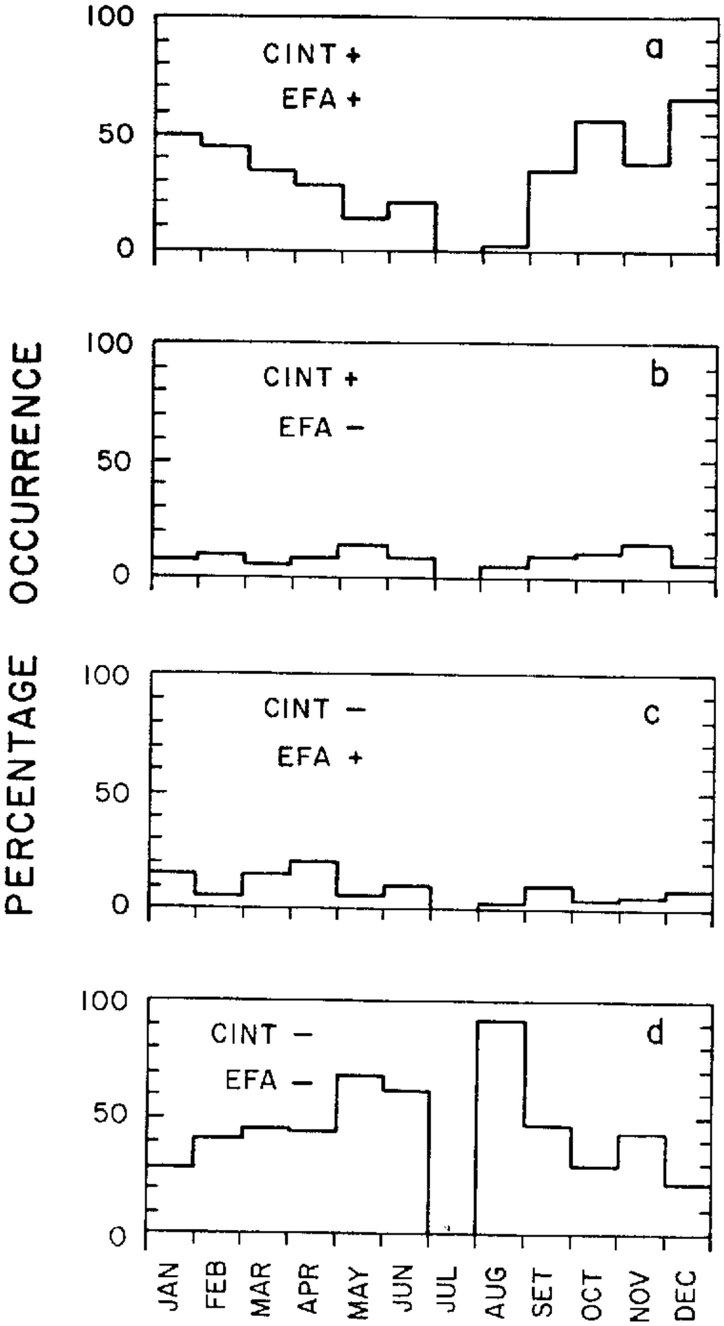
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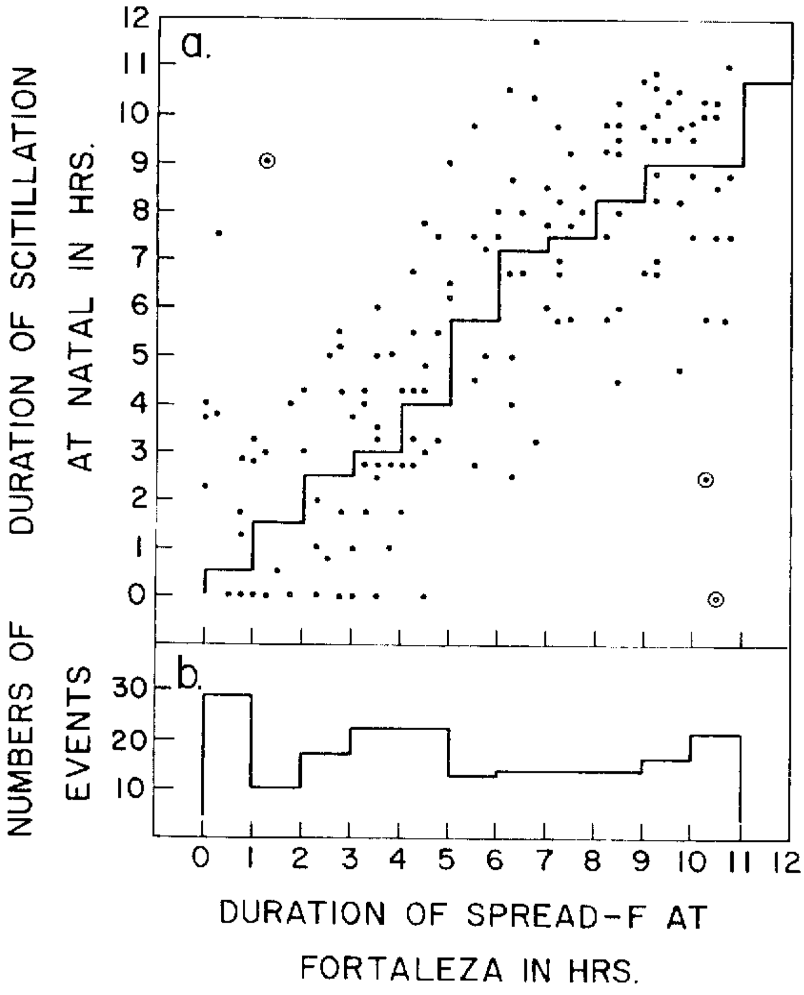
Fig. 2


a.
b.
DURATION OF SCITILLATION
AT NATAL IN HRS.
NUMBERS OF
EVENTS
0
1
2
3
4
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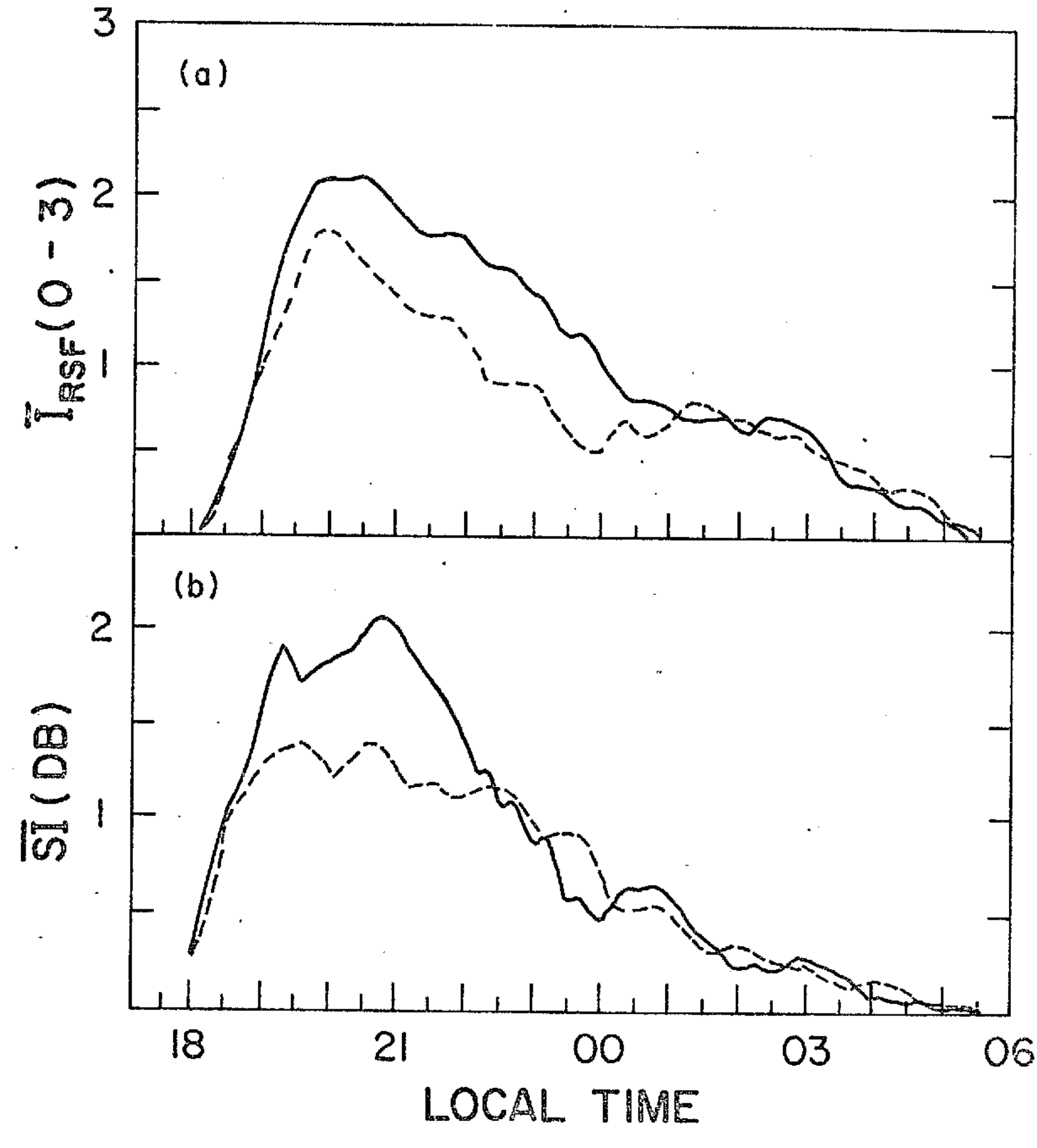
11
12
10
20
30
DURATION OF SPREAD-F AT
FORTALEZA IN HRS.

Fig. 3



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(a)
$\bar{\bar{I}}_{RSF}$(0 - 3)
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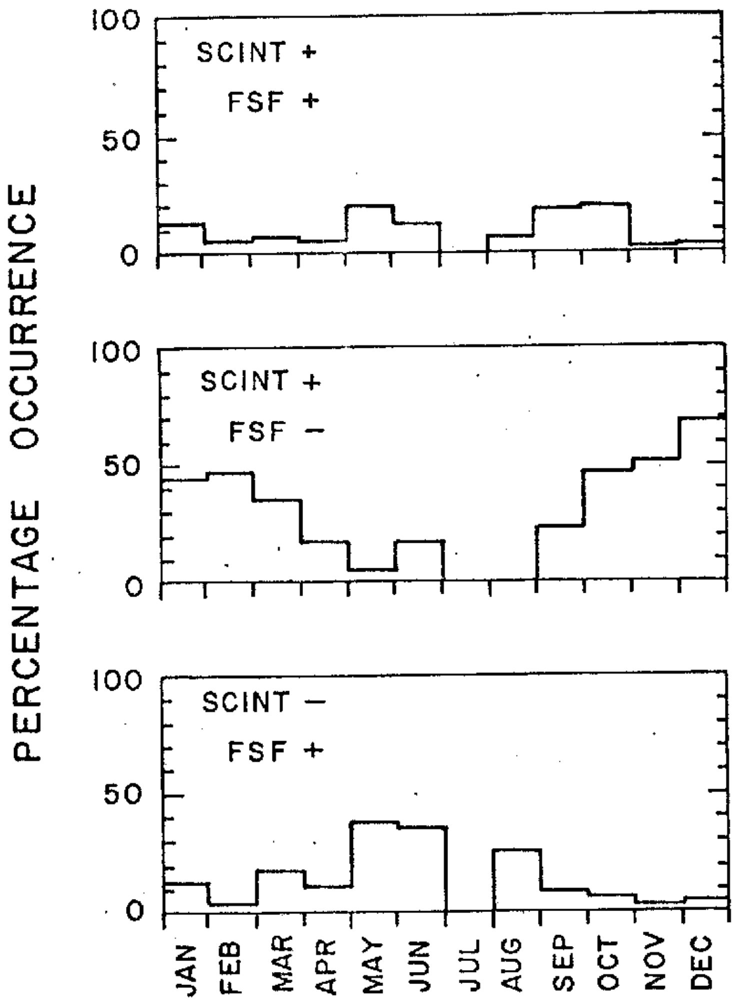
LOCAL TIME

Fig. 4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SCINT +
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Fig. 5

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83 A comparative study is carried out of the equatorial ionospheric irregularity occurrences, as observed by range spread F events over Fortaleza (4 degree S, 38 degree W, dip latitude 1.8 degree) and satellite VHF signal scintillation event over Natal (5.8 degree S, 33.23 degree W, dip latitude 4.8 degree S) for a one-year period 1978. Close association is observed in the occurrences and the durations of the irregularities at the two stations. Marked differences in the seasonal behavior of the occurrences of the irregularity events over these two stations are noted with respect to that over Huancayo, most important of them being that while the latter station presents equinoctial maxima in the occurrence rates (as over some African stations), the Brazilian stations show an additional and pronounced peak in December. This result is explained as possible evidence of magnetic declination control of the spread F irregularity generation and its seasonal dependence. The present results have important implications also on the coexistence of different irregularity scale sizes during equatorial plasma bubble irregularity events.
87 propagação
87 cintilação
87 atmosfera equatorial
87 pblha de plasma
87 disturbios ionosféricos
88 spread F
88 scintillation
88 equatorial atmosphere
88 plasma bubble
88 ionospheric disturbances
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A Comparative Study of VHF Scintillation and Spread *F* Events Over Natal and Fortaleza in Brazil

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A comparative study is carried out of the equatorial ionospheric irregularity occurrences, as observed by range spread *F* events over Fortaleza (4°S, 38°W, dip latitude 1.8°) and satellite VHF signal scintillation event over Natal (5.8°S, 33.23°W, dip latitude 4.8°S) for a one-year period 1978. Close association is observed in the occurrences and the durations of the irregularities at the two stations. Marked differences in the seasonal behavior of the occurrences of the irregularity events over these two stations are noted with respect to that over Huancayo, most important of them being that while the latter station presents equinoctial maxima in the occurrence rates (as over some African stations), the Brazilian stations show an additional and pronounced peak in December. This result is explained as possible evidence of magnetic declination control of the spread *F* irregularity generation and its seasonal dependence. The present results have important implications also on the coexistence of different irregularity scale sizes during equatorial plasma bubble irregularity events.

INTRODUCTION

In this paper we have carried out a comparative analysis of simultaneous observations of the equatorial ionospheric irregularities by ionosonde and satellite VHF signal scintillation techniques. These two techniques are sensitive to a spectrum of irregularity scale sizes ranging from decameters to kilometers. The morphology of these irregularities have been studied extensively over different longitudinal zones of the magnetic equator since the early investigation by *Booker and Wells* [1938] using ionograms over Huancayo (see also *Osborne* [1952], *Wright et al.* [1956] *Lyon et al.* [1961], *Aarons et al.* [1971], *Chandra and Rastogi* [1972], *McClure and Hanson* [1973], *Rastogi* [1980*a*], *Abdu et al.* [1981*a*]). These different studies have revealed marked longitudinal differences in their occurrence characteristics. Extensive studies on the global morphology of the irregularities observed by satellite VHF signal scintillation and in situ measurements have revealed further longitudinal differences in the occurrence characteristics of the irregularities (*Aarons* [1977], *Aarons et al.* [1980*a*]; see also a recent review by *Basu* [1981]). The global scintillation occurrence model calculated from OGO 6 irregularity measurements by *Basu et al.* [1976], in particular, shows pronounced enhancements in the occurrence of scintillation, in November and December months, in the longitudinal zone over Brazil. From analysis of ionosonde data taken over Fortaleza, a station situated exactly in a region of high scintillation rate, as per the results of *Basu et al.* [1976], we have shown that the occurrence rate of spread *F* over this station is significantly higher than over Huancayo, situated only some 38° westward [*Abdu et al.*, 1981*a*]. The spread *F* occurrence rates over Fortaleza is higher also in comparison with the rates over the African and Indian zones.

Association between the occurrences of scintillation and spread *F* events have been investigated for the low-latitude station Taipei in the Asian zone by *Huang* [1970] and for Huancayo by *Bandyopadhyaya and Aarons* [1970] and *Rastogi et al.* [1981], who have shown good correlation in the gross features of the two phenomena. Coexistence of the irregularities observed by these two phenomena and those responsible for VHF backscatter radar echoes (namely the meter scale), however, depends upon the phase of an irregularity event. For example, during the development phase of a plasma bubble event all these spectral bands have been found to coexist [*Basu et al.*, 1978; *Aarons et al.*, 1980*b*]. On the other hand, there exist differences in some detailed features of the seasonal and local time variations of the spread *F* and scintillation occurrences presented by *Aarons* [1977] and *Rastogi* [1980*b*] over Huancayo for similar phases of the solar activity cycles. Correlative studies of scintillation and spread *F* occurrences in longitudinal zone over Brazil, which appears to be a region of a global high in the occurrence of these irregularities are, therefore, thought to be useful for a better understanding of the global morphology of the equatorial ionospheric irregularities. One year of data (1978) on spread *F* occurrence observed by ionosonde over Fortaleza (4°S, 38°W, dip latitude 1.8°S) and the data on scintillation of the signal at 275 MHz from the satellite MARISAT 1 received at Natal (subionospheric intersection latitude and longitude at 350 km being 5.8°S and 35.23°W, respectively) for the same period are analysed in this paper.

SPREAD *F* AND SCINTILLATION EVENTS OVER FORTALEZA AND NATAL

We should point out that there are difficulties in statistically comparing the results obtained from two techniques that are sensitive to different irregularity scale sizes. Further, while the sounding technique is sensitive to irregularities in the subpeak electron densities of the *F* layer over a wide horizontal area, the scintillation technique responds to vertically integrated effects around the satellite ray path. Nevertheless, questions on the nature of the coexistence of different irregularity sizes in the different phases of an irregularity event and the horizontal extensions of the irregularity regions and the plasma bubbles that could reach up to a few hundreds of kilometers in the east-west direction, (and many times as

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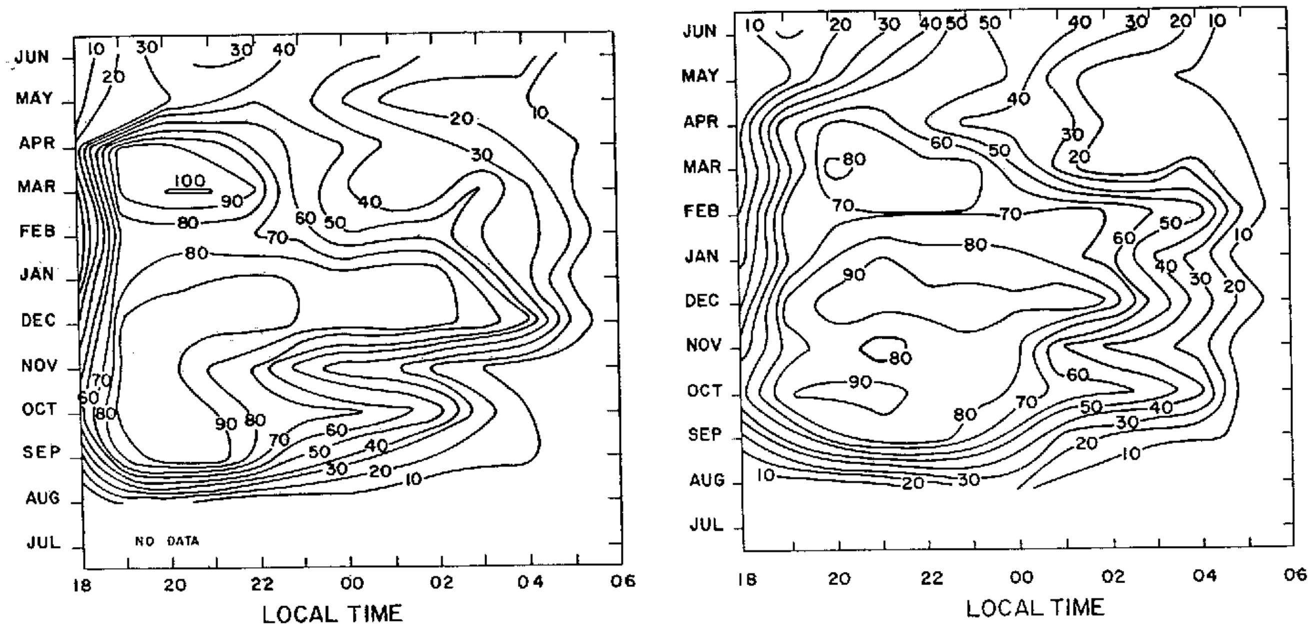

Fig. 1*a* Fig. 1*b*

Fig. 1. (*a*) Iso-occurrence contours of the monthly mean distribution, in percentages, of range type spread *F* over Fortaleza, plotted as functions of local time and months of the year 1978. Maxima in the occurrence rates may be noted in March, December, and October months. Data for July are missing completely. (*b*) Similar contours, as in (*a*), plotted for the case of scintillation events over Natal. (It should be born in mind that the sunspot number during January 1978 is less by 60 than it was during December 1978. However, the figure is plotted to show the equinoctial and summer behavior of the irregularity occurrences on an uninterrupted scale).

much in the magnetic north-south direction) would indeed argue for the usefulness of a comparative study.

A comparison of the evening onset times of the range type spread *F* and scintillation at the two stations, on a day to day basis, showed, on a few occasions, scintillation occurrences earlier, by 1 to 2 hours over Natal. Considering the east-west ionospheric separation between the two stations, of about 4.3°, these onset sequences might suggest generation of the irregularities localized in space as observed by *Aarons et al.* [1978]. However, on many occasions, in more than 50% of the cases, localized patches of irregularities were first observed over Fortaleza well before scintillation onsets over Natal. Seasonal versus local time behavior of range type spread *F* events over Fortaleza and scintillation events over Natal can be obtained from the contours of monthly mean iso-occurrence rates presented in Figures 1*a* and 1*b*, respectively. All events of range type spread *F* and scintillation were considered irrespective of their magnitudes or intensities. For drawing these contours the monthly mean occurrences of the events, at a given hour, expressed as percentage of the number of observations for that hour, was put down against the markings of the corresponding months and for local times from 1800 LT up to 0600 LT. The percentage occurrence distribution indicated in increments of ten are then obtained from linear interpolation along both the *x* and *y* axis. Figures 1*a* and 1*b* show that, in general, the occurrence rates are significantly higher over Fortaleza and Natal than those presented for Huancayo in the cases of scintillation by *Aarons* [1977] and in the case of spread *F* by *Rastogi* [1980*b*]. The nighttime maxima of the spread *F* and scintillation are occuring at about the same time, namely, between 1900 and 2200 LT during most of the months. In December, however, the peak occurrence rate can be seen extending up to morning hours around 0200 LT. The months of March, October, and December present highest occurrence rates of both the spread *F* and scintillation in 1978 (December presenting an annual high in the long duration events), which contrasts somewhat with the results for Huancayo presented by *Aarons* [1977] showing maxima in around November and February on either side of a secondary minimum around December (or January) during high as well as low sunspot years. The statistical results of scintillation index SI having values greater than 60% presented by *Yeh et al.* [1981] for Natal for the period 1976–1977 shows yearly maximum occuring between October and December months. The primary yearly minimum of occurrences of the irregularities during the northern solstice months (centered around June) over Brazil agrees with the results of *Aarons* [1977] and *Rastogi* [1980*b*] for Huancayo. It is interesting to note, as a matter of detail, that the contours of higher occurrences of scintillation over Huancayo (namely, those in November and February) in the results of *Aarons* [1977] is delayed by about 2 hours in local time (occuring around 2300 LT) with respect to corresponding contours of spread *F* presented by *Rastogi* [1980*b*] (occurring around 2100 LT), with the exception of a near-midnight peak in January (in Rastogi's results), during the solar minimum as well as maximum. A similar time difference does not seem to be very evident in the results over Fortaleza, although some indication of this seems to be present in the months of August to November and in February. In these months the percentage of occurrences of scintillation is less before about 2200 LT but higher at later hours, in comparison with the spread *F* occurrence rates. In March and April the percentage of spread *F* occurrence is generally higher throughout the night, compared to the scintillation occurrence.

A statistical representation of the nocturnal relative occurrences of the two phenomena at the two stations are presented in Figure 2. Data from simultaneous measurements available during 1978 are used, and four possibilities of the occurrences are considered as follows: percentages of the times when (1) the range type spread and scintillation were both present, (2) scintillation was present without spread F, (3) spread F was present without scintillation, and (4) both were absent. Close association is evident between the occurrences (or otherwise) of the two events in segments (*a*) and (*d*) of Figure 2 that also shows clearly a seasonal variation in the occurrence rate of the two phenomena. However, a few cases of independent occurrences were also present as suggested in segments (*b*) and (*c*) of Figure 2. These could be caused by short-lived (less than about 1 1/2 hours) events, since the separation of the ionospheric regions observed by the two techniques is around 480 km and the irregularity patches could be assumed to have an eastward velocity of the order of 100 m s^{-1} [*Aarons et al.*, 1978].

Another way of verifying the degree of possible association of the irregularity events over Fortaleza and Natal would be by studying the relative durations of the events at these stations. Such a comparison is presented in Figure 3. In preparing this figure, all the spread F events that have durations of n to $n + 1$ hours (where n varies from 0 to 11 starting from 1800 LT) were considered for Fortaleza for a given n at a time. Subsequently, the average durations of all the corresponding scintillation events over Natal were determined. The figure shows the histograms representing these mean values as well as all the individual values used in obtaining the means. Though there is a large degree of spread in the relationship of the durations of individual events, the almost one to one relationship presented by the mean curve confirms the association of the irregularity events at the two stations separated by 480 km (exceptional cases of events that apparently to not obey this trend, either by short life time or generation far away from either stations, are marked by open circles in the figure).

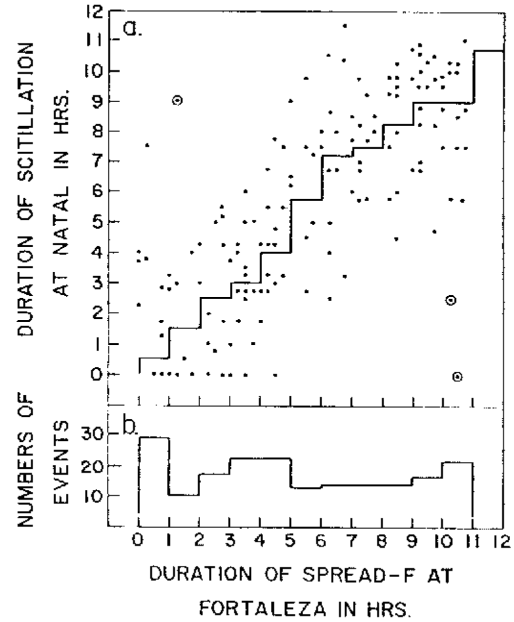

Fig. 3. (*a*) Plots of durations of scintillation events over Natal versus durations of corresponding events of range type spread F over Fortaleza. The histogram representing the mean trend is plotted as per the procedure described in the text. (*b*) Distribution of the number of events available in each one hour time interval considered in the analysis.

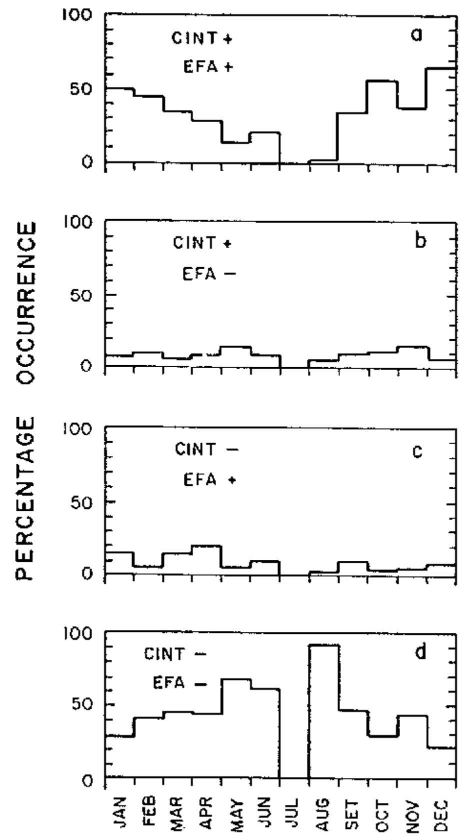

Fig. 2. Relative occurrence statistics of range type spread F over Fortaleza and scintillation over Natal for four possible combinations described in the text, plotted for all the months of the year 1978 (data for July are missing). The plus and minus signs are used to represent the presence or absence, respectively, of the phenomenon.

Association between the range type spread F and scintillation is evident from the response of both these phenomena to magnetic disturbances as well, as shown in Figures 4*a* and 4*b* for scintillation and spread F events, respectively. For this analysis, 12 magnetically perturbed epochs were considered for which data were available during 1978. Each of these epochs covered a few disturbed (or stormy) days followed by a few 'quiet' days, the transition from disturbed to 'quiet' conditions being arbitrarily set at $kp = 3^+$ during the recovery phase. During each of these epochs, a maximum number of four disturbed days and four 'quiet' days were considered and the mean nocturnal variations of spread F indices and scintillation indices plotted in this figure contain all the disturbed and quiet days in these two groups. During the premidnight period magnetic disturbance inhibits significantly the generation of the spread F and scintillation irregularities, a result that is in good agreement with the recent results of *Rastogi* [1981] and *Aarons et al.* [1980*a*] for Huancayo for the summer and equinoctial months (see these two papers for further references on the magnetic activity influence on spread F). There does not seem to be present any significant effect in the post midnight period in our results, which contrasts with the results of the above authors for Huancayo, showing appreciable enhancements in the irregularity generation, in the post midnight period, on disturbed nights as compared to quiet nights, during all seasons as well as during the solar activity maximum and minimum phases.

Figure 5 presents three histograms of the statistics for three different possibilities of the relative occurrences of frequency type spread F and scintillation similar to the results for range

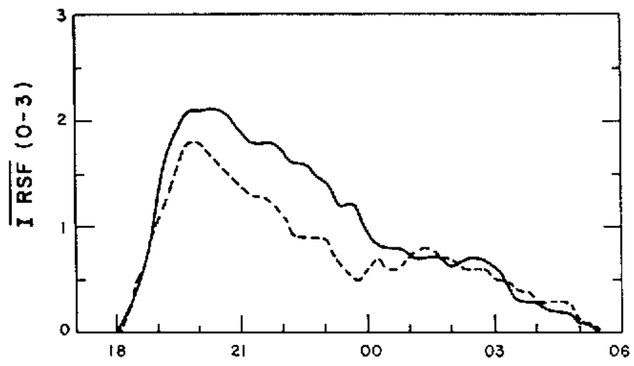

Fig. 4a

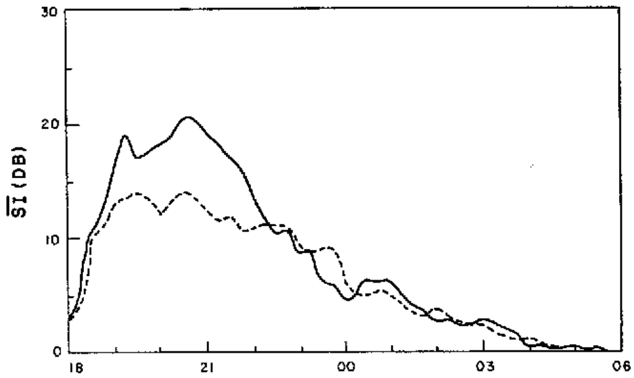

Fig. 4b

Fig. 4. (*a*) Nocturnal variations of range type spread *F* index during magnetically disturbed days (dashed line) as well as during 'quiet' days (solid line), determined from 12 events during 1978 according to the procedure described in the text. (*b*) Nocturnal variations of the indices of scintillation, on the 257 MHz MARISAT 1 transmission, registered over Natal, plotted for magnetically disturbed (dashed line) and 'quiet' days (solid line) as in Figure 5.

type spread *F* shown in Figure 2. The almost complete lack of association between the two bands of irregularities responsible for these two phenomena is in agreement with the results of *Huang* [1970] for the low latitude station, Taipei, and that of *Bandyopadhyaya and Aarons* [1970] and *Rastogi et al.* [1981] for the equatorial station Huancayo. These results confirm our earlier conclusion [*Abdu et al.*, 1981*a*] that the irregularities responsible for frequency type spread *F*, though of similar scale sizes as those responsible for range type spread *F*, are produced under conditions entirely different from those in which the irregularities producing VHF backscatter plumes, range type spread *F* and VHF-UHF scintillation are produced.

Discussion

An interesting aspect of the seasonal variation in the irregularity occurrences as seen both in our spread *F* and scintillation results is a pronounced December enhancement. Such a trend was seen also in the results of *Yeh et al.* [1981]. This December enhancement contrasts markedly with the secondary minimum (or a tendency toward that) in this month present in the results for other stations cited before. The difference with Huancayo, especially, is striking since this station is located in the American zone of the magnetic equator and only 38° westward of Fortaleza. A possible explanation for this different behavior of the irregularity occurrences could be sought in the following reasoning.

Irregularity generation in the post-sunset equatorial ionosphere is very much dependent upon the vertical drift velocity (V_z) and height of the *F* layer in the evening hours [*Farley et al.*, 1970; *Woodman*, 1970; *Abdu et al.*, 1983]. In particular, *Abdu et al.* [1983] have shown recently that good positive correlation is present between the amplitude of the evening prereversal enhancements in the vertical drift velocity (V_{zp}) and the indices of the range type spread *F* over Fortaleza. The evening enhancement in the V_z is believed to be occurring as a result of an enhancement in the eastward component of the *F* layer dynamo electric field that builds up due to the rapid decrease in the *E* layer conductivities at sunset hours, as described by *Rishbeth* [1981]. On the basis of ionosonde and backscatter results, *Abdu et al.* [1981*b*] have shown that in December the prereversal peak in V_z is significantly larger over Fortaleza than over Huancayo (or Jicamarca), whereas in equinoctial months they have nearly the same values at the two stations. This large V_z enhancement in December over Fortaleza could be arising from the large westward magnetic declination angle (21°W) over Fortaleza, which causes movement of the sunset terminator to be almost parallel to the magnetic meridian (namely, making small angle with the magnetic meridian), thus causing relatively faster decrease in the conductivities of the conjugate *E* layers in this month. On the other hand, over Huancayo the magnetic declination angle (4°E) does not offer conditions propitious for a decrease in the conjugate *E* layer conductivities at a rate as rapid as that which applies to Fortaleza. Since identical V_{zp} values in equinoctial months over the two stations correspond to com-

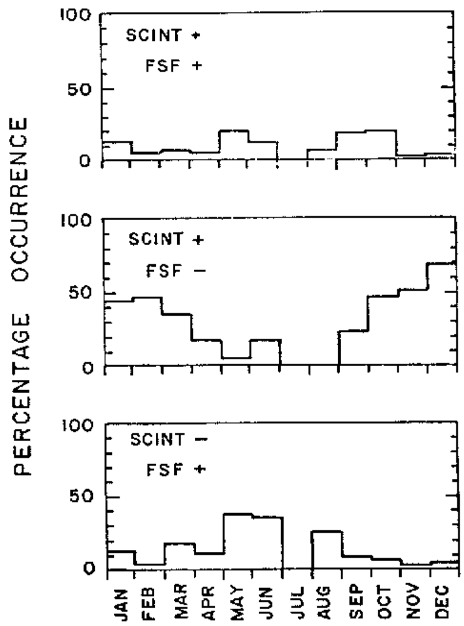

Fig. 5. Relative occurrence statistics of frequency type spread *F* over Fortaleza and scintillation over Natal for three cases, plotted for all the months during 1978. Data for July is missing. The plus and minus signs are used to represent the presence or absence, respectively, of the phenomenon.

parable equinoctial peaks in the irregularity occurrence rates at these stations, it is reasonable to expect that the enhanced V_{zp} in December over Fortaleza could be responsible for the enhanced occurrence of the irregularities in the same month over this station.

From simultaneous observations of irregularity events by backscatter radar and scintillation techniques in Peru, *Aarons et al.* [1978] determined that the east-west dimension of the irregularity structure could be of the order of 400 km and that the integrity of such a structure could be maintained for at least 3 hours. Our observation of the association of the irregularity event at Fortaleza and Natal is, in general, consistent with these values. In our one-year data, however, many of the events might be of shorter durations and with east-west dimensions significantly less than that found by *Aarons et al.* [1978]. Thus the time difference in the onsets of the irregularity events observed in many of the events cannot be directly used to infer eastward velocities. Further, the separation of the observing regions in our case is greater than 400 km.

Table 1 presents monthly average onset times of spread *F* over Fortaleza and scintillation over Natal during the months of the usual irregularity occurrences. The onset times are given in local standard time (LST) (with reference to 45°W longitude), which is used to record the data at both the stations, as well as in the local meridian times (LMT) at these stations. On the basis of the time differences in the onsets of the events at the two stations, when referred to a common standard time, it should be possible to infer eastward velocities of those irregularity patches that have shown clear time lags at Natal with respect to Fortaleza. However, there is an uncertainty in such determination owing to the absence of information on the direction from which the initial range spreading echoes appear in the ionogram. In fact, the initial echoes detected in the ionograms marking the onset of spread *F* could arise from regions horizontally separated by as much as 250–300 km from the vertical of the ionosonde. We can, therefore, make, perhaps, only a lower limit for the eastward velocities corresponding to the lowest possible separation of the region sensitive to the ionosonde over Fortaleza and the subionospheric point over Natal, which is around 200 km. The corresponding minimum limit on the eastward velocity would be around 100–110 m s^{-1} in the months of March and April when time differences of 30 and 32 min are observed. These values are consistent with the results of *Aarons et al.* [1978] and *Yeh et al.* [1981]. Since the time difference would depend very much upon the location of the irregularity generation between Natal and Fortaleza and also the sizes of the irregularity structure, besides the eastward velocity, it would not be possible to infer any useful information on the possible higher ranges of the eastward velocities from the data presented in Table 1.

Figures 2 and 3 show that only a few cases of uncorrelated irregularity events were observed at Fortaleza and Natal. These cases could be arising possibly from limited dimension and/or short life times of localized events. Another possible source would be spectral distribution of the scale sizes of the irregularities, which could be verified only from simultaneous observations of a common ionosphere region. Observations of meter scale irregularities sensitive to VHF radar and that of the hectometer to kilometer sizes producing VHF scintillation carried out in a common ionosphere volume by *Basu et al.* [1978] have shown that the former class of irregularities is not generally present when the latter is predominant in the late phase of an irregularity event. The lower wave length cutoff in such cases is not known. The small percentage of the cases of independent occurrences of the two events shown in Figures 2 and 3 might suggest that the short wave length limit during the late phase of an irregularity does not exclude decameter sizes responsible for the range type spread *F* events.

TABLE 1. Table Showing the Monthly Average Onset Times in LST and LMT of the Onsets of Spread *F* Over Fortaleza and Scintillation Over Natal

	Onset Times				
	Spread *F*		Scintillation		
Month/Year	LST*	LMT	LST*	LMT	Δ(LST) (min.)
Jan. 1978	1900	1928	1918	2003	18
Feb. 1978	1856	1924	1857	1942	1
March 1978	1858	1926	1930	2015	32
April 1978	1845	1913	1915	2000	30
Sept. 1978	1850	1918	1900	1945	10
Oct. 1978	1823	1851	1825	1910	02
Nov. 1978	1835	1903	1830	1915	−5
Dec. 1978	1842	1910	1845	1930	03

*LST referred to 45°W longitude.

CONCLUSIONS

We have analyzed one year of data (1978) on the occurrences of range type spread *F* over Fortaleza and those of the scintillations of the VHF signals from the satellite MARISAT 1 received at Natal, two stations located in a zone of globaly high irregularity occurrences rates over the magnetic equator. There is good association between the occurrences of the events and their duration at the two stations, suggesting that a great majority of the events represented motions of large scale irregularity structures having dimensions of a few hundreds of kilometers, in agreement with previous results. An important finding in our result is the presence of a pronounced December maximum in the occurrence rates of the irregularities responsible for both the spread *F* and scintillation events. This contrasts markedly with the reduced occurrences of these irregularities in the same month over Huancayo. We have explained this as evidence of a possible influence of magnetic declination angle on the generation of the spread *F* irregularities through the *F* layer dynamo-induced vertical drift of the evening equatorial ionosphere, in agreement with our previous results [*Abdu et al.*, 1981*b*]. Equinoctial maxima over Fortaleza and Natal, on the other hand, resemble those observed over Huancayo. The relative occurrence statistics of the spread *F* and scintillation events suggest also that the short wavelength cutoff in the late phase of a plasma bubble irregularity event does not exclude the decameter size irregularities.

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