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EQUATORIAL SPREAD F: STATISTICAL COMPARISON BETWEEN IONOSONDE AND SCINTILLATION OBSERVATIONS AND LONGITUDE DEPENDENCE

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ABSTRACT

Spread F on ionograms and scintillations of trans-ionospheric signals arise from an unstable structure of the ionospheric F- region occurring predominantly by night. The two techniques were applied to two pairs of sites in India, one near the magnetic equator and the other near the northern crest of equatorial ionization anomaly. At both pairs of sites no similarity of the statistical patterns derived from the two techniques was found except during solar maximum epoch. At the magnetic equator, scintillation and range spread F occur predominantly during premidnight period of equinoxes and increase with solar activity. At the anomaly crest, scintillation occurrence is generally rarer than at the magnetic equator with some exceptions. Post midnight scintillations are, predominant in summer, and generally decrease with increase in solar activity. A striking feature is a modest increase with solar activity at anomaly crest but an enormous one at the equator. Comparison of spread F occurrence at Indian and Brazilian equatorial locations show, unexpectedly, quite different statistics. This is attributed to the different magnetic declination angles at the two sites.

INTRODUCTION

The Equatorial Spread F (ESF) phenomenon derives from a highly dynamic state of the destabilized nighttime equatorial ionosphere that manifests as plasma irregularities spanning in scale sizes of several orders of magnitude from a few tens of cms to a few hundreds of kms. Observational data on these irregularities have, obviously, come from a multitude of experimental techniques. The most extensive database derives from reduction of ionograms and from observations of VHF scintillation. Analysis during the past few decades brought out the morphological aspects of the diurnal, seasonal and solar cycle variations of spread-F (Chandra and Rastogi, 1972, Huang et.al, 1987, Abdu et.al, 1998) and of scintillation (Basu et al, 1980, Rastogi, 1980, Aarons,1982, Pathak et al, 1995) at different locations. Satellite based measurements were useful in understanding the global morphology for specific seasons and solar activity conditions (Kil and Heelis, 1998). Intercompatability of the different data is desirable of course. The characteristics of the commonly observed VHF scintillation associated with different types of spread-F – range type and frequency type –seen on ionograms is another poorly understood aspect, although some studies exist (de Medeiros et.al, 1983), while new aspects of spread –F such as pre-sunrise -spread F at Fortaleza are emerging (Mac Dougall et al, 1998). In this paper, the characteristics of VHF scintillation observed at two locations in India are studied, one near the magnetic equator and the other near the equatorial anomaly crest, for the years 1987-89 covering low to high solar activity levels and are compared to spread –F at corresponding close by locations, in order to find out their intercompatability. Variations of spread –F for the same period at the Brazilian magnetic equatorial station, Fortaleza are compared with those at the Indian equatorial station, Kodaikanal to study its behavior at these widely separated longitudes and with different magnetic declinations.

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RESULTS AND DISCUSSION

Nocturnal, Seasonal and Solar cycle Variations of Scintillation Occurrence

The coordinates of the stations and the database used are summarized in Table-1.

Table-1:Stations List and Parameters Used in the Study

Station	Geogr.lat.	Geogr.long.	Dip lat.	Parameter measured	Remarks
TRIVANDRUM (EQUATOR)	7.8° N	75.8°E	0.6°S	VHF scintillation from FLEETSAT at 73°E	Coordinates are for 350 km subionos. point
RAJKOT (ANOMALY CREST)	20.5°N	70.2°E	15.3°N	"	"
KODAILANAL (EQUATOR)	10.2°N	77.5°E	0.8°N	Ionogram spread-F	From Published data
AHMEDABAD (ANOMALY CREST)	23.1°N	72.6°E	18.6°N	"	Scaled from ionograms or this study
FORTALEZA (EQUATOR)	3.9°S	38.5°W	3.5°S	"	"

In Figure 1 are shown the contour plots of percentage occurrence of scintillation of strength > 1 dB (3rd and 4th columns) on a grid of months vs. local time for the years 1987 through 1989, during which period the annual mean sunspot number increased from 28 to 158, the results thus demonstrating the dependence on season, solar activity and latitude. At Trivandrum (magnetic equator) in low sunspot year 1987, scintillation occurrence maximizes (40-50%) around 21 LT in the equinox months. In 1988 the premidnight equinoctial peaks gain in magnitude (~70%) as the solar activity increases. However in 1989, there appears an inverted pattern with an enormous maximum in June where lowest values appeared in the years before. A close examination reveals that scintillation onsets get earlier in the high sunspot year. For example, the 30% isoline occurs at ~1830LT in 1989 while it is delayed to ~1930 LT in 1987.

At the anomaly crest station, Rajkot, scintillation occurrence remains much smaller all the time. A shallow late night maximum is seen in June 1987, with almost no occurrence in other seasons. As the solar activity increases scintillation activity also builds up with peaks ~20-30% during the premidnight hours of equinoctial months of 1988, and the summer postmidnight occurrence decreases. During the high sunspot year, 1989, equinoctial and December solsticial occurrence during premidnight period increases to ~50% and the summer occurrence remains low (10-20 %) throughout the night. The patterns of 1988 are comparable at Trivandrum and Rajkot A considerable delay ~ 1-2 hrs may be noted between the onset times of scintillation at the equator and anomaly crest in the main equinoctial scintillation season, the delay decreasing with increase of solar activity. Similar delay of ~1-1.5 hrs was noted between onset times of spread F at equator and anomaly crest in Brazilian longitude by Abdu et al (2000) who related it to plasma bubble rise velocities.

Nocturnal variation of scintillation occurrence in terms of seasonal average values for high and low solar activity conditions are shown in Figure 2. At the magnetic equator occurrence is high (60-90%) in 1989 (high solar activity) during most part of the night in all seasons while at the anomaly crest it is substantially reduced. During low solar activity years at the equator occurrence peaks in the premidnight hours in winter and equinoxes while it shifts to post midnight hours in summer. At anomaly crest occurrence remains below 10% except in summer post midnight period.

The solar activity dependence was discussed above. As for scintillation, it is very important and positive at Trivandrum, but negligible at Rajkot. With spread F it is important and negative at Kodaikanal but positive at Ahmedabad and Fortaleza.

The characteristic patterns observed at the equator and anomaly crest can be explained by the mechanisms discussed by Abdu et al (2000). Scintillations at anomaly crest are generally due to plasma irregularities generated in the post sunset equatorial bottomside F region from instability processes leading to vertically growing, flux tube aligned, topside plasma depletions (bubbles) that eventually drift eastward. The vertical growth causes the bubble extremities to extend to latitudes away from the equator. Hence scintillation onset occurs at increasing latitudes at

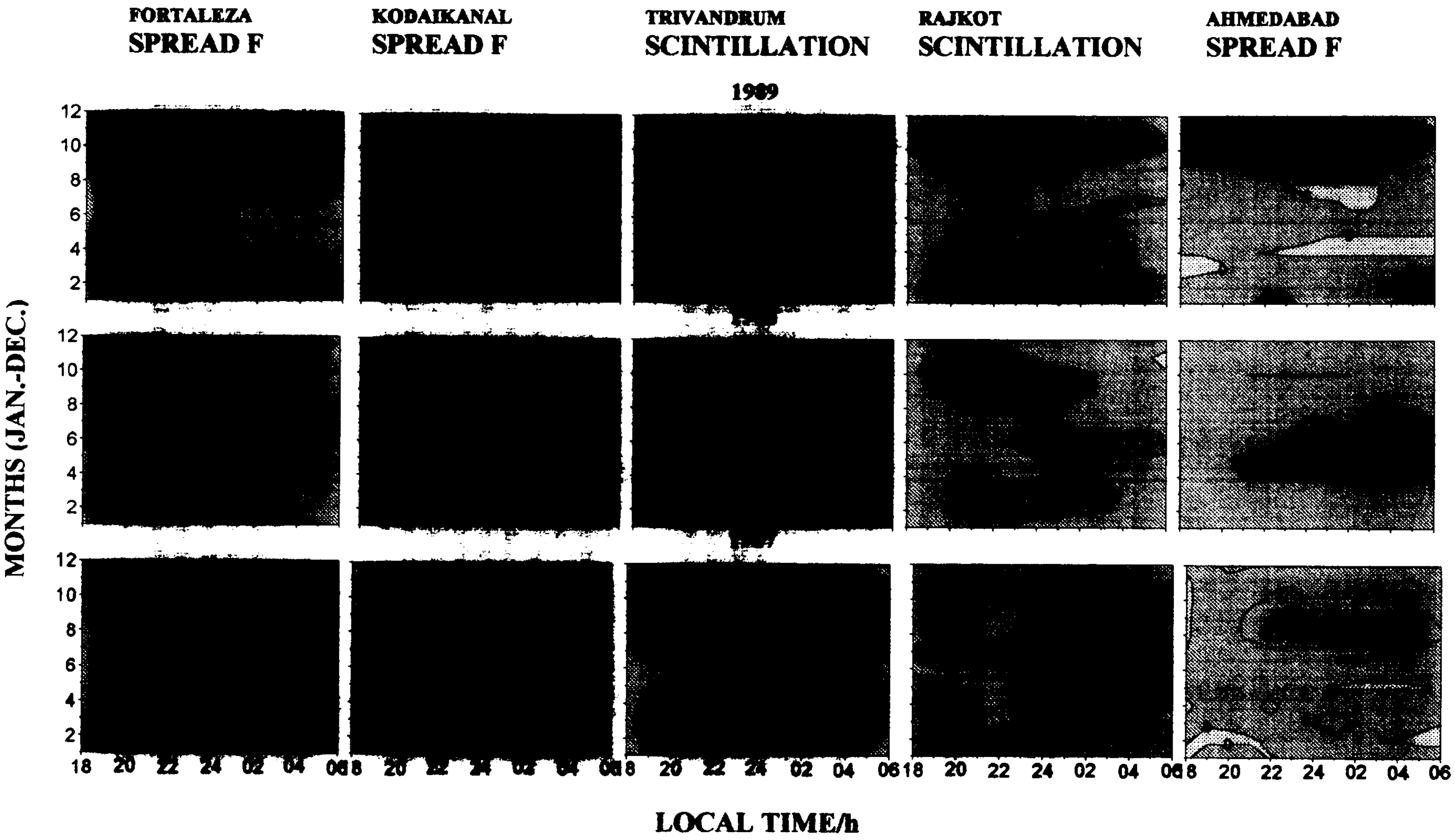

Fig.1 Contours of occurrence % of spread F and scintillations at the stations indicated. Kodaikanal and Fortaleza are magnetic equatorial stations in Indian and Brazilian zone, respectively, while Ahmedabad and Rajkot are equatorial anomaly crest stations in India.

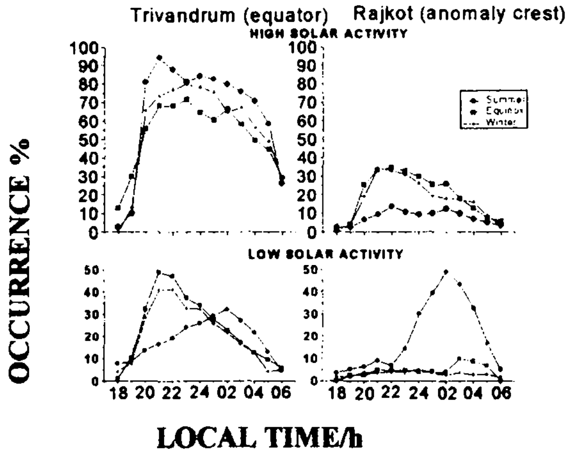

Fig.2 Seasonal dependence of noctumal variation of scintillation occurrence for high and low solar activity at equator and anomaly crest.

later times, if the radio signal propagation path from satellite to low latitude station intersects the irregularity region at F region heights, the elapsed time depending on the bubble rise velocities. For this to happen at Rajkot, the irregularities must extend to an altitude ~700 km over Trivandrum which occurs only during topside plasma bubble events. The probability of such events is greater during equinoxes of moderate tohigh sunspot years. Thus the similarity of occurrence patterns during equinoxes of moderate Rz year at both locations, but with reduced amplitude ~30% at Rajkot compared to ~70% at Trivandrum, is in agreement with this reasoning. This reasoning applies even better to the high Rz year, 1989 in which the equinoctial premidnight peak has increased to ~50% at Rajkot while it is ~80% at Trivandrum. That means a larger part of bubbles reach higher altitudes over the equator (due to higher rise velocities and concomitant shorter time delays) during high Rz condition to be effective in producing more scintillation occurrence at Rajkot. Thus the absence of scintillation at Rajkot during equinox and December solstice of 1987 although it is present at Trivandrum can be understood. The post midnight peak in summer over Rajkot is not likely to be related to plasma bubble phenomenon

Scintillation and Spread –F Occurrence Comparison

In Figure 1, comparing the occurrence contours of spread F at the equatorial station Kodaikanal (2nd column) with those of scintillation at Trivandrum (3rd column) and spread F at anomaly crest station, Ahmedabad (5th column) with scintillation at Rajkot (4th column) the compatibility of both techniques may be studied. This result is not conclusive however. At the equatorial location, the high and broad occurrence peak (>90%) of spread –F centered on midnight around the June solstice of 1987 is not associated with any corresponding feature in scintillation, the maximum occurrence of which around this time is ~40%. This may indicate that this spread –F is due to weak irregularities causing frequency type spread F, the probability of which is high at this time (Chandra and Rastogi, 1972) and of scale sizes not effective in scattering the VHF trans-ionospheric signals. However, the occurrence of scintillation and spread –F have comparable magnitudes ~40-70% during premidnight equinox when the probability of range type spread –F due to strong irregularities is also high (Sastri et.al, 1979) and they are effective in producing scintillations. In the high sunspot year 1989, spread-F shows high occurrence during the premidnight period of equinoxes and a peak of comparable magnitude during the midnight- postmidnight period in June solstice. The equinoctial spread F may be dominated by range type while in summer by frequency type. In 1989 with rather high solar activity (but not at all in 1987 when activity was low) the occurrence of scintillation >1dB is more frequent than spread –F. This may be due to the substantially higher probability of plasma bubbles in this season which extend to higher altitudes. These topside bubbles do produce scintillation at VHF and even GHz frequencies but do not influence the lower altitude spread –F echoes. It is interesting to note that in 1988 when the sunspot number is intermediate the spread F is more frequent, with similar equinoctial premidnight patter as the scintillation.

Comparing the corresponding panels for Rajkot and Ahmedabad at the anomaly crest location, there is no correspondence at all except in the high sunspot (1989) Sept- Dec. months during premidnight period. Abdu et al (1985) analyzing the equinoctial pre-midnight range spread F occurrence at Fortaleza (equator) and Cachoeira Paulista (anomaly crest) found a strong solar activity dependence at the anomaly crest, which they interpreted as due to solar activity dependence of plasma bubble rise velocities. The absence of significant spread F activity at Ahmedabad at other times, seasons and low solar activity can be also traced to the same reason.

Comparison of Spread F at Indian and Brazilian Longitudes

We now turn our attention to a comparison of spread F on ionograms at the equatorial stations, Kodaikanal and Fortaleza, (1st column) at Indian (75°E) and Brazilian (38°W) longitudes respectively, but almost on the dip equator though situated in the northern and southern hemispheres respectively and at rather different magnetic declination (~0° at Kodaikanal and 21° W at Fortaleza), for the years 1987 through 1989. The striking contrasts discernible from this figure are that: (a) spread F occurrence maximizes in the premidnight hours of equinoxes in Indian longitude while in the Brazilian longitude, the premidnight occurrence maximizes in the December solstice (local summer), this feature becoming more apparent as the solar activity increases, (b) in June solstice occurrence is considerably high in the midnight to post midnight period in Indian sector with a decreasing trend with increase of solar activity. In Brazilian sector the premidnight occurrence in June solstice, although considerably less than in December solstice, shows an increasing trend with solar activity. We note that Sastri et al (1979) analyzing 7 years of data have shown that range spread F occurrence at Kodaikanal maximizes in pre midnight hours except during June solstice of low solar activity years when it maximizes in post midnight period. Frequency spread dominates in post midnight period of both low and high solar activities. Moreover, Chandra and Rastogi (1972) found association between post sunset F region height rise and range type spread –F and between pre-dawn frequency type spread- F and foF2 build up, thus confirming the dominance of range type and frequency type spread –F during the pre midnight and post midnight periods respectively. Regarding the point (a) above it has been established (Abdu et al, 1981) that the magnetic declination plays an important role in deciding the spread –F occurrence season, which occurs when the sunset terminator and magnetic meridian at a given location are most nearly aligned. Due to the large westward magnetic declination angle, such alignment occurs in December solstice at Brazilian longitudes. At Indian longitude where the declination angle is close to zero such alignment occurs in equinoctial months, thus providing a first order explanation for the observed seasonal difference in pre midnight range spread F occurrence in these longitude sectors. Similar seasonal differences have been noted also between Huancayo (Peru) and Fortaleza again due to magnetic declination effect (Abdu et al., 1981, 2000). We have not investigated in this work the association between scintillation and spread-F at the Brazilian longitude. But it is appropriate to recall that de Mederios et al (1983) had investigated this aspect based on the data for 1978 and found that there is statistically very close relationship between premidnight spread-F occurrence at Fortaleza and VHF scintillation at Natal in that both show peak occurrence in March, October and December months. Further, even on a case by case basis there is very close association between the times and durations of occurrence of the two.

CONCLUSIONS:

The characteristics of scintillation occurrence, viz., its nocturnal seasonal and solar activity dependence in the Indian equatorial and low latitude region during an ascending phase of solar activity are described. This may become the starting point for developing a regional empirical model. Occurrence patterns of VHF Scintillations were found to be more often dissimilar to that of spread-F in ionograms such that results of the two techniques cannot be interchanged or used to replace each other. Also, spread-F occurrence at the magnetic (dip) equatorial stations in distant longitudes were found to show no statistical similarity. This may be attributed to an effect of magnetic declination. The associations between scintillation, bottomside range and frequency types of spread-F on ionograms, and the plasma bubble structure extending to topside are qualitatively described.

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