J. Ind. Geophys. Union (July 2010)
Vol.14, No.3, pp.195-209

Solar and geomagnetic activity control on equatorial VHF Scintillations in the Indian region

S.Banola, R.N.Maurya and H.Chandra[1]
Indian Institute of Geomagnetism, Navi Mumbai- 410 218
[1]Physical Research Laboratory, Ahmedabad- 380 009
E.mail :sbanola@iigs.iigm.res.in

ABSTRACT
A network of stations was operated monitoring amplitude scintillations of 244/251 MHz signal from FLEETSAT (73° E) in India for over a solar cycle. Latitudinal width of the equatorial belt of scintillation is higher during D-months and E-months compared to J-months. There is a positive correlation between the width of the belt and solar activity. Width of the belt decreases with magnetic activity. Equatorial scintillations are inhibited during magnetic disturbances with seasonal and solar cycle dependence. An analysis covering more than 200 geomagnetic storm events show scintillations at low latitudes can be either inhibited or triggered during storms depending on the phase of the storm and local time of occurrence.

INTRODUCTION

Radio waves traversing through the ionosphere suffer phase modulations due to the presence of ionization irregularities. The phase fluctuations give rise to the intensity fluctuations as the waves propagate to ground thereby forming a diffraction pattern. Temporal phase and intensity fluctuations are observed by a receiver at ground as the diffraction pattern formed moves past the receiver. This process is known as Scintillation. With the advent of satellites, radio beacon technique has been used extensively to study ionospheric irregularities through the scintillation effect (Koster 1966). The studies using signals from low orbiting as well as geostationary satellites have indicated that the equatorial scintillations are basically a nighttime phenomenon with maximum occurrence before midnight at all longitudes and are mainly associated with Spread-F irregularities (Mullen, 1973; Chandra and Rastogi, 1974, Chandra et al., 1979) of the ionosphere. Aarons (1982) and Basu & Basu (1985) have reviewed scintillations at low latitudes.

India provides a unique geographical feature of covering latitudes right from magnetic equator to well beyond the anomaly crest region. A chain of about 20 stations monitoring amplitude scintillations on 244/251 MHz signal from the geostationary satellite FLEETSAT (73° E) was set up under the All India Coordinated Programme on Ionospheric and Thermospheric Studies (AICPITS) to study the features of scintillations at low latitudes. Three campaigns with joint data analysis workshops were conducted during March-April 1991, September-October 1991 and February-March 1993 (Chandra, Vyas & Rao 1993; Sushil Kumar, Singh & Chauhan 2000, Vijaykumar et al.,. 2007). In general scintillations were found to occur in a continuous patch lasting few hours or patches of longer time duration near the magnetic equator, while away from the magnetic equator the patches were of smaller duration. There was a systematic delay in the onset time of scintillation at stations away from the magnetic equator and based on this vertical rise velocity of plasma depletions was estimated. The half width of the belt of equatorial scintillations was estimated to be 15° in the pre-midnight and 6° in the post-midnight period during first campaign and 10° and 8.5° during the second campaign.

OBSERVATIONS AND DATA

Indian Institute of Geomagnetism operated a ground network of 14 stations monitoring amplitude scintillations on 244/ 251 MHz signal, transmitted by geostationary satellite FLEETSAT (73° E long.) in low-latitudinal region in Indian longitudinal sector for more than a solar cycle. The receiving system consists of a Yagi-Uda antenna, a super-heterodyne VHF receiver, an analog chart recorder and a PC based multi-channel digital data logger (deployed in later years at selected stations). To examine solar cycle and magnetic activity dependence, scintillation data at Trivandrum, Tirunelveli, Pondicherry, Karur, Mumbai and Ujjain for the period 1989-2000 are analyzed. Locations of different station are shown in Fig.1. In

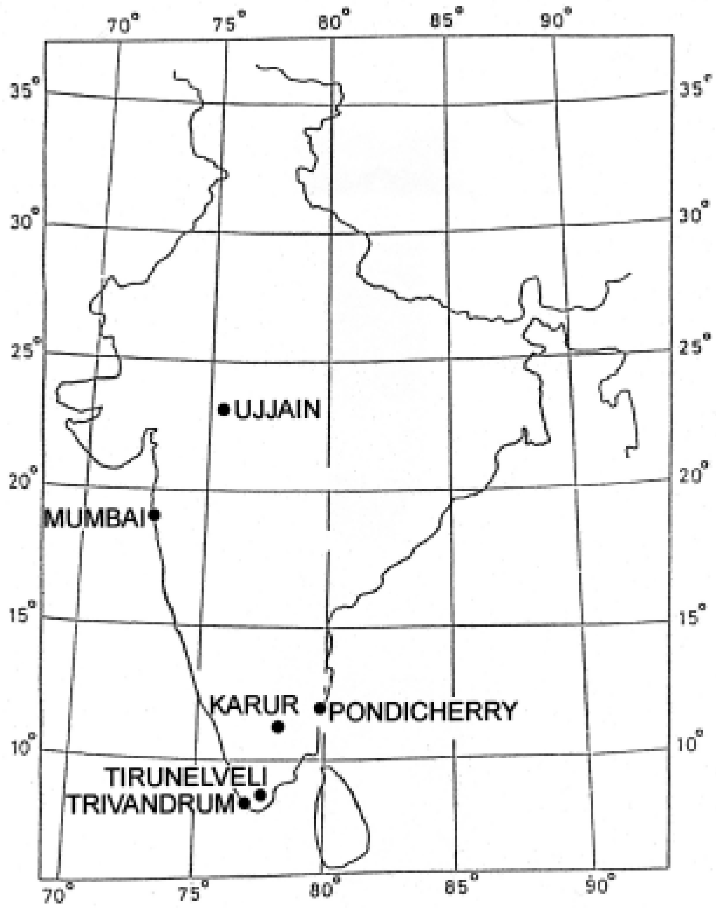


Figure 1. Locations of different VHF scintillation recording stations whose data is used.

the present study, analog chart data from these stations for every 15 min interval are scaled for scintillations exceeding peak-to-peak amplitude >1 dB. The quarter hourly occurrence of scintillations is compiled for each day. Percentage occurrence of scintillations are computed separately and used in the present investigation. Geomagnetic storms during 1989-1995 were selected from Solar Geophysical data (Prompt Report) and the results on the geomagnetic storm effects on scintillation are presented.

RESULTS AND DISCUSSION

Long series of simultaneous scintillation data over a solar cycle (January 1989 to December 2000) at low latitude stations in the Indian region are utilized to estimate the width of equatorial scintillation. Half width of the equatorial belt of scintillation is defined as the dip latitude at which the occurrence of scintillation is reduced to half of its value at the magnetic equator. Scintillation recordings from Tirunelveli/Trivandrum (dip lat. 0.6° N, close to dip equator, Pondicherry/Karur (dip lat. 4.4° N), located at the fringe of electrojet, Mumbai (dip lat. 13.5° N), a temperate station and Ujjain (dip lat. 18.6° N) in the anomaly crest region are used in this study. The seasons chosen are D-months (November to February), E-months (March, April, September, October) and J-months (May to August).

Latitudinal Variation

Annual average and seasonal average percentage occurrence of scintillation, averaged over the whole night (1800-0600 h local time) for a complete solar cycle 1989- 2000 are shown plotted as a function of latitude in Fig.2 separately for descending and ascending phases of solar cycle. It is noticed that during the moderate sunspot activity years of 1993 to 1998, though the enhancement is quite clear near the dip equator, the occurrence is considerably less at latitude greater than 5° dip. However, the

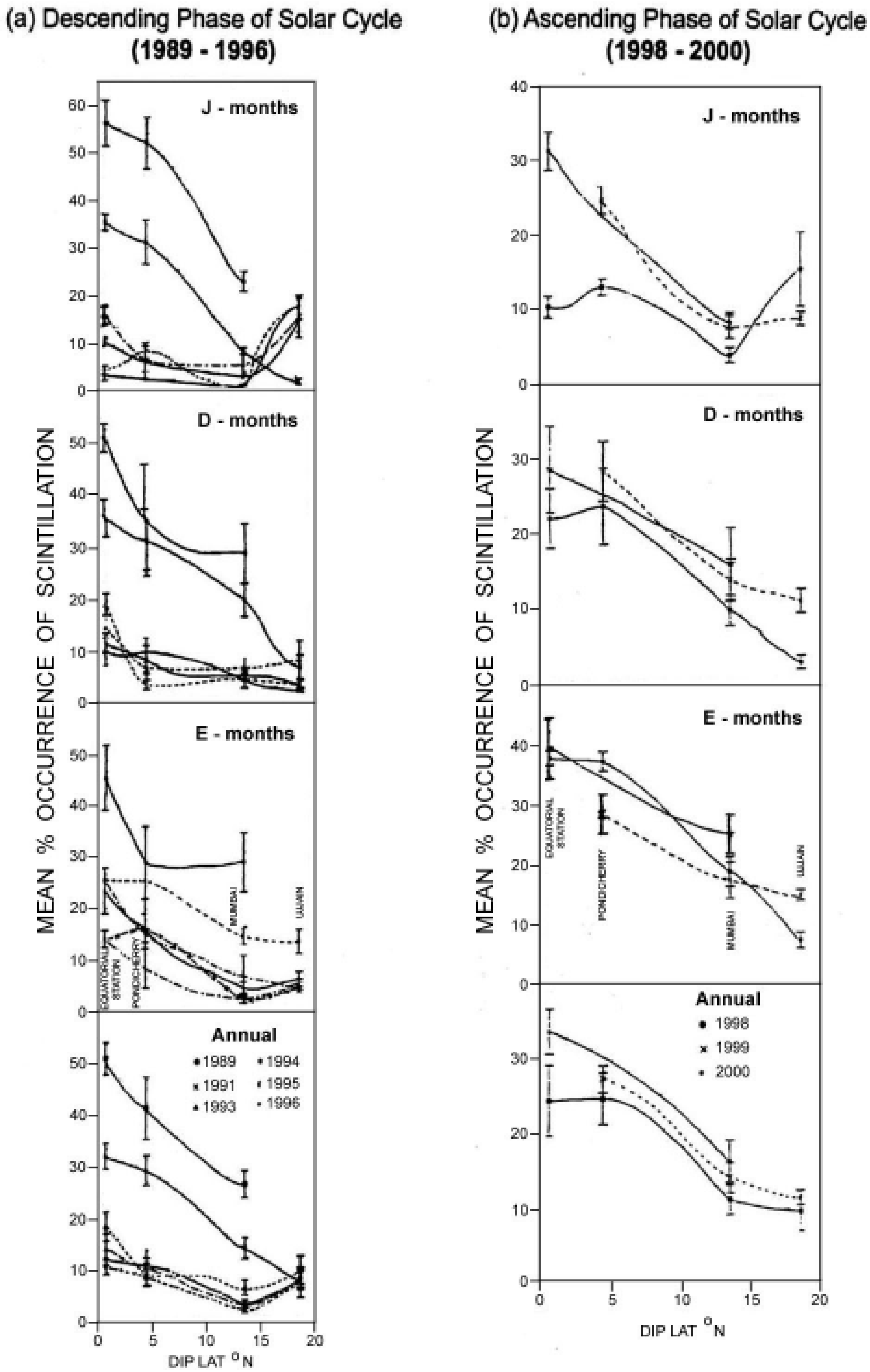


Figure 2. Percentage occurrence of scintillation, averaged over the whole night (18-06 hr), plotted as a function of dip latitude for the three seasons and their annual mean for each year during; (a) descending phase of solar cycle a complete solar cycle 1989-1996 and (b) ascending phase of solar cycle (1998-2000).

Table 1 Half width of the equatorial belt of scintillation estimated during different seasons and years 1989-2000 (- shows no data for that period)

Year	Sunspot No. (Rz)	J-months	D-months	E-months	Annual
1989	154	12	-	-	-
1991	144	10	14	15	12
1993	56	4	7	8	7
1994	31	5	12	12	10
1995	17	7	3	6	7
1996	8	5	7	5	6
1998	62	12	12	14	12
1999	96	-	-	-	-
2000	116	9	-	-	-

occurrence of scintillation at Ujjain, in the anomaly crest region during J-months of 1993 to 1998 was higher than the occurrence at Mumbai and Pondicherry and was comparable with the occurrence at equatorial stations. Mathew et al. (1991) using data at Rajkot, near anomaly crest region, have attributed this to a different source viz; mid latitude generation. The boundaries so determined during different seasons under varying solar activity conditions are given in Table1. In table symbol "—" shows no data or that boundary can not be determined from the curve. For the year 1989 it could be determined only for J-months as there were no data for Ujjain. For the year 1999 it could not be determined for any of the seasons due to absence of data for equatorial station (Tirunelveli). Similarly for D-months and E-months of the year 2000 it could not be determined due to absence of data at Ujjain.

Half width of the equatorial belt of scintillations is in general larger during E-months and D-months than during J-months for all the years of 1989-2000. It is farthest during E-months and varying from 15° to 5° between years of high sunspot number (1991) to low sunspot years (1996). For J-months it is varying from 12° to 5° while for D-months it is varying from 14° to 3°. Looking at the 6 years of data of 1991-98 when all seasons are covered, the average half width values are 9°, 10° and 7° for D-months, E-months and J-months respectively. The values are 14°, 15° and 10° respectively for the three seasons during high sunspot year of 1991, 9.5°, 11° and 8° for the medium solar activity period (1993, 98) and 5°, 6.5° and 6° for low solar activity period (1995-96)

Geomagnetic activity control of scintillation belt

Geomagnetic control of the width of the equatorial scintillation belt is studied from latitudinal variations of scintillation occurrence separately for geomagnetic quiet and disturbed days. Five International quiet (IQ) days and five disturbed (ID) days of each month for years 1991 and 1996 are selected for this study. Also groups of days with low, medium and high Ap values are considered with $Ap \leq 5$, $5 < Ap \leq 20$ and $Ap > 20$ respectively to show latitudinal variations in Fig.3. Half width of the equatorial scintillation belt estimated from Fig. 3 are given in Table 2

It is observed from Table 2 that with increase in geomagnetic activity half width of the scintillation belt decreases. For the year 1991 the half-width values are 15° for quiet days and 11° for disturbed days while for the low solar activity year 1996 these are 9.5° and 6.5° respectively for the quiet and disturbed days. Similarly for the low, medium and high Ap values the half width are 15°, 12° and 11° respectively for the year 1991 and 7°, 7.5° and 6° respectively for the year 1996. Thus the half-width of the equatorial belt of scintillation decreases with increasing magnetic activity.

Solar cycle variations

Fig.4 shows the effect of sunspot activity on the occurrence of scintillation, wherein month to month variation of mean percentages occurrence of scintillation is shown at stations close to dip equator (Trivandrum/ Tirunelveli), temperate station (Mumbai) and at anomaly crest region (Ujjain). It is

Table 2. Half-width of equatorial scintillation belt on days with different geomagnetic activity.

Year	R_Z	Quite days **Q**	Disturbed days **D**	Ap ⩽ 5 **Low**	5 <Ap⩽ 20 **Medium**	Ap > 20 **High**
1991	144	15	11	15	12	11
1996	8	9.5	6.5	7	7.5	6

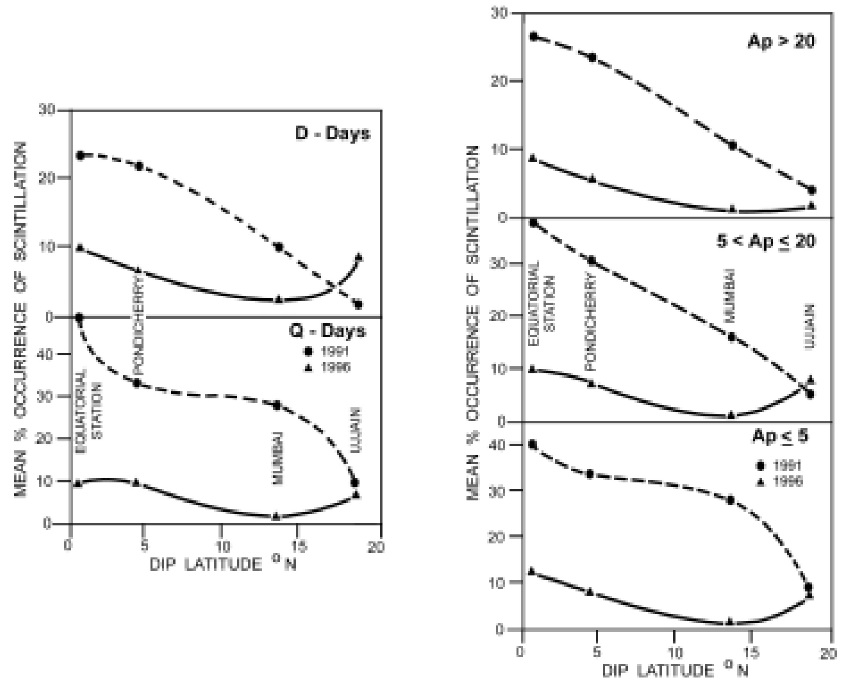


Figure 3. Mean percentage occurrence of scintillations averaged over the whole night (18-06 hr) plotted as a function of dip latitude for geomagnetic quiet and disturbed days (panel on left) and for Ap values of <5, 5-20 and > 20 for the years 1991 and 1996 showing the geomagnetic control on the width of the scintillation belt.

noticed from this figure that with increase in sunspot number mean percentage occurrence of scintillations increases at both equatorial station and at Mumbai. It is seen that during the low solar activity period 1993 to 1996 percentage occurrence at Ujjain is higher than that of Mumbai. Fig.5 shows thirteen months running average of percentage occurrence of scintillations at Mumbai and at equatorial stations (Trivandrum/Tirunelveli) against similar running average sunspot numbers. It is evident that the scintillations at equatorial stations are about 12% at R=0 and about 53% at R=160 while at Mumbai they are ranging from almost 0% to 25% for the periods of observations. Thus there is a decrease of scintillation activity both at equatorial region stations and Mumbai with the decrease in solar activity.

Chandra & Rastogi (1972) observed that the range type of spread F at equatorial station in Indian sector is more common in equinoxes. Tao (1965) has shown a region of ± 15° from the geomagnetic equator where the occurrence of spread F decreases to half of its value at equator during E-months and D-months but a narrower confinement during J-months. The boundary of scintillations (Δ), was shown to be dependent on season. A wider boundary (Δ ~30° dip latitude) during E-months and a narrower boundary (Δ ~ 11°) during J-months was reported (Sinclair & Kelleher 1969). Chatterjee et al. (1974) observed a belt of 11- 22° magnetic latitude in South America while Chandra & Rastogi (1974) found a belt of high scintillations of 8-10° latitude in the Indian region during the year of low solar activity, 1966. Pathan, Rastogi & Rao (1992) reported the boundary of equatorial scintillation in Indian region to be less than 10° for all the seasons for relatively low active year 1987, for the moderate year 1988 the boundary was confined to 10° during J-months but more than 12° during D- months and E- months while for high solar activity year 1989 it varied from 12° to 15° for all the three seasons. In this study it is observed that boundary of equatorial scintillation in Indian region is larger during D-months and E-months for all the years 1898- 2000. During low solar activity year 1996 boundary varies between 7° and 5° for all the seasons, while for high solar activity year 1991 (R= 144), it varies from 15° to 10°.

Rastogi (1982) found very little association of solar activity on scintillation occurrence in American sector. Rastogi, Koparkar & Pathan (1990) compared VHF scintillation data at 244 MHz recorded at Trivandrum for period July 1985 to June 1989 with 137 MHz scintillation data at Huancayo, an equatorial station in American sector during June 1969 - May 1975. They observed that scintillations are most frequent during equinoxes in India during both low & high activity years and during December solstices in American Sector. Scintillation at Trivandrum increased significantly with increase of solar activity but scintillation at Huancayo show comparatively less dependence on solar activity. Rastogi, Koparkar & Pathan (1990) showed that in American sector during high sunspot period, there seems to be rapid decrease in the occurrence

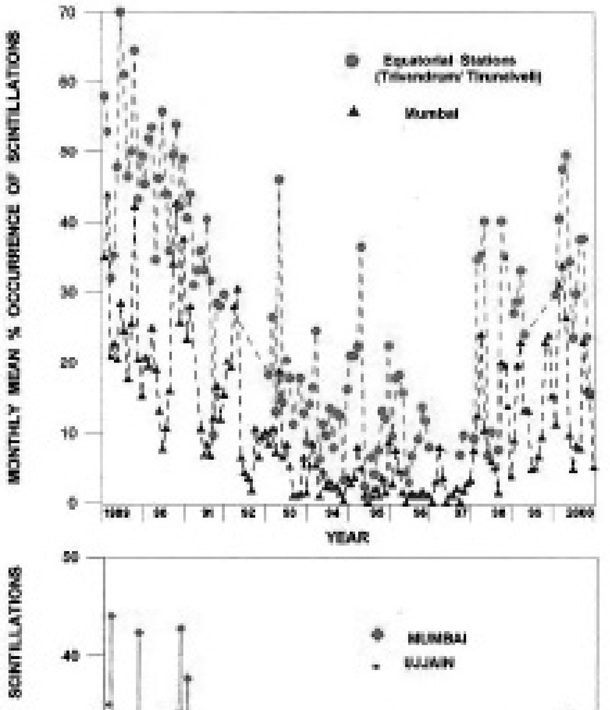


Figure 4. Month to month variation of mean percentages occurrence of scintillation shown at stations close to dip equator (Trivandrum/ Tirunelveli), temperate station(Mumbai) and at anomaly crest region (Ujjain) for solar cycle1989-2000.

probability of range spread after midnight. On an average an inverse correlation between range spread and solar activity is observed while frequency spread is independent of solar activity. For Kodaikanal (dip 3.5 ° N) Sastri et al. (1979) showed that range spread and frequency spread are positively correlated with solar cycle phase. Thus spread-F characteristics and hence Scintillation characteristics are different in the Indian and American sector.

For Indian sector, it was found that equatorial scintillation is positively correlated with sunspot number (Rastogi, Koparkar & Pathan 1990; Pathan, Koparkar & Rastogi 1991; Sushil Kumar et al..2000). Using scintillation data of Calcutta (16.8° N dip lat.), DasGupta, Mitra & Basu (1981) suggested that scintillation occurrence at Calcutta during D-months and E-months is of equatorial origin, while during J-months they are of mid latitude origin. Mathew et al (1991) also concluded similarly. Mathew et al. (1991) studied Scintillation at 244 MHz for 1987 to 1989 over Trivandrum and Rajkot. Equinoctial maxima were seen both for pre-midnight and post midnight during 1989 and 1988 for both stations whereas for low solar activity year 1987 pre-midnight maximum was seen at Trivandrum only. During J months, for Rajkot the maximum is in 1987 (especially for post-midnight). The results presented by them indicate that scintillations observed at Mumbai also appear to be of equatorial origin, as enough evidence of their association preceded by the activity at the equator is seen. DasGupta (2006) studied hourly percentage occurrence of L Band (1.5 GHz) and VHF (244 MHz) Scintillation at Calcutta during 1996-2000.L.band scintillations are effectively caused by irregularities of scale size of a few hundred of meters and VHF scintillations by irregularities in scale size range of one Km. At 1.5 GHz scintillations are practically absent after local midnight. The continuation of VHF scintillations beyond midnight is due to longer lifetime of the Km-scale irregularities. With increase of solar activity from 1996 scintillation occurrence also increases (maximum 45% in March 2000). During low sunspot year there are few occasions of scintillations at both VHF and L-band frequency at Calcutta caused by high altitude equatorial bubbles.

Seasonal and solar activity dependence of equatorial scintillations can be explained in terms of the effect of variation of pre-reversal enhancement of the eastward electric field with season and solar activity. Fejer et al. (1979) have shown from incoherent scatter radar measurement of F-region vertical drift at Jicamarca observatory, Peru that during solar maximum years, the evening pre-reversal enhancement is observed throughout the years but its amplitude is smallest from May to

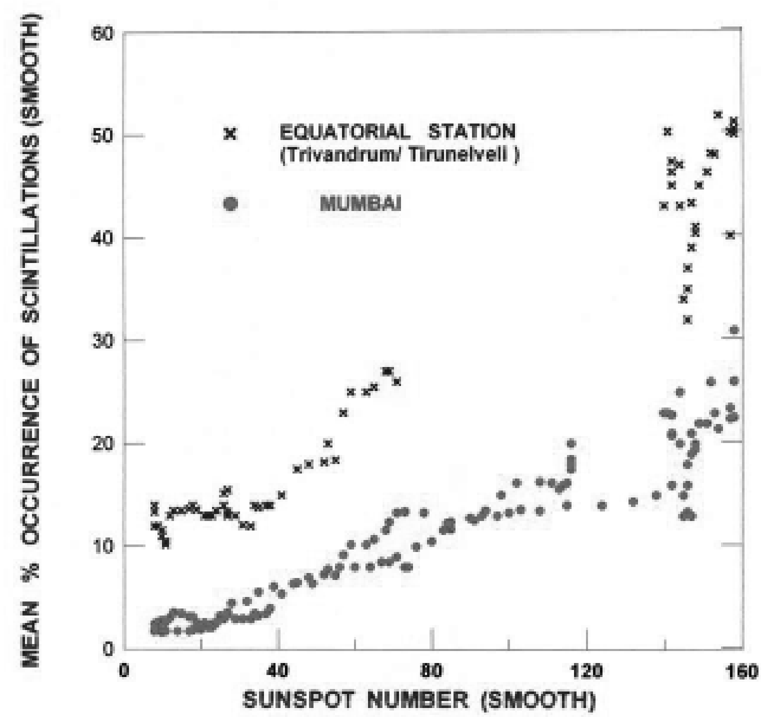


Figure 5. Thirteen months average of percentage occurrence of scintillations at Mumbai and at equatorial stations(Trivandrum/ Tirunelveli) against similar running average sunspot numbers.

August. For solar minimum years, the amplitude of pre- reversal enhancement is much less compared to solar maximum years. Also during low solar activity years, height of F region decreases resulting in sparse scintillation occurrence.

Magnetic activity association of VHF Scintillation

The association of the scintillation activity with the geomagnetic indices on global and regional scales is examined. Use is made of long series of scintillation recordings at two stations in the same longitudinal zone but widely separated in latitudes. Trivandrum (geog. lat. 8.5° N, long. 77.0° E; dip 1° N) or Tirunelveli (8.7°N, 77.8° E; dip 0.6° N), are the stations situated very close to the magnetic equator and, thus, may be assumed to be the seat of the generation of scintillation activity while Mumbai (lat. 19° N, long. 73° E; dip 26° N) is a station just south of the anomaly crest region far from the generation region. Scintillation data for about 7 years (1989-95), during high and descending phases of solar activity period are used in the study. Different parameters like K index derived from geomagnetic recordings from Alibag, Ap index and Dst index are used to study magnetic activity association of VHF scintillation.

To study the magnetic activity effects on scintillation occurrence, days during 1989-1991 were arranged in different groups depending on the daily Ap index and mean % occurrence during the night hours at Trivandrum and Mumbai were computed. Figure 6 shows the mean percentage occurrence of scintillations at Trivandrum and Mumbai for different ranges of Ap. The values of Ap for different ranges are also shown in the figure. The scintillation occurrence at both stations decreases with increase of Ap index. Though there is an indication of increase in the occurrence for Ap values higher than 76. Chandra and Vyas (1978) reported that while the occurrence of spread-F at Kodaikanal decreased with increasing Kp but in summer it showed an increase for high values of Kp.

To study scintillation occurrence during geomagnetic quiet and disturbed periods, the occurrence of scintillations at Trivandrum and Mumbai were estimated by taking five International quiet (IQ) days and disturbed (ID) days of each month for 3 years 1989-91. Yearly percentage occurrences are shown in Table 3.

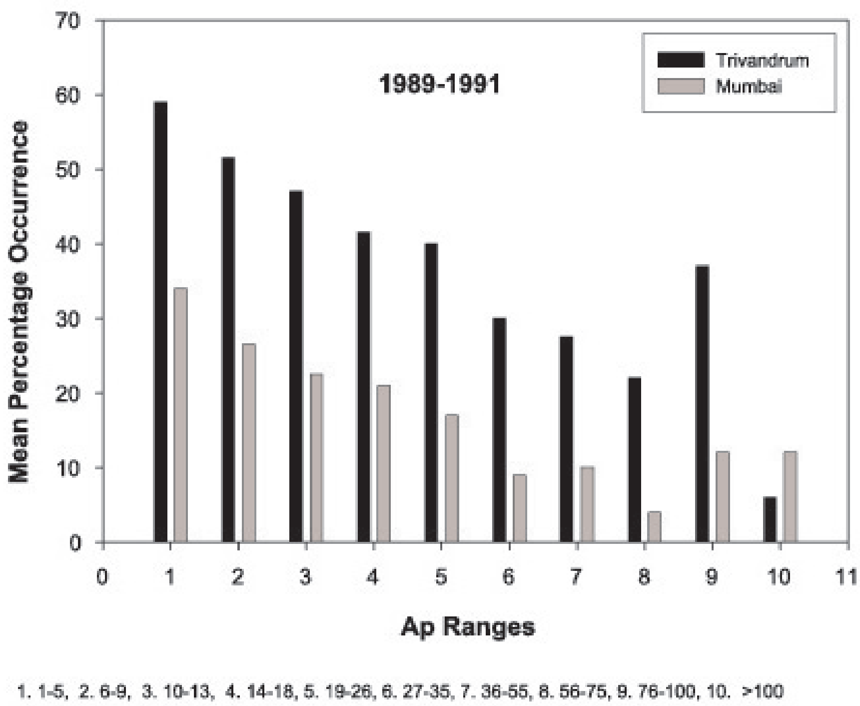


Figure 6. Histogram showing the Ap-index association with mean % occurrence of scintillation during 1989-1991 at Mumbai and Trivandrum (Ap index is divided into 10 groups). Fig. reproduced from Banola et al.(2001).

Table 3 Percentage Scintillation occurrence during quiet and disturbed conditions at Trivandrum and Mumbai during 1989-1991.

Year	Quiet Period		Disturbed Period	
	Trivandrum	Mumbai	Trivandrum	Mumbai
1989	60	38	28	12
1990	55	31	34	12
1991	40	23	19	10

The mean percentage occurrence of scintillation on quiet days averaged over 12 hours of the night (1800-0600 hrs LT) for the years 1989, 1990 and 1991 are 60%, 55% and 40% respectively for Trivandrum and 38%, 31% and 23% respectively for Mumbai. The decrease in the percentage occurrence over the three years is due to the decrease in solar activity from 1989 to 1991. Under geomagnetic disturbances scintillation occurrences decreased at both the stations.

The exact relationship between magnetic and scintillation activities is not very clear. Koster (1972) studied scintillation at Acrra, Ghana (lat 5.63° N, long 0.19° W, 8.47° S dip) and compared periods of scintillation with Kp for July-Dec 1970. He concluded that while a statistically significant relationship between scintillation and magnetic activity exists at Acrra, none was visible in the Huancayo data. He confirmed earlier findings of Bandyopadhyay & Aarons (1970) who found seasonal effects to predominant over geomagnetic activity. However, Sushil Kumar & Gwal (2000) and Pathan, Koparkar & Rastogi (1991) observed very strong negative correlation between scintillation occurrence and magnetic activity in the Indian sector.

Nocturnal and seasonal variation of scintillation activity

To study the seasonal dependence, the percentage occurrences of scintillation at every 15 min interval between 1800 hrs and 0600 hrs at Pondicherry and Mumbai are grouped into the three seasons, Summer (J-solstices), Equinoxes (E-months) and Winter (D-solstices) for years 1998 and 1999 separately and shown in Fig.7. It is observed that during the increasing sunspot years 1998-99 maximum scintillation activity occurred during equinoctial months followed by winter and summer months at both the stations. Scintillation occurrences at off-equatorial station, Mumbai are less than at Pondicherry during all the seasons except the post-midnight hours of summer when occurrences are comparable at the two stations. Scintillation occurrence at both the stations maximizes around 2100 hrs IST for both years (except during winter of 1999 at Pondicherry). With increase in solar activity from 1998 to 1999, scintillation occurrence also increases, resulting in a peak occurrence of about 70% in equinox, 65% in winter and 40% in summer at Pondicherry. While it is only 50% in equinox, 40% in winter and 15% in summer months at Mumbai during 1999.

Using VHF scintillation data of 16 stations, operated in India under AICPITS Chandra et al. (1993) studied occurrence characteristics of nighttime scintillations and reported a peak occurrence between 50% and 60% at the 3 equatorial stations, Trivandrum, Tiruchendur and Annamalainagar, which drops to less than 50% at Goa and Waltair and to less than 40% at Mumbai and Kolhapur. The peak occurrence rate is close to 30% at Nagpur, Rajkot, Ahmedabad, Calcutta and Ujjain in the anomaly crest region, while it is less than 20% for Agra and Varanasi and further reduces to 10% at Delhi. Sushil Kumar et al. (1993, 2000) studied the characteristics of scintillations at Bhopal, Varanasi and Agra during period 1993 and reported that the occurrence of scintillation is highest during equinoctial months, less during winter months and least during summer months.

Fig.8 shows nocturnal variations of scintillations during geomagnetic quiet (Q) and disturbed (D) days at Pondicherry and Mumbai for year 1998. Figure shows that there is a considerable suppression of scintillation activity in all three seasons at both the stations on disturbed days during pre midnight hours. Scintillation occurrences are larger on Q- days as compared to D-days, particularly in equinoctial and winter months at both the stations. It is also seen from Fig.8 that during post midnight periods, scintillations are more on D-days as compared to Q-days at both the stations during equinoxes and winter. Thus magnetic activity suppresses scintillation

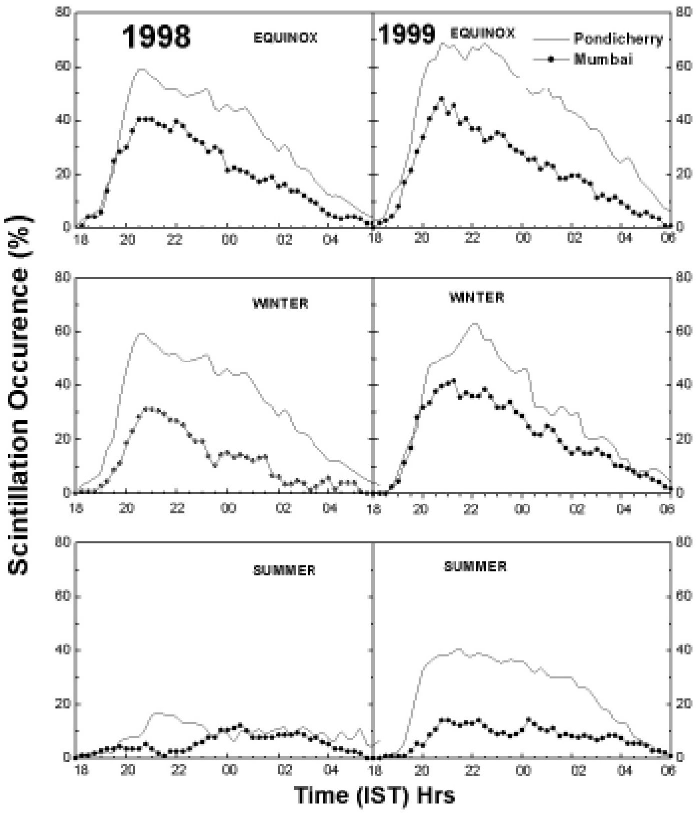


Figure 7. Nocturnal variation of scintillations during three different seasons at Pondicherry, and Mumbai for years 1998 and 1999.

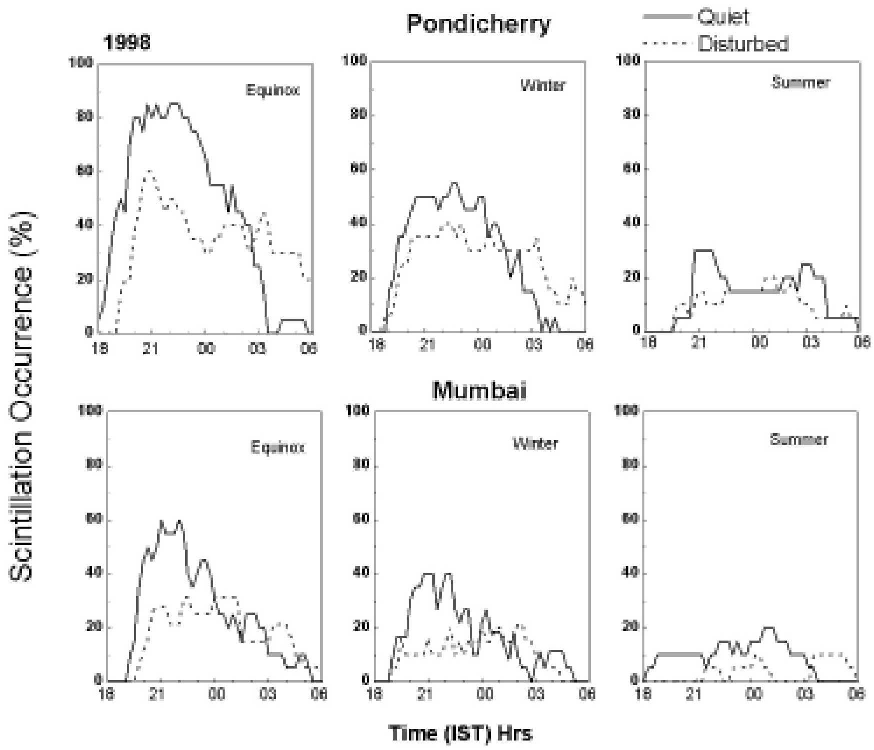


Figure 8. Nocturnal variation of scintillations during quiet geomagnetic (—) and disturbed (—) days at Pondicherry and Mumbai for the year 1998.

occurrence during all the three seasons at both the stations in the pre-midnight sector.

Sushil Kumar & Gwal (2000) and Sushil Kumar et al. (1993) further studied the effect of geomagnetic disturbances on scintillations at low latitudes and reported that the geomagnetic disturbances suppress the scintillations throughout the night at Bhopal, but at Varanasi the scintillations are suppressed in pre-midnight period while at Agra, the scintillations are suppressed in pre-midnight and considerably increased in post-midnight period. They inferred that the effect of geomagnetic disturbances on scintillations depends on season as well as on the latitude of the observing station. Vyas & Chandra (1994) reported marked reduction in the VHF scintillation occurrence over Ahmedabad for 1991-92 in the pre-midnight period.

Magnetic storm association of scintillation activity

To study the scintillation activity under magnetic storm conditions, Dst index has been used as a measure of magnetic activity. Dst index is computed from horizontal intensity data of 5 low-latitude stations, located well away from equatorial electrojet and auroral zones. The association of magnetic storms on the occurrence of scintillations at the two locations, equatorial and anomaly crest region is examined. Dst values and planetary magnetic activity indices Kp during selected storms were used for displaying. As Dst reflects the ring current intensity whereas Kp indicates the geomagnetic activity in the middle and low latitudes, there is a definite time gap between these two.

Aarons (1991) hypothesized three basic effects of the ring current in the generation or inhibition of equatorial F layer irregularities during magnetic storms and categorized the storms in three different ways : 1.Category I - If the maximum excursion of Dst takes place during daytime hours and well before sunset, the normal height rise of the F layer is disturbed and irregularities are inhibited that night, 2.Category II- If the large excursion occurs in the midnight to post-midnight time period, the layer height rises and then falls and creates irregularities and 3.Category III - If the large excursion of Dst takes place after sunset and before midnight, the layer height rise is not disturbed and irregularities form as on an undisturbed night.

Total 208 storms are considered for 7 years period 1989-95, classifying the storms by the time of maximum excursion of Dst (the minimum value of Dst) as per the three categories of Aarons (1991) as shown in Table 4. Examples of each of three categories of storms and associated occurrences or otherwise of scintillation activity at Trivandrum are shown in Fig.9. The top panel shows the ionospheric

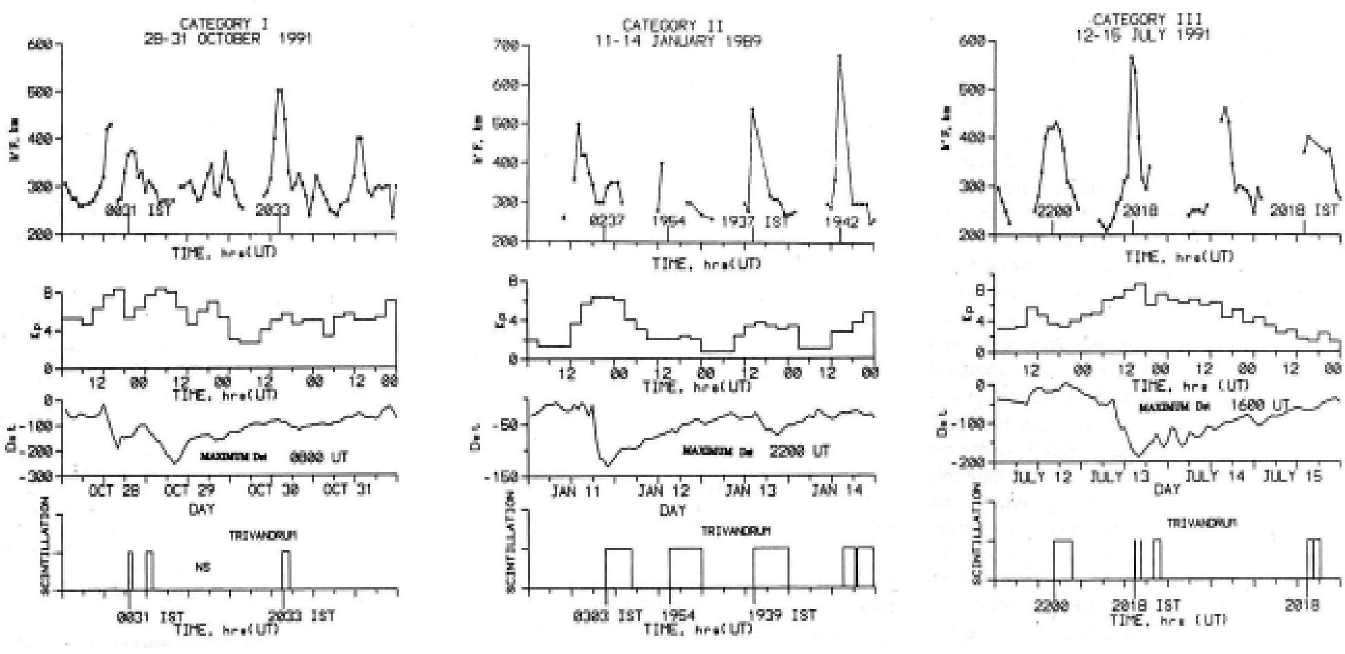


Figure 9. Examples of magnetic storms satisfying each three categories of Aarons Criterion. The top panel shows ionospheric F layer height changes at Kodaikanal (dip 4° N), two middle panels are Kp and Dst and the bottom panel shows occurrence times of scintillation activity at Trivandrum (Vertical blocks are patch durations).

Table 4 Statistics of geomagnetic storms during 1989-1995 satisfying Aaron's three Criteria at equatorial (Trivandrum/Tirunelveli) and near anomaly crest (Mumbai) region.

Year	Storm Type	Number of Storms	Aaron's criterion satisfied for	
			MUMBAI	TRIVANDRUM/ TIRUNELVELI
1989	I	15	8	9
	II	7	6	6
	III	11	8	9
1990	I	10	7	5
	II	3	3	3
	III	5	3	2
1991	I	12	7	7
	II	7	3	3
	III	7	2	3
1992	I	12	10	6
	II	6	4	5
	III	7	3	3
1993	I	21	16	14
	II	9	5	7
	III	11	9	10
1994	I	13	11	11
	II	7	3	5
	III	5	3	4
1995	I	17	16	14
	II	17	6	13
	III	6	5	4
Total for Years 1989-1995	I	100	75 (75%)	66 (66%)
	II	56	30 (54%)	42 (75%)
	III	52	33 (64%)	35 (67%)

F layer height changes at Kodaikanal (dip 4° N), two middle panels are Kp and Dst and the bottom panel shows occurrence times of scintillation activity at Trivandrum (Vertical blocks are patch durations). Left part shows severe magnetic storm for period 28-31 Oct 91, with Dst and Kp values in the 2 middle panels whereas top panel shows the ionospheric F layer height changes at Kodaikanal (dip 4° N) and the bottom panel shows scintillation patch durations. Commencement of magnetic storm occurred at 1054 UT (1624 IST) on 28 October. From about 1200 UT Dst value starts decreasing and attains lowest value of -251 nT at 0800 UT (1330 IST, daytime) on 29 October, with Ap index 128 and Kp varying from 5-

to 8+ . Range of horizontal component of magnetic field, H, at Alibag during the storm is 333. These pre-sunset levels meant that the effect on the electric field at the equator was to inhibit the normal rise in height of the F_2 layer, as shown on top panel which inhibits the irregularities during 29 night. On 28 Oct 91 scintillation onset time is 1901 UT (0031 IST) at Trivandrum during which F layer height increases rapidly to about 430 Km and then decreases to about 260 Km. Similarly on the evening of 30 October large height rise to about 500 Km at 1800 IST, which then falls and creates irregularities on the night of 30th October, 1991. The absence of scintillation activity during the night of 29 October is confirmation of Aarons' criterion.

Middle part is an example of moderate magnetic storm that occurred on 11-14 Jan 1989. Storm commencement time was at 1204 UT on 11 Jan attaining minimum Dst excursion of –132 nT at 2200 UT (0330) IST), ie after midnight, layer height rises up to 350 km and then falls and creates irregularities. On 12 January strong scintillation starts around 0303 IST at Trivandrum, i.e. after midnight and continues into post-sunrise time up to 1000 IST. Thus this storm follows Aarons II criterion. Similarly, on 12, 13 and 14 nights post-sunset steep height rises are noticed up to 400 km, 520 km and 680 km respectively resulting in spread-F and hence strong scintillations on all these days. Onset of intense scintillation at 0303 IST during the night of 12 January confirms Aarons II Criterion. Right part shows severe storm that occurred during 12-15 July 1991. Commencement time is 0925 UT on 12 July and attains minimum Dst value of –185 nT at 1600 UT (2130 IST ie. before midnight) on 13, with Ap value of 134 and Kp increases from 5- to 9-. At the time of maximum Dst excursion F-layer height rises rapidly to about 575 km which is associated with the onset of spread-F in the post-sunset period. Similarly, on 12, 14 and 15 July post-sunset height rises to 420 km, 450km and 400 km respectively are seen and strong scintillations are observed on all the three nights except on the night of 14 July 91. Presence of scintillation on both 12 and 13 night shows that Aarons criterion III is satisfied.

It is noticed from the Table 4 that for 100 storms of category I, scintillations are not present only in 66 cases in generation region, whereas scintillations are not present for 75 cases at Mumbai. (i.e., 66% and 75% of cases are satisfying Aarons criterion at respective stations). For category III, both at Tirunelveli/ Trivandrum and Mumbai about 65% cases are noticed to satisfy, whereas for category II out of 56 storms, for 42 cases (75%) scintillations are present at Tirunelveli and at Mumbai only for 30 cases (54%) the same was present. It is observed that there are 20 cases out of 56 storms of category II when scintillations are recorded at generation region (Trivandrum/ Tirunelveli) but not at Mumbai (i.e. Aarons criterion is satisfied to a greater extent at the generation region but not at the crest anomaly region).

Similar study was done earlier by Pathak et al. (1995) and Banola, Pathan & Rao (2001) considering different storms during 1988-91. They concluded that 60% cases are satisfying Aarons criterion in generation of irregularities responsible for scintillation activity at Trivandrum, Mumbai and Rajkot.

The necessary conditions for inhibition of irregularities and generation of irregularities during magnetic storms can be stated for certain states of ionosphere. For inhibition of irregularities, Koster (1972) has indicated that there were times during large magnetic disturbances near sunspot maximum when irregularities were 'suppressed'. The forcing factors in the inhibition or generation of irregularities appear to be primarily the height of the F_2 layer with the possible addition of the pre-reversal drift velocity, the rate of fall of the layer and the rate of change of density with height. Clemensha & Wright (1966) compared the height of F_2 layer with scintillations and found no case where scintillations commenced until the height began to fall. In addition, during magnetically disturbed days they found the post-sunset height rise to be considerably reduced. Many studies of the correlation of altitude with F layer irregularities at the equator have verified the inability to set a distinctive post-sunset height for irregularities to develop. In the post-sunset period the equatorial F region rises to higher altitudes, where ion-neutral collision frequency is quite small, thereby creating the conditions favorable for Rayleigh -Taylor (R-T) instability. However during magnetically disturbed days, post-sunset height rises may be inhibited (Jayachandra et al., 1987; Martyn 1959).

CONCLUSIONS

VHF Amplitude scintillations at 244/251 MHz were recorded at a number of stations in India over a solar cycle (1989-2000). Occurrence of nighttime scintillations in the Indian equatorial region maximizes in equinoxes followed by winter solstice. Scintillation activity increases with sunspot number.

Width of nighttime equatorial scintillation belt is estimated covering a complete solar cycle. The latitudinal extent of the belt is higher during D-months and E- months compared to J- months.

There is a positive correlation between the width of the belt & the solar activity. Width of the equatorial scintillation belt decreases with magnetic activity.

Equatorial scintillations are inhibited during the magnetic disturbances and this effect also shows seasonal and solar activity dependence. Scintillations at low latitudes can be either inhibited or triggered during storms depending on the phase of the storm & its local time of occurrence.

REFERENCES

Aarons, J., 1982.Global morphology of ionospheric scintillations, IEEE, 70, 360-378.

Aarons, J., 1991. The role of the ring current in the generation or inhibition of equatorial F layer irregularities during magnetic storms, Radio Sci., 26, 1131-1149.

Banola, S., Pathan, B.M. & Rao, D.R.K., 2001. Strength of the equatorial electrojet and geomagnetic activity control on VHF scintillations at the Indian longitudinal zone, Ind. J. Rad. Space Phys., 30,163-171.

Bandyopadhyay, P. & Aarons, J., 1970. The equatorial F-layer irregularity extent as observed from Huancayo, Peru, Radio Sci., 5, 931-938.

Basu, Su & Basu, S., 1985, Equatorial scintillations: advances since ISEA-6, J.Atmos. Terr.Phys., 47, 753-768

Chandra, H & Rastogi, R.G., 1972. Equatorial spread-F over a solar cycle, Ann. Geophys., 28, 709-716.

Chandra, H, & Rastogi, R.G., 1974. Scintillation of satellite signals near the magnetic equator, Curr. Sci., 43, 567-568.

Chandra, H. & Vyas, G.D., 1978. Magnetic activity and spread-F at Kodaikanal, Ind. J. Rad. Space Phys., 7, 163-164.

Chandra, H., Vats, Hari Om, Sethia, G., Deshpande, M.R., Rastogi, R.G., Sastri, J.H. & Murthy, B.S., 1979. Ionospheric scintillations associated with features of equatorial ionosphers, Ann. Geophys., 35, 145-151.

Chandra, H, Vyas, G.D., Rao, D.R.K., Pathan, B.M., Iype, A., Ramsekaram, B., Naidu A., Sadique, S.M., Iyer, K.N., Pathak, K.N., Gwal, A.K., Sushil Kumar, Singh, R.P., Singh, U.P., Singh, Birbal, Pawan Kumar, Navneeth, G.N., Koparkar, P.V., Rama Rao, P.V.S., Jaychandran, P.T., Sriram, P., Sethurama, R., Dasgupta, A., Basu, K. & Rastogi, R.G., 1993. Coordinated multistation VHF scintillation observation in India during March-April 1991, Ind. J. Rad. Space Phys., 22, 69- 81.

Chatterjee, S.K., Bandyopadhyay, A.K., Guhathakurta, B.K. & Bandyopadhyay, P., 1974. The equatorial scintillation belt as observed at Huancayo, Peru., Ann. Geophys., 30, 329-338.

Clemensha, B.R. & Wright, R.W.H., 1966. A survey equatorial spread F and its effect upon radio wave propagation and communication, edited by P.Newman, W.& J.Mackay, London, p18-28.

DasGupta, A., Mitra, A. & Basu S., 1981. Occurrence of nighttime VHF scintillations near the equatorial anomaly crest in the Indian sector, Radio Sci., 16, 1445-1458.

DasGupta, A.,2006. Long term control of solar activity on equatorial scintillations, ILWS Workshop, Goa, Feb.19-24,2006.

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

Jayachandran, B., Balan, N., Nampoothiri, S.P. & Rao, P.B., 1987. HF Doppler observations of vertical plasma drifts in the evening F region at the equator, J. Geophys. Res., 92, 11253 -11256.

Koster, J.R., 1966. Ionospheric studies using the tracking beacon on the Early Bird synchronous satellite, Ann. Geophys., 22, 103-107 .

Koster, J.R., 1972. Equatorial Scintilltions, Planet. Space Sci., 20, 1999-2014.

Martyn, D.F., 1959. The normal F region of ionosphere , Proc. IRE ,47, 147-155.

Mathew, B, Pathan, B.M., Iyer, K.N. & Rao, D.R.K., 1991. Comparative study of scintillations at the magnetic equator and at crest region of the equatorial anomaly in Indian zone, Proceeding of the Indian Academy of Science (Earth and Planet Sci.), 100, 331-337.

Mullen, J.P., 1973. Sensitivity of equatorial scintillations to magnetic activity, J Atmos. Terr. Phys., 35, 1187-1194.

Pathak, K.N., Jivrajani, R.D., Joshi, H,P & Iyer, K.N., 1995. Characteristics of VHF Scintillations in the equatorial anomaly crest region in India, Ann.Geophys., 13, 730-739.

Pathan, B.M., Koparkar, P.V., Rastogi, R.G. & Rao, D.R.K., 1991. Dynamics of ionospheric irregularities producing VHF radio wave scintillations at low latitudes, Ann. Geophys., 9, 126-132.

Pathan, B.M., Rastogi, R.G. & Rao, D.R.K., 1992. On the width and complexities of the equatorial nighttime radio wave scintillation belt in the Indian region, J. Geomag. Geoelectr., 44, 129-142.

Rastogi, R.G., 1982. Solar cycle effects on radio scintillations at Huancayo, Ind. J. Rad. Space Phys., 11, 215-221.

Rastogi, R.G., Koparkar, P.V. & Pathan, B.M., 1990. Nighttime radiowave scintillations at equatorial stations in Indian and American zones, J. Geomag.

Geoelectr., 42, 1.

Sastri, J.H., Sashidharan, K., Subramanyam, V. & Rao, S., 1979. Range and Frequency spread-F at Kodaikanal, Ann. Geophys., 35, 153-158.

Sinclair, J & Kelleher, R.F., 1969. The F region equatorial irregularities belt as observed from scintillation of satellite transmissions, J. Atmos. Terr. Phys. 31, 201-206.

Sushil Kumar, Singh, A.K., Chauhan, Pawan, Gwal, A.K., Singh, Birbal, & Singh, R.P., 1993. Multistation analysis of VHF radio wave scintillations at low latitudes, Ind. J. Rad. Space Phys., 22, 267-272.

Sushil Kumar & Gwal, A.K., 2000. VHF ionospheric scintillations near the equatorial anomaly crest region; Solar & magnetic activity effects, J. Atmos. Solar Terr. Phys., 62, 157-167.

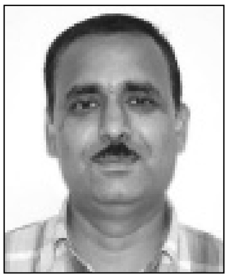
Sushil Kumar, Gwal, A.K., Rama Rao, P.V.S., Jayachandran, P.T., Prasad, D.S.V.V.D. , Singh, R.P., Singh, U.P., DasGupta, A., Basu, K., Sethuraman, R., Pathan, B.M., Rao, D.R.K., Banola, S., KesavRao, P.S., Naidu, Appala, Tyagi T.R., Vijaykumar, P.N., Chandra, H., Vyas,G.D., Singh, Birbal, Chauhan, Pawan, Iyer, K.N., Pathak, K.N., Shalgaonkar, C.S., Vyas, B.M. & Rastogi, R.G., 2000. Co-ordinated observations of VHF scintillations in India during February-March 1993, Ind. J. Rad. Space Phys., 29, 22-29.

Tao, K., 1965. Worldwide maps of the occurrence percentage of spread F in years of high and low sunspot numbers, J. Radio Res. Lab., 12, 317-356.

Vijaykumar, P.N., Tyagi, T.P., Singh, Lakha, Chandra, H, Vyas, G.D., Rao, D.R.K., Pathan, B.M., Iype, A., Ramsekaram, B., Naidu, A., Sadique, S.M., Iyer, K.N., Pathak, K.N., Gwal, A.K., Sushil Kumar, Singh, R.P., Singh, U.P., Singh, Birbal, Pawan Kumar, Navneeth, G.N., Koparkar, P.V., Rama Rao, P.V.S., Jaychandran, P.T., Sriram, P., Sethurama, R., Dasgupta, A., Basu, K., Rastogi, R.G., 2007. Some features of plasma bubble induced scintillations during the AICPITS campaigns of 1991. Ind. J. Rad. Space Phys., 36, 91-102.

'Vyas, G.D.& Chandra, H., 1994. VHF scintillation and spread-F in the anomaly crest region, Ind. J. Rad. Space Phys., 23, 157-164.

(Revised accepted 2010 July 2; Received 2010 May 4)



Dr.Sridhar Banola: Born on 22nd Dec.1963 in Varanasi, is currently working as Technical Officer-II in Indian Institute of Geomagnetism, Navi Mumbai. He completed M.Sc.(Tech.) Geophysics from Banaras Hindu University (B.H.U.), Varanasi in 1988 and joined IIGM on 27th August 1991. Worked under the supervision of Prof. D.R.K.Rao on 'VHF Scintillation Project' and obtained Ph.D. Degree in Geophysics from B.H.U in 2001. His current areas of research are Study of ionospheric irregularities using VHF Scintillation Technique, Space Weather Studies and Solar-Terrestrial Interactions. Participated in the 13th Indian Scientific Expedition to Antarctica (ISEA) during Dec.1993–April 1994 as summer team member and attended 35th COSPAR Scientific Assembly at Paris, France in July 2004. About 25 scientific papers have been presented in various Symposium/ Workshop/Seminars attended and 5 papers have been published in various national & international journals.

Mr. R.N.Maurya joined IIGM, Mumbai on 22 Nov.1982 and is currently working as Technical Officer-III. He was born on 7 Jan.,1962 in Varanasi and completed Engineering Diploma in Electronics. He is presently working in Instrumentation Laboratory and associated with various projects of the institute. VHF Scintillation Receiver designed by him is being used at 9 different stations in India monitoring VHF Scintillation at 250.65 MHz.

Prof. H.Chandra obtained M.Sc. (Physics) in 1964 from Agra University and started research in equatorial ionosphere at Thumba as research student of the Physical Research Laboratory, Ahmedabad. He obtained Ph. D. in 1970 from Gujarat University. His research interests cover ionospheric drifts, equatorial ionosphere, spread-F, scintillations, radar probing of mesosphere, lidar, in-situ measurements of equatorial ionosphere and mesosphere. He has published 200 research papers in national and international journals.