Radio Science, Volume 34, Number 1, Pages 241–255, January–February 1999

Long-term observations of VHF scintillation and total electron content near the crest of the equatorial anomaly in the Indian longitude zone

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Abstract. Ionospheric VHF scintillation ($SI \geq 3$ dB and saturated level) and total electron content (TEC) data obtained at Calcutta (subionospheric 21°N, 92.7°E geographic, 27°N dip) and ionosonde data at Kodaikanal (10.2°N, 77.5°E geographic, 3.5°N dip) for the period 1977-1990 have been analysed to show the importance of electrodynamic drift near the magnetic equator in controlling nighttime ionospheric *F* region ionization and irregularities in the equatorial region. Such long-term observations extending over a period of more than 13 years are possibly being reported for the first time from a location situated near the equatorial anomaly crest. Frequent and intense VHF scintillations near the equatorial anomaly crest during equinoctial and December solstice months around solar maximum years, have been identified with the equatorial *F* region irregularities. Simultaneous measurement of TEC at the same location shows that during solar maximum years the high *F* region ambient ionization is sustained for several hours in the postsunset period, often showing secondary enhancements during equinoctial months. Under solar minimum epoch, when scintillation is sparse, TEC in the above period shows a rapid decrease. At Kodaikanal, situated near the magnetic equator, during the equinoctial and December solstice months of solar maximum years, $h'F$ values rise by more than 100 km in about an hour around sunset. These features are seldom observed during solar minimum epoch. A causative connection among $h'F$ variation near the magnetic equator and the maintenance of high ambient ionization and occurrence of scintillation near the anomaly crest is established. Further, scintillation occurrence during the May-July months shows a remarkable hysteresis effect with solar activity level.

1. Introduction

In the last two decades, there have been tremendous developments in our understanding of the behavior of the equatorial ionosphere. Two outstanding features of the equatorial *F* region ionosphere are (1) the equatorial anomaly and (2) intense irregularities in electron-density distribution. It is now established that the equatorial electric field plays the dominant role in shaping the development of both daytime equatorial anomaly and nighttime density irregularities. During high sunspot number years, in a narrow latitudinal belt centered on the dip equator, the *F* region experiences an abnormal increase in height in the postsunset period. This increase in *F* region height is caused mainly by an enhancement of the eastward electric field. The field is eastward during the day and reverses to the west after sunset, around 2100 LT. Before reversal, there is a dramatic increase in the electric field [*Fejer*, 1991; *Hari et al.*, 1996]. The effect of prereversal enhancement of the eastward electric field is twofold and has both seasonal and solar activity dependences. The increased electric field causes an outflow of ionization from the trough region, thereby increasing the ionization density near the crests at the

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Paper number 98RS02576.
0048-6604/99/98RS-02576$11.00

expense of that at the trough. Near the anomaly crests, fresh influx of ionization combined with the neutral wind counteracts the normal decay of ionization and produces a secondary peak or a ledge in the ionization distribution [*Anderson and Klobuchar,* 1983; *DasGupta et al.*, 1985; *Huang et al.,* 1989]. Further, the prereversal enhancement of the eastward electric field raises the F layer at the magnetic equator to high altitudes, where recombination effects are negligible and conditions favorable for the generation of irregularities may be obtained [*Haerendel,* 1974; *Woodman and LaHoz,* 1976]. Through the Rayleigh-Taylor mechanism, the irregularities then develop into plasma-depleted bubbles and are upwelled to the topside of the ionosphere. The polarization electric field within the bubbles is higher, and as a consequence the bubbles rise to the topside at a velocity much greater than the ambient F region plasma drift [*Anderson and Haerendel,* 1979]. The above effect is most pronounced during the equinoctial months of sunspot number maximum years.

Jicamarca radar observations have frequently shown prereversal enhancement of the vertical drift velocity, attaining values in excess of 40 m/s during the 21st and 22nd solar cycle. The peak value of the postsunset vertical drift velocity is found to exhibit a pronounced solar activity dependent feature [*Fejer,* 1991; *Fejer et al.,* 1991, 1995]. Limited $h'F$ Doppler radar observations at Thumba in India [*Krishna Moorthy et al.*, 1979] also show features of the F region vertical drift similar to those at Jicamarca. Recent observations using the HF phase path technique [*Sastri*, 1996] have revealed that during equinoctial and December solstice months the postsunset peak vertical drift velocity over Kodaikanal is very sensitive to solar flux changes. The sensitivity to solar flux is, however, greater at Jicamarca in the American zone than at Kodaikanal in the Indian sector. This feature is virtually absent during June solstice.

Persistence of a high ambient ionization and injection of equatorial irregularities result in severe scintillation effects near the anomaly crest in the postsunset period. The intensity of scintillation is mainly controlled by the irregularity amplitude, ΔN. A higher background density N implies a larger integrated density deviation and hence intense scintillation occurrence [*Aarons et al.,* 1981].

The events of F region height rise at the magnetic equator, persistence of high ambient ionization, and occurrence of intense scintillation near the anomaly latitudes are all associated phenomena. An integrated picture of the equatorial F region ionosphere may therefore be developed through a coordinated study of the vertical ionization drift at the magnetic equator and background ionization distribution and scintillation near the anomaly crest in the postsunset period.

For the measurement of background ionization, the Faraday rotation technique is economical, while observation of scintillation for studying ionospheric irregularities is most popular. The prereversal enhancement of vertical drift of the equatorial F layer has been measured by various techniques, such as incoherent scatter radar, HF Doppler, ionosonde, etc. In spite of the fact that these are all well-accepted methods, systematic observations combining equatorial F layer vertical drift, total electron content (TEC), and associated scintillation have not yet been reported from anywhere on a long time base.

This paper presents the results of simultaneous observations of TEC and scintillation over a low-latitude station (Calcutta) and F layer virtual height variation at an equatorial station (Kodaikanal) for a period of more than one solar cycle (1977-90).

2. Data

Studies of amplitude scintillation of a transionospheric VHF radio signal (136 MHz) from the geostationary satellite ETS II during April 1977 through December 1990 are presented in this paper. The observations were carried out at the Haringhata Field Station (23°N, 88.5°E; geomagnetic, 12.3°N; dip, 32°N) of the University of Calcutta. The station offers an excellent platform for studying equatorial ionospheric irregularities. The 400-km subionospheric point of the satellite path falls just south of the northern crest of equatorial anomaly and maps up along the geomagnetic field lines to an altitude of 800 km above the magnetic equator. TEC measured by the Faraday rotation technique of the same signal has been utilized to show a relationship between occurrence of equatorial scintillation and ambient ionization. Ionospheric $h'F$ data obtained from an equatorial station, Kodaikanal, have also been used to establish the interrelationship between the F layer vertical drift at the magnetic equator and scintillation occurrence in an environment of high ambient ionization near the anomaly crest. The longitude difference (~15°) between Haringhata and Kodaikanal is large for a point-to-point correspondence but small enough to show an average correspondence between *F* region parameters. Moreover, the irregularities responsible for equatorial scintillation, as stated earlier, are generated near the magnetic equator in the postsunset period. Once generated, the irregularities move upward due to ExB drift and experience an eastward motion due to zonal winds. Hence location of an ionosonde station at a slightly western longitude would be preferable.

The scintillation data presented in this paper are scaled according to the usual third peak method [*Whitney et al.*, 1969]. The receiver was calibrated at least once a week according to the method described by *Basu and Basu* [1989]. The dynamic range of the receiver was about 22 dB.

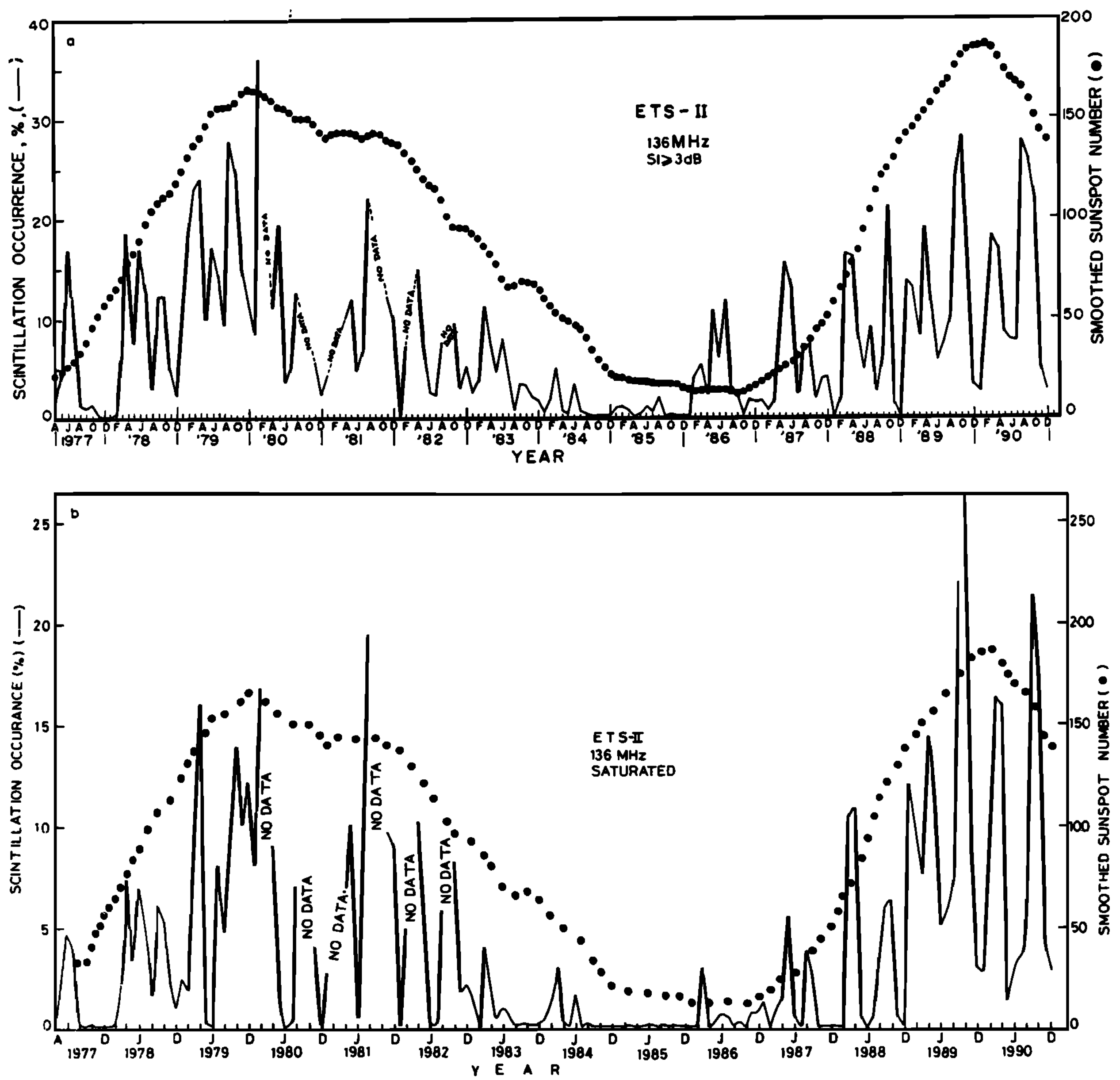

Figure 1. Variation of 136-MHz nighttime (1800-0600 LT) scintillation activity at (a) $SI \geq 3$ dB and (b) saturated level, during 1977-1990. The monthly mean smoothed sunspot numbers are shown (circles) to indicate the dependence on solar activity.

3. Results

3.1. Amplitude Scintillation at Calcutta

Scintillation morphology at this location exhibits a pronounced dependence on season and solar activity level. Figure 1 shows the monthly mean percentage occurrence of nighttime scintillation with *SI* ≥ 3 dB (Figure 1a) and saturated level (Figure 1b) observed at 136 MHz during the period April 1977 through December 1990. Monthly mean smoothed sunspot numbers have also been plotted in the same figure to show the solar activity levels in different months. In 1977, a year of low solar activity, scintillation essentially occurred during the May-July months. The scintillation index at 136 MHz ranged between 3 and 6 dB [*DasGupta and Maitra*, 1979]. As the sunspot number rapidly increased in 1978-1979, there was a dramatic increase in the percentage occurrence during the August-April months. In 1978, scintillation was observed during the two equinoxes and the December solstice besides the May-July period. During 1979-1980, the period of maximum sunspot number of the 21st solar cycle, equinoctial components were found to be much more prominent than those in the June solstice. The December solstice also showed an enhancement. From 1981 the sunspot number had a decreasing trend, and the scintillation occurrence in the equinoctial and December solstitial months exhibited a slow decline. This feature continued up to 1985-1986, the period of minimum sunspot number. In low-sunspot-number years, ionospheric scintillation at VHF is essentially a May-July phenomenon, with little or no scintillation during the other months. It should be noted, however, that there are individual occasions of scintillation at the latitude of Calcutta caused by high-altitude equatorial bubbles. Similar to the cases referred to by *Basu et al.*, [1988] and *Sahai et al.*, [1994], their frequency is no doubt less, but they are occasionally observed. The May-July occurrence pattern also shows increase with solar activity, but the dependence is much less pronounced than that observed in the equinoxes. Scintillation during the increasing sunspot number years of 1987-1990 exhibited the same features as were observed during the years 1978-1980. Figure 2 shows the above features of scintillation (*SI* ≥ 3 dB) at 136 MHz for different seasons taken separately during 1977-1990.

Scintillation at this location has certain distinctive characteristics. The equinoctial and December solstitial months of high-sunspot-number years have features different from those in the May-July months of low as well as high-sunspot-number years. Scintillation during August through April generally starts abruptly in the postsunset hours, reaching saturation within a few minutes. The fast and wall-to-wall fluctuations at VHF normally occur in well-defined patches of varying duration, extending from a few minutes to a couple of hours in the premidnight local time sector. Simultaneous Faraday rotation records exhibit TEC depletions [*DasGupta et al.*, 1983] or fast polarization fluctuations [*DasGupta et al.*, 1983; *Maitra et al.*, 1982] during the August-April scintillation events. Sometimes long-duration patches persist beyond midnight also, with a gradual decay of both fading rate and amplitude.

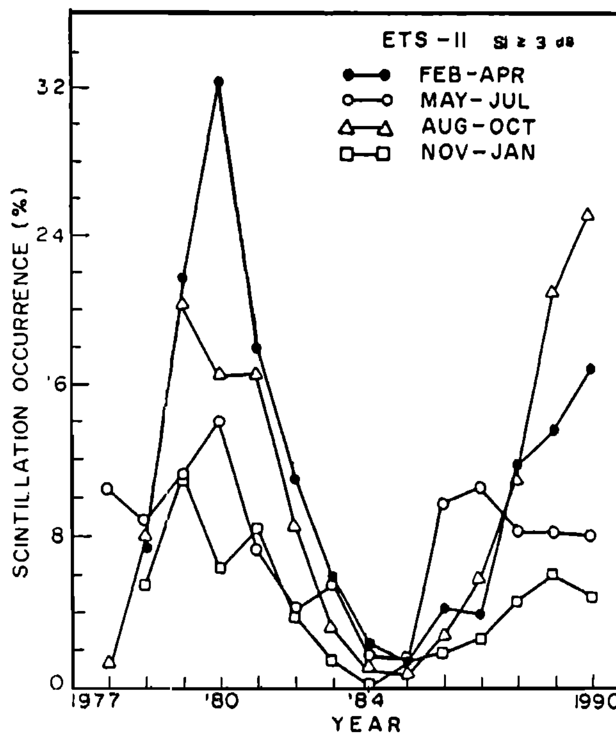

Figure 2. Occurrence of nighttime scintillation at 136-MHz (*SI* ≥ 3 dB) during 1977-1990 in different seasons, taken separately.

Scintillation in the May-July months is normally weak to moderate in the "3- to 6-dB range", seldom reaching saturation level. The fading is much slower than that recorded in the equinoxes and December solstitial months. The May-July phenomenon is more like the class II cases observed near the magnetic equator at Thumba by *Krishna Moorthy et al.*, [1979].

Scintillation normally occurs over a longer period of time, frequently extending up to the presunrise hours.

It is interesting to note that the ambient F_2 region maximum ionization (N_mF_2) and TEC during daytime and early evening hours at locations near the equatorial anomaly crests also show the seasonal maximum in the equinoxes. The two parameters have also been found to be more sensitive to solar activity during the two equinoxes [*DasGupta and Basu*, 1973]. The higher postsunset equinoctial scintillation in solar maximum years may be related to higher ambient ionization observed in this location around the period of interest. This point will be discussed in more detail in the next section.

Figure 3 shows the observations presented in Figure 2 in a different way, along with the corresponding mean 10.7-cm solar flux. Although the equinoctial scintillation pattern follows the solar flux variation, there is no remarkable point-to-point correspondence. The effect of solar activity on the seasonal variation of scintillation is also shown in Figure 4. In this case, scintillation occurrence ordered on a seasonal basis has been plotted as a function of the 10.7-cm solar flux. It is significant to note that a decrease in scintillation activity with the 10.7-cm solar flux during the declining phase of a solar cycle does not generally retrace the pattern followed during increasing phase. A hysteresis effect is noticeable in all these plots. The effect is most pronounced in the local summer months. It is interesting to note that the ambient F region ionization, as indicated by f_oF_2, also exhibits a similar hysteresis effect [*Davies*, 1990]. In any attempt to model scintillation occurrence, the above features should be taken into account.

3.2. The $h'F$ Over Kodaikanal Vis-a-Vis Ambient Ionization and Equatorial Scintillation at Calcutta

Scintillation activity near the crest of the equatorial anomaly is related to the seasonal behavior of the prereversal peak of the upward **ExB** drift at the magnetic equator [*Das et al.*, 1988]. It may be worthwhile to examine a statistical correspondence between the cause ($h'F$ variation) and the effect (TEC enhancement and scintillation occurrence). Figure 5 shows the variation of $h'F$ at Kodaikanal during 1986-1990. The behavior of TEC at Calcutta during the same period is also shown in the same figure. Figure 6 shows scintillation, TEC, and $h'F$ contours for the sunspot number maximum year 1979. The closeness of the $h'F$ contours may be taken as an indication of the F region altitude changes . Around sunset in the equinoctial months of 1979 and 1989-1990 the F region near the magnetic equator undergoes a very rapid upward vertical drift. Velocities of magnitude 50 m/s or more are frequently observed. As a result, F layer altitudes exceeding 400 km were often reached during the same period. The contours of TEC also in Figures 5 and 6 exhibit a prominent feature dependent on season. The persistence of high TEC values (30-100 TEC units) for several hours after sunset during the equinoctial and December solstitial months signifies the seasonal character. On individual days, the diurnal variation of TEC often shows clear secondary maxima (Figure 7) halting the normal decay process during the same local time. In the same interval, intense scintillation activity (with 30-50% occurrence at 136 MHz) was observed at Calcutta (Figures 8 and 6). Scintillation observed in this period was saturated, with a very fast fading rate. In fact, the strip chart recorder response time was too slow to follow the fast fadings, and quite often the trace became smudged.

On the other hand, the postsunset $h'F$ contours of local summer months (May-July) were not so dense, indicating a smaller vertical drift (10-20 m/s) of the F layer. The $h'F$ value seldom exceeded 400 km in the early evening hours. The postsunset TEC values show a rapid decrease, and the persistence of TEC is conspicuously absent. Scintillation during this period was mild to moderate, with a slow fading rate and lower percentage (~ 5-10%) occurrence.

Contrary to the high-sunspot-number years, during the minimum epoch of solar cycle (1986, with smoothed sunspot number ~16) the contours of $h'F$ (Figure 5) exhibit a large separation. The wide separation of $h'F$ contours at Kodaikanal around local sunset indicates that there was no large vertical drift to inhibit the normal postsunset decay of ambient ionization at the crest of the equatorial anomaly. Moreover, throughout the year the measured virtual heights of the F layer were observed to be quite low, seldom exceeding 300 km in the early evening hours. Only during the postsunset period of the autumnal equinox were the $h'F$ values observed to exceed 300 km. Simultaneously, Figure 5 shows that the TEC values in the postsunset period of equinoctial months are in the range of 10-15 TEC units, much lower than

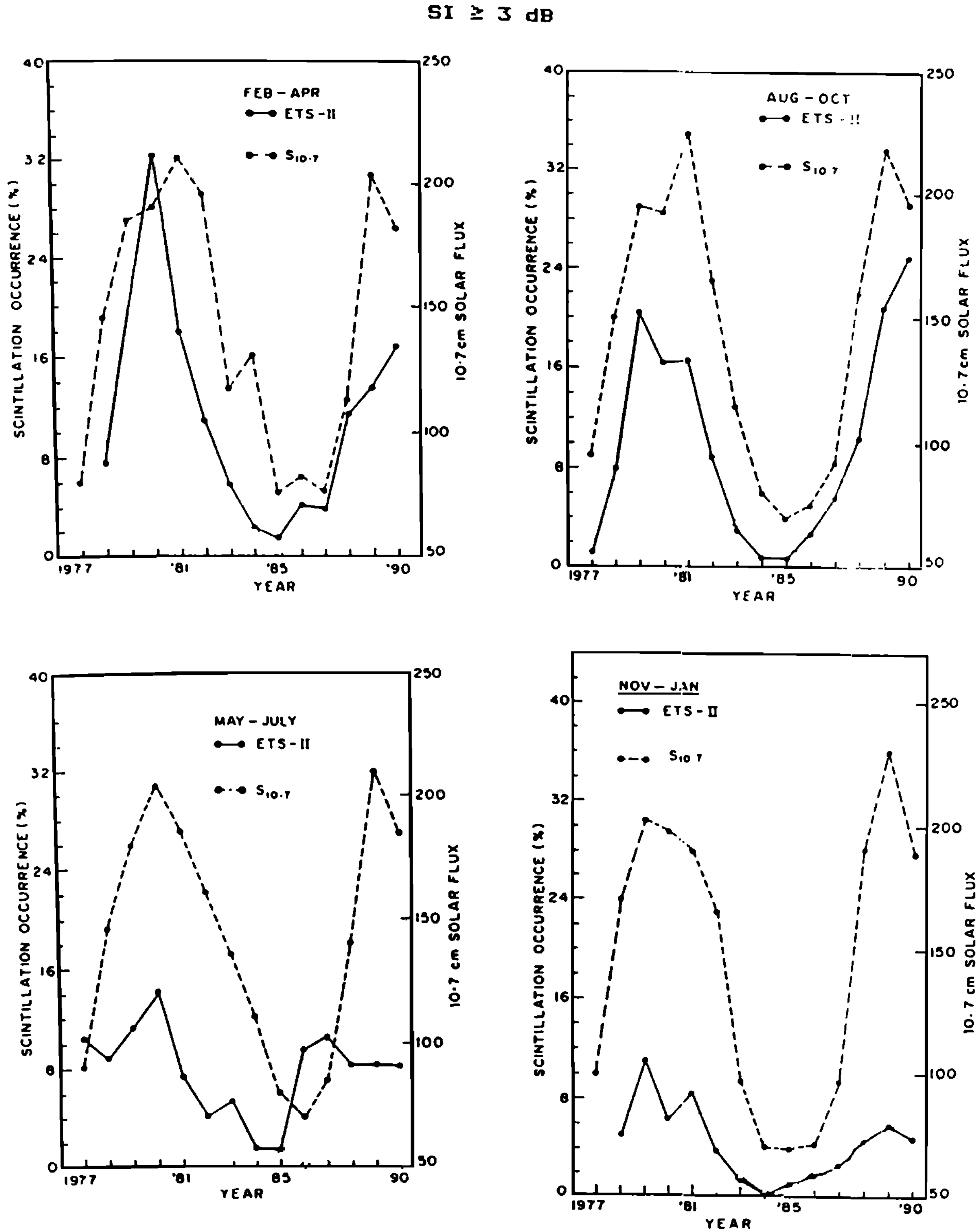

Figure 3. Variation of nighttime scintillation occurrence ($SI \geq 3$ dB) at 136-MHz with $S_{10.7}$ solar flux for different seasons during 1977-1990.

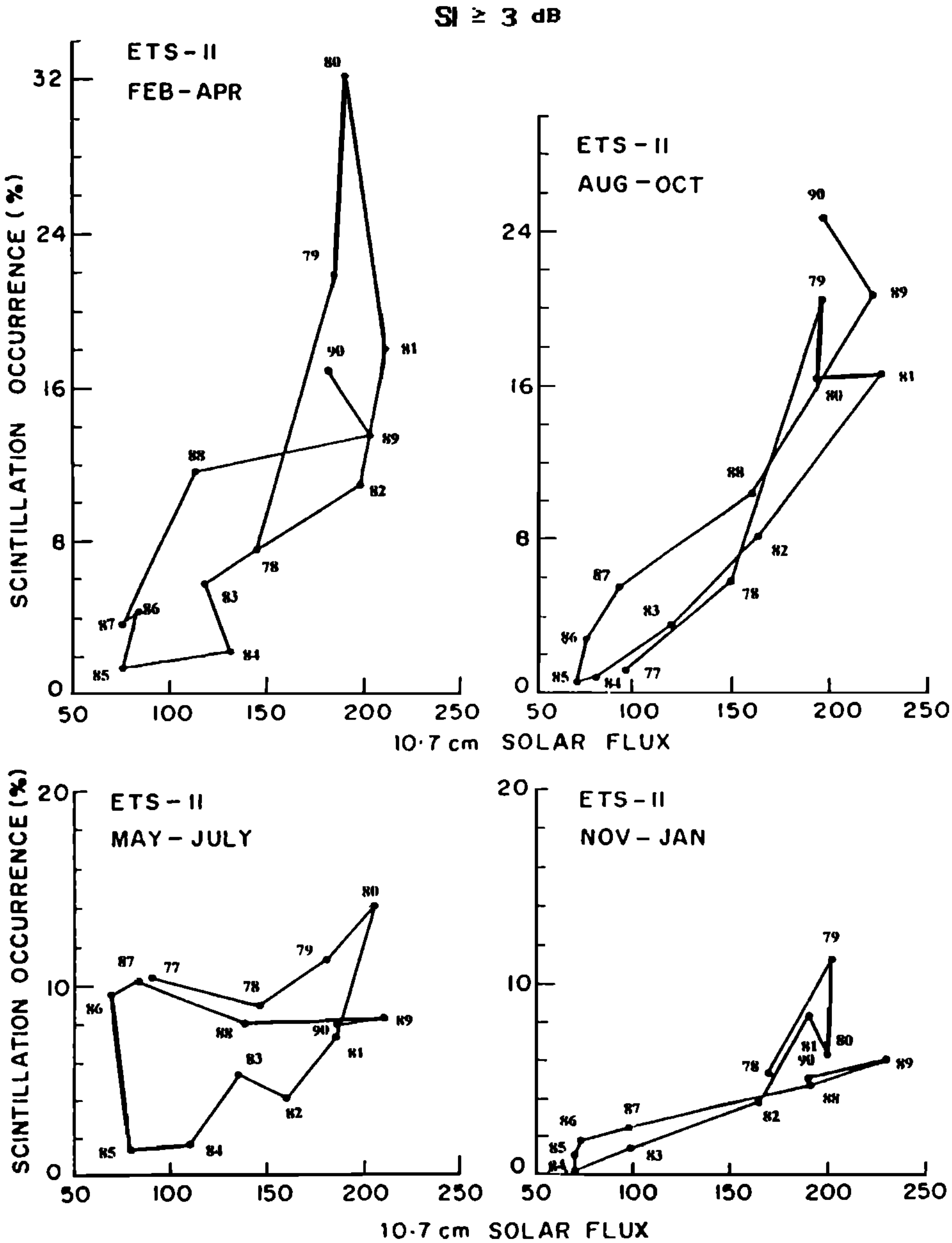

Figure 4. Variation of nighttime scintillation occurrence at 136-MHz ($SI \geq 3$ dB) as a function of $S_{10\cdot7}$ solar flux in different seasons during 1977-1990.

those in solar maximum epoch. There is no prominent persistence of TEC in postsunset hours. The contrast in the behavior of TEC between solar maxima and minima years, both as to level and time around sunset, is similar to that observed with f_oF_2 by *Aarons et al.*, [1981]. The corresponding scintillation contours (Figure 8) at VHF are sparse throughout the year 1986. During the May-July months, a moderate value of scintillation occurrence was observed around midnight but not in the early evening hours. The nature of scintillation, as stated earlier, was quite different from the equinoctial one and was mainly characterized by a slow fading rate.

It is interesting to examine the behavior of scintillation, ambient ionization, and $h'F$ in a year in between the sunspot number maximum (1979/1990)

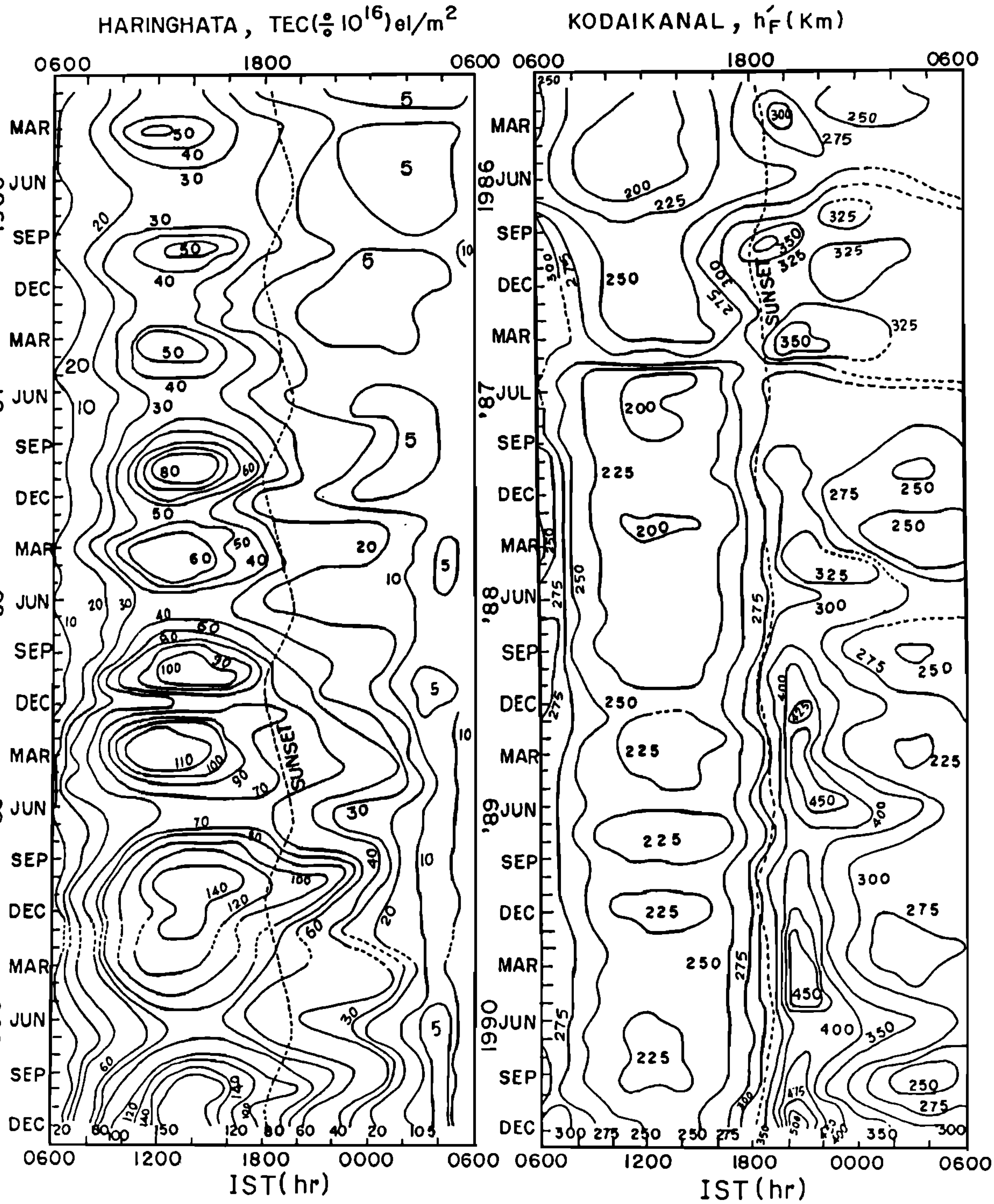

Figure 5. The $h'F$ contours of Kodaikanal and the total electron content (TEC) contours of Haringhata for the period 1986-1990. Dashed portions of the contours indicate insufficient data.

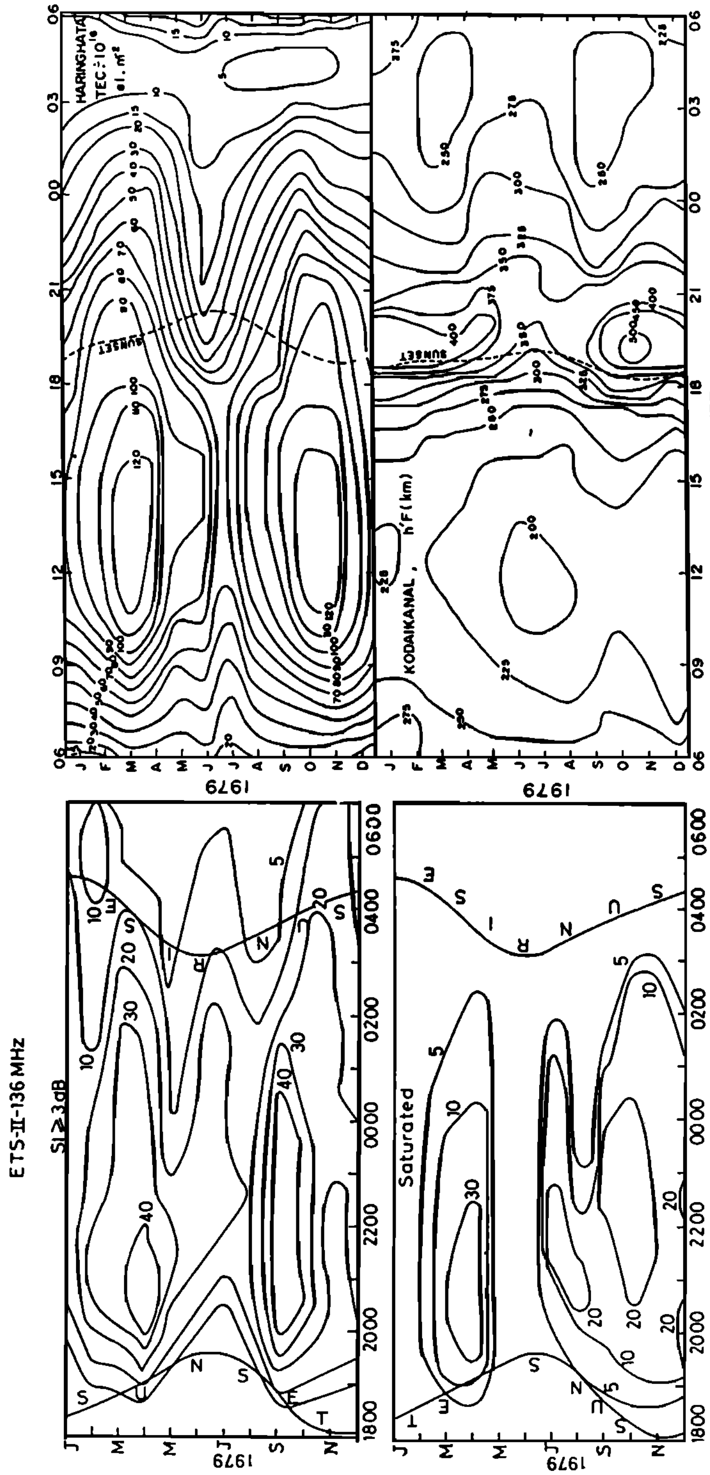

Figure 6. The 136-MHz scintillation contours at $SI \geq 3$ dB and saturated level for the year 1979. The $h'F$ contours of Kodaikanal and TEC contours of Haringhata for the same year are also shown.

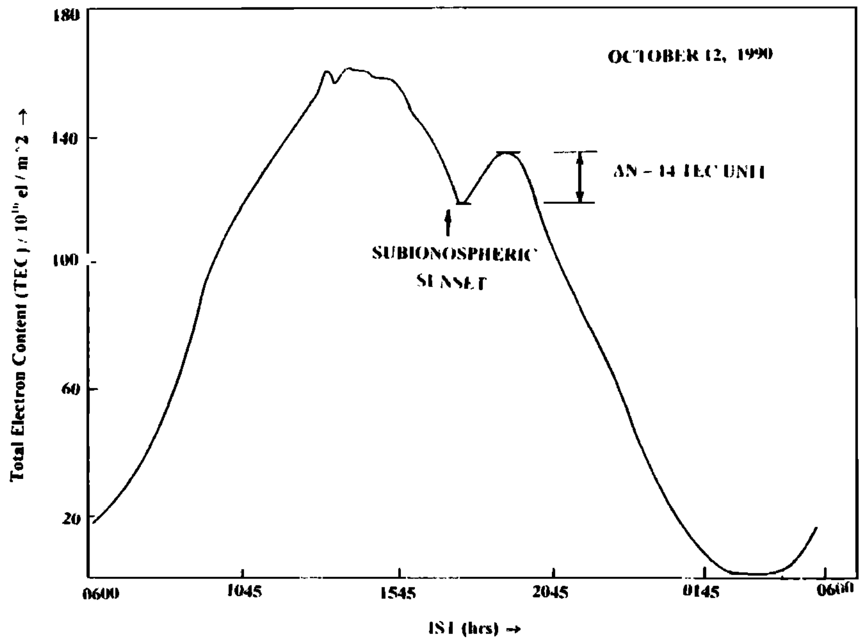

Figure 7. Diurnal variation of TEC showing the enhancement at the postsunset period.

and minimum (1986). The years 1984 and 1988 pertain to moderate-sunspot-number conditions, with sunspot numbers 46 and 100, respectively. Scintillation and $h'F$ contours for these years are shown in Figures 9, 8 and 5 respectively. A close examination of the contours of both $h'F$ and scintillation for these years reveals some differences compared with those of the other two years (1979/1990 and 1986). The differences are prominent in the pattern of TEC contour (Figures 5, 9 and 6) also. In the postsunset period, the F layer altitude is not very high, and the corresponding contours are not so closely spaced, as was observed in the solar maximum epoch (1979/1990). This indicates a smaller vertical rise velocity of the F layer plasma, which is in contrast to the remarkable phenomenon observed during high-sunspot-number years. The ambient ionization, as represented by TEC, decreased to a moderate value in the years 1984/1988 and to a low value in 1986. Further, there is a difference in the $h'F$ contour concentration for the two equinoxes, the autumnal equinox of 1988 having a higher sunspot number (~120) and the vernal equinox of 1984 exhibiting a higher sunspot number (~53). A distinct difference is also observed in the postsunset TEC contours of the March and September equinoxes. The scintillation contours of Figures 8, 9, and 6 show an overall lower occurrence in 1984 and 1988 compared with that in the solar maximum epoch. A similar difference in the scintillation activities at the two equinoxes is evident in Figures 8 and 9 as in the $h'F$ and TEC contours of Figures 5 and 9. A part of the difference in postsunset behavior may be attributed to the difference in solar flux ($S_{10.7}$) values during the two equinoxes. Additionally, a part of the equinoctial asymmetry may be attributed to neutral composition differences [*DasGupta et al.*, 1983].

In the years 1979, 1990, and 1986, the $S_{10.7}$ solar flux values during the March and September equinoxes are 186.6/198.8, 182.5/196.1, and 77.5/73.9, respectively, while the same for the two equinoxes of the years 1984 and 1988 are 129/79 and 113.2/160.2, respectively. The differences in the mean solar flux during the two equinoxes of 1986 (bottom out) and of 1979/1990 (rounded crest) may considered to be very small. However, in the declining or increasing phases, there is an appreciable difference between the $S_{10.7}$ values in the two equinoxes of 1984/1988 compared with the other solar activity epochs. This suggests a positive solar control over equatorial TEC values or ambient ionization and scintillation occurrence.

Since occurrence of scintillation and TEC enhancement is a regular feature of the premidnight hours during solar maximum years, a correspondence between scintillation occurrence and TEC

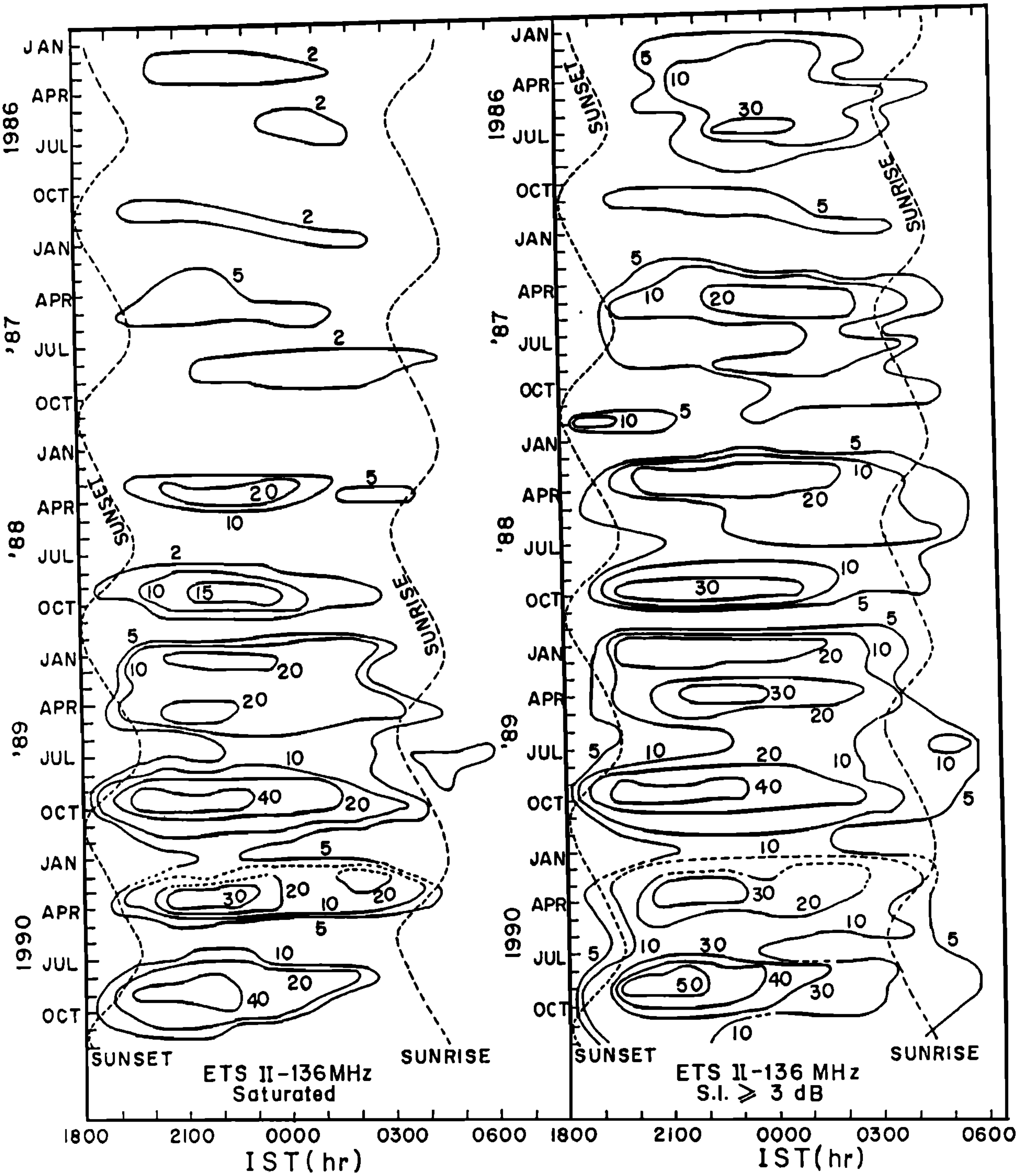

Figure 8. The 136-MHz scintillation contours at $SI \geq 3$ dB and saturated level for the years 1986-1990. Dashed portions of the contours indicate insufficient data.

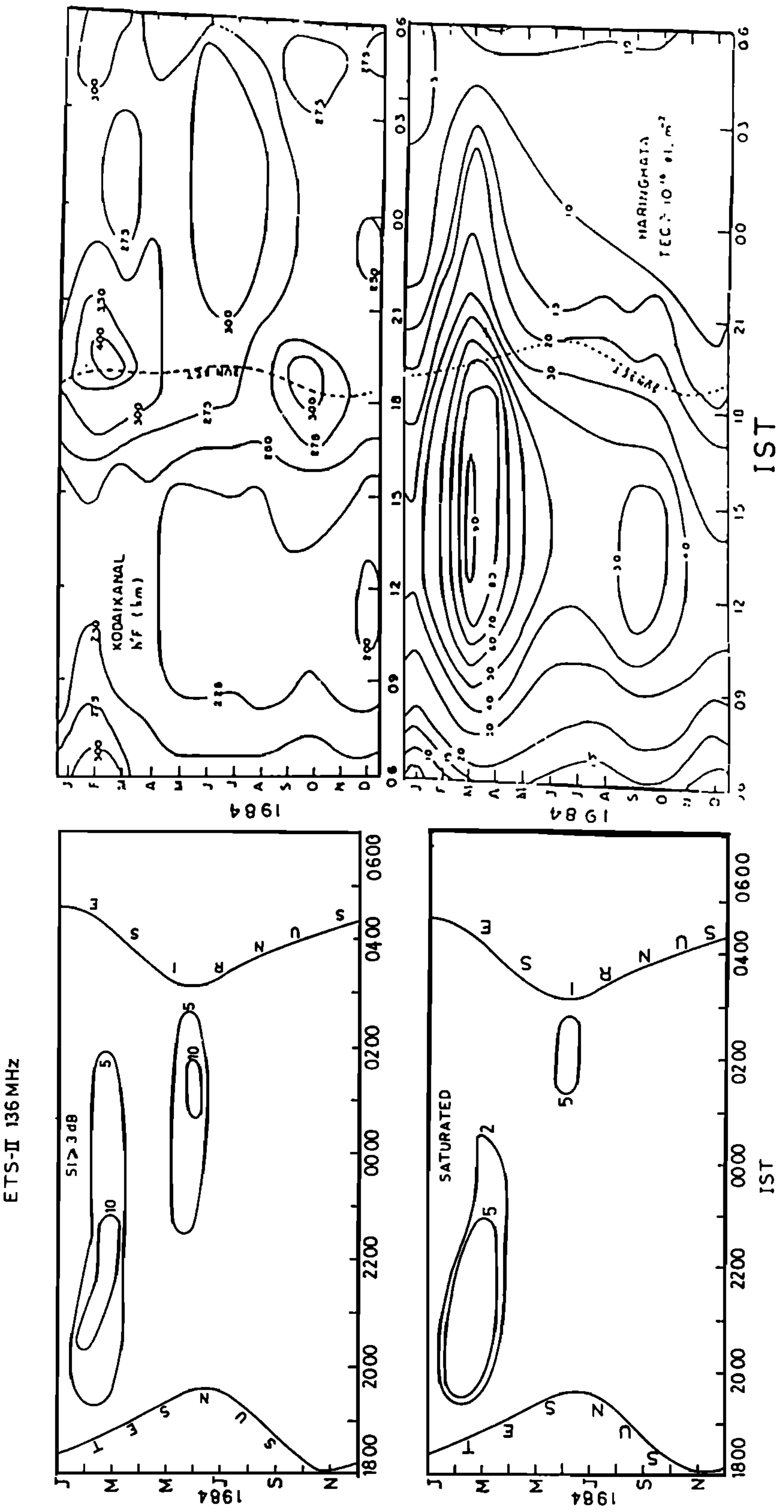

Figure 9. The 136-MHz scintillation contours at $SI \geq 3$ dB and saturated level for the year 1984. The $h'F$ contours of Kodaikanal and TEC contours of Haringhata for the same year are also shown.

enhancement at the anomaly crest is expected. A statistical investigation made by *Das et al.* [1988] shows a significant association between postsunset TEC enhancement, its local time, and onset of scintillation. It has been pointed out that scintillation occurring in between 0.5 and 2.5 hours of local sunset is associated with TEC enhancement in excess of 10 units ($x10^{16}$ el/ m^2).

4. Discussion

Long-term scintillation observations at Calcutta, which is situated near the northern crest of the equatorial anomaly in the Indian longitude zone, reveal a characteristic seasonal pattern of occurrence. During the years of high sunspot number (1979-1981 and 1989-1990), a prominent equinoctial component of scintillation activity emerges. The above observations are consistent with the present understanding of equatorial *F* region plasma processes. The frequent equinoctial occurrence of scintillation during the sunspot number maximum years implies that the plasma bubbles frequently attain altitudes of 800 km and above [*DasGupta et al.*, 1981].

In obtaining the occurrence statistics of scintillation at VHF, UHF, and microwave bands, the selection of the scintillation level is important. With a lower threshold value at 3 dB, the occurrence of scintillation at VHF at many equatorial locations would show a maximum during the June solstice. However, the choice of a higher scintillation level would give equinoctial maxima. In the present case the selection of scintillation level at 3 dB often shows high occurrence during the May-July months. VHF scintillation in the equinoctial and December solstitial months is normally saturated and very fast, whereas during the May-July months the fluctuations seldom exceed 6 dB and the fading rate is also slow. The marked change in the seasonal pattern of scintillation occurrence at VHF with SI_{dB} level implies that the equinoctial along with the December solstitial phenomena and the May-July behavior pertain to different mechanisms. It should be mentioned that this paper is based on a large volume of data scaled by the third peak method in SI_{dB} at 15-min intervals [*Whitney et al.*, 1969]. A robustly defined first-order measure of scintillation index such as the S_4 index [*Briggs and Parkin*, 1963] should be more useful in attempts to reach geophysical conclusions from the observations. However, the SI_{dB} level may be converted to S_4 using the relationship between the two parameters suggested by *Whitney et al.* [1969] and *Secan et al.* [1995].

Scintillation during the August-April period has been identified with range-type equatorial spread-*F* [*Rastogi and Aarons*, 1980; *Somayajulu et al.*, 1984]. The class II type slow scintillation observed at Trivandrum has been found to be associated with frequency spread in ionograms [*Krishna Moorthy et al.*, 1979]. At Arequipa, a low-latitude station situated in between the magnetic equator and the anomaly crest, the mild and slow scintillation events of the May-July months correspond to frequency spread. No ionosonde data are available at Calcutta. However, a comparison with Ahmedabad (23°N, 72.6°E geographic; 34°N dip) ionosonde data indicates that a part of the May-July scintillation event may be attributed to frequency spread.

Incidentally, the May-July period exhibits a pronounced seasonal maxima in the occurrence of sporadic *E* at these locations. An attempt was made to correlate the nighttime scintillation with sporadic *E* . Although in some years the correspondence was reasonably good, no definite trend could be established over the solar cycle. It is believed, however, that a part of the scintillation event during the May-July months may be attributed to sporadic *E* also. Stations near the crests of the equatorial anomaly are too far away from the magnetic equator to be included in the narrow bottomside sinusoidal (bss) irregularities belt [*Valladares et al.*, 1983; *Basu et al.*, 1986].

The occurrence pattern at the present location of the Indian longitudinal zone is in keeping with that of the African and American regions and is in contrast to that of the Pacific sector [*Aarons et al.*, 1980; *Aarons*, 1993; *Livingston*, 1980]. In the American, African, and Indian longitude zones, equatorial scintillation activity shows an identical seasonal pattern irrespective of locations of the observing station in the two hemispheres. The generation of equatorial irregularities at a particular longitude depends on the timing of the *E* region sunset relative to the occurrence of the prereversal peak of the upward **ExB** drift. In the process of irregularity generation, as the plasma within the whole flux tube takes part, the conductivity of the *E* region path connecting the two ends of the flux tube in two hemispheres will determine the shortening or opening of the *F* region plasma. Again, the conductivity at a particular longitude immediately after sunset will depend on the extent to which the E region path closing the field tubes is illuminated, and therefore it will depend on the inclination of the solar terminator with respect to the geomagnetic field lines. The seasonal maxima in the scintillation activity coincide with the periods of the year when the solar terminator is most nearly aligned with the flux tube [*Tsunoda*, 1985]. The occurrence of plasma density irregularities responsible for scintillation is most likely when the integrated E region Pedersen conductivity shows maximum longitudinal gradient. The rise velocity of the bubbles is mainly controlled by the field tube integrated Pedersen conductivity and amplitude of depletions and polarization electric field within it [*Anderson and Haerendel*, 1979]. The above two factors change with season and solar activity, controlling the heights to which the irregularities can rise.

Aarons [1993] suggests that each of the various mechanisms proposed to explain the observed features contributes in a basic manner to setting up or destroying the necessary conditions for the generation of equatorial irregularities. Development of a clear concept regarding the equinoctial and solstitial generation of irregularities requires ample use of various models and observations of gradient of electron density as a function of latitude and longitude.

5. Conclusion

The combined observations of scintillation, TEC, and $h'F$ demonstrate a causative connection among scintillation occurrence and TEC enhancement near the crest of the equatorial anomaly at Calcutta and virtual height variation near the magnetic equator at Kodaikanal. Simultaneous long-term observations of scintillation and TEC near the crest of the equatorial anomaly confirm the interrelationship between intense equatorial scintillation and a high level of ambient ionization in the postsunset period. The maintenance of high ambient ionization has been suggested [*DasGupta et al.*, 1985] to be related to the enhanced eastward electric field in the postsunset period, as revealed by the $h'F$ values at the magnetic equator. The dominant role played by the electrodynamic drift near the magnetic equator in the redistribution of background ionization in the equatorial region and in producing irregularities becomes obvious from the above results.

Acknowledgements. The authors thank S. Basu, Sunanda Basu, and J. A. Klobuchar for providing the VHF polarimeter and spares. The research is supported in part by the Department of Science and Technology, Government of India, through AICPITS project ESS/75/018/89 and by the University Grants Commission, New Delhi, through projects ECRA and CAS. This paper forms a part of the Ph.D. thesis submitted by one of the authors (S.K.C.) to the University of Calcutta. The authors are grateful to the referees (J. Aarons and E. Fremouw) for pointing out certain inaccuracies and for suggesting improvements.

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(Received March 11, 1997; revised December 16, 1997; accepted August 2, 1998.)