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A model of equatorial and low latitude VHF scintillation in India

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Using the observed VHF scintillations at equatorial and anomaly crest stations in India during the years 1987-1989, an empirical model is developed. The model employs the cubic spline technique to reproduce the variation of scintillation occurrence with local time, season, solar activity and latitude. The modelled values are compared with observed ones and the agreement is found to be quite good.

Keywords: Ionospheric scintillations, Scintillations, VHF scintillations, Cubic spline technique
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1 Introduction

The post-sunset equatorial ionosphere often develops electron density structures which cover a wide range of scale lengths from a few centimetres to several hundred kilometres. Of these, plasma irregularities with scale lengths ranging from a few kilometres to a few 10s of metres are responsible for the forward small-angle scattering of trans-ionospheric radio waves. Movement of these irregularities across the signal path as well as random changes in them give rise to fluctuations or scintillations in the amplitude and phase of the trans-ionospheric radio waves recorded by a ground receiver. Since the electron content of the F-region predominates (over entire ionosphere), F-region irregularities markedly affect trans-ionospheric radio propagation. For several decades, ionospheric scintillation observations have been made on a global scale, which have contributed to our understanding of their morphology[1], theoretical understanding of strong and weak scintillation in the framework of radiowave scattering[2] and their effects on communication systems[3-6]. Major scintillation activity is concentrated around the magnetic equator in the pre-midnight period, in the auroral region during nighttime and in the polar cap at all local times. During solar maximum, scintillations are much enhanced due to the enhanced background ionization density. In the equatorial region, the large scale irregularities (extending several hundreds kilometres) evolve in plume-like structures[7], extend to altitudes above 1000 km and, being field aligned, encompass a nominal magnetic latitude range of $\pm 15°$ around the magnetic equator. The scintillation activity is also much enhanced around $\pm 15°$ as compared to the magnetic equator, due to enhanced ionization at these latitudes, resulting from the equatorial ionization anomaly.

In view of their adverse effects on modern communication systems and the GPS navigation, on which critical applications such as air traffic control rely, there is growing concern on the potential impact of scintillation on these systems and the need for modelling scintillations. Scintillation models have been developed, especially for the equatorial region, by Fremouw and Secan[8] using phase screen scintillation theory and by Basu and Basu[9] utilizing *in situ* irregularity observations. Based on a 5-year series of observations at 254 MHz at Huancayo, Peru, Aarons[10] derived an analytical expression for scintillation index as a function of solar flux, magnetic activity index, local time, day of the year, etc., which has limited applicability for the Atlantic region. In the WBMOD (Wide Band Ionospheric Scintillation Model), Secan *et al.*[11-13] used a collection of empirically derived models to describe the global distribution of ionospheric irregularities and a power law phase screen propagation model to calculate the level of intensity and phase scintillations that these irregularities would impose on a user-defined system and geometry.

Recently, the cubic spline method[14] has been successfully applied to empirical modelling of ionospheric parametres, such as global equatorial vertical drift[15] and equatorial and low latitude range spread-F (a phenomenon closely associated with scintillations) on ionograms in the Brazilian longitudes[16]. In this paper, we apply the cubic spline technique to develop an empirical model of magnetic quiet time scintillation occurrence at Indian equatorial and low latitudes based on observations at two locations for three years, covering low-to-high levels of solar activity. The model reproduces the variabilities observed at these locations.

2 Data organization

Amplitude scintillation of 250 MHz signals from the geostationary satellite FLEETSAT (73°E) was measured at the Indian magnetic equatorial station, Trivandrum (sub-ionospheric point: 7.8°N geogr., 75.8°E geogr., 0.6°S mag. lat.), and the anomaly crest station Rajkot (sub-ionospheric point: 20.5°N geogr., 70.2°E geogr., 15.3°N mag. lat). The scintillations data during the years 1987-89 are used in the present paper. This was part of a national coordinated programme, All-India Coordinated Program on Ionosphere Thermosphere Study (AICPITS), in which several stations extending from equator to the anomaly crest and beyond operated. Out of these, the data from Trivandrum and Rajkot are used to derive the hourly percentage occurrence of scintillation of strength > 1 dB (or S_4 ~0.075) from 1800 to 0600 hrs LT for each month. Figure 1 shows contours of scintillation occurrence percentage on a grid of months versus local time for the equatorial location, Trivandrum (left panels) and the anomaly crest location, Rajkot (right panels) for the years 1987 through 1989.

These data are monthly averaged and distributed into the mean solar flux (F10.7), which is presented in Table 1.

3 Model development

The model takes into account local time, seasonal, solar activity and latitudinal variations of the scintilation occurrence.

The scintilation occurrence (*SO,* in percentage), as functions of local time, latitude, season/day and solar flux value is expressed as a simultaneous product of univariate normalized cubic-B splines as given below:

$$SO(t,d,F,\theta)=\sum_{i=1}^{17}\sum_{j=1}^{12}\sum_{k=1}^{3}\sum_{l=1}^{2}a_{i,j,k,l}N_{j,4}(t) \times N_{j,2}(d)N_{k,2}(F)N_{l,2}(\theta) \quad \ldots(1)$$

where, $N_{i,4}(t)$ is a cubic-B spline of order four applied to local time dependence (t), $N_{j,2}(d)$, $N_{k,2}(F)$, $N_{l,2}(\theta)$ are cubic-B splines of order two applied to seasonal (d), solar flux (F) and latitudinal (θ) dependences; $a_{i,j,k,l}$ are the monthly means of the scintillation occurrence percentage for each intervals of local time, month, solar flux and latitude. The local time and seasonal spline basis functions using 17 and 12 nodes,

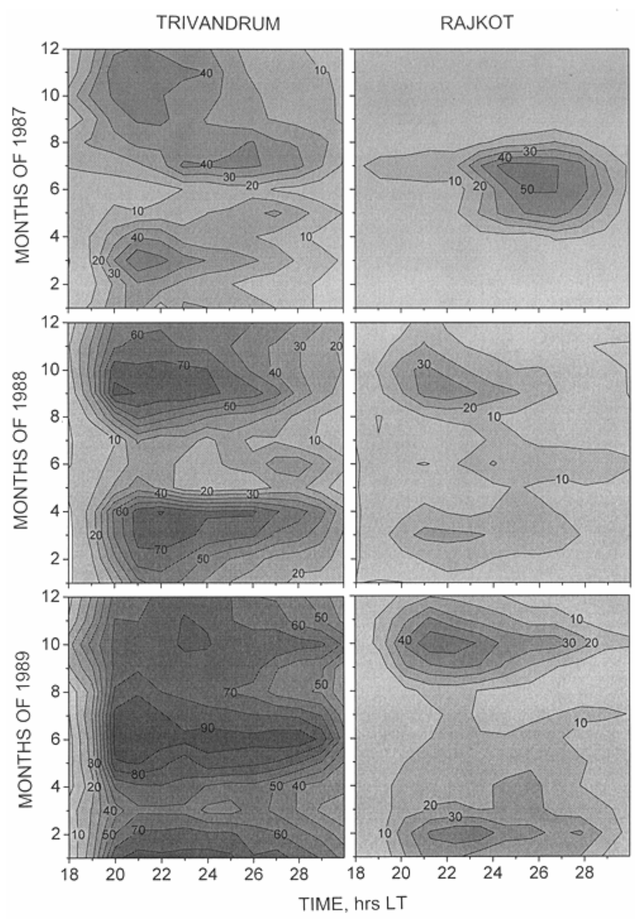

Fig. 1—Contour of scintillation percentage occurrence over the equatorial station Trivandrum (left panels) and the anomaly crest location, Rajkot (right panels), showing the local time seasonal dependence of scintillations occurrence

Table 1—Monthly values of the solar flux nodes

Year	Jan.	Feb.	Mar.	Apr.	May	June	July	Aug.	Sep.	Oct.	Nov.	Dec.
1987	70	70	73	85	90	80	87	92	87	97	99	91
1988	105	102	114	124	118	143	158	158	154	169	153	193
1989	228	217	203	191	194	247	188	222	228	207	230	206

respectively, are presented in Fig. 2. These basis functions are non-vanishing over limited intervals and add up to one at all *t*, *d*, *F* and θ (e.g., De Boor[14]). They are ideal to model a parameter with rapid changes, by a convenient placement of the mesh of nodes, as it was done by Scherliess and Fejer[15], to model equatorial vertical drifts near the terminators and by Abdu *et al.*[16] to predict spread-F over Brazil.

The 17 local time nodes chosen are distributed between 1600 and 0800 hrs LT at one-hour interval, seasonal/daily nodes are placed at the 15th day of each month. Three solar flux nodes are defined as shown in Table 1. Latitudinal nodes are fixed at Trivandrum and Rajkot.

4 Comparison of present model with observations

An illustrative form of the annual behaviour of the scintillation occurrence pattern is presented, in month versus local time format of iso-lines of scintillation occurrence percentage, in Fig. 3, for the equatorial station Trivandrum for solar minimum (upper panels) and maximum (lower panels). The left panels show the statistics based on observations and the right panels are the model results. There is an excellent agreement between the modelled and observed scintillation statistics. The two principal maxima during the pre-midnight period of equinoxes of low solar activity conditions are well reproduced in the model. Even the secondary maximum around midnight in June solstice is also well reproduced. The overall increase in scintillation occurrence with solar activity and the shift in the seasonal pattern are also consistently shown up by the model.

Figure 4 shows similar plots as in Fig. 3, but for the anomaly crest station Rajkot. The modelled curves in the right panels show excellent similarity with those observed (left panel). The most notable difference in the scintillation statistics over Rajkot as compared to Trivandrum is that, in the pre-midnight equinox season, the occurrence percentage over the former is smaller than that over the latter, at any level of solar activity. The summer (June solstice) occurrence pattern and its solar activity dependence are drastically different at the two locations. Also, over Rajkot the local time of scintillation onset is systematically displaced to later hours as compared to Trivandrum for all values of solar flux. These facts would suggest that, statistically, the scintillation events over the former location arises from vertical rise of flux tube aligned plasma bubbles, whose development originates at the bottom side of the equatorial F-layer represented by the spread-F/ scintillation at Trivandrum as proposed by Abdu[17], except in summer months, when scintillation at

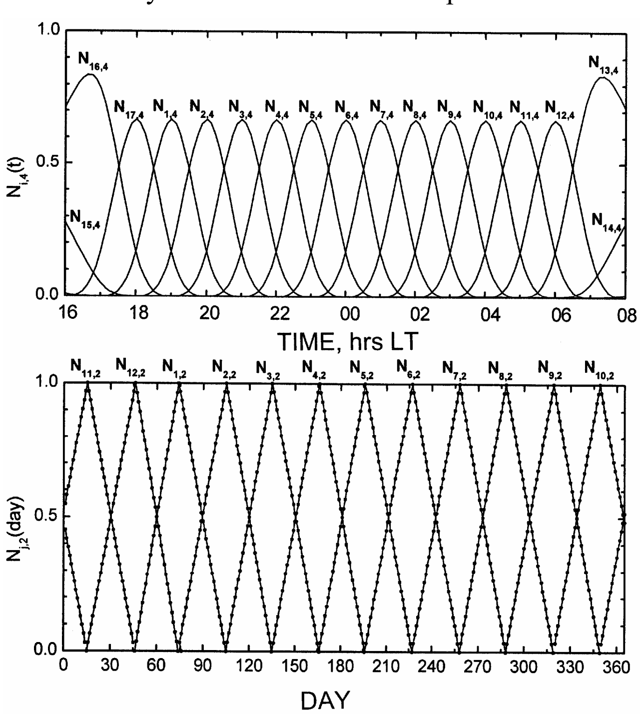

Fig. 2—Basis functions used for the cubic B spline fits (upper panel) in local time and (bottom panel) day of the year

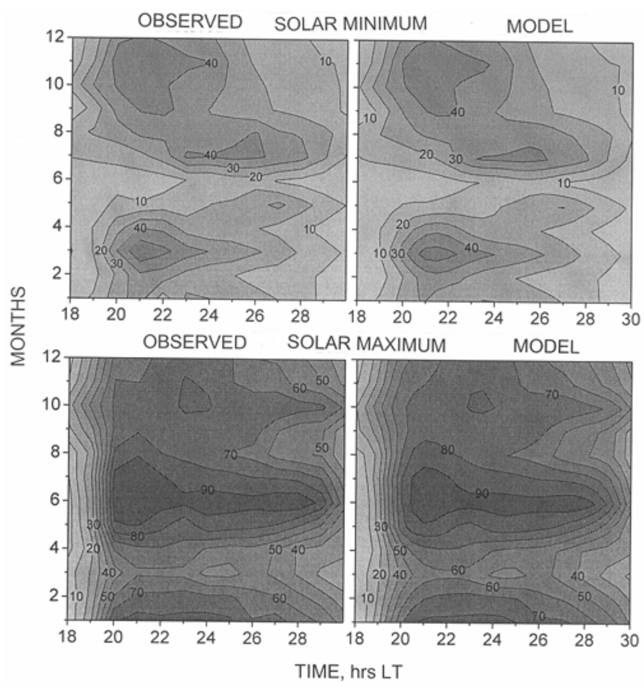

Fig. 3—Scintillation occurrence percentage over Trivandrum for solar minimum (upper panels) and solar maximum (lower panels). [Left panels represent the observations and the right panels are the models. Note the close agreement between observed and model values]

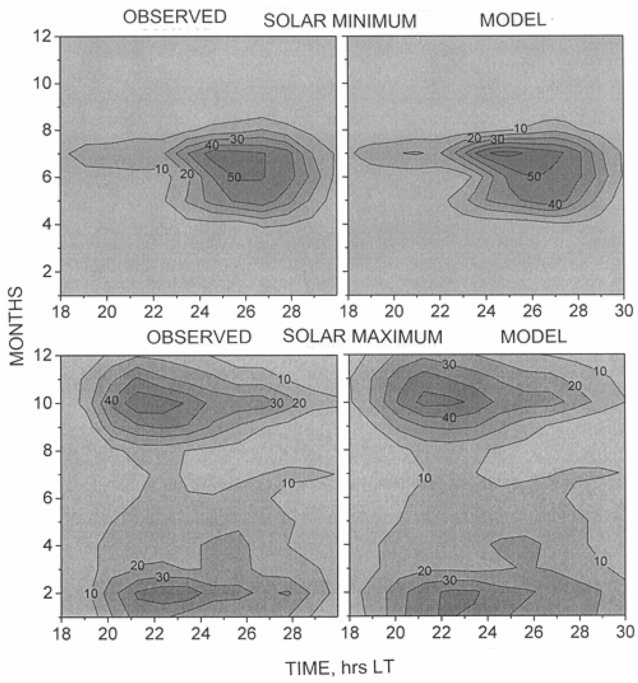

Fig. 4—Scintillation occurrence percentage over Rajkot for solar minimum (upper panels) and solar maximum (lower panels) [Left panels represent the observations and the right panels are the models.]

anomaly crest location may be of different origin. With increasing solar flux values, scintillation onset local time is advanced to earlier hours. This is the result of plasma bubble rise velocity over the equator increasing with increasing solar flux. These results of seasonal differences in the occurrence pattern at Rajkot versus Trivandrum would reflect the statistics of the plasma bubble rise velocity, having strong seasonal dependence, largest values, that is, most intense bubble events, occurring during equinoctial months.

A comparison between model and observation is better displayed in Figs 5-8, where the nocturnal variation of scintillation occurrence is shown. The solid circles show observed values, while continuous lines represent model values. Figures 5 and 6 are for the equatorial station for solar minimum and maximum, respectively, while Figs 7 and 8 show the corresponding variations for the anomaly crest station. The agreement between the observation and model is excellent in all the cases. The hourly nodal points used in the model seem to be sufficient for the model representation of scintillation occurrence percentage features for these cases.

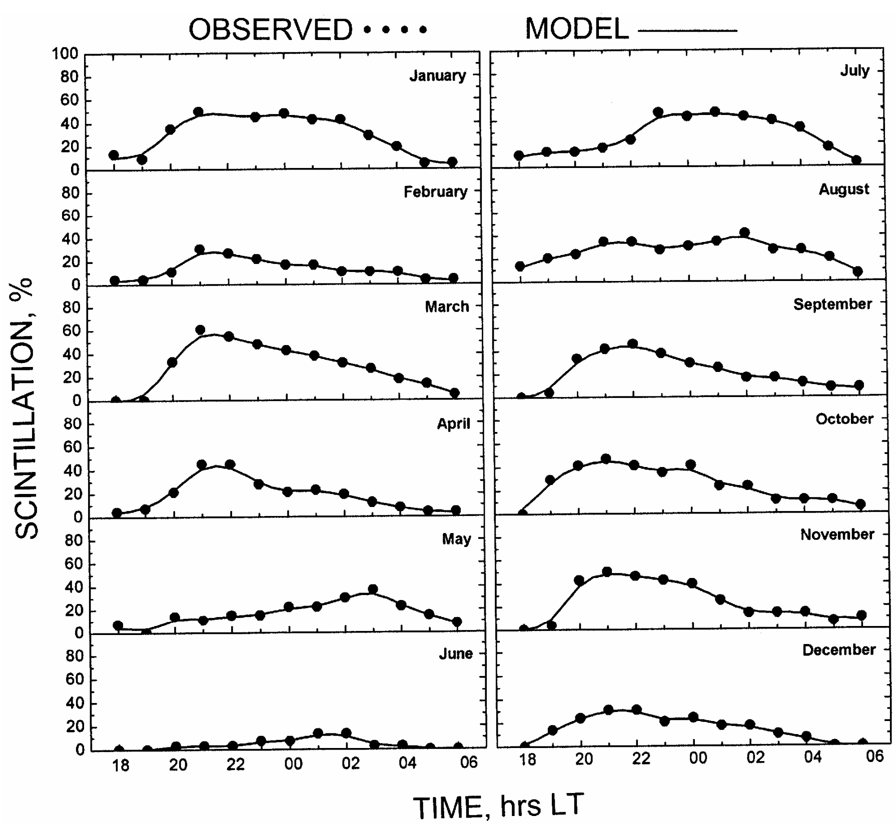

Fig. 5—Nocturnal local time variation of scintillation occurrence percentage over the equatorial station Trivandrum for solar minimum [The dark circle represents the observed and line segment represent the model values.]

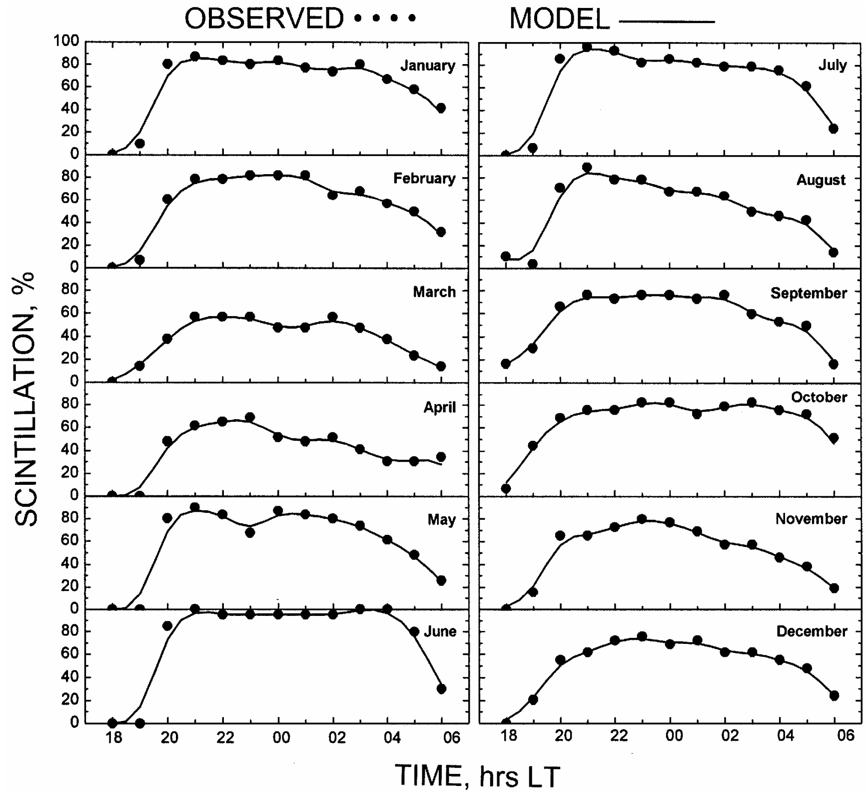

Fig. 6—Same as Fig. 5, but for solar maximum

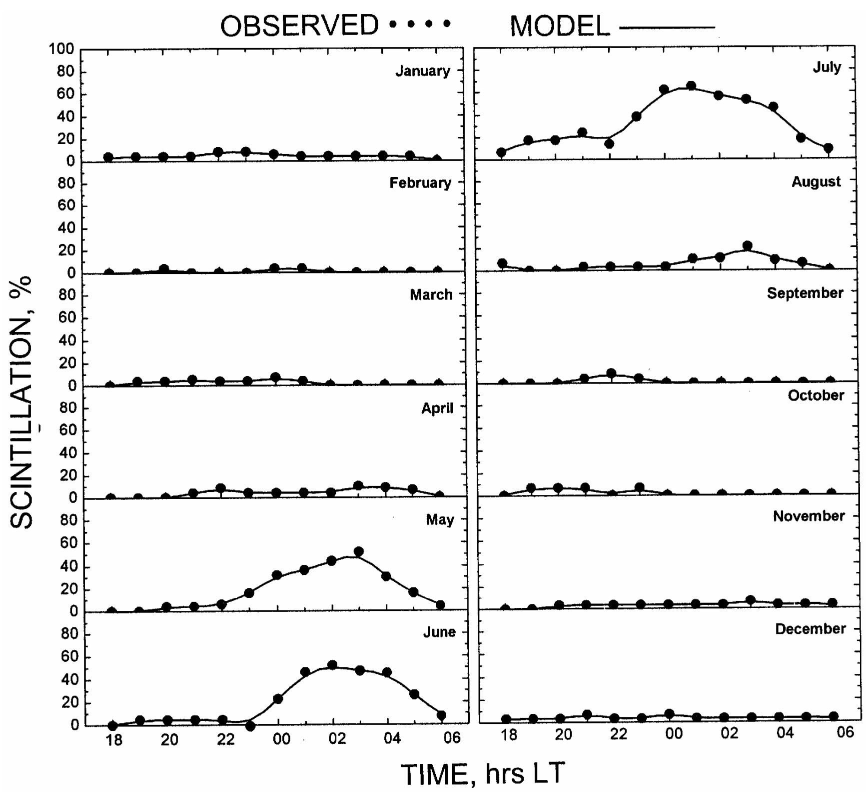

Fig. 7—Nocturnal local time variation of scintillation occurrence percentage over the anomaly crest station Rajkot for solar minimum [The dark circle represents the observed and line segment represent the model values.]

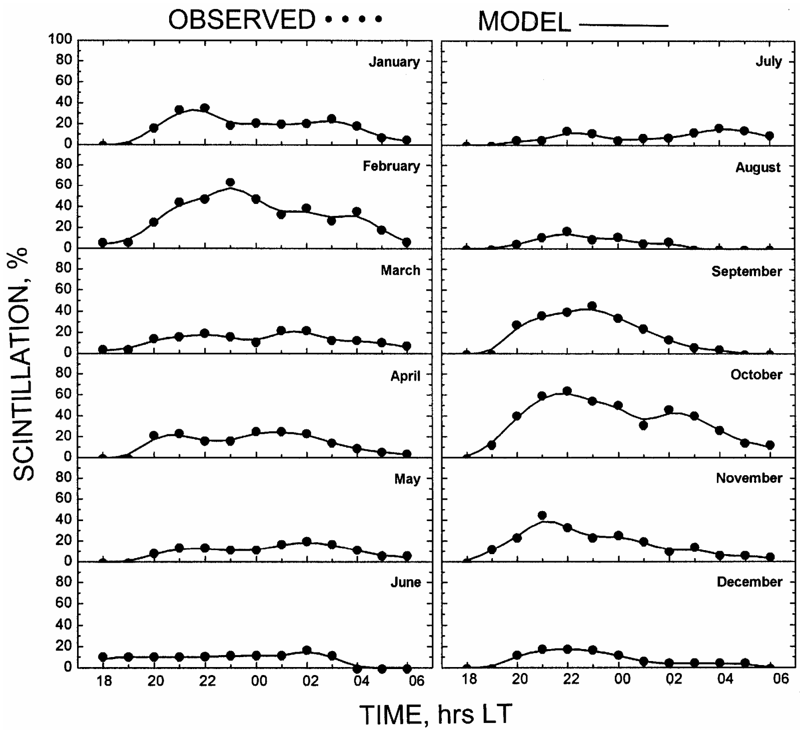

Fig. 8—Same as Fig. 7, but for solar maximum

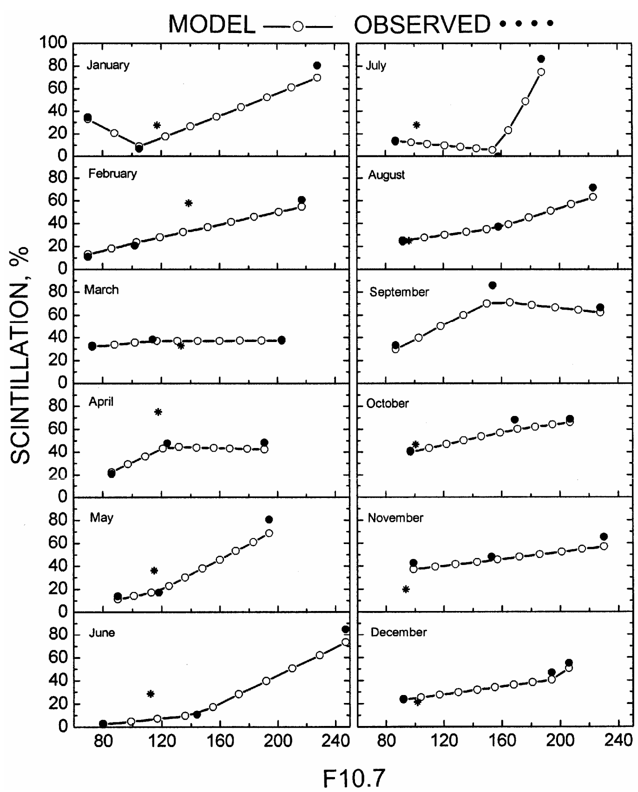

Fig. 9—Solar flux dependence of pre-midnight scintillation occurrence, for all months, over Trivandrum [The open circle represents the model and the dark circle represents the observed values.]

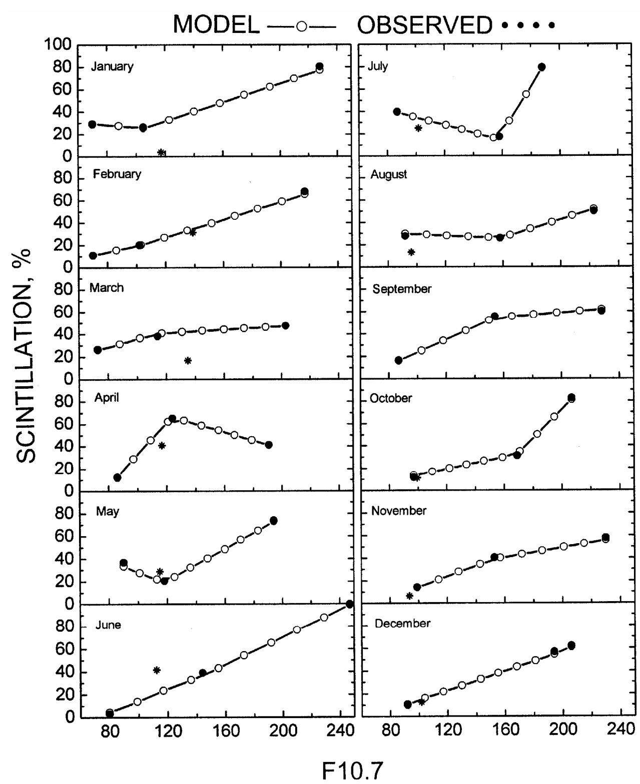

Fig. 10—Solar flux dependence of post-midnight scintillation occurrence, for all months, over Trivandrum [The open circle represents the model and the dark circle represents the observed values.]

The solar activity dependence of pre-midnight peak scintillation occurrence typically at 2000 hrs LT given by the model is compared with the observations in Fig.9 for the equatorial station Trivandrum. In addition to the modelled values (open circles) and input data (solid circle) for the years 1987, 1988 and 1989, the data for the year 1993 (star) with different solar fluxes, which were not an input to the model are also shown for validating the model. The agreement is quite good, except for the months of February and April for the year 1993, in spite of the large gap in data for solar flux values between 140 and 240. Similar comparison and validation for the typical post midnight hour (0300 hrs LT) is shown in Fig.10. The agreement between the model and observation is again good.

5 Summary and conclusion

We have proposed an empirical model for VHF scintillations at equatorial and low latitudes in India. The model is tested for two typical equatorial and anomaly crest locations. The observed and model values of scintillation parametres are in good agreement. This model needs further testing for different locations and solar activity conditions, which will lead to wider applicability of the model.

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