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Ionospheric plasma by VHF waves

R P PATEL, ABHAY KUMAR SINGH* and R P SINGH
Atmospheric Research Laboratory, Physics Department, Banaras Hindu University, Varanasi 221 005, India
*Department of Physics, Maharaja College, Arrah, Bihar, India

Abstract. The amplitude scintillations of very high frequency electromagnetic wave transmitted from geo-stationary satellite at 244.168 MHz have been recorded at Varanasi (geom. lat. 14° 55′N) during 1991 to 1999. The data are analyzed to determine the statistical features of overhead ionospheric plasma irregularities which are mostly of small duration < 30 minutes and are predominant during pre-midnight period. The increase of solar activity generally increases the depth of scintillation. The auto-correlation functions and power spectra of scintillations predict that the scale length of these irregularities varies from 200–500 m having velocity of movement between 75 m/sec to 200 m/sec. These results agree well with the results obtained by other workers.

Keywords. Scintillation; ionospheric irregularities; spectral index.

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1. Introduction

The homogeneous ionospheric plasma produce dispersion and spectral broadening of the electromagnetic signal propagating through it. If the plasma is randomly varying in space and time, then the amplitude and phase of the propagating waves will also be affected and fluctuate randomly in space and time. The fluctuations in the electron density known as irregularities present in the ionosphere cause amplitude, phase and frequency scintillations of the propagating VHF electromagnetic waves, which have been studied theoretically as well as experimentally [1–3]. Plasma instabilities are the most probable explanation for the generation of equatorial irregularities and particle precipitation for the high latitude [4]. Scintillations at low latitude are known to occur in discrete patches [5,6] and are part of equatorial irregularities.

In this paper amplitude scintillation statistics of the VHF signal, 244.168 MHz, recorded at low latitude station Varanasi are used to study morphological features of electron density irregularities present in the ionospheric plasma. The diurnal and seasonal variations and the effect of solar and magnetic activity on the occurrence rate of scintillations are described in §2. The scale length and velocities of irregularities are also computed in this section. The results are discussed in §3. Finally §4 summarizes the results.

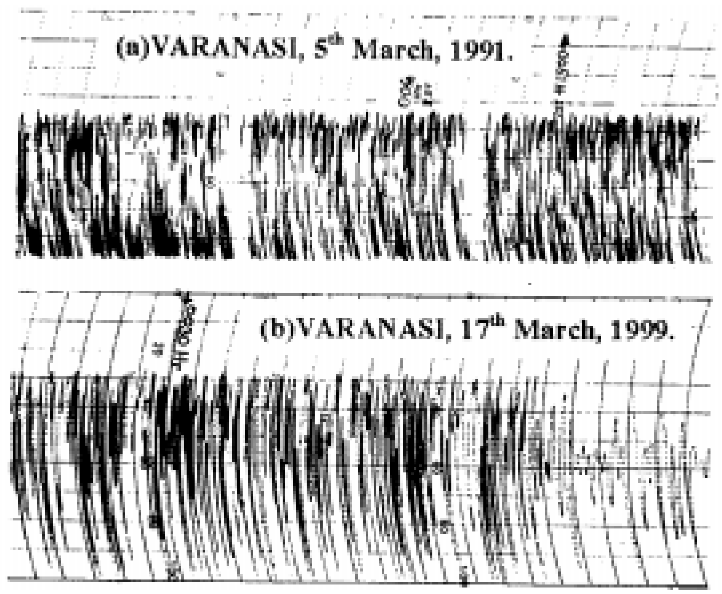

Figure 1. Two typical examples of scintillation recorded at Varanasi.

2. Observations and analysis

The amplitude scintillation of VHF signals transmitted from geo-stationary satellite FLEETSAT parked at 73°E longitude are continuously monitored using a VHF receiver AKASH, 11-element Yagi-Uda antenna and a strip chart recorder at Varanasi during 1991 to 1999. The amplitude fluctuations having peak to peak variations ≥ 1 dB have been considered for the present analysis. At Varanasi scintillations are frequently observed during nighttime, hence only nocturnal variation of irregularities in different months and seasons are studied. Some examples of recorded scintillations are shown in figure 1(a,b). At Varanasi, scintillations occur in small patches. The distribution of patch duration in the summer, equinox and winter seasons of the years 1991 to 1999 put together is shown in figure 2. The mean values of patch duration are 31.52, 13.6 and 52.16 minutes in winter, summer and equinox seasons respectively. The annual variation is also shown in the same figure with over all mean value 32.3 minutes. This shows that at Varanasi irregularities occur in small patches with patch duration usually < 30 minutes. One typical example of the nocturnal variation of scintillation index (%) computed by the method described by Whitney *et al* [7] is shown in figure 3. This also supports the patchy occurrence of scintillations at Varanasi.

The nighttime intensity scintillation statistics from 1991 to 1999 is shown in figure 4. The different hatchings show fade depth indices in dB ranging from ≥ 1 dB to 20 dB. The figure clearly shows that in summer months the fade depth is mostly less than 5 dB but in winter and equinox months it is between 5 and 15 dB. The fade depth indices ≥ 15 dB is very rarely observed only in April and October months.

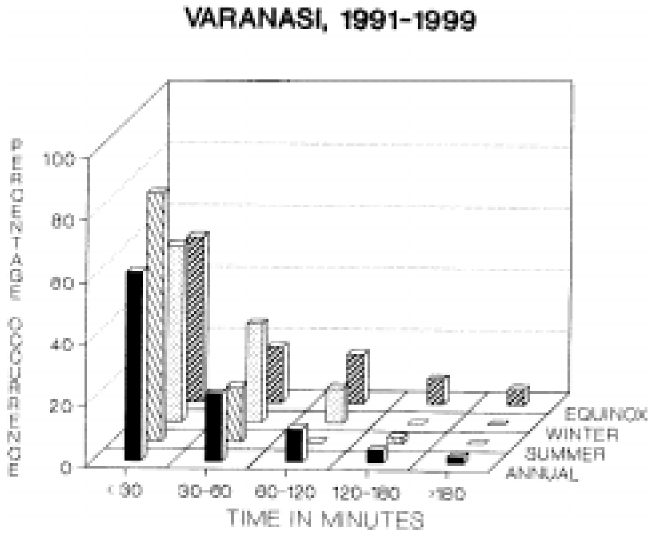

Figure 2. Distribution of patch duration in different seasons of 1991–1999.

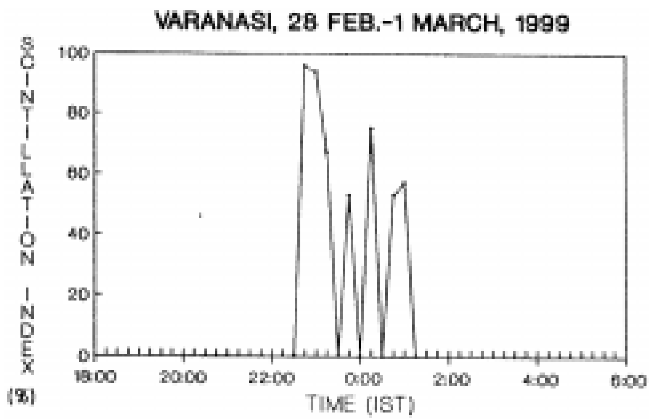

Figure 3. One typical example of the nocturnal variation of scintillation index (%) observed at Varanasi on 28th February–1st March 1999.

Several samples of scintillation records have been analyzed for estimating power spectrum, which contains the information of the relative power of irregularities in different spatial scales. One typical example of the power spectra computed from the data recorded on 22nd Jan. 1992 at 0114 IST is shown in figure 5. The spectra from roll-off portion and onward can be approximated by a straightline. In the present case it is between 0.1 Hz $\leq f \leq$ 1 Hz. This corresponds to the scale size ranges of 1000–100 m for an assumed drift velocity of 100 m/sec. This spectrum gives spectral slope-4 with S_4 index 0.82. The spectral slopes between 0.1–1.0 Hz have been computed for various samples and it is found that spectral index values range between -2 and -8 with a mean value of -4. This value is in close agreement with the *in situ* observations from SHAR [8].

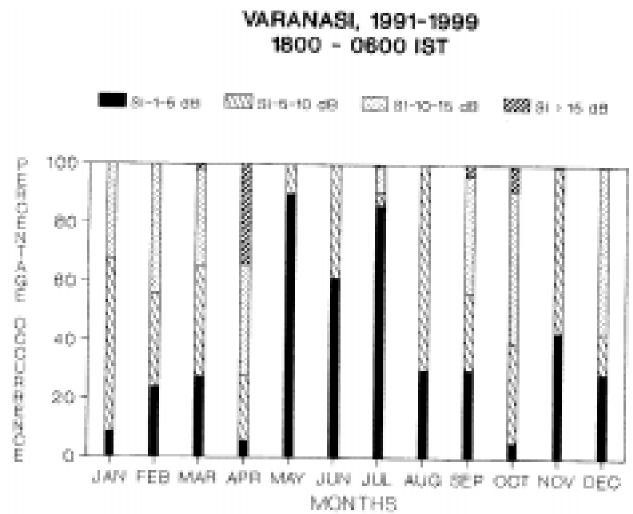

Figure 4. The occurrence of 15 minute fade depth indices of scintillation (in dB) for night time periods during 1991–1999.

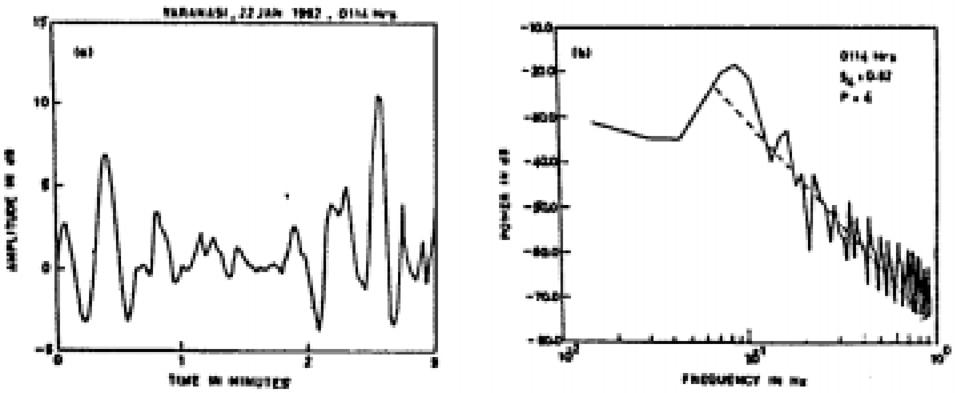

Figure 5. A typical example of (**a**) amplitude scintillation recorded at Varanasi on 22nd January 1992 at 0114 IST and their corresponding (**b**) power spectra.

From the weak scattering theory for a phase changing screen model, the velocity of the irregularities is given as [9]

$$V = (\lambda z)^{1/2} f_{\min}$$

where z is the height of the phase screen, λ is the signal wavelength and $f_{\min}$ is first Fresnel minimum in given spectra. From figure 5, $f_{\min} \cong 0.215$ Hz and taking $z = 350$ km, the velocity of irregularities is found to be 141 m/sec. The velocity is computed for various samples and it is found to lie between 75 m/sec and 200 m/sec. The characteristic length of the irregularities over Varanasi is determined from its definition according to which the size of the irregularity is equal to the distance at which the auto-correlation function falls to 0.5 [10]. We have computed half-correlation time and characteristic length for various samples and observed that the characteristic length varies between 200 m and 500 m.

3. Discussion

The general features of scintillations at Varanasi conform well to the nature of scintillations reported at the other low latitude stations. The properties of irregularities derived from the present study are in good agreement with the results reported from Ahmedabad, Bombay [11], Rajkot [5] and Bhopal [12]. At low latitude, the scintillations occur in small patches and the duration of patches represents the East–West dimension of the irregularity [5]. The mean value of patch duration at Varanasi is in good agreement with that of Rajkot [5]. The patchy occurrence of scintillations at low latitudes and more continuous at and near equatorial stations support the idea of upwelling of plasma irregularities in the equatorial F-region around post sunset and then subsequently moving towards low-latitude and breaking into smaller patches [13]. The continuous observation of scintillation at the equator and patchy occurrence at low latitudes could be explained by considering the radar back scattered maps of bottom side F-region which exhibit several plumes with varying altitudes. The scintillations at low latitudes will be observed only when a plume structure extends up to higher heights whereas in the equatorial belt scintillations can be generated even by plumes having lower heights. As the plume moves upward it breaks into pieces and causes patchy scintillations [13–15]. Equatorial scintillation being caused by larger number of plumes distributed in altitude can be observed continuously for longer time [15]. The plumes/plasma-bubbles may arise from the Rayleigh-Taylor instability mechanism in the early post sunset hours at the bottom side of the F-region in the equatorial plane. Subsequently it rises to the top of F-region under $E \times B$ drifts [13]. Using top-side sounding data Dyson and Benson [16] have reported that plasma bubbles/depletions extend along the entire magnetic flux tubes.

The patchy occurrence may also be associated to vertically moving internal gravity waves, which under suitable conditions excite plasma fluctuations at different altitudes. The growth of the transformed plasma modes under suitable conditions within wide range of scale sizes may lead to the fluctuations discussed above [17]. Prakash [18,19] has emphasized the role of gravity waves in producing seed irregularities in F-region and invoked a new mechanism for the production of irregularities through E-region gravity wave winds. Linson and Workman [20] have suggested that a low frequency instability existing in a weakly ionized plasma with a density gradient and a relative drift of ions and electrons across a magnetic field may cause development of enhanced ionization along the field lines. They have shown that in the low frequency gradient drift instability all wavelengths grow essentially at the same rate. Dwivedi and Tripathy [21] suggested the neutral induced low-frequency instability as the source of irregularities in D-region (80-95 km), which is driven by a finite neutral diffusion flow in a weakly ionized magnetoplasma. The neutral and ion fluids are coupled through frictional forces and the instability is electro-mechanical in nature. In fact simultaneous measurements of plasma, electric field and vertical neutral dynamics could provide more details about the processes associated with the ionospheric irregularities.

The increase of solar activity normally increases the depth of scintillation whereas the increase of magnetic activity suppresses the occurrence of scintillation [11]. At Varanasi, data show the enhancement in occurrence rate with the increase of solar activity. The role of magnetic activity is season dependent. Basu and Basu [22] reported that the height of the irregularities at the equator increases with an increase in solar activity. Dabas *et al* [23] analyzing scintillation data from a chain of stations showed that, with an increase in magnetic activity, the scintillation occurrence increases in the post-midnight period in all the longitude sectors while the pre-midnight phenomenon is dependent on season as well as on longitude. Recently, Kumar and Gwal [12] after analyzing scintillation data of Bhopal showed the decrease in nocturnal scintillation occurrence with the decrease in solar activity. The effects of magnetic activity vary with season and in general, inhibit the scintillation occurrence in pre-midnight period and enhance it a little in post-midnight period.

In situ measurements by rocket-born probes show different spectral slopes in different scale size ranges. Present observations in the scale size about 100 m to 1000 m indicate a mean spectral index value of -4 which is in close agreement with the *in situ* observed value of -4 at SHAR [8]. Power spectra of electron density irregularities derived from *in situ* measurements of electron density and electric field by rocket showed spectral indices of -1.7 and -5 at frequencies less than 60 Hz and greater than 60 Hz [24]. Recently, Raizada and Sinha [25] using rocket measured electron density and electric field data showed that the most intense irregularities occurred in three patches: 165–178 km, 210–257 km and 290–300 km. Power spectra of irregularities showed that the spectral indices of intermediate scales (100 m–2 km) were found to be in a range of -3.4 ± 0.5, whereas the spectral indices of transitional scales (10 m–100 m) have an average value of -4.32. By calculating the linear growth rate of generalized Rayleigh-Taylor instability, they suggested that these irregularities (intermediate scale sizes) could be produced by gradient drift instability and not by the Rayleigh-Taylor instability. Singh and Szuszczewicz [26] analyzed rocket and satellite data covering almost six decades of spatial scale length of irregularities. They showed that medium, intermediate and transition scales are characterized by spectral indices in the range of -1.5 ± 0.4, -2.4 ± 0.2 and -4.8 ± 0.2 respectively both in vertical as well as horizontal directions.

There is a need to study the power spectral features of scintillations at few stations simultaneously, covering equatorial region to low-latitude region, which will add other finer details of irregularities. Since, the whistler wave propagation is also aided by field-aligned irregularities, which give rise to scintillations, we have been carrying out whistler recording along with the scintillation recording to bring out more information about these irregularities [27].

4. Conclusions

Since Varanasi lies at the edge of equatorial anomaly zone and hence has its importance in the study of ionospheric irregularities. In this paper, we have briefly discussed the experimentally observed ionospheric scintillations and computed the various properties of irregularities over Varanasi. Based on the present study, the following conclusions are drawn.

(i) Scintillations are observed mostly in the nighttime and predominantly during pre-midnight period. The scintillations occur mostly in small patches and the patch duration generally being < 30 minutes.

(ii) The spectral index values generally range between −2 and −8 with a mean value of −4 for intermediate scale irregulariteis over Varanasi.

(iii) The drift velocity of scintillation producing irregularities over Varanasi is found to vary between 75 m/sec to 200 m/sec.

(iv) The characteristic length of these irregularities varies from 200 m to 500 m.

Further, the parameters of the irregularities determined by us are in good agreement with those reported for other low-latitude stations.

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