Scintillation Producing and Whistler Ducting Ionospheric Irregularities

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Abstract

The propagation of electromagnetic waves through the ionosphere in the presence of irregularities is differently affected in different frequency ranges. Very high frequency waves are scattered whereas very low frequency waves are guided through the ducts formed by the irregularities under suitable conditions. We have analyzed VLF and VHF waves recorded at Varanasi (geomag. Lat. = $14^0\ 55^/$ N, long.= 154^0 E, L = 1.07) during the period January 1991 to December 1999. The occurrence rate of VLF waves is low and sporadic and they are generally observed during nighttimes. The VHF scintillations at Varanasi are also mostly observed during nighttimes. A correlation study of these two simultaneously recorded signals has been carried out. The recorded events of VLF whistlers/emissions and VHF scintillations are largely uncorrelated. However, there are a number of days when these two events are simultaneously observed. Analysis of these correlated events show that at time and under certain suitable conditions, the ionospheric irregularities may help VLF wave propagation and also cause scattering of VHF signals resulting into either weak or strong scintillations.

1. Introduction

In the equatorial region irregularities are generated through the process of generalized Rayleigh-Taylor instability [1] and move upward due to E × B drift motion. Some of these rise high enough and become field-aligned [2]. The irregularities moving along geomagnetic field lines break in to small pieces, which are observed at low latitude stations is small. The high frequency waves are known to be scattered from these irregularities resulting in to amplitude/phase/frequency scintillations. Amplitude scintillation was recorded at Varanasi and morphological features of over-head irregularities were studies [3, 4]. The VLF waves having larger wave-length are not scattered, however, they could be reflected from the surface of the irregularity and under suitable condition irregularities may act as a guide and may force the wave to propagate along the geomagnetic field lines. Singh et al. [5] have discussed that the overhead field aligned irregularities may produce VHF scintillation and VLF ducting simultaneously provided whistler wave is present with suitable orientation. In this paper, we briefly report the analysis of simultaneously observed VLF and VHF waves recorded at Varanasi during the period January 1991 to December 1999.

2. Experimental Observation and Data Analysis

The whistler-mode waves generated due to lightning discharges are being recorded on routine basis. The amplitude scintillation of VHF beacon signal at 250 MHz is also recorded simultaneously. The data from January 1991 to December 1999 for both types of observations have been analyzed. Figure 1 shows schematically the location of Varanasi station situated at the foot of geomagnetic field lines along with the position of geo-synchronous satellite transmitting VHF signals. The field-aligned irregularities are also shown in the figure, which may cause ducting of VLF waves and scintillations of VHF beacon signals simultaneously. In this schematic arrangements VHF signal is available all the times where as VLF signal could be randomly present when there is lightning at the conjugate points and also the lightning is suitably oriented so that VLF wave could be launched along the geomagnetic field lines.

3. Results and Discussions

3.1. Observation of VLF Waves

Whistler mode waves propagate along geomagnetic field lines with almost little or no attenuation. Therefore, these waves could bounce between the conjugate points many times before finally being absorbed in the medium. This is valid at mid and high latitudes, where the major portion of the path of propagation lies in the magnetosphere. The case is different for low latitudes station Varanasi, where the major part of the path of propagation lies in the upper ionosphere. The irregularities in the ionosphere may inhibit the VLF wave propagation depending upon its orientation and intensity.

The whistlers recorded at Varanasi mainly during nighttime with predominant occurrence in the post-midnight period. Analysis of recorded whistlers have dispersion value between 10-15 $sec^{1/2}$. Some times, we have also observed whistlers having larger dispersion. Such waves have been explained by considering field-aligned propagation along higher L-values and after exiting from the ducts in the ionosphere enter into the earth-ionosphere wave-guide with wave-normal angle aligned in such a way that it propagates towards equator [6]. At Varanasi, increased whistler activity is observed almost simultaneously with increased K_P-index. This is interpreted in terms of increased number of ducts during geomagnetic storm period. These morphological features suggest that the whistlers received at Varanasi have propagated in the field-aligned whistler mode and they are observed in large numbers only during geomagnetic storm periods. The marked enhancement in whistler activity has been interpreted in terms of ionized duct formation during magnetic active period [7]. Figure 2 shows the sonograms of whistlers recorded at Varanasi on 8/9th March, 1991 and arranged in a sequence of increasing time from 00:50 Hrs to 02:33 Hrs during which K_P – index varied between 4_- to 3_+. The power spectrum analysis of the occurrence rate of the whistlers and their estimated dispersion show a periodicity of the order of one hour [8], which is attributed to a cyclic process in the growth and decay of ducts. Thus, the estimated lifetime of the duct comes out to be about one hour.

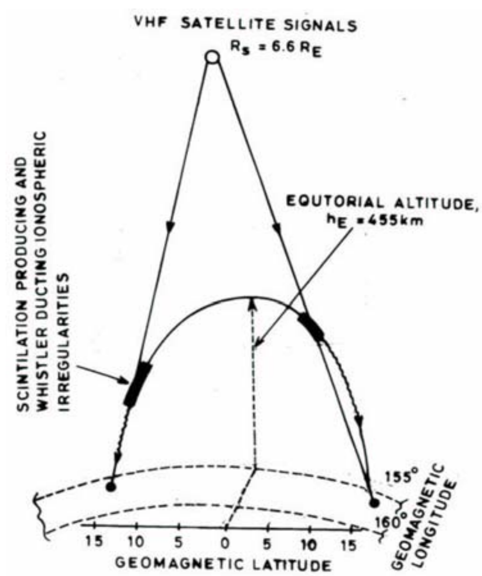

Fig.1. Schematic diagram showing the location of satellite, geomagnetic field lines, field-aligned irregularities and the ground station Varanasi.

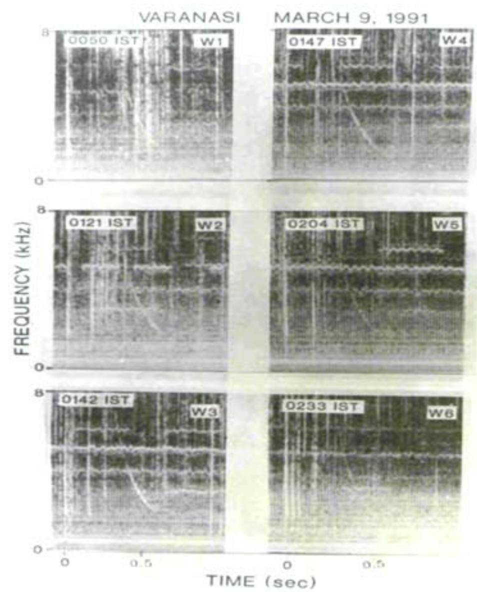

Fig.2. Sonograms of whistlers recorded at Varanasi on 8th-9th March 1991.

3.2. Observation of VHF Waves

The ionization irregularity present in the ionosphere causes phase modulations of the traversing radio waves and its horizontal movement leads to the temporal fluctuations in phase and amplitude. The variation of occurrence rate of VHF scintillation was examined by analyzing the data on the diurnal, monthly and seasonal basis. Further, the data was also analyzed to study the effect of solar and geomagnetic variations. At Varanasi Scintillations are observed mostly in the nighttime and predominantly during pre-midnight period. The scintillations occur mostly in small patches and the mean value of patch duration at Varanasi is ~ 30 minutes [3]. The seasonal control on scintillation index is strong with maximum activity in equinox. The increase of solar activity normally increases the occurrence of scintillation, whereas the increase of magnetic activity suppresses the occurrence of scintillation [4]. The spectral index value generally ranges between -2 and -

8, with a mean value of -4 for intermediate scale irregularities over Varanasi. The characteristics length of the scintillation producing irregularities varies between 200 m to 1800 m [9].

Booker [10] has suggested that in the case of intense scintillation, the received signal is the scattered part of the signal and the amplitude distribution is of the Rayleigh type. Thus, the overhead irregularities present in the ionosphere in the pre-midnight period are able to scatter the signal in the forward direction with angular spectrum of scattered waves mainly concentrated within certain beam angle. The scintillations may be understood in terms of forward scattering having wide beam angle. These results are in accordance with the hypothesis that the plasma irregularities are generated at the equatorial latitudes, move upwards and drift towards higher latitudes. During their movements, the electron density patch disintegrates into smaller and smaller irregularities.

3.3. Simultaneously observed VLF and VHF Waves

The scrutiny of the simultaneously recorded data at this latitude shows that there is no define correlation between whistler mode wave and VHF scintillation. A large number of whistlers were observed on certain nights but no scintillation observed. This is the commonly observed features. On many days scintillations were recorded but no whistler were observed. Only on limited number of days the VLF emissions, whistlers, tweeks and its higher harmonics were simultaneously observed along with the VHF scintillations.

One typical example of simultaneously observed VHF scintillations and VLF whistlers on 18th March, 1991 are shown in figure 3 (a,b). From the analysis of the whistlers, the derived parameters are: equatorial gyrofrequency f_{Heq} = (185 ± 101) kHz, nose frequency f_n = (63 ± 34) kHz, Dispersion D_0 = 29.2 ± 0.3) sec$^{-1/2}$, L=value = (1.68 ± 0.31), equatorial electron density n_{eq} = (5.0 ± 4.4) × 10^3 cm^{-3} and total electron content in the tube N_T = (1.13 ± 0.19) × 10^{13} cm^{-2} Tube^{-1} [6]. This shows that it is the mid latitude whistler wave which has propagated along L = 1.68. The L-value corresponding to Varanasi station is L = 1.07. Thus, the propagation mechanism is not aided by the overhead ionospheric irregularity. The propagation mechanism might have involved ducted propagation along L = 1.68, followed by the earth-ionosphere wave-guide mode with suitable wave-normal orientation so that it could be received at low latitudes.

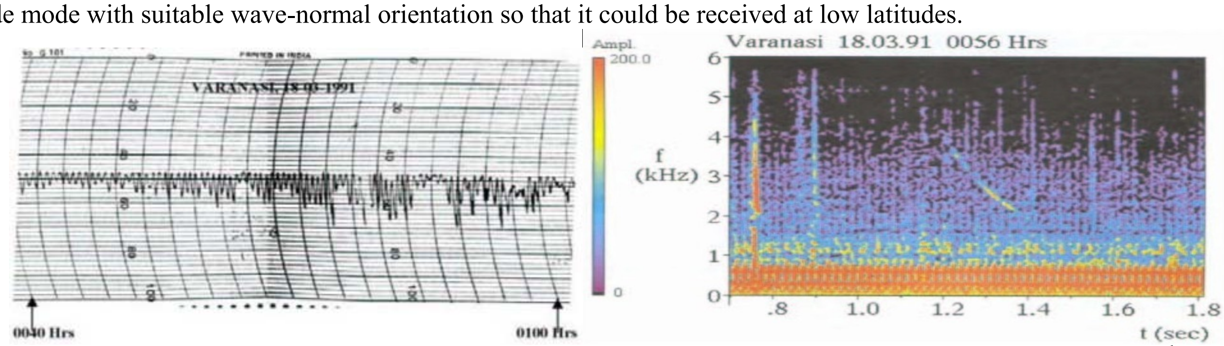

Fig. 3a,b. Typical example of simultaneously observed (a) VHF scintillations and (b) VLF whistlers on 18th March 1991.

In order to understand a typical behavior of uncorrelatedness of the two events (VLF ducting and VHF scattering), it is essential to discuss in brief the processes controlling the occurrence of VLF waves and VHF scintillations. It is known that the VLF waves are either generated in the same hemisphere near observation point or near the conjugate point in the opposite hemisphere. In the former case, the wave will be ducted by the overhead field-aligned irregularities and two hop whistlers or long whistlers are expected to be observed. Such types of whistlers have not been observed during simultaneous recording of whistlers and scintillations. Usually at low latitudes, the larger parts of whistler path is in the ionosphere, the absorption dominates and the possibility of their reception becomes poor. Thus, we find that a single plasma density irregularity causing ducting of whistler wave and also producing VHF scintillations is less probable event. The simultaneity of the two phenomena caused by single in homogeneity has to meet some strict conditions, namely, there has to be whistler source with proper orientation in the observer's hemisphere and the amplitude of launched whistler should be sufficiently large so that even after attenuation, the waves after two times propagation could be detectable. In such a situation one could observe two-hop (even-hop) whistlers along with VHF scintillations. The sources of odd hop whistlers lie near the conjugate points. Thus along with overhead irregularities if there is an active lightning with proper orientation to generate whistlers near the conjugate points and also there is field-aligned irregularities to duct and guide the whistler mode waves, then VHF scintillations and VLF waves will be received simultaneously although the involved irregularities may be altogether different. This clearly indicates that simultaneity of the two events is not necessarily caused by a single field-aligned irregularity. Relatively more probable correlation between one-hop whistlers generated in the conjugate region and ducted by the ionospheric irregularity may exist [5]. Simultaneity of these two events may be caused by two separate plasma irregularities causing short whistlers and scintillations.

4. Conclusions

Based on the present study the following points emerge:

(i) At low latitude whistler propagation is affected by the intense field-aligned plasma irregularities.

(ii) During geomagnetic storm periods additional field-aligned ducts are created which give rise to an enhanced number of whistler receptions.

(iii) The characteristic length of the scintillation producing irregularities varies between 200 m to 1800 m.

(iv) The recorded events of VLF whistlers and VHF scintillations are largely uncorrelated. Even the simultaneously recorded short whistlers and VHF scintillations may have been caused by plasma irregularities present in two different hemispheres.

5. Acknowledgements

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