J. Ind. Geophys. Union (April 2010)
Vol.14, No.2, pp.139-148

Simultaneous observation of VLF and VHF wave in the presence of ionospheric irregularities

R.P.Patel, K.Patel[1], A.K.Singh[1] and R.P.Singh[1]
Department of Physics, M.M.H. College, Ghaziabad - 201 009
[1]Atmospheric Research Lab., Physics Department, Banaras Hindu University, Varanasi - 221 005
Email: abhay_s@rediffmail.com; rppatel12@yahoo.co.in

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. To study these effects, we have analyzed VLF and VHF waves recorded at Varanasi during the period January 1991 to December 1999. VLF waves from natural lightning discharges and VHF amplitude scintillations of signals at 250 MHz transmitted from FLEETSAT geo-stationary satellites have been used. The occurrence rate of VLF waves is low and sporadic and they are generally observed during nighttimes. The VHF scintillations at Varanasi are also generally observed during nighttimes. The whistler waves generally propagated along the magnetic field lines, which is dipolar and lies in the ionosphere for the Varanasi station. 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.

INTRODUCTION

The irregularities in the plasma density in the ionosphere are generated by plasma instabilities in association with tidal dynamics in the lower atmosphere. The instabilities operative in the ionosphere varies from region to region depending upon the latitude, longitude and heights of the ionosphere. In the equatorial region irregularities are generated through the process of generalized Rayleigh-Taylor instability (Kelley 1989; Sultan 1996; Basu 2002) and move upward due to $\mathbf{E} \times \mathbf{B}$ drift motion. Some of these rise high enough and become field-aligned (Aarons 1985; Groves et al., 1997). The irregularities moving along geomagnetic field lines break in to small pieces, which are observed at low latitude stations in small patches (Singh et al., 1993; Chandra et al., 1993). The high frequency waves are known to be scattered from these irregularities resulting into amplitude/phase/frequency scintillations. Amplitude scintillation was recorded at Varanasi and morphological features of over-head irregularities were studied (Singh et al., 1993; Singh & Singh 1997; Singh, Patel & Singh 2004). 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. This is more true for waves may be ducted/diffused depending upon the nature of irregularities encountered in the path of propagation (Walker 1972). Singh et al., (1994) have discussed that the overhead field aligned irregularities may produce VHF scintillation and VLF ducting simultaneously provided whistler wave is present with suitable orientation.

At Varanasi, we have been recording VLF whistler mode waves as well as VHF amplitude scintillations for several years. The VLF waves have been analyzed and generation and propagation mechanism of these waves were studied (Singh et al., 1994). The wave gets dispersed during propagation through the ambient medium. Dispersion analysis is used to estimate the medium parameters such as electron density of magnetosphere, total electron content in a flux-tube, upward/downward transport of flux, electric field etc (Sazhin, Hayakawa & Bullough

1992; Singh, Singh & Singh 1998). On the other hand, the analysis of VHF scintillation data yields drift velocity, scale length, amplitude etc. of electron density fluctuations of E and F-regions of ionosphere which is forming the ionospheric irregularity. Thus, the combination of two frequency regions of the electromagnetic spectrum is quite suitable for the exploration of medium and processes operating in the region of influence.

In this paper, we briefly report the experimental facilities for data recording and analysis available at Varanasi. Generation features of observed VLF waves are discussed. The power spectrum analysis of occurrence rate has been carried out to estimate the duct-life time. The estimated electric field is found to be of the order of 0.1 mV/m. The information derived from VHF amplitude measurement is also reported. The location of Varanasi makes it important to observe both the VLF whistler-mode waves and VHF scintillations simultaneous at the same place, which was not reported at any other locations so far. Simultaneous observation of VLF wave and VHF scintillation is reported in tabular form in Table1. The results are discussed in the light of available measurements. Finally, conclusions of this study are presented here.

Table 1. Simultaneous occurrence of whistler mode waves with Scintillations (W.T.E = Whistler Triggered Emissions)

S.No.	Date	Time IST (Hr)	Whistler mode waves	Tweeks	Scintillation	ΣK_p-Index
1.	30-01-1991	0000-0145 Hr	2 (Short)	12	Strong	8
2.	04-02-1991	0115-0145 Hr	7 (Short)	11	Strong	11_{-}
3.	11-02-1991	0015-0100 Hr	6 (Short)	15	Strong	24_{+}
4.	15-02-1991	2230-2315 Hr	12 (Short)	20	Moderate	17_{-}
5.	18-02-1991	2000-2300 Hr	10 (Short)	11	Strong	7
6.	20-02-1991	2200-0200 Hr	4 (Short)	6	Strong	13
7.	21-02-1991	2230-2300 Hr	3 (Short)	8	Moderate	16
8.	04-03-1991	0030-0215 Hr	7 (Short)	9	Strong	17_{-}
9.	08-03-1991	2000-2130 Hr	55 (Short)	8	Weak	25_{+}
10.	15-03-1991	2245-0015 Hr	2 (Short)	7	Strong	11
11.	18-03-1991	2200-2315 Hr	2 (Short)	13	Moderate	14_{-}
12.	19-03-1991	2315-0100 Hr	4 (Short)	7	Strong	20
13.	24-03-1991	0000-0100 Hr	3 (Short)	5	Strong	54
14.	31-03-1991	0000-0130 Hr	1 (Short)	3	Strong	16
15.	14-04-1991	2330-0200 Hr	2 (Short)	4	Weak	13
16.	30-12-1991	2330-0045 Hr	2 (Short)	11	Strong	23_{+}
17.	05-02-1992	2145-2230 Hr	3 (Short)	7	Strong	13_{+}
18.	16-06-1992	2230-2315 Hr	12 (Short)	15	Strong	9_{-}
19.	28-02-1993	0015-0130 Hr	4 (W.T.E)	15	Weak	26_{-}
20.	15-05-1998	2345-0300 Hr	-	20	Strong	13_{-}
21.	18-07-1998	2100-0245 Hr	-	17	Strong	11
22.	11-02-1999	2215-0215 Hr	-	13	Strong	27_{+}
23.	23-03-1999	2300-0330 Hr	-	15	Strong	12_{-}

EXPERIMENTAL OBSERVATION AND DATA ANALYSIS

The whistler-mode waves of natural origin (lightning discharge) are being recorded on regular basis using a simple T-antenna, pre/main amplifier and cassette recorder. The amplitude scintillation of VHF beacon signal at 250/244 MHz is recorded using a receiver, Yagi-Uda antenna and a chart recorder. The data from January 1991 to December 1999 for both types of observations have been analyzed. Fig. 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. In the next section, we present the results of the present study.

RESULTS AND DISCUSSION

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 situation is different for Indian stations (Varanasi, Agra and Jammu), which lie in the low latitude region on the earth-surface. The problem is two-fold; (i) the major part of the path of propagation lies in the upper ionosphere where irregularities and some time collisions affect the propagation of the wave. The irregularities may inhibit/aid the VLF wave propagation depending upon its orientation and intensity. It may scatter the wave or produce diffusion in the frequency-time spectra (known as dynamic spectra), (ii) The curvature in dipolar magnetic field lines at low latitudes is dominant and affect the propagation. Because of this, whistler mode propagation is inhibited at low latitudes and the rate of whistler wave observation is quite low, although

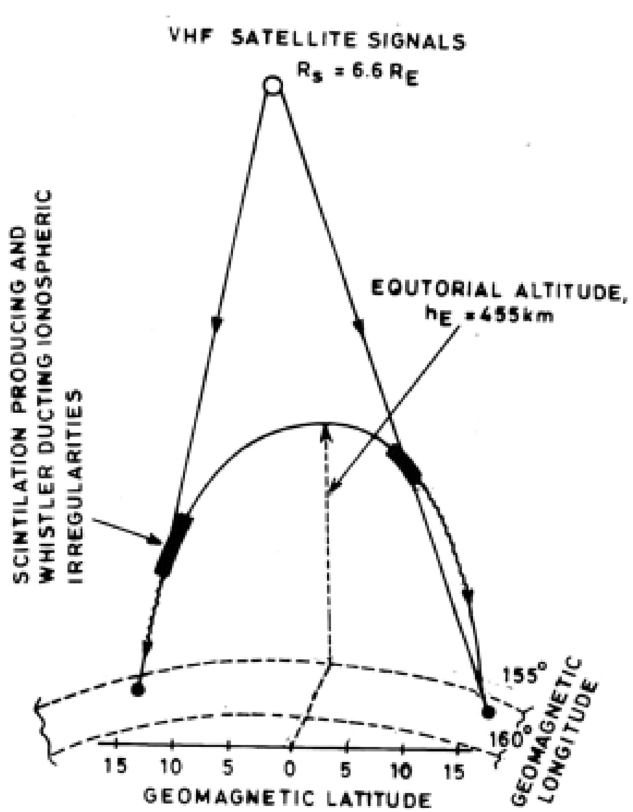


Figure 1. Schematic diagram showing the location of satellite, geomagnetic field lines, field-aligned irregularities and the ground station Varanasi.

the source rate is quite high. Based on our observations during the last several years, below we present the general features of whistler-mode waves recorded at Varanasi: (i) Whistler waves are observed usually during nighttime with predominant occurrence in the post-midnight period. The observation of these waves during day time is due to heavy attenuation, (ii) Analysis of whistler waves recorded during these periods has dispersion value between 10-15 $sec^{1/2}$. The dispersion value assuming field aligned propagation also lies in this range. Some times, we have also observed whistler waves 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. These waves will be received at low latitudes with larger dispersion (Singh et al., 2003; Singh & Singh 2004), (iii) Whistlers with lower cut-off frequency 1.7 – 2.5 kHz are frequently observed which indicates that there exists some recurrent path of propagation around 15^0 geomagnetic latitude, (iv) A large number of tweeks of the first, the second and third harmonics are observed during the reported period and it is found that their cut-off frequencies are approximately in the ratio 1:2:3, (v) 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 and (vi) Along with whistler waves, we have also observed various types of whistler mode VLF emissions like chorus, hiss and triggered emissions. These emissions are frequently observed at mid and high latitudes and they are explained in terms of wave particle interaction.

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 (Somayajulu & Tantry 1968; Somayajulu, Rao & Tantry 1972; Singh 1993). Fig. 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 (Singh & Singh 1999), which is attributed to a cyclic process in the growth and decay of ducts (Okuzawa et al., 1971). Thus, the estimated lifetime of the duct comes out to be about one hour. Somayajulu, Rao & Tantry (1972) have shown that while for a duct to form it might require 30 min or even less time, but the growth of its full size might take 3 hours. Lalmani (1984) has also evaluated duct life time of the order of one hour.

The various whistler duct formation mechanisms are: (i) electric field formation mechanism (ii) electron precipitation mechanism and (iii) protonosphere-ionosphere plasma coupling mechanism. The radial electric field in the magnetosphere produces $\mathbf{E} \times \mathbf{B}$ drift of flux tubes. The flux tube interchange causes enhancements and depressions in the electron plasma density. Park & Helliwell (1971) showed that an electric field of 0.1 mV/m in the equatorial plane can modulate the plasmasphere and give rise to enhancements and depressions of density of the order of 5% in 30 min and after one hour multiple peaks and valleys are formed. This indicates the formation of fine structure multiple ducts in main duct (Strangeways 1986). The source of electric field could be thunder cloud electric field (Singh 1992), electrostatic field in the ionosphere due to an unsymmetrical wind (Cole 1971) etc. The electron precipitation mechanism is based on the concept that magnetospheric plasma density enhancements would give rise to enhanced electron precipitation (Brice 1970). Thus a feedback mechanism involving magnetosphere-ionosphere plasma coupling and magnetosphere-ionosphere electrostatic coupling is set up which causes density enhancement and depressions (Schultz & Koons 1973). The protonosphere-ionosphere plasma coupling mechanism is based on the concept that the irregular ionosphere-plasmasphere coupling fluxes would produce irregularities in magnetospheric electron density. This mechanism may operate during and following substorms. At other times, plasma flow is unlikely to contribute significantly for duct formation. From these brief discussions it is apparent that all ducts are probably not formed by the same mechanism. Further, the electric field perturbing the magnetospheric plasma plays a dominant role in the duct formation.

The ionization irregularity present in the ionosphere causes phase modulations of the transversing radio waves and its horizontal movement leads to the temporal fluctuations in phase and amplitude. The amount of fluctuations is related to the strength of irregularities. For the purposes of analysis, we considered amplitude fluctuations having peak-to-peak variations ≥ 1 dB. The variation of occurrence rate of VHF scintillation was examined

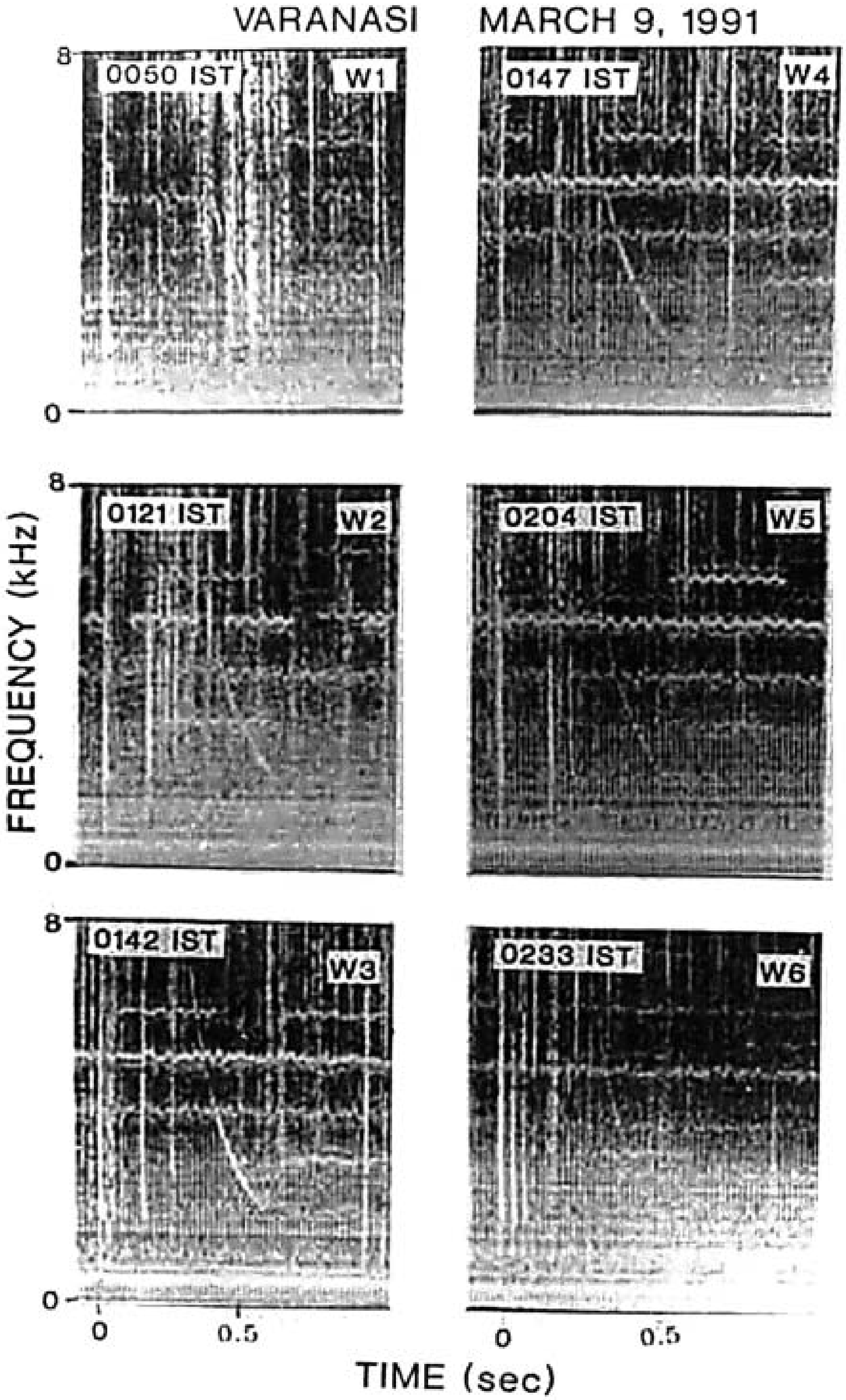


Figure 2. Sonograms of whistlers recorded at Varanasi on 8th-9th March 1991.

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. The effect of geomagnetic activity was examined by comparing the occurrence rate of scintillations on five international quiet days and five disturbed days in a month. Following information are obtained from the statistical analysis of VHF scintillations recorded at Varanasi: (i) Scintillations are observed mostly in the nighttime and predominantly during pre-midnight period. The observation of VHF scintillation during daytime is a rare phenomenon. This may be due to enhanced production rate during daytime leading to percentage decrease in amplitude of irregularities, (ii) Pre-midnight scintillations are generally intense and of fast fading rates, while post-midnight scintillations are weak and of slow fading rates, (iii) The scintillations occur mostly in small patches and the mean value of patch duration at Varanasi is ~ 30 minutes (Singh & Singh 1997), (iv) The fade depth indices are mostly less than 5 dB in Summer months but in Winter and Equinox months it lies between 5 dB and 15 dB, (v) The occurrence of scintillation peaks for different months at different time of night. The seasonal control on scintillation index is strong with maximum activity in equinox, (vi) The increase of solar activity normally increases the occurrence of scintillation, whereas the increase of magnetic activity suppresses the occurrence of scintillation (Singh, Patel & Singh 2004), (vii) The spectral index value generally ranges between 2 and 8, with a mean value of 4 for intermediate scale irregularities over Varanasi and (viii) The characteristics length of the scintillation producing irregularities varies between 200 m to 1800 m (Singh, Patel & Singh 2006).

Booker (1981) 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. The forward scattering properties of the irregularities are largely characterized by their outer scale. Thus, a particular scintillation phenomenon can be understood in terms of the value of outer scale of the irregularity and the associated scattering angle. Also, it is known that the irregularities with small density gradients cause weak scattering whereas irregularities with large density gradients cause strong scattering. The shape of irregularities help in focusing or defocusing of scattered components. For strong scintillations, the irregularity acts like a lens with a scale defined as

$$L_{lens} = \left(\frac{\lambda z}{2\pi}\right)^{1/2} \left[2\overline{(\Delta\phi)^2}\right]^{1/4}$$

where $\Delta\phi$ is phase fluctuation and for strong scattering $\Delta\phi > 1$ radian. For irregularity at z = 400 km height, the smallest value of the lens scale is ~ 280 m. For weak scattering $\Delta\phi < 1$ radian, implying that the lens scale would still be smaller than 280 m.

Based on these arguments, we infer that the overhead irregularity at Varanasi has lens scale ~ 280 m in pre-midnight period whereas the lens scale < 280 m in the post-midnight period. 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.

The simultaneously recorded data for VLF whistler mode waves and VHF scintillations are available from January 1991 to December 1999. The scrutiny of the simultaneously recorded data at this latitude shows that there is no define correlation between whistler mode wave and VHF scintillation namely: (i) A large number of whistlers were observed on certain nights but no scintillation observed. This is the commonly observed features, (ii) On many days scintillations were recorded but no whistlers were observed and (iii) Only on limited number of days the VLF emissions, whistlers, tweeks and its higher harmonics were simultaneously observed along with the VHF scintillations.

We have summarized the simultaneously observed events in Table 1. One typical example of simultaneously observed VHF scintillations and VLF tweeks on 5th March 1991 are shown in fig. 3 (a,b) and the other typical examples of simultaneously observed scintillations and VLF whistlers on 18th March, 1991 are shown in fig. 4 (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$^{"1}$ (Singh et al., 1999). 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. From the Table 1, it is evident that even when the two events occur simultaneously, no conclusions can be drawn on their morphological features such as occurrence number, intensity, type of VLF activity and strong/weak scintillations with fast or slow fading rates.

In order to understand a typical behavior of uncorrelated occurrence of the two events (VLF ducting and VHF scattering), it is essential to discuss in brief the processes of 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 inhomogeneity 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

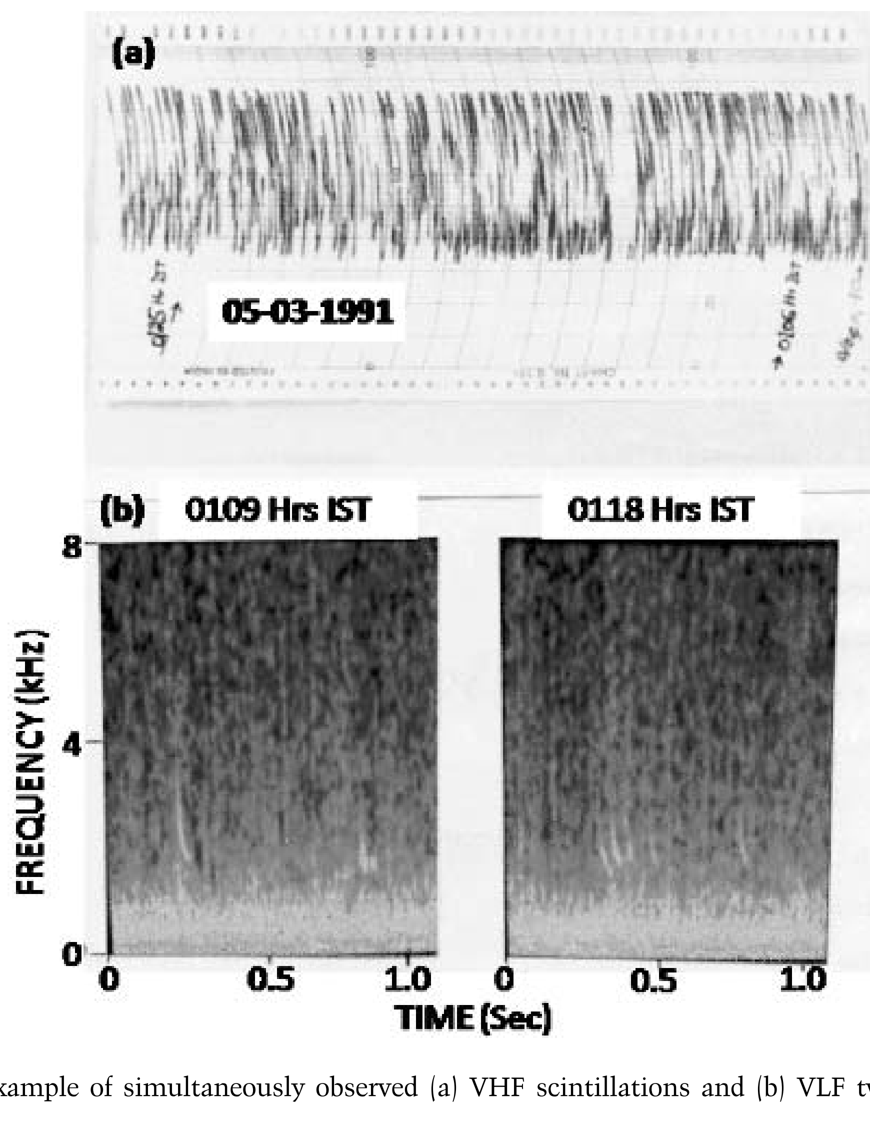
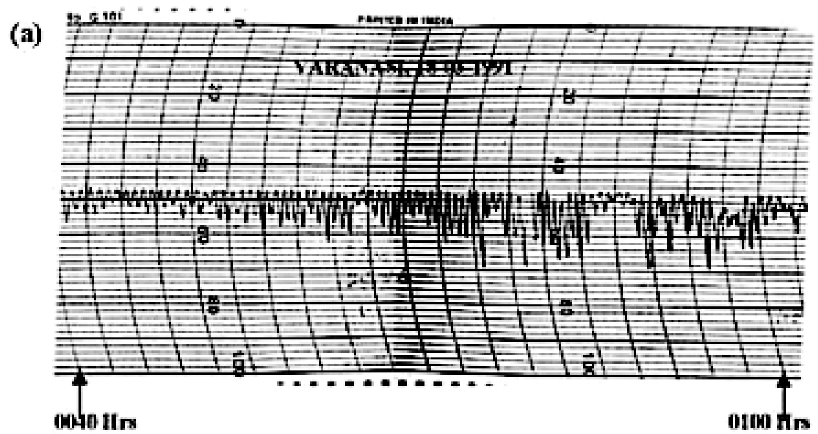


Figure 3. Typical example of simultaneously observed (a) VHF scintillations and (b) VLF tweeks on 5th March 1991.



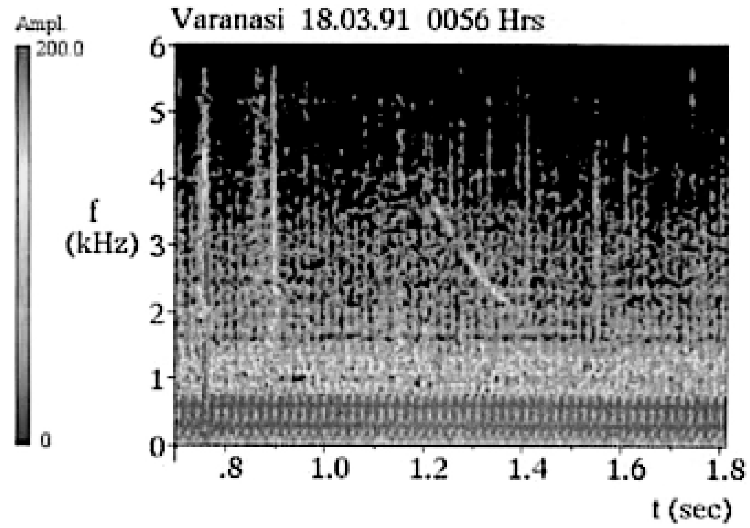


Figure.4. Typical example of simultaneously observed (a) VHF scintillations and (b) VLF whistlers on 18th March 1991.

large so that even after attenuation, the waves could be detectable after two times propagation. 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 (Singh et al., 1994). 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 (Singh et al., 1994). Simultaneity of these two events may be caused by two separate plasma irregularities causing short whistlers and scintillations as shown in Table 1.

CONCLUSIONS

At low latitude whistler propagation is affected by the intense field-aligned plasma irregularities (Singh, Singh & Singh 1998). During geomagnetic storm periods additional field-aligned ducts are created which give rise to an enhanced number of whistler receptions. The overhead ionospheric irregularities in the pre-midnight period cause strong scattering whereas in the post-midnight period, the irregularities may cause weak scattering. The characteristic length of the scintillation producing irregularities varies between 200 m to 1800 m. The recorded events of VLF whistlers and VHF scintillations are largely uncorrelated. Total of 19 events of simultaneous VLF whistler-mode waves and VHF scintillations events have been observed. In which 10 events occurred in disturbed days and 9 events in quiet days. Even the simultaneously recorded short whistlers and VHF scintillations may have been caused by plasma irregularities present in two different hemispheres.

ACKNOWLEDGEMENTS

The work is partially supported by the Department of Science and Technology, New Delhi and partly by ISRO, Bangalore. R. P. Patel is thankful to Department of Science and Technology, Government of India, New Delhi for awarding research project under SERC-Fast Track Scheme for young Scientists (SR/FTP/PS-12/2006).

REFERENCES

Aarons, J., 1985. Equatorial F-Layer irregularity patches at anomaly latitudes, J. Atmos. Terr. Phys., 47, 875-883.

Basu, B, 2002. On the linear theory of equatorial plasma instability: Comparison of different descriptions, J. Geophys. Res., 107 (A8), 1199, doi: 10. 1029/2001JA000317.

Booker, H.G., 1981. Application of Refractive Scintillation Theory to Radio Transmission through the ionosphere and the solar wind and to reflection from a Rough ocean, J. Atmos. Terres. Phys., 11, 1215-1233.

Brice, N. M., 1970. Artificial enhancement of energetic particle precipitation, J. Geophys. Res., 75, 4890.

Chandra, H., Vyas, G.D., Rao, D. R. K., Pathan, B.M., Iype, A., Sekaran, B.R., Naidu, A., Sadique, S.M., Salgaonkar, C.S., Tyagi, T. R., Vijaykumar, P. N., Lakh Singh, Iyer, K.N., Pathak, K. N., Gwal, A.K., Kumar, S., Singh, R.P., Singh, U. P., Singh, B., Jain, V.K., Navneeth, G.N., Koparkar, P.V., Ramarao, P. V. S., Jaychandram, P. T., Sriram, P., SantoRao, N. Y. S., DasGupta, A., Basu, K., and Raastogi, R. G., 1993. Coordinated multistation VHF scintillation observations in India during March-April, 1991, Ind. J. Radio & Space Phys., 22, 69.

Cole, K.D., 1971. Formation of field-aligned irregularities in the magnetosphere, J. Atmos. Terres. Phys., 33, 741.

Groves, K. M., Basu, S., Weber, E.J., Smithan, M., Kuenzler, H., Valladares, C. E., Sheehan, R., Mackenzie, E., Secan, J. A., Ning, P., McNeill, W.J., Moonan, D.W. & Kendra, M.J., 1997. Equatorial scintillation and system support, Radio Science, 32, 2047-2064.

Kelley, M. C., 1989. The Earth's ionosphere in plasma physics and electrodynamics, Academic Press, San Diego, CA.

Lalmani., 1984. Some aspects of whistler duct lifetimes at low latitude, J. Geophys. Res., 56, 53.

Okuzawa, T., Yamanaka, K. & Yoshino, T., 1971. Characteristics of low latitude whistler propagations associated with magnetic storms in March, Rept. Ionosphere and Space Res. Japan, 25, 17.

Park, C.G. & Helliwell, R. A., 1971. The formation by electric fields of field aligned irregularities in the magnetosphere, Radio Science, 6, 299-304.

Sazhin, S.S., Hayakawa, M. & Bullough, K., 1992. Whistler diagnostics of magnetospheric parameter, A review, Ann. Geophys., 10, 293-308.

Schultz, M. & Koons, H.C., 1973. Whistler duct formation a magnetospheric instability, Aerospace Report No.TR-0073-(3260-20)-15.

Somayajulu, V. V. & Tantry, B. A. P., 1968. Effect of magnetic storms on duct formation for whistler propagation, J. Geomag. Geoelec., 20, 21-31.

Somayajulu, V. V., Rao, M. & Tantry, B. A. P., 1972. Whistlers at low latitude, Indian J. Radio Space Phys., 1, 102.

Singh, R. P., 1992. Thunder cloud electric field and charge particle precipitation, Memorirs Geolo. Soc. Ind., 24, 469-482.

Singh, R. P., Singh, U. P., Singh, A. K. & Singh R. N., 1993. Scintillation study at Varanasi, Ind. J. Radio and Space Phys., 22, 17-21.

Singh, R. P., Singh A. K., Singh, U. P. & Singh, R. N., 1994. Wave ducting and scattering properties of Ionospheric irregularities, Advances in Space Research, 14, 225.

Singh, A. K. & Singh, R. P., 1997. Observations and modeling on nocturnal ionospheric irregularities in low latitude region, J. Geomag. Geoelectr., 49, 1114.

Singh, R. P., Singh, A. K. & Singh, D. K., 1998. Plasmaspheric parameters as determined from whistler spectrograms, A review, J. Atmos. Solar Terr. Phys., 60, 495-508.

Singh, A. K. & Singh, R. P., 1999. Duct lifetimes at mid latitudes, Periodica Polytechnica Ser. El. Eng., 43, 43-52.

Singh, R. P., Singh, D. K., Singh, A. K., Hamar, D. & Lichtenberger, J., 1999: Application of matched filtering and parameter estimation technique to low latitude whistlers, J. Atmos. Solar Terr. Phys., 61, 1081-1092.

Singh, R. P., Patel, R. P. & Singh, D. K., 2003. Triggered emissions observed at Varanasi (India), Planet. and Space Science, 51, 495-503.

Singh A. K. & Singh R. P., 2004. Observations of discrete VLF emissions at low latitudes and their generation mechanism, Earth Planet Science, 56, 1067-107.

Singh, R. P., Patel, R. P. & Singh, A. K., 2004. Effect of solar and magnetic activity on VHF scintillations near equatorial anomaly crest, Ann. Geophysicae, 22, 2849-2860.

Singh, A. K., Patel, R. P. & Singh, R. P., 2006. Statistical features of overhead Ionospheric irregularities and its generation mechanism at low latitude, J. Atmos. and solar-Terres. Phys., doi: 10.1016/j.jastp.2006.02.002.

Strangeways, H. J., 1986. A model of the electron temperature variation along geomagnetic field lines and its effect on electron density profiles and VLF paths, J. Atmos. Terr. Phys., 48, 671-683.

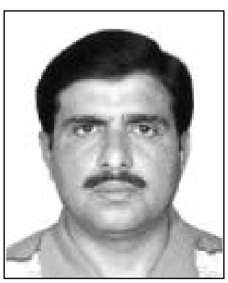
Sultan, P. J., 1996. Linear theory and modeling of Rayleigh-Taylor instability leading to occurrence of equatorial spread F, J. Geophys. Res., 101 (A12), 26875-26892.

Walker, A. D. M., 1972. The propagation of very low frequency radio waves ducts in the magnetosphere, Proc. R. Soc. A329, 219.

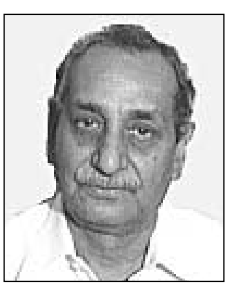
(Revised accepted 2010 February 20; Received 2009 June 10)

Dr. Ravindra Pratap Patel is currently Lecturer in Department of Physics, M.M.H. College, Ghaziabad. He obtained Ph. D. from Banaras Hindu University, Varanasi in 2002. He has participated in 20th Indian Antarctic Scientific Expedition during December 2000 to April 2001 as a summer team member. During research period he was awarded project fellow and Senior Research Fellow. After Ph. D. he was awarded Research Associate from Council of Scientific and Industrial Research, New Delhi and Young Scientist under the FAST-TRACK scheme project from Department of Science and Technology, New Delhi. He was attended the Committee on Space Research (36th COSPAR Scientific Assembly) in 2006 held at Beijing, China. His research interest includes: Space Weather Studies of Upper Atmosphere, Study of Ionospheric Irregularities using VHF and L-Band Scintillations, Study of VLF Whistler - Mode waves, Electrodynamics of the Atmosphere-Ionosphere etc.

Mrs. Kalpana Patel, is a research scholar, just submitted her Ph. D. thesis under the supervision of Dr. Abhay Kr. Singh (Associate Professor), in the Department of Physics, Atmospheric Research Lab., Banaras Hindu University, Varanasi. Her field of research interest is Ionospheric Irregularities. She has passed her B.Sc. as first class from Shri Agrasen Kanya Autonomous P.G. College, and M.Sc. as first class from Department of Physics, Udai Pratap Autonomous College of Purvanchal University. She is one of the active members in her Atmospheric Research group of the Department of Physics, Banaras Hindu University.



Dr. Abhay Kumar Singh is currently Associate Professor in Dept. of Physics, Banaras Hindu University, Varanasi. He obtained Ph.D. from BHU, Varanasi in 1993. He was Lecturer in Maharaja College, Ara from 1996 to 2005 and then joined as Reader in Department of Physics, BHU, Varanasi in 2005. He was BOYSCAST Fellow at Department of Theoretical Space Physics, Umea University, Umea, Sweden from 2002 to 2003 awarded by DST, New Delhi. His research interest includes: Space Weather Studies of Upper Atmosphere, Study of Ionospheric Irregularities using VHF & GPS scintillations, GPS based Total Electron Content (TEC) & Water Vapor content measurements, Study of VLF Whistler-Mode waves, Electrodynamics of the Atmosphere-Ionosphere-Magnetosphere, Seismo-electromagnetics to study Earthquake Precursors, Atmospheric studies involving aerosols, dust storms, winter fog, and their radiative and climate effects.



Prof. R.P. Singh is Ex-Vice-Chancellor V.K. S. University, Ara, Bihar and Ex-Head of Department of Physics, Banaras Hindu University, Varanasi. He obtained Ph.D. from BHU, Varanasi in 1969. He joined department of Physics, BHU as Lecturer in 1974 and became reader in 1983. He became Professor of Physics in 1991 and retired in 2005 as HOD of Physics. Then he joined as Vice-Chancellor of Veer Kuwar Singh University, Ara in 2005. He has supervised 14 Ph.Ds and published about 200 research papers in different national and international journals. He visited various countries like France, USA, Hungary etc. for participating various meetings and seminars. His research interest includes: Study of VLF Whistler-Mode waves, Space Weather Studies of Upper Atmosphere, Study of Ionospheric Irregularities using VHF Scintillations, Electrodynamics of the Atmosphere-Ionosphere-Magnetosphere, Seismo-electromagnetics to study Earthquake Precursors etc.