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Studies on sferics over Kolkata in relation to rainy and winter seasons

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The VLF spectral characteristics of the sferics over Kolkata (22.56°N, 88.5°E) are studied in relation to the rainy and winter seasons. The nature of sferics during rainy and winter seasons is determined for different times of the day. The recorded data of sferics from Kolkata exhibit many interesting monitoring possibilities due to the involvement of the characteristics of atmospheric and ionospheric parameters. The recorded sferics exhibit diurnal variation of electron density of the lower ionosphere. Many interesting features are observed including sunrise and sunset effects.

Keywords: VLF sferics, Ionospheric propagation

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1 Introduction

Sferics are electromagnetic waves generated by lightning strokes all over the world. Radio waves in the VLF range are guided within the spherical waveguide formed between the earth and lower ionosphere with little attenuation. The sudden variation of electric field due to cloud discharge can be expressed as continuous Fourier series. The amplitudes of Fourier components are measured at 1, 3, 5, 7 and 12 kHz by detecting them with a time constant of 7.5 s. The detected level is calibrated in terms of the amplitude of recorded Fourier components. The recorded amplitude is an average of the number of sferics appearing at the antenna. In the absence of local cloud activity, there is an ambient level of average amplitude which is a function of time. This amplitude shows diurnal and seasonal variations depending upon local and global cloud activity. During clear days, gain of the amplifier is to be adjusted to a low value so that the output becomes insignificant. The output variation has been observed only during occurrence of local cloud activity. With moderate gain of the amplifier, simultaneous contributions from distant and local cloud activities have been recorded. So the winter record is a signature of global activity because of no cloud activity in the locality. During rainy season, local cloud activity is dominant and the global structure is suppressed. The amplitude of the sub-ionospherically propagating VLF sferics depends on the electrical conductivity of lower ionosphere and that of the ground. Some analyses are also reported thoroughly by worldwide monitoring of VLF-LF propagation and atmospheric noise[1]. The results of observations on different aspects of the Integrated Field Intensity of Sferics (IFIS) at Tripura have been reported[2]. From the regular measurements of atmospheric vertical potential gradient and VLF sferics at Kolkata, correlation studies between the amplitude spectrum of VLF sferics and vertical electric field are made[3]. It is reported that diurnal variation of vertical electric field averaged over 20 fair weather days maintains good connectivity with diurnal variation of VLF sferics activity.

Singh *et al.*[4] explored the lightning generated waves and discussed their diagnostic features, and presented results of the recorded data at Varanasi (25.33°N, 83°E). They also collected data from Bichpuri, Agra (27.2°N, 78°E), Jammu (32.7°N, 74.9°E), Srinagar (34.10°N, 72.2°E) and Bhopal (23.26°N, 77.6°E) and the results are briefly summarized and interpreted in their work. The attenuation coefficient for different modes for the finite conductivity of the Earth's surface and the inner ionospheric layer has been evaluated and presented graphically. The computation has been made for waveguide heights 88, 92 and 96 km, respectively. It has been noted that attenuation increases greatly as the frequency approaches the cut-off frequencies. Attenuation also increases when layer height decreases. This attenuation versus frequency characteristics explains the lower limit of the frequency of the waves. Moreover, the attenuation increases with the increase of mode number. Watkins *et al.*[5], from a long period (25 years) data at 10 kHz, observed VLF noise levels at Halley are found as a product of the thunderstorm source function and the transfer function for propagation to the receiver from the Earth-ionosphere waveguide. The variations of VLF power with sunspot number and with 11 year solar cycle period have been believed to be due to influence of EUV flux on the ionospheric D-region. A short-period (1997-1998) data analysis of VLF sferics at 9.3 kHz, recorded at Antarctica, showed a good correlation between VLF power measurement and tropical temperature variation[6]. Clilverd *et al.*[7] studied diurnal and annual variations at 10 kHz radio noise from lightning discharge. They noted largest variation of 10 dB in diurnal pattern and attributed this to the thunderstorm activity of South African zone. Their analyses suggest that between two identical tropical source regions, one situated in the east and the other in the west of polar receiver site, the region to the west tends to dominate the diurnal variation. The detailed study of ELF and VLF radio waves has also been published by Barr *et al.*[8] Among different features, the amplitude of the transmitted signal shows a minimum at sunrise, called sunrise effect. The sunrise effect in VLF signal has been reported by Clilverd *et al.*[9] thoroughly over a long north-south path. The results have been interpreted using waveguide mode theory.

It is true that local manmade phenomena like electric motor sparks, TV station time-signal, high concentration of airborne particles and aitken nuclei, etc. affect the observation in the VLF range. The VLF frequencies which are less affected by the local phenomena are selected for the observation of distance sferics. A pre-experimental study was made to detect the VLF signatures of manmade noise, which are excluded for the observation of distant sferics. In spite of that, if there are any local short-time fluctuations caused by the local events, it can be nullified when the statistical averaging over a long time (around one hour) on the observed data is made. The actual values of the atmospheric relaxation time are from 5 to 40 min at the Earth's surface. For this, it is possible to apply the quasi-static principle to variations with periods of over an hour. Following this principle, Ogawa eliminated the short period fluctuations due to local pollutants and aerosols in his measurements[10]. He took overlapping mean values of 30 min at first, which covered the maximum relaxation time during the concerned period. Next, he continued taking overlapping means until the short-time fluctuations vanished. In his analysis, it was found that fluctuations were almost eliminated and the diurnal courses of elements were characterized in 4 or 5 h period. In the same manner, short-period fluctuations on each diurnal variation were eliminated, taking an overlapping averaging period of one hour, which is almost double the atmospheric relaxation time in fair weather. After obtaining each diurnal variation, the data was further averaged to get the seasonal and statistical results.

The variation of amplitude of VLF sferics at a particular location depends on the source characteristics as well as propagation characteristics. The distribution of lightning activities all over the globe follows an average universal pattern. But the location, where the sferics is observed, includes the effect of the ionosphere also. Especially, during local sunrise and sunset, the amplitude of sferics intensity goes to minimum, known as 'sunrise effect' and 'sunset effect'. There are also other factors like solar flares, geomagnetic storms, etc. which can change the characteristic global variation of VLF sferics at a particular geographic location over the Earth. If the records of rainy and winter days are compared, the magnitude of variation is observed to be different from each other. The times of occurrences of sunset effect and sunrise effect also shift from season to season. These are the evidences that the level of atmospherics is related to local effects. In this paper, the results of analyses of sferics data over Kolkata are reported in relation to rainy and winter seasons.

The sferics level during rainy seasons is determined for different times of the day. The level stands for the amplitude of Fourier components. In the present measurement, it is governed by the intensity of source and the nature of propagation path from the source to the receiver. Except 2000 hrs IST, the levels at 3 and 5 kHz are smaller than other levels. The frequency of peak of spectrum is seen to be time dependent. It is the frequency at which amplitude of Fourier component is maximum. This is an average governed by individual source intensity and rate of occurrence of sferics. It may be noted that the intensity is proportional to square of amplitude. So in dB scale variation of amplitude is convertible by using the multiplying factor '2' as usual. During the months of rainy seasons, levels at frequencies 1, 7, 12 kHz are found to be comparable. The level of 3 kHz shows a minimum at all hours of rainy seasons.

The analyses of the sferics level of atmospherics during winter seasons have been carried out for different times of the day. The levels at 3 and 5 kHz frequencies are remarkably low compared to the levels at other frequencies.

The VLF occurrence characteristics of the sferics over Kolkata are presented here. Earlier, power spectrum analysis was made of the data of lightning activity recorded at very low frequency sferics at Roorkee (29.52°N, 77.59°E) and Pretoria (25.44°S, 28.12°E) (ref. 11). The diurnal variation of sferics is also presented in the paper. The sferics consists of two components: radio waves coming directly from cloud discharges and those coming from distant sources via ionospheric reflection. The relative magnitude of these two components determines the diurnal behaviour, which is expected to be dependent on geographical positions. Data of VLF sferics have been recorded at 1, 3, 5, 7 and 12 kHz at Tripura (23°N, 91.4°E) and at Kolkata continuously.

2 Experimental setup

2.1 Antenna

For the observation of power spectrum of VLF sferics at 1, 3, 5, 7, 9 and 12 kHz, a straight horizontal copper wire of 8 SWG having 120 m length is used in the form of an inverted L type antenna. The antenna, which is installed 30 m above the ground, is capable of receiving vertically polarized atmospherics in the ELF-VLF bands from near and far sources of lightning discharges.

The antenna is mounted between the roof tops of two buildings. Due to wall effect, the effective height is assumed to be reduced by 20%. The high value of antenna height gives appreciable induced emf in the antenna. The large horizontal length yields large antenna capacitance even with large height.

2.2 Recording system

The recordings of VLF sferics are made by computerized data acquisition systems. Two types of data acquisition systems are used: (a) a PCI 1050, 16 channel 12 bit DAS card and (b) a 8-channel, 12 bit software chart recorder which uses MAX186 chip as an ADC. The data are recorded round-the-clock at the sample rate of one data per second.

In the data acquisition systems, the input multiplexers have a built-in-over-voltage protection arrangement. All the I/O parts are accessed by 32 bit I/O instructor thereby increasing the data input rate. It is supported by a powerful 32 bit API, which functions for I/O processing under the Win 98/2000 operating system.

3 Observations and analyses

The average of the diurnal variations during rainy seasons (June, July and August) are shown in Fig. 1 at different frequencies. The diurnal behaviour is

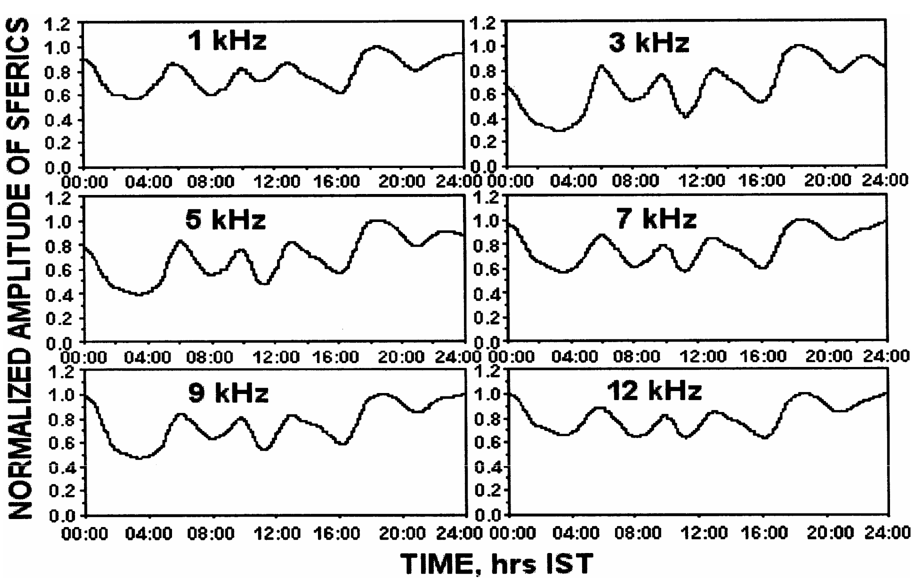

Fig. 1 — Diurnal variation of sferics in rainy season (June, July and August, 2004) at various frequencies [The strength of the sferics has been shown in terms of the normalized value of induced voltage at the antenna]

recognized when mean data of clear days over a month or so is averaged. In the present analyses, all the days of rainy season are being considered. For this, the diurnal variation is not so clear. During rainy seasons, the level decreases from midnight to dawn around 0400 hrs IST. Before sunrise the level increases showing a maximum at around 0600 hrs IST. It is called pre-sunrise enhancement. After sunrise, the level starts to fall showing a minimum at around 0800 hrs IST. This is almost a regular feature with a slow drift with time in the absence of overhead or very neighbouring cloud activity. This sunrise effect is termed as sunrise fade. The magnitude of this fall is termed as sunrise depth. After the sunrise fall, the level rises for about two hours. This is called recovery effect. Around midday, the level shows a dip. The level then increases showing maximum value at around 1300 hrs IST. Before sunset, the level increases and during sunset the level exhibits maximum. It is called sunset maximum. Following sunset, the level again falls to certain value which is called post-evening minimum. The average line shows that the midnight level is higher than midday level. If the sunrise minimum is marked A and midday minimum B, the relative values of the levels of A and B are found to be frequency dependent. At 1 kHz, level of B is greater than that of A, whereas in all other frequencies, level of A is greater than B.

The average of the diurnal variations during winter seasons (November, December, January and February) is shown in Fig. 2. During winter season, the level decreases from midnight to dawn around 0300 hrs IST. It is called pre-sunrise fade. Its magnitude is termed as pre-sunrise depth. The level remains low till 1100 hrs IST. After that, the level rises and remains high till afternoon. During sunset, the level decreases and exhibits a minimum. It is called the winter sunset minimum. Following sunset, the level rises to certain value at midnight. Except at 1 kHz, the maximum of the whole diurnal record occurs at midnight. The average line shows that the midnight level is greater than midday level.

The VLF spectral characteristics of the atmospherics have been studied in relation to the rainy and winter seasons. The sferics level of atmospherics during rainy season is shown in Fig. 3 for different times of the day. Except at 2000 hrs IST, the levels at 3 and 5 kHz are smaller than the other levels. The time dependent nature of the frequency of peak spectrum is shown in Table 1. During all the months of rainy season, levels at frequencies 1, 7 and 12 kHz are comparable. Level of 3 kHz is minimum at all the hours of rainy season.

The spectrum of the level of atmospherics during winter season has been shown in Fig. 4 for different times of the day. At 0000 hrs IST, the level increases with frequency. At 0400 and 0800 hrs IST, the levels at 3 and 5 kHz are smaller than the other levels. At 0400 hrs IST, the levels at these frequencies are remarkably low compared to levels at other frequencies. The frequency of peak of spectrum is time dependent. This is shown in Table 2. At 1200

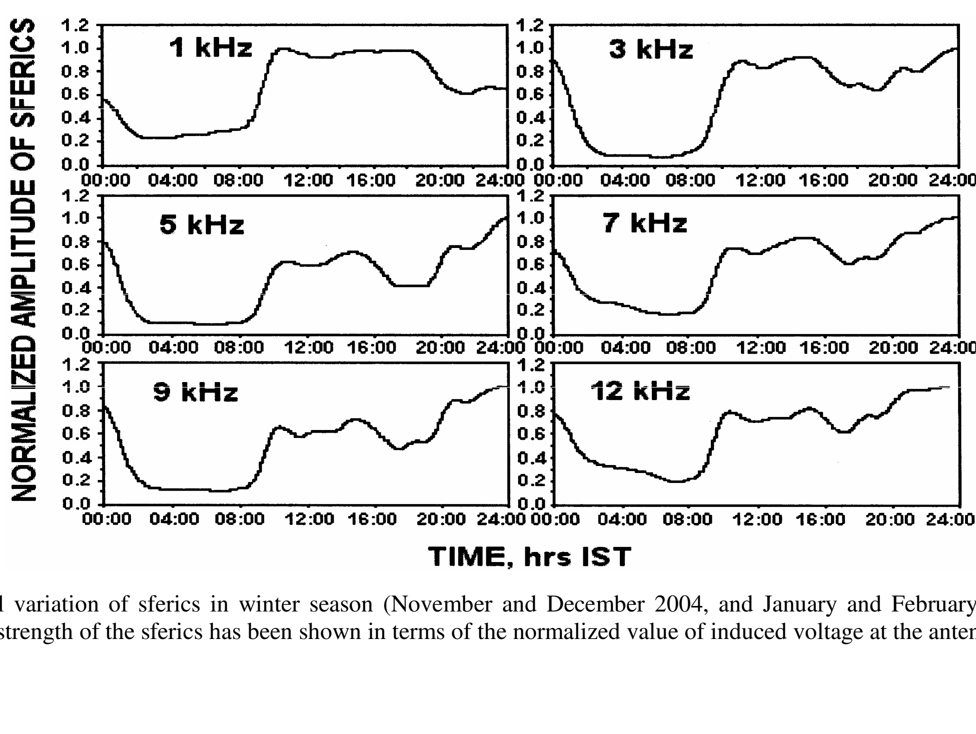

Fig. 2 — Diurnal variation of sferics in winter season (November and December 2004, and January and February, 2005) at various frequencies [The strength of the sferics has been shown in terms of the normalized value of induced voltage at the antenna]

Table 1 — Spectral behaviour of maximum and minimum level of atmospherics in rainy seasons

Time, hrs IST	Frequency of max. level, kHz	Frequency of min. level, kHz
0000	12	3
0400	1 and 12	3
0800	1 and 12	3
1200	1	3
1600	1	3
2000	5	3

Table 2 — Spectral behaviour of maximum and minimum level of atmospherics in winter seasons

Time, hrs IST	Frequency of max. level, kHz	Frequency of min. level, kHz
0000	12	1
0400	12	3
0800	1	3
1200	1	5
1600	1	5
2000	12	3

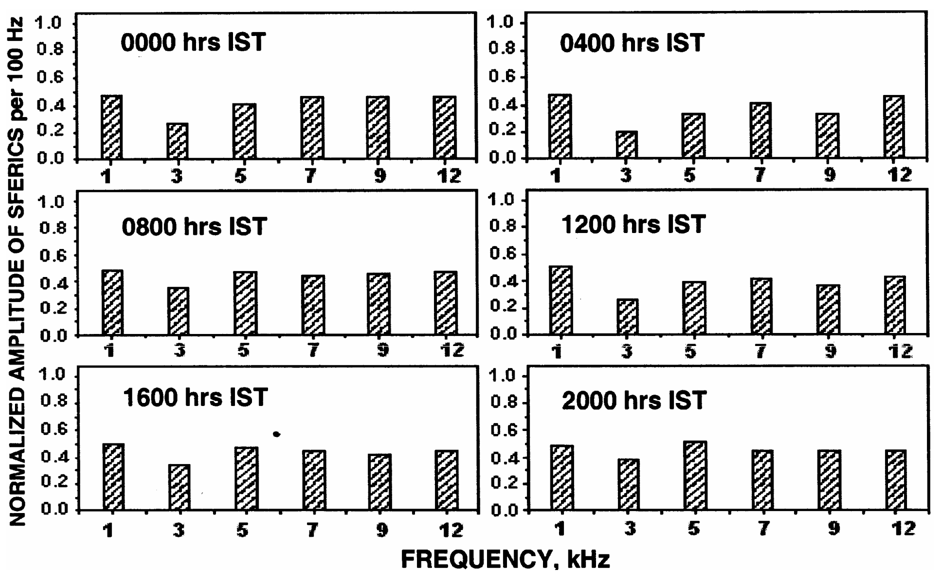

Fig. 3 — Sferics spectrum at various times in rainy days

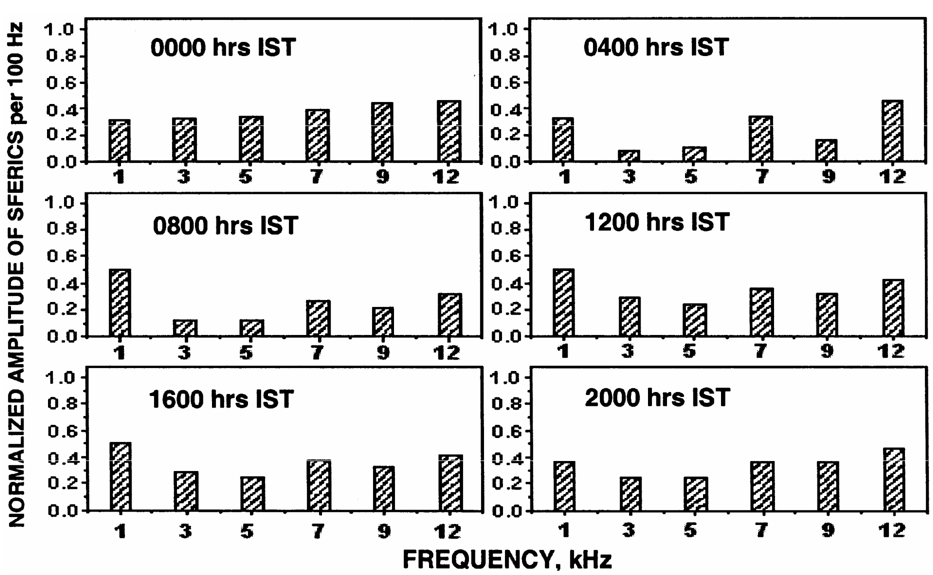

Fig. 4 — Sferics spectrum at various times in winter days

and 1600 hrs IST, levels at frequencies 1 and 12 kHz are comparable. The level of 5 kHz is minimum at all the hours considered.

4 Normalization procedure and signal level

In the analysis, spectrum of the averaged VLF sferics data is plotted at different times of the day. The normalization of the spectrum amplitude is achieved at a particular time by dividing the amplitude of each frequency with the maximum value at that frequency. Using that, the normalized value per 100 Hz bandwidth is calculated. For this purpose, the normalized value at each frequency is divided by the receiver bandwidth and then multiplied by 100. For diurnal variations of VLF sferics, the data of the averaged VLF sferics for the diurnal variations are shown for different frequencies. In this way, all the results are presented for equal bandwidth.

Kolkata, located in the eastern part of India, has a sub-tropical climate. It is situated on the Gangetic delta and is very close to the Bay of Bengal. As such, Kolkata weather is heavily influenced by the sea. There are three major seasons at Kolkata, e.g. summer, monsoon and winter. The summer is quite hot in Kolkata, the temperature reaching to a maximum of about 41°C in the month of May. From March to June, it is summer in Kolkata, when south-westerly monsoon winds flow. Humidity is high during summer. Sometimes, occasional showers are seen accompanied by dusty violent whirl-winds. The period between June and September is the monsoon season when Kolkata experiences heavy rains. Monsoon is influenced by southeast monsoon winds. The average annual rainfall is about 1582 mm. The downpour is the maximum in the month of August. December to February is the winter season in Kolkata. The early morning times are usually foggy. The temperature varies between 12° and 14° C and does not go below 10° C. The weather during the winter is very calm in Kolkata.

For the analyses of data, rainy season is considered from mid-June to mid-September, whereas the winter season is considered from 1 December to mid-February. The normal signal level in rainy season is about 40 dB and in winter season it is about 30 dB, both above 1 μV. Some characteristics of signal level variation during sunrise, sunset and midday during rainy and winter seasons are furnished as follows:

4.1 Rainy season

In rainy seasons, sunrise effects and recovery effects are obvious at all frequencies. The magnitudes of sunrise effects, recovery effects, depth of midday maxima and post evening maxima for rainy season are shown in Table 3.

4.2 Winter season

In winter season, the magnitude starts to fall from midnight and the fall is appreciable upto dawn. After that, variation is small and is till 0900 hrs IST. The dependence of these values of the fall on frequency is depicted in Table 4. In the evening, the level rises until midnight except 1 kHz. The rise in level at different frequencies is shown in Table 5.

5 Discussion

The electromagnetic radiation below 100 kHz frequencies has the characteristics of being able to travel long distance guided between earth and ionosphere. The waveguide formed between the lower ionosphere and Earth's surface is good for very low frequency (VLF) propagation round the earth. The conductivity parameter determining the status of the ionospheric radio wave propagation is controlled by

Table 3 — Some characteristics of signal level variation during rainy seasons*

Events	Frequency, kHz					
	1	3	5	7	9	12
Sunrise effect	26.8	28.3	27.9	25.2	19.8	23.6
Recovery effect	21.8	20	20.1	17.2	15.9	17.3
Depth of mid day minima	9.2	34.3	29.9	21.9	24.9	16.9
Post evening maxima	99.9	100	99.2	99.5	99.8	99.8

*all values are in % of maximum values

Table 4 — Some characteristics of signal level variation during winter seasons*

Events	Frequency, kHz					
	1	3	5	7	9	12
Fall at late night	33.9	75.9	67.2	43.7	62.9	45.3

*all values are in % of maximum values

Table 5 — Rise in levels after evening

Events	Frequency, kHz					
	1	3	5	7	9	12
Rise in level from evening to midnight	*	34.3	57	34.2	46.9	37.7

*The effect is too small to state at 1 KHz the solar conditions. It is well-established that low frequency (LF) signals propagate over long distance exhibit diurnal variations due to temporal variation of electron density in the lower ionosphere.

The difference between midnight and midday levels in rainy season is 6.5 dB on the average. In fact, this difference is frequency dependent. This is highest at 3 kHz and lowest at 9 kHz. The difference between midnight and midday levels in winter season is 8 dB on the average. This is highest at 3 kHz and lowest at 7 kHz.

The atmospheric activity in general is higher at night due to which the sferics exhibits higher level at night time than daytime. The rate of occurrences of lightning is higher at night. In winter, local cloud activity is low and the sferics level is governed by distant sources. The higher level at night in the winter season is due to fair-weather condition at night. For interpretation of the results, several years data is needed.

For VLF propagation in earth-ionospheric waveguide, the nature of ground reflector can be treated to be invariant. The characteristic variations of D-region parameters must appear as signature in the recorded signals which are exhibited in different plots.

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