Research Article

A comparative study of ELF and VLF noise characteristics of nor'wester at a low latitude tropical station

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Abstract
Two pre-monsoon thunderstorms (nor'westers) in the Gangetic West Bengal have been considered to study the effect of source activity and wave propagation at a low latitude station. Lightning discharges, due to cumulonimbus cloud, propagate in the form of electromagnetic radiation have received in the form of sferics by sensitive receiver in ELF and VLF bands simultaneously. Local meteorological observatory recorded the wind speed of April 1, 2018 as 85 km/h blowing from the northwesterly direction while that for April 17, 2018 as 98 km/h blowing from the same direction. In addition to wind speed other meteorological parameters, viz. temperature, humidity and pressure have also been taken into account with a view to find the source activity. Kolkata Doppler Weather Radar observations showing the squall line and cloud top height during the peak activity of the storms have also been analyzed for the two occasions. We have made the spectral recordings of sferics round-the-clock during the disturbed weather caused by the pre-monsoon thunderstorms. The results obtained from the multi-technique observations are interpreted and discussed.

Keywords Noise · Thunderstorm · Sferics · Source activity · Radio wave propagation · Doppler weather radar

1 Introduction

Violent thunderstorms during the pre-monsoon months, March to May, in the Gangetic West Bengal are popularly called 'KalBaisakhi' or 'Nor'westers' as they originate from North–West direction. It usually occurs during late afternoon hours over Kolkata (22.5726°N, 88.3639°E) due to cumulonimbus cloud followed by precipitation that persists for an hour or so. The initial sign of nor'wester is usually a low bank of dark cloud in the northwest region of Kolkata, the upper outline of which looks like an arch. It moves slowly at the initial stage and then rapidly with a strong gust or squall. Occasionally, the wind blows even with similar to hurricane force. Kolkata experienced the first nor'wester of the season on April 1, 2018 and another severe one on April 17, 2018. Lightning, a powerful sudden flow of electricity associated with the said nor'westers occurred largely as we noticed from our observatory and also reported from the local meteorological station [1]. Lightning discharges accompanied by nor'westers propagate in the form of electromagnetic radiation [2] and we received the same in the form of sferics by our sensitive receiver in ELF and VLF bands simultaneously. Some interesting characteristics we recorded in these frequency bands are reported in the paper. Investigations on ELF/VLF waves have scientific importance as they largely reflect from the D-region of the Earth's ionosphere (60–90 km altitude) and are suitably guided in the Earth-ionosphere waveguide. In addition, ELF/VLF waves are an efficient means of subterranean mapping or for the purpose of

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detecting underground structures. In this paper we have analyzed the effect of source activity and wave propagation at a low latitude tropical station, Kolkata, considering the characteristics of two pre-monsoon thunderstorms in the Gangetic West Bengal. Doppler Weather Radar observations of the squall line as well as wind speed and other meteorological parameters during the two thunderstorms showing interesting results have also reported in addition to sferics data in the ELF and VLF bands.

2 Particulars of the two nor'westers

A squall can be converted to a nor'wester if it has a speed of at least 45-50 km/h and maintains the same wind speed for at least a minute after hitting a region [3]. The meteorological observatory at Alipore (Kolkata) recorded the wind speed of April 1, 2018 nor'wester as 85 km/h blowing from the northwesterly direction while that for April 17, 2018 as 98 km/h. blowing from the same direction. As a typical record the wind direction of April 17, 2018 is shown in Fig. 1.

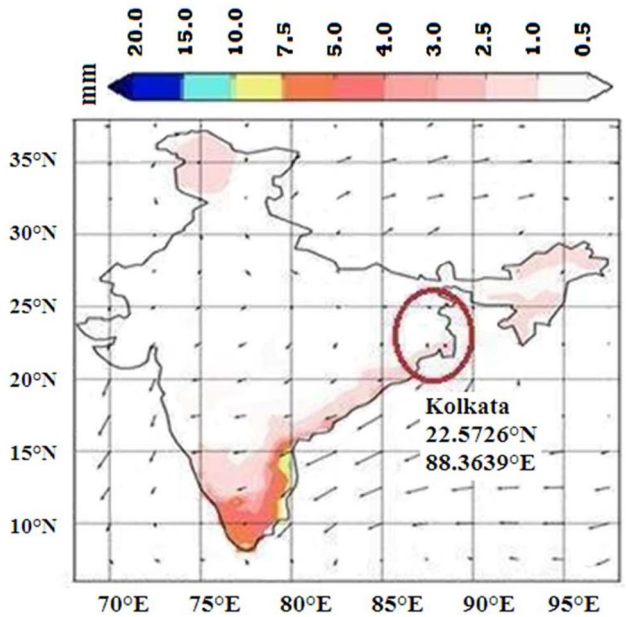

Fig. 1 Wind direction of April 17, 2018

The gusty winds accelerated the movement of the cloud mass in both the occasions and finally triggered the nor'westers. Also, exceptionally tall cloud column was formed owing to high vertical wind speed from the surface, but it started dissipating once it crossed Kolkata and moved towards the sea. Particulars of the two concerned nor'westers in April 2018 are given in Table 1.

For all calendar dates for the month of April 2018, we have plotted (Fig. 2) the surface temperature, considering the actual high, actual low, average high and average low values. Table 2 reveals high and low weather summary for April 2018 in Kolkata.

3 Doppler weather radar data

Doppler Weather Radar (DWR) operated at Kolkata generates pulses at 10 MHz has been used to get information about the pre-monsoon thunderstorms. The DWR plays a vital role in detecting and forecasting severe weather, as it can probe the atmosphere with very high spatial and temporal resolution. The DWR data are sampled on spherical coordinates (range, azimuth, and elevation) with a high resolution. Kolkata DWR observations showing the squall line and cloud top height during the peak activity of nor'westers as experienced on April 1, 2018 and April 17, 2018 are presented in Fig. 3a, b respectively. The vigorous squall activities for both the days are prominent in the figure. The heights of the cumulonimbus cloud were more than 18 km for both the occasion.

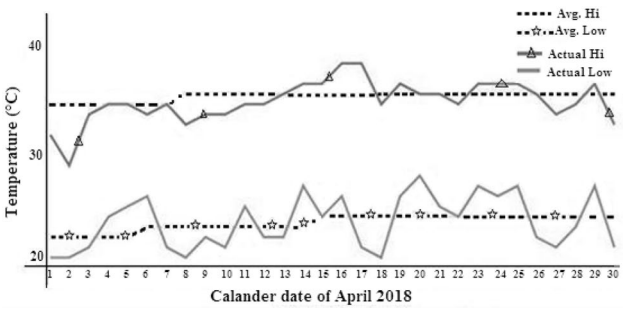

Fig. 2 Temperature graph for the month of April 2018

Table 1 Particulars of the two pre-monsoon thunderstorms in April 2018

Date	Onset time in IST	Offset time in IST	Duration in min	Speed in km/h initially	Speed in km/h	Duration of peak activity in min
01.04.2018	18:30	19:27	57	22	85	25
17.04.2018	18:55	19:50	55	35	98	20

Table 2 High and low weather summary for April 2018 in Kolkata

Onset date of nor'wester	High/low meteorological parameters	Temperature (°C)	Humidity (%)	Pressure (mbar)
01.04.2018	High	32	88	1008
	Low	20	65	1013
17.04. 2018	High	40	94	1004
	Low	23	33	1010

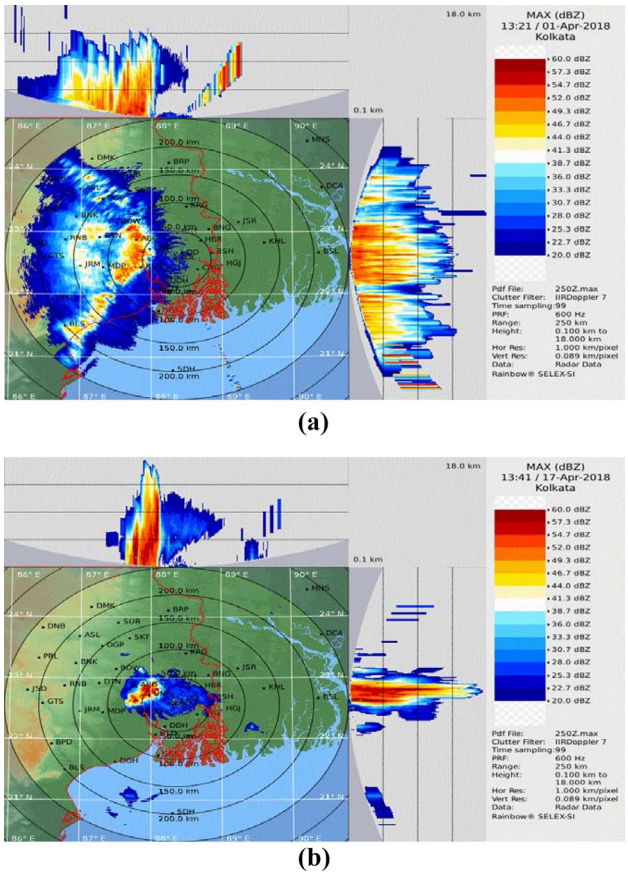

Fig. 3 Kolkata DWR observations of squall line and cloud top height during peak activity of nor'wester on **a** April 1, 2018 and **b** April 17, 2018

4 ELF/VLF noise measuring equipment and technique

Radio receiver used for recording sferics (alternately termed as atmospherics) both in ELF and VLF bands is shown by a block diagram in Fig. 4. The receiver is designed in a fashion so that it can be successfully used for a wide dynamic range [4]. The main sections of the receiving unit, viz, the signal generator, modulator, filter and the spectrum analyzers have illustrated in the figure through different blocks.

In this ELF/VLF noise measuring receiver, besides recording sferics signal in the respective bands, the arrangement for simultaneous audio recording arrangement can also be done.

In the electronic circuit of the receiver, the following labels are similar as 'nodes' and are also used in some interpreter functions for defining the source node:

L1: Left input from the in-phase component from a software defined radio
R1: Right input from a quadrature component from a software defined radio
L2: Output from the first DSP black box, etc.

Most of the connections and components in the receiving system may be altered (switched/activated/connected) just by clicking. Waveforms of the input and output signal can be magnified for the vertical and horizontal axes. In the unit, the spectrum analyzer has the provision to connect to both the audio input and output. It can be configured in a special setup screen, clicking into the analyzer block in the circuit window. The spectrum analyzer is designed in a manner so that at the output of it, the Fast Fourier Transform (FFT) can be visualized as spectrum graph or waterfall. Fast Fourier transform (FFT) is an algorithm to compute the discrete Fourier transform (DFT) of a sequence. In fact, our object is to utilize Fourier analysis for converting a signal from its original domain to a representation in the frequency domain.

The receiver employed for the purpose of receiving radio signal has the capacity to accommodate frequencies in both ELF and VLF bands. We have the freedom and accordingly in the ELF range we can choose frequency below 3 kHz and in VLF from 3 kHz onward up to 30 kHz.

5 Received noise characteristics in the ELF/VLF bands

The received spectral patterns of radiation when analyzed exhibit a close similarity in the characteristic changes. This is assumed to be happened corresponding to discharges associated with the pre-monsoon thunderstorms from the very beginning of the mature stages of thunderstorms

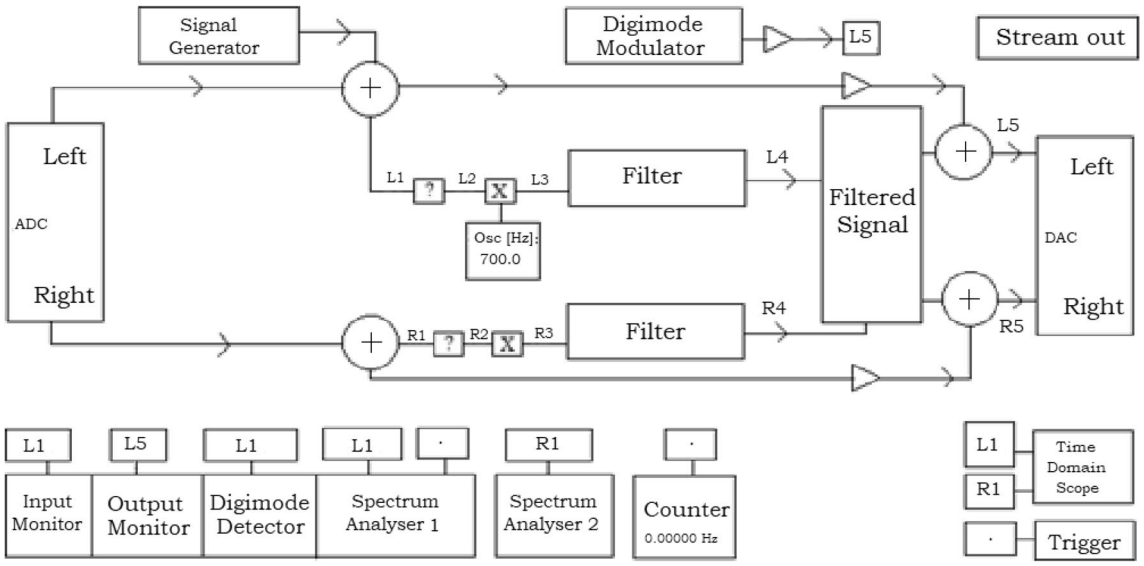

Fig. 4 Block diagram of main functions of the receiver [5]

when the leader stroke of the lightning propagates down from cloud-to-ground [6]. The similarities in the spectral pattern in the two concerned frequency bands imply that the discharge mechanism and the source activity have strong similarity for the two events. Spectral patterns of the field intensity of sferics on an undisturbed day (March 28, 2018) in the ELF and VLF bands have shown in Fig. 5. The figure shows that when the sky was clear and free from meteorological disturbances caused by pre-monsoon thunderstorms, the variation of the noise level is insignificant in the ELF to VLF range. The purpose of introducing Fig. 5 is mainly to compare the ELF/VLF signal pattern on an undisturbed clear day compared to the signal behaviors during the pre-monsoon thunderstorm days, as exhibited in Figs. 6 and 7. The marker position panel shows information about the source activity. The display on the cursor-panel depends on the display mode that can be switched by clicking on the frame.

We made round-the-clock record of the spectral pattern of sferics covering both ELF and VLF bands on the two dates of severe nor'westers, April 1, 2018 and April 17, 2018. The spectral behavior of the sferics has presented in Figs. 6 and 7 respectively. From a consideration of Figs. 6 and 7, a strong similarity in the spectral pattern is noted, indicating that both of them are originated from similar sources, viz. lightning discharges in the present case. However, the difference of the intensity level in dB is owing to the changes of the associated electromagnetic radiation and the source locations from the position of observing the received signal. The two records on both the dates of nor'westers exhibit a notable change in the intensity pattern when compared the ELF noise level with that of VLF. Early report by Kimpara [7], in fact, suggested that the integrated field intensity of sferics reveals a peak activity at about 10 kHz.

5.1 Simultaneous audio recordings

Besides receiving the spectral patterns of sferics, we have simultaneously made audio recording arrangement, which provided interesting findings that can be divided into three categories: (1) short bursts of radiation, may be called radio atmospherics [8], (2) reducing sound pitch, popularly identified as whistling atmospherics [9] and (3) an extremely high pitched tone, mainly utilized for sensing remote ionospheric disturbances [10].

6 Discussion

The most powerful source related to ELF/VLF waves is earth's environment, when the atmospheric lightning exhibits primary role. In remote sensing, the reflectivity of the ionospheric D-layer with ELF and VLF bands can be a rare weapon. In D-layer, out of many inputs, discharges owing to lightning may be considered as one of the very significant agents. It is worthy to note that any investigation on the D-layer is very difficult because the altitudes are very high for balloons and too low for satellites observations. The study becomes further complicated by the complex properties of the medium itself by which the radio waves are propagating through. As the ELF/VLF waves are assisting by both the earth and the ionosphere, we must consider the propagation properties of radio

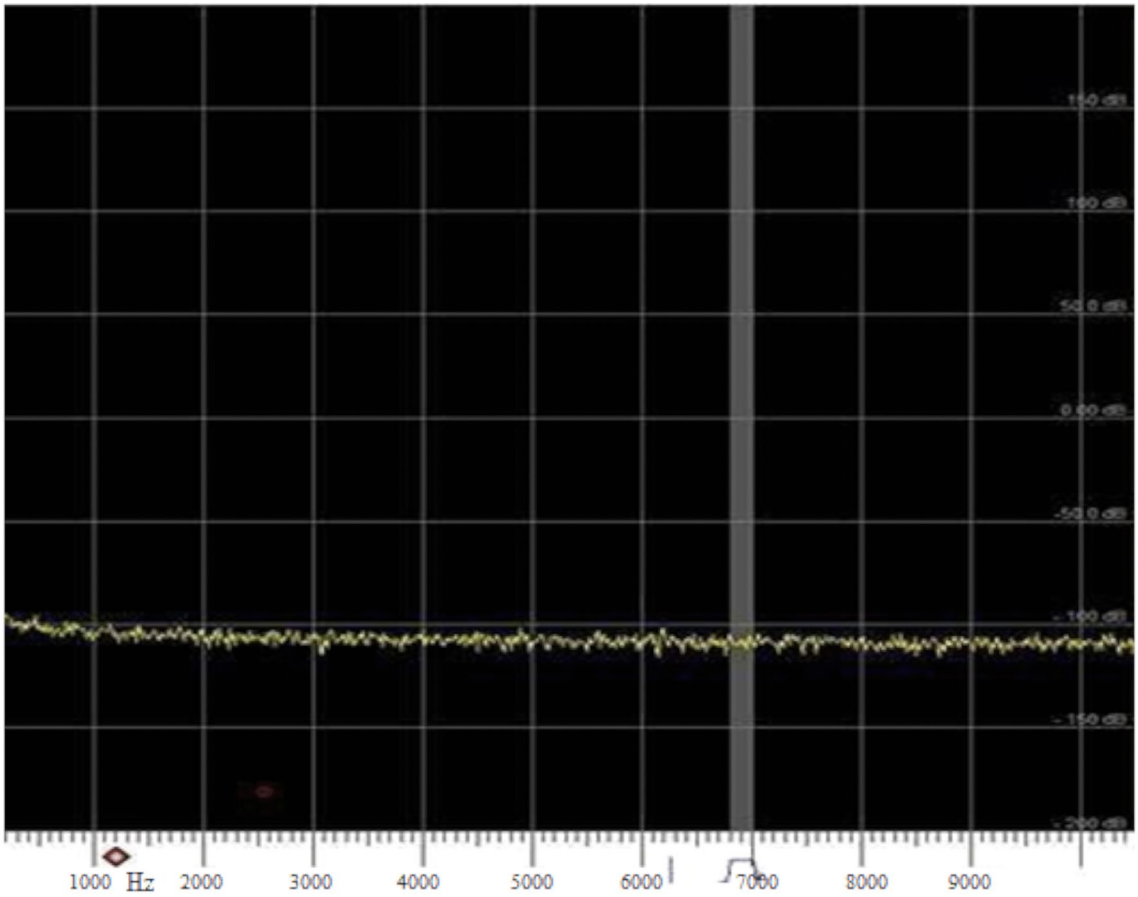

Fig. 5 Spectral pattern of the field intensity of sferics on an undisturbed day (March 28, 2018) in the ELF/VLF bands

waves which are originating from atmospheric lightning discharges. In pursuance of generating ELF/VLF waves, we need an antenna similar to a wavelength of 100 km with a frequency of 3 kHz. So, we require exploring an alternative method of ELF/VLF wave generation which uses the same currents to turn upper atmosphere into a big radiating aerial system [11]. In Fig. 8 we have shown the behavior of propagation of VLF waves compared to that of MF–HF waves as well as microwaves.

Electric field related to lightning is very difficult to measure as this involves putting instruments in a turbulent thundercloud. Because of this complexity, the radio signature of a lightning strike is detected by alternative means. Reception of ELF/VLF wave permits to find almost the exact location of majority discharges using a few numbers of ELF/VLF receivers scattered around [12]. Characteristics of average spectra reported due to electromagnetic radiation fields from some particular atmospheric lightning events. These are usually concerned on preliminary breakdown processes downward negative stepped- and dart-leaders return strokes in cloud-to-ground lightning cg and also for intra-cloud lightning i.e. flashes besides upward positive leaders in artificially triggered lightning flashes [13]. The spectral patterns obtained from lightning discharges are mainly by the Fourier transformation of wideband records of electric fields obtaining from lightning. The similarities in spectral pattern of two frequency ranges for two concerned nor'westers related atmospheric lightning events implies that these events have common discharge mechanisms.

We now compare some other related observations taken in recent years using the ELF/VLF radiation sources. It has been reported that ELF noise appears almost similar to Gaussian distribution associated with occasional impulses while, on the other hand, VLF noise shows more impulsive characteristics [9]. The observations further permit modeling of wideband ELF/VLF communication performances, providing improved knowledge of the behavior of natural background noise. Mezentsev et al. [14] compared the energy spectra of sferics in the very low frequency band and modeled radio emissions from terrestrial gamma ray flashes (TGFs) simultaneous with the recorded VLF sferics. It was noted that the VLF energy spectra are consistent with the observed VLF sferics whose waveforms and

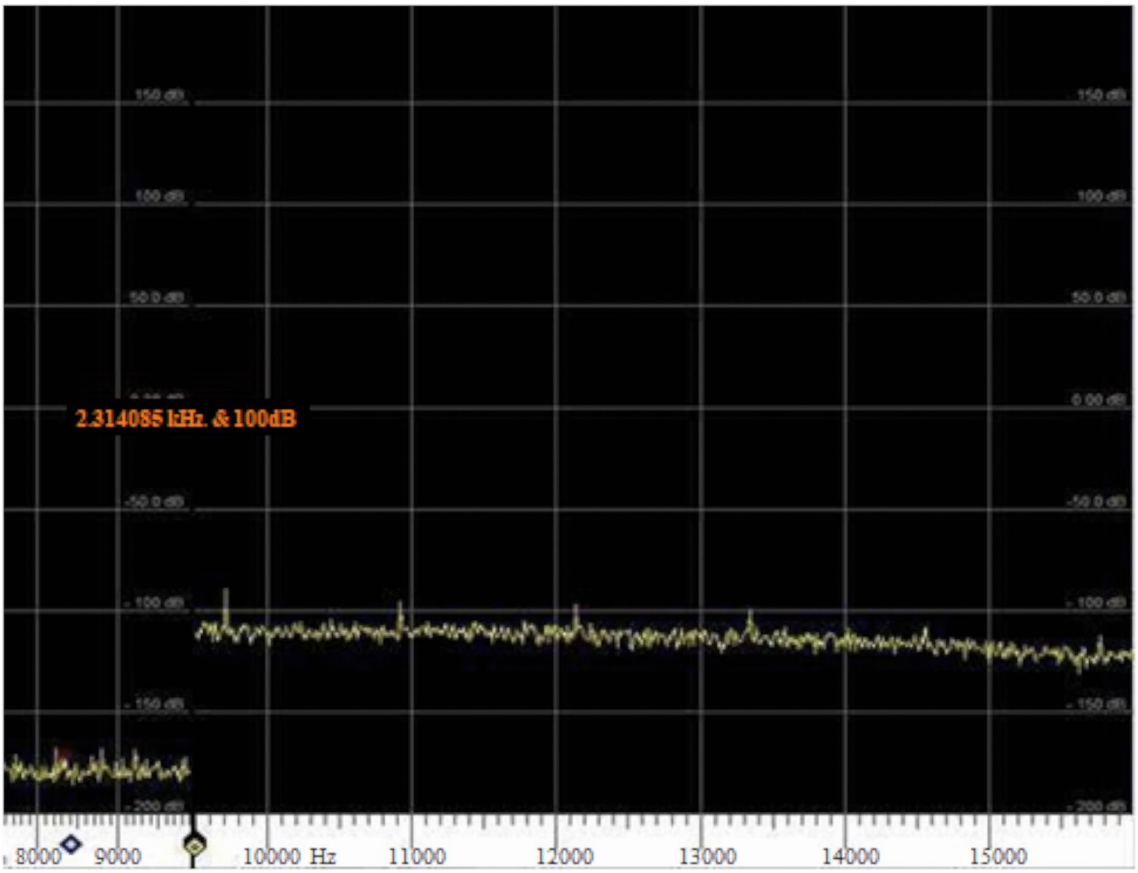

Fig. 6 Sample records of the spectral pattern of the field intensity of sferics in the ELF/VLF bands on April 1, 2018

spectra refer clearly to a double-pulse structure. From the study the authors established a link between TGF duration and the VLF cut off frequency in the energy spectrum of TGF radio emission. Very recently, Yang et al. [15] compared the frequency characteristics of the excited ELF/VLF radiation sources in the amplitude modulated (AM) and dual-beam beat-wave (BW) modes. Their analysis reveals that in the AM mode, the amplitude of the ELF/VLF signal diminishes as the radiation frequency increases while in the BW mode the overall amplitude of the signal enhances with the radiation frequency.

7 Conclusions

The effect of radio wave propagation and the activity of the sources wherefrom the sferics originate have shown interesting results when received in the ELF and VLF bands simultaneously. For investigating the characteristics of tropical nor'westers, we have made multi technique studies which include some meteorological parameters like wind speed, temperature, humidity and pressure. More parameters need to include giving priority to simultaneous directional observations. Injection of ELF/VLF signals into magnetosphere can lead to many physical phenomena, particularly, when these waves interact with the radiation belt particles [16]. The signals transmitted may act as a diagnostic of the lower ionosphere, as the propagation of the radio signal at very long distances depends on ionospheric reflection. When a signal is transmitted from a satellite to the ground or vice versa, it must pass through the ionosphere. As the lower part of the ionosphere, changes rapidly during the sunset hours, ELF/VLF waves can provide us a very reliable and continuous means of monitoring the lower ionosphere and hence inferring communications outages which can be monitored by gamma ray bursts [17, 18].

Scientists and engineers at different parts of the globe are seriously thinking over the years about the EM waves generated from lightning is possible to be harvested. Harvesting electrical energy from lightning is still a major challenge as it has yet very difficult to predict the exact location where lightning strike will occur. A comparatively simple technique, as a first step, might be the direct harvesting of atmospheric charges but again to collect a considerable amount of energy very large constructions are

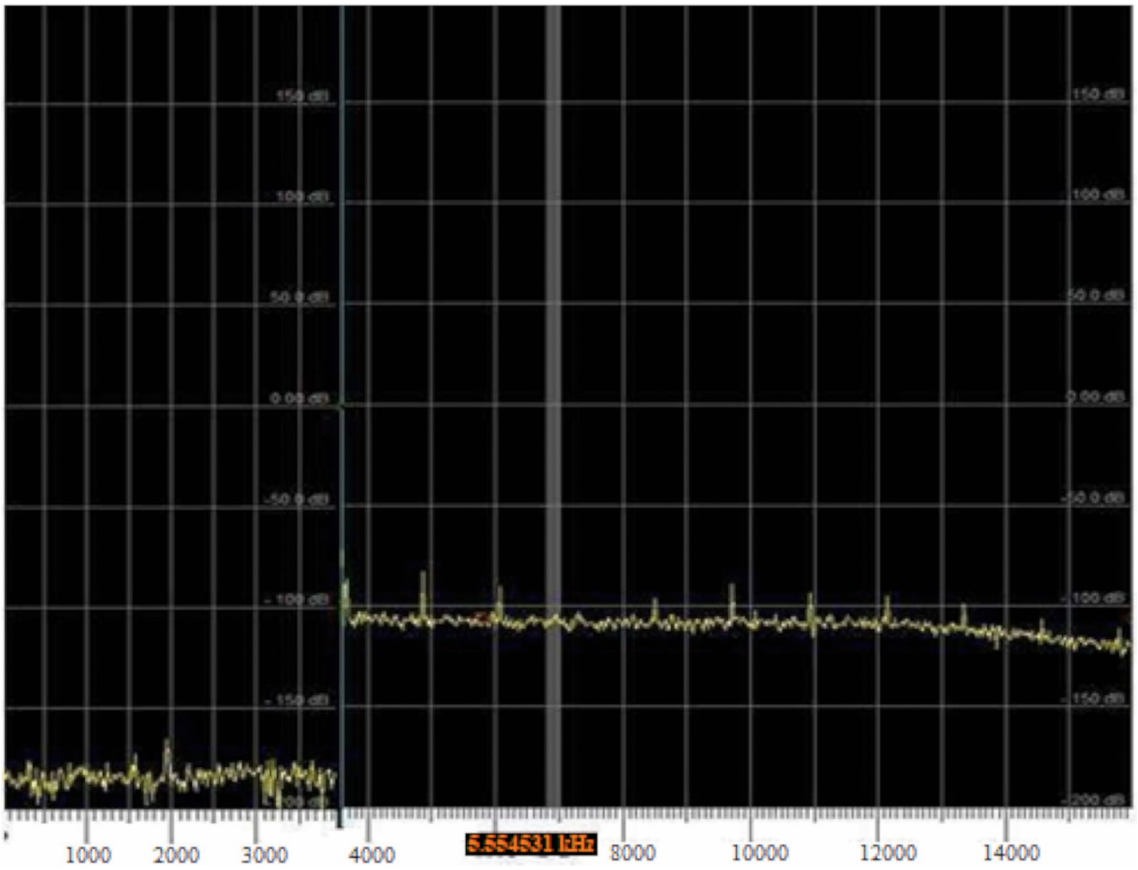

Fig. 7 Sample records of the spectral pattern of field intensity of sferics in the ELF/VLF bands on April 17, 2018

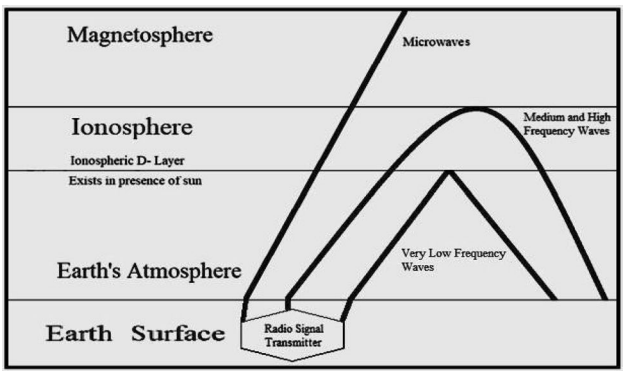

Fig. 8 Propagation of VLF waves compared to MF–HF waves and microwaves

essential which is relatively hard for utilizing efficiently the high voltage so obtained.

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Compliance with ethical standards

Conflict of interest The authors declare that they have no competing interests.

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