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Study of pre-monsoon thunderstorms over Kalyani from radio frequency spectra

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Lightning in the form of electromagnetic radiation, in very low frequency (VLF) and low frequency (LF) bands, is received on 1 April and 7 April 2015 from 10 kHz to 300 kHz over Kalyani during pre-monsoon thunderstorms. Their characteristics, viz. the spectral pattern and other relevant properties, are examined with the help of radio frequency (RF) spectra. Another severe thunderstorm experienced, over a wide area covering different parts of South Bengal including Kalyani, on 11 April 2013 has also been recorded in the form of integrated field intensity of atmospherics at 27 kHz receiver. After analysing, some interesting results are reported related to radio signal reception originating from lightning as electromagnetic radiation.

Keywords: Lightning, Thunderstorm squall, Radio wave propagation

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1 Introduction

According to the India Meteorological Department classification of the year into seasons, the three months - March, April and May of the year constitute the 'hot weather period' and is called the pre-monsoon season[1]. During this hot weather period, the eastern and north-eastern states of the subcontinent, like West Bengal, Bihar, Assam, Odisha (parts) and Bangladesh, experience dramatic appearance of a special type of violent thunderstorm known as Nor'wester. In India, pre-monsoon is the warmest season of the year and referred as the hot weather season[2]. The hot weather period is familiar for its intense convective activity over land areas. Thunderstorm as a whole is a very vast subject and a significant amount of work has been done in this field during the past few decades[2,3]. The various aspects of the subject include the physics of the thunderstorms, its structure, synoptic and climatological aspects, radar and satellite studies, etc. Thunderstorm is a natural phenomenon and has socio-economic impact. In the pre-monsoon period (Mar-May), thunderstorm is of great concern in the Gangatic plains of South Bengal. It has adverse effects on the inhabitants, whenever it becomes severe. During the pre-monsoon months, the eastern and north-eastern parts of India that include Gangatic West Bengal, Assam, Odisha are affected by high frequency of severe thunderstorms. The West Bengal state is subdivided into two major zones, viz. the North Bengal and the South Bengal[4]. The present observational site at Kalyani (22.97°N, 88.43°E) lies in South Bengal and is at a distance of about 150 km from the Bay of Bengal. The information and physics associated with the Nor'westers of Bengal have been investigated from time to time but the knowledge gathered is yet scanty and therefore, demands further study using latest improved techniques and instruments. In this paper, studies on pre-monsoon thunderstorms, experienced in South Bengal in two different years and recorded as electromagnetic radiation in the laboratory at Kalyani, have been made.

2 Experimental setup and Techniques implemented

The pre-monsoon thunderstorms on 1 April and 7 April 2015 were monitored and recorded. The experimental setup used included Log-periodic Dipole Array (LPDA), Spectrum Analyzer and Digital Storage Oscilloscope (DSO). The setup was arranged for capturing the radio signals originating from lightning discharges in the VLF and LF bands.

The wind-proof time-shared LPDA, constructed at Kalyani for receiving radio signals (emitted during disturbed condition of the atmosphere), is used to

investigate its plasma behaviour. In fact, the log-periodic antenna, constructed at Kalyani, has the capability to prevent possible damages owing to high speed air movements even during the days of Nor'westers. Digital Storage Oscilloscope (DSO) of GDS-1000 series as well as the Spectrum Analyzer are used for recording. Low Noise Amplifier (LNA) is used to amplify very weak signals captured by LPDA. In the present system, two low noise amplifiers are used to amplify the received signal through the amplifier, which is fed for connecting the master computer. The arrangement of the receiving system is shown in Fig. 1.

3 Characteristic power spectra in VLF and LF bands

Characteristic average power spectra corresponding to different frequency intervals in the VLF and LF bands from 10 kHz to 300 kHz are considered for electromagnetic radiation fields originating from some specific lightning events related to preliminary breakdown processes, downward stepped and dart-leaders, and return strokes. The spectra are obtained by a spectrum analyzer used for recoding the output of the receiving system connected to the antenna through low noise amplifier. The spectral patterns when analyzed reveal very interesting results. A close similarity in the spectral patterns has been observed in the two frequency bands chosen for recording the data. Some typical records are shown in Fig. 2 to justify the similarity in the records. In course of the present observations, recording of the data started from 10 kHz and continued at all harmonically related frequencies up to 300 kHz. The mean spectral patterns for all those frequencies are then taken into analysis by plotting the noise level corresponding to different frequencies. This is presented in Fig. 3, which clearly reveals a fall of the intensity level as frequency increases. With a view to verify the frequency *vs* mean power of the noise level, the spectral data taken on the day of another similar occasion of pre-monsoon thunderstorm on 7 April 2015 is plotted. Supporting the earlier findings, the spectral data shows the same pattern. The frequency versus noise level plot, thus, confirms the existing knowledge of frequency-intensity behaviour due to electromagnetic signal propagation during lightning.

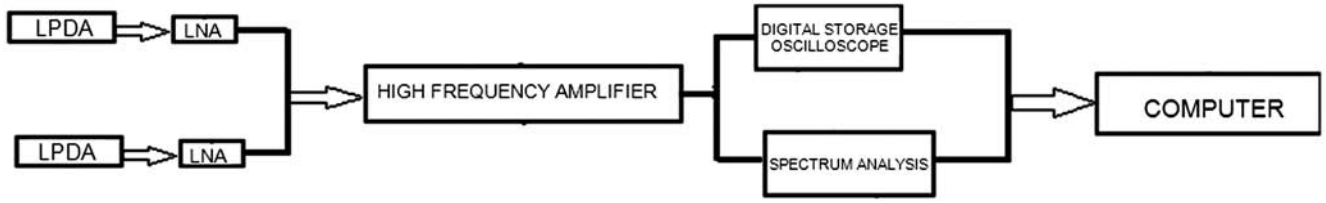

Fig. 1 — Arrangement of the receiving system

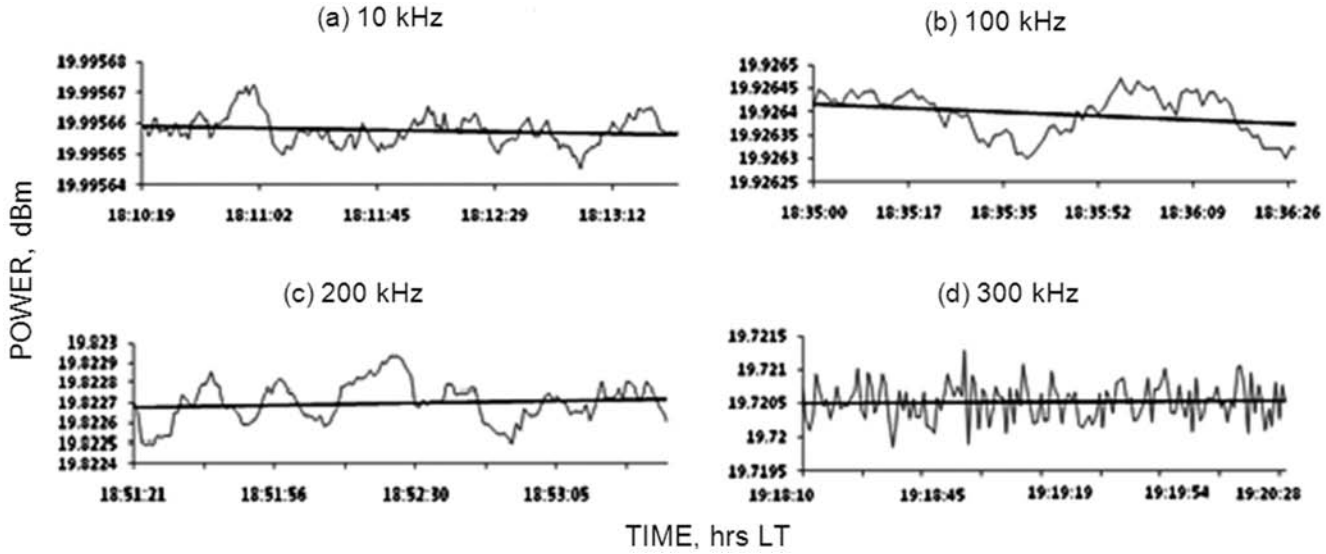

Fig. 2 — Some typical records of the spectral pattern at 10 kHz, 100 kHz, 200 kHz and 300 kHz

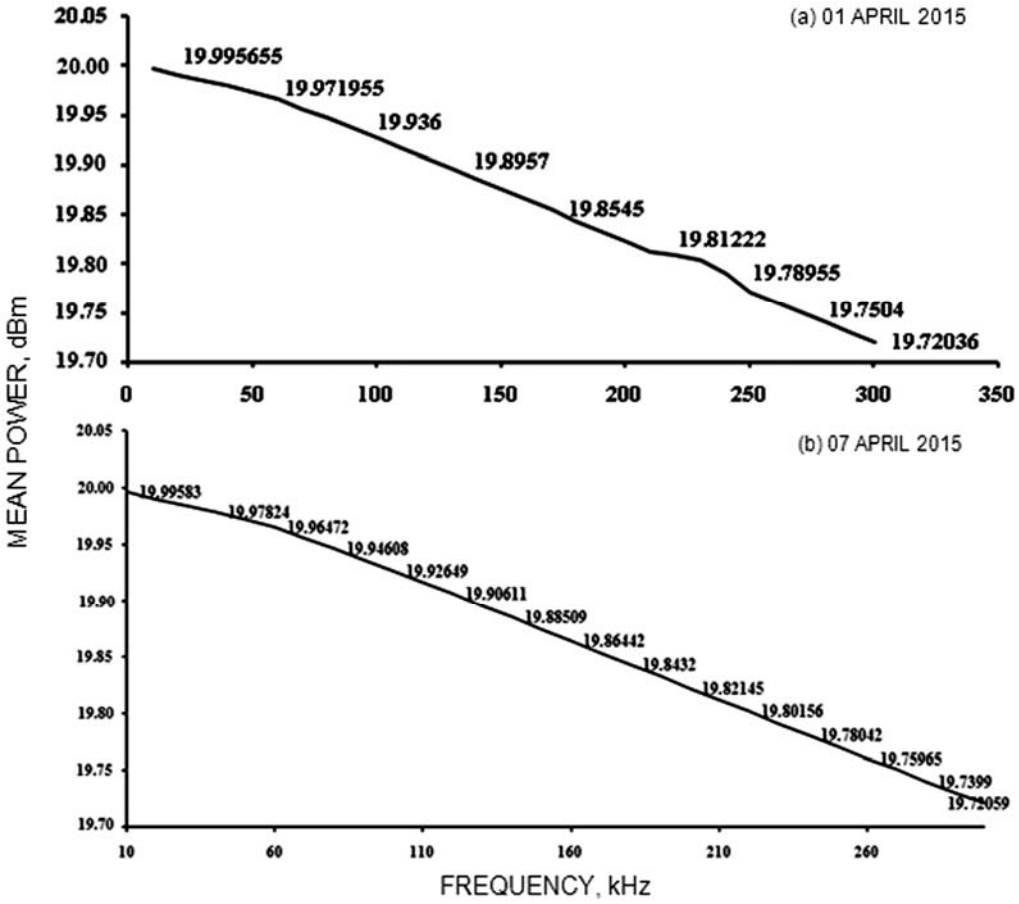

Fig. 3 — Frequency *vs* mean power of the noise level on: (a) 1 April 2015; and (b) 7 April 2015

4 Squall of 11 April 2013

A thunderstorm and a light drizzle hit Kolkata and a major part of southern Bengal on evening of 11 April 2013. Before the formation of this evening squall, last four days were excruciating and the heat was unbearable. The accompanied rain was caused by a trough of low pressure stretching from sub-Himalayan Bengal and Sikkim to the North coast of Andhra Pradesh across Gangetic Bengal and Odisha. The squall of 11 April 2013 did not last long at Kalyani; it remained for about 25 minutes only but over Kolkata, the activity of the storm was severe. The squall originated in Odisha because of the trough of low pressure and then blew over the Southern Bengal.

4.1 Atmospherics record during the Nor'wester

The atmospherics are significant with regard to electrical phenomena in different types of cloud during meteorologically active periods. Measurements of Integrated Field Intensity of Atmospherics (IFIA) are expected to provide different features for the study of ionospheric propagation[5]. IFIA is the resultant of a large number of individual impulses due to lightning. The impulses numbering several thousand per second and can be received directly as well as by reflection from the ionospheric layers by the sensitive receiver. IFIA at Kalyani is being recording round-the-clock over the years. The receiver employed for the present observation at 27 kHz is designed and constructed in the laboratory in such a manner so that it can successfully handle variations of field intensities originated from meteorological disturbances over a wide range. It can also be used for investigating the sudden enhancement of atmospherics (SEA) or sudden absorption of atmospherics (SAA) associated with solar flares. The unit has tuned stages followed by a detector and DC amplifier, which in turn feed the recorder. The type of antenna used with the receiver is governed by the nature of polarization of the signal to be received and also occasionally by the direction of arrival of the wave while the dimension of the antenna with horizontal part 30 ft and vertical part 10 ft largely depends on the wavelengths, the ratio of the

signal picked up by the antenna to the inherent receiver noise. The polarization of the atmospheric field is mainly vertical in the designated frequency range. In the present observation, an inverted-L antenna is used whose vertical part would receive this field with an omni-directional azimuthal pattern. The function of the horizontal part is simply to add to the top capacitance of the antenna causing an increase of current to the vertical part.

The field intensity of atmospherics on an undisturbed day shows a regular variation. Figure 4 shows an atmospherics record of the laboratory at Kalyani on 10 April 2013, a day before the date of the concerned Nor'wester. When daytime and nighttime atmospherics levels are considered, it is found from the figure that the nighttime atmospherics level is higher than that at daytime. In absence of the D-layer during night hours, the electromagnetic signal propagation becomes better when the E-layer is the main contributor in its propagation. With the sunset, i.e. with the disappearance of the D-layer, an enhancement in the signal level is found.

Figure 5, on the other hand, exhibits the present record of field intensity of atmospherics during the pre-monsoon squall of 11 April 2013. In the figure, GRA is Gradual rise of atmospherics; SEA_1, first sudden enhancement of atmospherics; SEA_2, second sudden enhancement of atmospherics; SRA_1, first steady recovery of atmospherics; and SRA_2, second steady recovery of atmospherics. The atmospherics record reveal that during Nor'wester, the enhancement of the level occurs in three different stages, GRA, SEA_1 and SEA_2 while the steady recovery following the sudden enhancements occurs

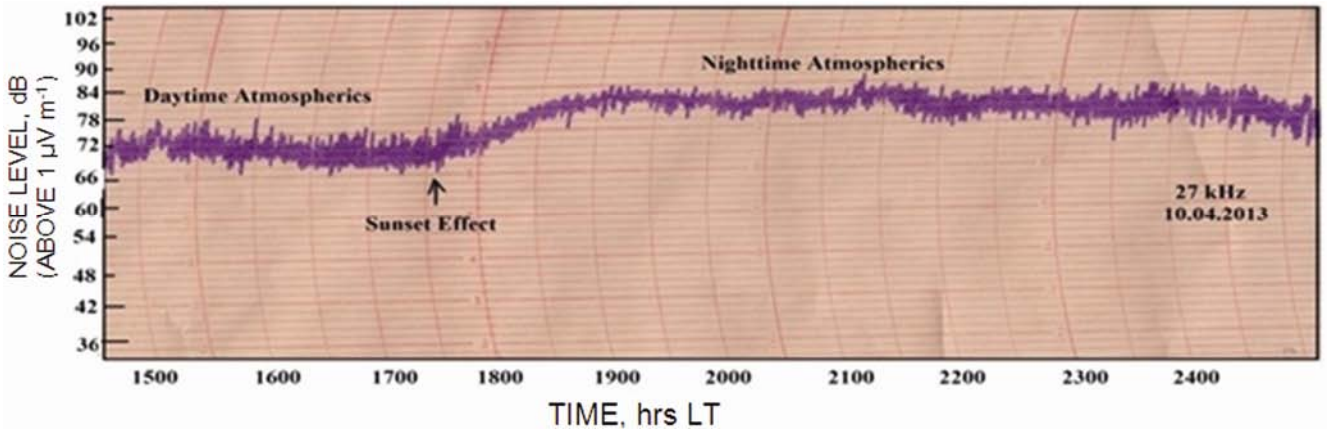

Fig. 4 — Regular behaviour of integrated field intensity of atmospherics at 27 kHz on an undisturbed day

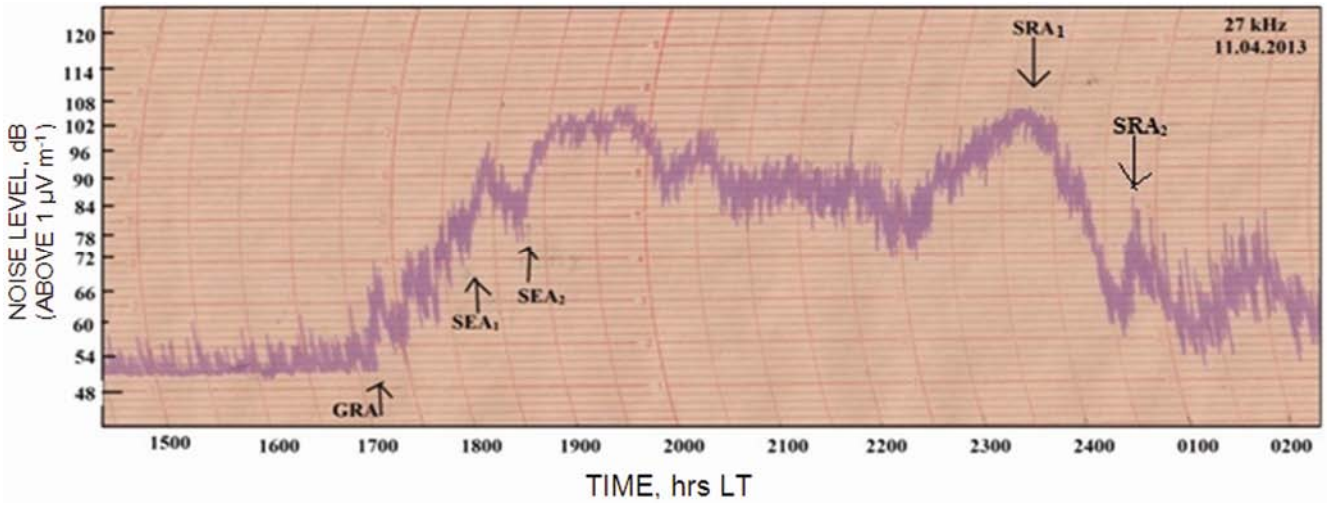

Fig. 5 — Integrated field intensity of atmospherics during the pre-monsoon squall [GRA: gradual rise of atmospherics; SEA_1: first sudden enhancement of atmospherics, SEA_2: second sudden enhancement of atmospherics, SRA: steady recovery of atmospherics]

in two stages, SRA_1 and SRA_2. F is assumed to be associated with the developing, mature and dissipating stages of the concerned thunderstorm.

5 Discussion

The Nor'wester, a low bank of dark cloud in the north-west, approaches at first slowly and then more and more rapidly with a strong squall and characterizing frequent thunder and lightning followed by down pour of rain. The thunderstorms occur in association with cumulonimbus (CB) clouds[6]. The occurrence of a Nor'wester over the area is mainly due to the lower level moisture flow from the Bay of Bengal. Meteorological investigations reported that during the summer months, there is normally moist southerly air in the lower levels over Bengal and dry westerly or northwesterly air in the upper levels. In between the moist and dry air mass, there remains an isothermal region or region of contrast. The distribution of air masses gives rise to the conditions of latent instability over Bengal in summer months. From the upper air observation, it has been further reported that this instability is always manifested but may exist in a latent state, which only needs an impulse known as 'trigger action' for the energy to be released with great violence, in general. The released heated moist air goes higher up in order to produce thick CB or thunder cloud. The gradual rise of atmospherics as noted in the round-the-clock record of IFIA is assumed to be associated with the development of early stages of thunderclouds[7]. When it forms a full fledged thunderstorm, i.e. getting the mature stage, a sudden enhancement in the atmospherics record is produced while during the dissipating stage, a gradual fall in the record can be seen. Once a thunderstorm occurs due to insolation acting as trigger, the cold air from primary thunderstorm can spread in the direction, generally, from north westerly to south easterly direction and Nor'westers can start as the cold air moves forward. In this way, a number of thunderstorms can be produced with a time sequence in course of the occurrence of Nor'westers.

In an early study of thunder squalls at Kolkata, it was found that majority of the pre-monsoon thunderstorms are originated from Hazaribagh and Asansol area[8] and their speed of travel is found to be 50 - 60 km h^{-1}. A well documented case of a positive cloud-to-ground flash shows that the pulses observed in the electric field preceding the return stroke are due solely to the upward propagation of a negative

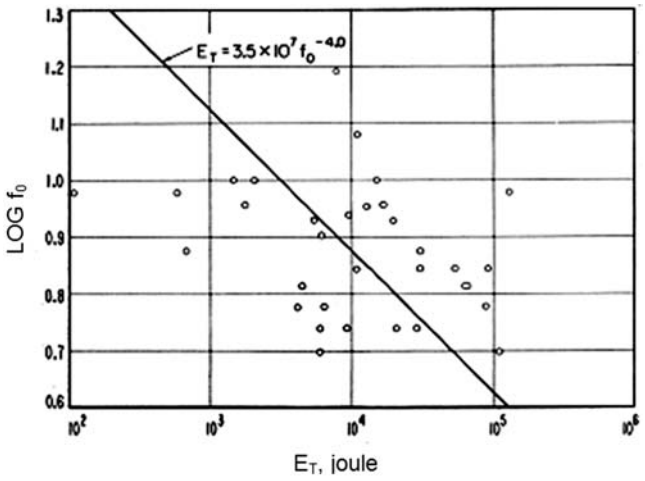

Fig.6 — Frequency of spectral peak *vs* total radiated energy [*Source*: Taylor & Jean, *J Res Natl Bur Stand-D. Radio Propag (USA)*, 63D (1959) 199]

connecting leader[9]. Bipolar lightning is usually defined as a lightning flash where the current waveform exhibits a polarity reversal[10]. The most striking anomaly recorded in the observation of 1 April 2015 storm is that though the aerial distance of Kolkata is not too far from Kalyani, yet Kolkata was apparently clear and sunny in some parts while the vigorous charge activity followed by torrential and incessant rainfall was experienced at Kalyani appearing something extraordinary in behaviour.

During the severe atmospheric condition owing to the localized cloud activity, the atmospherics intensity level attains a higher value; while with the disappearances of clouds, the level comes down to its earlier scale[8]. The variation characteristics as recorded in Fig. 5 may be assumed to originate from sources of lightning discharges associated with the Nor'wester and the propagation involved in producing the typical pattern of atmospherics noted. In fact, the variations in the noise level appears to be related to the cumulonimbus cloud formed and subsequently producing the thunderstorm that covers the developing, mature and dissipating stages[9,11].

In the present analysis, the intensity versus frequency of the radiation (Fig. 3) is examined, which clearly exhibits a fall of the intensity level with frequency. This is also supported by early observations of Taylor & Jean[12] who analyzed the frequency (f_0) of spectral peak versus total radiated energy (E_T). They showed a clear relationship between the frequency of spectral peak and the total radiated energy as given in Fig. 6. Although in the figure they plotted, the data points are scattered but

there is a slight tendency for the more energetic sferics to attain energy peaks at the lower frequencies.

6 Conclusion

VLF or LF sferics are mainly produced during cloud to ground (CG) lightning discharges[13]. It is complicated to investigate the characteristics of ionospheric D-region owing to low electron densities ($\sim 10^9$ m^{-3}) and high electron-neutral collision frequencies ($\sim 10^6$ s^{-1}). However, as the VLF waves are reflected from the D-layer of the ionosphere, these waves may be treated as a tool for exploring information regarding the layer[14,15]. Study with tweeks to examine the D-region properties of ionosphere is a subject of great interest and in fact, have been performed by many researchers[16-19]. A simultaneous study of spectral pattern proposed in the present observation during severe disturbances may provide further insight in this field.

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