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AILA-2009: Its Effects on VLF IFIA and Probable Scientific Explanation

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Abstract. Remarkable effects of severe electrical activity of a thunderstorm (AILA) have been observed on May 25, 2009 on the records on Integrated Field Intensity of Atmospherics (IFIA) at frequencies 3 kHz and 9 kHz over Kolkata (latitude: 22.56°N, longitude: 88.5°E). It was followed by severe thundershowers and lightning. The outcome of scientific evaluation of the recorded data along with some other specific characteristics will be presented in this paper.

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1 Introduction

On the continents, the lightning discharges are observed in near equatorial zones. The electromagnetic signals from lightning discharges are called atmospherics or sferics. Lightning signals are spread out along the Earth-ionosphere waveguide. The world data about lightning discharges are used for the study of weather prediction, storms, cyclones, tsunami and other irregular as well as complicated weather phenomena [1-6].

The Fourier spectrum of atmospherics extends from extra low frequency (ELF) to high frequency (HF). The contribution is mostly from very low frequency (VLF) band. During severe thunderstorms, contribution to the radiation field from VLF band is greatly remarkable. Enormous investigations appeared during the past several decades suggesting solar-terrestrial relationship in atmospheric electricity.

The sferics are very much significant in regard to electrical phenomenon in different types of clouds during meteorologically active periods. At Kolkata, we are in privileged position to study Atmospheric Radio Noise Field Strength (ARNFS) from the local cloud discharge as well as from the distant sources from Australia, Japan and Africa. The variation of electric field ΔE can be expressed in Fourier transform as

$$\Delta E(d,t) = \int a(d,\nu)\exp(i\nu t)\mathrm{d}\nu,$$

where

$$a(d,\nu) = \int \Delta E(d,t)\exp(-i\nu t)\mathrm{d}t$$

gives the amplitude of Fourier component due to electric lightning pulse at a distance d. Experimental observations revealed that the peaks of the Fourier components would lie in the VLF range. The ELF component, though smaller in magnitude compared to VLF component, exhibits appreciable variations in dB scale during thunderstorms. The received Fourier component at frequency ν at a distance d can be expressed as

$$a(d,\nu) = G(\nu)W(d,\nu),$$

where $G(\nu)$ is the spectral source function and $W(d,\nu)$ is the waveguide transmission function. $W(d,\nu)$ is dependent on the ionospheric conductivity parameter which is again dependent on electron density. Any variation in source function will result in variation in the received IFIA. In the Department of Radio Physics and Electronics, Calcutta University, we have developed a permanent set-up for monitoring ELF-VLF sferics.

There is no broadcast transmitter in the ELF-VLF range between 50 Hz and 10 kHz. If the receiver is placed well away from unintentional short range electromagnetic interference, such as electrical power lines and electrical machinery, the spectrum is dominated largely by electromagnetic radiation from cloud discharge. Also, no work has yet been reported on IFIA during large thunderstorms over Bay of Bengal.

In the area of atmospheric electricity, we are taking continuous records of ELF-VLF IFIA at frequencies 3 kHz and 9 kHz from Kolkata (latitude: 22.56°N, longitude: 88.5°E) to detect and interpret different solar and geophysical events. Important works on the variation of air-temperature, electric field, air-earth current and conductivity over the surface of the Earth at tropical latitudes ($\pm 25°$) and temperate latitudes ($\pm 60°$) during the fair-weather and also under disturbed conditions and their interrelation with the solar radiations, global thunderstorm activities as well as with the concentration and nature of aerosol content in the lower atmosphere are being carried out [7-12].

Maximum potential intensity of tropical cyclones is estimated through thermodynamic modelling works [13-16]. The characteristics of cyclone as well as the distribution of the epicenters of cyclones are being determined through the recording of electromagnetic radiation of thunderstorm discharges by VLF receiver systems at Kamchatka [17,18].

A strong thunderstorm front passed over the Northern part of Bay of Bengal during May 23-26, 2009. Strong lightning discharges had been observed visually in Kolkata [6]. On May 25, 2009, remarkable signatures upon the sferics were detected due to severe cyclonic storm, AILA, followed by deep thundershowers and lightning.

This work deals with the investigations of the effects of the ocean on cyclone development and on the morphological structure of IFIA during intense occurrence of cyclone. Nature of IFIA in relation to tropical cyclone is also considered. We compare the morphological structure of IFIA during AILA with those during other kind of thunderstorms, viz., pre-monsoon, monsoon and post-monsoon thunderstorms. Some specific characteristics about the very large enhancements of the IFIA have been discussed. The results of analyses and scientific explanation of the observed effects on sferics at frequencies 3 kHz and 9 kHz recorded from Kolkata on the event of this AILA are being reported.

2 General Features of AILA

AILA, a severe cyclonic storm, crossed over Kolkata on May 25, 2009, at about 1430 hrs IST. Due to South-West monsoon over the Bay of Bengal, the horizontal pressure gradient, North-South wind gradient and relative vorticity were increased. It developed upper air-cyclonic circulation which extended up to mid-tropospheric level and became associated with convective cloud cluster. Low pressure area formed over the said region due to the influence of cyclonic circulation. It transformed into a depression that intensified to a deeper one. The system moved along the Northerly direction and converted to cyclonic storm. This signature was further increased to form AILA.

AILA was detected and tracked by Conventional Cyclone Detection Radar (CDR) at Paradip and Doppler Weather Radar (DWR) at Kolkata. INSAT, METEOSAT, WINDSAT satellites monitored the phenomenon AILA. Cyclonic low level circulation formed on May 21, 2009 at 0830 hrs IST over Bay of Bengal (latitude: 16.5°N, longitude: 88.0°E) at a distance of 600 km from Sagar Island. INSAT image for severe cyclone is shown in Figure 1. On the next day morning, the area maintained low pressure. The system started to move in Northward direction, became strengthened which formed depression on May 23, 2009 at 1130 hrs IST and gradually became further intensified during its propagation. It then changed to a deep depression and converted to a cyclonic storm at latitude: 18.5°N, longitude: 88.5°E on May 24, 2009 at 1730 hrs IST accompanied by severe thunderstorm, lightning, wind shear, turbulence, rainfall and other meteorological outcomes. This severe cyclonic storm (AILA) that happened near Sagar Island (latitude: 21.5°N, longitude: 88.0°E) on May 25, 2009 at 1130 hrs

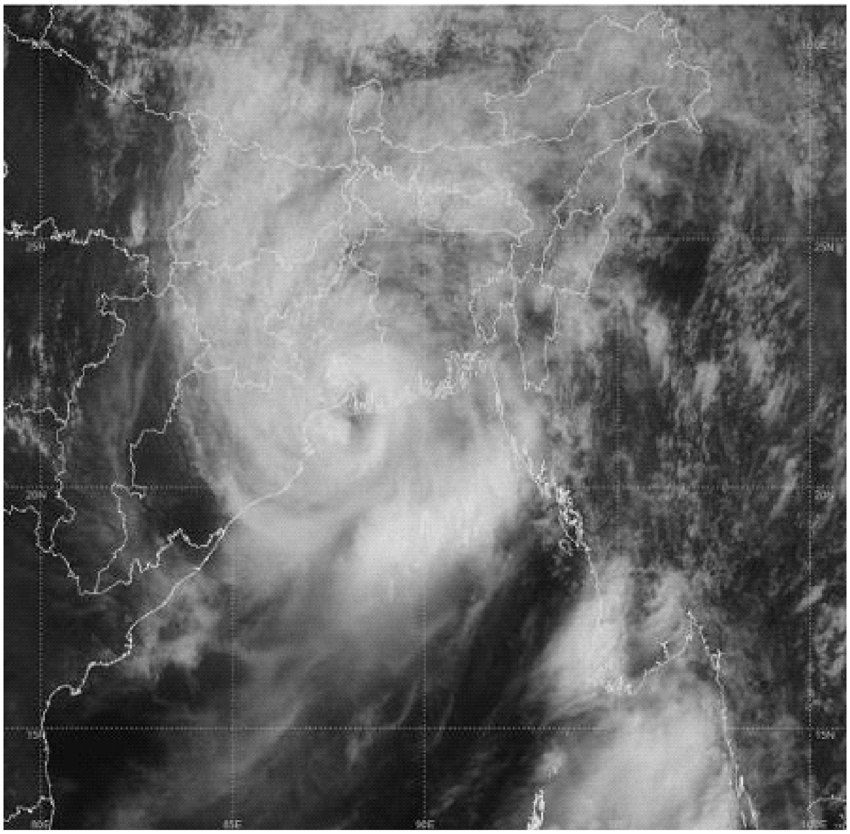

Figure 1. INSAT image for Severe Cyclonic Storm (AILA).
Courtesy: www.imd.gov.in/section/nhac/dynamic/AILA.pdf

IST crossed over Sagar Island on May 25, 2009 at around 1330 to 1430 hrs IST. INSAT image during landfall of AILA is depicted in Figure 2. It then slowly diminished, converted into cyclonic storm at the Gangetic West Bengal, close to Kolkata, on May 25, 2009 at 2030 hrs IST. It crossed Kolkata with wind speed 100 to 110 km/h along with strong lightning. It continued with strong and vigorous exposition. Deep depression developed on May 26, 2009 at 0830 hrs IST over Sub-Himalayan West Bengal and Sikkim, followed by depression at 1130 hrs IST near Bagdogra, developing low pressure at the Sub-Himalayan and neighbourhood regions on May 27, 2009 at around 1430 hrs IST. INSAT measured the intensity of the cyclone at different locations during its movement in terms of T number. It changed from a value of T1.0 to a maximum value T3.5 at the time of severe cyclonic storm occurred on May 25, 2009 at 1130 hrs IST. METEOSAT and WINDSAT measured the wind shear of the storm. The for-

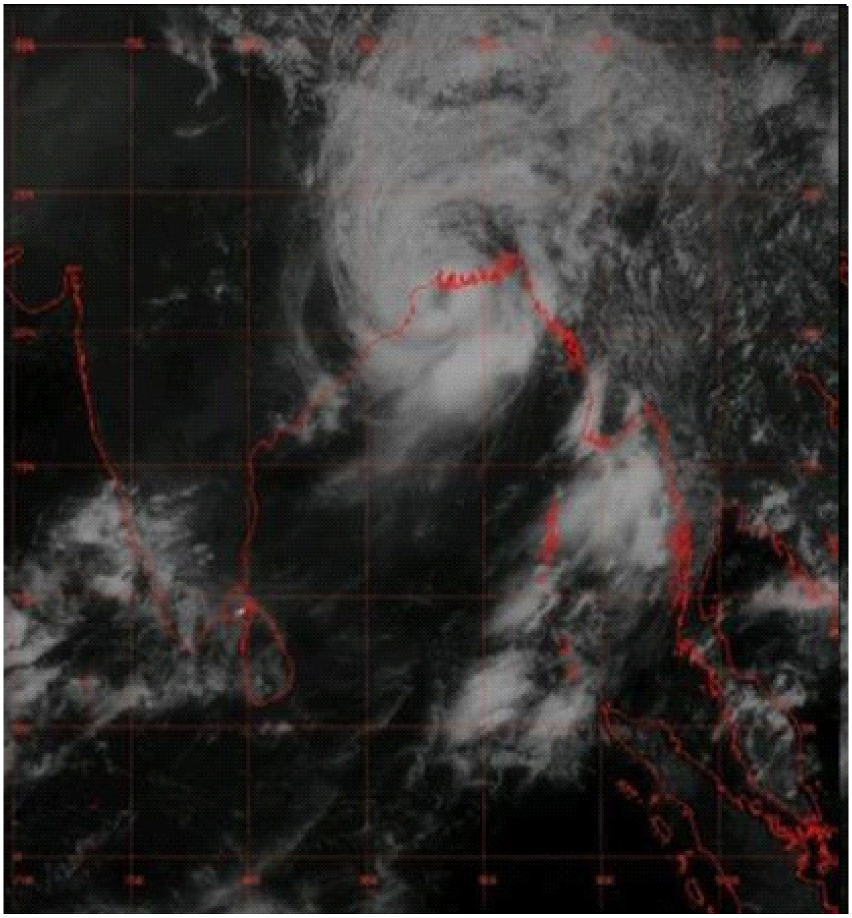

Figure 2. INSAT image during landfall of AILA.
Courtesy: www.imd.gov.in/section/nhac/dynamic/AILA.pdf

mer showed the value of wind shear on May 23, 2009 ($\sim$ 10–20 knot), whereas the later measured the value ($\sim$ 25–30 knot) at the same time. Strong Southerly surge of the monsoon current led the wind speed relatively stronger in the South-East sectors. METEOSAT measured the sea surface temperature (SST) as about 28°C, which was about 0.5 to 1.0°C above normal.

3 Experimental Arrangements

Round the clock measurements of the IFIA at frequencies 3 kHz and 9 kHz have been regularly recorded at Kolkata over the last several years excepting

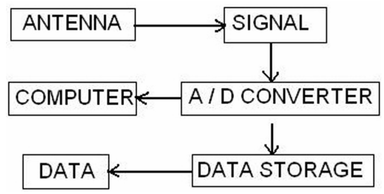

Figure 3. Block diagram of VLF measurement system.

some breaks due to power failures. For the reception of atmospherics, a straight horizontal copper wire of 8 SWG with 120 m length is used in the form of an inverted L type antenna. The antenna is installed 10 m above the ground. The antenna is sensitive to the vertical electric field of the electromagnetic signals. The outputs of the antenna are fed to tuned radio receives. A block diagram of the recording system is given in Figure 3. The radio receivers are first tuned at 3 and 9 kHz with a quality factor of 250. The overall gain of the amplifier is maintained around 40 dB. The tuned AC components are then detected to produce DC voltage. The time constant of detection is 10 s. The detected voltage level is proportional to the amplitude of AC components at 3 and 9 kHz. The voltages after detection are recorded by computerized data acquisition system through a PCI 1050, 16 channel 12 bit DAS card. These are then processed and being stored in a computer. The r.m.s. values of the filtered data are analyzed regularly using Origin 5.0 software.

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 emf induced in the antenna. The large horizontal length yields large antenna capacitance even with large height.

4 Observational Results

Spectral characteristics of sferics at 3 kHz and 9 kHz have been studied during the period of occurrence of AILA at Kolkata. The levels of sferics at 3 kHz and 9 kHz during AILA are shown in Figure 4 and Figure 5. The levels have vastly been enhanced from their ambient values maintained during the 15 adjacent days.

Figure 4 depicts the temporal variation of the sferics at 3 kHz on May 25, 2009 (red coloured curve) together with its normal trend obtained from the average of 15 days adjacent to the day of occurrence of AILA (black coloured curve). Error bars denote standard deviations. During the day of AILA, the IFIA at 3 kHz exhibited a step-like increase from its ambient value at about 1100 hrs IST, and continued up to 1300 hrs IST and then increased following another step which is again followed by gradual increase till 1830 hrs IST. The time required for

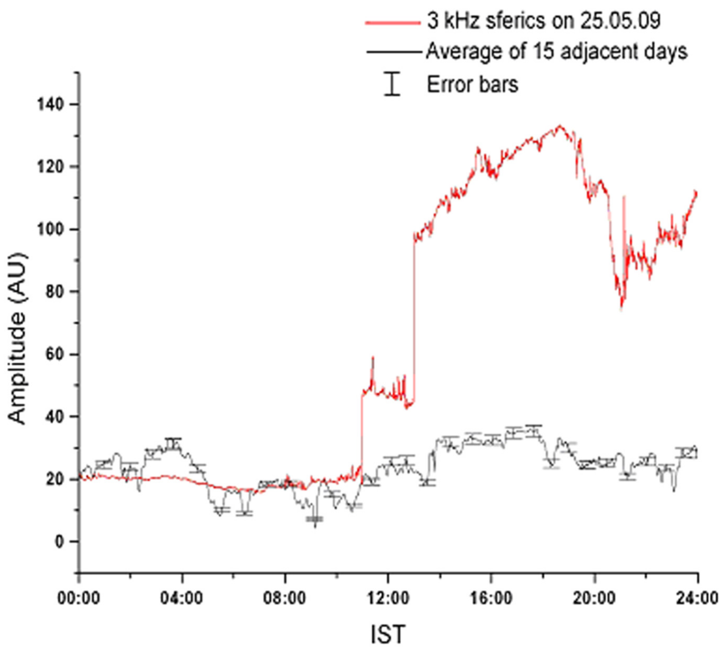

Figure 4. Temporal variation of sferics at 3 kHz on May 25, 2009, by the red coloured curve. The average of adjacent 15 days of occurrence of AILA is shown by the black coloured curve. The standard deviations are shown by error bars.

the enhancement from ambient level to maximum level is 7 hr 30 min. After that, it started to decrease. The value increased from 20 to 130 units, an increase of 6.5 times or 16.3 dB during the period when AILA crossed over Kolkata. The level then decreased to some extent until local midnight, although the value maintained significantly higher level than the average. The nature of decrease of IFIA from the maximum value also showed two sharp steps. The observed enhancements were well above the standard deviation which signified the occurrence of severe cyclonic storms, AILA.

Similar plots for IFIA at 9 kHz are shown in Figure 5. The nature of variation is almost similar to that of 3 kHz. The IFIA at this frequency showed the first step at about 1100 hrs IST and continued up to 1200 hrs IST. It then showed the second step which is followed by small variations till 1830 hrs IST. The time required for enhancement from ambient level to maximum level is 7 hr 30 min. After that, it started to decrease. The value increased from 20 to 140 units, an increase of 7 times or 16.9 dB. The nature of decrease of IFIA from the maximum value also consisted of two sharp steps as in the case of 3 kHz. A comparative study of the observations at two frequencies is shown in Table 1.

It is to be noted that the enhancement of amplitude at 9 kHz is more than that at

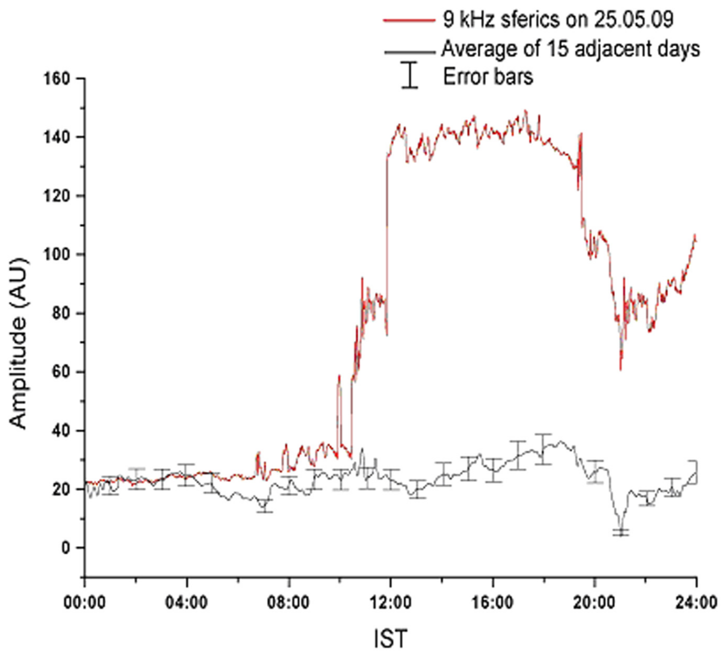

Figure 5. Temporal variation of sferics at 9 kHz records of May 25, 2009 are shown by the red coloured curve while the average of adjacent 15 days of occurrence of AILA is given by the black coloured curve. The standard deviations are shown by error bars.

3 kHz. The value started to decrease from about 1900 hrs IST when AILA started to reduce its outrage and gets converted into a cyclonic storm. The amplitude came down to normal level of 20 units at about 0800 hrs IST of the next morning (May 26, 2009).

The morphological structure of IFIA is now compared with other pre-monsoon and post-monsoon thunderstorms occurring over the locality of Kolkata within an aerial distance of 100 km. Figure 6 and Figure 7 show a typical variation of IFIA during a pre-monsoon thunderstorm occurring over Kolkata and its vicin-

Table 1. Various features of IFIA during AILA

Frequency (kHz)	3	9
Enhancement in 1st step (dB)	8	12
Enhancement in 2nd step followed by a small gradual increase (dB)	8.3	4.9
Overall Enhancement (dB)	16.3	16.9
Time interval from ambient level to maximum (hr)	7.5	7.5
Magnitude of principal fall (dB)	4.2	7.4
Time for the principal fall (hr)	2.25	2.35

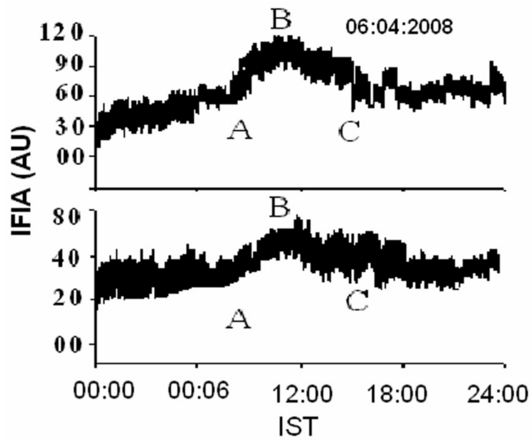

Figure 6. Temporal variation of IFIA at 3 and 9 kHz on a day of pre-monsoon thunderstorm. The IFIA increased gradually from A to B and decreased from B to C.

ity. The levels of IFIA are not consisted of sharp steps during its enhancement from ambient level to the thunderstorm associated maximum. The time of enhancement to the maximum level from the ambient level and the magnitude of enhancement are found to be noticeably smaller than those obtained in the case of AILA related IFIA. The sharp steps were also missing during the decrease from maximum value. Table 2 expresses the nature of variation of IFIA at two

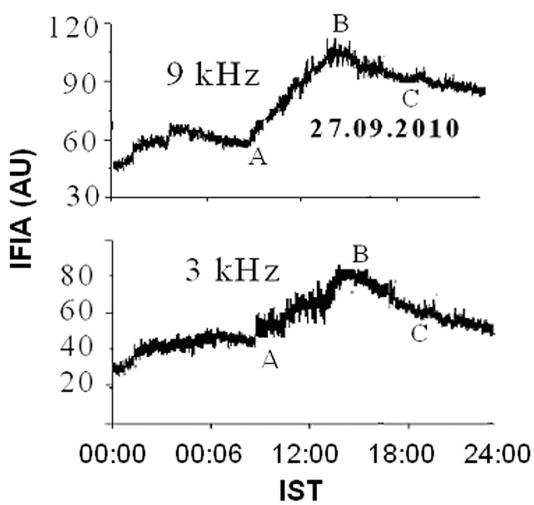

Figure 7. Temporal variation of IFIA at 3 and 9 kHz on a day of post-monsoon thunderstorm. The IFIA increased gradually from A to B and decreased from B to C.

Table 2. Various features of IFIA during pre-monsoon and post-monsoon thunderstorms

Period of observation	Frequency (kHz)	Magnitude of enhancement (dB)	Time interval from ambient level to maximum (hr)	Magnitude of main fall (dB)	Time of fall (hr)
Pre-monsoon	3	7.4	4.25	6.2	1.75
	9	9.6	4.25	8.2	1.85
Post-monsoon	3	5.2	5.25	5.6	1.2
	9	8.4	5.75	7.2	1.3

frequencies averaged over 5 pre-monsoon and 4 post-monsoon thunderstorms.

A comparison of the nature of variation of IFIA averaged over two frequencies during AILA, pre-monsoon and post-monsoon thunderstorms is shown in Table 3. The average of enhancement at these two frequencies during AILA is found to be 16.6 dB whereas it became 8.5 dB during pre-monsoon and 6.8 dB during post-monsoon with the observed maximum value to be 10.3 dB and 8.5 dB, respectively. The rise time of IFIA from ambient level to maximum was 7.5 hr in the case AILA and it was 4.25 hr during pre-monsoon and 5.5 hr during post-monsoon with a maximum value observed as 5.75 hr and 6.4 hr, respectively. The principal fall after the occurrence of maximum value in IFIA was found to be 5.8 dB in the case of AILA whereas the average of the principal fall in the case of other pre-monsoon thunderstorm yielded 7.2 dB and 6.4 dB during post-monsoon thunderstorms.

5 Discussion

The meteorologically-assigned cloud associated with the thunderstorm is the cumulus. All thunderstorms go through three stages which are called the cumulus or developing stage, the mature stage and the dissipation stage [19]. In cumulus stage, or developing stage, masses of moisture are lifted upwards into the atmosphere. The moisture rapidly cools into liquid drops of water by adiabatic expansion. It then appears as cumulus cloud. The air tends to rise in an updraft through the process of convection. The matured stage produces most of the precipitation and updraughts. It is a fully operating system with water vapour condensing as it rises with the updraughts. Excess air and moisture mostly in the form of precipitation is released at this state. A storm will remain in its matured stage so long as the updraughts can supply water vapour to the storm. Lightning and thunders are more prominent during this stage. When the precipitation would start, the thunderstorm dominates by the downdraught. The cool air carried to the ground by the downdraught cuts off the inflow of the thunderstorm, the updraught disappears and the thunderstorm starts dissipating. At this stage, lightning becomes less frequent and ceases completely once the storm becomes

Table 3. Comparison of different features of AILA, pre-monsoon and post-monsoon thunderstorms

Thunderstorm	Nature of enhancement	Magnitude of enhancement averaged over two frequencies (dB)	Duration of enhancement (hr)	Nature of decrease	Magnitude of decrease averaged over two frequencies (dB)	Duration of decrease (hr)
AILA	consisting of sharp steps	16.6	7.5	consisting of sharp steps	5.8	2.3
Pre-monsoon (except AILA)	gradual enhancement	8.3 (max value observed 10.3 dB)	4.25 (max value observed 5.75 hr)	gradual fall	7.2	1.6 (with maximum of 2 hr)
Post-monsoon	gradual enhancement	6.8 (max value observed 8.5 dB)	5.5 (max value observed 6.4 hr)	rapid fall	6.4	1.25 (with maximum of 1.5 hr)

weak.

Atmospherics are the results of electrical discharges that occur in a thunderstorm and commence when electrical charges are built up within a cloud. When a charge is built up above a critical level, discharge commences producing lightning. In the active stages of a severe thunderstorm, Intra cloud (IC) flashes can outnumber the cloud to ground (CG) flashes vastly. In general, positive charges are located in the upper levels of thunderstorm clouds, while negative charges are located at the bottom of clouds.

The region inside a storm where polarity shifts from negative to positive is the charge centre, which is observed above the freezing level, and this is also the point where the lightning can originate.

The features of thunderstorm cloud electrical activity have been investigated [20]. The average electric moment in a lightning flash is about 10^5 Cm. Sufficient charges are to be generated and separated to establish large-scale vertical electric fields of at least a few hundreds of kilovolts per meter to produce lightning. Numerous field campaigns and laboratory experiments are performed to understand thunderstorms and cloud electrification. A series of results followed from field campaigns that have been performed over a period of 20 years [21-24]. The important conclusions assert that the source of the lightning events lies midway between the positive and negative charge centers.

The IFIA is mainly contributed by IC. The peak activity and the subsequent decay of the duration of enhancement in IFIA are related to the lifetime of various stages of thunderstorms. The stages take an average of 30-60 minutes to go through.

The present observation shows that in the case of AILA, thunderstorm enhancement in IFIA started 7.5 hours prior to the main phase. These times are 4.25 and 5.5 hours in the case of pre-monsoon- and post-monsoon thunderstorms, respectively. The lightning begins during cumulus stage and its intensity becomes maximum at the matured stage. The lightning activity decays out during dissipating stage. The observed result of very large enhancement in IFIA implies that the spectral source function, $G(\nu)$, of atmospherics is very strong in AILA thunderstorm. Following continuous development and dissipation of different regions of the structure, 7.5 hours has been elapsed before AILA attained its peak electrical activity. During the dissipation of some part of the strong source, other parts are in the developing stage. The total time interval to attain the peak electrical state in AILA is greater than that of the other thunderstorms. According to the record of IFIA, AILA is characterized by two-step enhancement from ambient level to the maximum value. From the nature of step rise in IFIA, we can say that AILA has gone through two sub-matured stages with respect to electrical activity. Large amount of fast charge separation during simultaneous occurrence of downdraughts and updraughts in the strong source may be expected to produce step enhancement in IFIA during AILA.

The integrated effect of atmospherics from all the other thunderstorms showed gradual increase of the IFIA. During the matured stage, the strength of AILA must be greater than that of integrated strength in ordinary thunderstorms during pre-monsoon and post-monsoon. This can be accounted for the larger value of IFIA during AILA. The dissipation of AILA took lager time compared to dissipation of normal thunderstorms in pre-monsoon and post-monsoon.

Sferics generated mainly from the lightning discharges propagate through the Earth-ionosphere waveguide throughout the globe maintaining an ambient value in its amplitude. Lightning generated transient field enhanced the VLF amplitude during the occurrence of AILA as seen in Figures 4 and 5. The magnitude of the received signals affects the 9 kHz signal more as because intensity of lightning generated electromagnetic waves are dominated surrounding 9–10 kHz.

6 Probable Explanation of the Observed Results

When severe thunderstorm, lightning, rainfall, wind shear, turbulence and other meteorological outcome pass through the near ground surface of the atmosphere, the effective energy of AILA gets randomized. The collision rate between the constituent particles of the medium is increased instantaneously. Also, lightning discharges enhance non-linear electromagnetic coupling [25]. As a result, instability is produced causing ionization in the region. The relative electron-ion drift velocity may exceed the value for the onset of Kelvin-Helmholtz instability. The compressivity property of the medium driven by the velocity shears at the frontal path of AILA increases the growth rate of Kelvin-Helmholtz instability which generates electromagnetic field. This field interacts with the VLF Sferics thereby exhibiting the observed effects in the Sferics signals at these two frequencies.

7 Conclusion

From the observations and results, the following conclusions can be made:

- The spectral source function of the AILA hitting the landmarks around the Bay of Bengal, Sub-Himalayan and neighbourhood regions on May 27, 2009 at around 1430 hrs IST was very strong compared to that of other thunderstorms in the same locality.
- The electrical activity is characterized by step enhancement in IFIA indicating that there would exist an intermediate matured electrical state before attaining its maximum level.
- Both growth and dissipation times of electrical activity were higher in AILA compared to those in other thunderstorms in the same locality.

Sufficient studies are made about the cause and the effects of AILA, but how to stop such paradigm and devastations! The answer is beyond the existing knowledge. Only the location of its origin and its nature are determined by high power radar systems, so that people can be alerted much in advance to take care of safety and survival. Our work here is an attempt to resolve some characteristic aspects of the problem.

The paper considers the effects of VLF radiation from intense thunderstorm discharges at frequencies 3 kHz and 9 kHz, occurring during the strong cyclone passing over the Bay of Bengal. It is clear from Figure 4 that at the frequency of 3 kHz, the intensity of the received radiation has a step-like increase during the strong cyclone. The first increase of the intensity was at 1100 IST on May 25, 2009, the second one at 1300 IST on the same day. Total increase of the intensity, from Table 1, was 16.3 dB. Similar picture was observed at the frequency 9 kHz, where the total increase of the intensity was 16.9 dB.

It should be noted that intensity measurements were carried out in the immediate vicinity of the strong cyclone, in Kolkata. Such investigations are important to analyze the causes of radiation and distribution which are associated with strong cyclones. The authors here took an attempt to give scientific explanation of the observed effects related to the appearance and development of cyclonic and thunderstorm activity.

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Courtesy: www.imd.gov.in/section/nhac/dynamic/AILA.pdf

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