Deployment of Lightning Sensors for understanding of Lightning Thunderstorm precipitating systems over North-East Region of India

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Abstract : ***Lightning is a natural but destructive phenomenon that affects various locations on the earth's surface every year. Hence, lightning detection system has been developed and 4-sensors are deployed over North-Eastern Region of India (NERI) with a spatial separation ranging from 105 km to 347 km. A systematic study is carried on calibration and validation of four digital lightning sensors at Regional Meteorological Centre, India Meteorological Department, Guwahati for a period of three months i.e., March, April and May 2011. Simultaneously, the Rain drop Size Distribution (RSD) and rain integral parameters data is obtained from PARSIVEL disdrometer located less than one meter spatial separation. From the preliminary studies on total cloud lightning have found intra and inter-cloud(IC) lightning tend to fluctuate significantly during the lifetime of thunderstorms. The advantage of this study is to support operational meteorological community as prior studies failed to link lightning characteristics to currently used radar interrogation techniques.***

IndexTerms - : thunderstorms, lightning, radar reflectivity, rainfall, rain drop size distribution

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I. Introduction

Lightning is a natural electric discharge phenomenon consisting of cloud-to-ground (CG) and intra-cloud (IC) flashes, and accounts for many human casualties and significant property damage worldwide every year. Lightning activity is closely associated with severe convective events (Ashley & Gilson 2009;Fan Wu et al., 2016). Lightning is one of the foremost aspects of operational thunderstorm forecasts that are a challenge to predict accurately and with as much lead time as possible. Lightning presents significant risk to life and property. Due to the risk lightning presents, many outdoor operational activities, especially aircraft fueling, must be suspended when lightning is expected. In order to accurate detection and forecasting of lightning occurrence and severe weather phenomena, a firm understanding of lightning is required, along with a good network of lightning detection systems and other meteorological sensors (Mukherjee et al., 1964; Standler and Winn, 1979; Soula and Chauzy, 1991; Pawar and Kamra, 2002Mils et al., 2010; Zhang et al., 2011; Fan Wu et al., 2016).

Lightning discharges in thunderstorms are an indication of the intensity of atmospheric convection. Atmospheric convection occurs under unstable atmospheric conditions, either due to the heating of the boundary layer by solar radiation during the day, or by mixing of air masses of different densities. Lightning frequencies are therefore related to the regions of greatest instability in the Earth's lower atmosphere. Many studies in the past have tried to show that lightning characteristics can be used to categorize the thunderstorms, because severe weather is associated with unique lightning characteristics (Standler and Winn, 1979; Soula and Chauzy, 1991; Pawar and Kamra, 2002). Williams et al (1999) have studied the behavior of total lightning activity in Florida severe thunderstorms. They found that the most obvious and systematic characteristics of severe thunderstorm was the rapid increase in total lightning flash rate, 1–15 minutes prior to severe weather manifestation such as high surface wind, hail and tornado at the ground. Lightning discharge characteristics from cumulonimbus clouds have been investigated by many scientists (Rakov and Uman, 2003). The physics of intra-cloud, cloud to ground discharge and their features are discussed in detail by several workers (Gomes et al., 1998; Gomes and Cooray, 2004; Pontikis et al., 2004; Sharma et al. 2005). The effect of propagation of lightning generated radio frequency has also been investigated (De et al., 2005).

Past experimental, theoretical and modeling studies over northeastern part of India (NER) India, on the relationships between storm dynamics, severe weather, and lightning activity have been least understood (Koteshwaram and Srinivasan, 1958; Kanjulal*et al* 1989; Pawar and Kamra, 2002). A few studies have shown a connection between global lightning activity and the Earth'stemperature(Williams, 1992, 2005; Price, 1993), the amount of water vapour in the upper tropospheric(Price and Asfur, 2006), the production of nitrogen oxides (NO_x) in the atmosphere (Price et al., 1997; Schumann and Huntrieser, 2007), and cloud cover(Sato and Fukunishi, 2005). Hence lightning monitoring may be useful for studying both severe weather and climate change.

Ground-based lightning detection networks are continuously improving and growing in importance to scientists and operational weather forecasters. As the variety of users expands, it becomes increasingly important to understand the detection capabilities of these networks. The ground based Network of Lightning Sensors (NLS) detects more accurately cloud-to-ground (CG) flashes (Dowden et al., 2002; Rodger et al., 2004). Based on literature, so far a few studies attempted over NER of India to obtain accurately lightning flash rate and duration during very severe thunderstorms. Due to these reasons, we deployed network of four lightning sensors over NER of India to diagnose thunderstorm initiation, active stage and dissipation by collecting high temporal resolution lightning flashes.

II. Methodology

2.1 Instrumentation and Data Base

The PARSIVEL (PARticleSIze and VELocity) disdrometer is a surface-based laser-optical system for measuring hydrometer type and size distributions. PARSIVEL Disdrometer is manufactured by OTT Messtechnik, Germany. Loffler-Mang and Joss (2000) and Yuter et al. (2006) provided a detailed description of this instrument. Briefly, the PARSIVEL probe is a laser-based optical disdrometer that can simultaneously measure both sizes and fall velocities of precipitation particles. The core element of the instrument is an optical sensor that

produces a horizontal sheet of light (180 mm long, 30 mm wide, and 1 mm high). The particle passing through the light sheet causes a decrease of signal due to extinction. The amplitude of the signal deviation is a measure of particle size, and the duration of the signal allows an estimate of particle fall velocity. Particles with diameters between 0.2 and 25 mm and fall velocities between 0.2 and 20 m/s are detectable by the instrument. The particle size and velocity are each categorized into 32 size and velocity bins, respectively, with different bin widths. The precipitation particles are differentiated and classified as drizzle, rain, sleet, hail, snow or mixed precipitation. It measures precipitation optically one meter above the earth's. The data determined thereby are processed and stored by a fast digital signal processor. The primarily determined data are the size and the velocity of each individual precipitation particle, from which the size spectrum, the amount of precipitation, the equivalent radar reflectivity, the visibility and the kinetic precipitation energy as well as the kind of hydrometeors are derived.
The lightning data have been collected from the lightning imaging sensor (LIS) database during the period from 2010 to 2011 for the pre-monsoon months (March, April and May). The LIS is a TRMM satellite-based instrument and detects cloud-to-ground (CG) and intra cloud lightning activities within the troposphere. In the next section, a brief description on the development of lightning sensor operation principle and specifications are depicted.

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2.2 Development of Lightning Sensor

Lightning sensors detect and locate electrical activity in thunderstorms using a number of different methodologies. These include direction finding (DF) (Krider et al., 1976), time-of-arrival (TOA) techniques (Lee, 1989), a combination of these two (Cummings et al., 1998), and interferometry methods (Hayenga and Warwick, 1981). All techniques need a number of sensors within a network to get reliable data on the location of a lightning flash. The DF method uses two orthogonal magnetic loop antennas, where the azimuth angle to the flash is obtained by simple trigonometry. However, we developed a sophisticated captive intelligence device to identify the lightning strikes and lightning duration more precisely within a vicinity of 80 km. Figure 1(a) shows the lightning sensor block diagram. The device employs a three dimensional electromagnetic sniffer probe that continually tracks all electromagnetic activity in a radius of 75 km and identifies the lightning strokes. The sensor consists of Micro controller (CPU) inside, having data flash for storage and code flash for program logic. Internal battery is available for power supply CPU. Lightening detection front end consist of captive intelligence to identify the lightning strikes. CPU will log the strike counts in data flash. RS485 data accessibility is provided through ESD protection and Line driver. Figure 1(b) shows the lightning sensor schematic diagram.

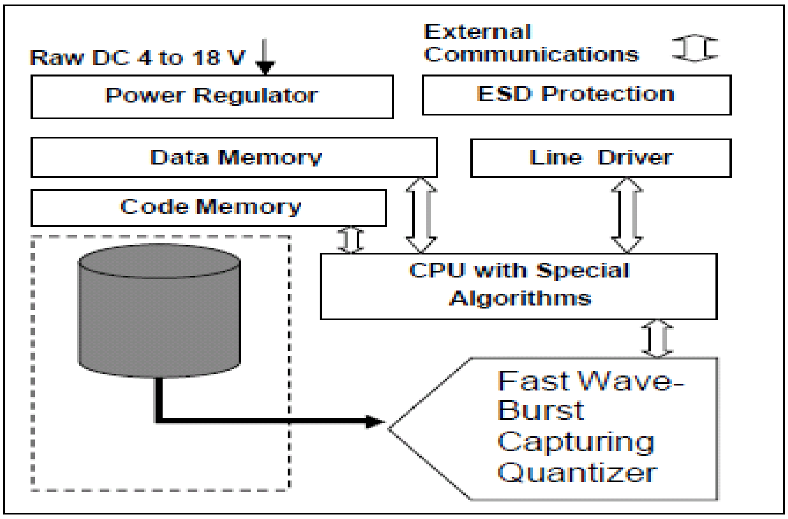

Fig.1 (a): Block diagram of Lightning Sensor.

The sensor has a Kom-Bus(1.0/2.0) compatible RS485 external communication which is fully isolated and can be easily accessed using ASCII text commands and responses on an industry standards RS485 half-duplex port. It measures Strikes per Minute (SPM) counter that can be stored in a FIFO queue of up to 100 entries (the depth can be customized). Both cumulative as well as SPM readings of the previous 100 minutes can be accessed by external host systems. The SPM FIFO stores the strikes in a user-defined period of smaller or larger length than one minute, too, allowing a longer period watch possible between acquisitions. The lightning sensor can be installed in parallel with upto 64 sensors of the same or different meteorological parameters in a Data Logging unit. It can also be easily integrated into other logging environments including PCs.

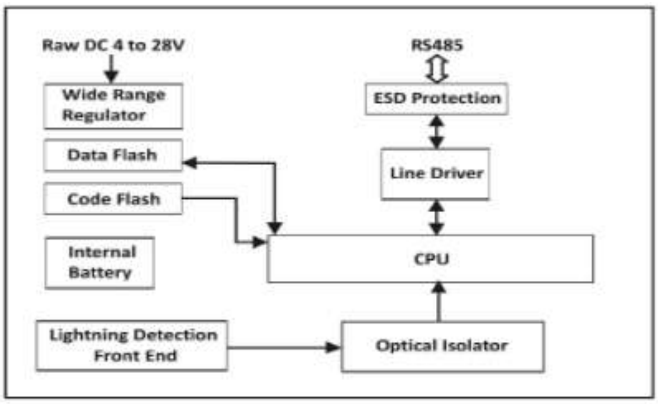

Fig.1(b):Schematic diagram of Lightning Sensor

The specifications of the lightning sensor are shown in following Table 1.

Parameter/Specification	Conditions	Min	Type	Max	Units
Type of Sensor	3-D Electromagnetic Sensor				
Type of Sensing	Ferrite Antenna				
LightningDetectionRange		0		75	Km
Resolution			0.1		Degrees
SPM Register time width	User Selectable	0.1		100	Minutes
Environmental					
Storage Temperature		-45		+85	^oC
Operating Temperature		-40		+65	^oC
Rated Environment			Dry Heat to Sea Water		
Electrical					
Supply Voltage		4	9-12	28	V
Specification Dependencies on Supply	All Specifications Independent of Supply Voltage				
Supply Current	Active		<1		mA
Supply Current	Autonomous Mode		<0.4		mA
Power-On Latency				1	S
Power on setting time	Filter at Minimum			2	S
Physical					
Weight	Cable not Included		<1		kg
Top Diameter			<100		mm
Length			<500		mm
Deployment					
Location			Out Door		
Cable Length				250	m
Outputs					
Type	Serial Digital (UART)				
Electrical Interface	RS485				
Measurements	Free Running				
Baud Rate	User Settable, 9600 Factory Set Value				
Start, Stop Bits	1,1				
Response	Free Running String or Externally Commanded				

Manufacture supplied software utility and customized by our group to configure / download data from the sensor. As depicted in Figure 2 (screen shot of the utility/customized software) by using “Download Data” to download the recorded data to a file (csv format). The utility prompts for a file name while downloading data. User can type any name without extension. “.csv” will be added to the filename automatically. If user wish to erase and reset the memory of the senor, the “Erase Entire Memory” button to be utilized. To reset the lightning counter to zero, use “Reset Counter” button.

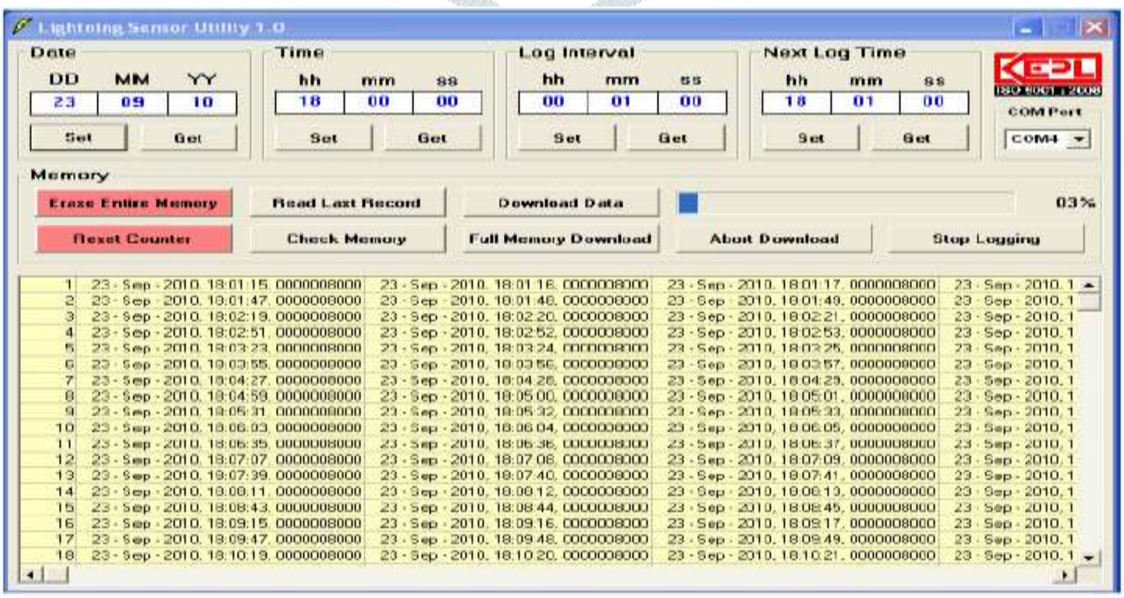

Fig.2: Data retrieval application software

2.3Validation of Lightning Sensors

World Meteorological Organization (WMO) and the Intergovernmental Panel on Climate Change (IPCC) called for standardization of ground based remote measurement instrumentation to be assured through intercomparisons. Due to this reason, quality assurance of lightning sensors is becoming more important and also introduction of new more sophisticated sensors and processing algorithms. There is a strong need for lightning activity (associated with severe thunderstorms, monsoon and tropical cyclones) to develop and implement the basic guidelines for a quality management. The primary observation tools were quite simple when Battan, 1965 counted the lightning flashes by visual method. Later, with the development of the cloud-to-ground (CG) flash detection networks, many more sophisticated studies have been conducted.

Satellite observations have short sampling time, which in turn results in snapshots of few minutes of the lightning activity only. Hence, it is extremely difficult to measure lightning flashes and duration for entire convective precipitating cloud system. Hence, calibration and validation (CAL/VAL) of lightning sensors are essential to assess the performance and collect reliable observational data. At India Meteorological Department (IMD), Regional Meteorological Centre, Guwahati, we have constructed four beds and installed four lightning sensors for calibration and validation as shown in Figure 3.This experiment was conducted for three months between March and May 2011 and 6-event of lightning with thunderstorm precipitation observed over Guwahati. Four lightning sensors were recorded 6 lightning episodes data. These sensors detect the electromagnetic radiation emitted by lightning discharges. These data converted into detailed information of the lightning flash and lightning duration. A flash is a complete lightning event, either cloud-to-ground (C-G), cloud-to-cloud (C-C), or a combination of both. In C-G flashes at least one and often several highly luminous return strokes occur during a time of the order of 1 sec in approximately.

On 19 April 2011, severe thunderstorm with lightning occurred on 19 April 2011 over Guwahati is depicted in Figure 4. From the figure it is observed that the temporal data of number of lightning strokes data collected from 4-lightning sensors are detecting nearly same number of lightning strokes and duration. This study evaluates the detection efficiency (DE) of the NLS over NERI relative to total lightning observations from the satellite-based Tropical Rainfall Measuring Mission (TRMM) Lightning Imaging Sensor (LIS) for 23-lightning events observed from March 2011 to May 2012 over NERI (as shown in Fig.5). Thompson et al. (2014) conducted an early evaluation of the ENTLN relative to the TRMM/LIS (1 January 2010 and 30 June 2011.

Fig. 3: Calibration and Validation of Lightning sensors at RMC, Guwahati. Network of 4-lightning sensors and (b)4-Data acquisition systems. 4th lightning sensor cables are connected to Note Book Computer for collecting data from the Sensor .

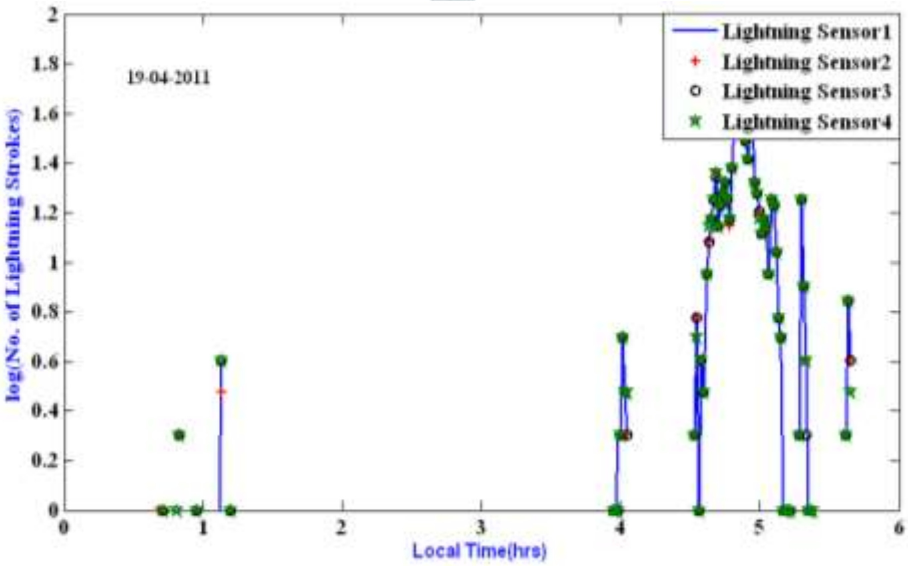

Fig. 4 Lightning data obtained during thunderstorm by the network of sensors.

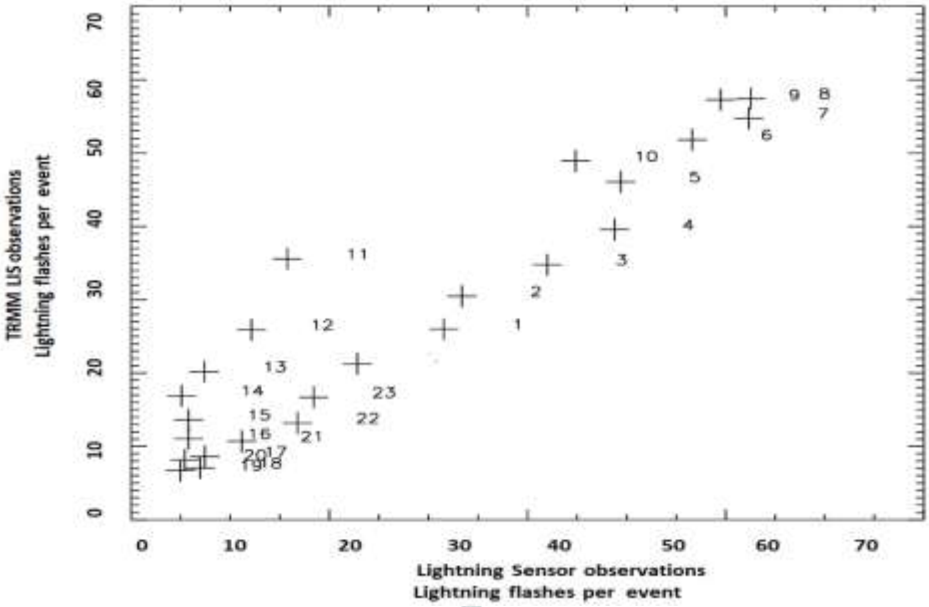

Fig.5: Scatter plot of 23-cases thunderstorms with Lightning flashes between TRMM LIS and Lightning sensor observations.

III. RESULTS AND DISCUSSION

3.1. Deployment of Network of Lightning Sensor over North-Eastern Region of India:

Four-lightning detector/sensor were installed at RMC-Guwahati, Meteorological Office, Doppler Weather Radar (DWR) Mohanbari Air Field, Mohanbari, Assam University, Silchar, and Assam Agricultural University, Jorhat, Assam (as shown in **Fig.6**) to understand the occurrence and monthly occurrence of lightning associated with thunderstorm activity during different seasons.

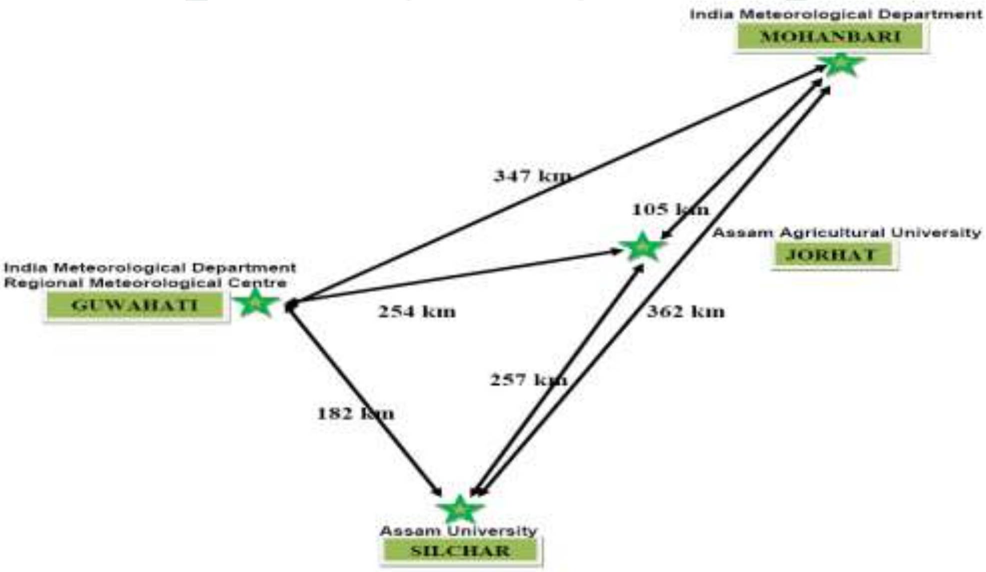

Fig.6: Location of Network of lightning sensors installed over North-Eastern Region (NER) of India.

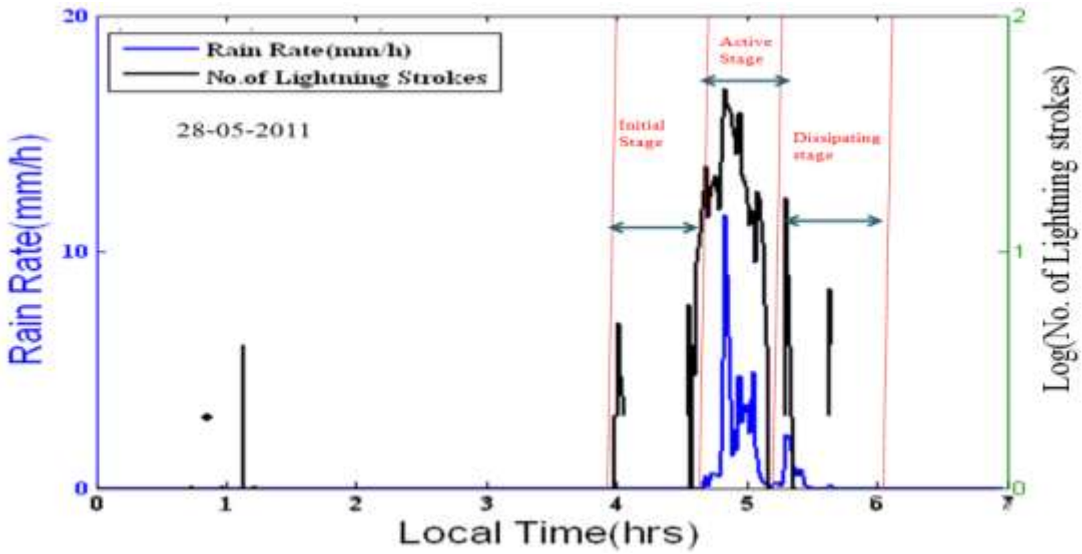

Fig.7: Variation of lightning flash rate and Rain rate during different stages of the storm.

At RMC, Guwahati, we have collected fourteen thunderstorm events are identified using lightning sensor along with other ground based sensors observations. We have chosen, 28-05-2011 to check the performance of the lightning sensor during STORM – 2011. Figure 7shows the lightning flashes measured at ground during the thunderstorm. As shown in figure 7, we have divided this thunderstorm into three stages – initial, active and dissipating stages based on lightning flash rate. The initial stage lasted for about 45minutes and lightning flash rate remained between 10 and 15 fpm. The active stage started at about 0450 IST and lasted only for 15 minutes up to 0505 IST. The lightning flash rate increases sharply to about 49 fpm within 1 to 2 minutes and remains between 20 and 35 fpm during active stage. In the active stage, flash rate increases at a rate of about 36 fpm/min. As described by Williams *et al* (1999) such a sudden jump in lightning flash rate is sometimes associated with the increase in updraft and severe weather at the ground. In the dissipation stage, the flash rate decreased slowly and reached near to zero at about 0530 IST. According to several studies, the simultaneous observations of CG flash and rain activities show parallel variations (Battan, 1965; Kinzer, 1974; Piepgrass et al. 1982). Most of the studies on thunderstorm show an increase in rain generally corresponds with an increase in CG flash rate.

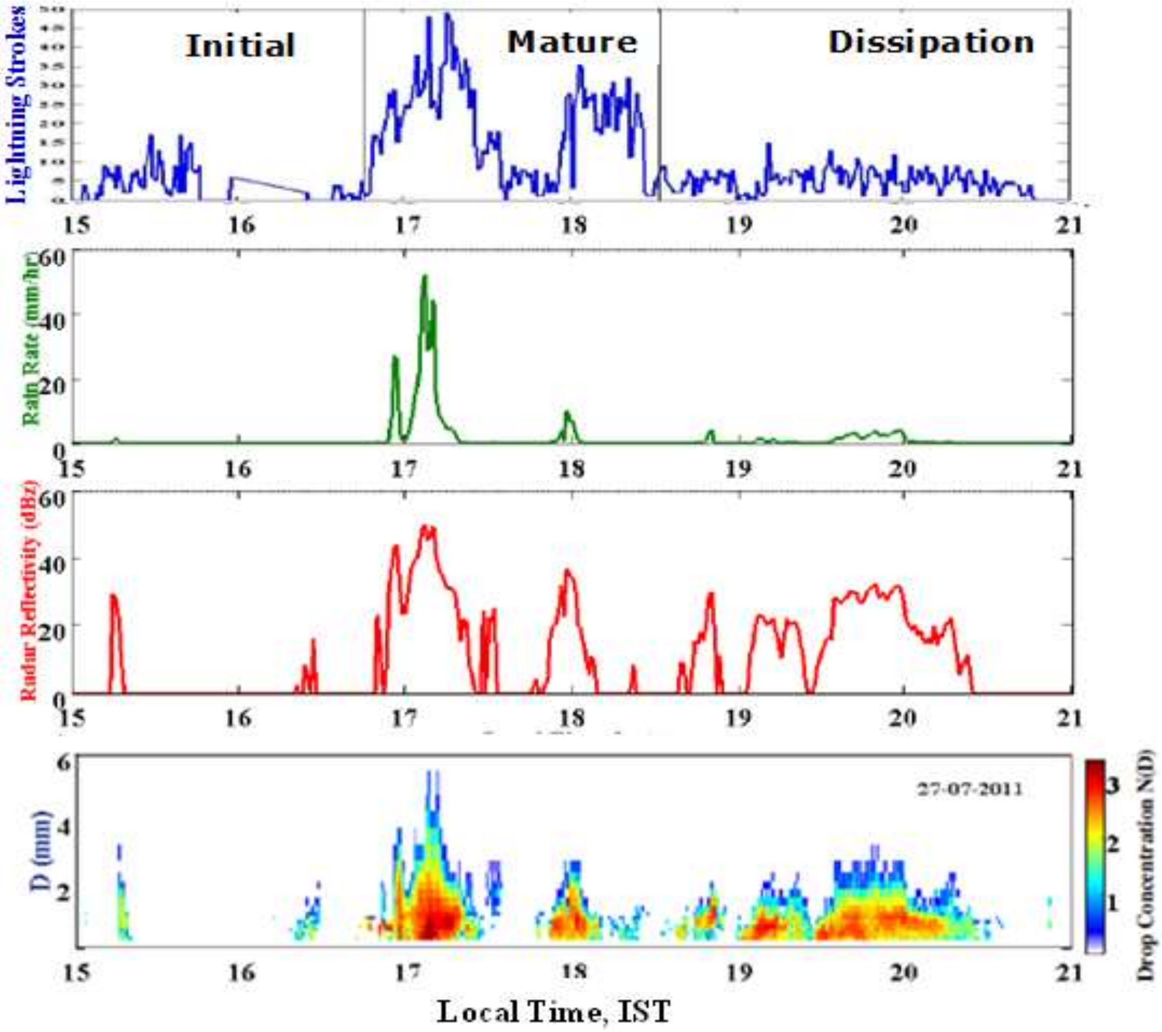

Fig.8: Lightning sensor and Disdrometer observations during passage of severe thunderstorm on 27-07-2011. Temporal variations of (a) lightning strokes (lightning sensor), (b) Rain rate mm/hr. (c)Radar Reflectivity, dBZ, (d) Median volume diameter data deduced from PARSIVEL Disdrometer.

As shown in figure 8(a), we have divided this thunderstorm into three stages – initial, active and dissipating stages based on lightning flash rate. During the initial stage of lightning event not much rainfall and rain drop concentration is observed. The active stage of lightning maximum values of all rain integral parameters is observed. In the dissipation stage, stratiform rain cloud rain integral parameters are noticed.

Each convective cell had an average total flash (i.e. Network of lightning sensors detected flashes only) duration (or total flash time interval) of 25.8 minutes. This duration was defined as the total time from when the first lightning stroke was detected to when the last IC flash occurred in a thunderstorm. The CG duration was defined in a similar way (i.e. time difference between first and last occurring CG). Average and median flash rates (both total and CG) were calculated for the 14 cases by counting the number of flashes that occurred within each event and dividing by the thunderstorm total flash duration. The mean and median total flash rate as detected by the 4-lightning sensor was 1.4 and 1.3 flashes min^{-1}, respectively (Fig. 10). The average CG flash rate at 0.66 flashes min-1 for the 14 cases was lower than the mean total flash rate. Case 11 exhibited both the highest total flash rate and the greatest CG flash rate with 4.4 and 1.7 flashes min^{-1}, respectively. From figure 9, it is distinctly evident that lightning characteristics at four locations are completed different due to the topographic effects and also local weather conditions.

Many meteorological applications use lightning observations from both ground- and space-based lightning detection systems. These systems detect optical or radiometric lightning signals, and their data are growing in importance to scientists and operational weather forecasters. Total lightning observations are useful for both storm warning and public safety applications.

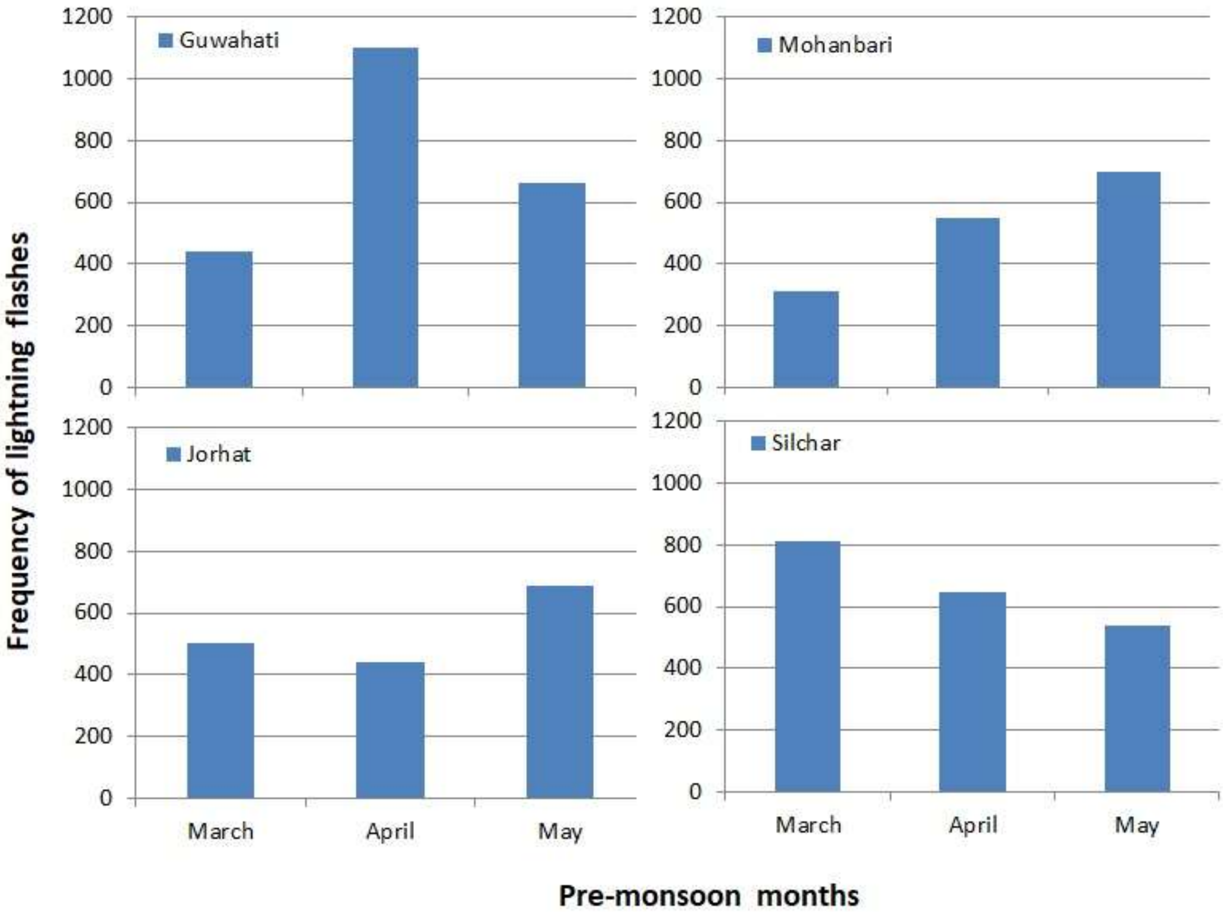

Fig. 9: The frequency of average flash rate of lightning activity over Guwahati, Mohanbari, Jorhat and Silcharin the North eastern region of India during the pre-monsoon season

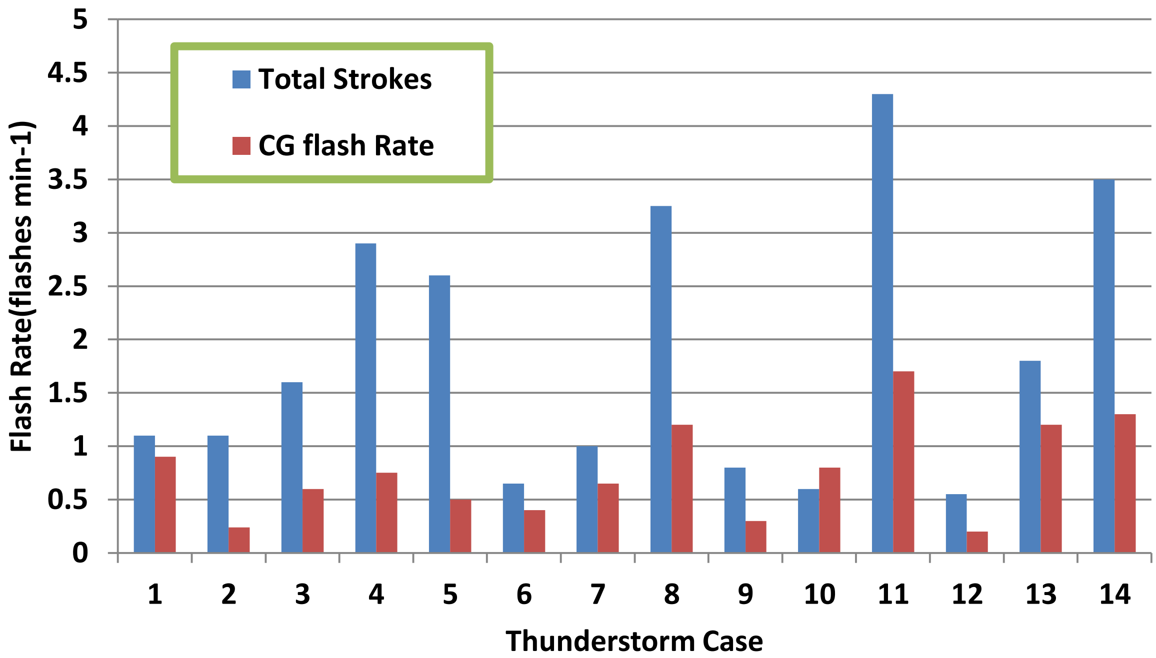

Fig.10: Total flash rate (flashes min^{-1}) (blue bars) and CG flash rate (red bars) for each thunderstorm case.

Rapid increases in total lightning flash rate often precede severe weather (Williams et al. 1999). This knowledge has been used to develop a lightning jump algorithm that provides early warning of severe weather events (Schultz et al. 2009, 2011; Gatlin and Goodman 2010). Lightning data also have been used to refine satellite precipitation estimates (Xu et al. 2013, 2014), improve hurricane intensity forecasts (DeMaria et al. 2012), and provide initial conditions for weather forecasting models (Fierro et al. 2012). Lightning observations have additional public safety applications related to airport operations, recreational activities, and sporting venues. As the number of networks and variety of users expand, it becomes increasingly important to understand the detection capabilities of these networks.

IV. Summary and Conclusion

This paper presents network (four) of ground-based lightning sensors used for monitoring of thunderstorms that produce hazardous weather conditions around NERI during pre-monsoon. A precise report is carried on calibration of four digital lightning sensors at Regional Meteorological Center, India Meteorological Department, Guwahati for a time of three months ie March, April and May 2011. At the same time, the Rain drop Size Distribution (RSD) and rain integral parameters information is acquired from PARSIVEL disdrometer. From the calibration studies it is found that 4-digital lightning sensors are working satisfactorily. The benefit of this investigation is to help operational meteorological group as earlier examinations neglected to interface lightning attributes to presently utilized radar cross examination procedures.

V. ACKNOWLEDGMENT

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