Establishment of lightning detection sensors network in India: retrieval of essential climate variables and vulnerability mapping

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Abstract

A network of 25 lightning detection sensors (LDS) has been established by National Remote Sensing Centre (NRSC), Indian Space Research Organization (ISRO). In the present network, sensors are located in the north-east, east coastal, central and southern locations of India. Geo-location of the lightning occurrences is estimated using time of arrival algorithm. Thus obtained lightning occurrences have been used to derive climate variables (ECVs) and to understand the vulnerable regions. We carry out overlay analysis on a Geographical Information System (GIS) platform on the monthly aggregate number of CG flash occurrences to identify the vulnerable Indian states during July 2019 to November 2020. We note that December-January reported the least number of cloud-to-ground (CG) flash occurrences while, August-September were the months with most number of CG flash occurrences. We also note that during the period under the scrutiny in this report, Chattisgarh, Jharkhand, Odisha, Maharashtra and Madhya Pradesh states recorded the most number of CG lightning flash occurrences.

Introduction

Atmospheric lightning is a complex scientific phenomenon which involves extreme dynamical state of the atmosphere resulting in an extremely intense electromagnetic radiation. The extremities of event are often linked to superstitions in general public, however, the cause and effects of the events leading the researcher to investigate the events. It is now understood that the atmospheric lightning is a natural atmospheric discharge phenomenon that occurs either between earth and clouds, or, among oppositely charged clouds which are of cumulonimbus and nimbostratus category (*Rokov and Uman, 2003*). Apart from the convective processes being the main cause of lightning occurrences, it has been shown that events such as volcanic eruptions, snowstorms and tornados with which wind shears are associated can trigger the lightning occurrences (e.g. *Behnke et al., 2011*). A lightning flash is a process which has multiple steps such as charge separation processes and condition of breakdown leading to the step leader formation, which are not yet well understood. It has been shown that when electric potential between the clouds or cloud and ground exceeds the air insulation threshold, the step leader is formed. After the first step leader forms, the convective plume or clouds in the channel undergo repeated actions till the potential difference within the channel falls below the breakdown threshold. Thus, the lightning flash occurs between cloud and ground depleting cloud borne charges. Further, the bottom of the cloud, which is charged up, induces opposite charge on the surface of the earth. The opposite charge developed on the earth starts travelling towards the cloud known as streamer. Often these downward step leaders join the upward streamers and complete the lightning channel. A streamer in the form of return stroke when joins the downward leader, it makes the lightning strikes visible (e.g., *Proctor, 1997; Rokov and Uman, 2003*).

Understanding the atmospheric lightning flashes/strikes and their occurrences is one of the most important questions of the Earth's climate science. Real-time, lightning data have profound importance in climate science, air quality research, and atmospheric nitrogen budget, apart from this being one of the major natural disasters (*Price, 2013; Romps et al. 2014; Singh et al., 2017; Srivastava, 2020; Yadava et al., 2020*). It is also noted that with changing climate and global warming, the occurrences of lightning are expected to increase (e.g, *Romps et al., 2014; Saha et al., 2017*). The lightning also impacts the abundance of NOx which impacts the atmospheric chemistry (e.g., *Finney et al., 2016; Pawar et al., 2017*). This may in-turn may impact the climatological distribution of chemical constituents (e.g., *Murray et al., 2013; Nade et al., 2020*). The Cloud to ground lightning is highly disastrous and an underestimated threat to infrastructure and people. Therefore, with growing importance of extreme weather events and their impact on the society, World Meteorological Organization (WMO) in the year 2016 included the number of cloud-to-ground lightning flashes as an essential climate variable (ECV).

In terms of the space borne exploration, optical imaging sensors, Lightning Imaging Sensor (LIS) on board the Tropical Rainfall Measuring Mission (TRMM), provided snap-shot information and did help in characterizing the occurrences of lightning. At present, GOES-R mission is operational which covers American/ Europe sector using the Global Lightning Mapper (GLM) sensor, akin to LIS. Apart from their luminous impact caused by the heating the ambient which are used in the space based monitoring, lightning flashes create radio waves in 3 kHz to 10 MHz range of the spectrum (*Le Vine, 1986; Weidman et al., 1989*). These radio signals are utilized for the continuous monitoring and to evolve societal applications such as identification of potential vulnerable zones and now-casting, ground based radio frequency based receivers have been found very useful. Using this method, several countries have established a very dense network of long-range lightning detection sensors (e.g., *Rodger et al., 2006; Orville et al., 2008; Betz et al., 2009*). In Indian sector, India Meterological Department (IMD) through Indian Institute of Tropical Meteorology (IITM) has initiated a lightning location network (IITM-LLN).

In a feasibility study by National Remote Sensing Centre (NRSC), initially, six long range sensors were installed at various locations which revealed a need for a network having higher density of stations with more overlapping coverage, i.e. smaller base line in between receivers (*Taori et al., 2020*). In that report, it was shown NRSC-Lightning Detection Sensor (LDS) network is capable of detecting the lighting flashes/strikes and identification/delineation of potential danger/vulnerable zones using single sensor data was feasible (*Taori et al., 2018, 2020*). These reports pointed that errors in individual sensor and magnetic direction-finding method used can be large to an extent of 1000 m. Further sometimes due to local static charges induced by electrical noise can also be treated as flashes which basically are noise. In this regard, time of arrival (TOA) algorithm is found to be the best suited when it comes to the accuracy of positioning of lightning flashes is concerned which is recommended by the WMO. Present report explains the establishment of a sensor network based on TOA method of geo-location with detected atmospheric lightning flashes and also compares the results obtained from configured sensors with the existing IITM sensor network. After the comparison, the essential lightning climate variable is also generated as per the WMO criteria. The vulnerability of various states in India is also estimated during July 2019 to November 2020.

Lightning Data From Lds Network

2.1. Sensor properties and establishment:

NRSC has installed 25 LRX-1 sensors which are powered by Boltek Inc., UK, in network with coverage in north-east, east coastal, central and southern locations of India. The Boltek LRX sensors are long range sensors works in frequency range of 1 Hz to 30 MHz which work on time of arrival (TOA) algorithm where correlated lightning flashes are determined based on GPS stamped waveforms. More details on the sensors are elaborated elsewhere (e.g., *Cummins et al., 1998;Drue et al., 2007; Shlyugaev et al., 2014*). In this, low frequency range (1 Hz – 5 KHz) is used for the detection of long range static discharge pulse/waveform; the (5 KHz – 1 MHz) are used for finding the geo-location of static pulses while the higher frequency ranges are used for the inter-cloud or cloud-to-cloud pulse detections. The electromagnetic radiation emitted with every static discharge is omni-directional, which is detected by multiple sensors simultaneously. The waveforms are transmitted to central server which performs correlation before carrying out further analysis. Each sensor can detect discharge occurring up to 3000 km range; however sensitivity reduces with the distance. It has been noted that as the distance of sensors from the event of occurrences increase more than 300 km, the errors in determining the location becomes asymptotic (e.g., *Thomas et al., 2004*). *Figure 1* shows present sensor establishments under the NRSC-LDS Network. Also shown together with locations is a circle of 300 km radius around the locations.

2.2.Geolocation method:

The geolocation of lighting occurrences is based on time of arrival method. In this, assumption is that several stations are precisely time synchronized. When a lighting discharge occurs, a constant difference in the arrival time at two stations defines a hyperbola, and multiple stations provide multiple hyperbolas whose intersections is identifies the source location. When at least four sensors detect the discharge, the unambiguous detection of source location is achieved. A detailed theoretical analysis of this early methodology, referred to as location by hyperbolic intersections, was performed by *Lewis et al., (1960)* and *Proctor et al (1971)*. This method was more recently described by *Rokov (2013)* and is being widely utilized by major lighting detection networks in the world such as National Lightning Detection Network (NLDN) (e.g., *Cummins et al., 1998*), lightning detection network (LINET) (e..g, *Betz et al. 2009*).

In the present configuration, data from multiple distributed lightning detectors is transmitted in real-time to a central server for processing. The central server uses the lightning signal timestamp from several detectors to calculate an exact strike location and assign the associated parameters. These calculated point data is then stored in this server and flushed to another system for further analysis. Using the TOA method, the NRSC- LDS network started functioning from June 2019. This report uses data from July 2019 to November 2020 duration, i.e., first 17 months of observations to showcase the present capability of the network.

2.3. Comparison with IMD/IITM data:

The India Meteorological Department (IMD) through Indian Institute of Tropical Meteorology (IITM) operates a network of lightning detection sensors which are powered by Earth Network, USA sensors. *Figure 2* shows pan India basis comparison of Cloud-to-Ground lightning flash occurrences for 2 days (03 July 2019 and 08 July 2019) between NRSC and IITM lightning detection sensor network data. We carried out correlation analysis between these images and found a reasonable agreement between them (2-D correlation estimates were 0.83 and 0.74 for 03 July and 08 July images respectively). We carried out these image correlation analyses for about 90 days of data during July-August 2019, January-February 2020 and found the 2-D correlation to vary from 0.71 to 0.93. To showcase the comparison in smaller spatial scale, we scaled down our comparison to state level and for example, *figure 3* shows comparison of lightning occurrences for Odisha state. We note a good comparison of lightning occurrence characteristics. Assuming the IITM network as ground data a given tolerance of 750 m in both data sets, the Kappa statistics (total number of points: 294) is estimated to be 0.76 suggesting a good correlation between the two measurements.

Results And Discussion

3.1. Generation of Essential Climate Variable (ECV)

As suggested by the Global Climate Observing System (GCOS), WMO, total number of cloud to ground lightning flashes/strikes per day (UT) in 10 km x 10 km grid scale is considered to be a lightning ECV (GCOS,2016). To estimate this over India, we need to aggregate the point data received from the central server for the specified grid. To meet this, 10 km cell size grid was generated using fishnet tool of ARCGIS software (version may be written, v 10.5). This grid constitutes 96000 grid cells to cover Indian region. Overlay analysis was performed using 10km grid file and day specific shape-file to give lightning counts for each grid cell for a particular day. In this way output is lightning counts per day in 10km x10km grid cells. *Figure 4* shows the prepared grids having 10 km x 10 km resolutions (left panel), point data (central panel) and the NRSC- LDS gridded data of 29 May 2020 exhibiting the ECV map (right panel). The ECVs thus provide an aggregate scenario of point data representing 10 km x 10 km area which is important for investigating a broad distribution of CG lightning occurrences. This data is hosted at nrsc.gov.in for independent usages and information for various agencies freely.

3.2. Seasonal Variation of CG Lightning Occurrences:

The ECVs thus generated can be utilized for making monthly composite mapsto study the seasonal behavior of CG lightning occurrences which would indicate the vulnerable regions. In a monthly composite map the aggregate number of CG flash occurrences is shown for all the days of that month. The variability in the monthly composite maps during July 2019 – November 2020 is shown in *Figure 5* exhibiting a strong seasonal variability. It is noteworthy that August and September months show the largest occurrences. Further, it also evident in the maps that Chattisgarh and Odisha states are most vulnerable state in India for the CG lightning occurrences. *Figure 6* illustrates the observations of *figure 5* in line plots. The state-wise numbers of CG flash occurrences for the mainland in India are shown in the top panel of *figure 6,* while the numbers of CG flashes per unit area, i.e., the CG flash occurrence density is depicted in the bottom panel of *figure 6*. Important observation is that there are two occurrence peaks, one small peak in March-April over Chhatisgarh, Maharashtra, Odisha and Jharkhand states being vulnerable in order, while, other major peak occurring at Chhatisgarh, Odisha, Jharkhand and Maharashtra states. The flash density plot suggests that during the major peak, Chattisgarh, Jharkhand, Odisha and West Bengal to be the vulnerable. The flash density map for the whole mainland India is shown in *figure 7*. The plot suggests two peaks of occurrences with a minor peak in March while the major peak occurring during August – September.

The above findings are somewhat different than that one presented by *Kandalgaonkar et al (2005)*, which was based on Lightning Imaging Sensor (LIS) on the Tropical RainfallMeasuring Mission (TRMM) satellite data showed that over India during March-April major CG lighting flash occurs. However, in another study, *Cecil et al. (2014)*, based on Optical Transient Detector(OTD) on the MicroLab-1 satellite and LIS on the TRMM satellite data showed that over Eastern Indian site, the major peak of annual cycle occur in August-September months. Our results therefore support the findings of *Cecil et al (2014)*. We believe that the differences between *Kandalgaonkar (2005)* and the present investigation may also be a result of time bias of the measurements because the satellite data captures a snapshot information which based on assumption are used to provide sub-daily products as elaborated by *Negri et al.(2002).*

To investigate the temporal variation of the CG lightning occurrences, we perform diurnal analysis on 3 states of varied geography, Odisha, Sikkim and Manipur for 3 different months, August, September and November. The results are plotted in *figure 8* where, top panel show results for Sikkim, central panel represents Manipur while the bottom panel exhibits the diurnal variation observed over Odisha. We note that during November, lightning occurrences are very low to define any preferential diurnal cycle. However, During August, Sikkim data show a diurnal cycle with peak of occurrences at around 20-23 h UT, while, the Manipur data show two distinct peaks occurring at 09-10 h UT (small peak) and 22-23 h UT (major peak). The Odisha too show two peaks of lightning occurrences in August month with a major peak occurring at 10-11 h UT and smaller peak at 17 h UT. In September months, the CG lighting occurrences over Odisha peak around 10-14 h UT, while Manipur data show a slight preference of peak occurrence at 16 h UT and Sikkim data exhibiting two peaks in occurrences, at 09-10 h UT and 22-23 h UT (major peak).

It is also important to note that when we compare the number of events occurred in the year 2020 compared to the year 2019 (figure 5), the dominant events occurrences in terms of geography are changing. While the year 2019 show that Madhya Pradesh and Maharashtra were the states with larger number of CG occurrences, while, in the year 2020, Chattisgarh and Odisha topped. Also, the numbers of CG flashes for Madhya Pradesh and Maharashtra in the year 2020 were lesser than the events noted in 2019. At the same time, the Chattisgarh and Odisha show significantly larger number of CG flash occurrences in the year 2020. This suggests that the vulnerability of a given location may vary from one year to the other. This indicates that multiyear uninterrupted data is required for the generation of a robust vulnerability maps.

The present set up has a limitation in coverage as the Northern and Western states have no sensor established. This also means that statistics presented here may be a bit biased. With the understanding shown in this report, we plan to upscale the network coverage to fill the gaps in such a way that a proper representation of each location in India can be obtained.

Declarations

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