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RESEARCH ARTICLE

Lightning Development over the Distinct Climate Regions of Uttarakhand, India

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Abstract

Objectives: Lightning activity and its connections with meteorology and aerosol loading over Uttarakhand, with varying topography and climates, is studied using ISS Lightning Imaging Sensor (LIS) aboard international space station (ISS) data during the period 2018–2021. **Methods:** To understand the variation of lightning activity with meteorology and aerosol loading the correlation of lightning activity with different meteorological parameters such as surface temperature, convective available potential energy (CAPE), aerosol optical depth (AOD), and convective precipitation is studied. **Findings:** Very poor correlation is observed between lightning flash counts with the meteorological parameters. Annual variation of lightning activity over Uttarakhand shows maximum during the monsoon season (June–September) with a peak during the pre–monsoon season (March–May) month April. The high frequency of western disturbances defined as warm low-pressure systems associated with moisture originated over Mediterranean Sea travelling from west to east across the northern states are responsible for peak lightning activity during pre–monsoon month April and maximum lightning activity in the monsoon season is attributed to the monsoon convection. **Novelty:** The study made the spatio – temporal variation of lightning over Uttarakhand and also reveals the connection between lightning and different meteorological parameters in different climatic conditions of Uttarakhand which is first defining the importance of large-scale meteorological processes in the development of lightning in Uttarakhand.

Keywords: Lightning; Meteorological Parameters; Aerosol optical depth and Convective Available Potential energy (CAPE)

1 Introduction

Lightning is considered one of the major hazards, which is responsible for hundreds of death every year. It is developed due to the convective activities in the cumulonimbus clouds[1]. Lightning activities are increasing at the rate of 0.096 fl km^{-2} a^{-1} over the south Asia region[2]. In the lightning clouds, the negative charge is concentrated on the atmospheric temperature range -10 °C to -20 °C and the positive charge is spread in deeper layers above the negative charge. The development of an electric field within the cloud depends on cloud types, cloud base heights and the sunrise effect [3,4]. Both lightning and rainfall are the products of convection but the key difference is the dependence on the updraft speed[5]. Based on satellite and Indian lightning location sensor datasets, it is observed that nearly 93 % of lightning activities are occurring in the Himalayas due to western disturbances[6]. Recently, Midya studied the thunderstorm over Kolkata and found that more than 30 lightning events per minute at the highest wind speed of 50 km/h[7], Umakanth claims that lightning-related deaths are increasing and it has a 75% correlation with rainfall over Kerala[8]. Whereas in another study, he also reported a strong correlation (r= 0.83) between the flash rate density & Convective Available Potential Energy (CAPE) over Andhra Pradesh[9]. Dust storms also have a significant contribution to lightning activities, dust events provoke 30% positive lightning activities (200 flashes per min) over the northwest & north-eastern part[10]. Global warming is also increasing lightning activity and electrifying clouds due to a raise in surface temperature[11]. Lightning activities are also affected by the El Niño Southern Oscillation (ENSO) and are responsible for the increment in the lightning activities over the eastern India region[12].

CAPE is a measure of buoyancy force, which plays an important role in determining vertical updraft velocity. CAPE is dominating over the northeast region as well it is strongly impacted by the progress of the monsoon[13]. In the Himalayan region, CAPE and surface temperature are responsible for the instability (50-60 % relative humidity at 700 hpa) and lead to an ideal condition for intense lightning[14]. The satellite and model datasets are indicating that lightning activities are also governed by the aerosol concentration and it is increasing with the aerosol concentration[15,16]. The lightning activities also depend on elevation, the slope of mountains and vegetation over the Himalayan region. Lightning activities are dominating over the dry higher terrain slope/elevation as well as moist lower terrain slope/elevation in the north-west & north-east Himalayan region of India[17].

Based on the previous literature review, we have identified some major gaps that the earlier studies have focused only on the spatiotemporal variation of lightning activity variation with different meteorological parameters and the Influence of ENSO, based on an old dataset from 1998 to 2014. In the past 20 years, the mortality rate due to lightning has increased by 52.8 %[18]. Therefore, we need to address these issues seriously with the latest data sets and we need to explore the lightning activity over distinct topography and climate regions of Uttarakhand.

2 Methodology

2.1 Data–sets

The lightning data is collected from Lightning Imaging Sensor (LIS) on board the International Space station (ISS) during the period 2018–2021. The lightning imaging sensor detects total lightning (Cloud to ground, cloud to cloud, and intra-cloud) and is used to detect the distribution and variability of lightning. The spare LIS was placed aboard International Space Station (ISS) in Feb 2017 for a two to the four-year mission. The LIS is a part of the Department of Defence (DoD) Space Test Program (STP)-H5 science and technology development payload. The lightning imaging sensor detects lightning at millisecond timing with a storm-scale resolution over a wide range of the earth's surface. The lightning imaging sensor with 90% detection efficiency records lightning occurrence, measures the radiant energy and determines the lightning location. The coverage area of LIS is +/- 55 degrees latitude[8].surface temperature, CAPE and convective precipitation with 0.25° x 0.25° grid resolution data for the period 2018-2021 are retrifromERA5 (Fgeneratreanalysis)website http://climate.copernicus.eu/products/climate-reanalysis. Aerosol optical depth (AOD) of 550 nm with 1°x1° grid resolution data is retrieved from Moderate Resolution Imaging Spectroradiometer (MODIS)T(https://giovanni.gsfc.nasa.gov/giovanni)for the period 2018 – 2021. More details of different region of India & World[13,15]

2.2 Location and climate of the area of Investigation

Uttarakhand lies on the south slopes of the Himalaya ranges in the northern part of India with boundaries latitude 28°43'-31°27' N and longitude 77°34'-81°02' E (Figure 1). The state is surrounded by China in north Nepal in the east and Himachal Pradesh in the northwest. The state's mostly hilly region is governed by two climates, hot and moist sub-tropical in the southern part to cold alpine in the upper reaches in the northern parts. Its location is shown in Figure 1 with different climatic regions. The topography of the region varies from 200 to 7817 meters above mean sea level. The whole year is divided into four seasons,

winter season (December-February), pre–monsoon season (March–May), south-west monsoon season (June–September), and post-monsoon season (October–November) [19].

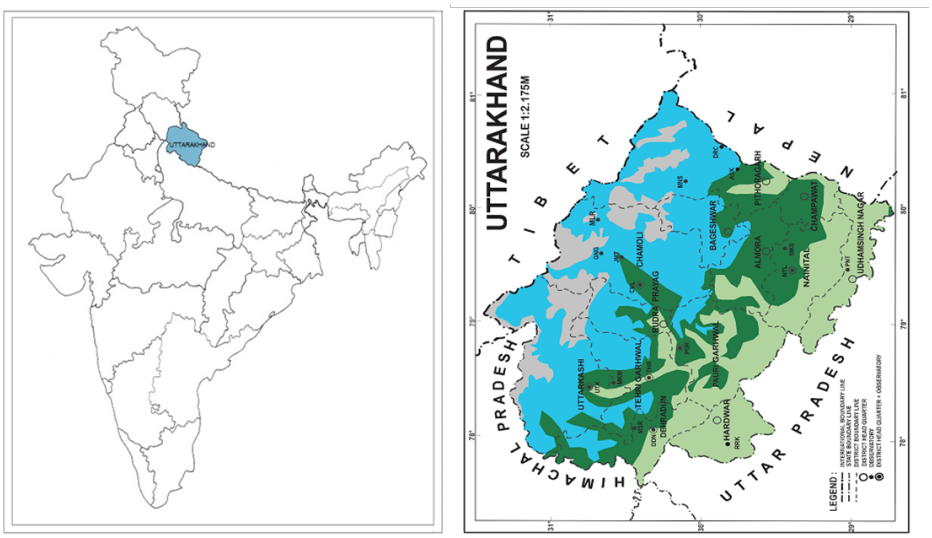

Fig 1. Location and topographical map of Uttarakhand, *Source: IMD report 2014*

3 Results and Discussion

3.1 Annual variation of lightning and meteorological parameters

Figure 2 represents the annual variation of lightning activity over Uttarakhand. Lightning over this region starts increasing from the pre–monsoon month of March (61flashes) and attains peak value during the month of April (623 flashes), thereafter starts decreasing during monsoon season (224 flashes) with fluctuating values during June–September. Lightning activities are more during the monsoon season as compared to pre–monsoon, post–monsoon and no lightning activity in the winter season. The increase in lightning activities in the Himalayan region is perhaps due to a raise in surface temperature and long vertical thermal profiles of clouds during the pre–monsoon season [20]. In the year 2021, Tinmakar and his team, have studied the lightening activities over India in the dry (Before Monsoon) & wet during (Monsoon) and found that the correlation coefficient of AOD (20%), rainfall (28%) and cloud ice content (34%) higher in dye than wet season [6]. Recently researchers have found that lightning activities are also affected by the temperature and carbon dioxide in India [21].

Annual variation of surface temperature shows increasing from pre–monsoon season month March (7.32 °C) and attains maximum value during monsoon season month July (20.01 °C). Furthermore, starts decreasing during post–monsoon season and reaches to minimum value during the winter season (1.26 °C). A similar trend is observed in aerosol optical depth and convective precipitation with peak value during July at 0.76 & 0.0056 m respectively (Figure 3). An increasing trend is observed in CAPE during pre–monsoon (65.34 J/kg) and monsoon seasons (380.43 J/kg) with a peak during September (472.32 J/kg) month and a minimum during the winter season (12.42 J/kg) (Figure 3). The increment in the surface temperature and CAPE during pre-monsoon leads a thermodynamic instability of the atmosphere, as a result, air parcels will raise above freezing points to form ice particles, which is considered a promoter of lightning activities [13]. None of the meteorological parameters follows the trend of the lightning flash count, which shows that contribution of meteorological parameters in the development of lightning activity over Uttarakhand is less. This clearly emphasizes the role of large-scale meteorological processes such as western disturbance [15] orographic convection and monsoon convection in the development of lightning activity in this region. The contribution of orographic convection over Uttarakhand is explained by Gautam in his recent publication in the year 2022 [22].

Western disturbance is a synoptic system with origin over the Mediterranean Sea, Black Sea, & the Caspian Sea. This cyclonic circulation is extending up to 0.9 km in the lower Troposphere that moves from the west-east over north India. These western disturbances with a 2 to 4 days life period visit the state with a frequency of about 4 during March–April [6]. These western disturbances are mainly responsible for the lightning development over Uttarakhand during pre–monsoon season.

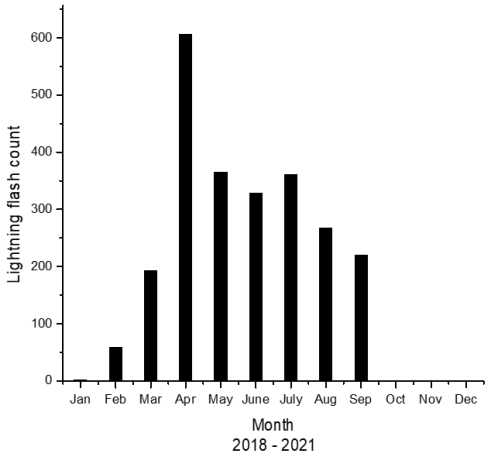

Fig 2. Monthly variation of lightning flash count over Uttarakhand during the period 2018 - 2021

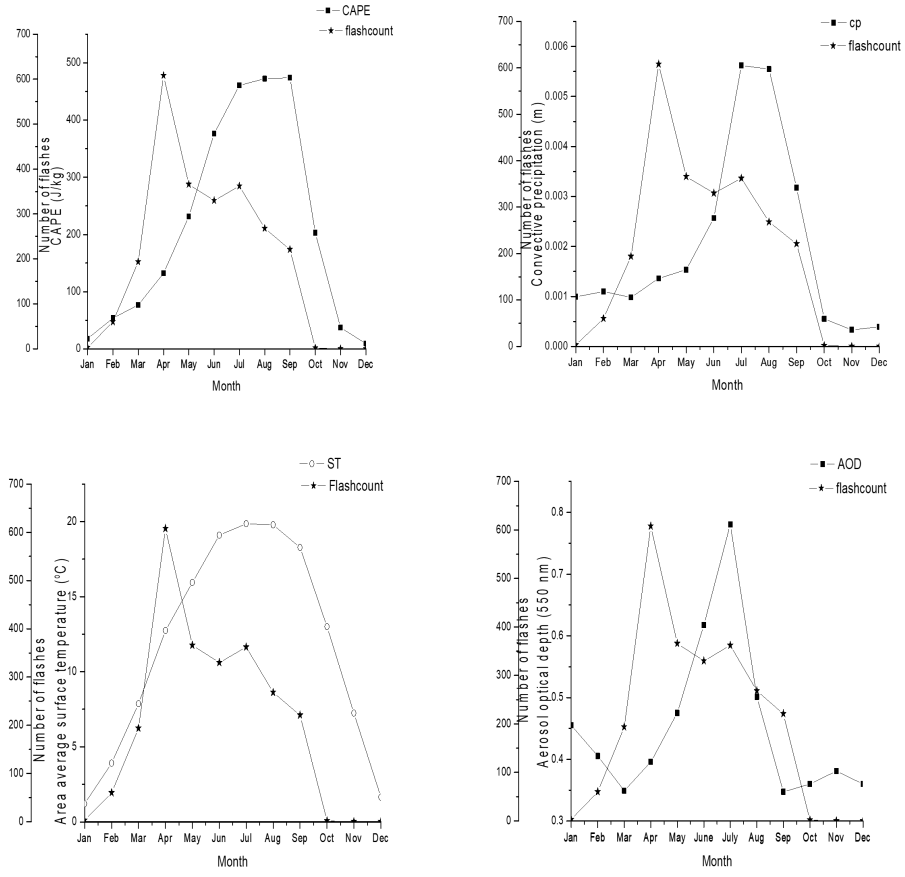

Fig 3. Monthly variation of convective available potential energy (CAPE0, convective precipitation (cp), surface temperature (ST), and Aerosol optical depth (AOD), respectively

The association of lightning activities and western disturbance is supported by Indian researchers such as Murugavel & Shukla in their regions [23,24]. According to a recent study, the winter-time lightning over the foothills of the Himalayas region is due to the contribution of western disturbance [14]. Lightning activity is maximum during monsoon season over this region with fluctuating trend from June to September. The convection over this region from June to September is mainly due to the advance of the south-west monsoon. Lightning activity is minimum or almost no lightning activity is observed in the winter season over this region.

3.2 Correlation of lightning with meteorological parameters

The correlation coefficient (r) and the corresponding p values (with a significance level of 0.05) of lightning flash count and meteorological parameters convective available potential energy, aerosol optical depth, and convective precipitation is not significant (Figure 4). But the correlation between lightning flash count and surface temperature is significant. This clearly shows that the meteorological parameters which are responsible for the local convection (except surface temperature) are not significant and indicates the importance of convection due to surface temperature (ST), large scale meteorological processes like monsoon convection, convection due to orography, and western disturbance in the development of lightning activity over Uttarakhand.

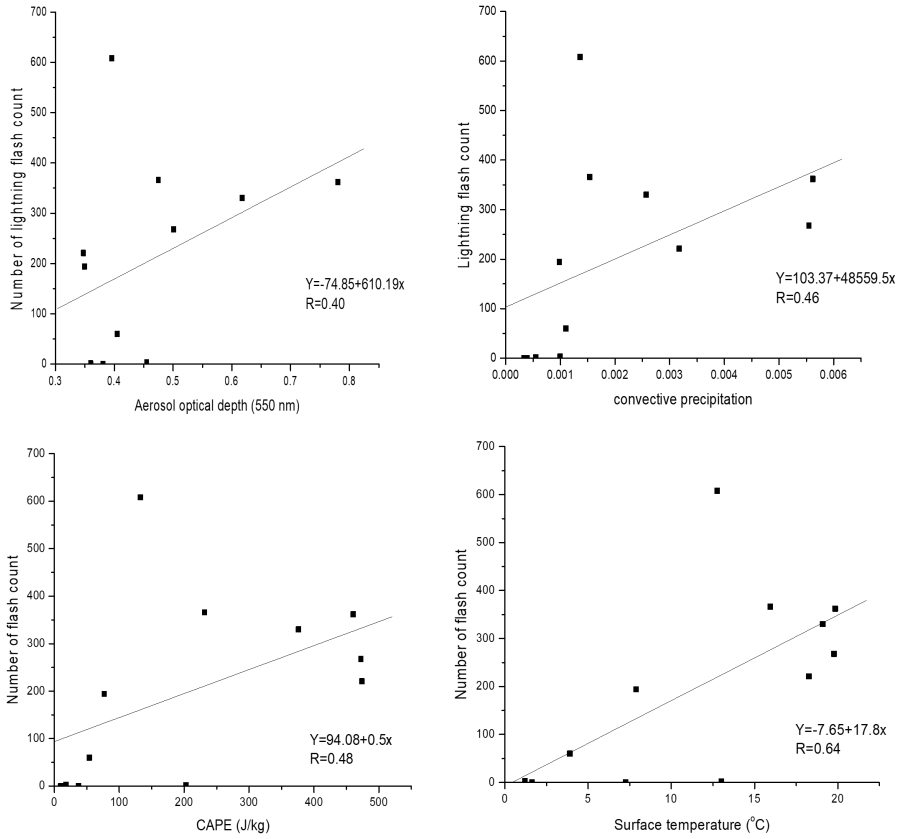

Fig 4. Correlation of lightning flash count with AOD, CP, CAPE, and ST, respectively

3.3 Spatio-temporal variation of lightning

The spatial variation of lightning over Uttarakhand is found to start from the winter season & spread across the state reaching peak value in the pre–monsoon season month of April highest 235 lightning events (Figure 5). The concentration of lightning flash count is more over the central, west, east and southern slopes of Uttarakhand compared to the northern districts of the state. The lightning flash count spread across the state during pre–monsoon and monsoon seasons with a decreasing trend

from May reaching to minimum value during post–monsoon & winter seasons. Maximum lightning activity is observed over south-western part of the state, where the lightning activity starts in February (42 lightning events) and continues to increase till the end of the monsoon season month of September. South-east is the other region of the state where the lightning activity is maximum. Lightning activity is minimum in the northern parts of the state. Similarly, Gautam and his team also plotted the spatial variation of lightning activities over Uttarakhand & the western part of Uttar Pradesh, they reported that the central and south-eastern parts of Uttarakhand have high lightning activities than the north-western part due to aerosol loading [22].

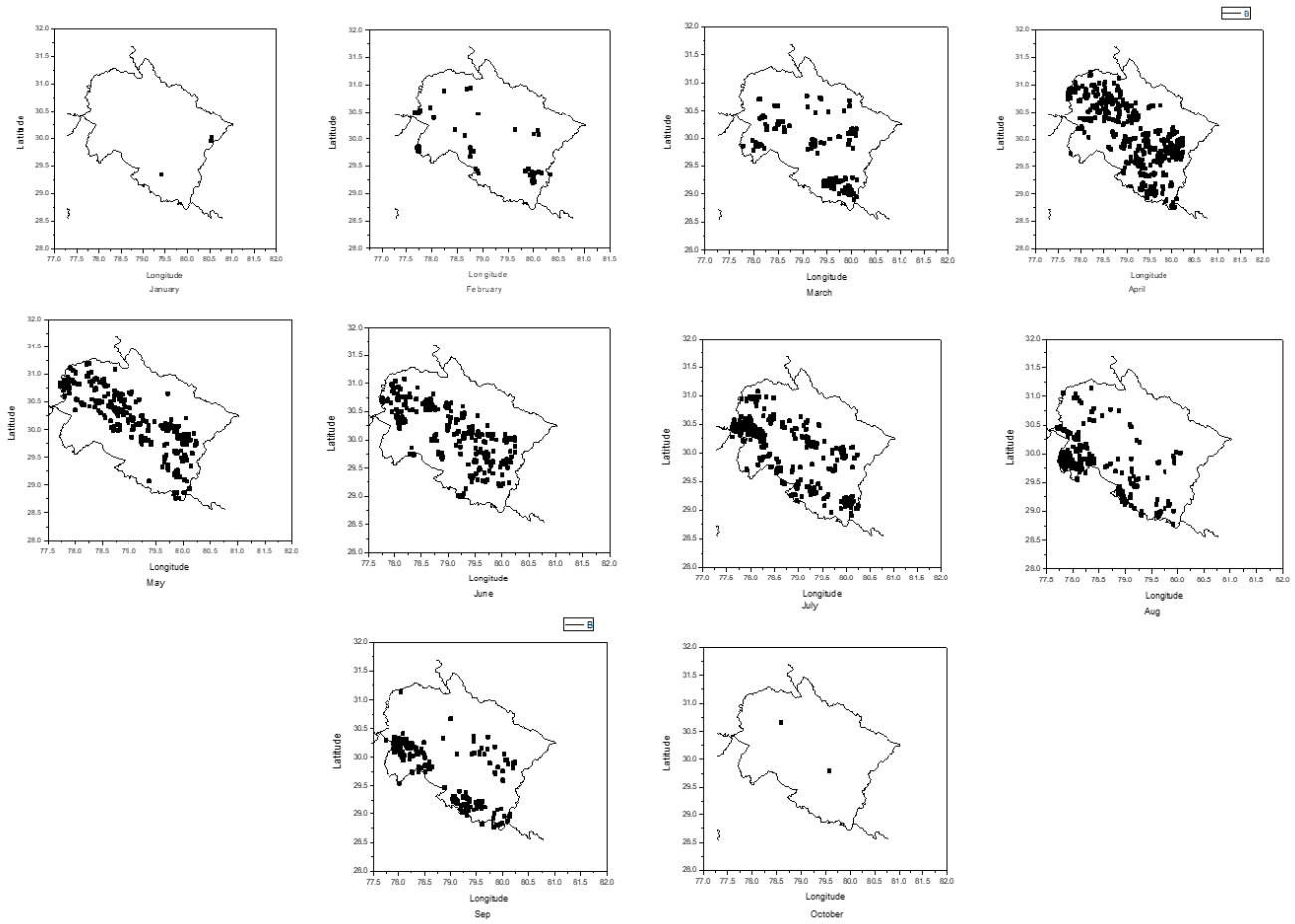

Fig 5. Spatio-temporal map of lightning flash count over Uttarkhand during the period 2018 - 2021

According to Koppen's climate classification of Uttarakhand based on precipitation and temperature, the western region is governed by a hot summer, subtropical monsoon and mild dry winter climate [25]. The hot summer in the pre–monsoon and the subtropical monsoon convection in the western region are responsible for the lightning activity during both seasons. The eastern part of the state is associated with mild winters and short warm summers. The lightning activity in the state is mainly due to the high frequency of western disturbances during March and April. Monsoon convection is responsible for the development of lightning activity over this region during monsoon season.

4 Conclusion

We have investigated the role of temperature, convective rainfall, CAPE & AOD on lightning activities and written down some of the important results in this conclusion section. We have reported that the lightning activities are increasing from March (61 flashes) and reaching the peak value during April (623 flashes) due to increased surface temperature & thermodynamics instability in pre–monsoon season. The maximum surface temperature (20.01 °C), convective precipitation (0.0056 m), and AOD (0.76) have been recorded during July, whereas maximum CAPE (472.32 J/kg) has been recorded during September

perhaps due to monsoon. We have also investigated the correlation between lightning activities & meteorological parameters such as temperature (r=0.68), convective precipitation (r=0.46), AOD (r=0.40) and CAPE (r=0.48), which indicated that the lightning activities are not depending upon only meteorological parameters. Some other processes such as western disturbance, monsoon convection, and orography have a significant role. The present study reveals that the lightning activities are maximum over the south-western and south-eastern regions of Uttarakhand, The lightning activities start in February (42 lightning events) and reached peak value during April month (235 lightning events). The lightning over the state is mainly due to the western disturbance in the pre–monsoon season and the monsoon convection.

5 Limitation of the study

1. The study is focused on Uttarakhand only.
2. Only three-year datasets are used in the manuscript.
3. Only Surface temperature, Convective precipitation, AOD and cape are used in this study.

6 Future Scope

1. This study can be extended to the remaining other Himalayan regions such as Jammu & Kashmir, Himachal Pradesh and north –eastern states.
2. More parameters such as Bowmen Ratio, Vegetation Index and slope can be added in upcoming manuscripts.
3. This manuscript will be very beneficial for beginner researchers, our findings will be helpful to select the different parameters of lightning activities.
4. This manuscript is very helpful to understand the different lightning zones over Uttarakhand and helpful to fabricate lightning protection & safety policies.
5. Lighting is one of the essential climatic variables, therefore, more research is required to understand climate change.
6. To understand the importance of meteorological processes in lightning development further study is suggested.

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