The possible impact of atmospheric aerosol and other factors on lightning over the rugged terrain of Nepal

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Abstract— **Electrification of thunderclouds and lightning initiation from within the cloud remain the mysteries among scientists and researchers. Meteorological and atmospheric factors that play a vital role in generating thunderstorms over the mountainous terrain of Nepal further add ambiguity. Atmospheric aerosol contents and Convective Available Potential Energy (CAPE) are believed to play major roles in generating thunderstorms. In this study, thunderstorm activities over the mountainous country Nepal have been investigated in association with Aerosol Optical Depth (AOD) and the CAPE for six years between 2015 to 2020. Lightning stroke density was used to measure thunderstorm activity and their possible association with atmospheric aerosol, and CAPE. For the investigation, we chose the pre-monsoon period that begins in March and ends in June, because thunderstorm activities are prevalent during this period. Our preliminary investigation shows that atmospheric aerosol plays a significant role in generating thunderstorms, and those thunderstorm activities significantly dropped in the year 2020, corresponding to the reduction in the value of Aerosol Optical Depth (AOD). However, AOD alone does not play a pivotal role in thunderstorm activities. The correlation coefficient of average AOD with that of stroke density was about 0.57 exhibiting a weak correlation in March. Similarly, CAPE has also been found to play a significant role for thunderstorm activities. Its correlation coefficient with stroke density is found to be about 0.59 during the pre-monsoon exhibiting a weak correlation in the month of March and exhibits highest correlation during the Month of April, 2015 as compared to the other months. Although CAPE and Aerosol play significant roles in generating thunderstorms, they alone are not the determiner and that other climatic factors should also be considered.**

Keywords—Nepal, lightning, thunderstorm, AOD, CAPE

I. Introduction

Lightning is one of the most common atmospheric activities that every human civilization has witnessed since time immemorial. The beginning of the scientific study of lightning is attributed to Benjamin Franklin, dating back to 1752. Many facts on the physics of lightning have been unveiled since then. However, several intriguing aspects still remain unanswered. One of such questions remains unanswered is the development of electrical charge within the thunder cloud and its association with other atmospheric factors such as surface temperature, humidity, convective available potential energy (CAPE), aerosol content, precipitation, etc.

Lightning originates from electrification in convective cloud systems and is modulated by cloud dynamics and microphysics [1], [2]. Supercooled liquid water and ice crystals are two essential ingredients for charge separation and thunderstorm electrification that can explain the occurrence of most lightning in the mixed-phase region in the temperature range of 0 to −40°C [3], [4]. Added aerosol particles contribute to the cloud microphysical processes by serving as cloud condensation nuclei (CCN) or ice nuclei that eventually create a conducive environment for the charge formation in the thundercloud. However, the effect of added aerosol loading in lightning invigoration has not been understood very well as of today.

It has been shown in laboratory studies that collisions between all these particles (especially ice and graupel) in this mixed-phase region of clouds are critical for the charge transfer between cloud particles [3], [4]. Predominant ice crystals in the mixed-phase region, with small amounts of supercooled water and graupel, little electrification, and little lightning have been observed [5].

Cloud particle collisions are the primary mechanism for cloud electrification. In order that the cloud electrification invigorates in the mixed-phase region, a strong updraft is needed. Studies show that, on different temporal and spatial scales, small changes in surface temperature result in large changes in thunderstorms and lightning activity (a nonlinear link) [6], [7]. Furthermore, the increase in CAPE in the present climate shows an increase in thunderstorms [6]. However, it appears that the CAPE in thunderstorms actually increases in a warmer climate, while in the fair-weather troposphere, the overall instability decreases [8]. Based on the observations of lightning ground flashes in association with the product of CAPE and precipitation over the Contiguous United States (CONUS), it was proposed that lightning flash rate change proportionally with the product of CAPE and precipitation rate [9].

While the impact of the atmospheric factors on lightning and thunderstorms remains unclear, the complexity of such factors over the rugged mountainous terrain of Nepal is rather perplexing.

In order to understand the role of such factors, we investigated the impact of Aerosol Optical Depth AOD as a measure of atmospheric aerosol and CAPE on lightning activities over Nepal.

II. Analysis and Results

In this study, we have investigated the association of lightning strikes with various atmospheric factors that may play a role in cloud electrification and hence create a conducive environment for lightning discharge over the terrain of Nepal. For the investigation, we utilized the lightning data GLD 360 from VAISALA [10], [11] that has also been used in [12] for the same region, and aerosol data from the MODerate resolution Imaging Spectro-radiometer (MODIS) Aqua satellites acquired between 2015 and 2020. The values of CAPE and surface temperature were obtained from the European Centre for Medium-Range Weather Forecasts (ECMWF).

Utilizing the available data acquired from various sources, maps for lightning stroke density, AOD and CAPE were obtained by using shape files being provided by the Department of Survey, the Government of Nepal. It was noticed that the values of CAPE were not available over the whole of Nepal but there were certain bands where the data were missing. It is therefore, lightning data were selected for those regions along which the CAPE data were available. However, for AOD, lightning stroke data were plotted over the whole Nepal.

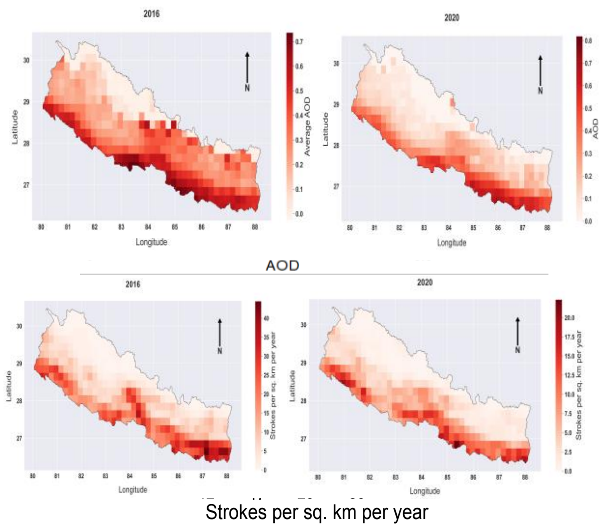

Figure 1: Examples of the plots for AOD and lightning stroke density for the years 2016 and 2020. The upper panels are the maps for AOD and the lower panels are the maps of lightning stroke density.

It is observed from the maps plotted for AOD and lightning strokes from 2015 to 2020, that both AOD and lightning stroke density are maximum in the southern part of the country.

Both AOD and lightning density are found to be relatively low in the middle hills and least in the high mountains. It is further observed that the lightning stroke densities are high over the regions of high AOD values. Also, it is observed that both lightning stroke density and AOD are relatively sparse in the year 2020, compared to the previous five years (see figure 1). This was the year when most of the anthropogenic activities producing aerosols were suspended due to lockdown imposed across the globe owing to the COVID-19 pandemic. This indicates that aerosol could play a significant role in the occurrence of lightning activities.

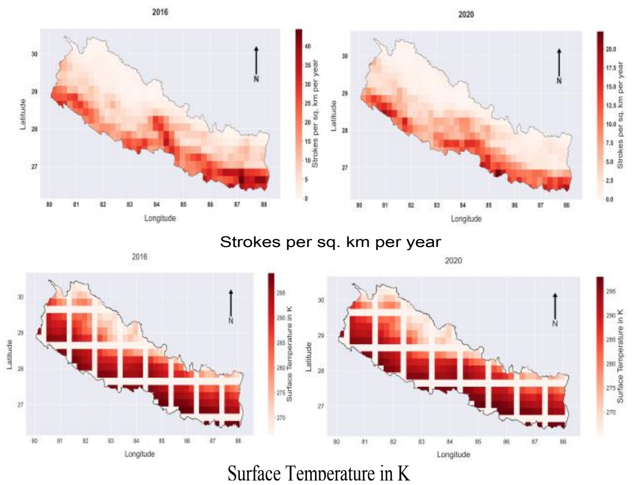

Figure 2: Example plots of lightning stroke density (upper panel) for the pre-monsoon period of years 2016 and 2020 and surface temperature for the same period (lower panel).

As is seen in the maps in figure 2, lightning stroke density during the pre-monsoon period has reduced from 2016 to 2020 whereas the surface temperature does not exhibit a significant change. This further justifies that AOD plays an important role in the charge electrification of thunderclouds.

Since CAPE has been reported to play a vital role in the variations of lightning activities over CONUS [9], we have investigated the variations in thunderstorm activities with CAPE over the rugged terrain of Nepal. While plotting the CAPE data over Nepal we observed that there are several bands where the CAPE data were missing. Although those data could have been extrapolated, we plotted the lightning strikes over the same region. We plotted the data pertinent to both the variables for each pre-monsoon month (March-June) and for the years 2015 to 2020. An example of such a plot is depicted in figure 3. As can be noticed from figure 3, it was not possible for us to make any conclusion from the corresponding maps of CAPE and lightning strikes for the regions under computation.

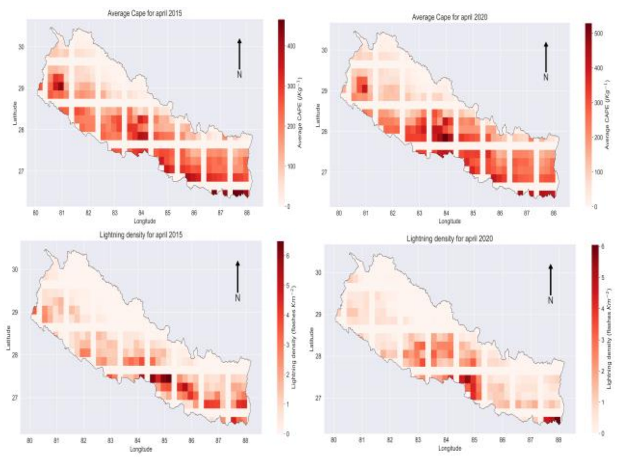

Figure 3: Example plots of value of CAPE (upper panel) and lightning stroke density (lower panel) over Nepal for the month of April of the years 2015 and 2020.

Owing to our limitation towards making any significant conclusion on the role of CAPE for lightning activities, we extracted corresponding data from each 20 km× 20 km square box obtained using fishnet. Both the data for lightning strikes and CAPE were then averaged for each selected region and the correlation coefficient was computed. Such computation was conducted for each pre-monsoon month and for all the pre-monsoons of the years under consideration. Figure 4 depicts plots of correlations between CAPE and lightning stroke for the pre-monsoons of 2015 and 2020, and that for the months.

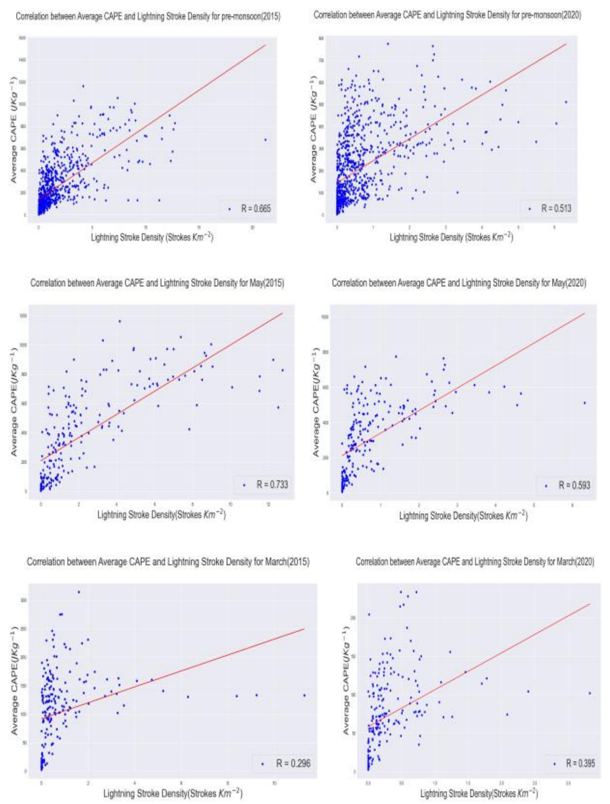

Figure 4: Example plots of correlation between the average value of CAPE and lightning stroke density for the pre-monsoon periods 2015 and 2020 (top panel), plots for months of May (2015 & 2020) for which the value of correlation coefficient was maximum (middle panel) and plots for the month of March (2015 & 2020) for which the correlation was comparatively very weak.

As seen in figure 4, lightning strikes exhibit a fairly good correlation with CAPE during the pre-monsoon showing weak correlation in March and fairly strong correlation in May. The average value of the correlation coefficient for the period under investigation was obtained to be 0.59 with a minimum value of 0.244 for the month of March 2019 whereas, a maximum value of 0.733 for the month of April 2015. Investigation on the role of CAPE in producing lightning over the mountainous terrain shows a fairly good correlation though, it is premature to claim that CAPE is the determining factor for thunderstorm activities. Furthermore, due to the fact that data pertinent to CAPE covering the whole region was not available, may enable us for making a conclusion.

Similar, plots were also computed between the AOD and lightning strikes. Figure 5 (a) shows maps of average AOD and lightning strike density for the same months as that of CAPE and lightning strikes in figure 4. The average value of the correlation coefficient for the pre-monsoon period under consideration was obtained to be 0.569 with highest correlation (r=0.774) in 2019 and lowest correlation (r=0.547) in 2016 as shown in figure 5 (b). Of all the months under investigation, extremely weak correlation (r=0.037) was observed for the month of March 2018, and a strong correlation (r=0.661) was observed for the month of May 2020. Although the lightning activity exhibits a fair correlation with AOD, the best correlation was obtained when the atmosphere was least polluted in the year 2020. Based on the outcome of this investigation it is apparent that atmosphere with heavily loaded aerosol content does not help increase the thunderstorm activities.

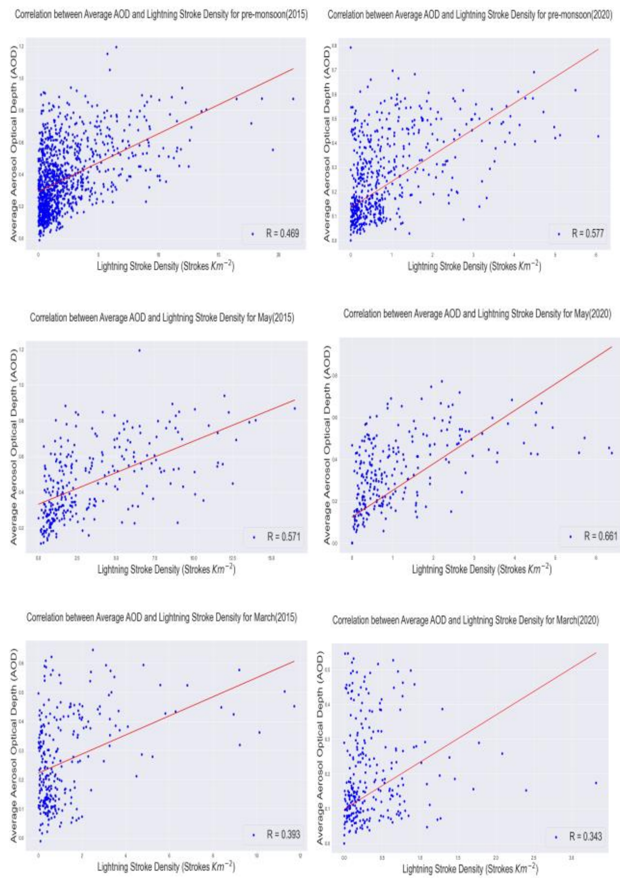

Figure 5(a): Example plots of correlation between the average value of AOD and lightning stroke density for the pre-monsoon periods 2015 and 2020 (top panel), plots for months of May (2015 & 2020) for which the value of correlation coefficient was maximum (middle panel) and plots for the month of March (2015 & 2020) for which the correlation was comparatively weak.

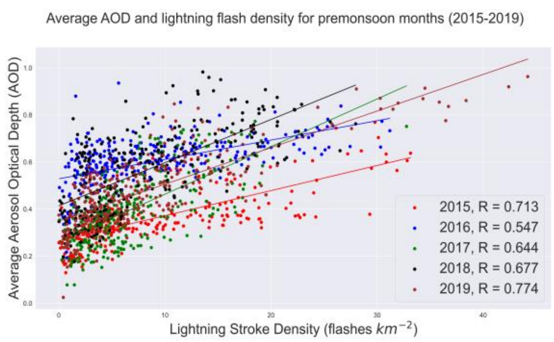

Figure 5(b): Example plots of correlation between the average value of AOD and lightning stroke density for the pre-monsoon periods 2015 and 2019 plotted in single panel. Highest correlation was obtained for the pre-monsoon period of 2019 and lowest correlation was obtained for the year 2016.

III. DISCUSSION

Global lightning and thunderstorm activity is driven first and foremost by the Earth's climate, driven by solar insolation that varies with latitude, longitude (land/ocean), season, and hour [8]. The climate drives circulation patterns that promote thunderstorms in the tropics and mid-latitudes and inhibit thunderstorms in the subtropics and polar regions. Locally, thunderstorm activity depends on surface temperature, water vapor, the tropospheric lapse rate, as well as aerosol loading [8]. These parameters can impact the intensity and polarity of lightning in thunderstorms [8]. Despite all the above conclusions drawn based on several studies in the past, it is not yet very clear what atmospheric factor plays a crucial role in the microphysics and dynamics of the thunderclouds that result in lightning activities. In addition, the meteorological variability over the mountainous region is not very well understood. In this context, in the present work, we have attempted to investigate the association of lightning activities measured in terms of stroke density with other atmospheric factors. The results of this investigation show that CAPE plays an important role in emanating lightning activities. However, the aerosol plays an important role when the atmosphere is less polluted, whereas more investigation should be carried out in order to obtain any concrete conclusions. Nevertheless, aerosol loading in the atmosphere certainly aggravates climate change not only by creating a blanket for global warming but also by causing Himalayan glaciers to melt rapidly. Furthermore, aerosol, if altered by lightning activities could impact atmospheric nitrogen oxides (NOx) and tropospheric ozone, thereby contributing to global warming. This study provides some key information on the role of atmospheric factors in changing thunderstorm activities and that such information will be useful to undertake appropriate measures toward climate action.

IV. SUMMARY AND CONCLUSION

Lightning activities have been monitored in association with other atmospheric factors. Our investigation has shown that lightning activities are affected by AOD in general. However, a more detailed study has to be carried out for further confirmation on a daily basis. The preliminary results also suggest that lightning was significantly reduced with the reduction in AOD, while the surface temperature did not change significantly. Nevertheless, aerosol can be attributed to the enhanced lightning activities and hence lightning can be argued as a proxy for climate change. This further confirms that atmospheric aerosol plays a significant role in climate change over the Himalayas directly by melting the glaciers and indirectly enhancing the lightning that eventually produces greenhouse gases.

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