Understanding the Seasonal distribution of Lightning Fraction over the Indian Region and incorporation in the Numerical Weather Prediction Model

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Abstract

The Four years of IITM LLN lightning observation data are used to determine the seasonal and spatial (over different geographical locations) distribution of the ratio of intra-cloud lightning (IC) to cloud-to-ground lightning (CG) in thunderstorms over the Indian sub-continent. Pre-monsoon thunderstorms exhibit more IC discharge comparatively to monsoonal thunderstorms; hence IC:CG ratio is also high in pre-monsoon. In this paper, we have shown that CG lightning is approximately 20% of total lightning in pre-monsoon whereas 25% of total lightning in monsoon all over the Indian region. The ratio is high (6-10) in the north-western parts and low (0.5-3.5) in the north-eastern parts. There is not a prominent latitudinal variation of IC and CG ratio, but a climatological seasonal variability exists over all regions. High CAPE associated with a stronger vertical updraft enhances the cold cloud depth and expands the mixed phase region, which can broaden and uplift the size of the upper positive charge center inside a thunderstorm while the middle negative charge center remains at the same temperature level. Therefore it enhances the occurrence of IC discharge between the upper positive charge center and middle negative charge center, hence increasing the IC:CG ratio of a thunderstorm. The implication of these observed results has the importance to separate CG lightning flash from total and can be used in numerical models to give a proper prediction of CG lightning in hazard mitigation.

Introduction

Total lightning is a combination of intra-cloud lightning (IC) and cloud-to-ground lightning (CG). There is regional variability in the estimation of the fraction of CG lightning flash rate from the total lightning flash rate (Goodman & Christian, 1993; Cummins et al., 1998; Goodman et al., 2000).). At the equator, approximately 10% of the total lightning and at the 65° latitude, about 60% of total lightning reaches the ground from the thunderstorms. Therefore, the total lightning flash rate for individual storms may require knowledge of the long-term regional differences in the relative contribution of intra-cloud (IC) and cloud-to-ground (CG) flashes to the total flash rate, reflected in the IC:CG ratio. There are very limited studies assessing the IC:CG ratio and its spatial and seasonal variability over the Indian sub-continent. Moreover, recent studies (Mallick et al., 2022) have shown that lightning-related loss of human lives and loss of properties primarily happens during the monsoon season in the Indian region. So it is essential to identify a particular region where the CG lightning fraction dominates seasonally. So, in this present study, we analyzed ground-based high-resolution lightning data obtained from the IITM lightning location network (LLN) over India for the years 2019-2022 to estimate the geographical, latitudinal, and as well as seasonal (mainly Monsoon and Pre-monsoon season) distribution of IC:CG ratios.

Data & Methodology

The IITM LLN has been established in the year 2018 all over India (see Figure 1 for sensors locations) by the Earth Network. This network detects CG lightning in the frequency range of 1 kHz to 1 MHz with 90% detection efficiency, IC lightning in the frequency range of 1MHz to 12 MHz with 50% detection efficiency, and location accuracy of 300m (Mudiar et al., 2021). The total lightning for four years (Dec 2018 to Nov 2022) detected by IITM-LLN was counted at each 0.25° × 0.25° grid. Then the IC: CG ratios (Z-ratios) are calculated over India in each 0.25° × 0.25° grid considering the detection efficiency (Bandholnopparat et al., 2020) using the relation:

$$\text{Z-ratio} = \frac{(\frac{N_{IC}}{d_{IC}})}{(\frac{N_{CG}}{d_{CG}})} \qquad (1)$$

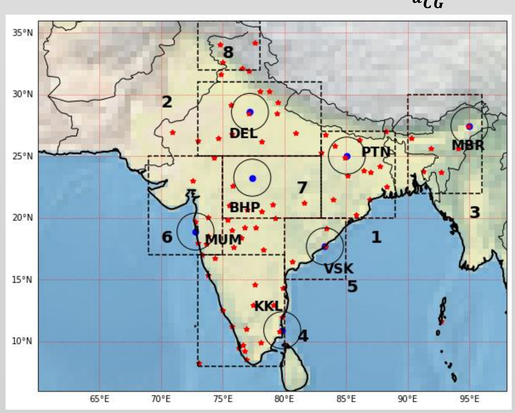


Fig 1: IITM LLN sensors location with eight different regions with S band radar location

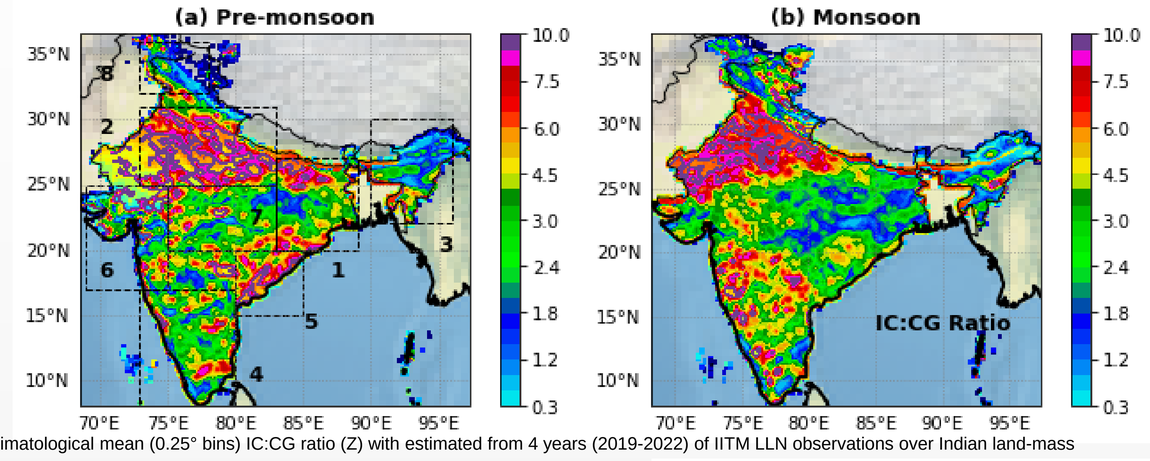
Where N_{IC} and N_{CG} represent the total number of IC lightning flashes and CG lightning flashes respectively. Whereas d_{IC} and d_{CG} denote the detection efficiency of IC and CG lightning flash over India, respectively.

S- band Doppler radar data are utilized to find the cold cloud depth of different lightning producing storms from pre-monsoon and monsoon.

A WRF model simulation has been done with the observed Z ratios over Region 7.

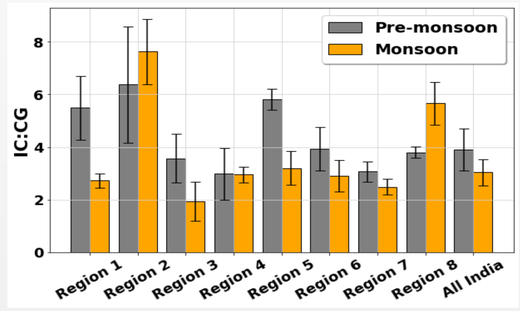
Results & Discussion

Geographical distribution of Z ratio



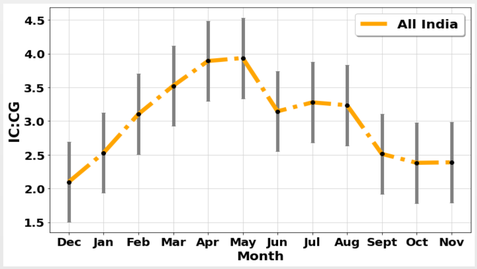
Climatological mean (0.25° bins) IC:CG ratio (Z) with estimated from 4 years (2019-2022) of IITM LLN observations over Indian land-mass

- **Higher anomaly of Z ratio is observed to be in the northwest region.**
- **Lower anomaly of Z ratio is observed to be in the northeast region in all climatic regimes.**
- **Most of the parts how high values in pre-monsoon compared to monsoon (except northwest parts).**

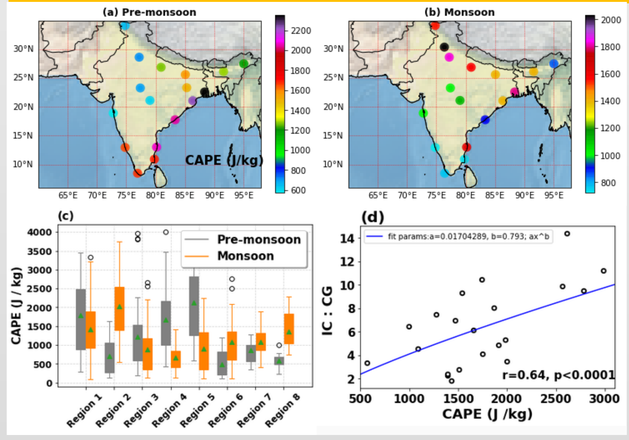


Seasonal variation of Z ratio

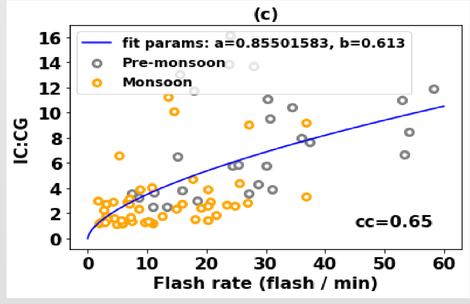
- **Maximum Z ratio is observed to be in May**
- **Minimum Z ratio is observed to be in December**
- **Just after monsoon onset, the ratio sharply decreases.**
- **Seasonal convective updraft may impact on the seasonal variability of Z ratio.**



Convective vigor dependence



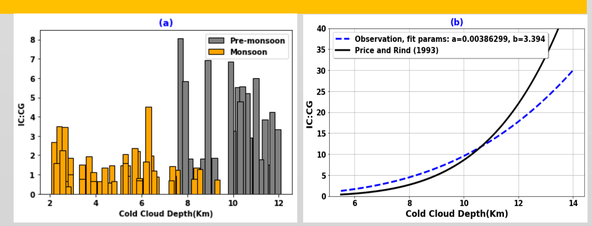
Total Flash rate dependence



- **High flash rate mostly associated with high IC discharge.**
- **In pre-monsoon season, the relation may be more prominent.**
- **In some storms in monsoon , the relation is observed to be weak.**

Cold cloud depth dependence

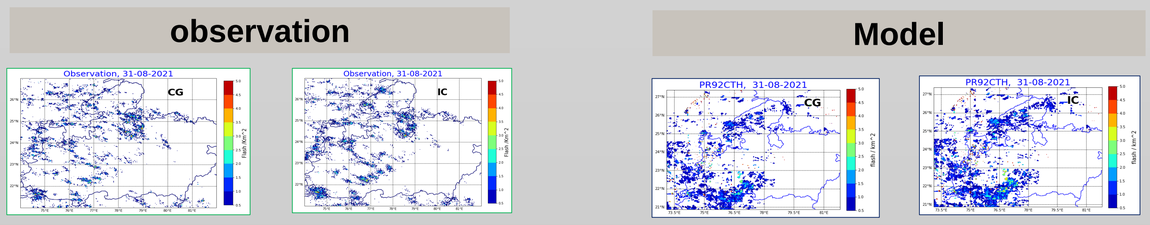
- **High cold cloud depth may be proportional to high Z ratio.**
- **Pre-monsoon storms exhibit lightning with high Z ratio.**
- **Type of storms may influence on the Z ratio characteristics.**



(a) IC:CG ratio as a function of cold cloud. (b) The black color curve line represents the PR93 scheme and the blue dash curve line signifies the observed relation.

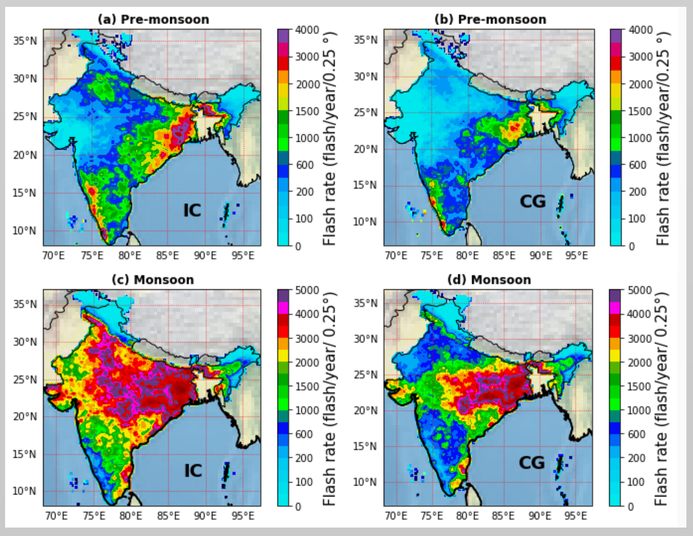
IC & CG Separation from NWP Model

WRF lightning simulation (31.08.2021) over Region 7



Climatological distribution of IC & CG

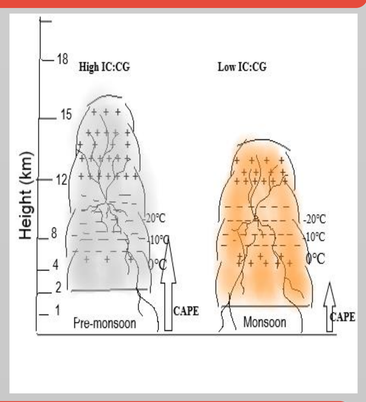
- **In Pre-monsoon, most of the lightning activity is observed to be along east coast, southern-peninsular, northeastern region.**
- **Northwestern region shows a higher proportion of IC lightning activity.**
- **In Monsoon, lightning activity goes down in southern peninsular especially along the west coast.**
- **Convective vigor is observed to be shifted from east coast to northwest with major IC lightning activity.**



Four years (2019-2022) average distribution of IC & CG lightning rate (flash / year/ 0.25°) for Pre-monsoon and Monsoon in (a-b) and (c-d) respectively.

Conclusion

- **A stronger vertical updraft associated with high CAPE enhances the cold cloud depth.**
- **It may expand the mixed phase region, which can broaden and uplift the size of the upper positive charge center inside a thunderstorm.**
- **In contrast, the middle negative charge center remains at the same temperature level.**
- **Therefore, this process may enhance IC discharge between the upper positive charge center and the middle negative charge center, increasing the IC: CG ratio of a thunderstorm.**



Acknowledgements

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