Lightning Strikes in India: Analysis of Spatial Displacement and Forecasting Improvements

***Harvir Singh*[1,2]*, *Anumeha Dube*[1], *Raghavendra Ashrit*[1] *Prashant K. Srivastava*[2] *and VS Prasad*[1]
[1]*National Centre for Medium-Range Weather Forecasting, Ministry of Earth Sciences, Noida, India*
[2]*Institute of Environmental and Sustainable Development, Banaras Hindu University, Varanasi, India*
Corresponding Author: harvir.ncmrwf@gmail.com
https://orcid.org/0000-0003-1355-7628

Introduction:

Lightning is caused by an imbalance of electrical charges within clouds or between clouds and the Earth, primarily during thunderstorms. This process is fuelled by convection, where warm, moist air rises, especially in tropical regions near the equator. These areas experience the highest lightning activity due to their year-round warm, humid conditions and atmospheric instability. Globally, lightning causes about 24,000 deaths annually, with India reporting significant impacts. In 2023, lightning claimed 429 lives from April to July, with states like Bihar and Odisha most affected. Rising temperatures have increased lightning frequency, particularly in India's pre-monsoon and monsoon seasons. Advanced forecasting systems, like high-resolution numerical weather prediction (NWP) models, such as the WRF-ELEC model, are improving lightning forecasts. However, precise event localization remains challenging due to lightning's unpredictable nature. Enhanced satellite and ground-based observations alongside reliable models are essential to mitigate lightning-related casualties and damage.

India experiences maximum lightning strikes during the pre-monsoon (March-May) and monsoon (June-September) seasons. Pre-monsoon strikes, driven by high temperatures and atmospheric instability, are frequent in northeastern, central, and northern regions. During the monsoon, lightning is common along the west coast and monsoon trough zones, particularly in western Ghats and peninsular India. Observations from 2021 to 2024 highlight peak lightning activity in northeast India during pre-monsoon and central/northern regions during the monsoon season.

Data and Methodology: The Indian Institute of Tropical Meteorology Lightning Detection Network (IITM-LDN) uses 83 advanced sensors to monitor lightning activity across India in real-time, detecting cloud-to-ground and in-cloud strikes with high precision (up to 300m accuracy). With frequencies ranging from 1-12 MHz, it achieves 90% efficiency for cloud-to-ground lightning and 50% for in-cloud events. This data, gridded to 4km resolution, supports nowcasting systems and disaster management through collaborations with the India Meteorological Department (IMD) and state governments. Complementing this, the NCMRWF Unified Regional Model (NCUMR), operational since 2021, provides high-resolution regional forecasts with explicit convection and daily updates for up to 72 hours. Utilising a 4D-Var data assimilation method, the model integrates radar, satellite, and conventional observations. To verify lightning forecasts (2021-2024), the METplus MODE tool performs spatial analysis, comparing attributes like centroid distance and intensity between forecasts and IITM-LDN data—this study pioneers MODE's application for lightning verification in India, refining forecast accuracy and disaster preparedness.

Results: Figure 1 illustrates displacement errors in lightning forecasts for lead times of Day-1, and 2 during the MAM and JJAS seasons (2021-2024). Displacement errors, measured in degrees' latitude/longitude, are categorised as <1SD, <2SD, and outliers. For objects with counts exceeding >15, 60%-71% have <1SD error, mostly ±0.5°, with northward spread in Day-2. Similar patterns are observed during JJAS, with 68%-77% (<1SD) and 90%-94% (<2SD) for various thresholds. Errors are typically <±1° across all directions, though higher lead times show greater displacement, particularly northward. This highlights challenges in spatial accuracy for higher lead times and intense lightning activity.

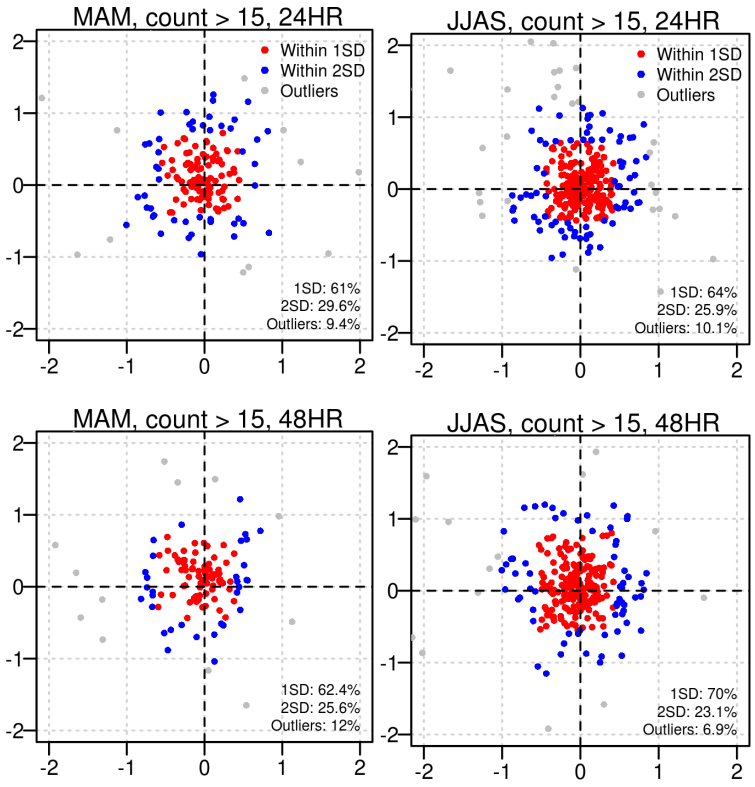

Fig. 1. Scatter plots showing the centroid distance displacement errors (east-west; XD and north-south; YD) for the MAM 2021-2024 and JJAS 201-2024 in the 24 HR to 48 HR forecasts for lightning counts exceeding 15 flashes /day. Where red dots show the centroid distance displacement errors for 1 standard deviation (1SD), blue dots for within 2SD and grey dots as an outlier.

References:

1. Davis, C. A., B. G. Brown, and R. G. Bullock, (2006a), Object-based verification of precipitation forecasts. Part I: Methodology and application to mesoscale rain areas. Mon. Wea. Rev., 134, 1772–1784.
2. Davis, C. A., B. G. Brown, R. Bullock, and J. Halley-Gotway, (2009), The method for object-based diagnostic evaluation (mode) applied to numerical forecasts from the 2005 nssl/spc spring program. Weather and Forecasting, 24 (5), 1252 – 1267, https://doi.org/10.1175/2009WAF2222241.1.