Latest studies on understanding and predicting rapid intensification of tropical cyclones and lightning in the thunderstorms

Program: Monsoon Mission

Sub-program: Short and medium range prediction / Parameterization and analysis

Indian Institute of Tropical Meteorology, Pune, Ministry of Earth Sciences, India

Tropical Cyclone

Climatology and characteristics of rapidly intensifying tropical cyclones over the North Indian Ocean

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Background

1. Rapid intensification (RI) refers to a phenomenon where the maximum sustained winds of a tropical cyclone (TC) increase by at least 30 knots in a 24-hour period.
2. Forecasting and understanding the factors that contribute to RI is crucial for minimizing the impact of tropical cyclones on coastal communities. RI is particularly concerning in the context of climate change, as warmer ocean temperatures can provide more fuel for tropical cyclones, potentially leading to more frequent and intense storms.
3. We considered data for 39 years (1982-2020) from JTWC and studied the climatology of RI TCs of frequency, intensity, and track . We considered the TCs of the cyclonic storm (CS) and above category to this study.
4. The TCs with an intensity change of less than 30 knots in 24 hours as non RI (NRI) TCs for composite study.
5. We considered RI duration as the duration through with the intensity change in consecutive 24 hrs is greater than equal to 30 knots.

Results and Discussions

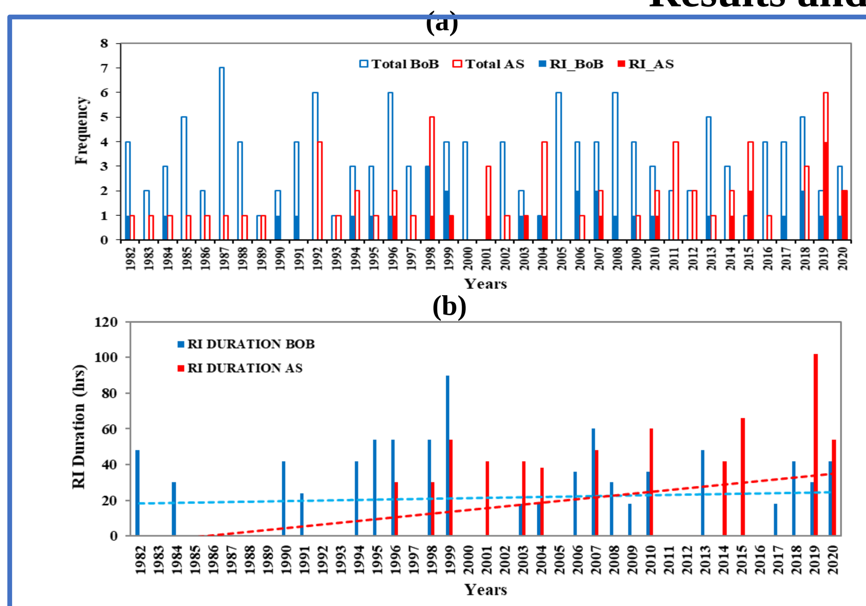

Figure 1 Time series of **(a)** total and RI TC frequency and **(b)** RI duration for BoB and AS

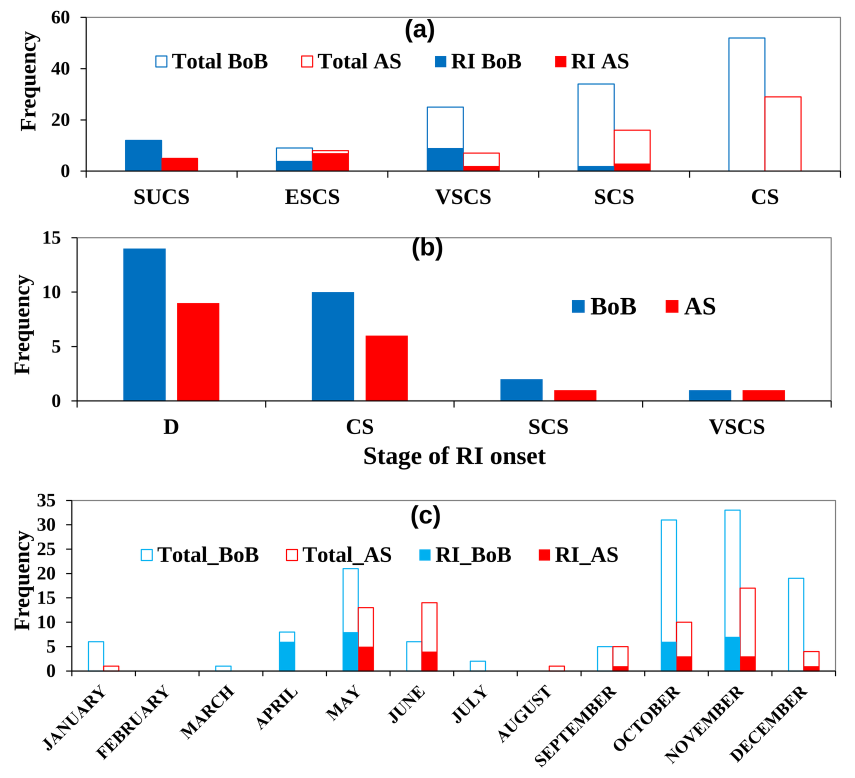

Figure 2 **(a)** Frequency of TCs achieving various categories that exhibit RI during their lifetime **(b)** Frequency of RI TCs based on the category in which the RI onset happens **(c)** Month-wise distribution of total and RI TCs frequency for greater than CS category TCs.

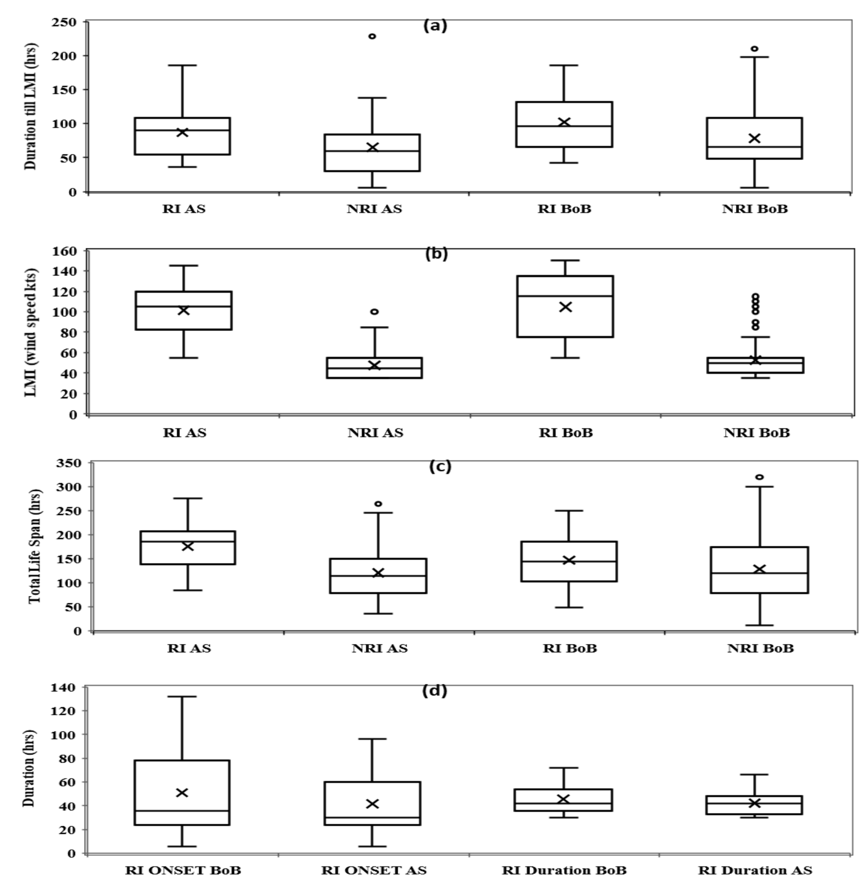

Figure 3 Box and whisker plots for the (a) Duration from genesis till LMI(**b)** Lifetime Maximum Intensity (max intensity achieved) of RI and NRI TCs **(c)** Total life span (depression-dissipation) of RI and NRI cyclones and **(d)** duration from genesis till RI onset and duration of RI phase

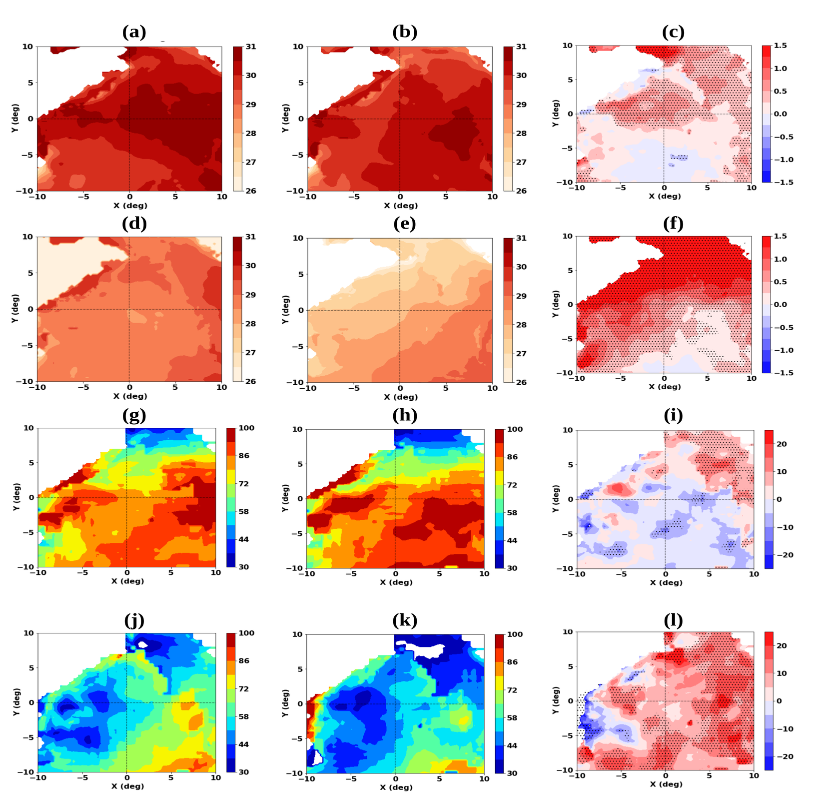

Figure 4 (a-c) composite of sea surface temperature (SST, °C) for RI, NRI, and difference (RI – NRI) for pre-monsoon TCs (d-f) same as that of (a-c) but for the post-monsoon TCs (g-l) same as that of (a-f) but for the tropical cyclone heat potential (TCHP, Kg cm^{-2}). The dots in difference plots represents the gridpoints where the difference is significant at 95 percent confidence level

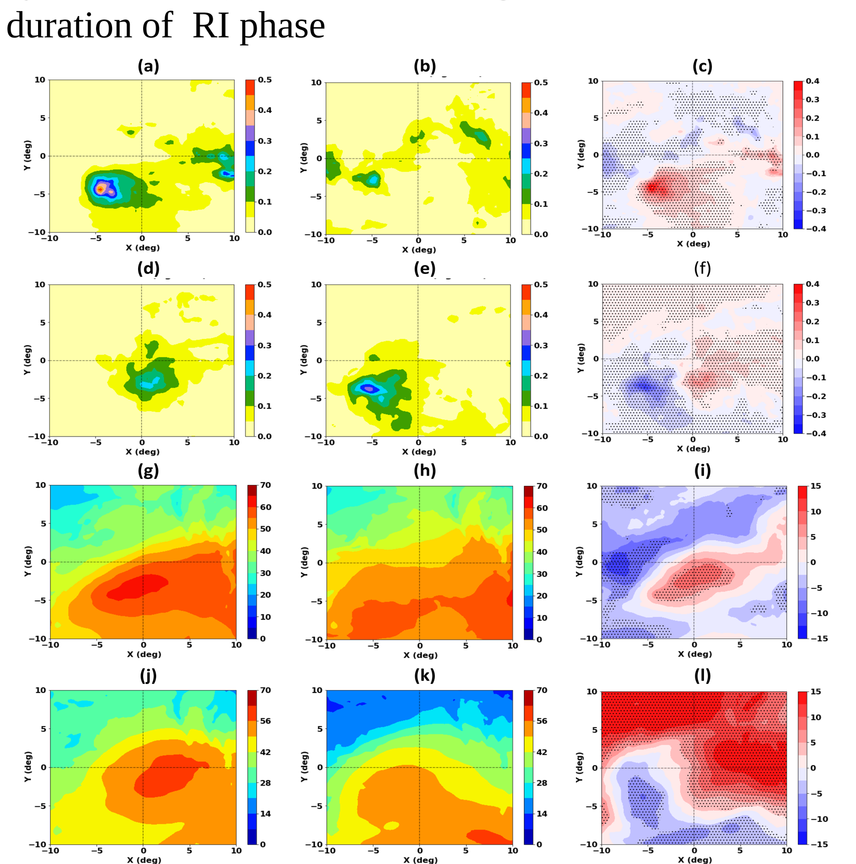

Figure 5 (a-c) composite of total columnar liquid water (CLW, kg m-2) for RI, NRI, and difference (RI – NRI) for pre-monsoon TCs (d-f) same as that of (a-c) but for the post-monsoon TCs (g-l) same as that of (a-f) composite of total column water vapor (CWV, kg m-2). The dots in difference plots represents the gridpoints where the difference is significant at 95 percent confidence level.

CONCLUSIONS

- There is a significant (95% confidence level) increasing trend in the frequency of TCs including RI TCs over the Arabian Sea (AS).
- The duration to achieve the LMI and the intensity achieved is significantly (95% confidence) higher for RI TCs than in NRI cases in both basins.
- All TCs that reached super cyclonic storm (SuCS) strength underwent RI. RI onset occurs mainly during the initial stages.
- The total number of cases is higher during the post-monsoon than pre-monsoon season, but the percentage occurrence of RI cases is higher (significant at 95%) in the pre-monsoon.
- The sea surface temperature, tropical cyclone heat content, positive sea surface height anomaly, and surface latent heat flux exchange from the ocean to the atmosphere are all significantly higher for RI TCs.
- Higher mid-level relative humidity, columnar water vapour, liquid water, and frozen water content is significantly noticed for RI TCs.

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Towards the Development of Lightning Prediction System

with longer lead time (using IITM GFSv2 T1534) & location-specific (machine learning based) forecast

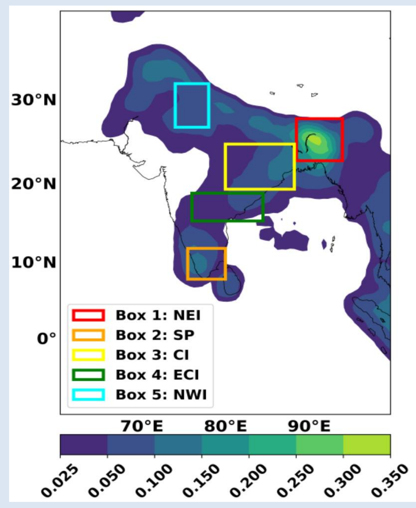


Figure 1: Pre-monsoon (March–April–May or MAM) mean flash rates (flash count km^{-2} day^{-1}) obtained from Lightning Imaging Sensor (LIS)/Optical Transient Detector (OTD) Gridded 1995–2015 Climatology data sets. Colored boxes highlight five thunderstorm-prone regions as defined by Halder & Mukhopadhyay (2016). This figure is published in Sarkar et al (2022).

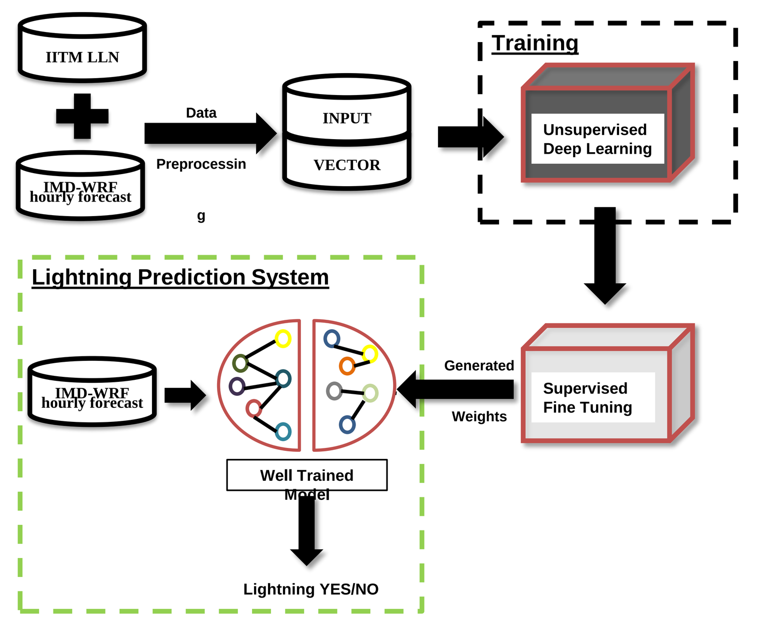
Background

- Indian landmass due to its position in the tropics received extensive amount of lightning each year, with March-April-May receiving highest lightning (Zipser 2006).
- NCRB reports lightning related death make up 38.6% of deaths related to natural disaster in India..
- Lightning related deaths in the country has increased by 52.8% in past two decades (Ray et al 2021).

Objective:

Development of lightning prediction system with (a) longer lead time using Indian Institute of Tropical Meteorology (IITM) Global Forecasting System (GFS) model as well as (b) a location specific lightning prediction system utilizing high resolution observation network of IITM lightning location network (LLN) with machine learning based hybrid model.

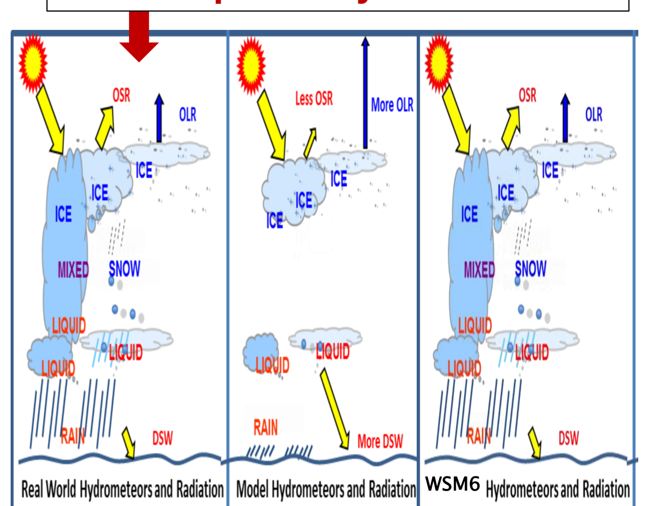
Location specific Lightning forecast



Step toward early lightning warning system for India

Development of lightning parameterization in Global Forecasting System (GFS)

Lightning is modulated by the mixed-phase hydrometeors



Absence of mixed-phase hydrometeors made GFS in unsuitable for lightning parameterization

GFS using modified WSM6 Microphysics: Opens the path for lightning parameterization in GFS

In WSM6, six prognostic tendency equations are solved to compute the tendencies of hydrometeors including mixed phase.

Tendencies:

$$\frac{\partial}{\partial t}(n) = \boldsymbol{ADV}(n) + \boldsymbol{TURB}(n) + \boldsymbol{SEDIM}(n) + \boldsymbol{SOURCE}(n)$$

where $n = [n_r, n_i, n_s, n_{clw}, n_g, n_v]$ represents the concentration of rain, ice crystals, snow, cloud water, graupel and water vapor.

Modified WSM6 has been successfully implemented in GFS T1534 by Dr Sahadat Sarkar, Sc D, IITM

Presently only ECMWF Operational IFS gives lightning forecast across

Fidelity of existing global model (IFS) based lightning prediction

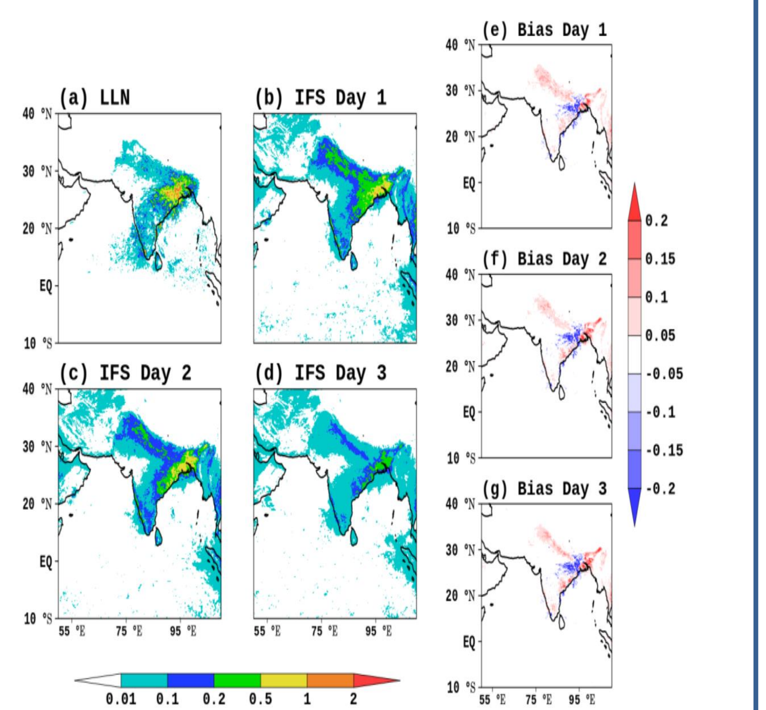


Figure 2: MAM 2020 mean flash density (flash count km^{-2} day^{-1}) (**a**) observed by LLN and forecasted by IFS for (**b**) Day 1, (**c**) Day 2, and (**d**) Day 3 lead times. (**e**–**g**) shows the forecast bias (flash count km^{-2} day^{-1}) for Day 1, Day 2, and Day 3 lead times, respectively. This figure is published in Sarkar et al 2022.

Qualitative and quantitative analysis of the ECMWF lightning forecast has shown that the lightning forecast with a 72-h lead time can capture the spatial and temporal variation of lightning with a 90% skill score.

This work has been published in 2022 under the title *"Evaluation of ECMWF Lightning Flash Forecast over Indian Subcontinent during MAM 2020"* in journal *Atmosphere* special issue *Precipitation and Convection: From Observation to Simulation by* Sarkar et. al. For the link of the article please scan the QR.

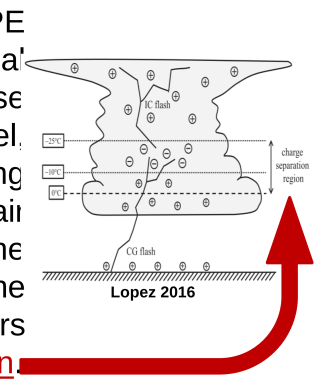
SCAN for further details

Output from the WSM6 microphysics and RSAS-saMF convective schemes of GFS T1534 will be used to derive lightning flash density as defined by Lopez 2016:

$$f_T = \alpha Q_R \sqrt{CAPE} min(z_{base}, 1.8)^2$$

$$Q_R = \int_{z_0}^{z_{-25}} q_g(q_{cond} + q_s)\rho\ dz$$

where f_T lightning flash density, α is a calibration constant, CAPE convective available potential energy, z_{base} convective cloud-base height, q_g, q_s, q_{cond} being graupel, snow and cloud condensate mixing ratios, respectively, ρ is local air density and Q_R a proxy for the charging rate resulting from the collisions between hydrometeors inside the charge separation region.



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