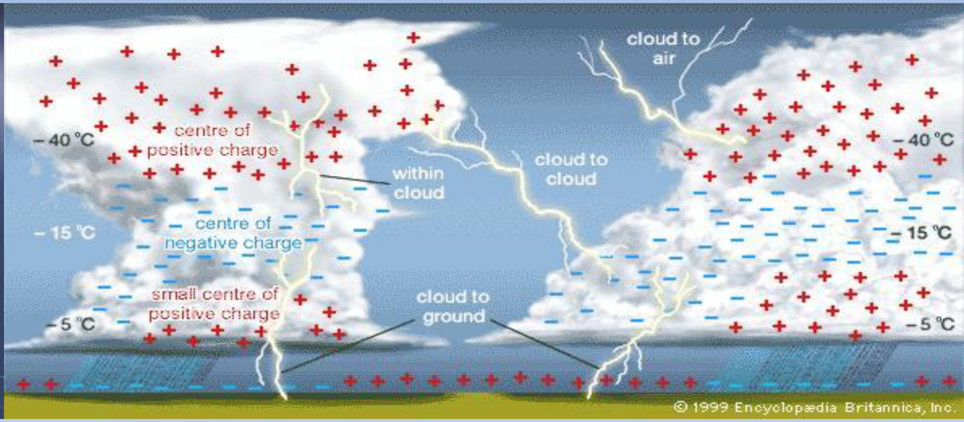
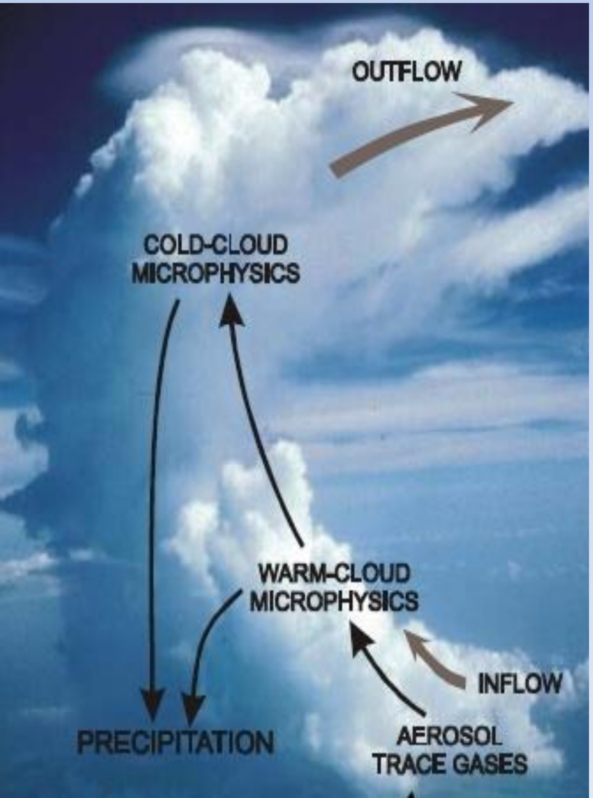
Modeling of Thunderstorm/Lightning for its Hazard Predication





Presented by:

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In Collaboration with
MoES TS working groups, IMD Team, & NCMRWF Team

National Workshop on Impact Based Weather Forecasting
Organized by India Meteorological Department
(30/08/2021 to 03/09/2021) 02-092021

Outline of the presentation

- ✓Brief on lightning/thunderstorm over India.
- ✓ Conventional approach for lightning/thunderstorm prediction and dynamical model.
- ✓ What is new approach for dynamical ‘lightning’ prediction?
- ✓ Understanding physical processes for lightning/thunderstorm for improvement (Model development).
- ✓ Conclusions, possible mechanisms & future scope.

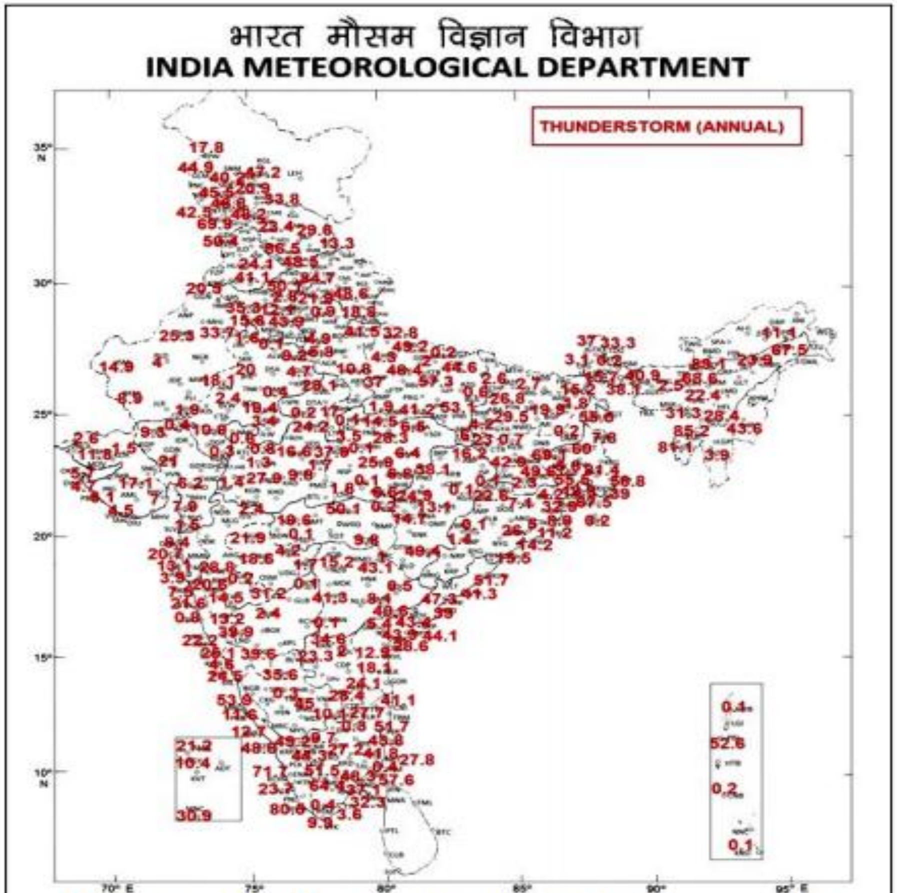


Figure 1: Average annual frequency of thunderstorms in India during 1981-2010 (IMD)

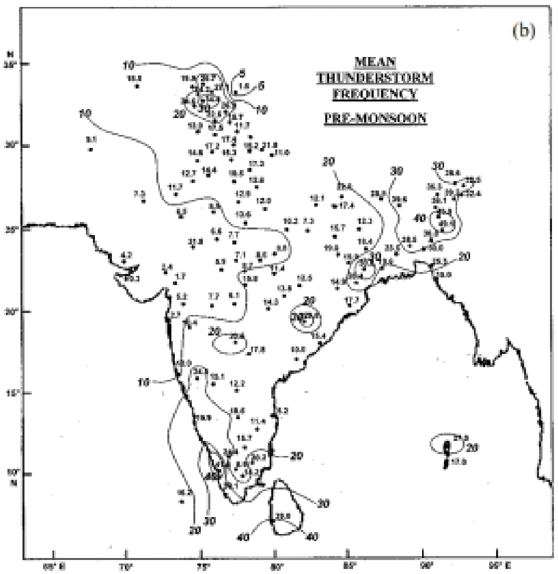
Table 1: Year wise deaths reported due to Thunderstorm & lightning and Torrential Rains

Year	Thunderstorm & Lightning	Torrential Rains	Total
2001	1507	114	1621
2002	1383	1296	2679
2003	1792	257	2049
2004	1842	133	1975
2005	2064	557	2621
2006	2387	259	2646
2007	2790	100	2890
2008	2553	148	2701
2009	2113	132	2245
2010	2622	123	2745
2011	2550	170	2720
2012	2263	203	2466
2013	2833	142	2975
2014	2582	156	2738
2015	2641	195	2836
2016	1489	NA	1489
2017	2057	NA	2057
2018*	328	NA	328

*= as per media report 2nd May 2018 to 10th July 2018

Source: Annual Report, NCRB, and Ministry of Home Affairs, Government of India

Lightning & Thunderstorms over India



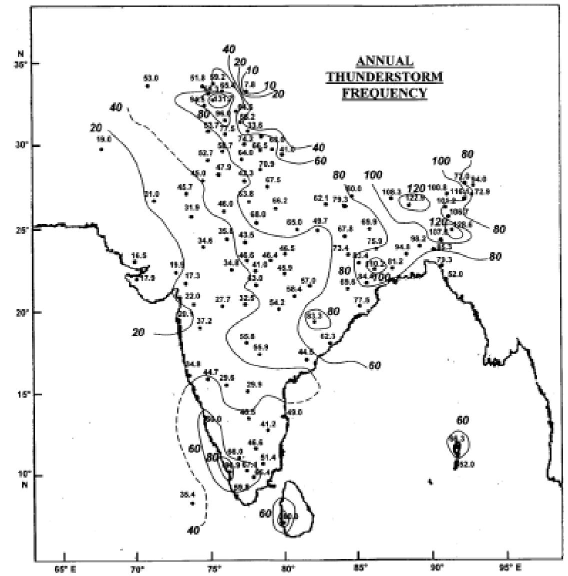
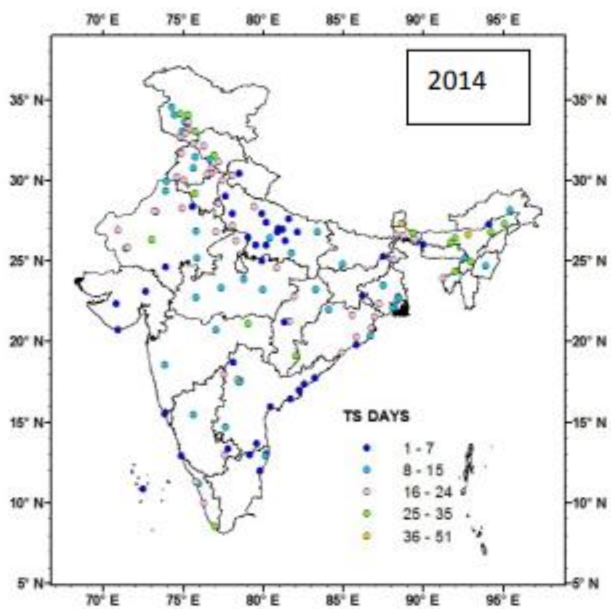
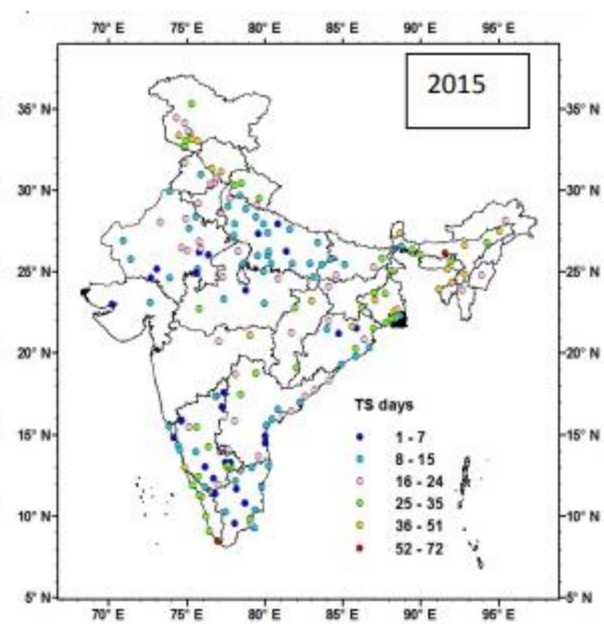


Fig. 5. Annual frequency of thunderstorm

Tyagi , 2007

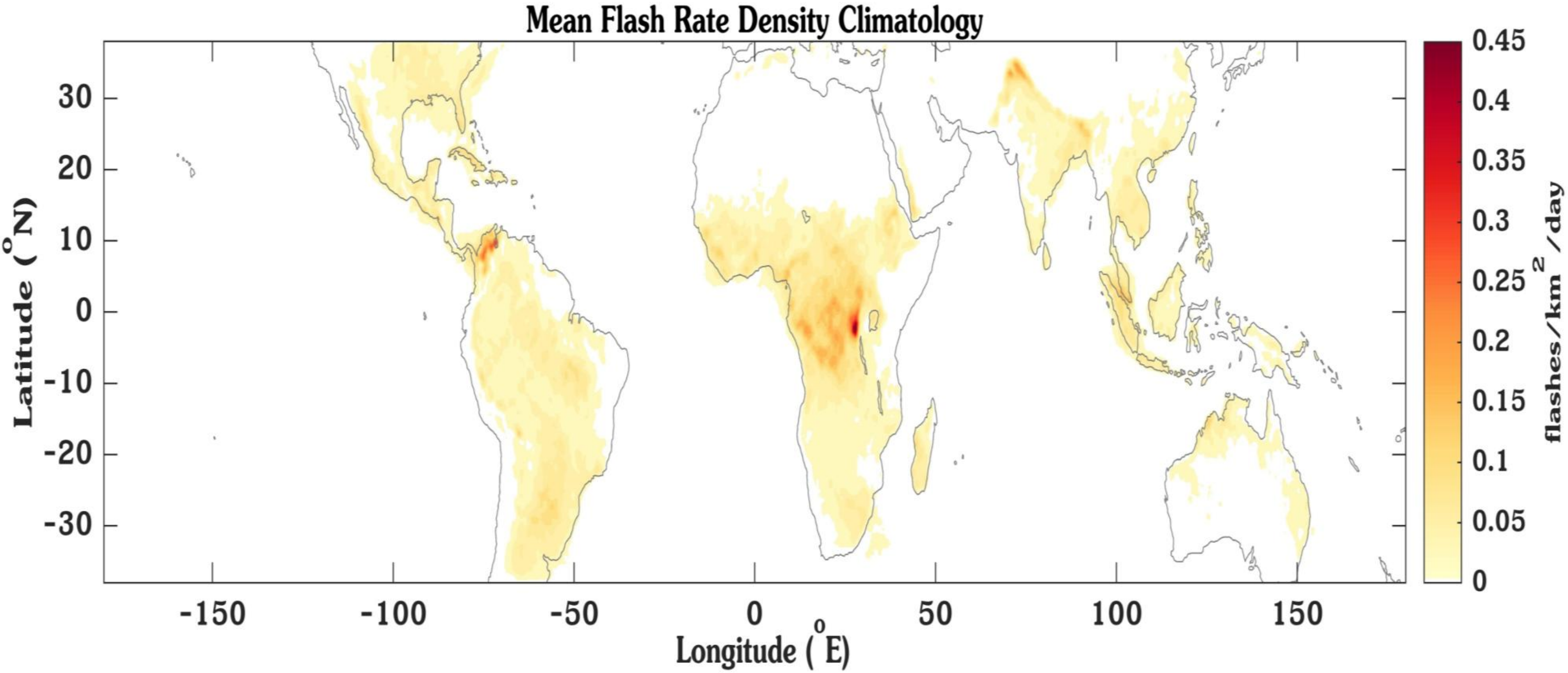


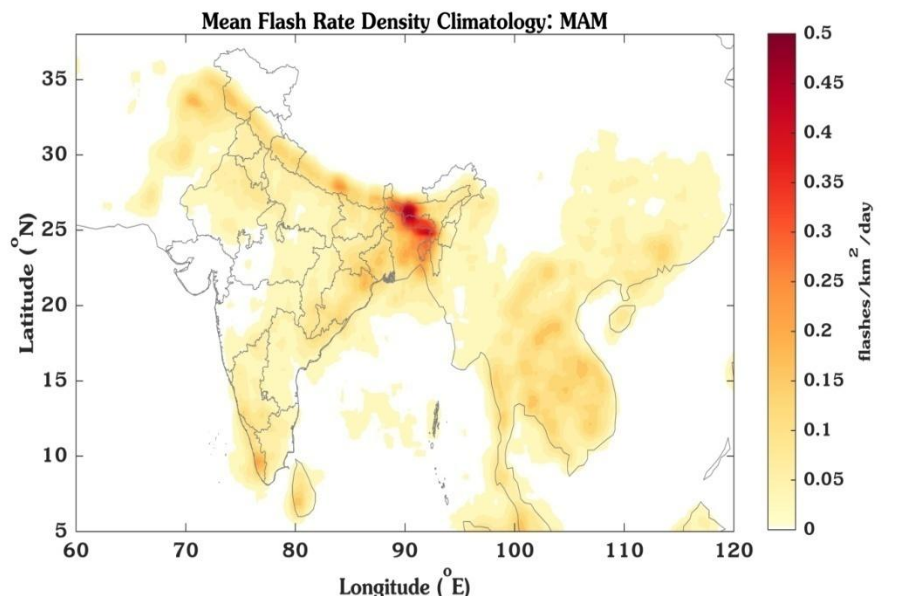


Ray et al., 2017

Figure 1: Spatial Distribution of Thunderstorm Days over India during Storm Period-2014 & 2015

TS-Lightning Modeling Team, Monsoon Mission, IITM, Pune





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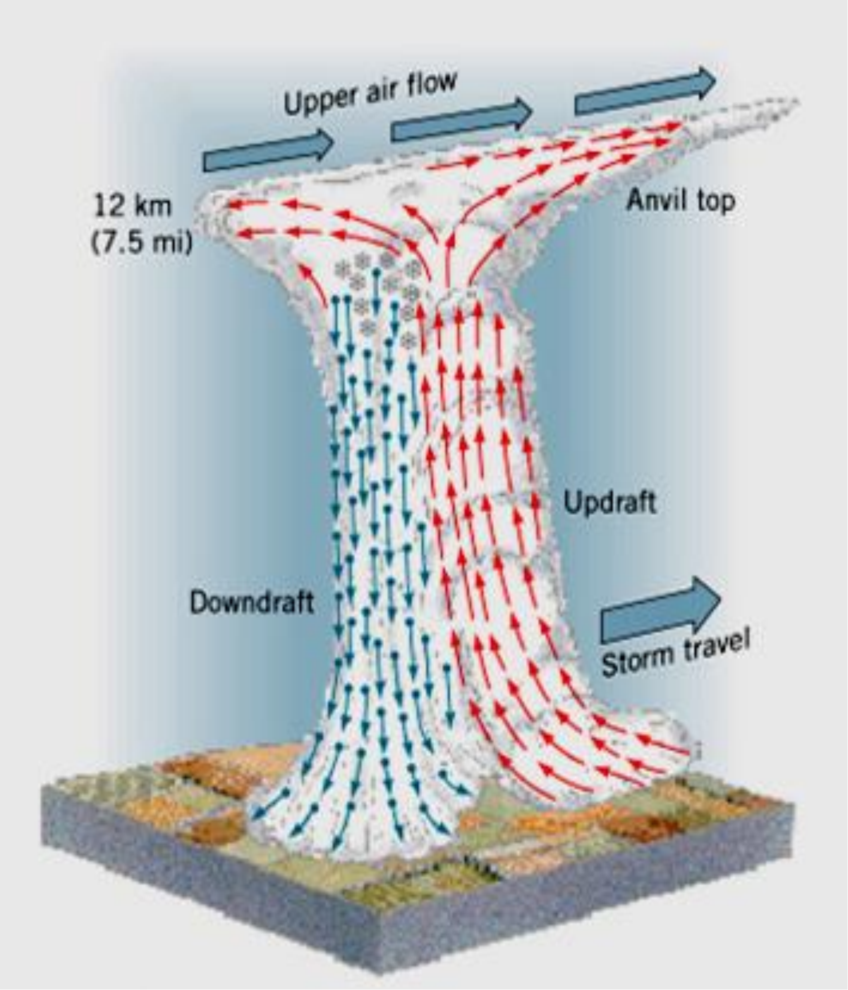
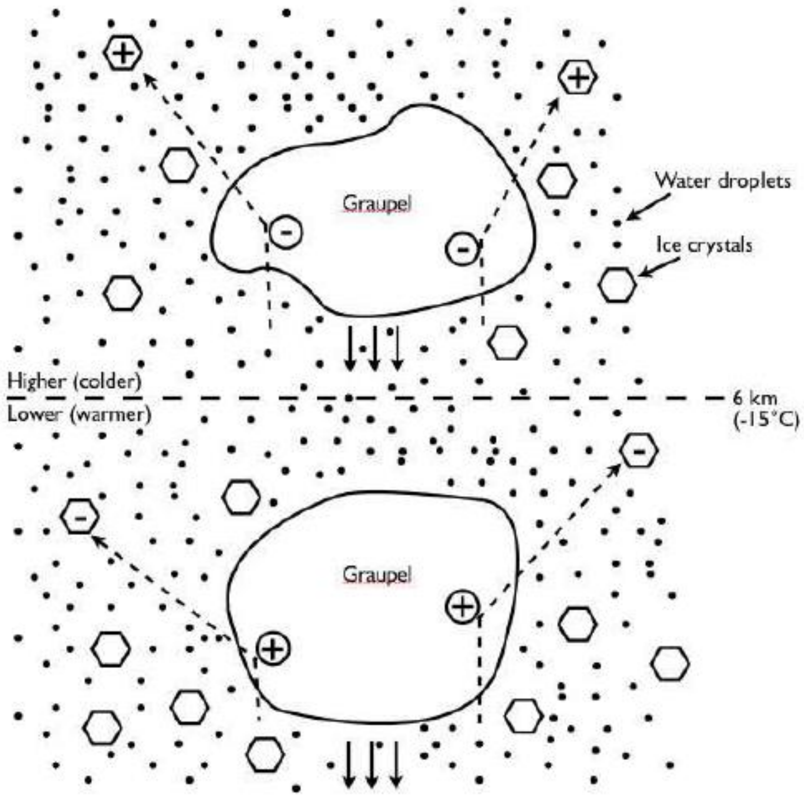
- **Thunderstorms form when we have an unstable, moist atmosphere resulting in strong vertical motions**
- **Can produce hail: this is when an ice particle is continuously cycled through the convection cell before becoming heavy enough to fall out**
- **Can also produce lightening: as water is moved within the cell, it develops a fictional charge; the discharge occurs through a spark, i.e. lightening**



Thunderstorm and Microphysics



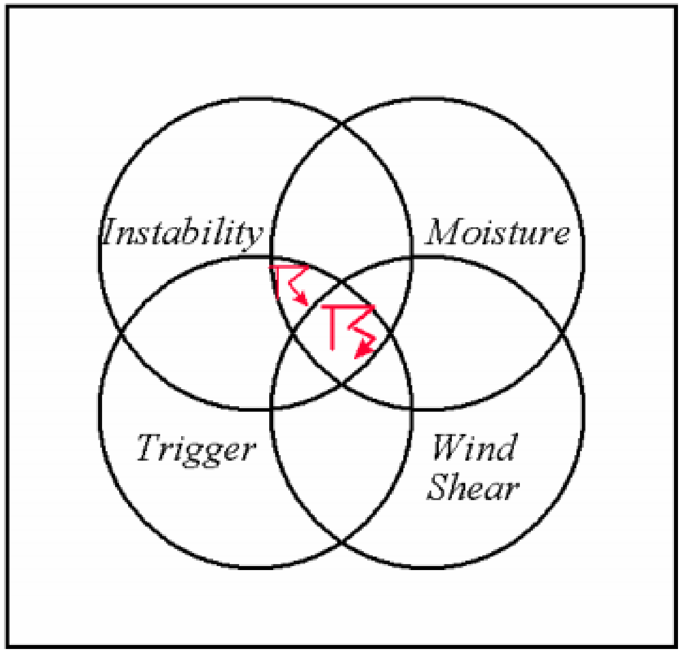


Figure 2: Ingredients necessary for long-lived thunderstorms.

Source: http://umanitoba.ca/faculties/environment/envirogeog/weather/temp/shortterm/MOD_042D2-2003-08-25.pdf

Conventional approach of thunderstorm forecasting

There also exits the conventional approach of forecasting the probability of TSs using thermodynamic instability indices (such as Lifted Index, K Index, Surface Lifted Index, Humidity Index, Bulk Richardson Number, CAPE, CINE and Cloud Physics Thunder Parameter etc.) (e.g., *Mukhopadhyay et al., 2003; Chaudhari et al., 2010, Ghosh et al., 2004, Rajeevan et al., 2010, Madhulata et al., 2013*).

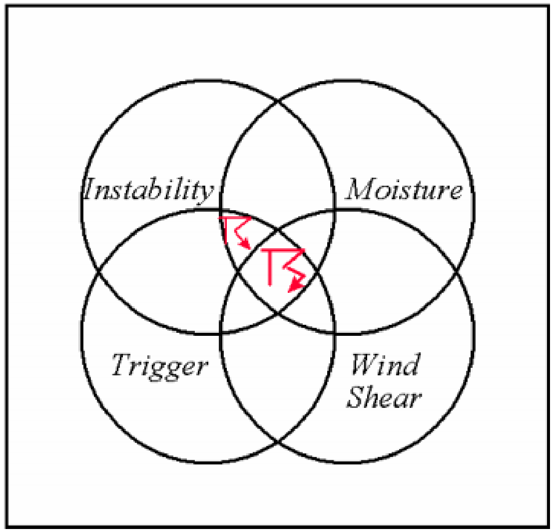


Figure 2: Ingredients necessary for long-lived thunderstorms.
Source: http://umanitoba.ca/faculties/environment/envirogeog/weather/temp/shortterm/MOD_042D2-2003-08-25.pdf

Why dynamical model?

Application of **state-of-the art numerical model** and its sensitivity to different microphysical schemes have been tested for TSs over India by several researchers (***Rajeevan et al. 2010; Litta and Mohankumar 2007; Halder et al., 2015 and many more***). Features of a severe TS event were simulated using WRF model (***Litta and Mohanty 2008***) and it was found that **high-resolution models have a potential to provide unique and valuable information for severe TS forecasts**.

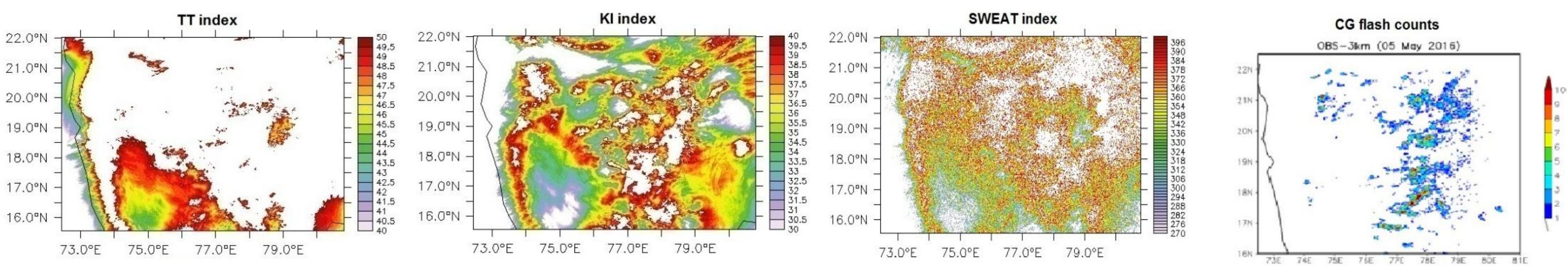
Severe Weather Parameters/Index: Model

Events	TT index	KI index	SWEAT index
29-02-2016	47.5 (48.3)	37.6 (38.8)	306.7 (235.6)
01-03-2016	49.2 (47.3)	38.9 (39.8)	310.2 (239.8)
29-04-2016	49.2 (48.7)	36.13 (36.75)	355.4 (324.4)
05-05-2016	53.65 (49.8)	38.3 (35.8)	415.5 (326.7)
06-05-2016	51.5 (50.6)	37.7 (36.4)	390.5 (370.7)
15-03-2017	50.8 (48.02)	37.9 (37.8)	308.2 (234.8)
29-04-2017	48.2 (49.0)	34.8 (35.3)	340.0 (353.0)

TOTAL TOTALS INDEX:	K-INDEX:	SWEAT INDEX (SEVERE WEATHER THREAT):
<44 TS unlikely 44-48 Scattered TS 48-52 Few severe TS >52 Severe TS	< 15 no probability for TS; 15-20 20% probability for TS 21-25 20-40% probability for TS; 26-30 40-60% probability for TS 31-35 60-80% probability for TS; 36-40 80-90% probability for TS >40 near 100% probability for TS	<272 TS unlikely 273-299 Non-severe TS 300-400 Severe TS

Ref: Ghosh et al, 2004; Rajeevan et al., 2010; Madhulata et al., 2013

Severe Weather Parameters/Index - Spatial



Objectives: To develop a system for lightning/thunderstorm prediction using dynamical model

System for Thunderstorm Observation, Prediction and Monitoring (STORM)

HOME | INTRODUCTION | MODEL | GEFS TS PREDICTION | WMO SCOPE | BULLT. ON TS NOWCAST | IMD DIAG. PROD. | SWIRLS | SAT. & LIGHTING OBS.

WRF based Lightning flash prediction Dynamical Lightning Parameterization (DLP)

Dynamical lightning parameterization (DLP) used in the state-of the art numerical weather prediction model (e.g., WRF3.8.1) (Price and Rind, 1992; Wong et al., 2013) establishes the direct link between the charge separation mechanisms and collisions between hydrometeors to relate storm electrical activity and therefore lightning discharges to the characteristics (e.g. amount, fall velocity) of hydrometeors (graupel, hail, cloud ice, snow and supercooled liquid water droplets) as well as to the intensity of the convection itself (e.g. updraft velocity, convective available potential energy).

The most commonly used method for parameterizing lightning flash rate is by Price and Rind (1992, 1993, 1994), which uses Vonnegut's (1963) theory on the geometry of the charged regions and its scaling assumptions for the convective cloud characteristics (updraft velocity, cloud top height, maximum reflectivity) to estimate both total and cloud-to-ground lightning flash rates. The cloud top height is determined by the threshold of reflectivity (20 dBZ) and temperature (0° C).

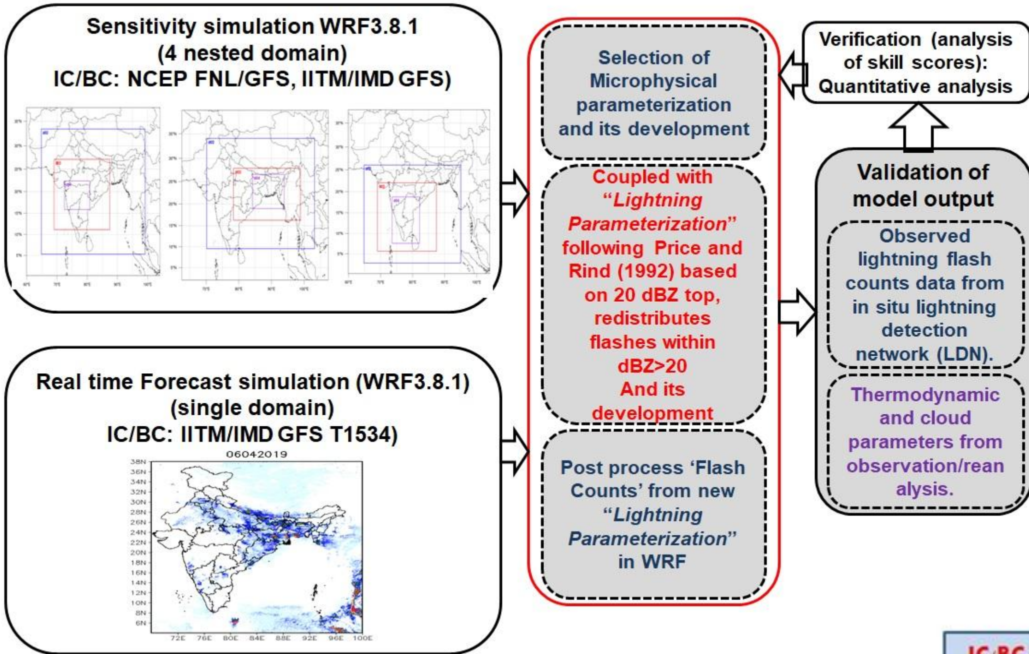
Here in DLP it is used based on 20 dBZ top, redistributes flashes within dBZ > 20 (for convection resolved model runs) (Mohan, Vani, Hazra et al., 2019; Hazra, Mohan, Vani et al., 2019). For the real time model (single domain, 3 km horizontal resolution) forecast run, daily two cycles is performed with initial condition (IC) of 00 UTC and 12 UTC in IITM "Aaditya" HPCS. The initial condition (IC) is obtained from IMD (GFS T1534). One day (24 hours) accumulated total lightning flashes are provided and 3 hourly accumulated lightning flashes and overlaid maximum reflectivity products (from IITM WRF model with DLP scheme) are also presented to indicate the probability of lightning occurrence over the entire country.

Webpage:

http://srf.tropmet.res.in/srf/ts_prediction_system/index.php

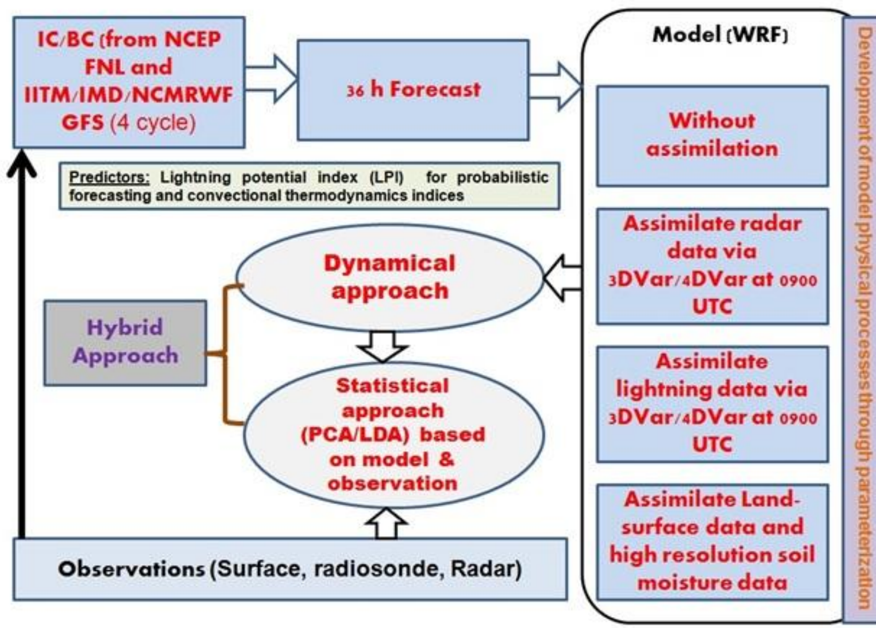
New product (CG-lightning flash counts) From dynamical model (WRF)

Research roadmap of lightning/thunderstorm Prediction



- For the real-time operational forecast of lightning/thunderstorm over pan India and surrounding countries as suggested by IMD with 1951 x 1851 grid points.
- Model simulation time is highly important to get the product in hand with sufficient lead time.

	Convection	Microphysics	Lightning para.
M - I	Yes	Yes (2m & 1m)	* Yes – PR92
M - II	No	Yes (2m & 1m)	# Yes – PR94
M - III	No	Yes (2m & 1m)	$ Yes - LPI



* Price, C., and D. Rind (1992) – Based on buoyancy & convective flux, CAPE, cloud condensate

Price, C., and D. Rind (1994) - Based on dbz, CAPE, cloud condensate

$ Yair et al., (2010) – Vertical velocity & cloud condensate

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Lightning Parameterization

Finally, the total (IC and CG) lightning flash density (f_T; in flashes km^{-2} day^{-1}), is determined as

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

$$Q_R = \int_{z0}^{z-25} q_{graup}\, (q_{cond} + q_{snow})\, \overline{\rho} dz$$

$$q_{graup} = \beta \frac{P_f}{\overline{\rho}\, V_{graup}}$$

$$q_{snow} = (1-\beta) \frac{P_f}{\overline{\rho}\, V_{snow}}$$

LPI Parameterization

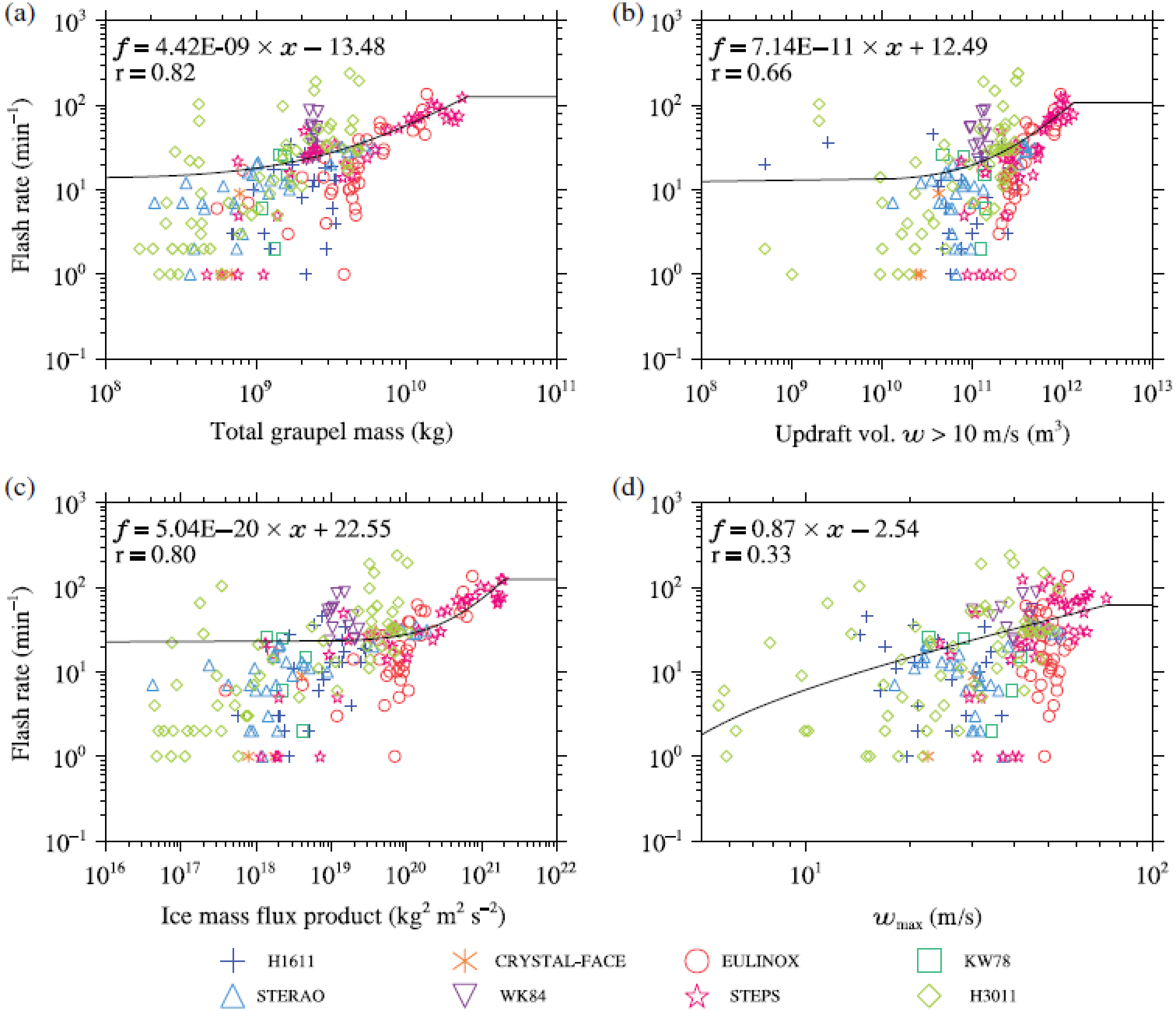
The LPI (J kg^{-1}) is defined by

$$LPI = \frac{1}{V} \iiint \varepsilon w^2 dxdydz$$

$$\varepsilon = 2(Q_i Q_l)^{0.5} / (Q_i + Q_l)$$

$$Q_i = q_g \left[\left((q_s q_g)^{0.5} / (q_s + q_g) \right) + \left((q_i q_g)^{0.5} / (q_i + q_g) \right) \right]$$

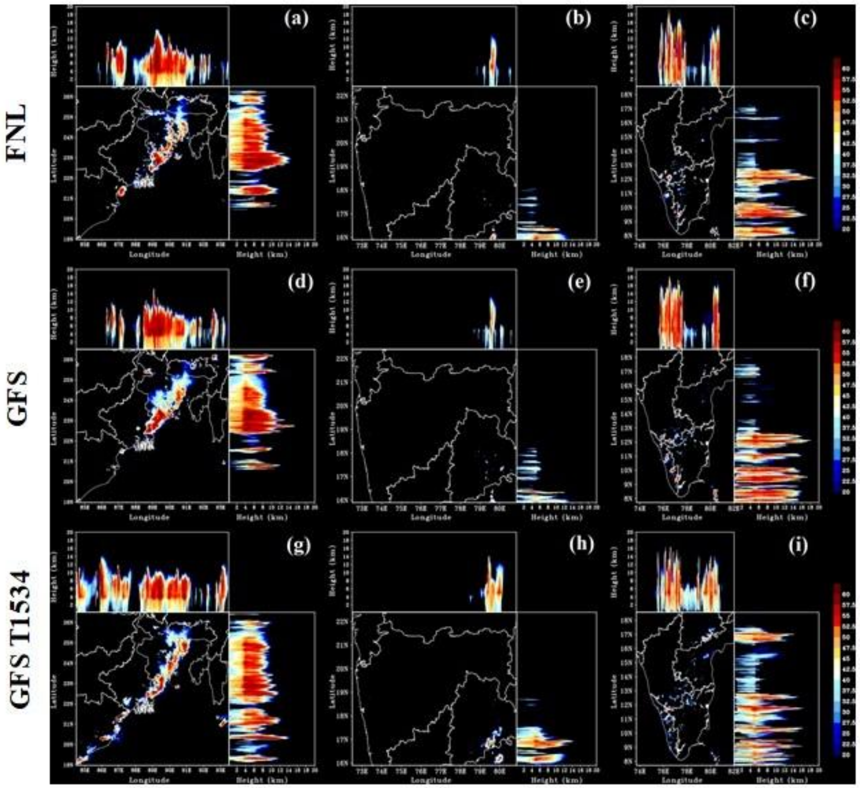
Thanks to **Dr. M. C. Barth**, NCAR for scientific collaboration for the development of dynamical lighghtning parameterization (DLP) scheme.



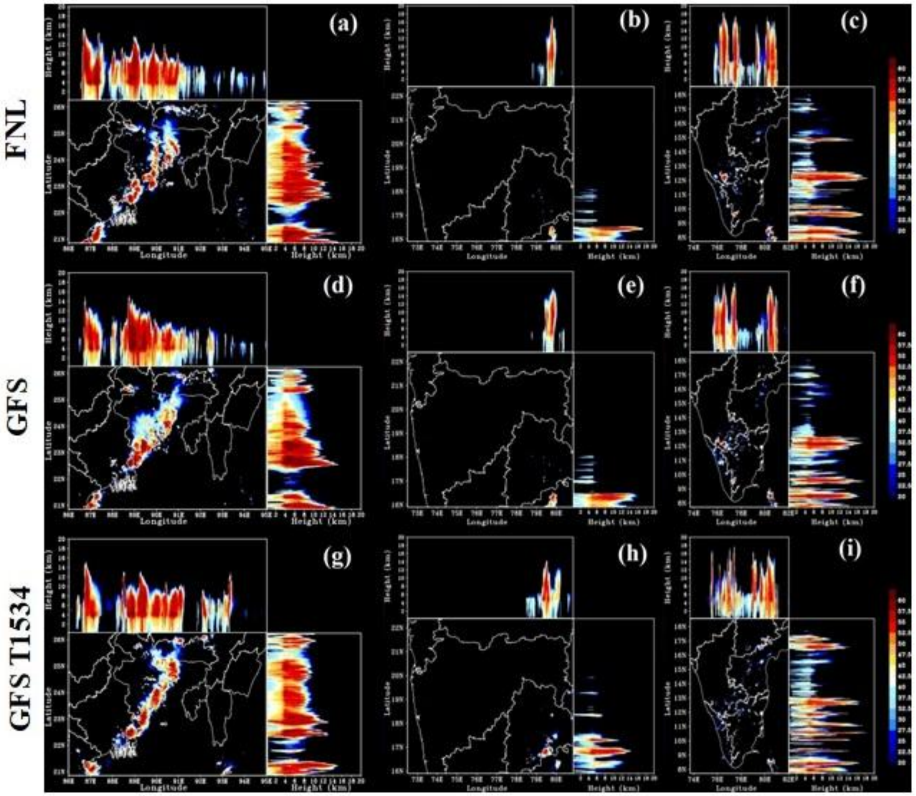
Bovalo et al., 2019, QJRMS

Convection captured in lightning/thunderstorm case

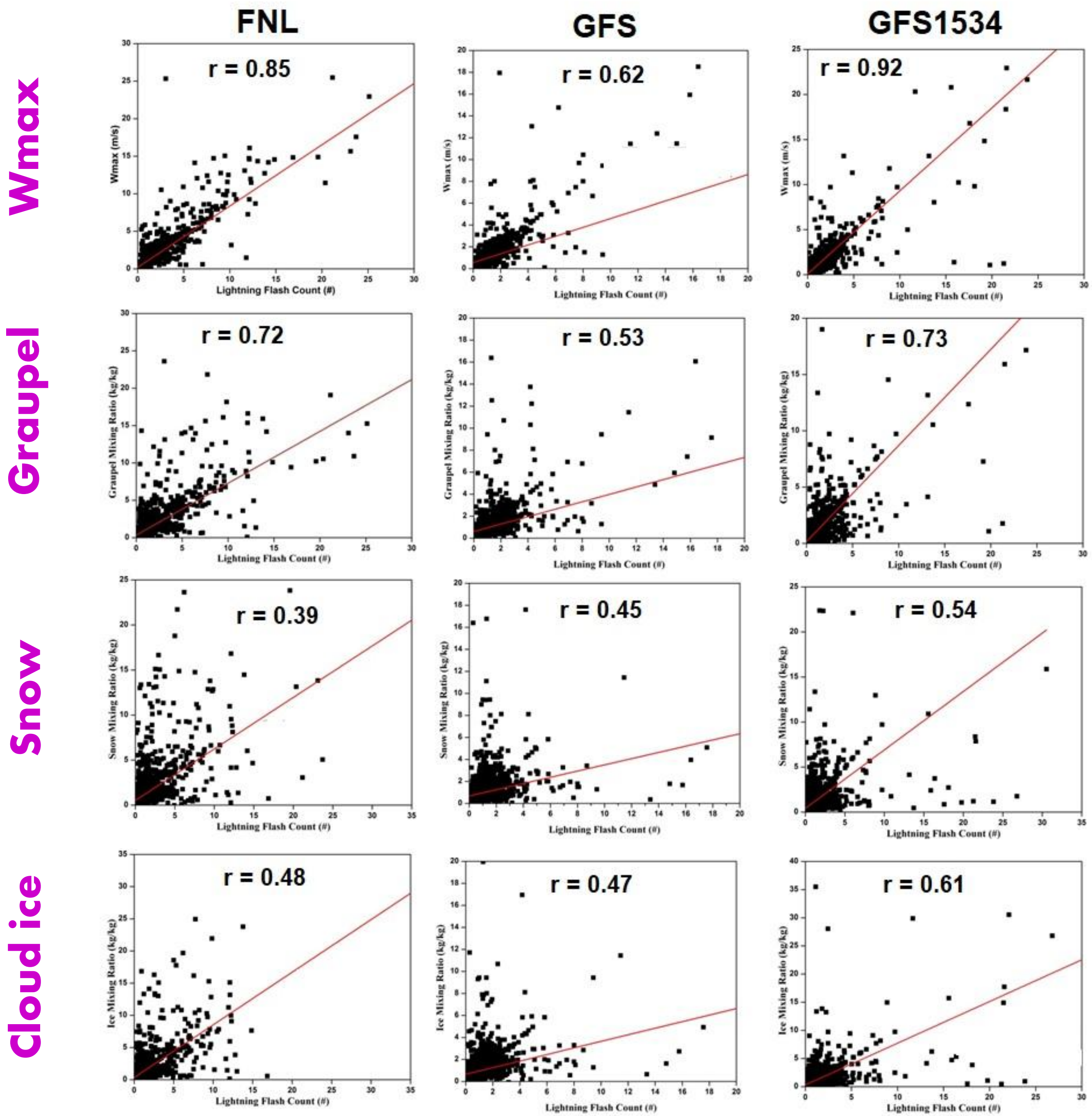
Reflectivity from domain of 1 km res. (4 NDS)



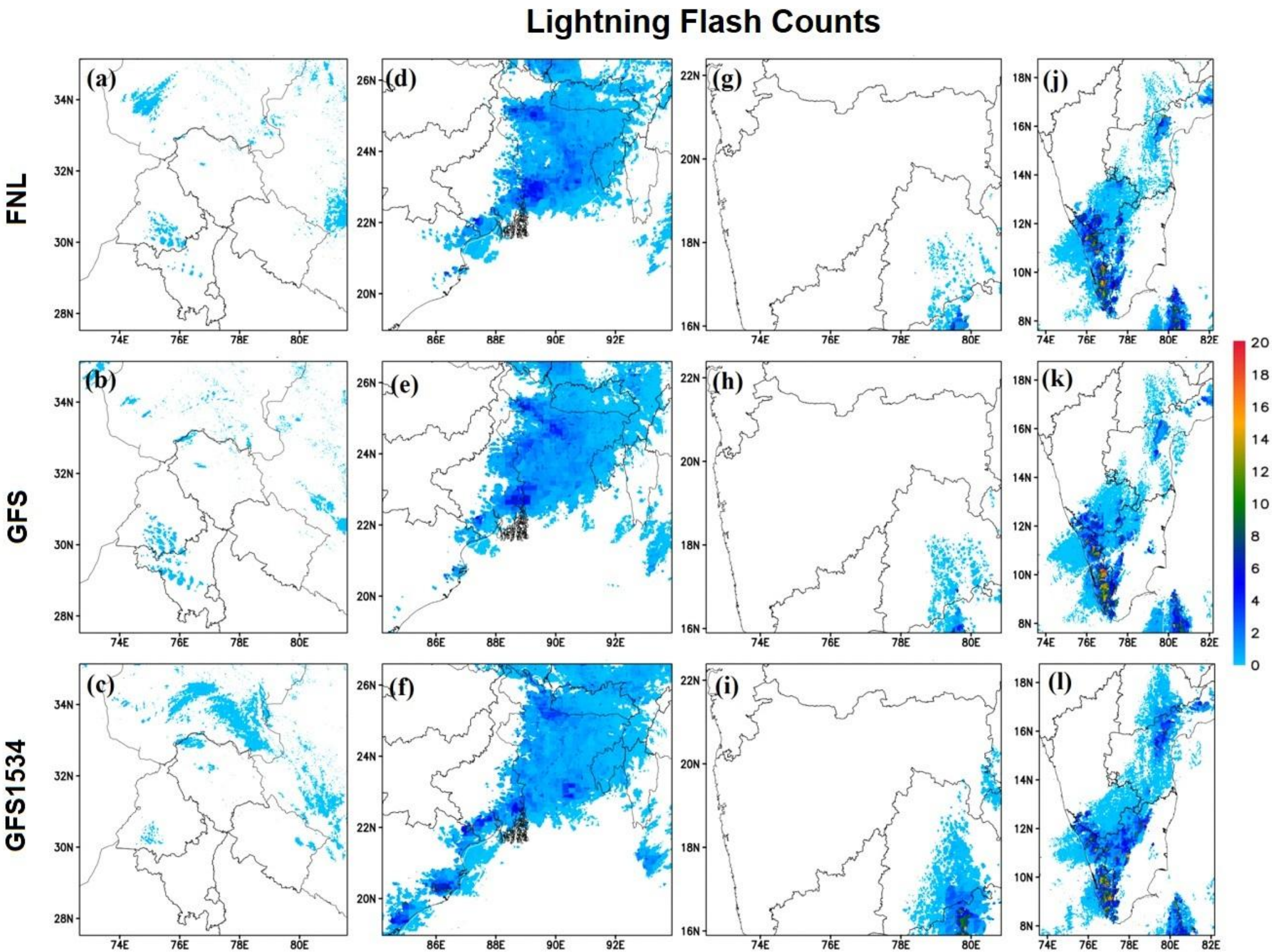
Reflectivity from domain of 1 km res. (2 NDS)

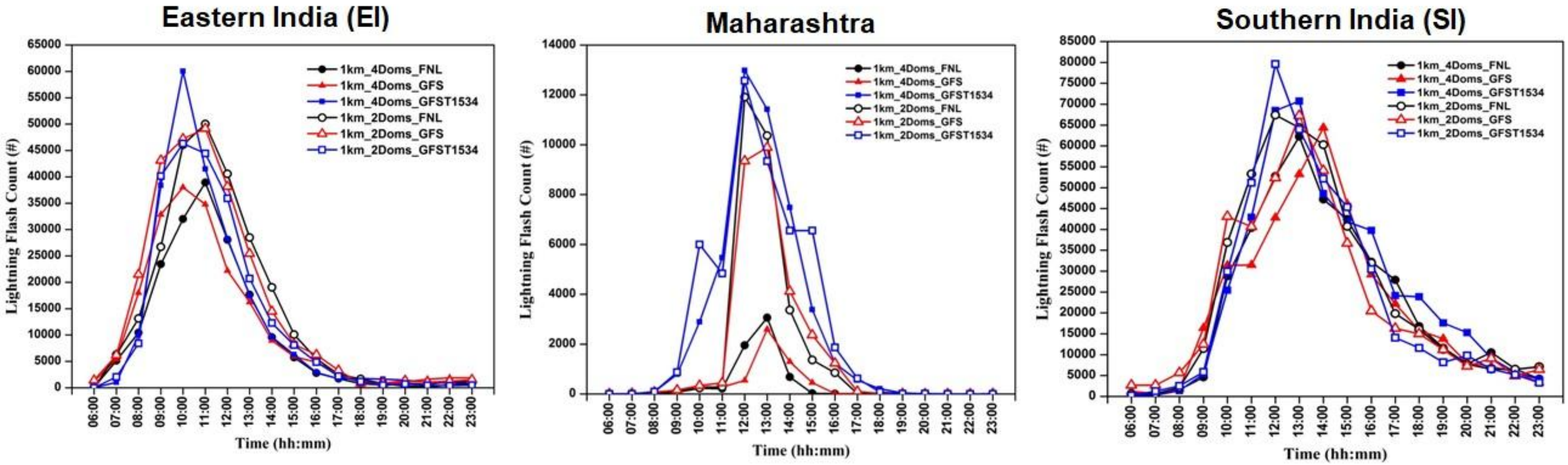


- **For the real-time operational forecast of lightning/thunderstorm over pan India and surrounding countries as suggested by IMD with 1951 x 1851grid points.**
- **Model simulation time is highly important to get the product in hand with sufficient lead time.**

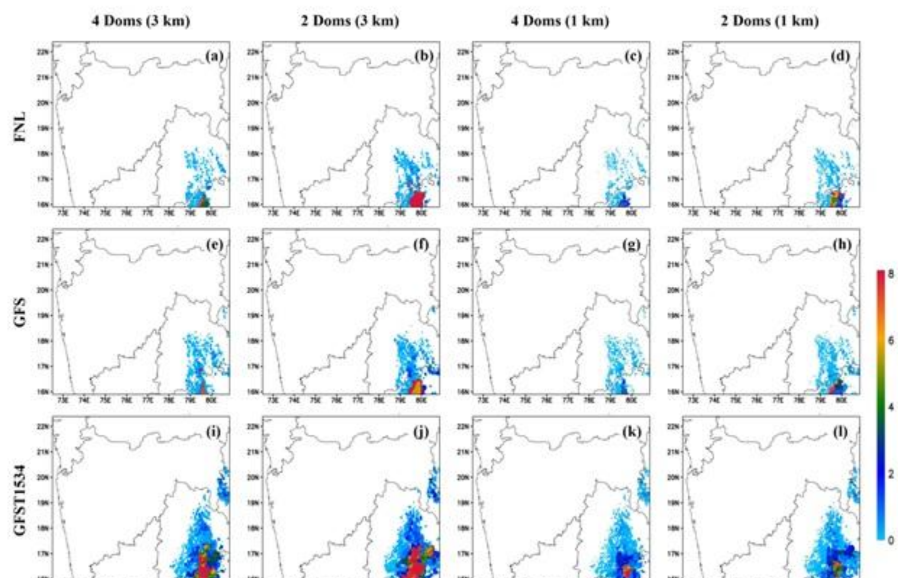


FNL
GFS
GFS1534
Wmax
Graupel
Snow
Cloud ice
r = 0.85
r = 0.62
r = 0.92
r = 0.72
r = 0.53
r = 0.73
r = 0.39
r = 0.45
r = 0.54
r = 0.48
r = 0.47
r = 0.61
Wmax (m/s)
Graupel Mixing Ratio (kg/kg)
Snow Mixing Ratio (kg/kg)
Ice Mixing Ratio (kg/kg)
Lightning Flash Count (#)


Lightning Flash Counts
FNL
GFS
GFS1534
(a)
(b)
(c)
(d)
(e)
(f)
(g)
(h)
(i)
(j)
(k)
(l)
0
2
4
6
8
10
12
14
16
18
20



Lightning Flash Counts over Maharashtra



Spatial distribution of lightning flashes and LPI

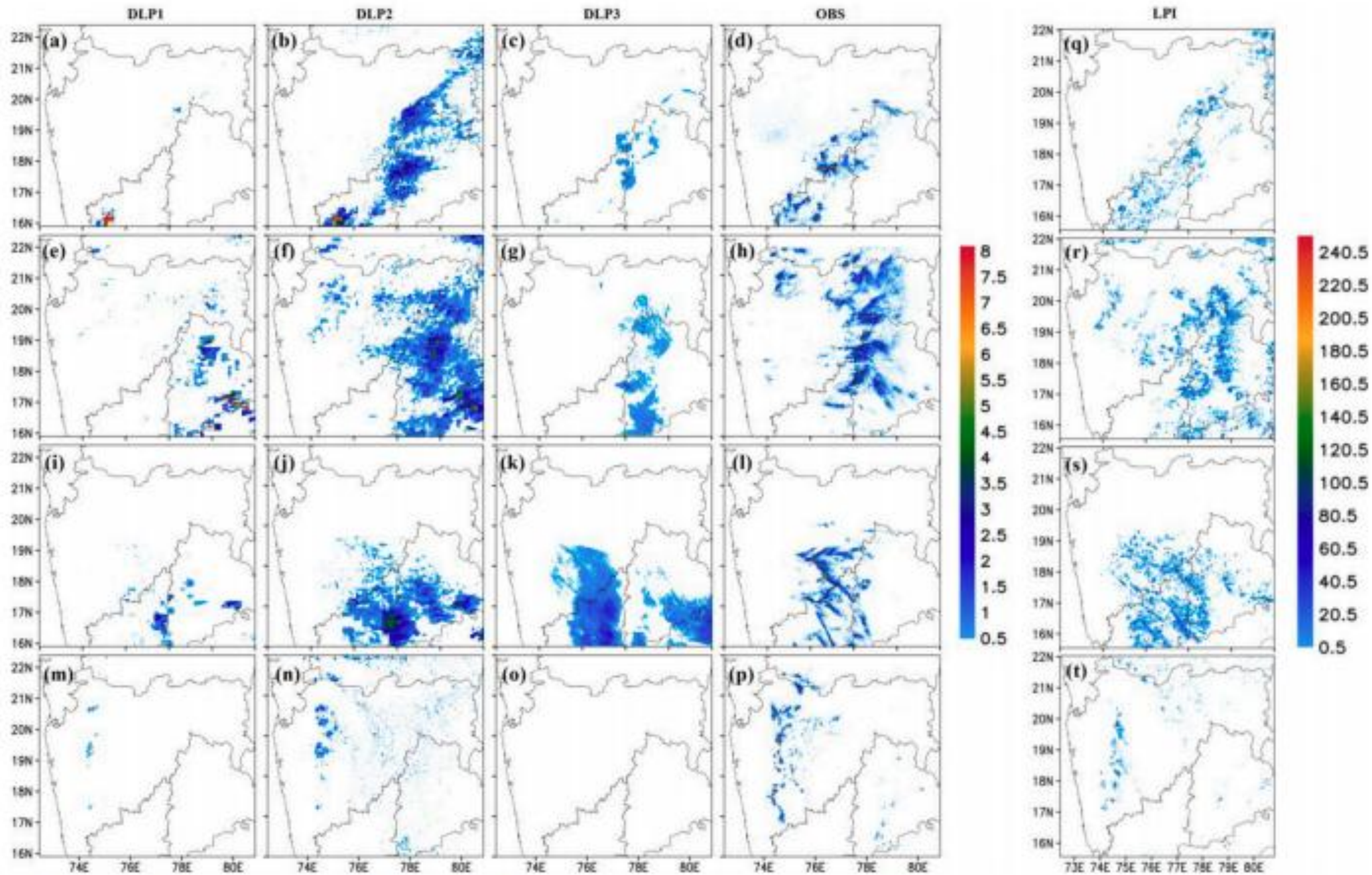


Fig. 10. Spatial distribution of 24 h accumulated lightning flashes (# day^{-1}) from different lightning parameterizations along columns DLP1 (a,e,i,m), DLP2 (b,f,j,n) and DLP3 (c,g,k,o) and (d) observation (d,h,l,p) and lightning potential index (LPI; q,r,s,t) for Cases along rows 29 Apr 2016 (a,b,c,d), 05 May 2016 (e,f,g,h), 15 Mar 2017 (i,j,k,l), and 25 May 2017 (m,n,o,p).

Mohan et al., 2021 (AR)

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Evaluating different lightning parameterization schemes to simulate lightning flash counts over Maharashtra, India

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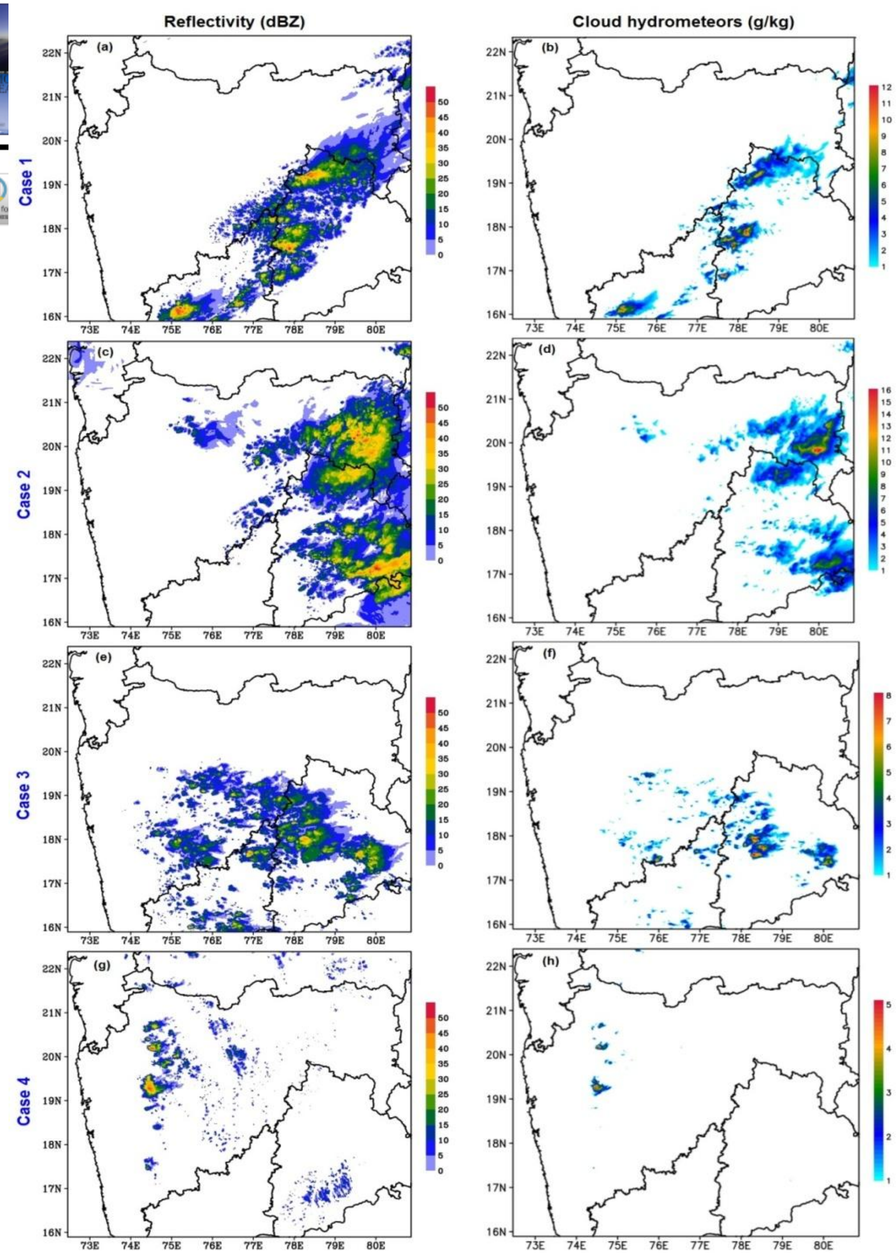
[c] Centre for Atmospheric & Oceanic Sciences, Indian Institute of Science, Bangalore, India
[d] Ministry of Earth Sciences, New Delhi 110003, India

The results show:

- **(i) Better spatial pattern and frequency distribution of lightning flashes,**
- **(ii) Accumulated rainfall, maximum reflectivity and time evolutions are in good agreement with flashes,**
- **(iii) Correlation between simulated flash and hydrometeors are higher,**
- **(iv) The number of matching grid boxes due to randomness is also higher, 74.9%, 56.5%, 68.1% and 82.7% of matching grid boxes for the four cases**
- **(v) The results based on LPI are also in consistent with the results of DLP2.**



Mohan et al., 2021 (AR)

Spatial distribution of lightning flashes from several lightning parameterizations

The lightning parameterizations used for the calculation of lightning flash rate (F) by offline as well as online using the storm parameters from the model simulation.

Abbreviation	Storm Parameter	Relationship
	Online (Dynamical) Lightning Calculations	
DLP2, DLP3	Cloud Top Height (20 dBZ)	$F = 3.44 \times 10^{-5}\ Z_{20dbz}^{4.9}$
DLP1	Maximum Vertical Velocity	$F = 5.00 \times 10^{-6}\ w_{max}^{4.5}$
LPI	Hydrometeors, vertical velocity	$LPI = 1/V \iiint \varepsilon\, w^2\, dx\, dydz$
	Offline (Diagnosed) Lightning Calculations	
PR92CTH	Cloud Top Height (20 dBZ)	$F = 3.44 \times 10^{-5}\ Z_{20dbz}^{4.9}$
PR92W	Maximum Vertical Velocity	$F = 5.00 \times 10^{-6}\ w_{max}^{4.5}$
UV5	Updraft Volume, w > 5 m/s	$F = (1.1 \times 10^{-1}) \times UV5$
UV10	Updraft Volume, w > 10 m/s	$F = (2.1 \times 10^{-1}) \times UV10 + 8.8$
VOL35	35 dBZ Echo Volume	$F = 0.072\ xVOL35$
GEV	Garupel Echo Volume	$F = (7.0 \times 10^{-2}) \times GEV$
IWP	Integrated Ice Water Path	$F = (33.33 \times IWP) - 0.17$
MC09	McCaul Method	$F = (0.042\ (w\ q_g)) + (0.20 \int \rho\ (q_g + q_s + q_i)\ dz)$

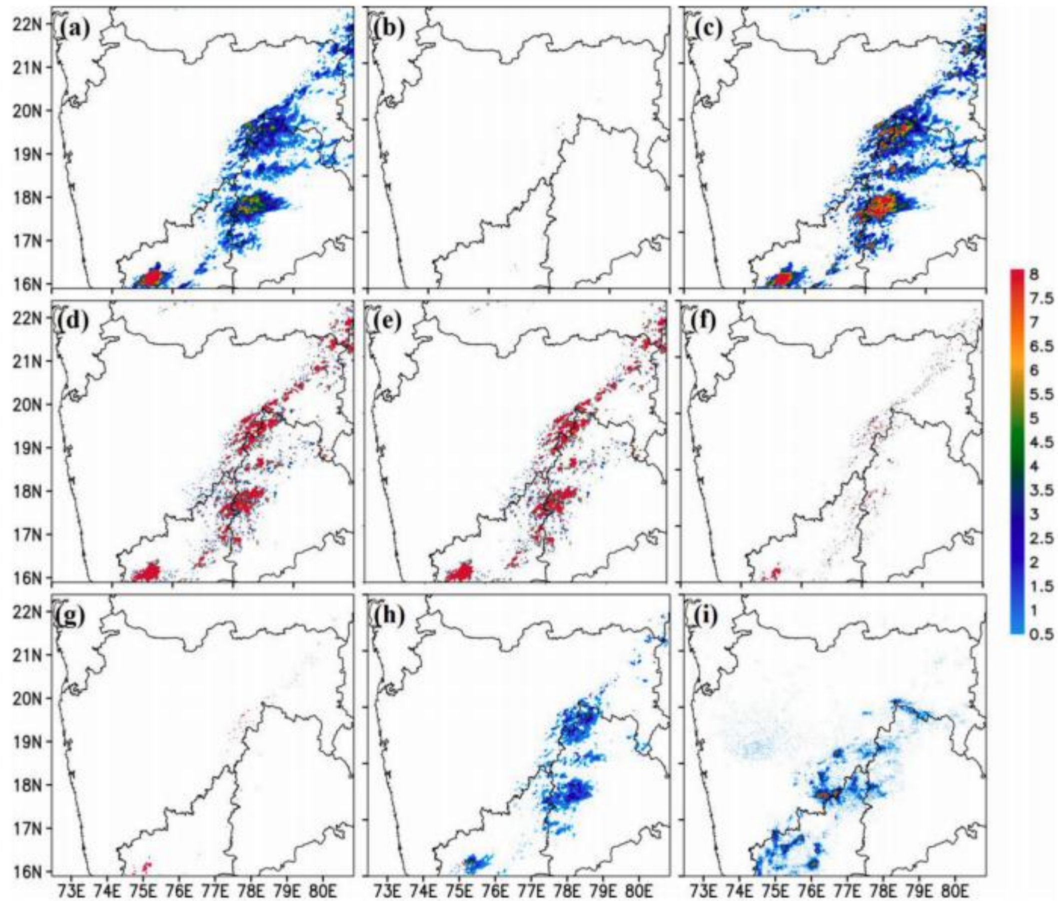


Fig. 9. Spatial distribution of calculated flashes for 29 April 2016 based on different storm parameters (a) PR92CTH, (b) PR92W, (c) IWP, (d) VOL35, (e) GEV, (f) UV5, (g) UV10, (h) MC09 and (i) observed flashes.

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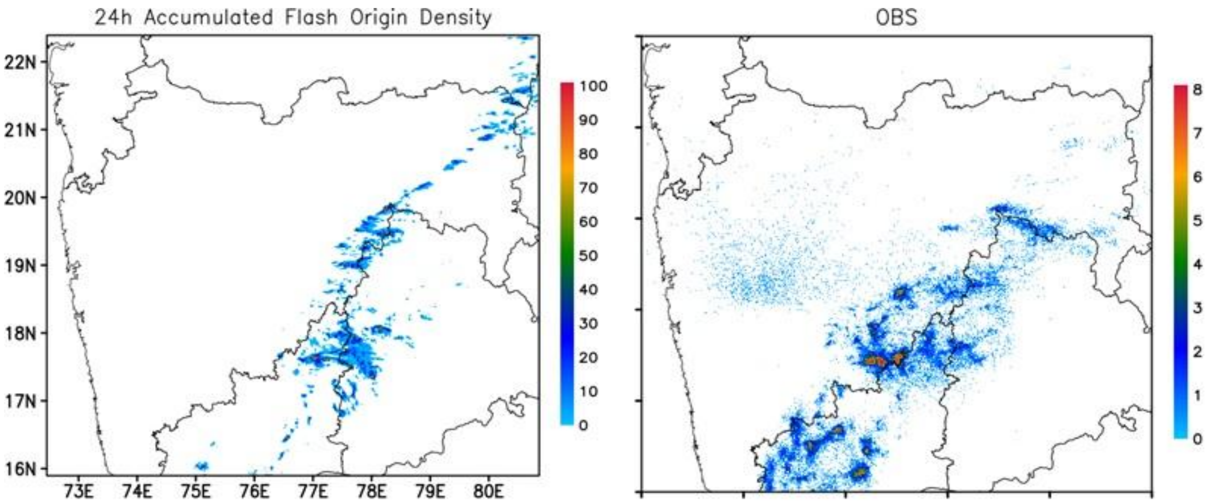
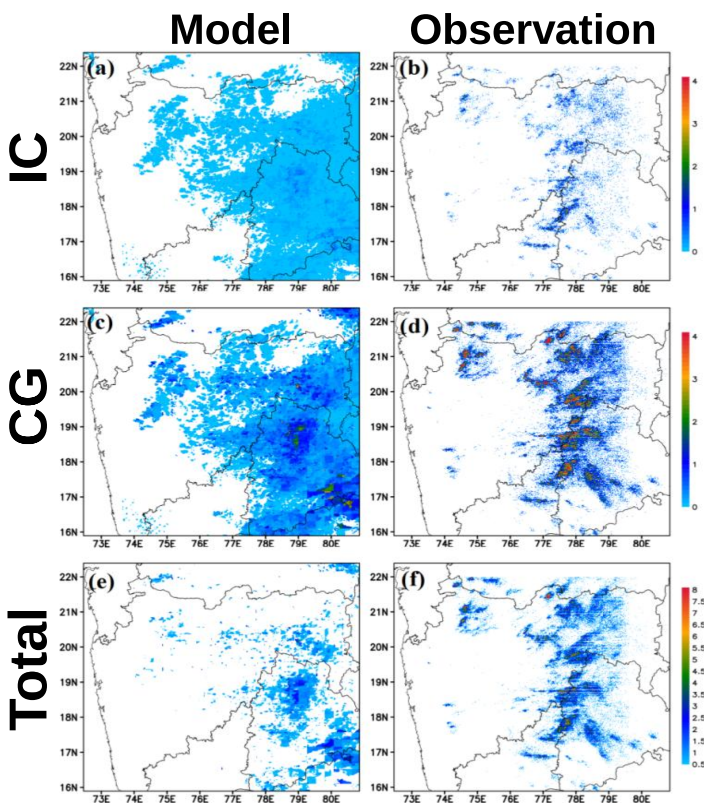
Electric Field Parameterization



An explicit electrification and lightning parameterization in Weather Research and Forecasting model (E-WRF) by Fierro et al., (2013) has been evaluated for one thunderstorm case (29 April 2016) over India.



Importance of observation correction

The detection efficiency of the lightning sensors is 50% for IC lightning and 90% for CG lightning. Therefore, it is important to note that correction of model simulated lighting data is also essential.

Corrected lightning flash counts based on **detection efficiency** from model (left panel) and observation (right panel) for the case 05052016. The corrected IC flash counts in the upper panel, corrected CC flash counts in the middle and total lightning flash counts in the bottom panel.

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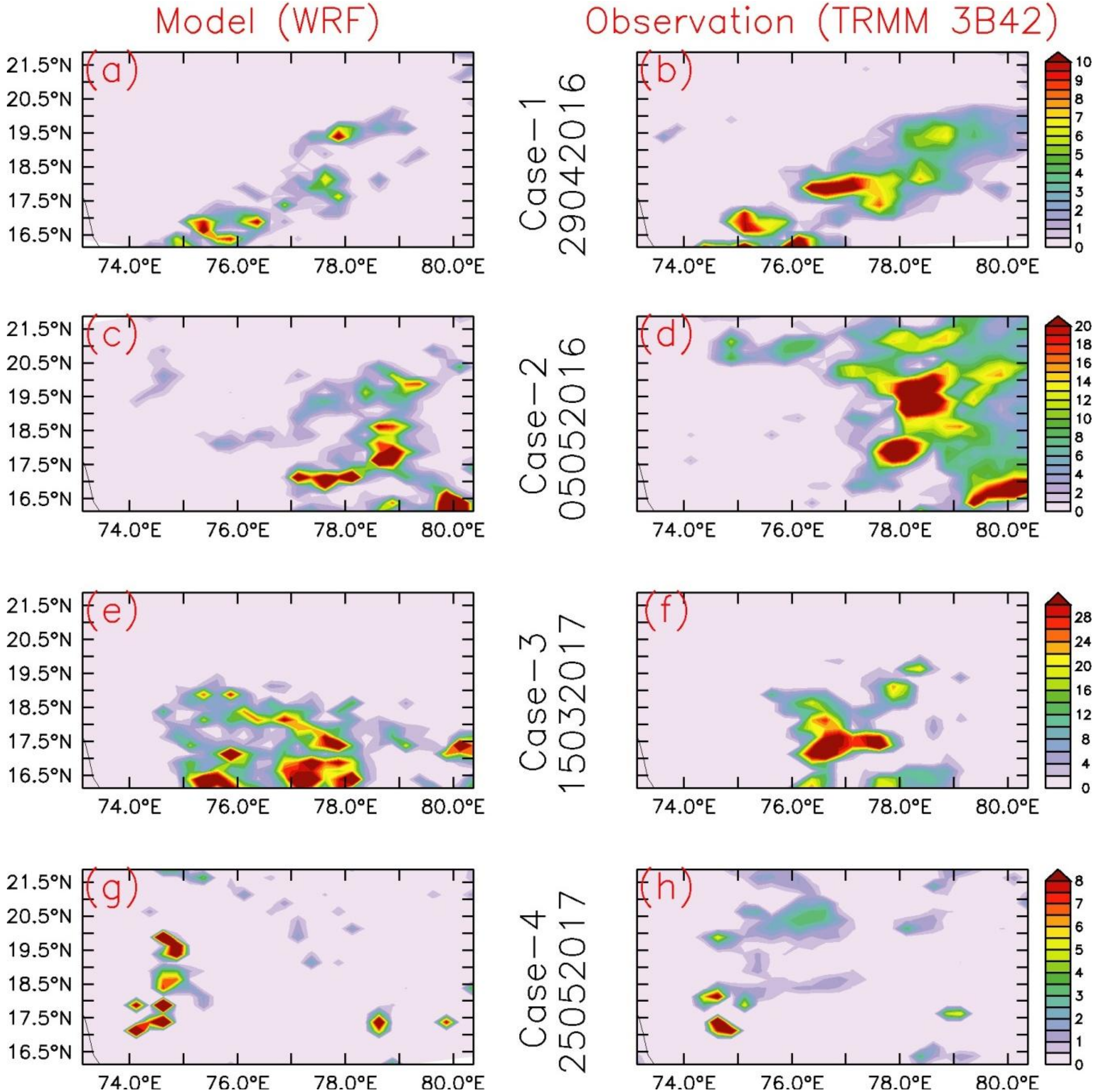
Rainfall



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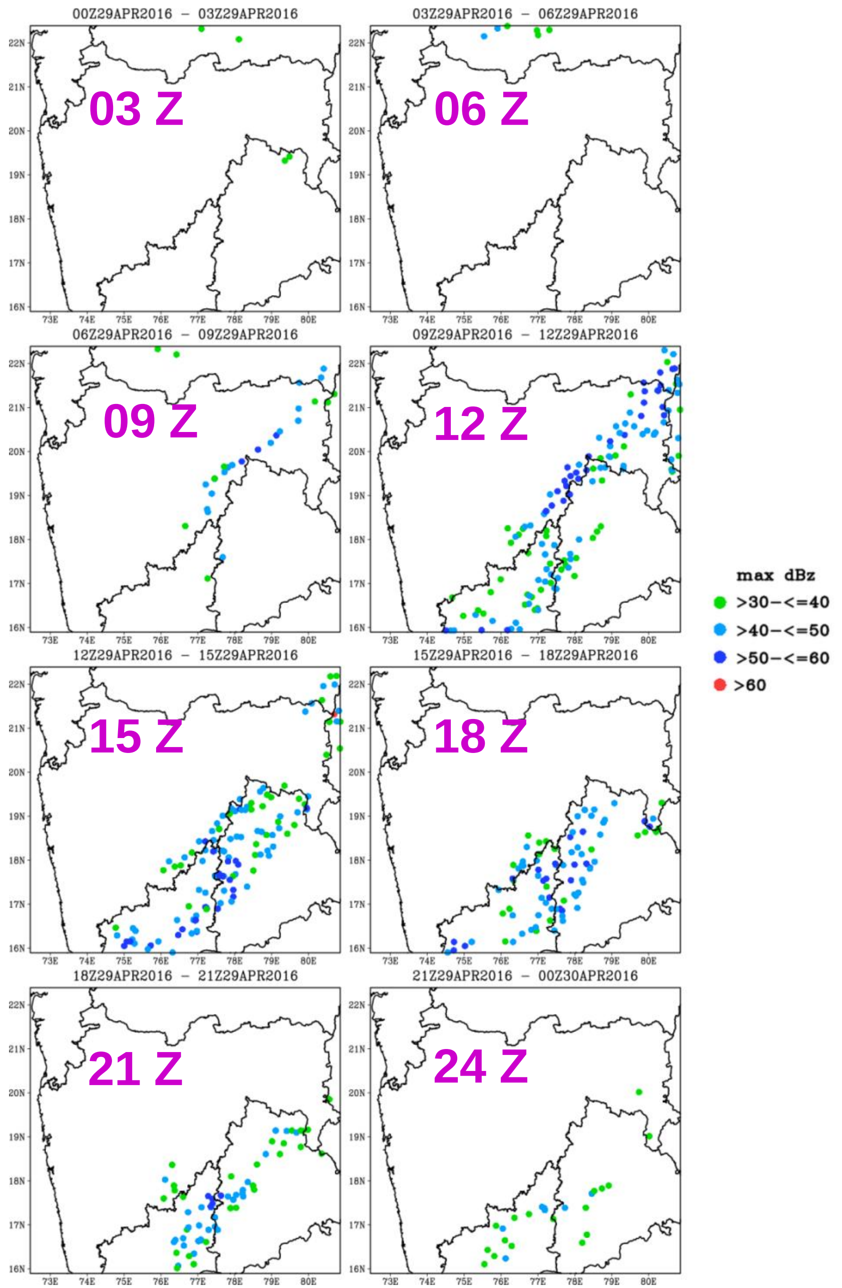
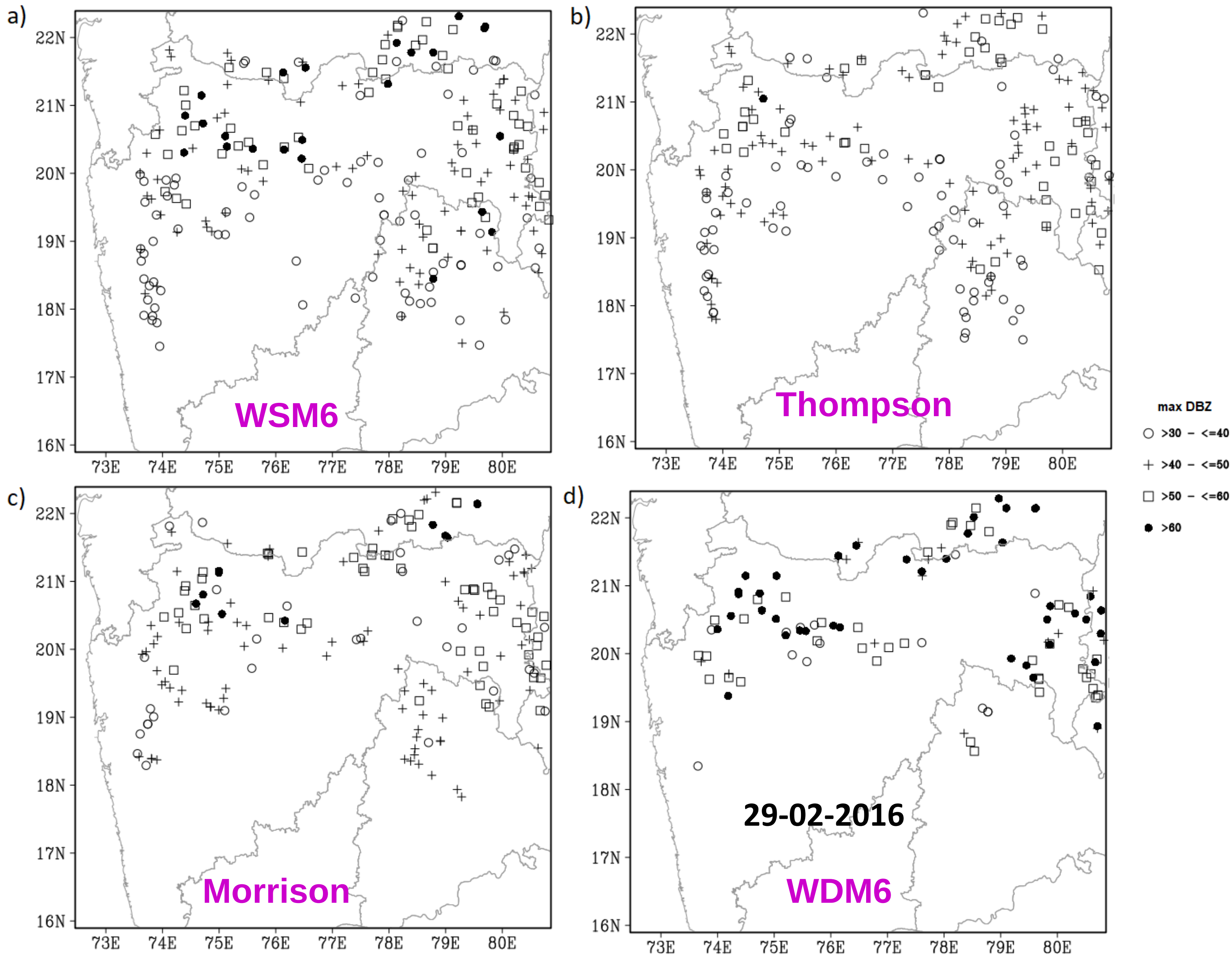
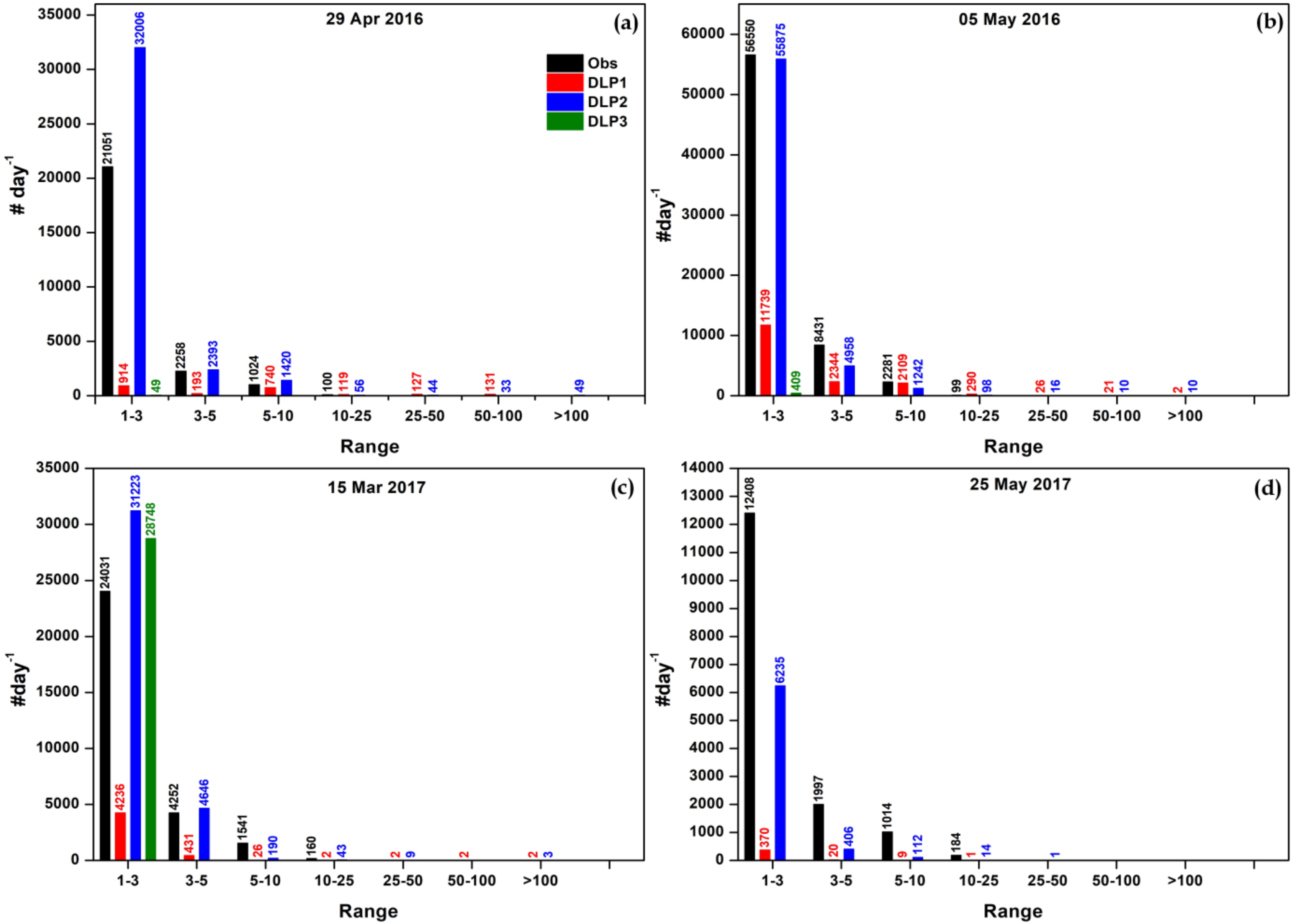
3-hourly evolution of maximum reflectivity. Different colours represents bin of max_dBz.



Mohan et al., 2021 (AR)



a)
b)
c)
d)
22N
21N
20N
19N
18N
17N
16N
73E
74E
75E
76E
77E
78E
79E
80E
WSM6
Thompson
Morrison
WDM6
29-02-2016
max DBZ
>30 – <=40
>40 – <=50
>50 – <=60
>60



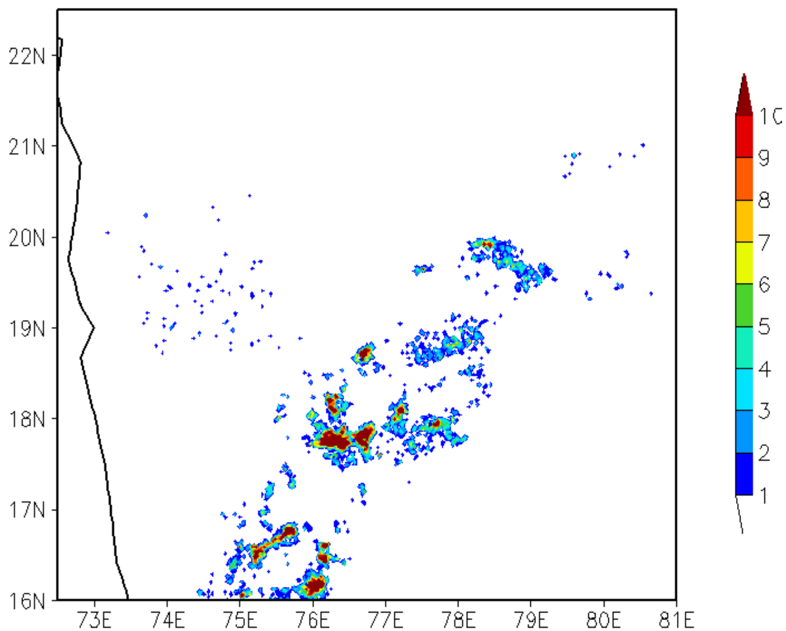
29 Apr 2016
(a)
Obs
DLP1
DLP2
DLP3
day-1
Range
1-3
3-5
5-10
10-25
25-50
50-100
>100
21051
914
32006
49
2258
193
2393
1024
740
1420
100
119
56
127
44
131
33
49
05 May 2016
(b)
#day-1
56550
11739
55875
409
8431
2344
4958
2281
2109
1242
99
290
98
26
16
21
10
2
10
15 Mar 2017
(c)
24031
4236
31223
28748
4252
431
4646
1541
26
190
160
2
43
2
9
2
2
3
25 May 2017
(d)
12408
370
6235
1997
20
406
1014
9
112
184
1
14
1

Validation & Verification

Case 1: 29th Apr, 2016

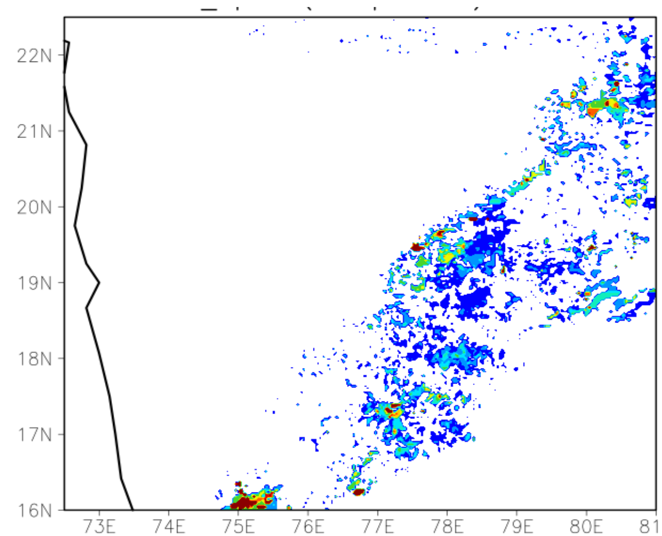
Maharashtra Lightning Detection Network (MDLN)

Observed CG Lightning Flashes on 29 Apr 2016

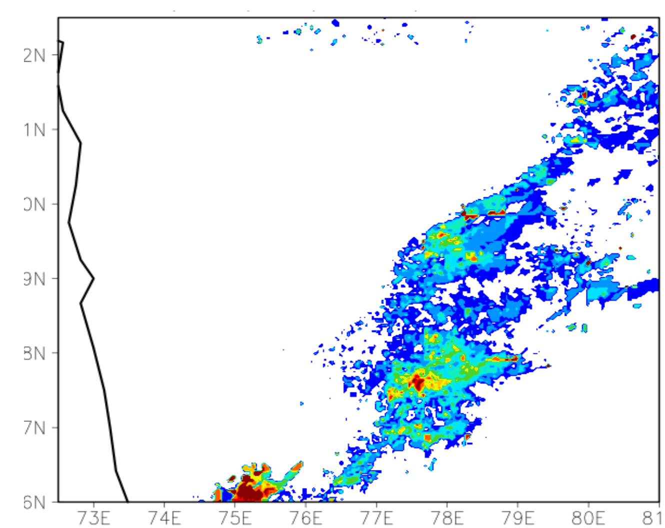


Cloud to Ground (CG) Lightning Flashes - Model

WSM6, PR94



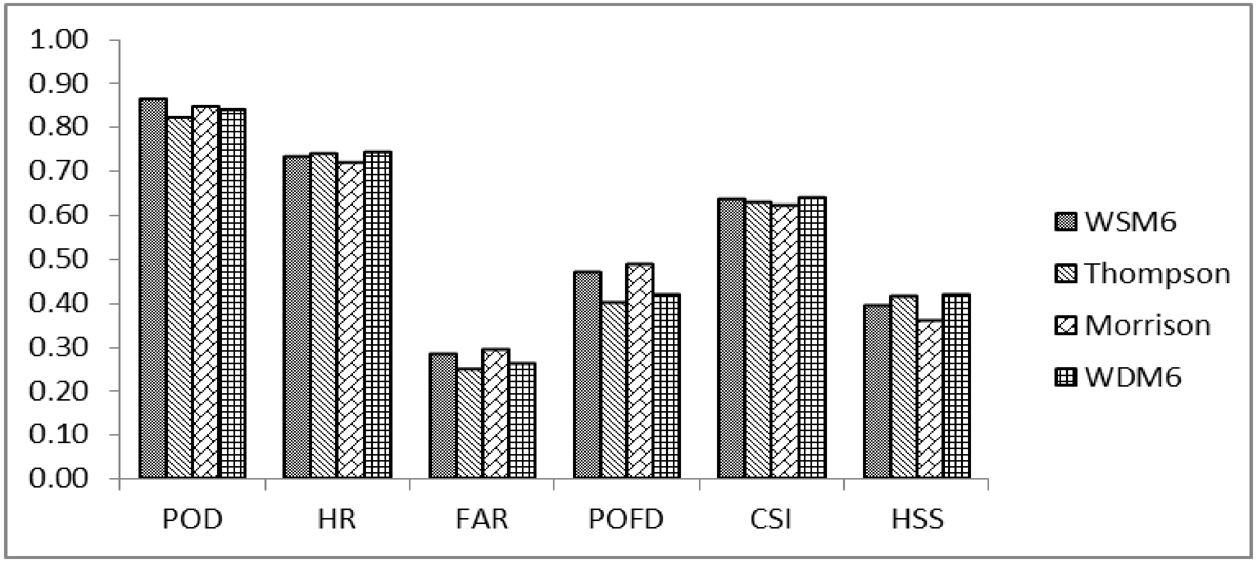
Morrison, PR94



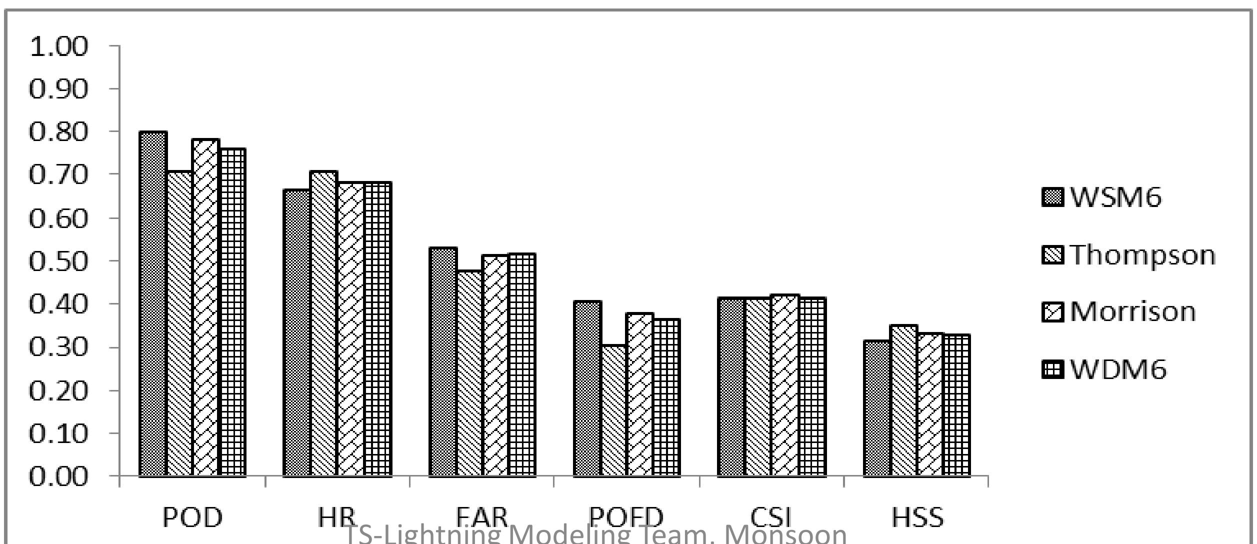
TS-Lightning Modeling Team, Monsoon Mission, IITM, Pune

Lightning Skill Score with all MP's for a) 50 km and b) 10km region

(a)

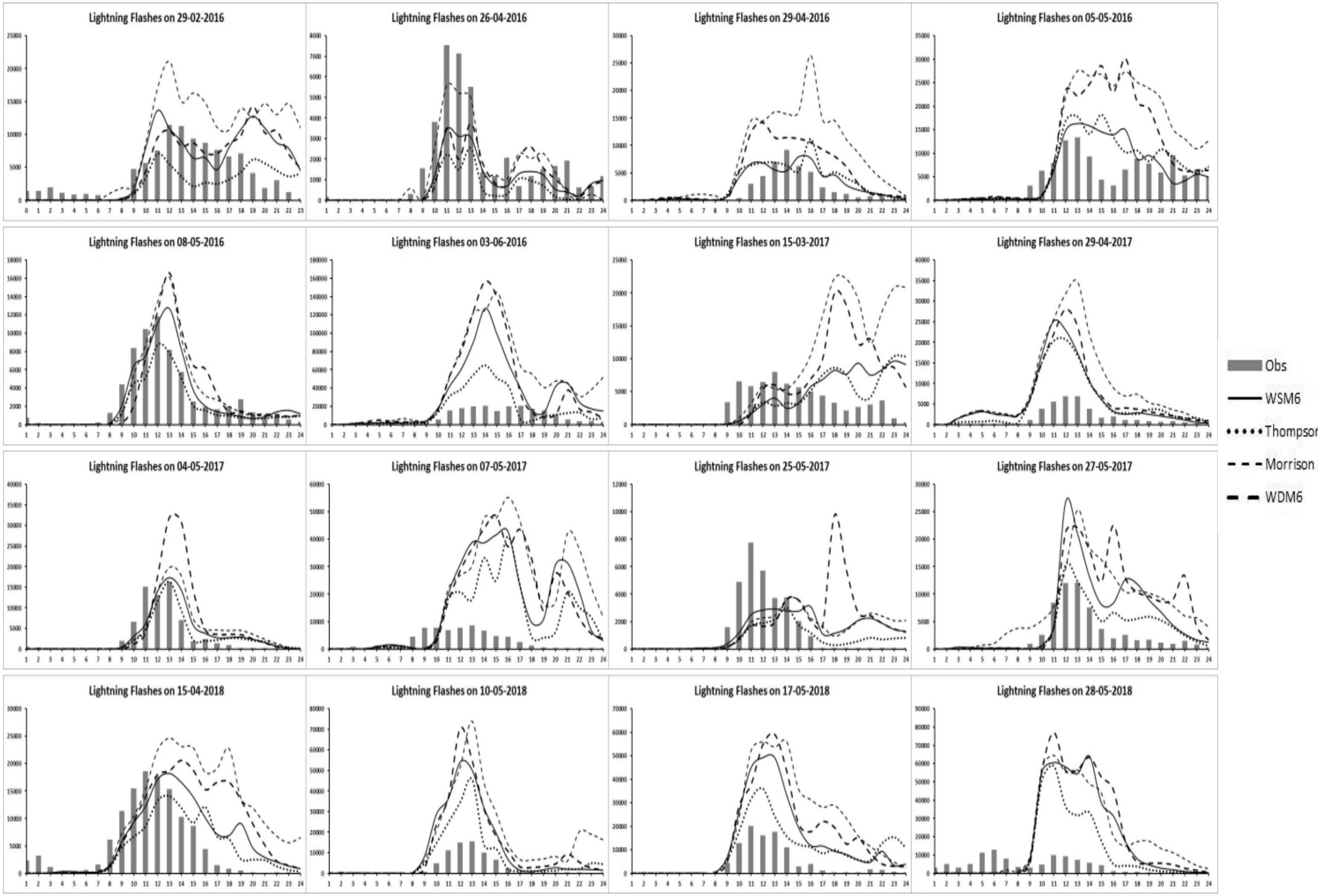


(b)



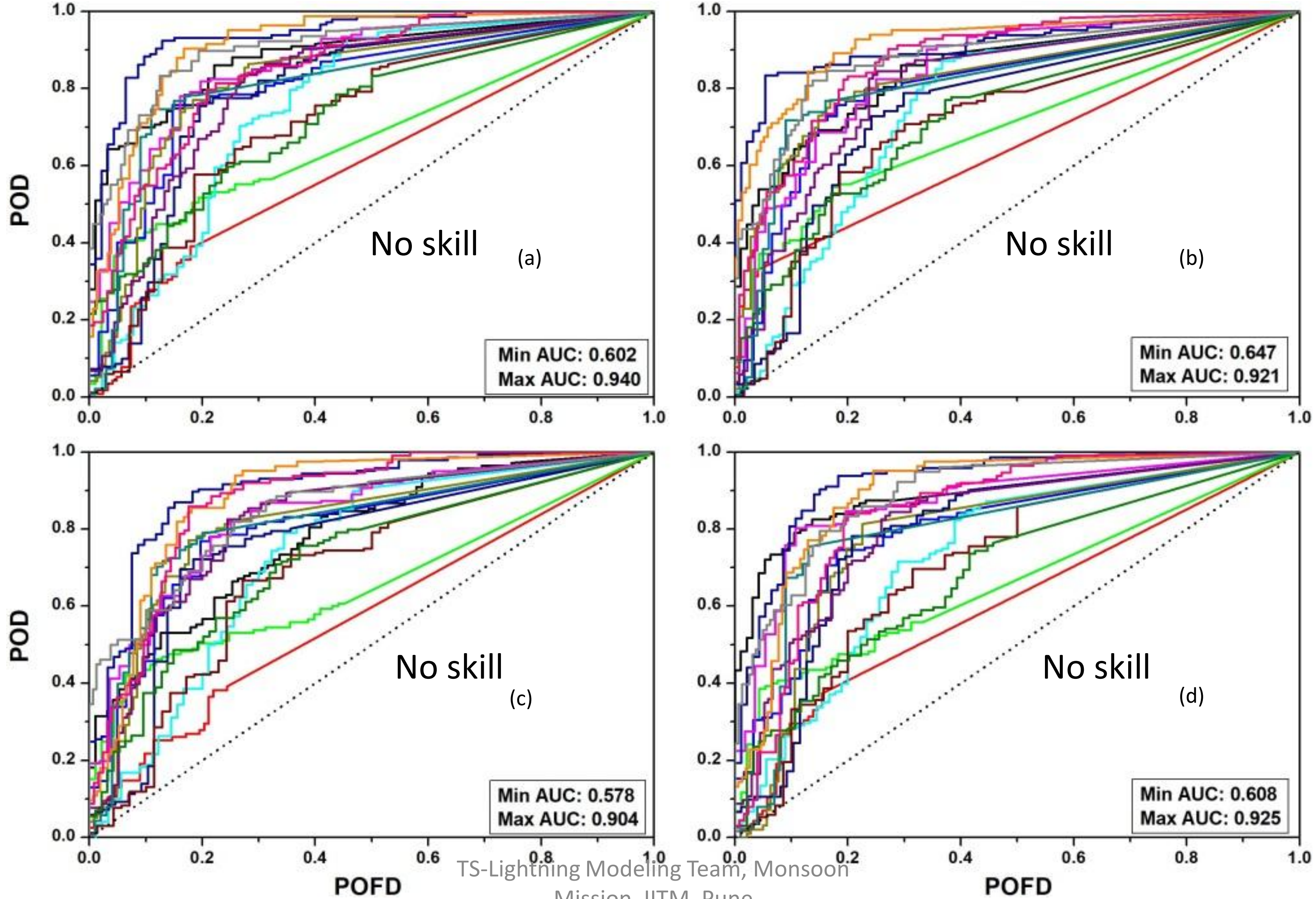
Gayatri et al., 2021 (WAF)

Diurnal variation of Lightning

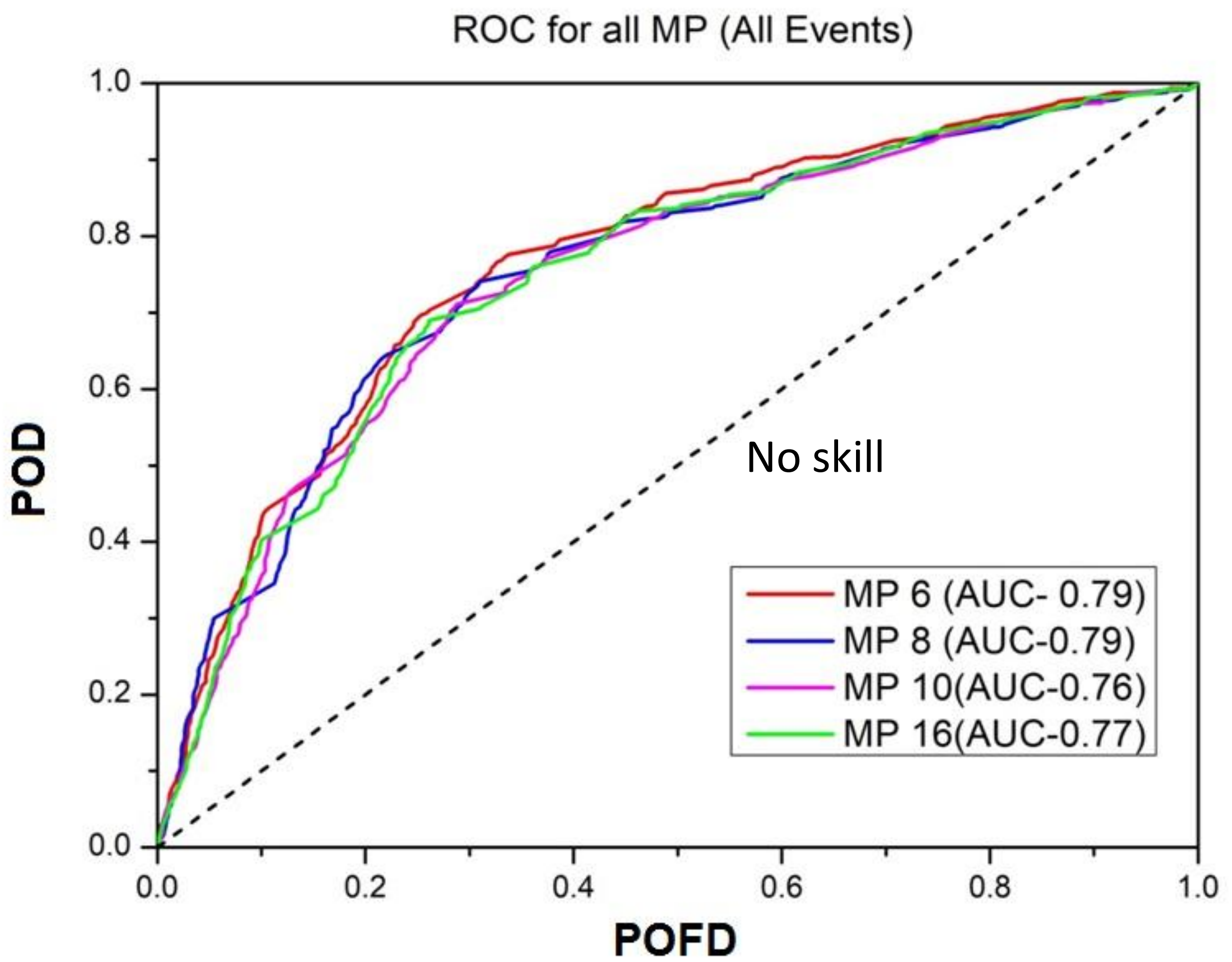


Gayatri et al., 2021 (WAF)

Receiver Operating Characteristic (ROC) Curve for all events for 50 km region a)WSM6 b)Thompson c) Morrison d) WDM6



ROC Curve (Receiver Operating Characteristic)

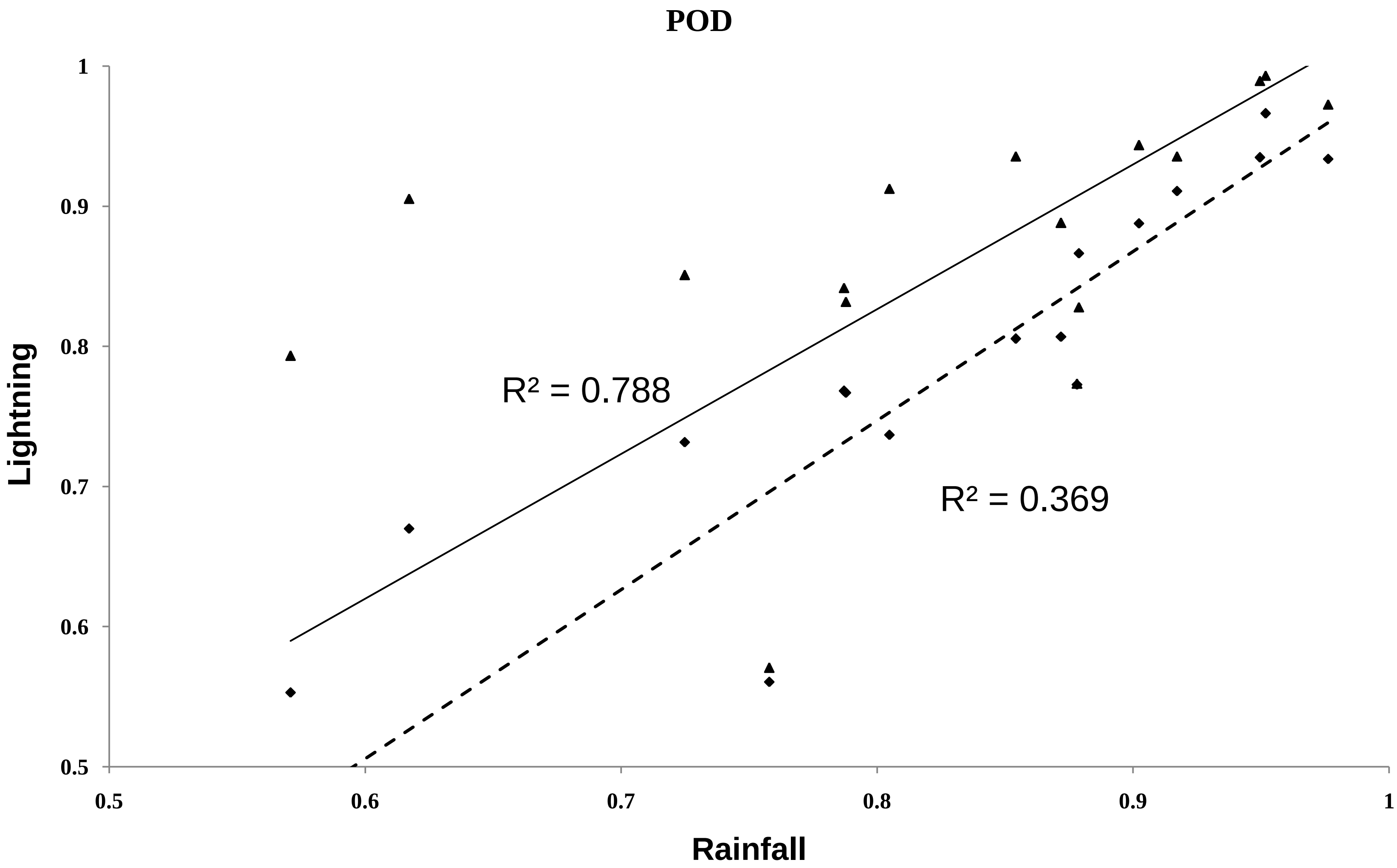


The ROC curve is a probability curve to asses the performance.

Averaged AUC for all events

Gayatri et al., 2021 (WAF)

Scatter plot of POD for Rainfall and Lightning



Spatial Agreement and Standard Deviation

		WSM6		Thompson		Morrison		WDM6	
		Spatial Agreement	**Standard Deviation**	**Spatial Agreement**	**Standard Deviation**	**Spatial Agreement**	**Standard Deviation**	**Spatial Agreement**	**Standard Deviation**
Event 1	**29-02-2016**	0.73	6.00	0.77	5.49	0.63	6.93	0.72	6.10
Event 2	**26-04-2016**	0.91	2.08	0.95	1.07	0.92	1.96	0.91	2.08
Event 3	**29-04-2016**	0.81	3.60	0.86	2.98	0.75	4.09	0.79	3.75
Event 4	**05-05-2016**	0.65	7.20	0.70	6.71	0.55	7.68	0.63	7.31
Event 5	**08-05-2016**	0.80	4.33	0.86	3.46	0.76	4.84	0.82	4.07
Event 6	**03-06-2016**	0.61	8.17	0.68	7.48	0.52	8.60	0.60	8.28
Event 7	**15-03-2017**	0.74	4.51	0.76	4.36	0.68	4.90	0.74	4.54
Event 8	**29-04-2017**	0.72	4.04	0.79	3.57	0.68	4.20	0.70	4.11
Event 9	**04-05-2017**	0.81	3.46	0.88	2.72	0.74	3.99	0.79	3.61
Event 10	**07-05-2017**	0.68	4.65	0.77	4.09	0.62	4.90	0.66	4.75
Event 11	**25-05-2017**	0.86	2.55	0.94	1.55	0.83	2.83	0.86	2.52
Event 12	**27-05-2017**	0.77	4.51	0.82	3.90	0.69	5.05	0.76	4.52
Event 13	**15-04-2018**	0.65	6.42	0.71	5.95	0.54	6.85	0.66	6.34
Event 14	**10-05-2018**	0.78	3.63	0.84	3.12	0.71	4.08	0.76	3.74
Event 15	**17-05-2018**	0.65	5.28	0.74	4.76	0.58	5.54	0.63	5.37
Event 16	**28-05-2018**	0.78	3.58	0.83	3.13	0.73	3.89	0.77	3.61
Average		**0.75**	**4.63**	**0.81**	**4.02**	**0.68**	**5.02**	**0.74**	**4.67**

Results: Real time operational forecast

New product (CG-lightning flash counts)
From dynamical model (WRF)

Reflectivity based “Dynamical Lighting Parameterization (DLP)”

EXPERIMENTAL LIGHTNING FLASH PREDICTION - VERIFICATION

Real-time forecast based on

INITIAL CONDITION (IC): GFS T1534 (Provided by IMD Team)

WRF (With DLP-scheme)- 3 km resolution

Note: Includes Day1(09042019)

Prepared by*: Greeshma M. Mohan, Gayatri Vani, Anupam Hazra and Team for *Lightning/TS forecast, Indian Institute of Tropical Meteorology, Ministry of Earth Sciences, India.

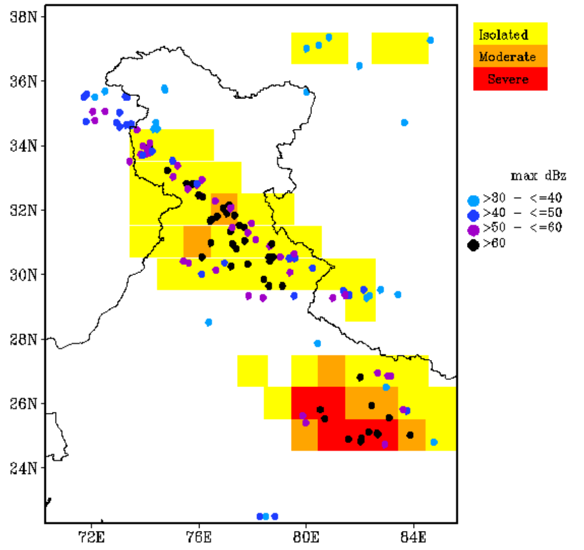
24 h Accumulated Lightning Threat

(Forecast for 21 Feb 2019)

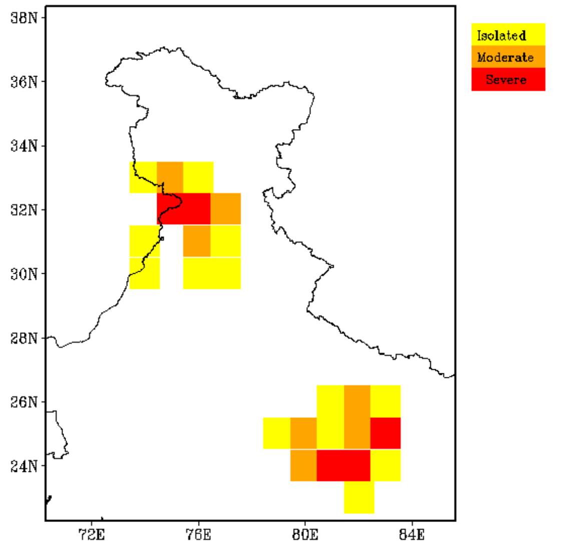
Lightning Threat Level	Threat Level Descriptions
Extreme	"An Extreme Threat to Life and Property from Lightning." Within 12 miles of a location, a moderate likelihood of CG lightning (or 50% thunderstorm probability), with storms capable of excessive CG lightning. AND/OR...a high likelihood of CG lightning (or 60% to 70% thunderstorm probability), with storms capable of frequent CG lightning. AND/OR...a very high likelihood of CG lightning (or 80% to 90% thunderstorm probability), with storms capable of occasional CG lightning.
High	"A High Threat to Life and Property from Lightning." Within 12 miles of a location, a low likelihood of CG lightning (or 30% to 40% thunderstorm probability), with storms capable of excessive CG lightning. AND/OR...a moderate likelihood of CG lightning (or 50% thunderstorm probability), with storms capable of frequent CG lightning. AND/OR...a high likelihood of CG lightning (or 60% to 70% thunderstorm probability), with storms capable of occasional CG lightning.
Moderate	"A Moderate Threat to Life and Property from Lightning." Within 12 miles of a location, a very low likelihood of CG lightning (or 10% to 20% thunderstorm probability), with storms capable of excessive CG lightning. AND/OR...a low likelihood of CG lightning (or 30% to 40% thunderstorm probability), with storms capable of frequent CG lightning. AND/OR...a moderate likelihood of CG lightning (or 50% thunderstorm probability), with storms capable of occasional CG lightning.
Low	"A Low Threat to Life and Property from Lightning." Within 12 miles of a location, a very low likelihood of CG lightning (or 10% to 20% thunderstorm probability), with storms capable of frequent CG lightning. AND/OR...a low likelihood of CG lightning (or 30% to 40% thunderstorm probability), with storms capable of occasional CG lightning.

Source: NCAR, USA

Model



Observation



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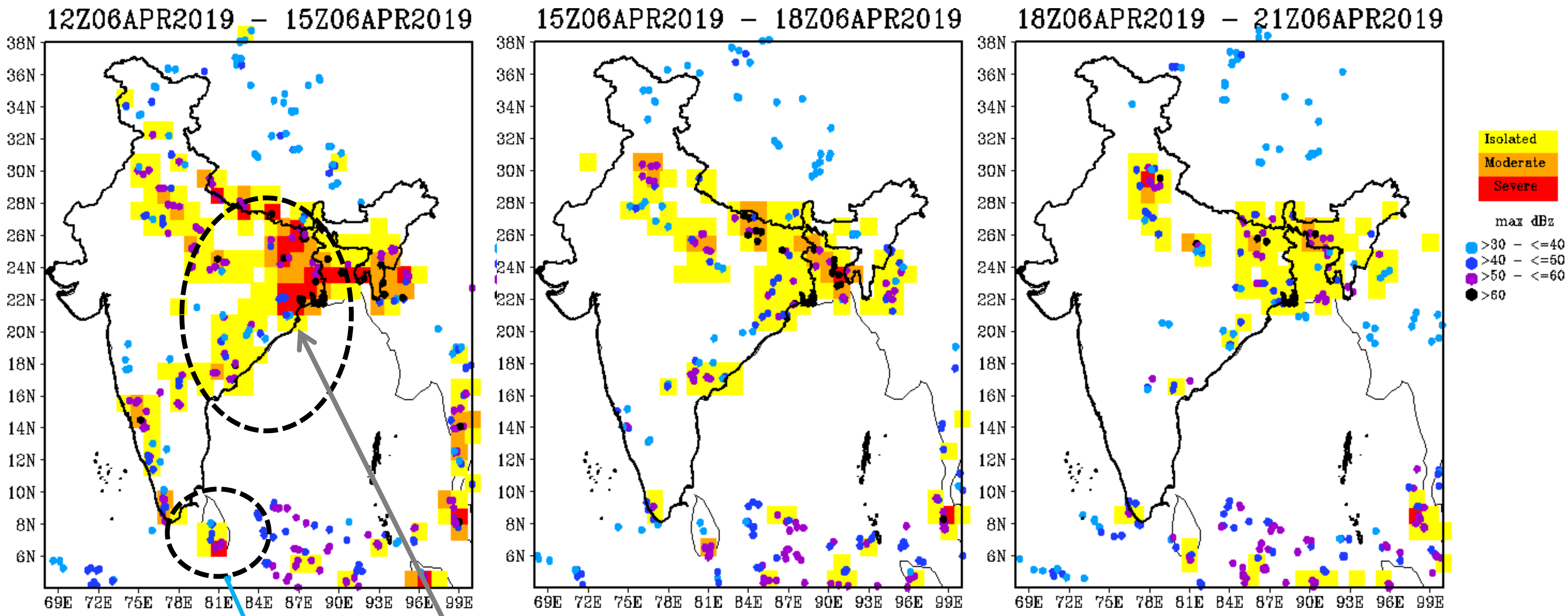
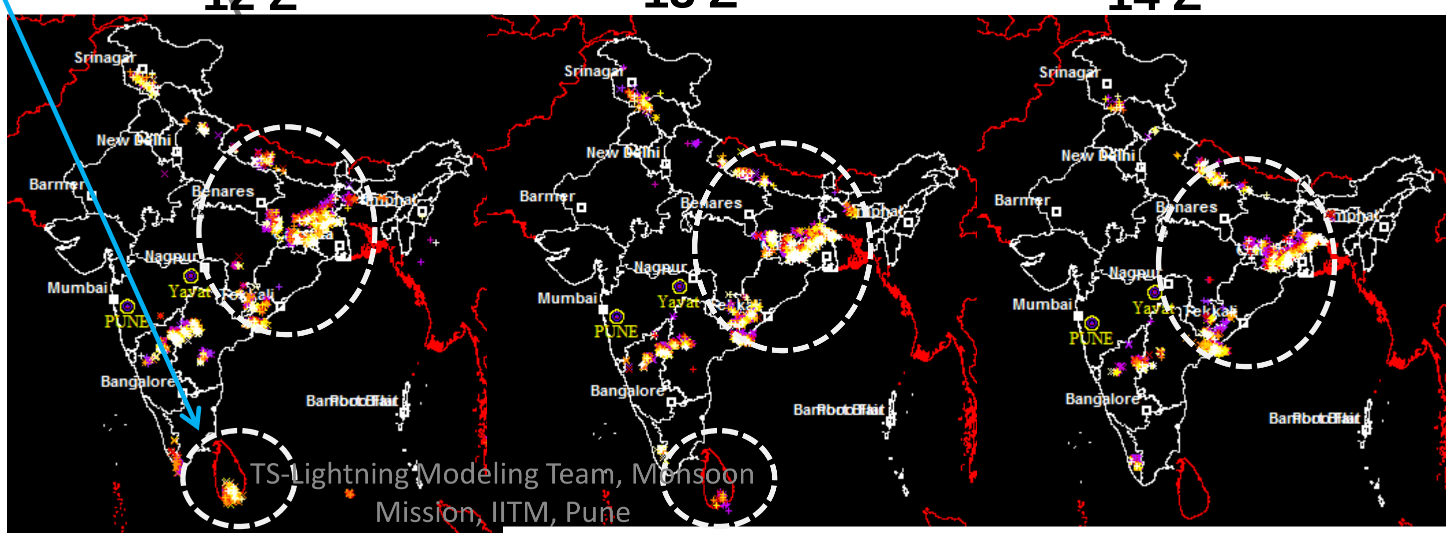
Forecast for: 06 April 2019

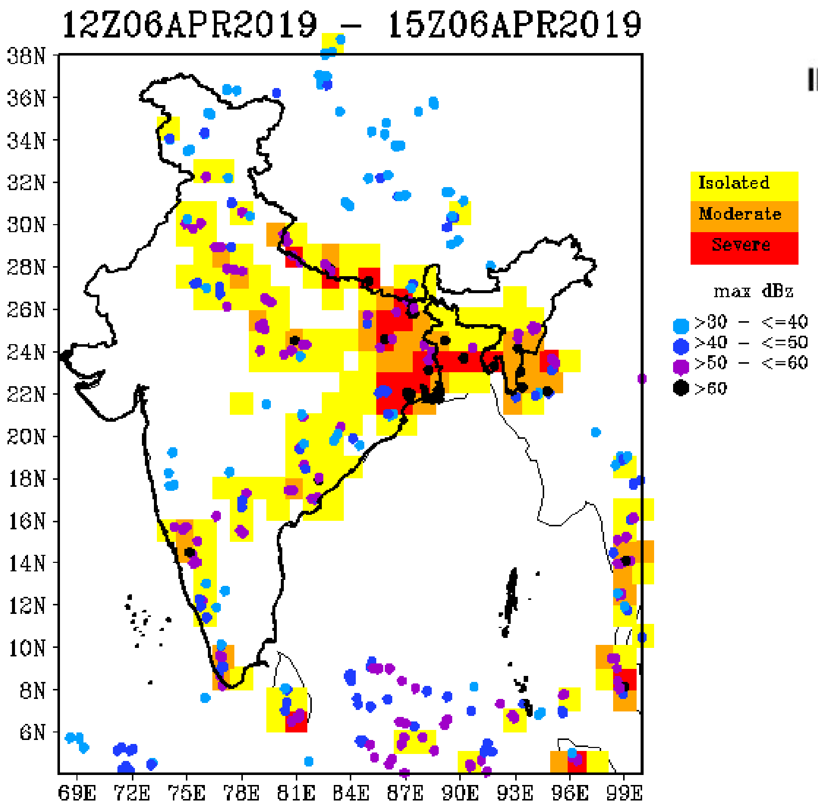


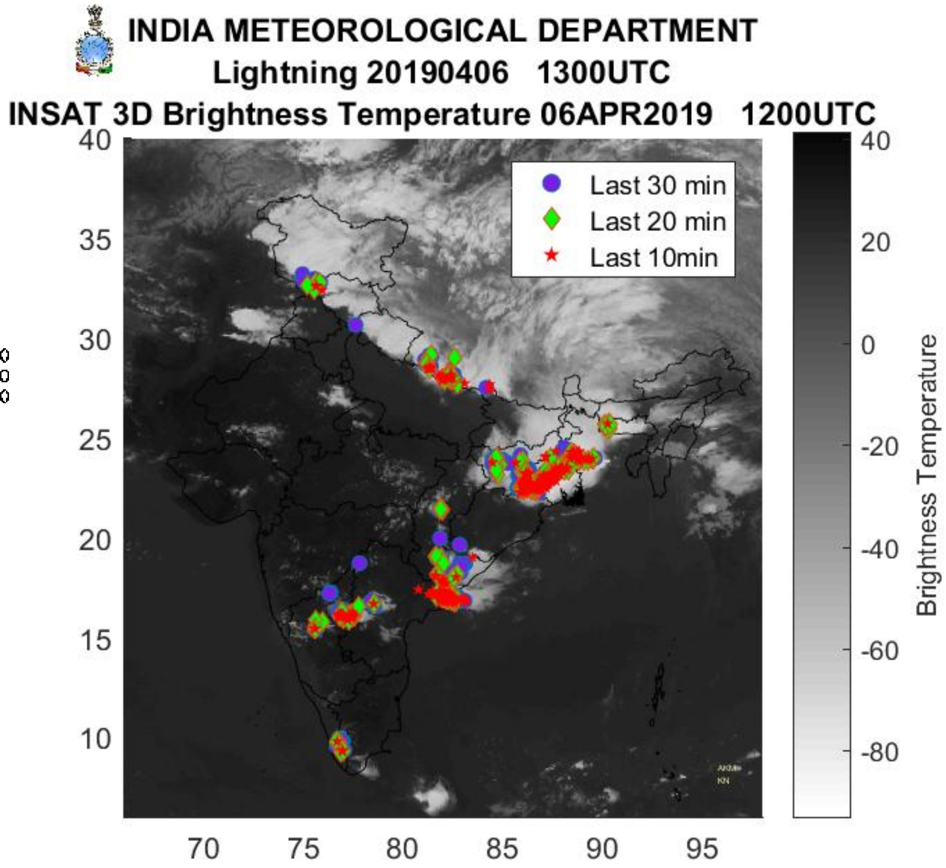
IMD report: Kolkata and experiencing severe thunderstorm, gusty wind and lightning since around 6PM. **Thunderstorm and lightning also happening over coastal Odisha and also many places of gangetic planes.**

Observation (Lightning network) – Screen shot)

12 Z 13 Z 14 Z







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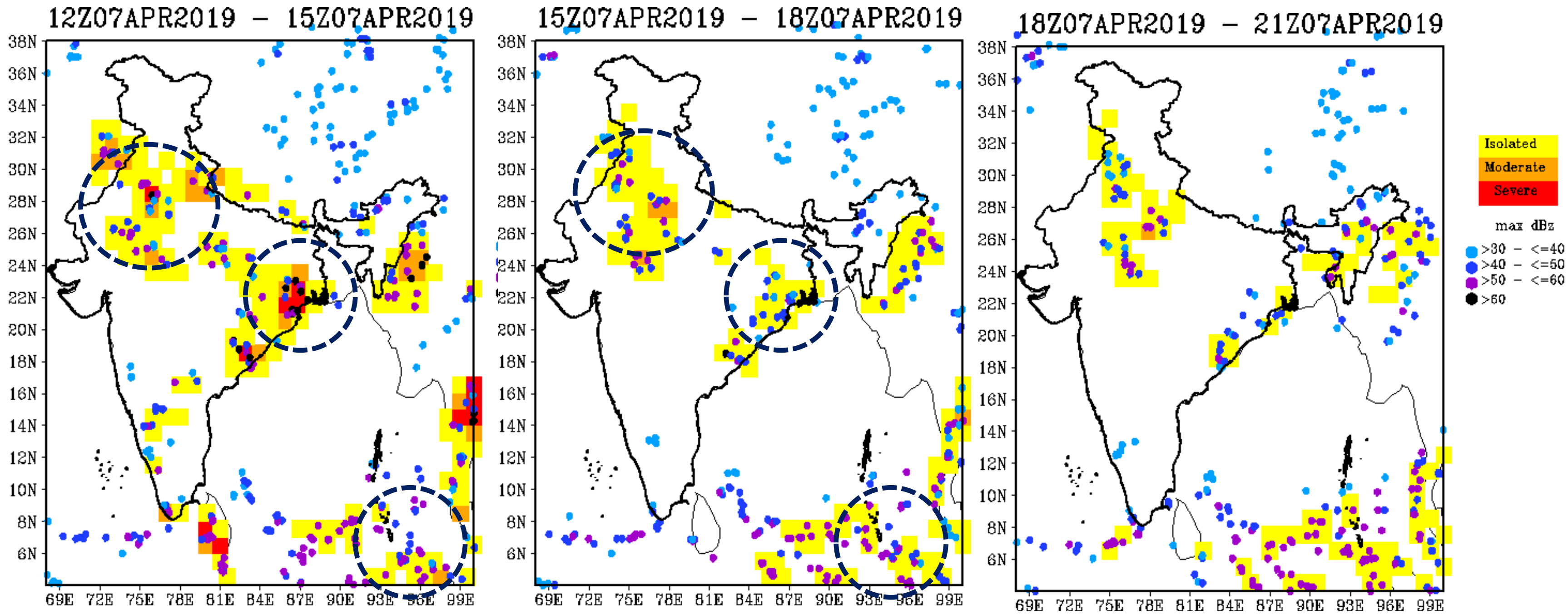
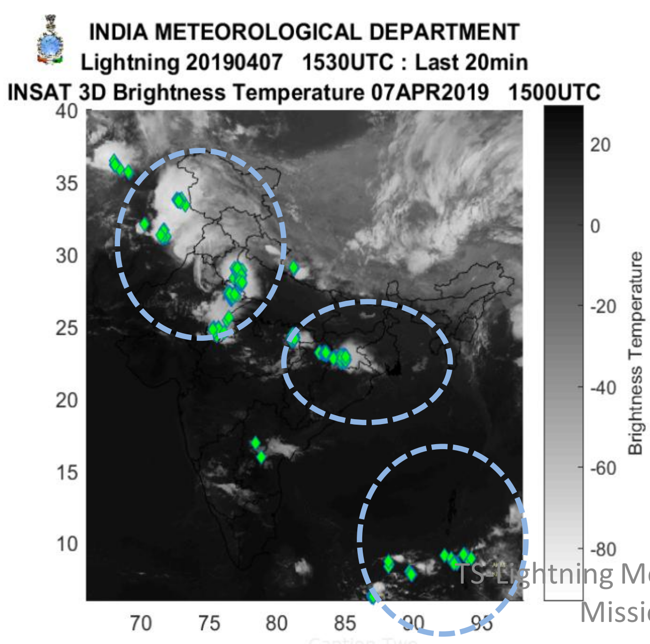
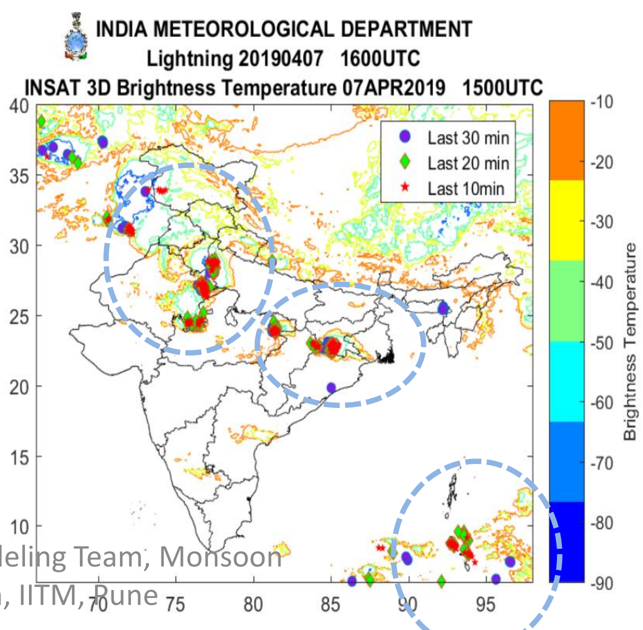
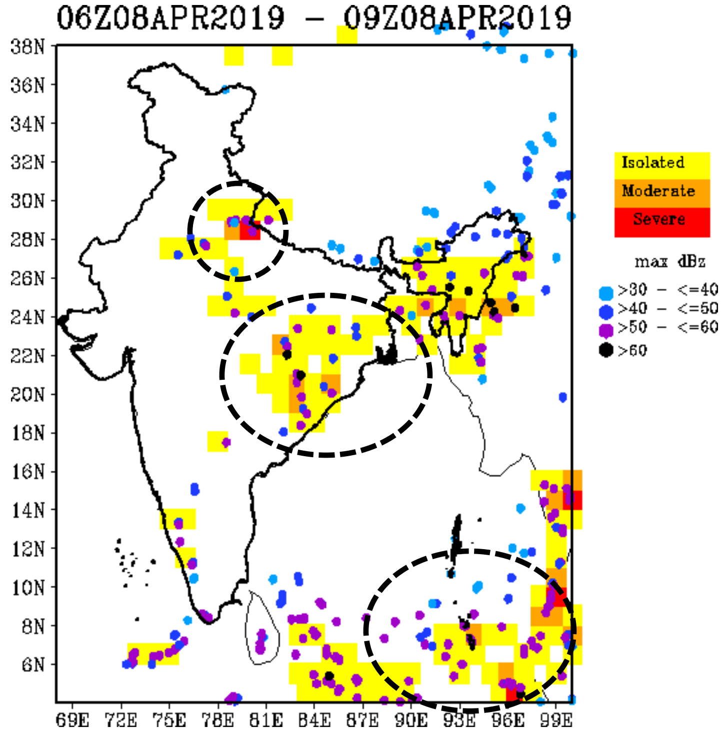
Forecast for: 07 April 2019

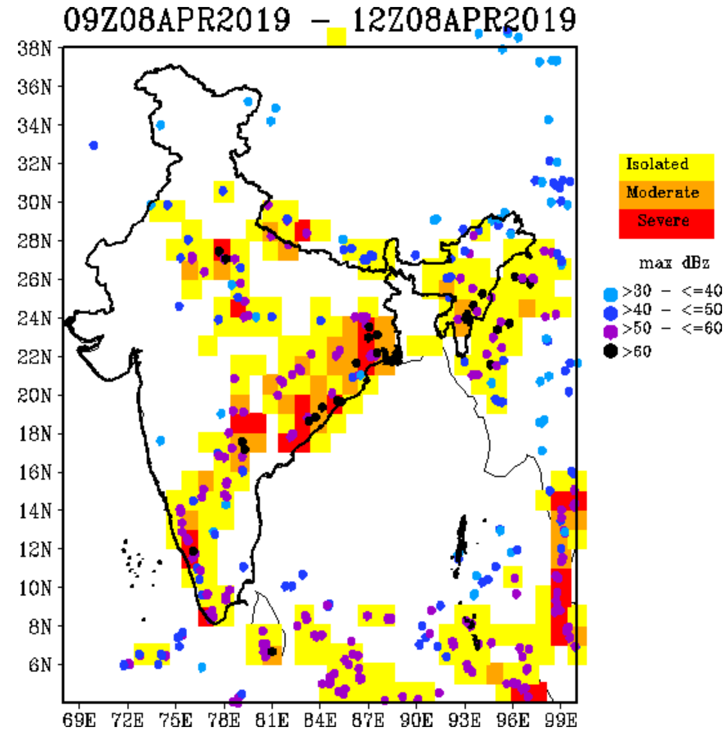


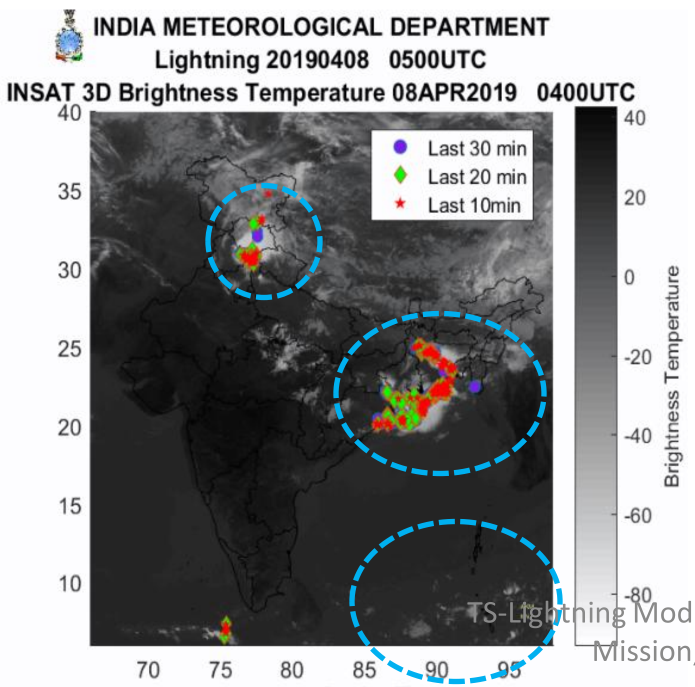


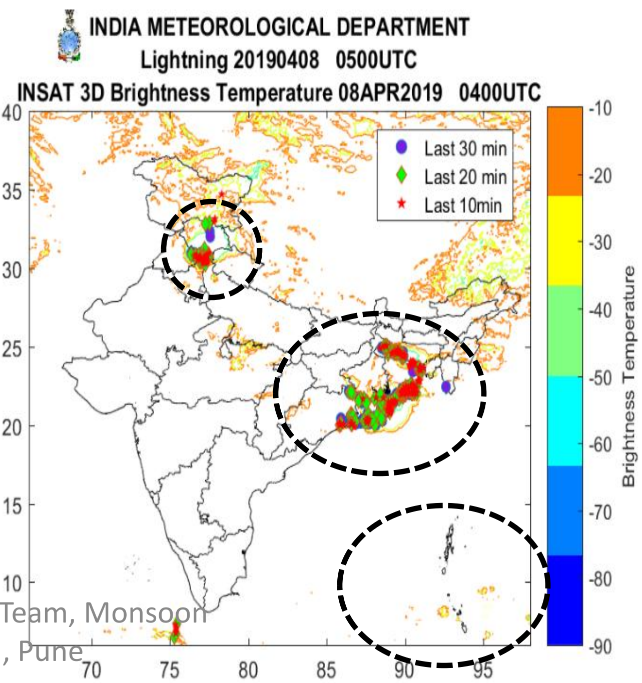


Forecast for: 08 April 2019









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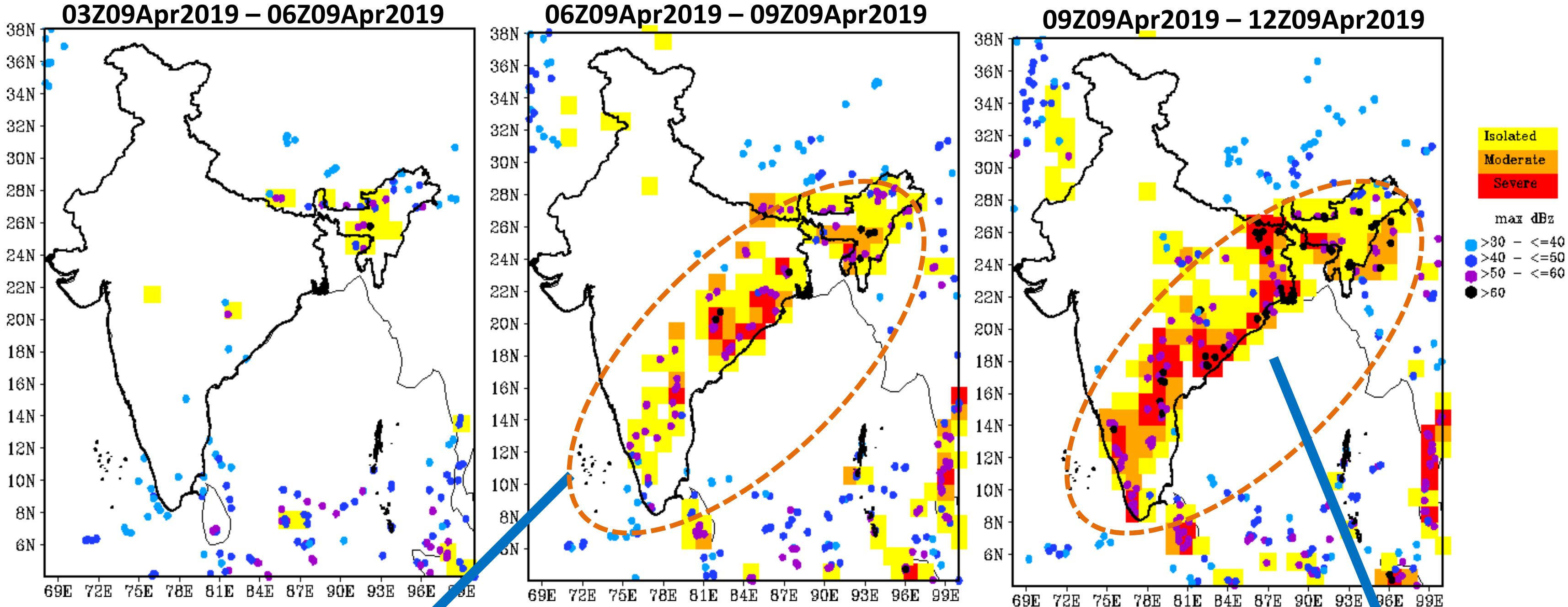
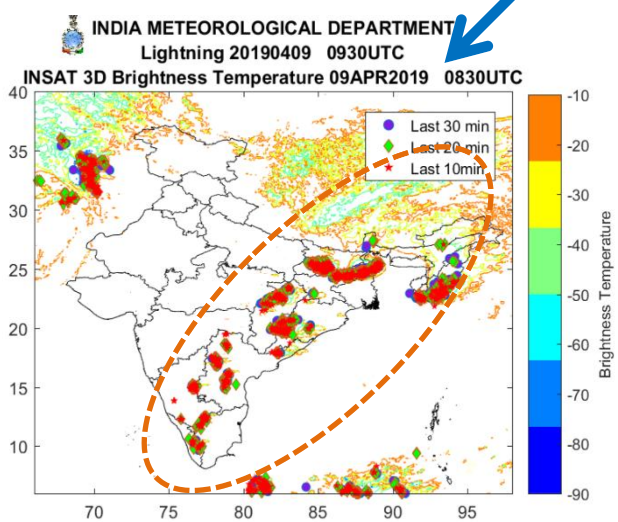
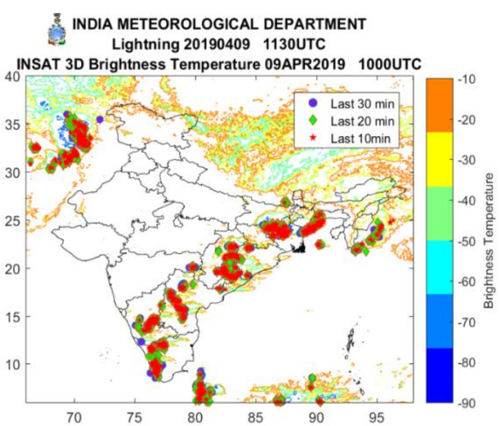
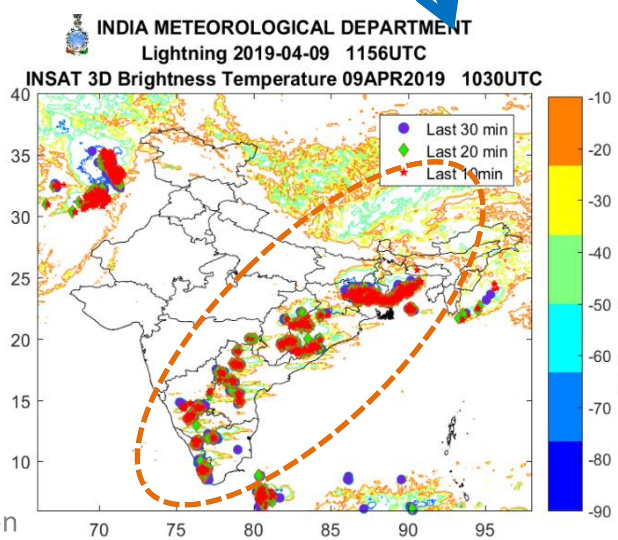
3 hourly Accumulated Total Lightning flash (Max. reflectivity overlaid)









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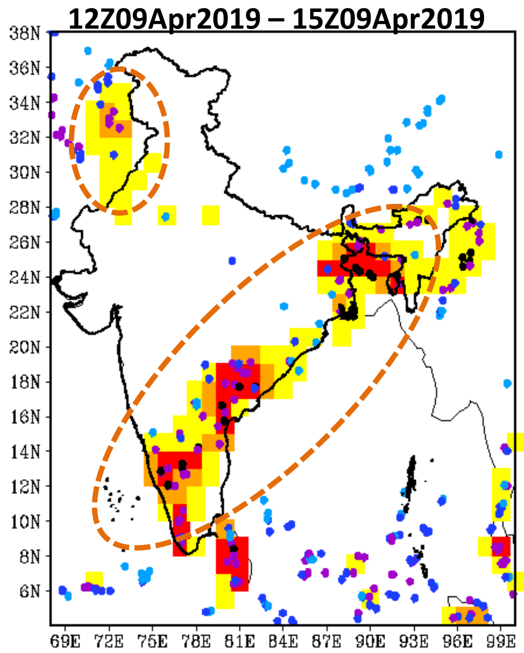
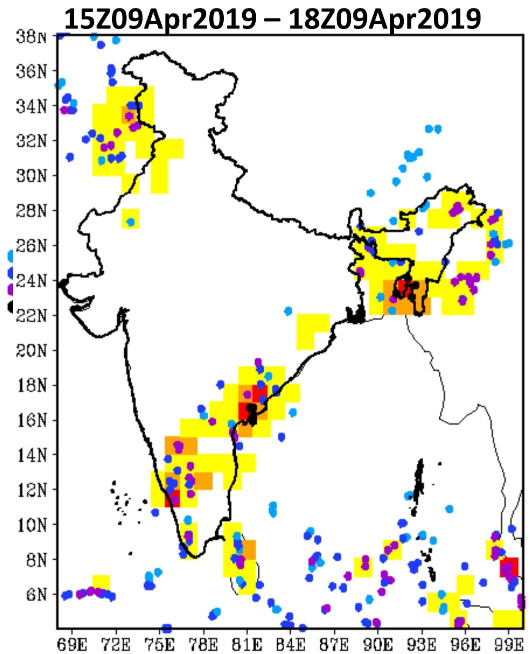
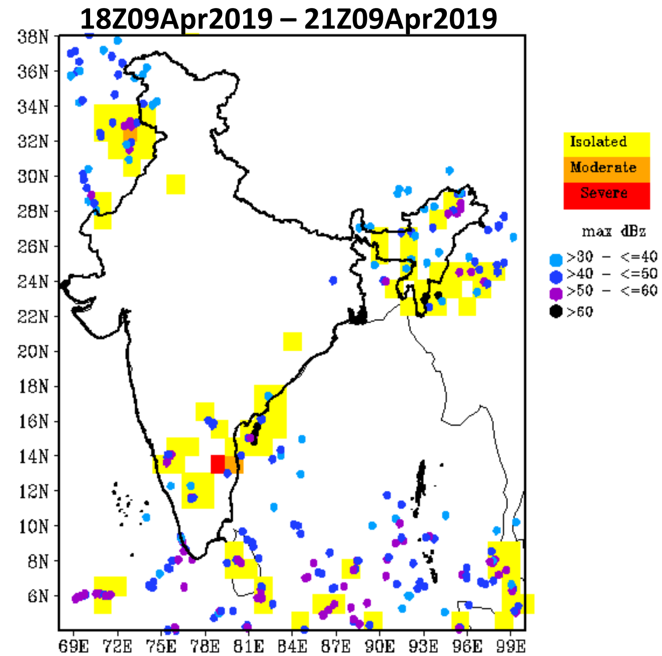
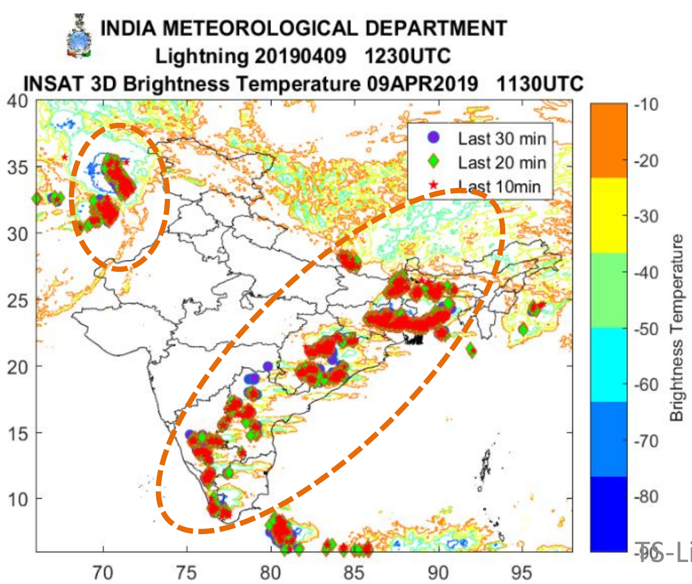
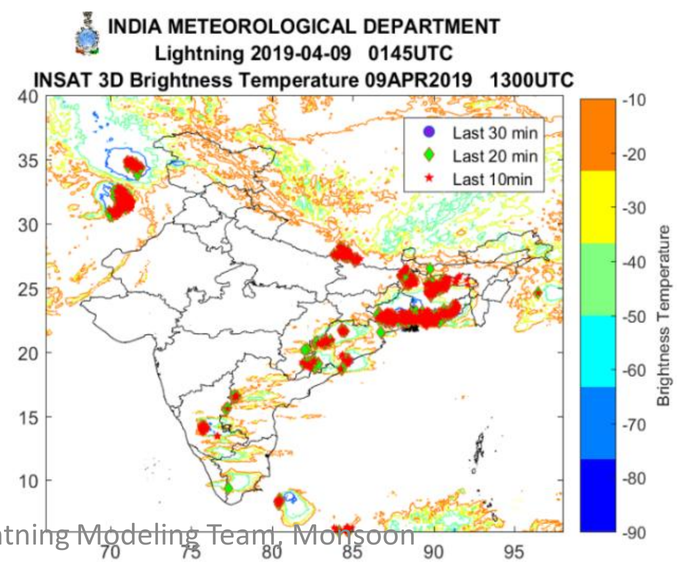

12Z09Apr2019 – 15Z09Apr2019


15Z09Apr2019 – 18Z09Apr2019


18Z09Apr2019 – 21Z09Apr2019
Isolated
Moderate
Severe
max dBz
>30 - <=40
>40 - <=50
>50 - <=60
>60


INDIA METEOROLOGICAL DEPARTMENT
Lightning 20190409 1230UTC
INSAT 3D Brightness Temperature 09APR2019 1130UTC
Last 30 min
Last 20 min
Last 10min
Brightness Temperature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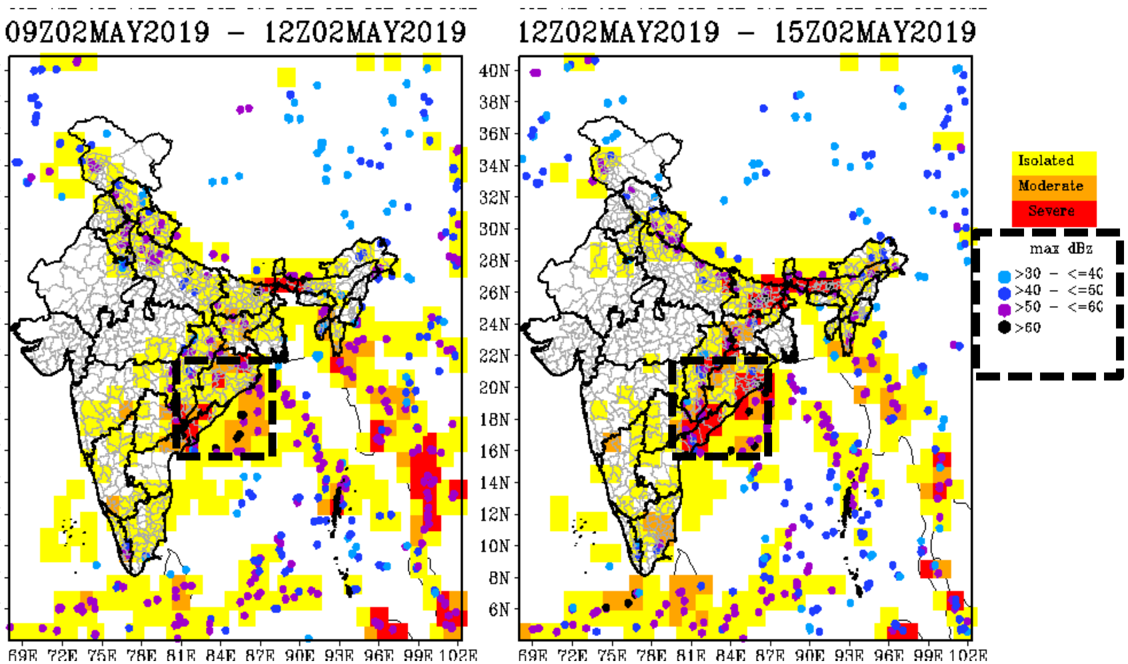
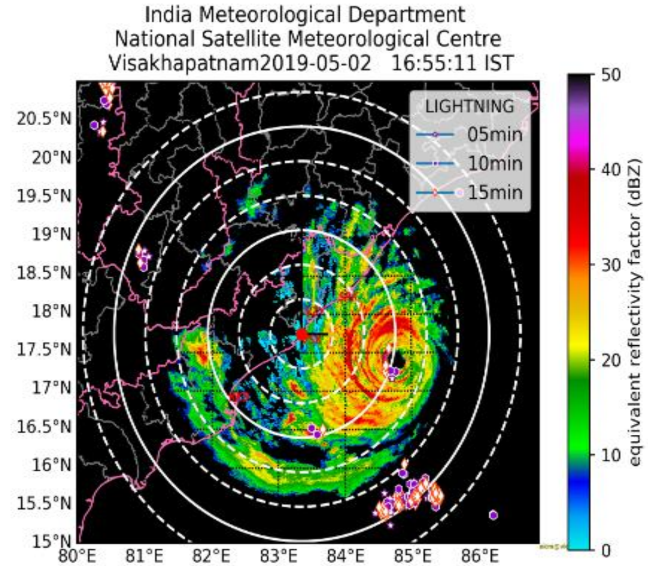
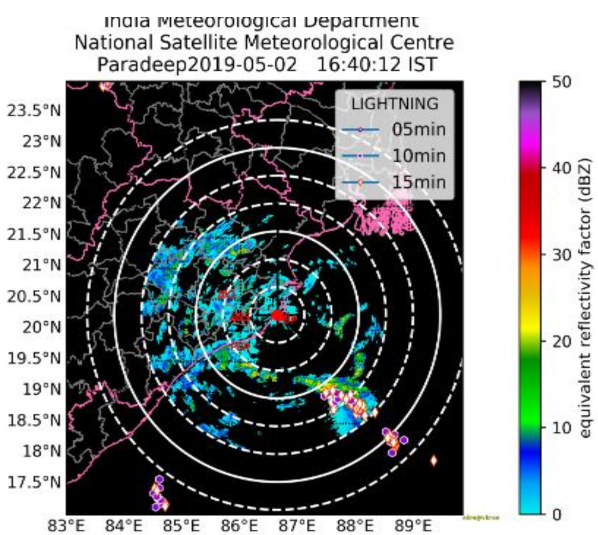
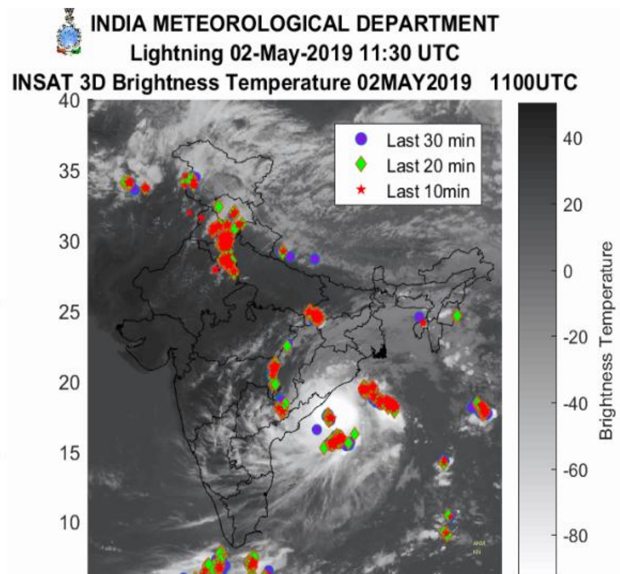
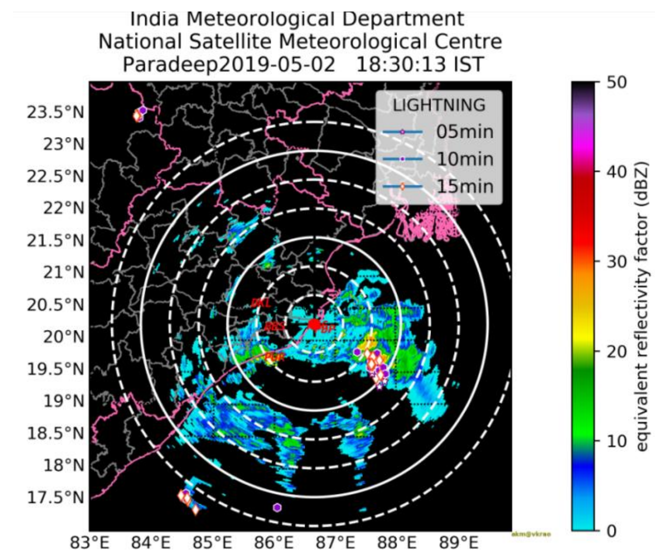
Lightning 2019-04-09 0145UTC
INSAT 3D Brightness Temperature 09APR2019 1300UTC
Last 30 min
Last 20 min
Last 10min
Brightness Temperature











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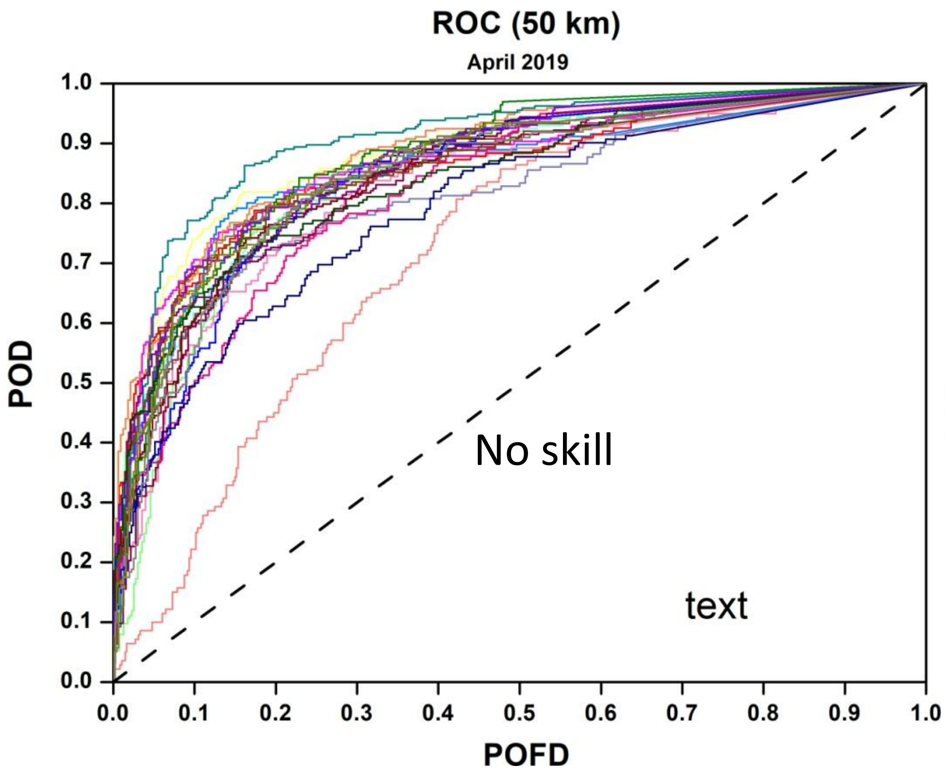
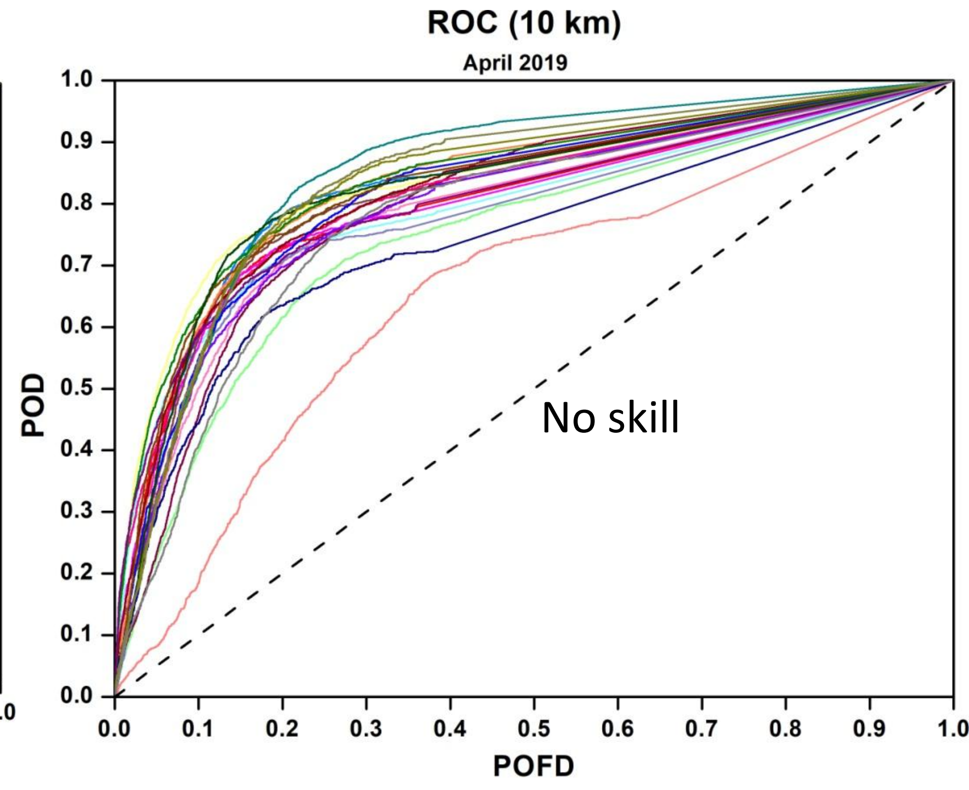
ROC Curve (Receiver Operating Characteristic)

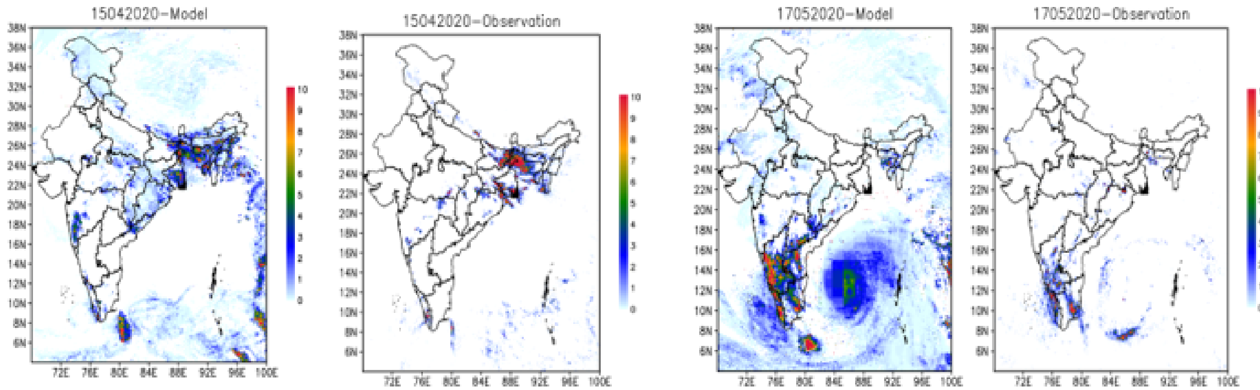




The ROC curve is a probability curve to asses the performance.

Lighting prediction present system (MM-IITM)

April 2020

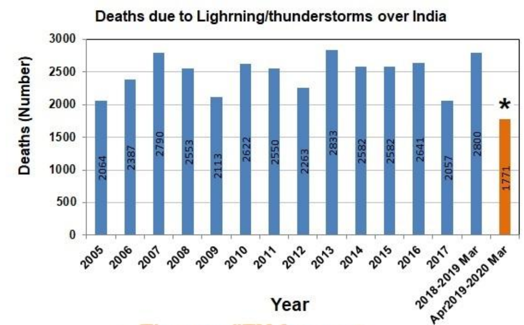


May 2020

By in-house developing and introducing Lightning Prediction System (under Monson Mission Phase-II Project at IITM)

Forecast started from March 2019

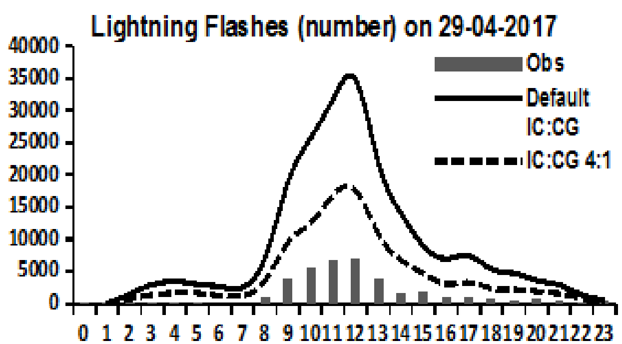
	POD	HR	FAR	POFD	Area Under Curve (AUC)	Matching Grid
2019 (Mar-May)	0.912	0.72	0.65	0.512	0.856	0.756
2020 (Mar-May)	0.931	0.75	0.67	0.491	0.805	0.786



* The year IITM forecast using dynamical model (DLP)

Model Development for Lightning flash prediction (Based on observed IC/CG ratio)

Deaths reduced by nearly 37% from 2,800 deaths between April 1, 2018 to March 31, 2019 to 1,771 during the same period in 1st April 2019-31st March 2020



Important Note:

- POD is very high with very less 'misses'.
- False Alarm is more, which is related to 'overestimation' in some days.
- Overestimation can be reduced by development.

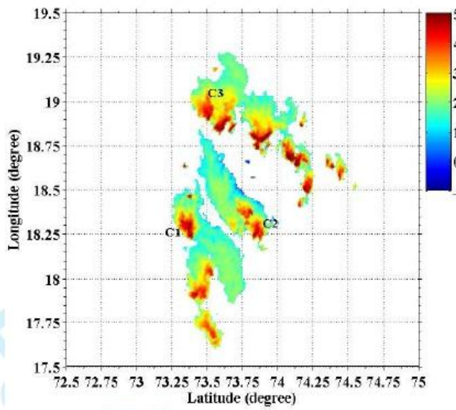
Monsoon Mission Phase II

Model Development:

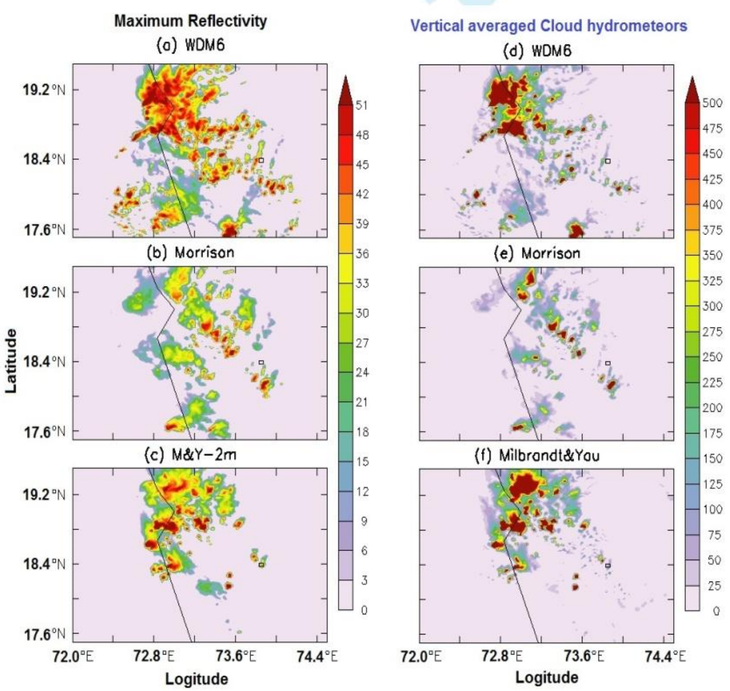
Understanding of physical processes (Basic Research)

Max_reflectivity: X-band Radar (IITM)

Source: Subrata K. Das



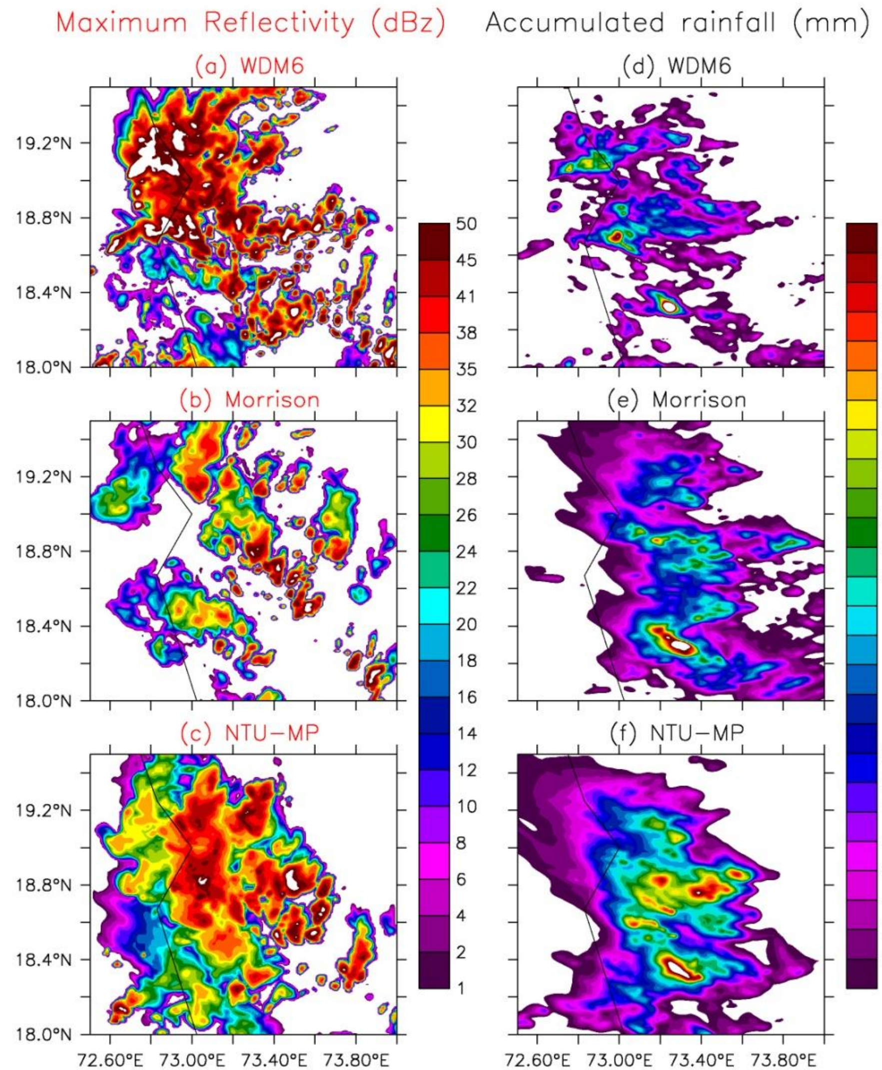
Horizontal map of column maximum radar reflectivity factor (dBZ) at 0922 UTC, 12 October 2011.



Max_reflectivity & Hydrometeors: Model

Das, Hazra et al., 2020

Max_reflectivity & Rainfall: Model



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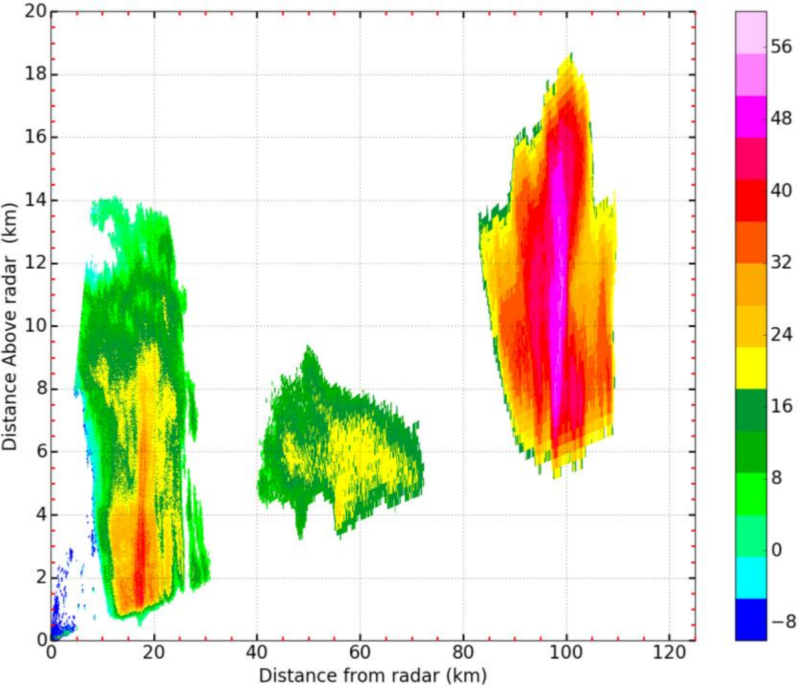
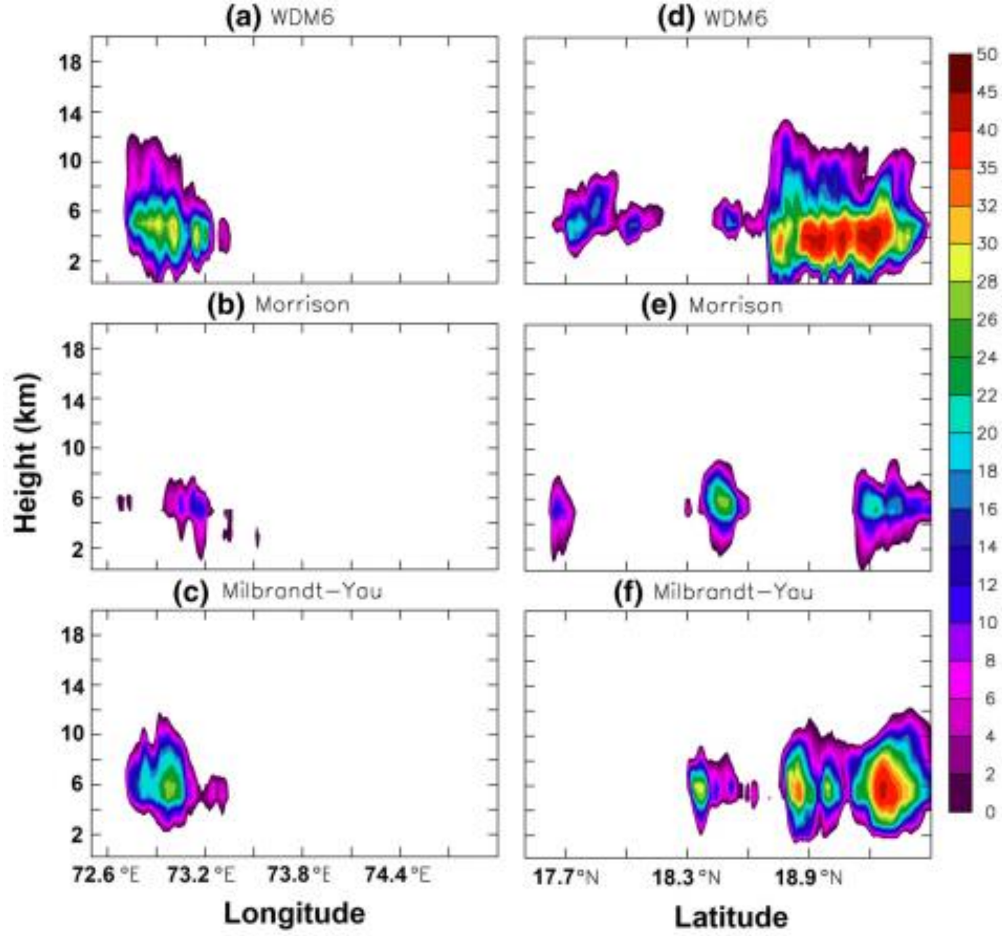
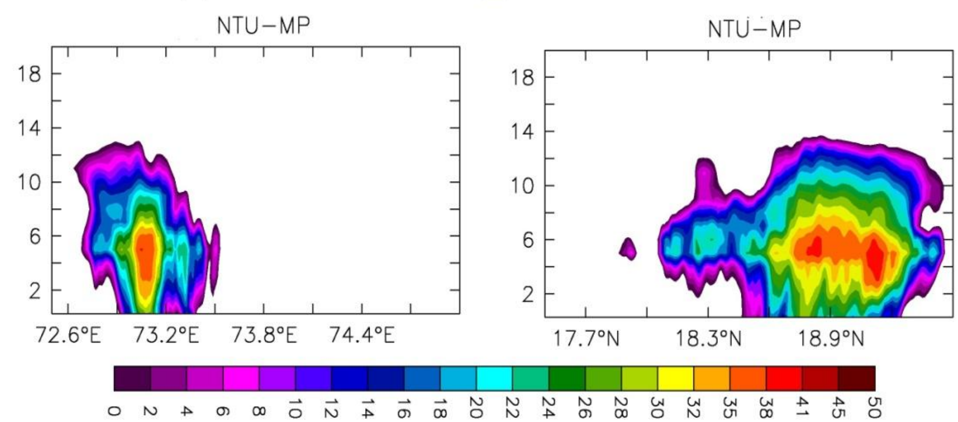
X-band radar observation



RHI scan of radar reflectivity factor (dBZ) taken at 198° azimuth.

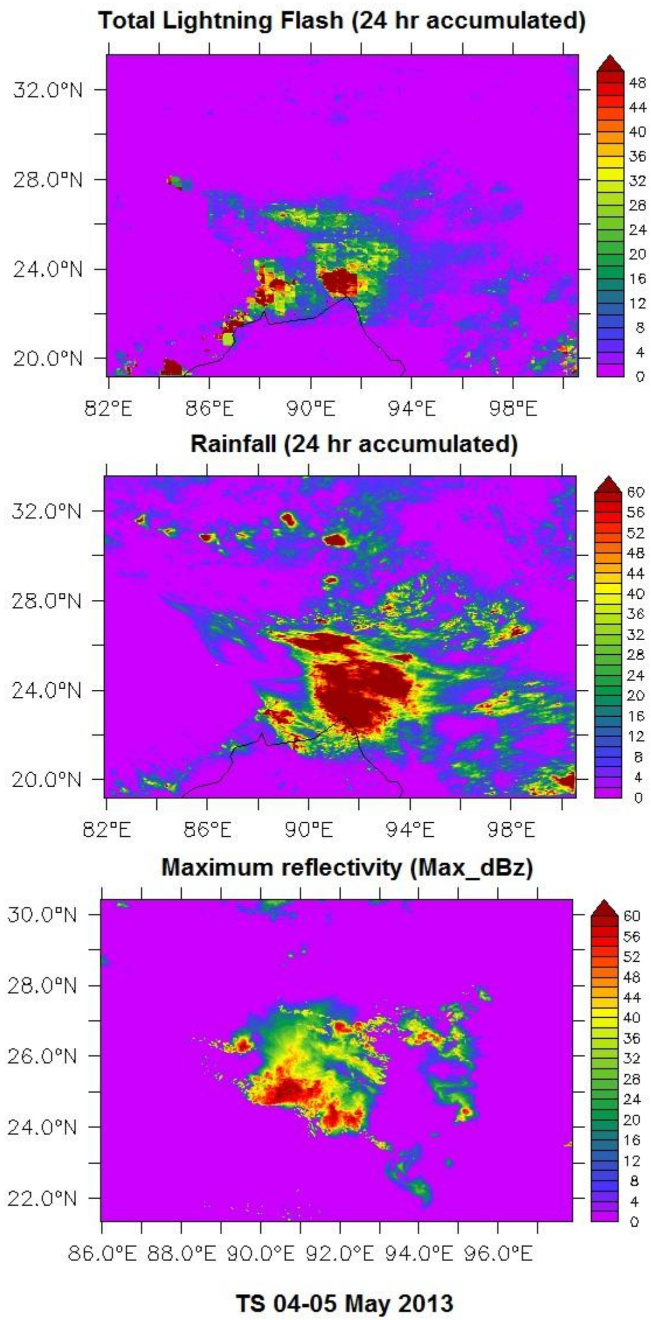
Source: Dr. Subrata K. Das

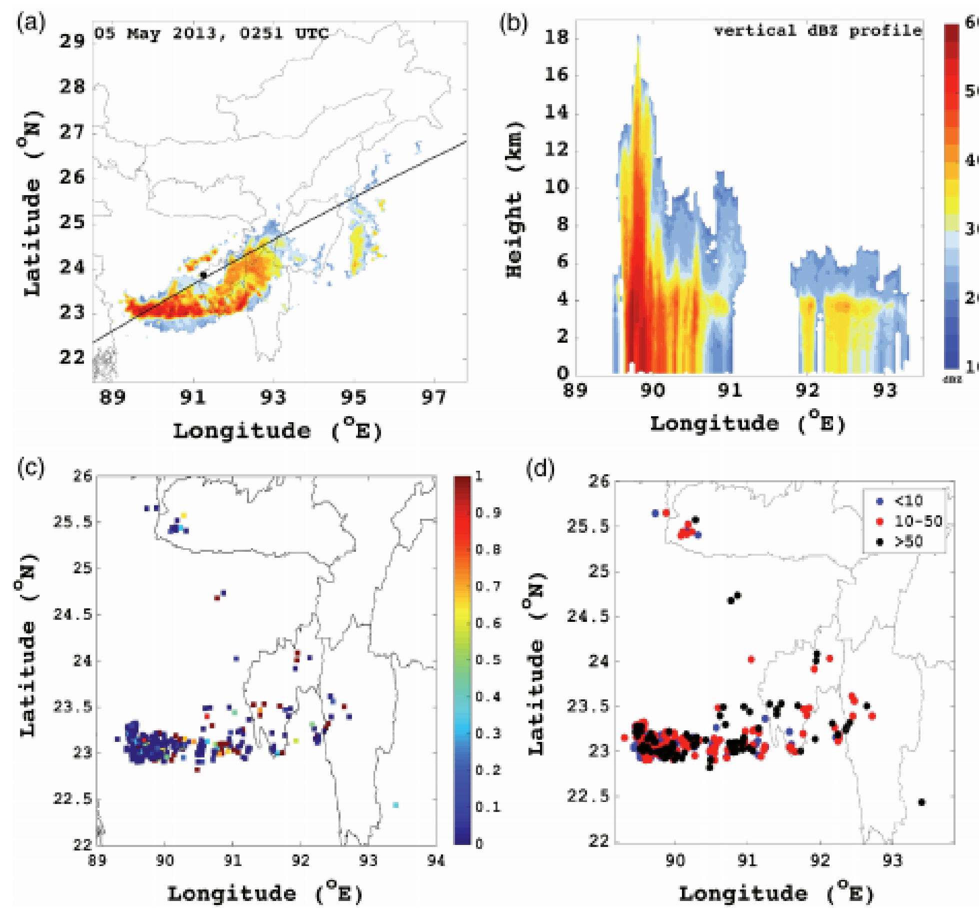




Case study: Lightning, Rainfall, Reflectivity

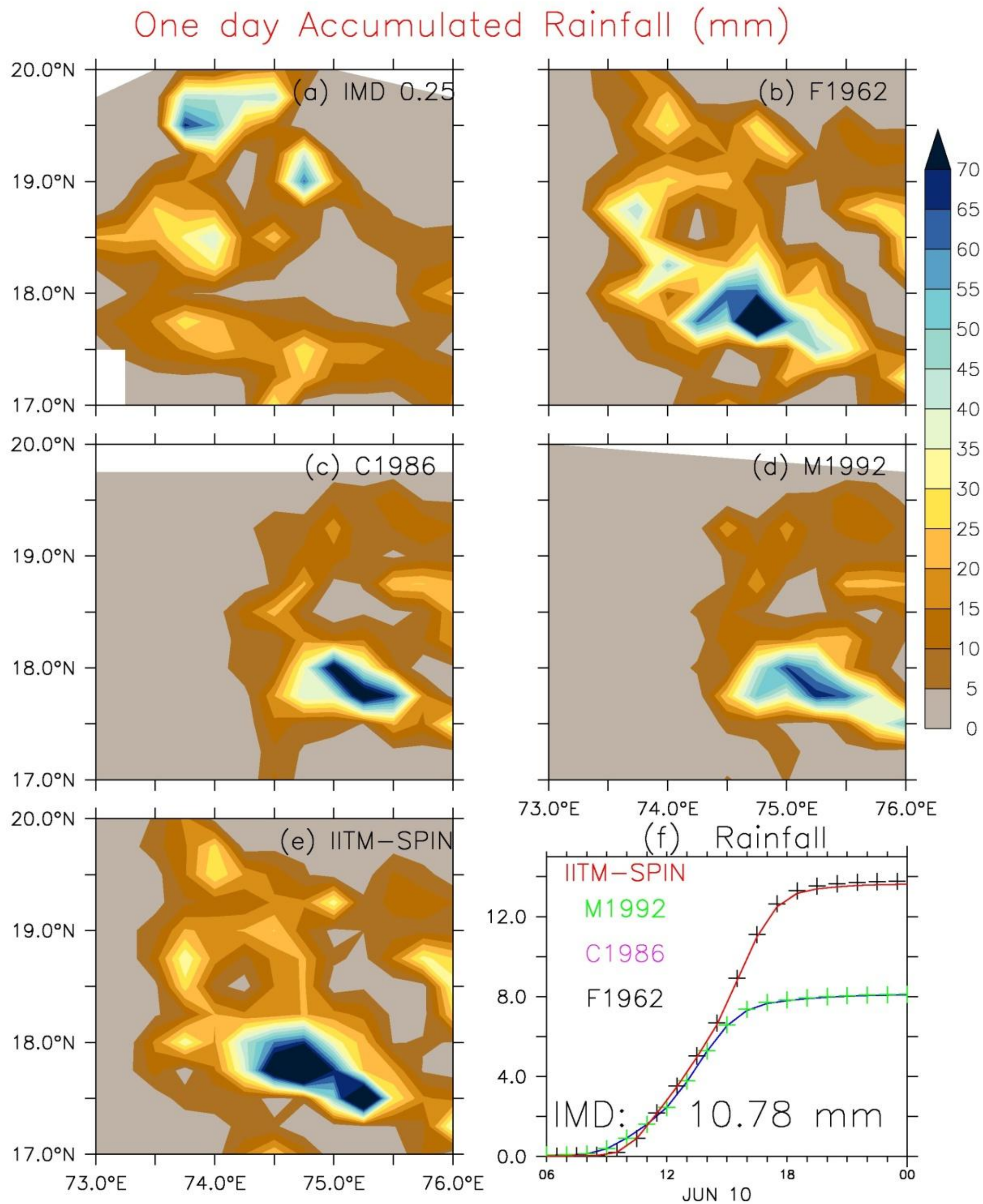
Choudhury, Konwar, Hazra et al., 2020 (QJRMS)



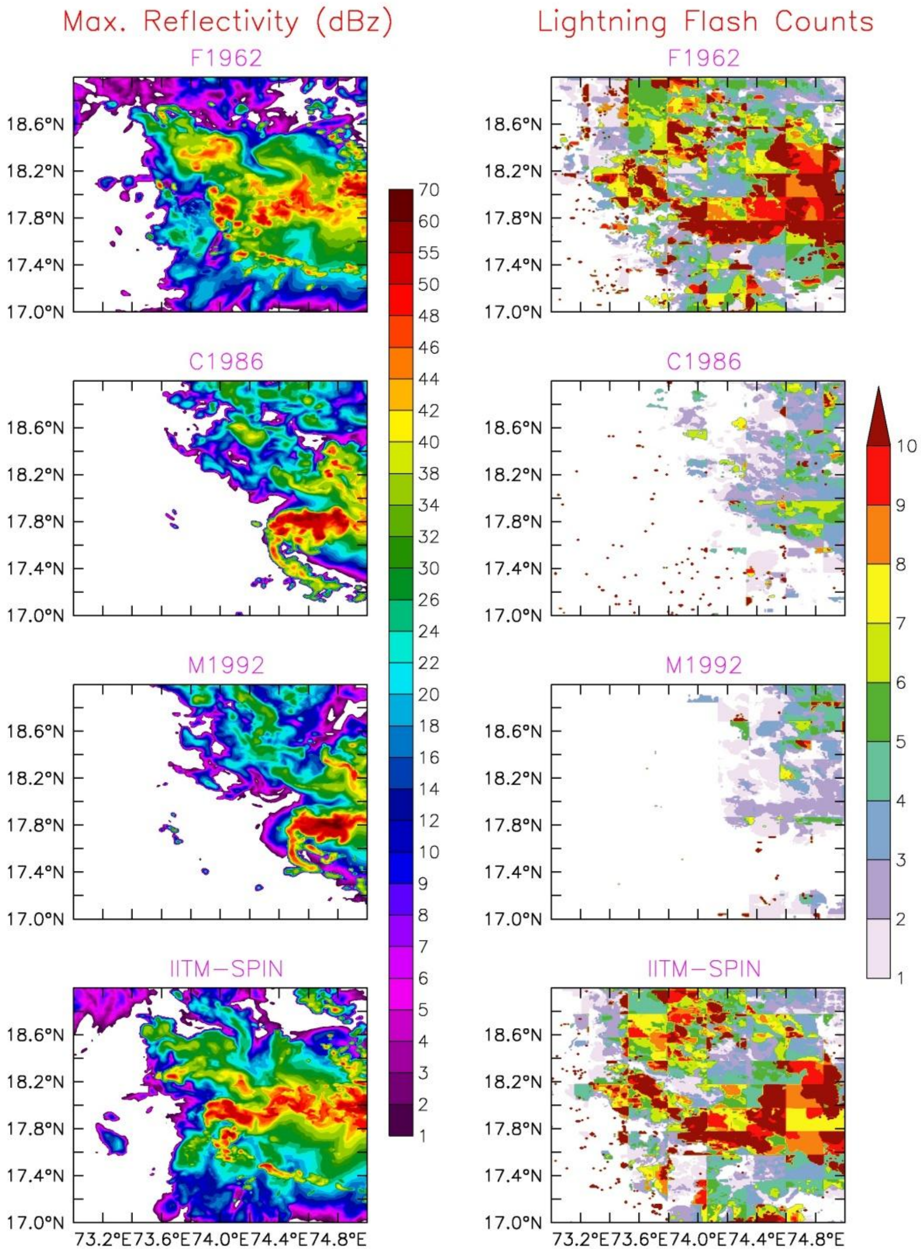


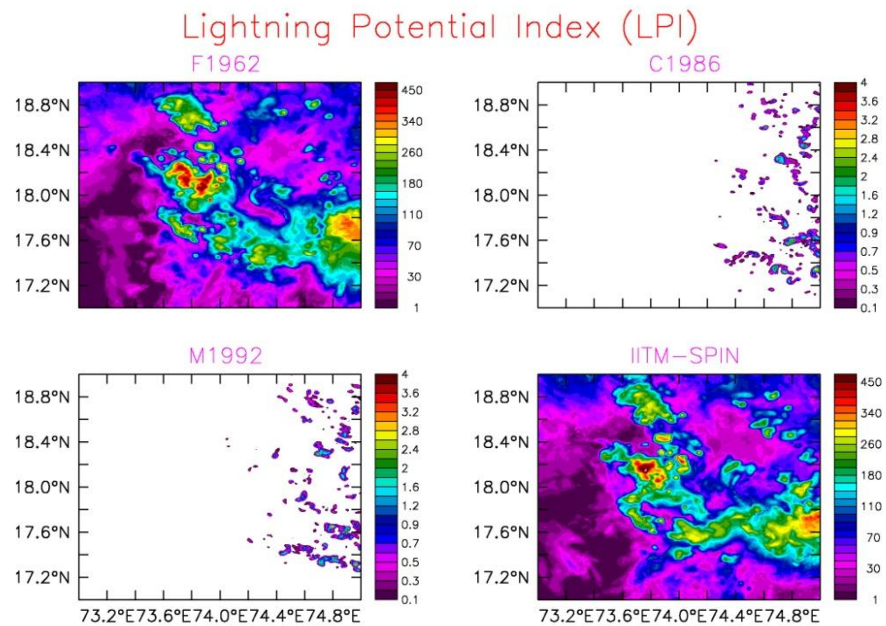
(a) TRMM reflectivity (dBZ) pass over the event that occurred on 5 May 2013. (b) Vertical profile of reflectivity (dBZ) through the black line shown in (a). (c) Colour map of the normalized flash counts from the event (flash counts divided by maximum flash count of 677). The colour bar indicates flash counts. (d) The grouped flash event counts, that is, low (50, black).

Microphysical Parameterization (Ice-Phase/Ice Nucleation)



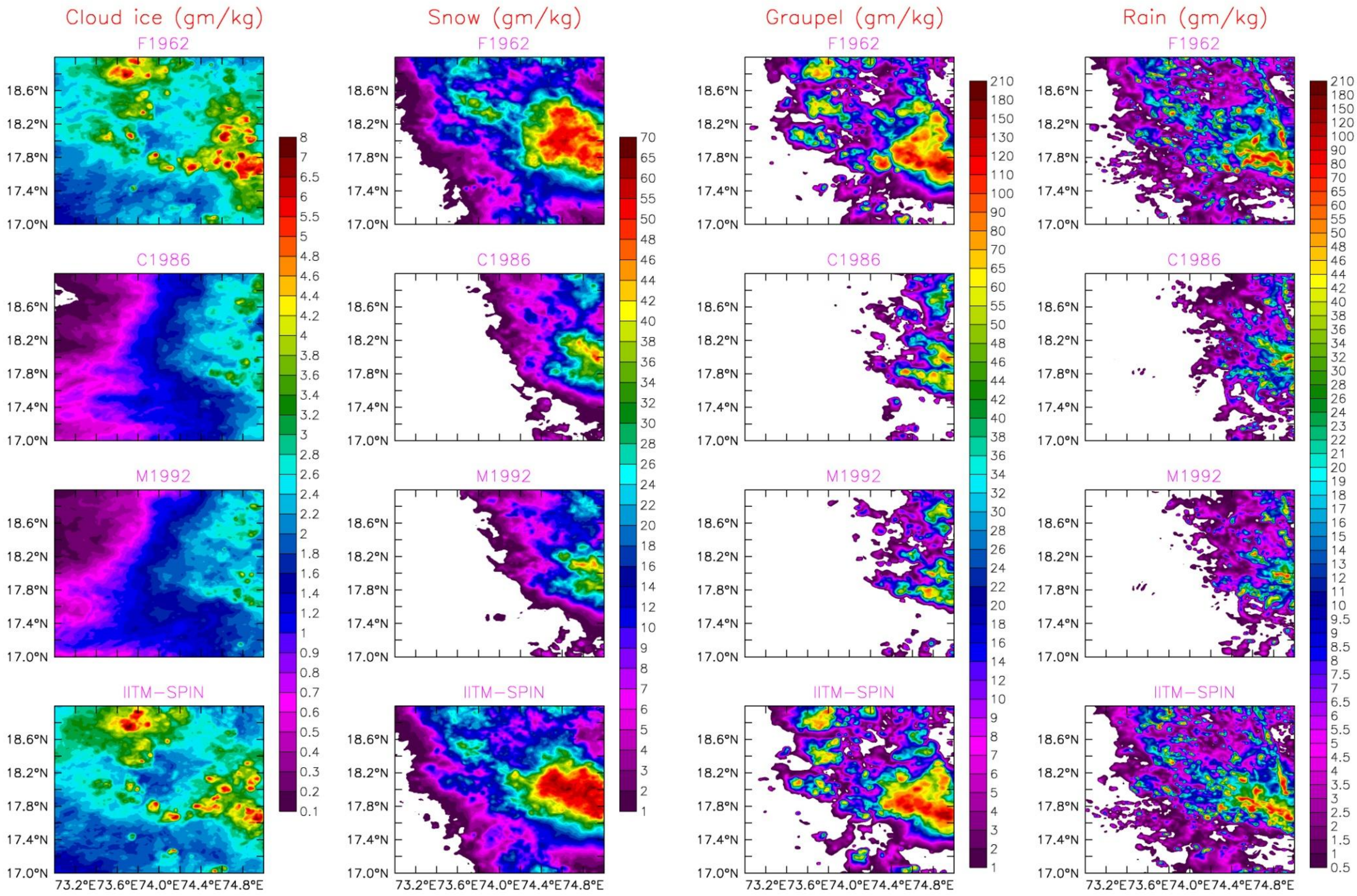
Microphysical Parameterization (Ice-Phase/Ice Nucleation)





TS-Lightning Modeling Team, Monsoon Mission, IITM, Pune

Cloud Hydrometeors



Approach-II

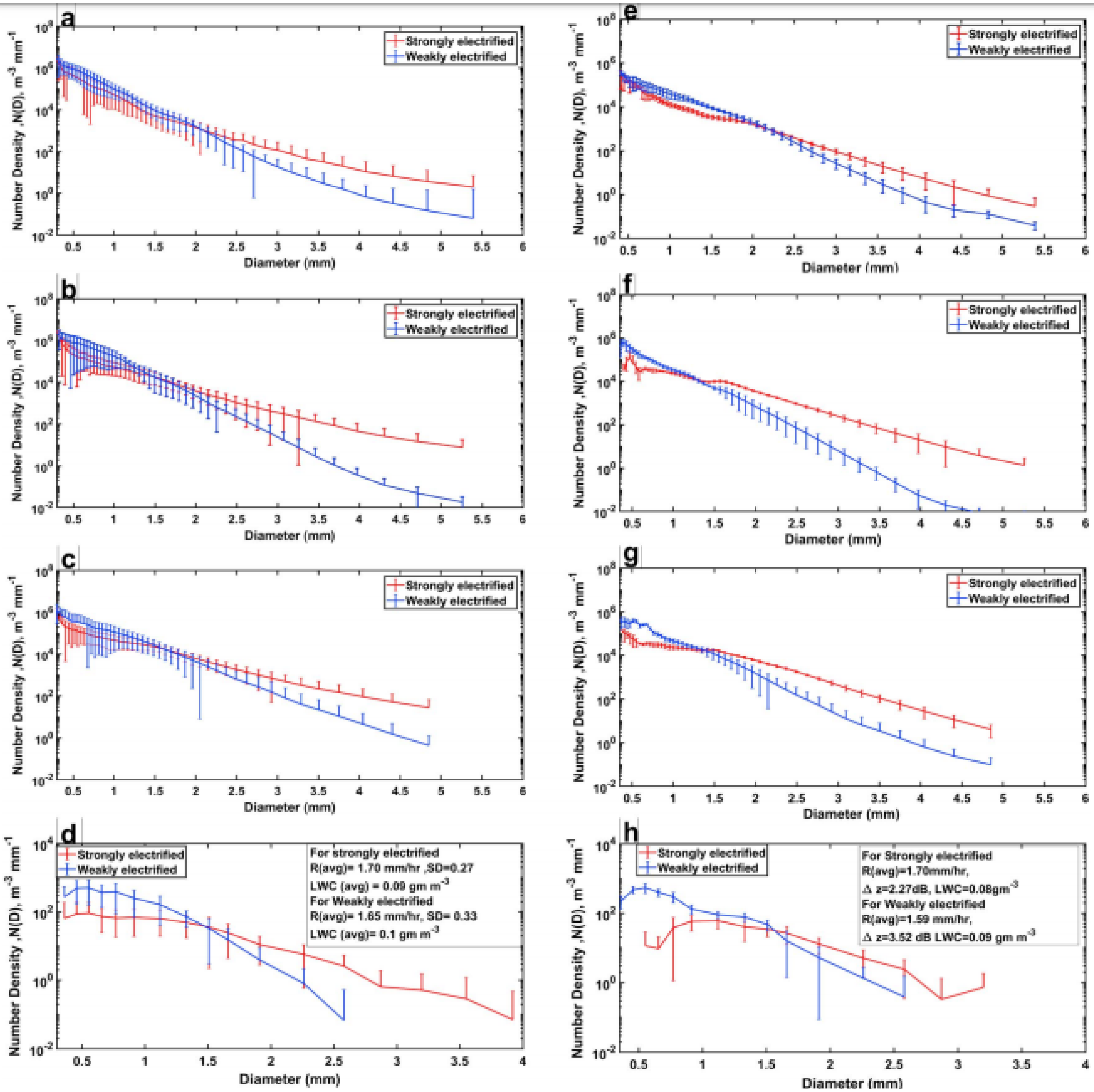


Figure 9. Composite raindrop size distribution (six events in each composite) at selected altitudes for strongly electrified and weakly electrified clouds as observed by MRR at (a) 2,400 m, (b) 1,200 m, (c) 600 m, and (d) at surface observed by JW disdrometer. The right panel depicts the altitude evolution of DSD under the similar strength of bright band for strongly electrified and weakly electrified events (Figures 1c and 1g) observed by MRR at (e) 2,400 m, (f) 1,200 m, (g) 600 m, and (h) at surface observed by JWD. The vertical bars represent the standard deviations of the respective DSDs. Heights are measured from the location of MRR.

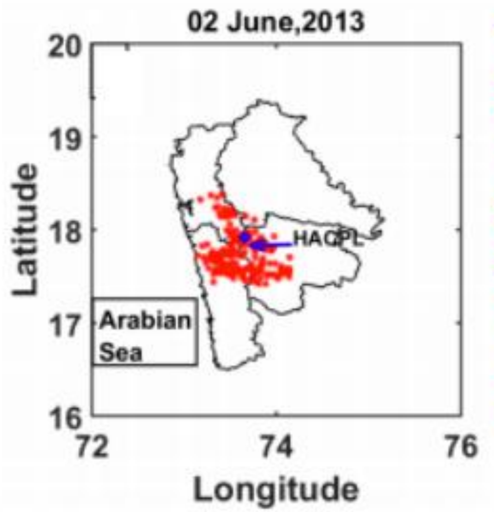
Electric field and drop size distribution

Rain drop size distribution by Marshal-Palmer

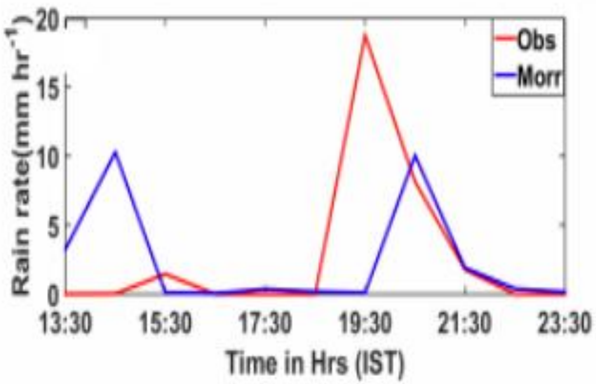
Need to Revisit

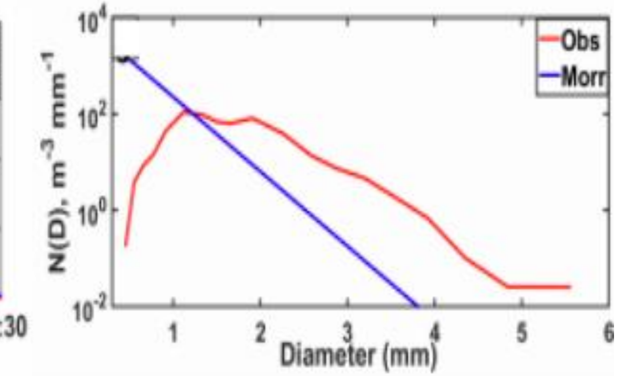
Mudier, Pawar, Hazra et al., 2018, JGR

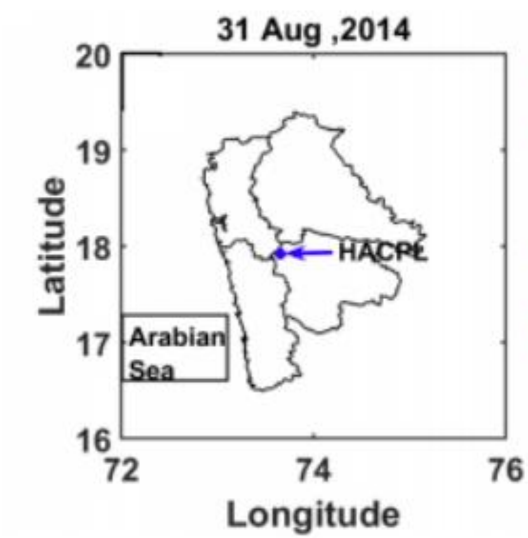
1. Electrical route for the modification of raindrops



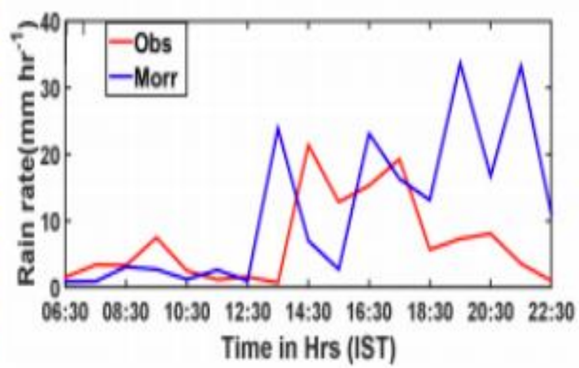
Strongly Electrified

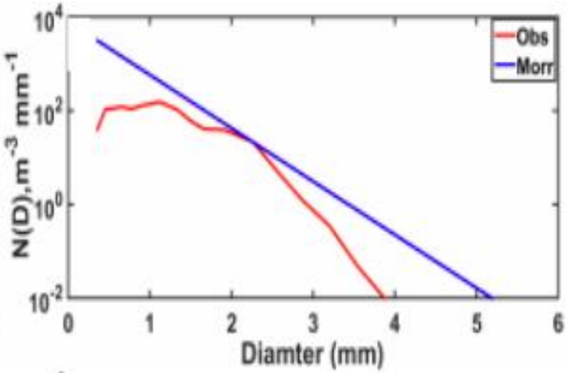


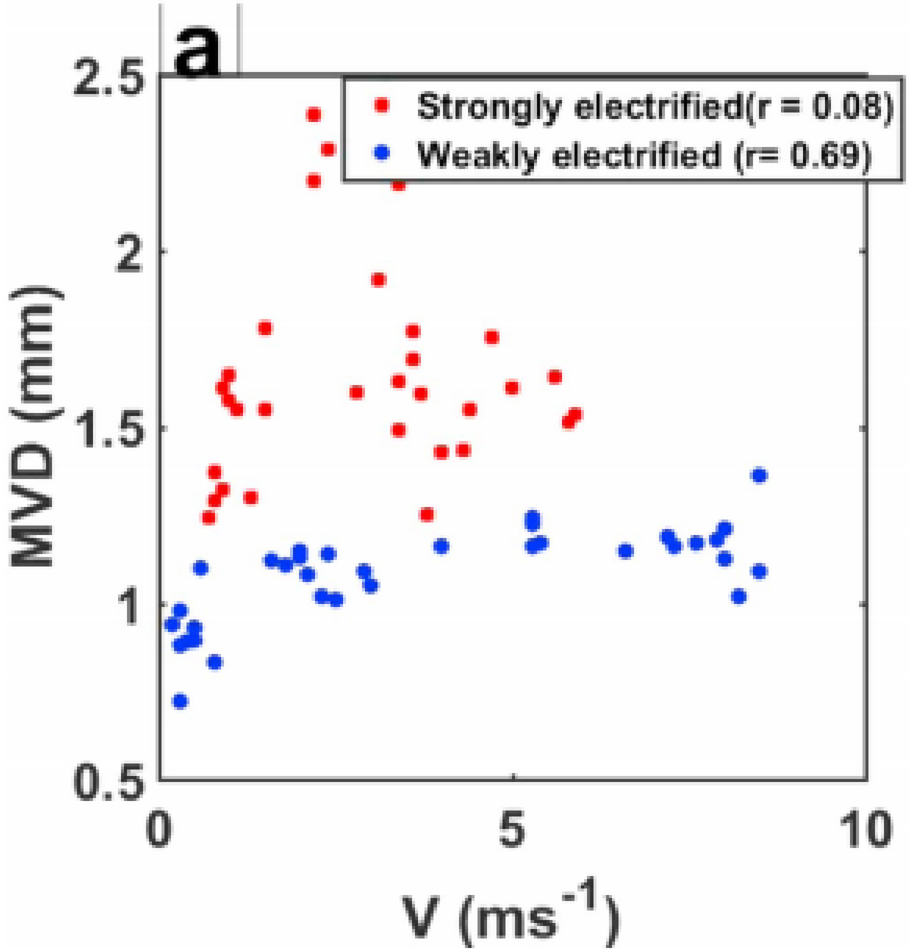




Weakly Electrified





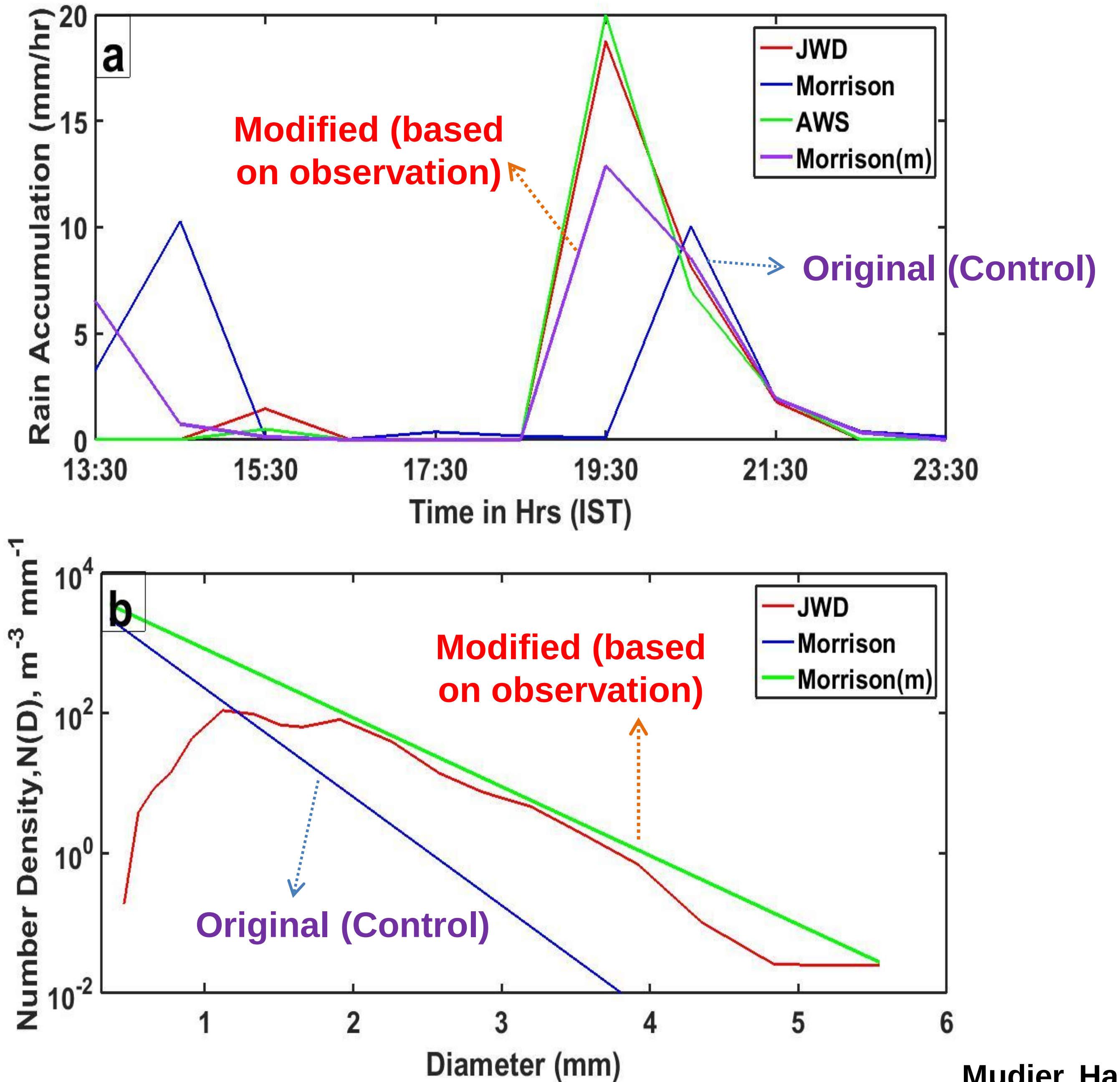


Mudier, Pawar, Hazra et al., 2018, JGR

✓ Numerous studies have shown that the electric fields inside thundercloud and lightning discharges can influence the microphysical and dynamical properties of thundercloud (Ausman & Brook, 1967; **Bhalwankar et al., 2004; Kamra & Ahire, 1989; Kamra et al., 1991**; Rasmussen et al., 1985; Richards & Dawson, 1971; Taylor, 1964).

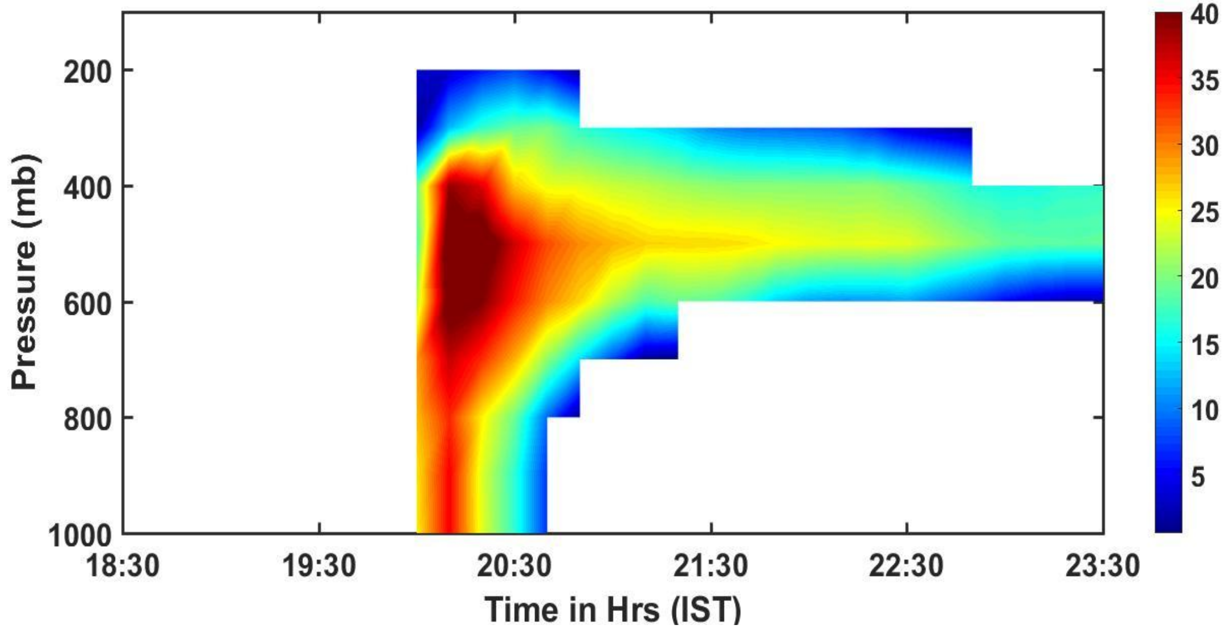
✓ **Bhalwankar and Kamra (2007)** studied the effect of vertical and horizontal electric fields on charged and uncharged water drops in the **laboratory** and concluded that the presence of vertical electric field can **broaden the rain DSD** and hence enhance the **growth rate of raindrops.**

Accumulated rain and Rain DSD

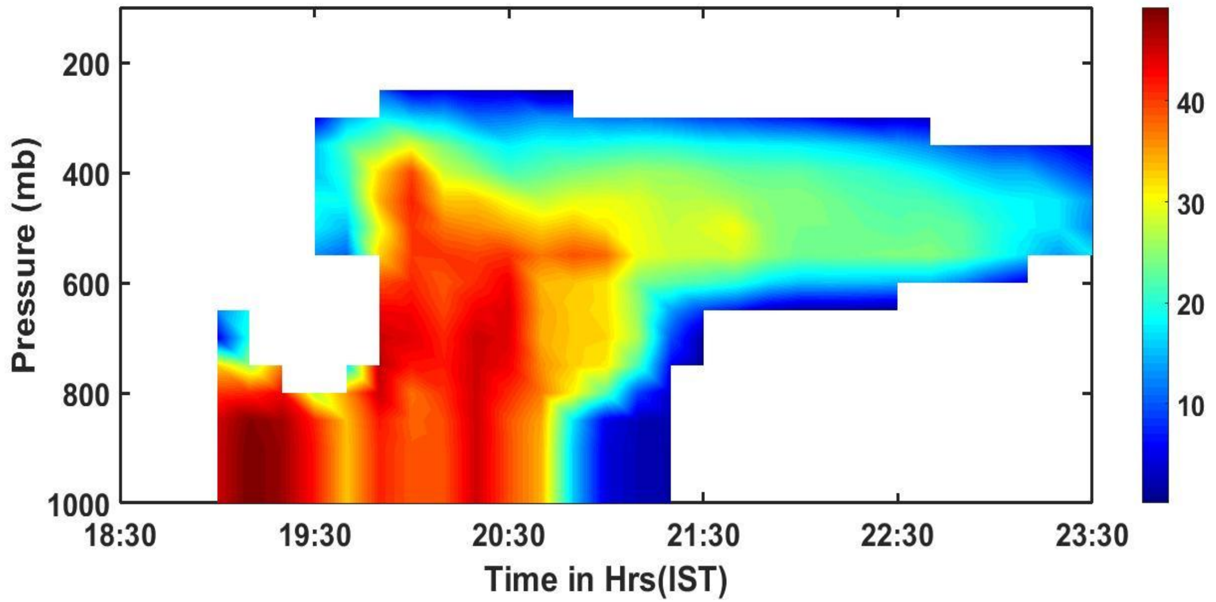


Mudier, Hazra et al., 2019

Vertical profiles of DBZ



Original (Control) – model (WRF)



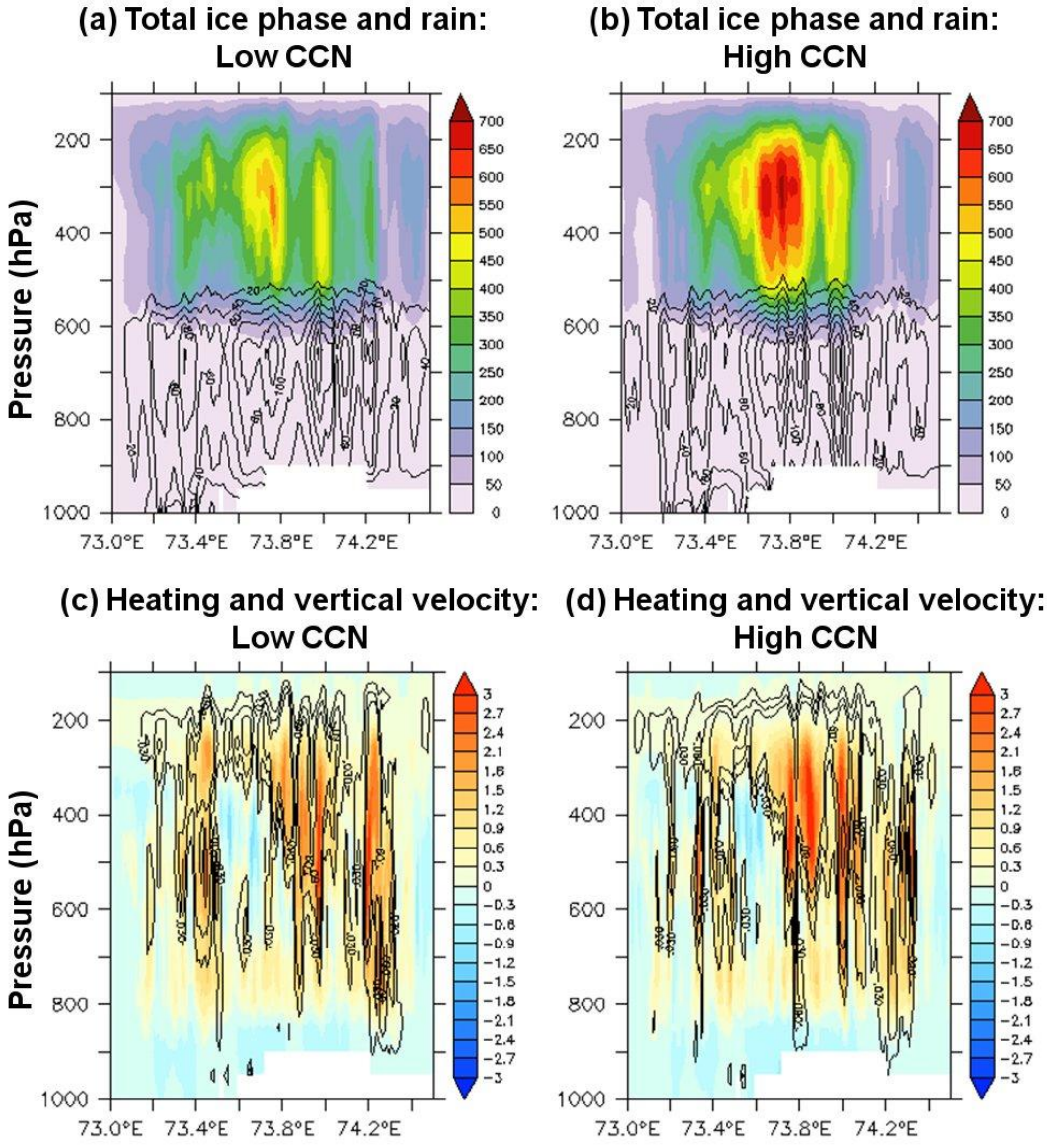
Modified (based on observation) – model (WRF)

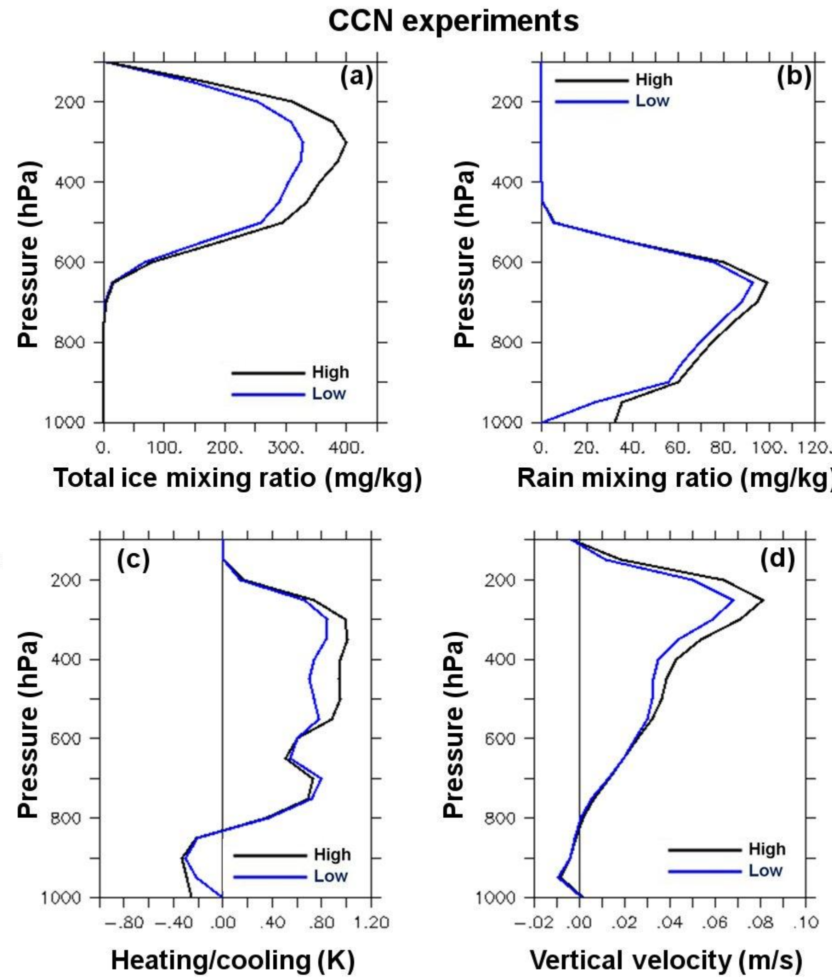
Mudier, Hazra et al., 2019

Approach-III

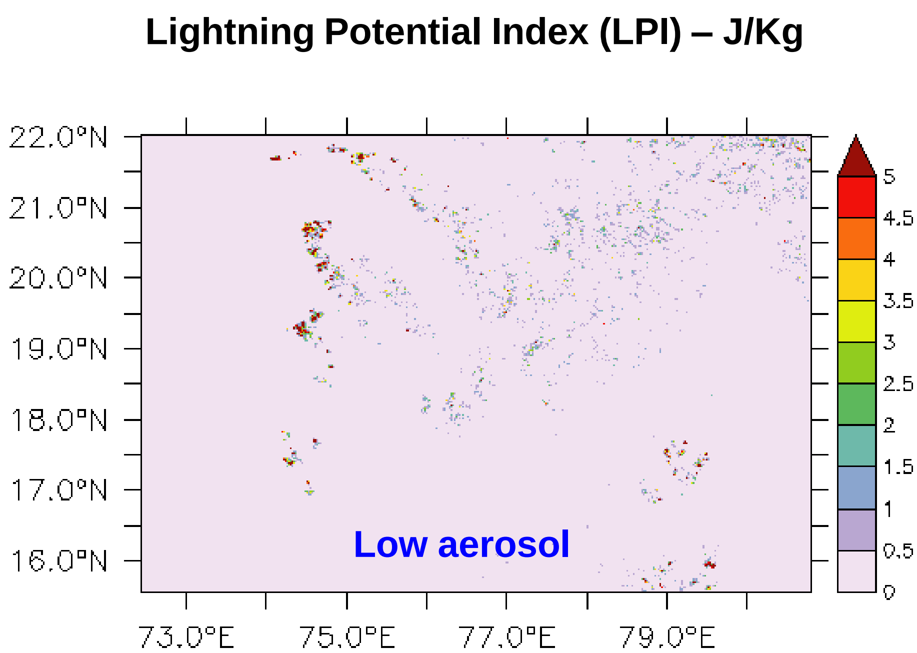
Role of aerosols which act as cloud condensation nuclei (CCN)

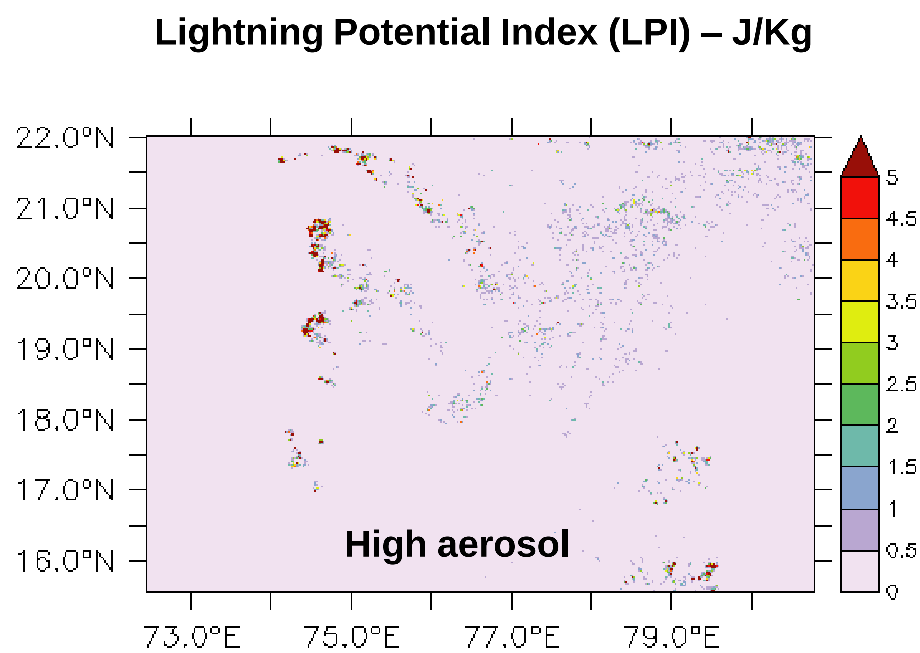
Role of aerosols which act as cloud condensation nuclei (CCN)

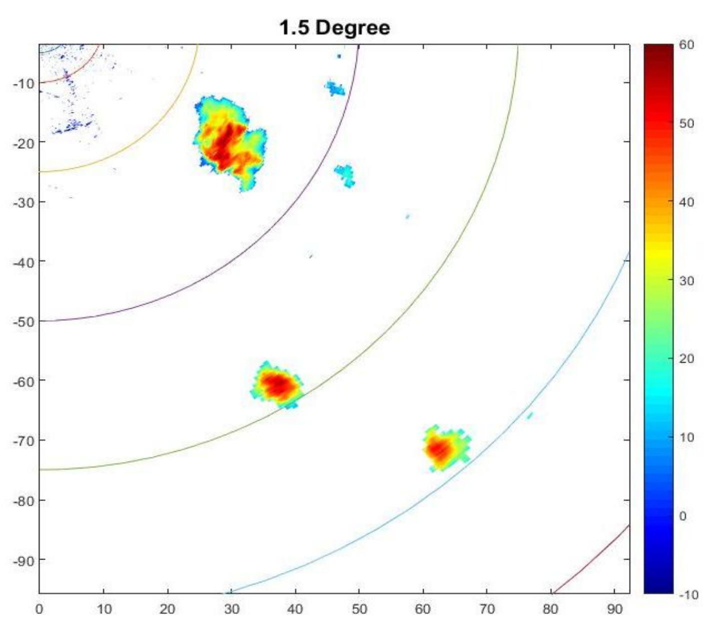


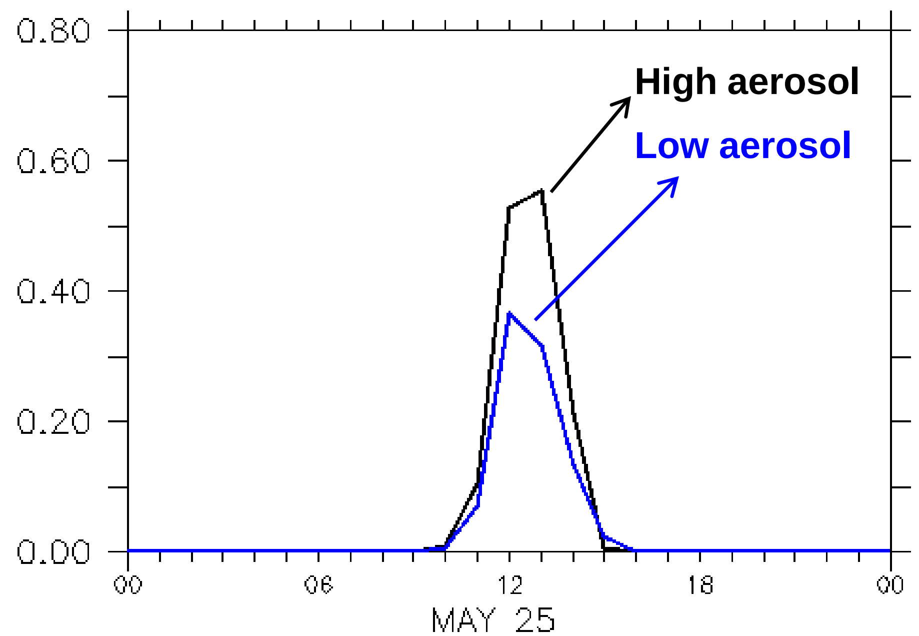


Thanks to **Prof. J.-P. Chen, NTU**, Taiwan for scientific collaboration for the development of cloud microphysical scheme.

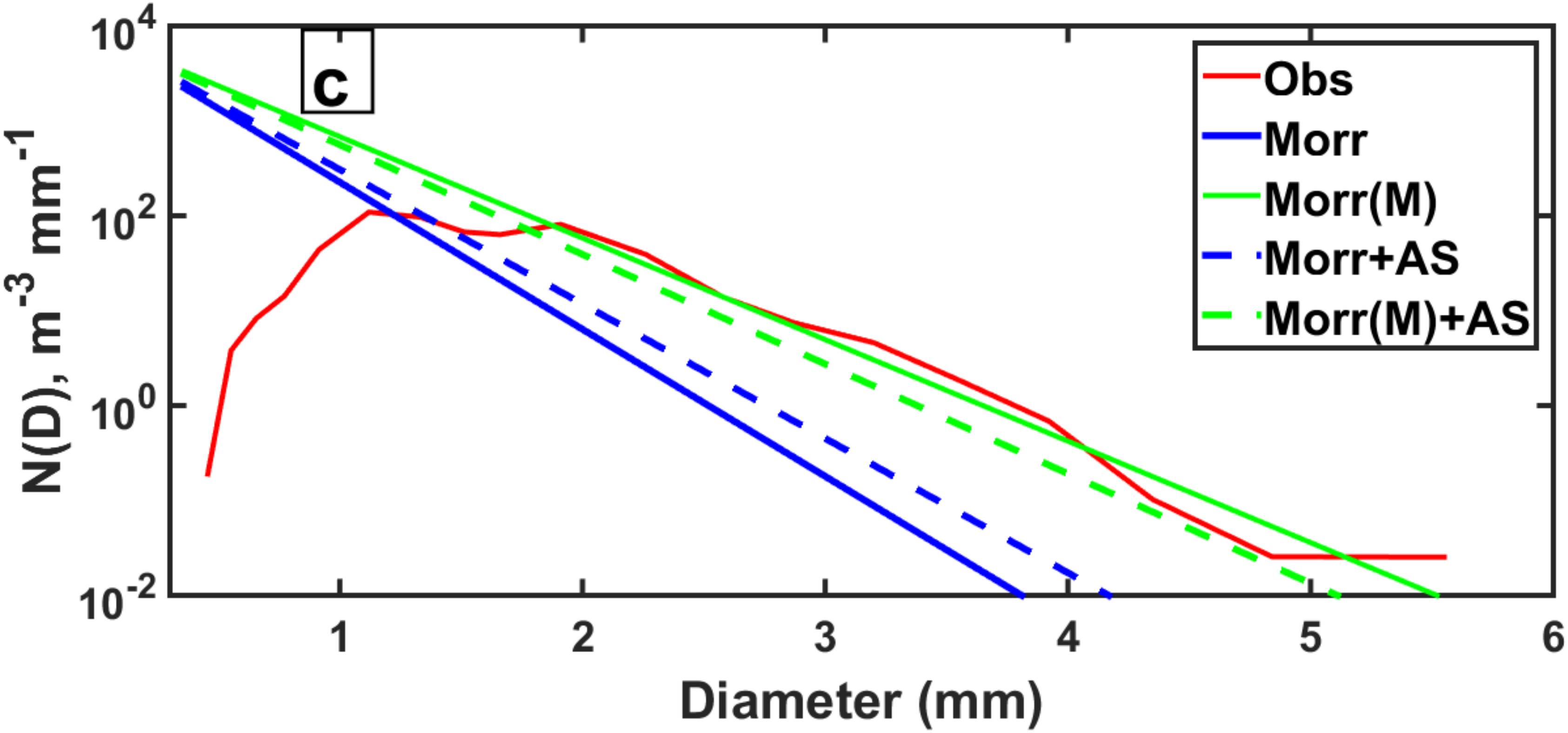




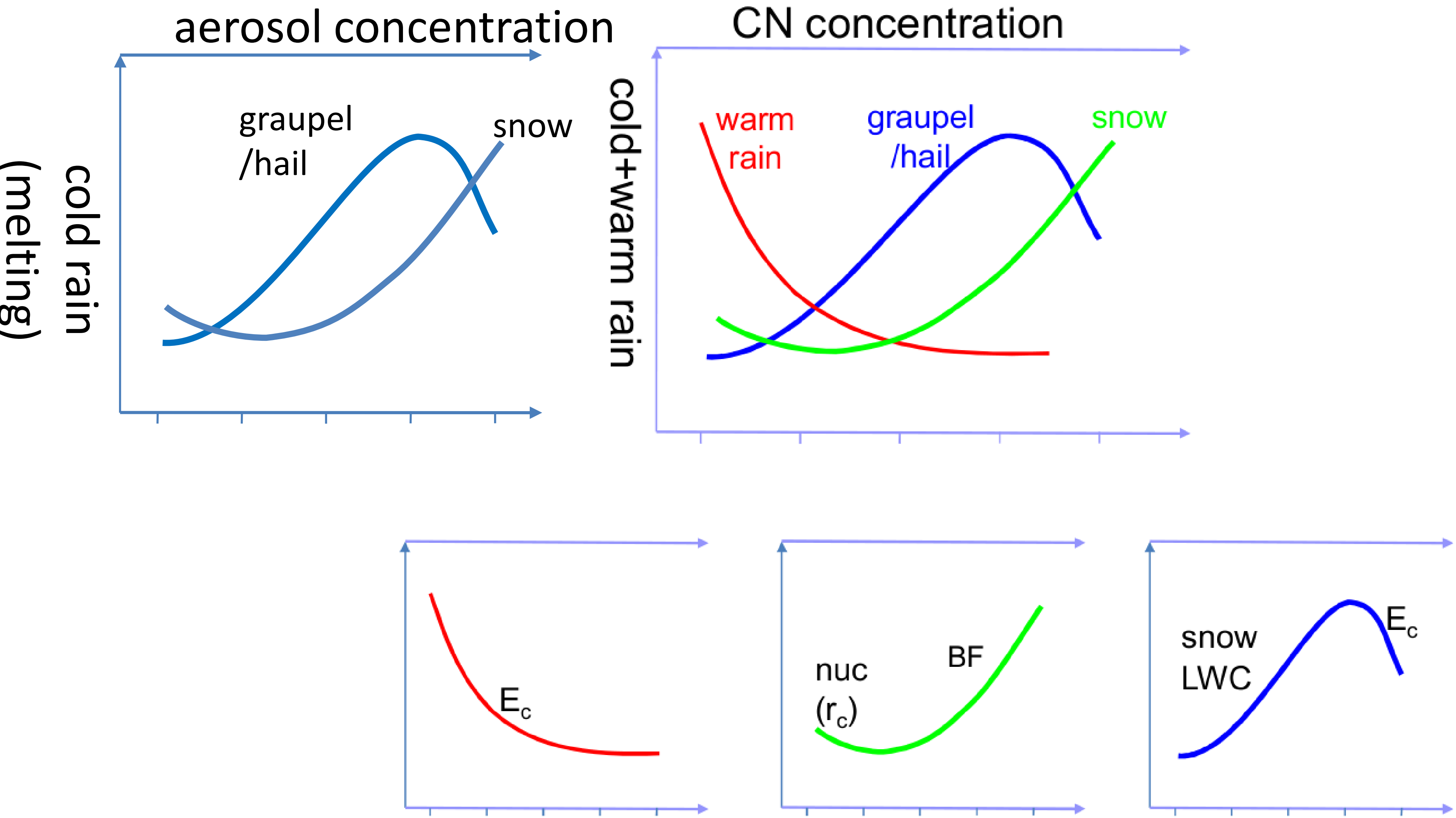




X-band Radar from HACPL



c
Obs
Morr
Morr(M)
Morr+AS
Morr(M)+AS
10^4
10^2
10^0
10^{-2}
N(D), m^{-3} mm^{-1}
1
2
3
4
5
6
Diameter (mm)


aerosol concentration
cold rain
(melting)
graupel
/hail
snow
CN concentration
cold+warm rain
warm
rain
graupel
/hail
snow
E_c
nuc
(r_c)
BF
snow
LWC
E_c

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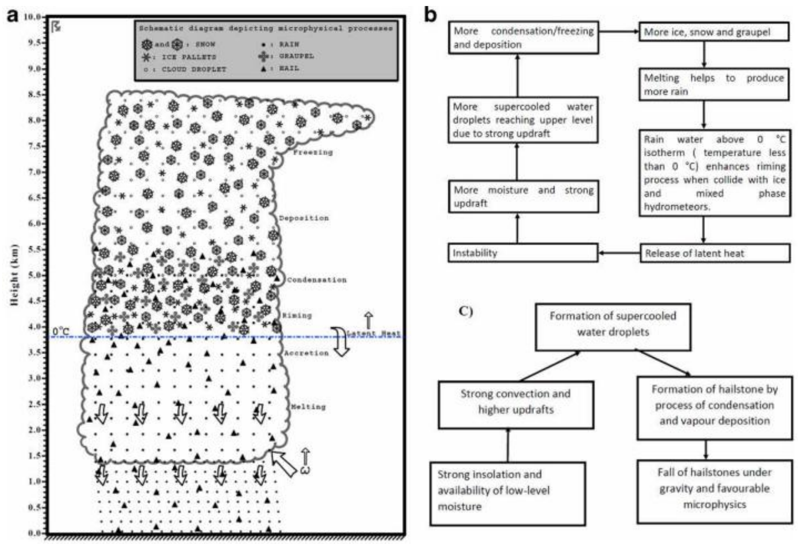
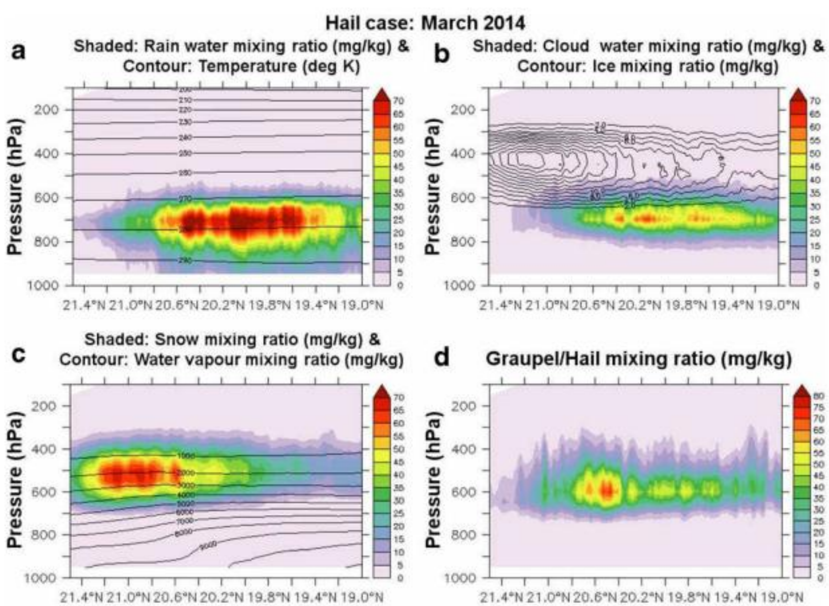
https://doi.org/10.1007/s13143-021-00235-4
Online ISSN 1976-7951
Print ISSN 1976-7633

ORIGINAL ARTICLE

Microphysical Features of Unprecedented Hailstorms Over Central Region of India During February – March 2014

Manish Rameshchandra Ranalkar[1] · H. S. Chaudhari[2] · A. Hazra[2]

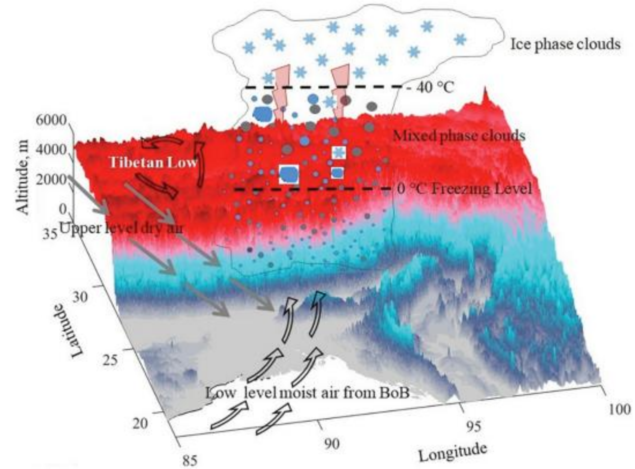


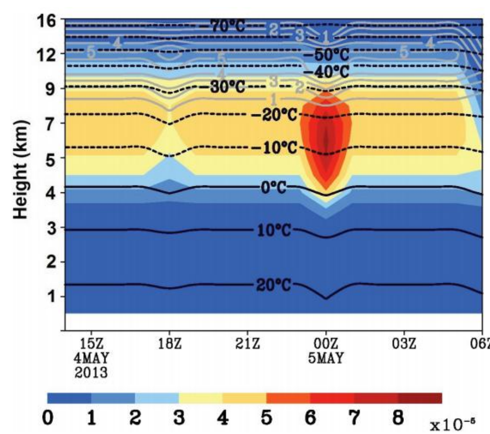


RESEARCH ARTICLE

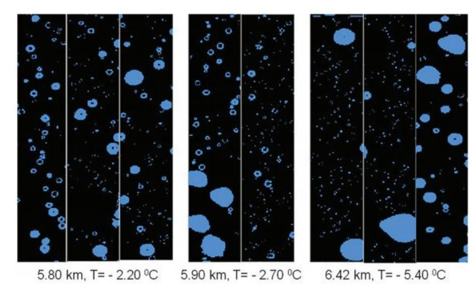
A diagnostic study of cloud physics and lightning flash rates in a severe pre-monsoon thunderstorm over northeast India

B. Abida Choudhury[1] | Mahen Konwar[2] | Anupam Hazra[2] | Greeshma M. Mohan[2] | Prakash Pithani[2] | Sachin D. Ghude[2] | Atri Deshamukhya[1] | Mary C. Barth[3]





Cloud hydrometeors (kg·kg−1) for 4–5 May 2013 using WRF model



Images of hydrometeors in growing convective cloud tops from CAIPEEX obs.

Conclusions

Few important points are highlighted here:

❖ **First time in India, lightning/thunderstorm simulations are made using dynamical lightning and LPI parameterization.**

❖The dynamical lightning parameterizations schemes (Price and Rind, 1992; Wong et al., 2013) are introduced in the regional climate model (WRF) for simulation cloud-to-ground (CG) lightning flashes.

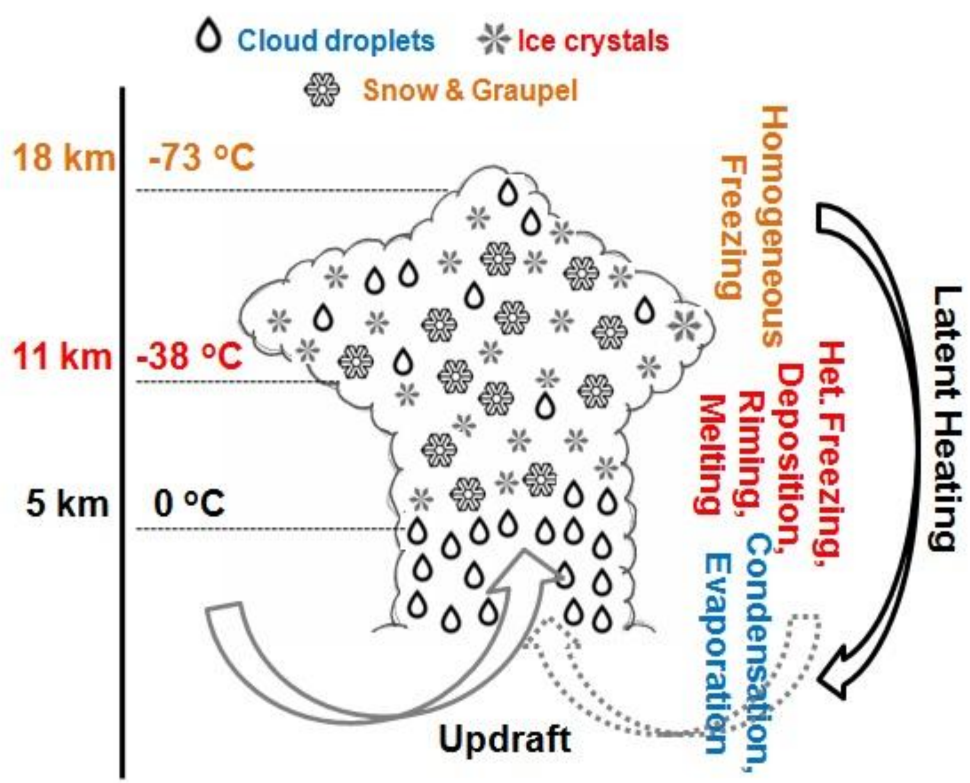
❖The dynamical Lightning Potential Index (LPI) as formulated by Lynn and Yair (2008, 2010) and Yair et al. (2010) is also implemented in WRF to simulate thunderstorm cases over India.

❖**The results of the CG-flash counts from the model are validated with the observed CG Lightning data from Maharashtra Lightning Detection Network (MLDN).**

❖**The spatial patterns of rainfalls are also validated with observed data (TRMM and GPM). The verifications are carried out to evaluate the skills, false alarm and hit rates etc., which shows that the new product can be used lightning/thunderstorm prediction.**

Possible mechanism:

The response to CG lightning flash counts and surface rainfall depends on the relative strength of following rain initiation and growth mechanisms in Thunder cloud:



Factors causing the increasing or decreasing trends are depended on

- ❖ Size of cloud ice initiated from frozen cloud drops
- ❖ Wagner-Bergeron-Finderson conversion
- ❖ Conversion from cloud ice including aggregation
- ❖ Liquid Water Content
- ❖ Collision efficiency for either accretion or riming
- ❖ Invigoration of convection.

Future

Need 2-moment microphysical parameterization to account aerosol effect in Global climate model.

Ice Nuclei

Classical nucleation theory based heterogeneous ice nucleation parameterization

(Chen-Hazra-Levin, 2008; Hoose-Kristjansson-Chen-Hazra 2010)

Spectrometer for Ice Nuclei

Cloud Condensation Nuclei

Interaction between aerosol (CCN), dynamics and cloud microphysics on transition of MISO

(Hazra-Goswami-Chen, 2013)

CCN Counter

Classical nucleation theory: deposition nucleation & immersion freezing

Ice microphysics

The surface nucleation rate J_s describes the rate of formation

→ **it scales with time (s^{-1}) and particle surface area (m^{-2})!**

$$J = 4\pi r_N^2 J_s$$
$$= 4\pi r_N^2 A_1 n^* Z$$

Where J_s is the surface nucleation rate with:

A_1 = rate of collisions to overcome nucleation barrier

n^* = number of critical clusters (per unit surface area)

Z = Zeldovich factor

$$n^* = n_1 \cdot \exp\left(-\frac{\Delta g_g}{kT}\right) \qquad Z = \frac{1}{n_g} \cdot \sqrt{\frac{\Delta g_g}{3\pi kT}} \qquad n_g = \frac{4 r_g^3}{3 \upsilon_w}$$

$$J = 4\pi r_N^2 \, A_1 \, n_1 \cdot \exp\left(-\frac{\Delta g_g}{kT}\right) \frac{1}{\frac{4 r_g^3}{3\upsilon_w}} \cdot \sqrt{\frac{\Delta g_g}{3\pi kT}}$$

This form of the classical nucleation theory is valid for both immersion freezing and deposition nucleation!

Chen-Hazra-Levin (2008), ACP; Hoose, Kristjánsson, Chen, Hazra (2010), JAS

Classical nucleation theory: deposition nucleation & immersion freezing

$$J = 4\pi r_N^2 \, A_1 \, n_1 \cdot \exp\left(-\frac{\Delta g_g}{kT}\right) \frac{1}{\frac{4 r_g^3}{3\upsilon_w}} \cdot \sqrt{\frac{\Delta g_g}{3\pi kT}}$$

In this formula, the following parameters are specific to the mode of ice formation:

Deposition Nucleation

$$A_1 = 4\pi r_g^2 \cdot \frac{e}{\sqrt{2\pi m_w kT}}$$

$$r_g = \frac{2\upsilon_w \sigma_{i/v}}{\Delta g_b} \qquad \Delta g_b = kT \ln S_i$$

$$n_1 = \frac{e}{\nu_s \sqrt{2\pi m_w kT}} \cdot \exp\left(\frac{-\Delta g_d}{kT}\right)$$

$$\Delta g_g = \Delta g_g^\circ \cdot f = \frac{4\pi}{3} \sigma_{i/v} r_g^2 f = \frac{16\pi \upsilon_w^2 \sigma_{i/v}^3}{3\Delta g_b^2} \cdot f$$

Immersion Freezing

$$A_1 = \frac{kT}{h} \cdot \exp\left(\frac{-\Delta g_a}{kT}\right)$$

$$r_g = \frac{2\upsilon_w \sigma_{i/w}}{\Delta g_b} \qquad \Delta g_b = KT \ln \frac{e_{sw}}{e_{si}}$$

$$n_1 = 1.0 \cdot 10^{19}\ \mathrm{m}^{-2}$$

$$\Delta g_g = \Delta g_g^\circ \cdot f = \frac{4\pi}{3} \sigma_{i/w} r_g^2 f = \frac{16\pi \upsilon_w^2 \sigma_{i/w}^3}{3\Delta g_b^2} \cdot f$$

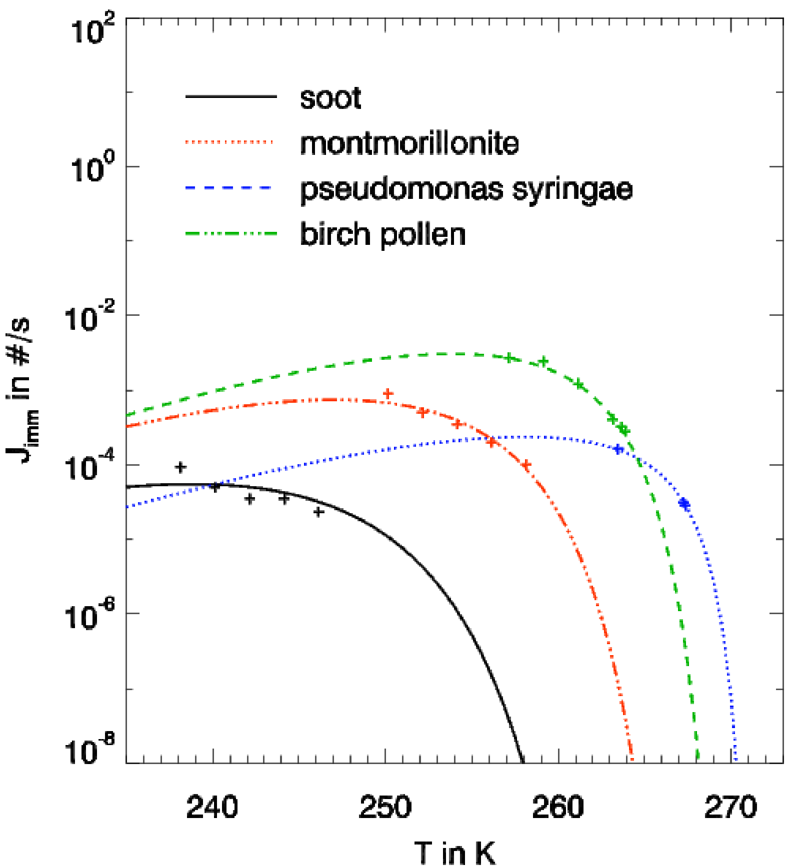
Nucleation thermodynamic parameters determined from laboratory data

$$J = A' \cdot r_N^2 \cdot \sqrt{f} \cdot \exp\left(\frac{-\Delta g^{\#} - \Delta g_g \cdot f}{kT}\right)$$

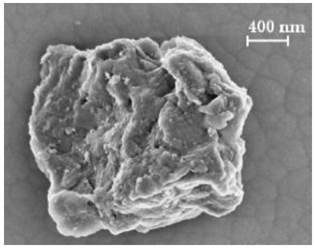
A' & Δg_g are ambient parameter

Properties of IN:

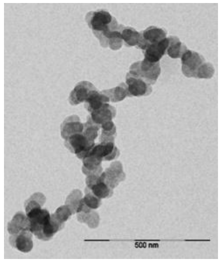
1. **Particle radius**
2. **Activation energy**
3. **Wetting coefficient or contact angle**

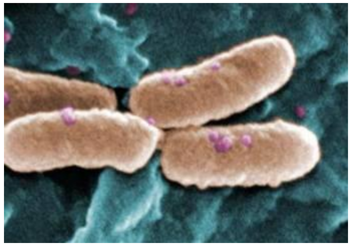


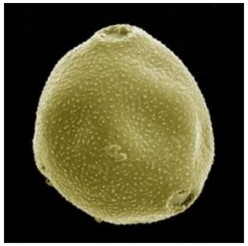
species \ parameter	θ	$\Delta g^{\#}$
soot	33.2	13.8
E. herbicola	16.0	12.7
P. syringae	12.5	12.8
P. aeruginosa	5.30	12.2
Grass	18.4	15.5
Oak	20.6	15.1
Pine	17.8	13.2
Birch	18.8	15.0
Eucalyptus	18.4	15.7
China rose	20.3	15.8
Hematite (0.03)	69.4	9.90
Hematite (0.13)	63.4	14.3
Asian dust	15.2	1.17
Saharan dust	14.7	1.31
Arizona test dust	7.85	2.32



Montmorillonite (Welti et al , 2009)


Soot (M. Jargelius)


Pseudomonas aeruginosa (J. H. Carr)


Birch pollen (J. Derksen)

Chen-Hazra-Levin (2008), ACP; Hoose, Kristjansson, Chen, Hazra (2010), JAS

Thanks