Data Assimilation experiments for Operational Weather Forecast in NESAC

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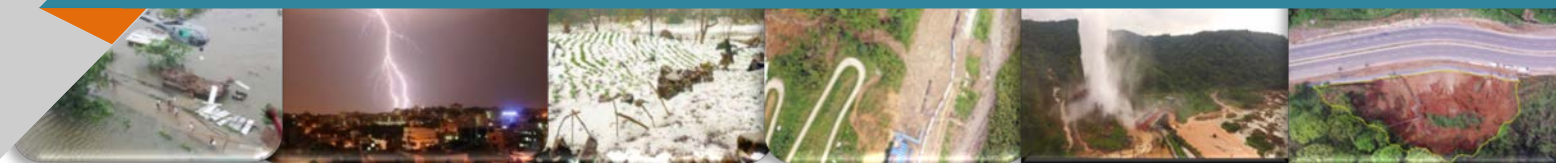
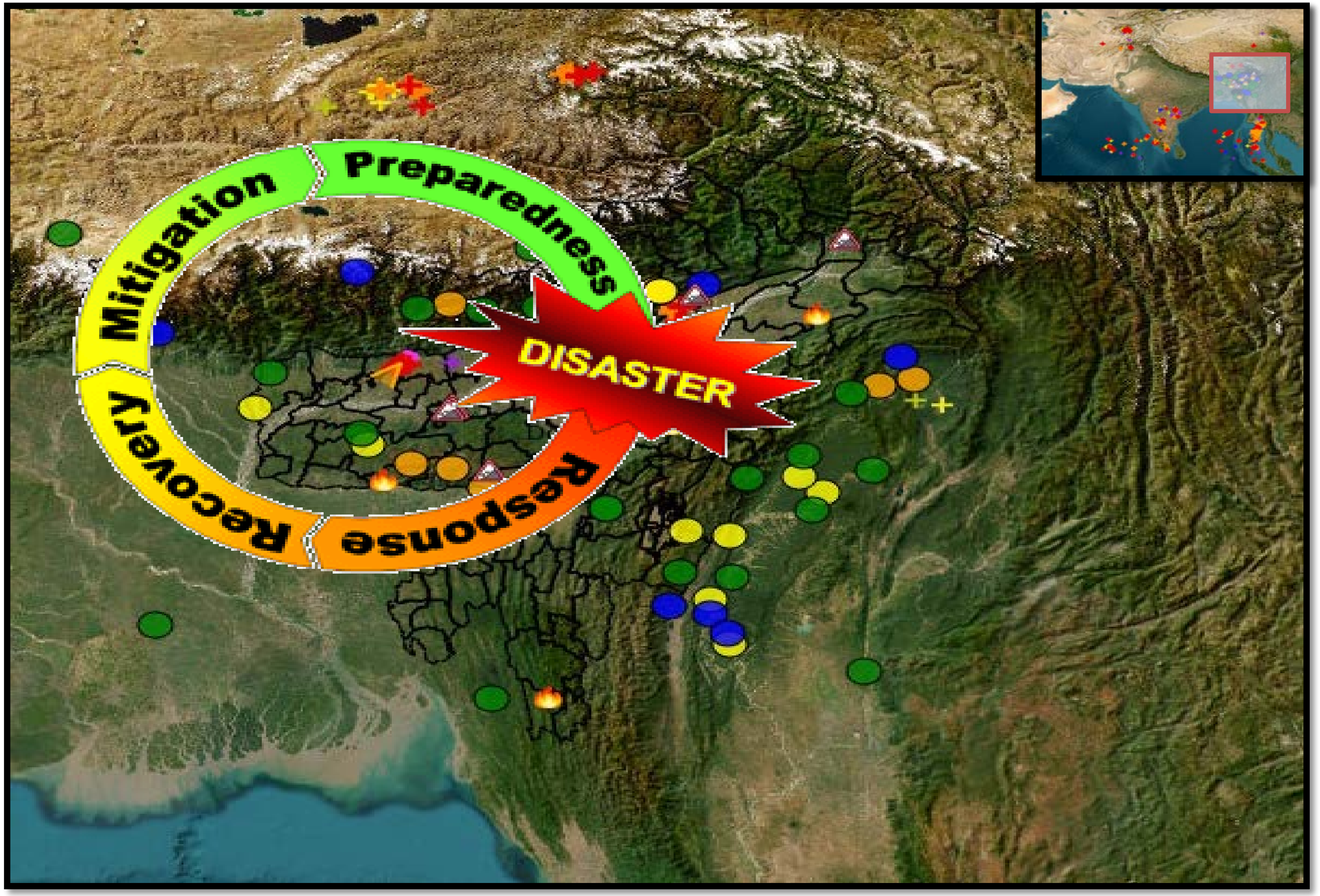


Northeastern Region of India & the prevailing disasters

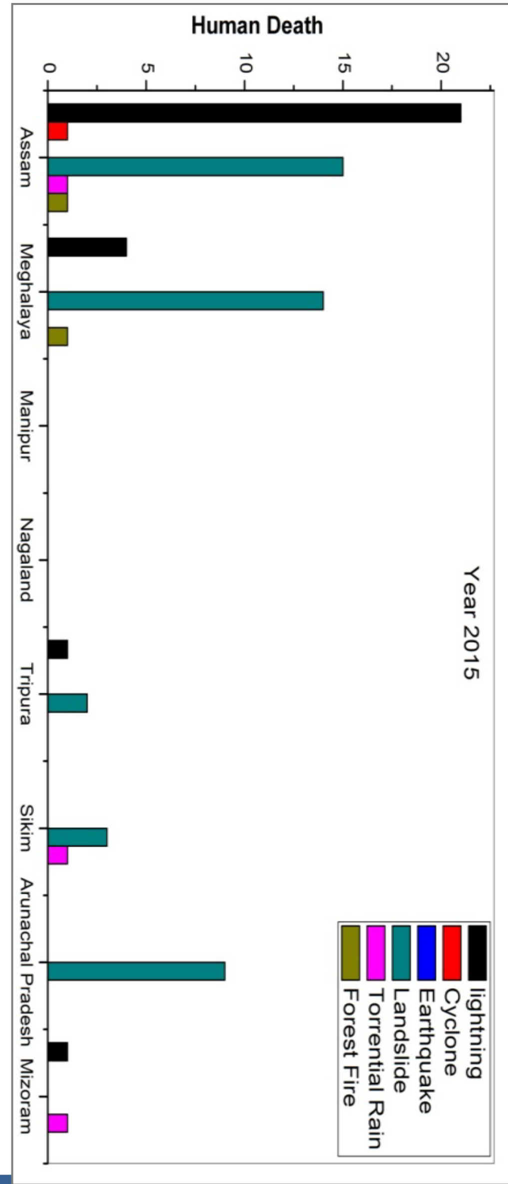
- The region is located in a seismically active zone (V), making it vulnerable to frequent **earthquakes**.
- The region receives heavy rainfall during the monsoon season, leading to frequent **floods and landslides**.
- Pre-monsoon **thunderstorm and lightning** is another major problem
- The hilly terrain of the region also makes it prone to **avalanches**
- **GLOF** turns out to be another emerging problem for NER



NER-DRR@NESAC : It's Relevance

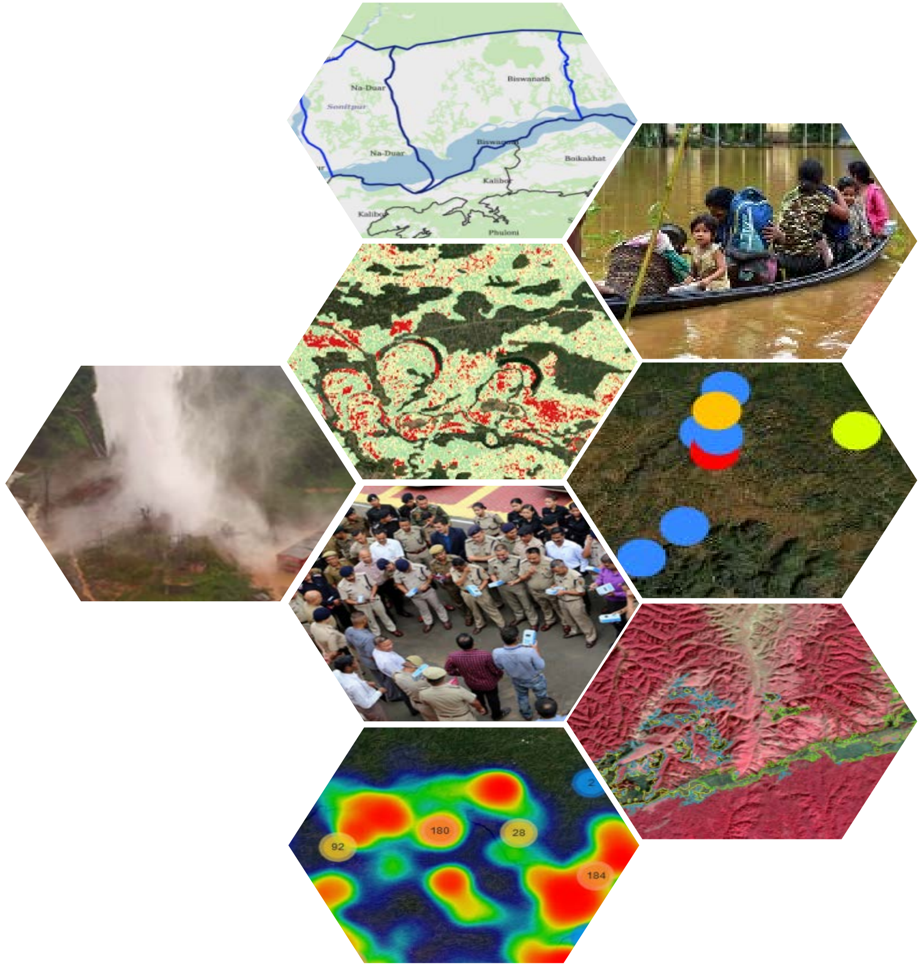
DOS approval for setting up NER-Disaster Risk Reduction : 7th March, 2012

States of NER	Relevant Disasters and priority level											
	Flood		Landslide	Earthquake	Agri.drought	Forest fire	Cyclone	Thunder storm	Hail storm	Cloud burst	River Bank Erosion	Epidemiological hazards
	Riverine	Urban										
Assam	VH	H	L	H	M	L	M	VH	M		VH	H
Arunachal Pradesh	M	L	VH	H	M	L		M		M	M	L
Meghalaya	M	M	M	H	M	M	M	H	M	M		M
Manipur	M	M	M	H	M	M					M	H
Nagaland	L	L	M	H	M	H		M				M
Mizoram	L	L	M	H	M	H	VH	H				M
Tripura	M	M		H	M	M	H	H			L	M
Sikkim	M	L	VH	H		L	M	M				L



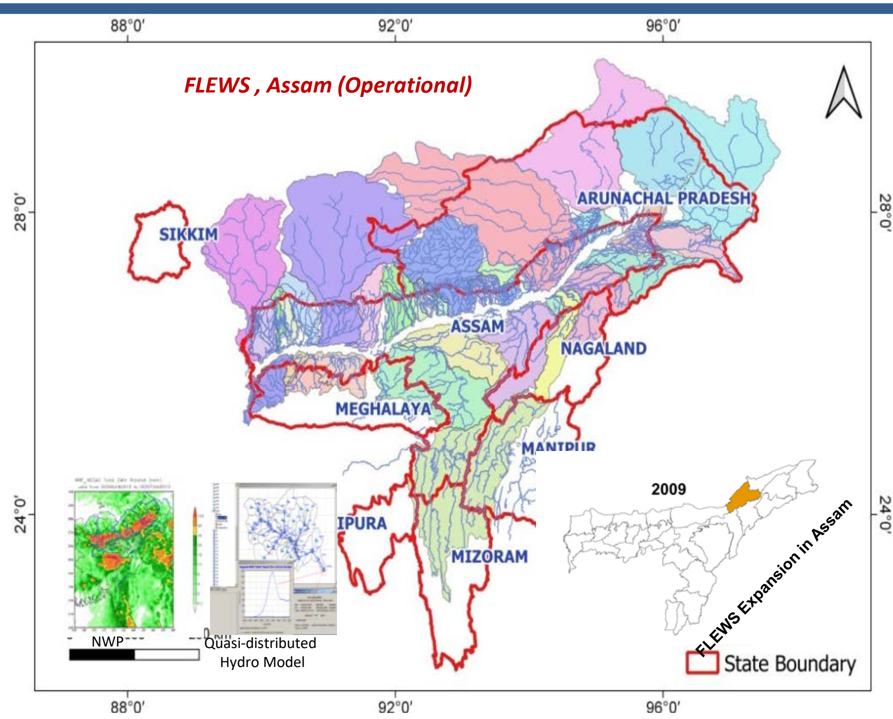
Role of NER-DRR

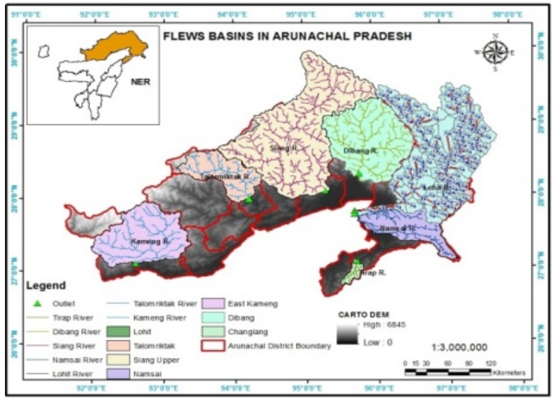
- ✓ Provide **single window delivery** of all possible space based support for management of disasters
- ✓ Creation of **comprehensive geo-spatial database** for different disaster vulnerable areas
- ✓ Development of **relevant tools & simulations** for effective decision making on various disasters
- ✓ Generation of **actionable products** and services as per the requirement of the region
- ✓ Faster and enhanced **dissemination of space enabled services** via Satellite based connectivity
- ✓ Ensures most **advanced and reliable mode of communication** for better disaster mitigation



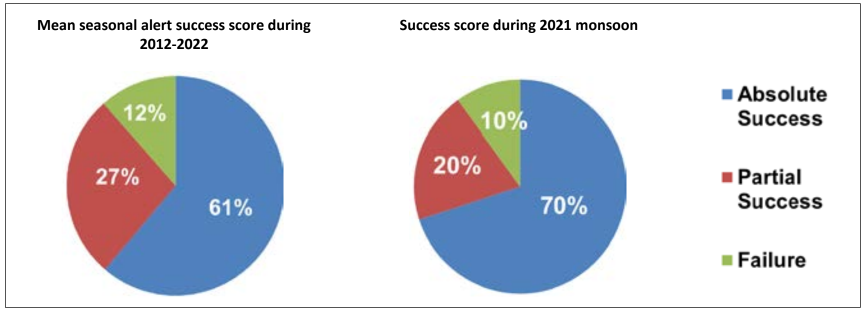
FLEWS in Assam & NER

- FLEWS, Assam has completed 10 years as an operational exercise in four phases during 2012 to 2022
- An average seasonal alert success score of 85% (both absolute and partial) with lead time ranging from 12 to 48 hours have been maintained.



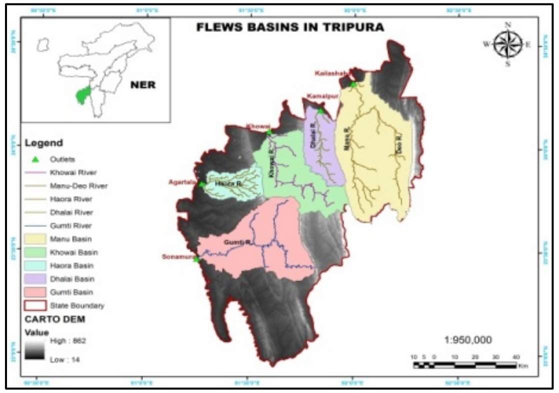


FLEWS, Arunachal Pradesh

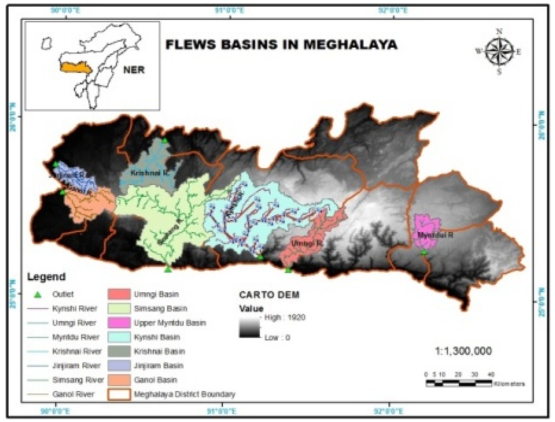


FLEWS in NER (Pilot)

Experimental flood alerts are being issued for the flood prone districts of Arunachal Pradesh, Meghalaya and Tripura during monsoon 2020 - 2022. Others states like Nagaland, Mizoram, Manipur, Sikkim are also under development.



FLEWS, Tripura



FLEWS, Meghalaya

INTRODUCTION to NWP at NESAC

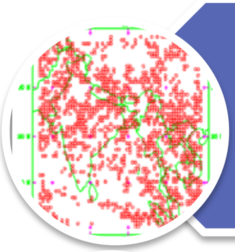
Weather Research Forecasting model is a mesoscale non-hydrostatic NWP model which has been implemented at NESAC in 2009 and the first attempt of operational forecast is made during the 2010 monsoon season.

Major Contribution:

1. FLEWS : Flood early Warning system
2. Thunderstorm Nowcasting
3. Lightning forecast
4. Rainfall forecast for Hydro Electric Plants

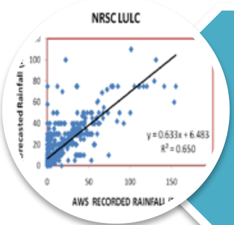
Increased Resolution

- 27:9:3
- 15:5



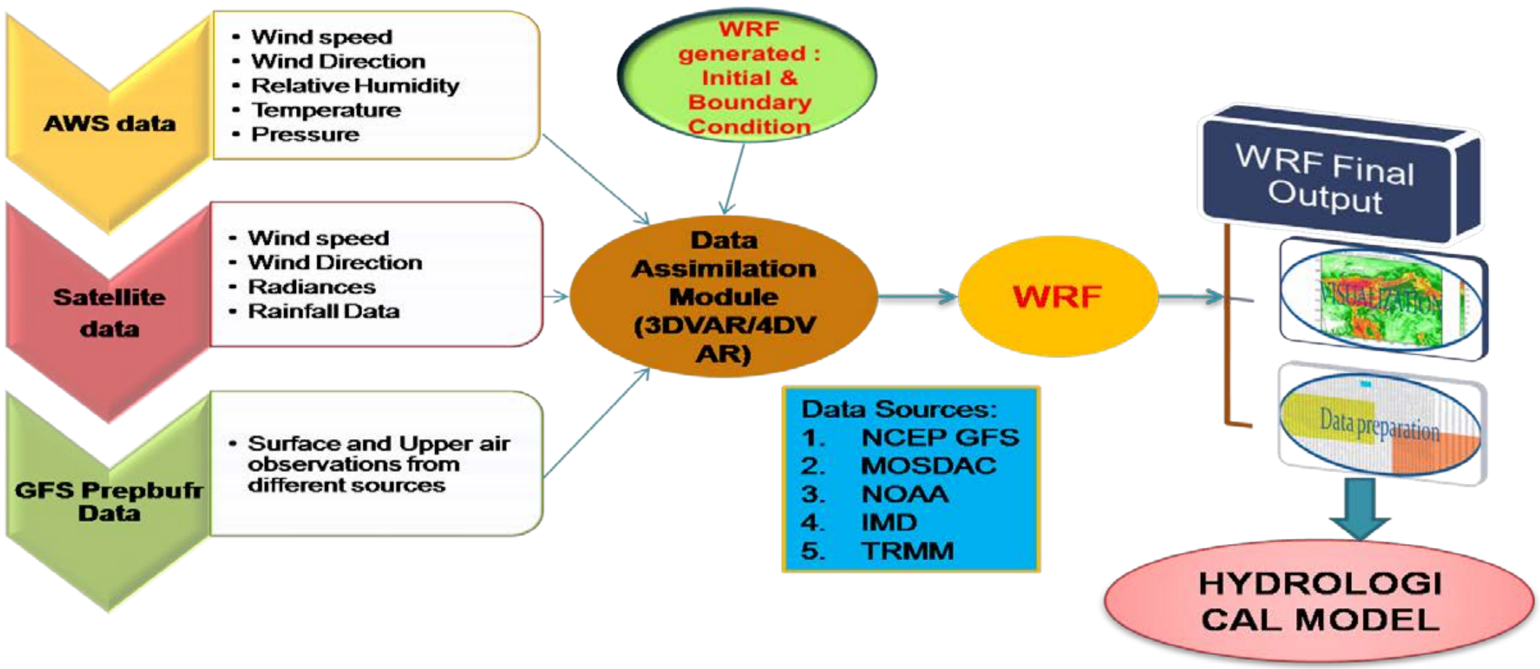
Data Assimilation

- 3DVAR, 4DVAR
- ENSEMBLE KALMAN FILTER

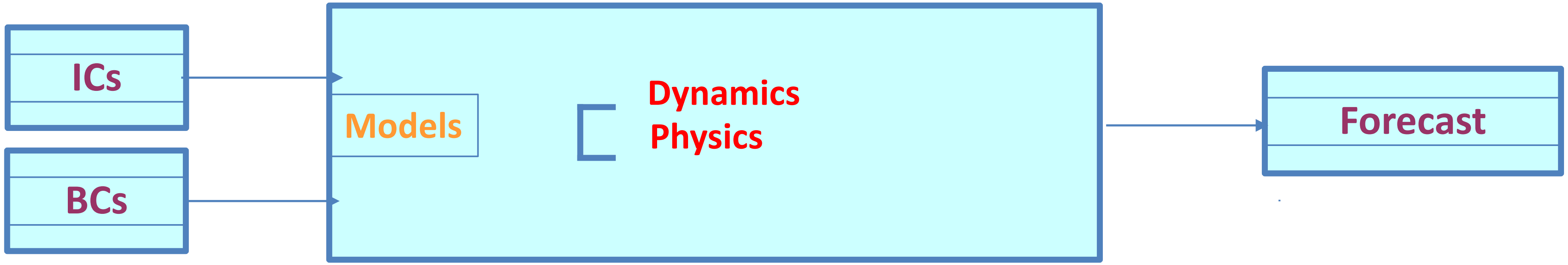


Validation

- Comparison with AWS , satellite data

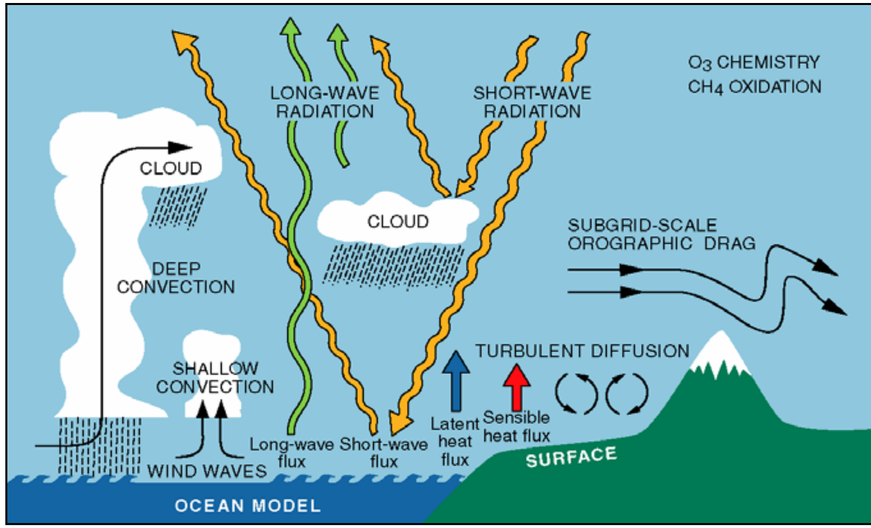


MODEL ARCHITECTURE

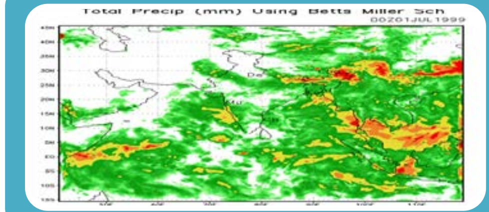


In the WRF Model, parameterizations include:

- Cumulus convection
- Microphysics of clouds and precipitation
- Radiation (short-wave and long-wave)
- Turbulence and diffusion
- Planetary boundary layer and surface layer
- Interaction with Earth's surface



Sensitivity of WRF model to parameterization schemes

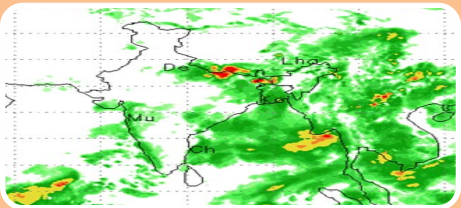


(1) It is observed from the comparison with observation data that the KF andGrellscheme show a little deviation from the actual spatial coverage. In all cases show a shift towards south.

(2) **Betts Miller** with Unified Noah land-surface model is morerealistic (PRASANTA MALI NCMRWF)

In this numerical study heavy rainfall events are better represented by **Kain-Fritsch** (KF) scheme than Betts-Miller-Janjic(BMJ) andGrell-Deveneyi(GD) schemes.

(O. S. R. U.BhanuKumar et al.)



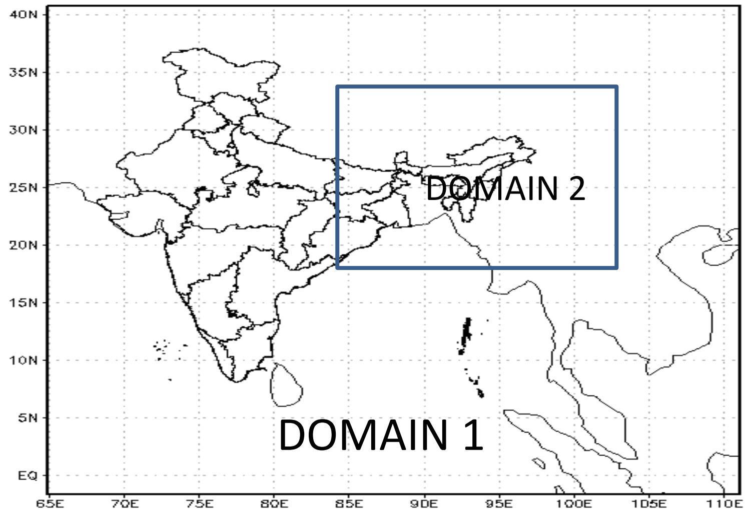
KF scheme could simulate the distribution of rainfall, but location of maximum rainfall was different.

(R. Anil Kumar et al)

Thompson scheme simulated surface rainfall distribution Closer to observations, the other three schemes (Lin, WSM6, Morison)overestimated observed rainfall.

(M.Rajeevanet al)

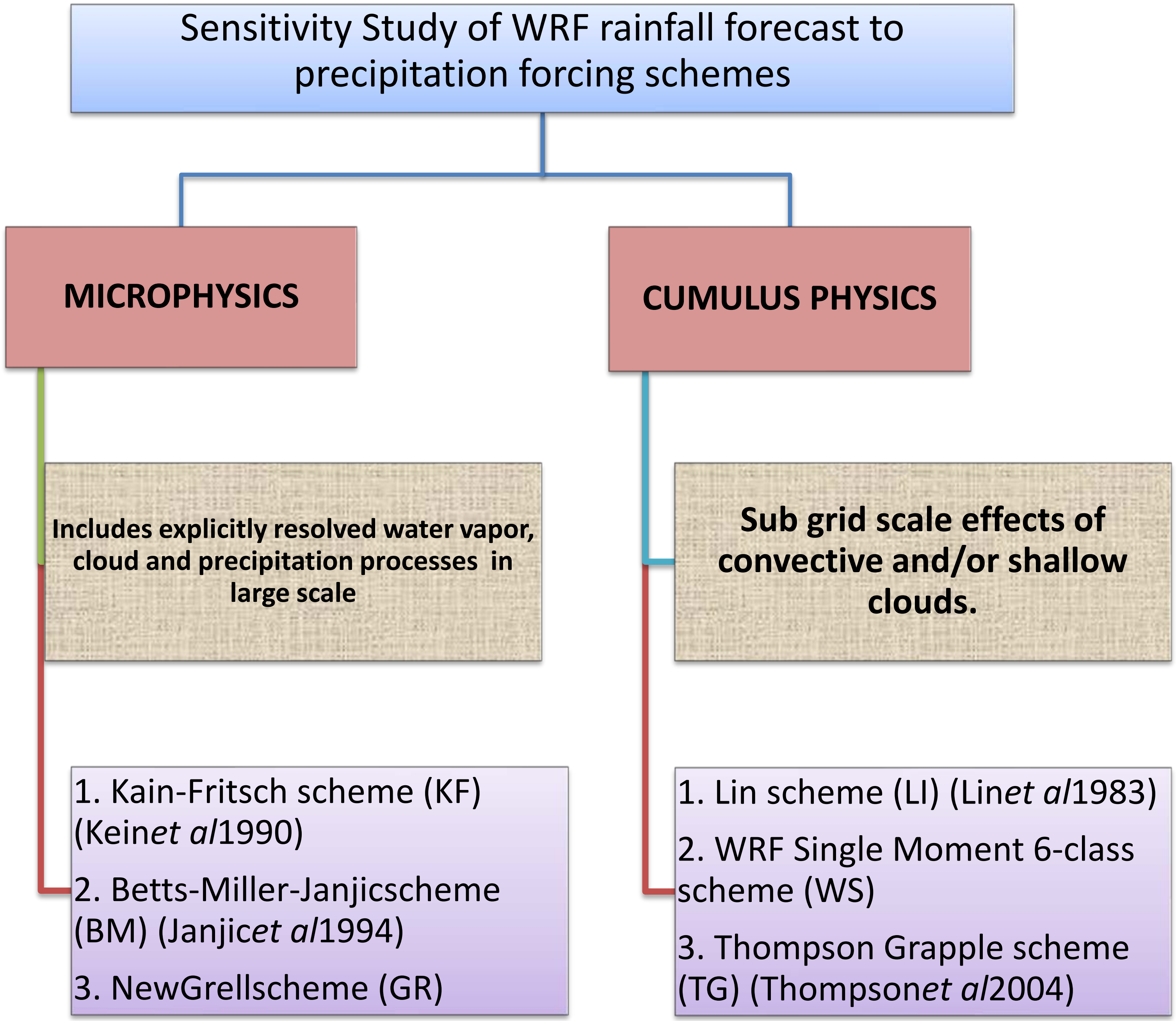
MODEL SETUP

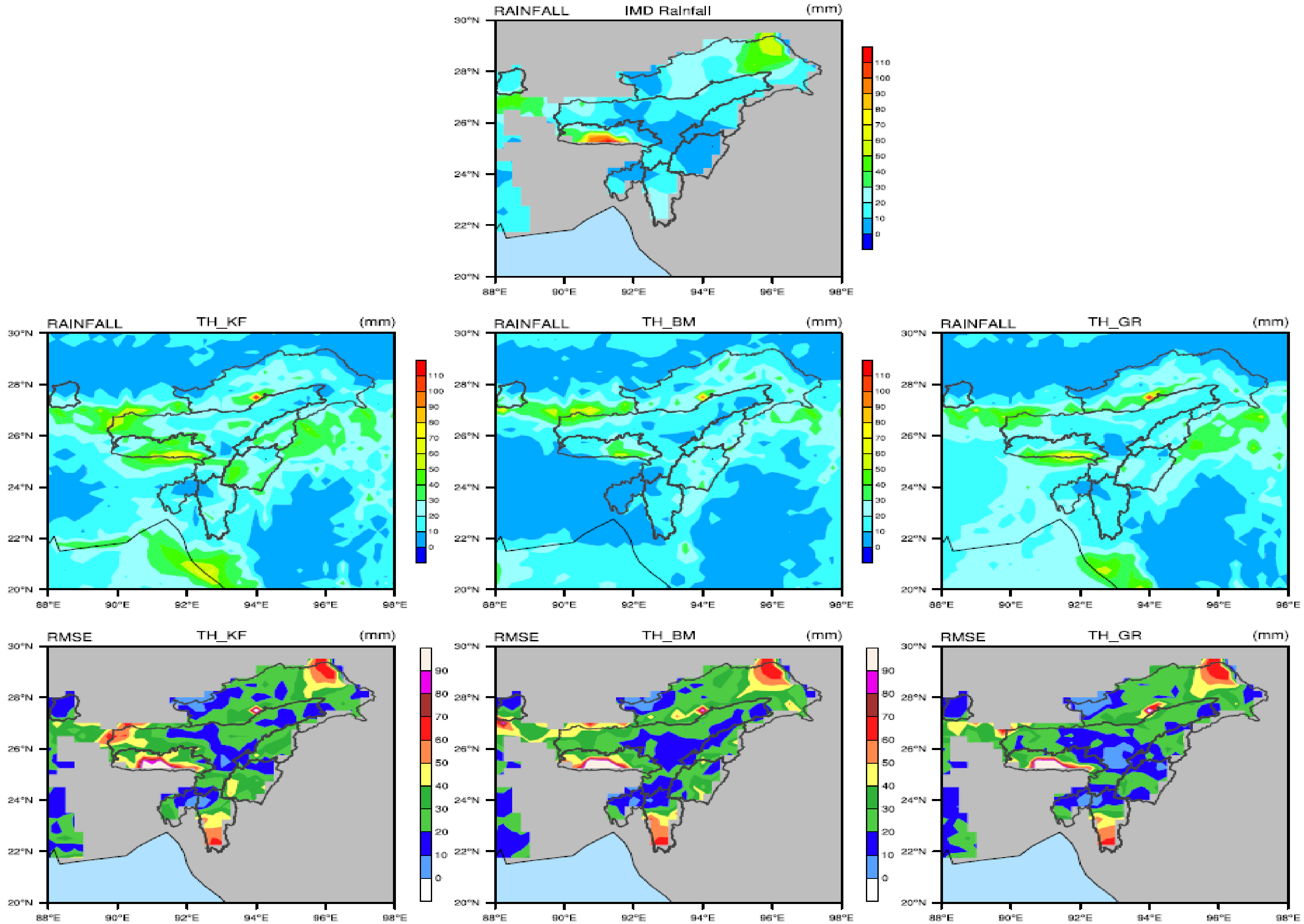


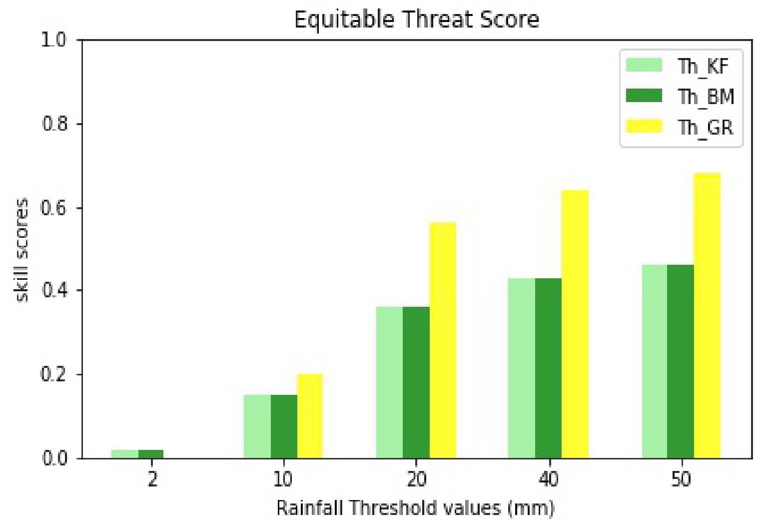
Long Wave Radiation	RRTM Scheme
Short Wave Radiation	Dudhia Scheme
Surface Layer Option	Monin Obukhov
Land surface Option	NOAH LSM
PBL	YSU Scheme
Time integration scheme	Third-order Runge-Kutta
Horizontal Grid	Arakawa C grid

Central Lat Lon	21°N 88°E
Number of grids	180 ×180
Horizontal resolution	27 km
Vertical levels	36
Time step	80 sec
Projection	Mercator

DATA:
- NCEP GFS Initial data at 0.5°×0.5° resolution

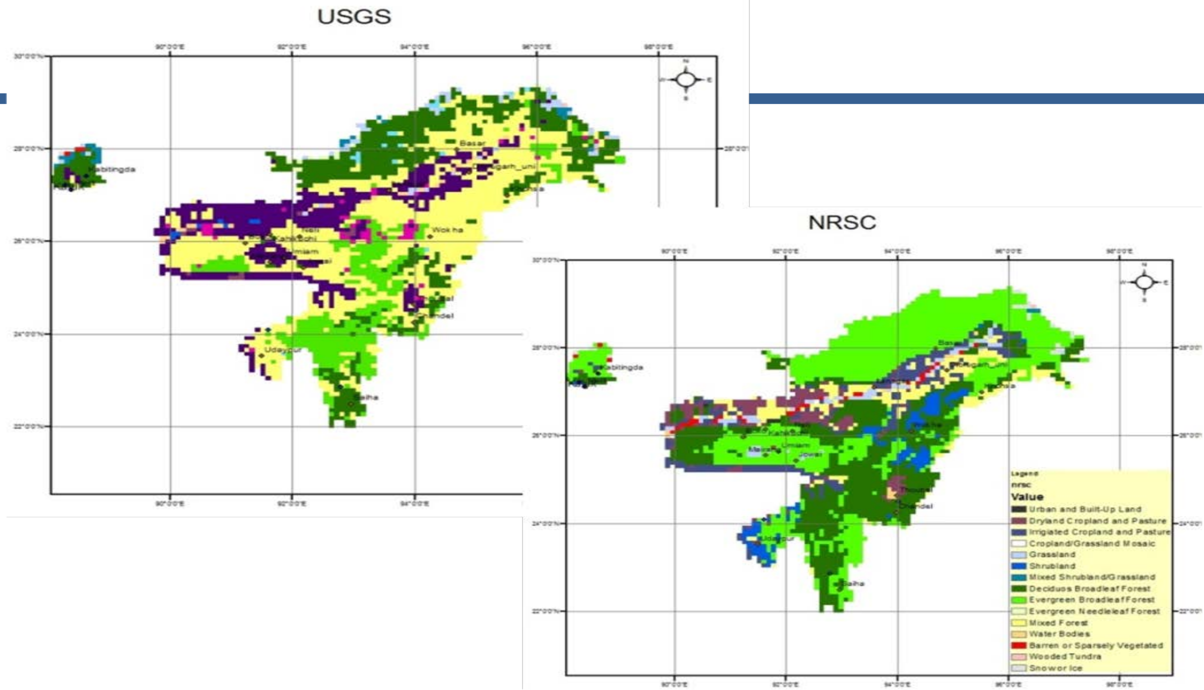

Sensitivity Study of WRF rainfall forecast to precipitation forcing schemes
MICROPHYSICS
CUMULUS PHYSICS
Includes explicitly resolved water vapor, cloud and precipitation processes in large scale
Sub grid scale effects of convective and/or shallow clouds.
1. Kain-Fritsch scheme (KF) (Keinet *al*1990)
2. Betts-Miller-Janjicscheme (BM) (Janjicet *al*1994)
3. NewGrellscheme (GR)
1. Lin scheme (LI) (Linet *al*1983)
2. WRF Single Moment 6-class scheme (WS)
3. Thompson Grapple scheme (TG) (Thompsonet *al*2004)

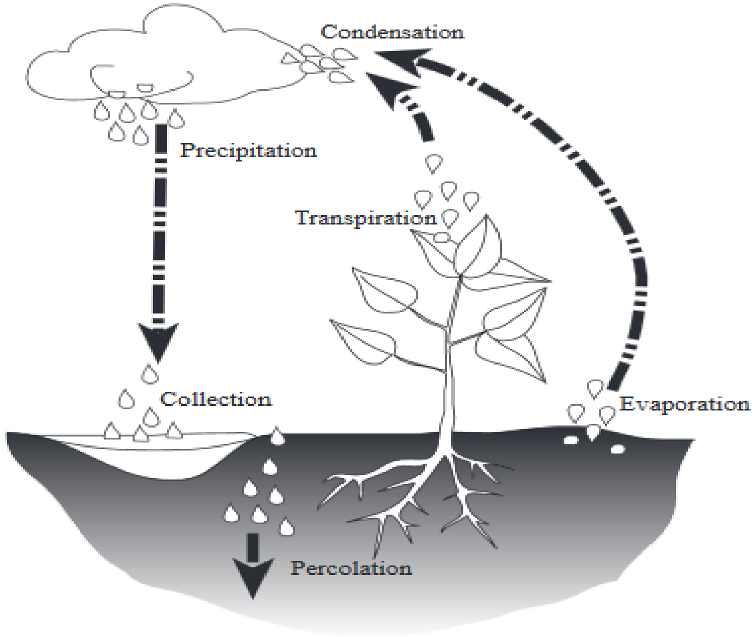




Top plot is for IMD gridded rainfall. Middle row represents spatial plot of rainfall from model experiments namely TH_KF, TH_BM, TH_GR. The bottom row represents RMSE (mm) for the mentioned experiments

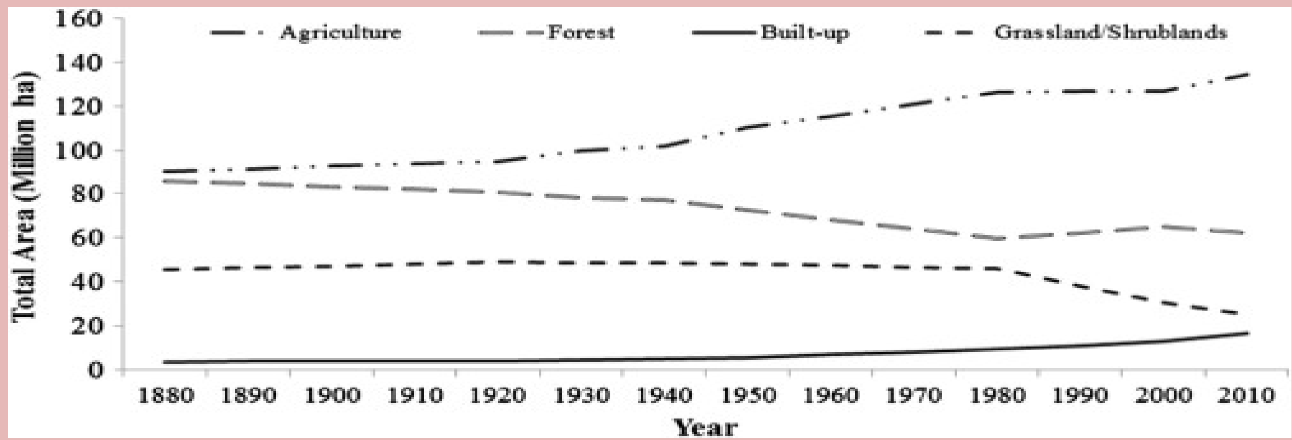
WRF model Sensitivity To LULC Changes





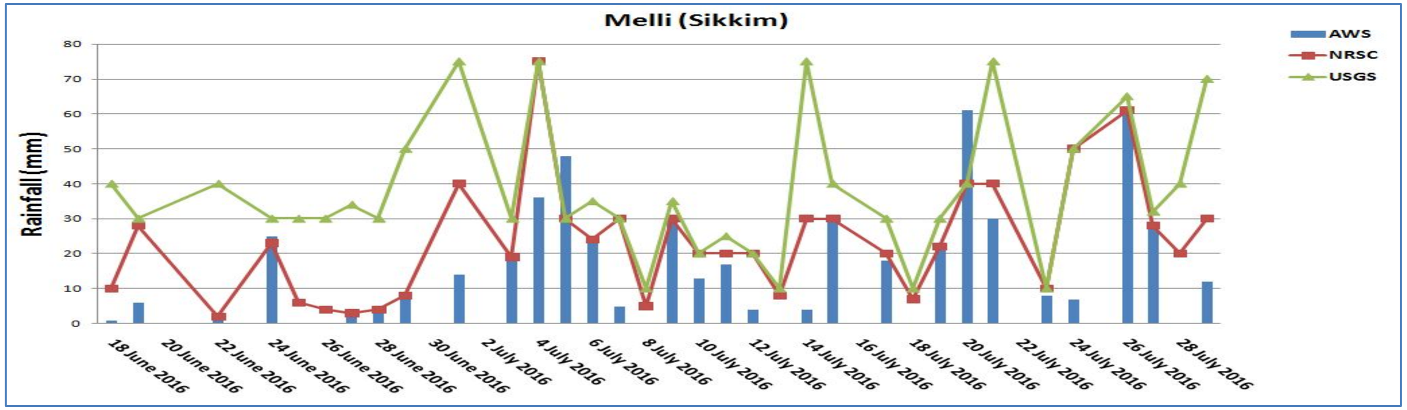
- The surface variability not only determines the microclimate but also affects mesoscale atmospheric circulation (Hartmann, 1994; Weaver and Avissar, 2001; Yang, 2004).
- Evapotranspiration(ET) accounts for approximately 20–25% of the rainfall in Northeast India during (August and September) (Pathak et al, 2014).

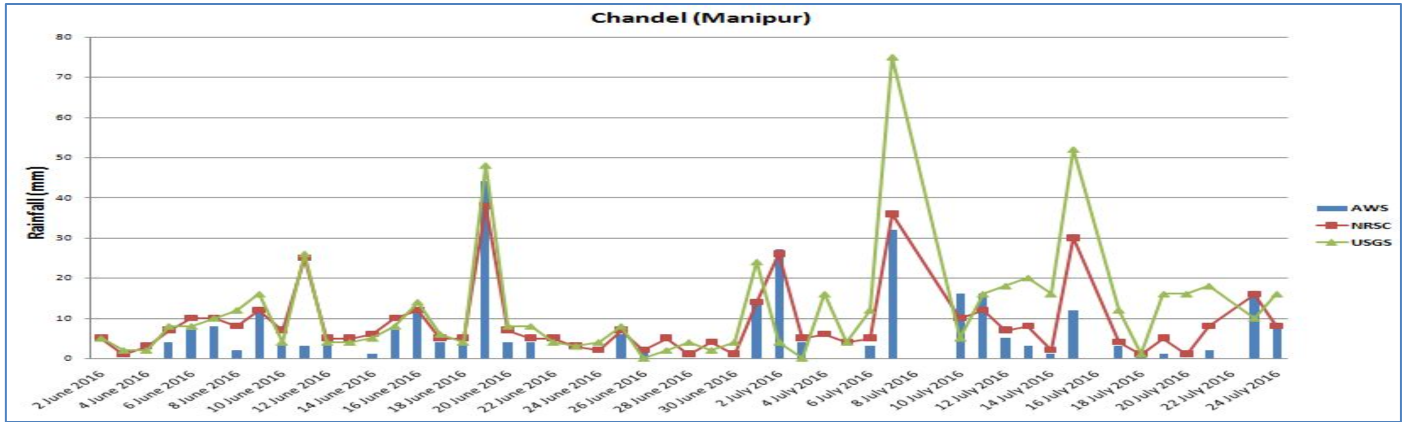
Temporal pattern of land cover and land use change during 1880–2010.

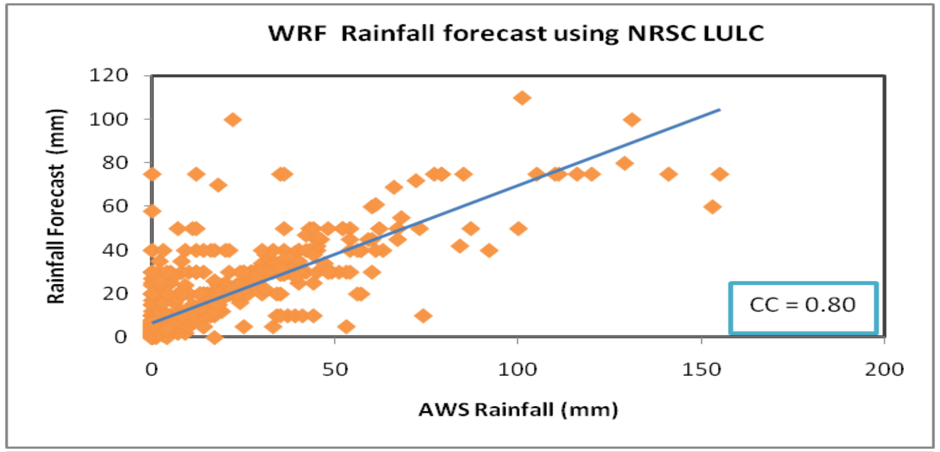


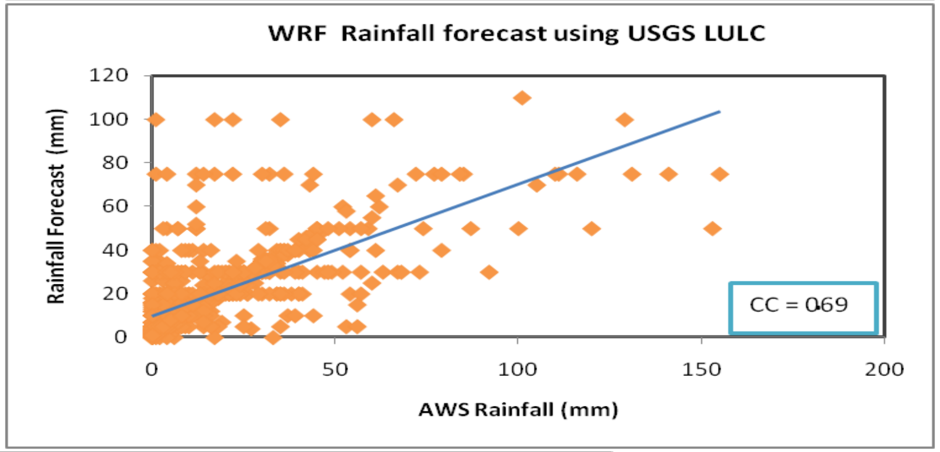
Hanqin Tian, Kamaljit Banger, Tao Bo, Vinay K. Dadhwal

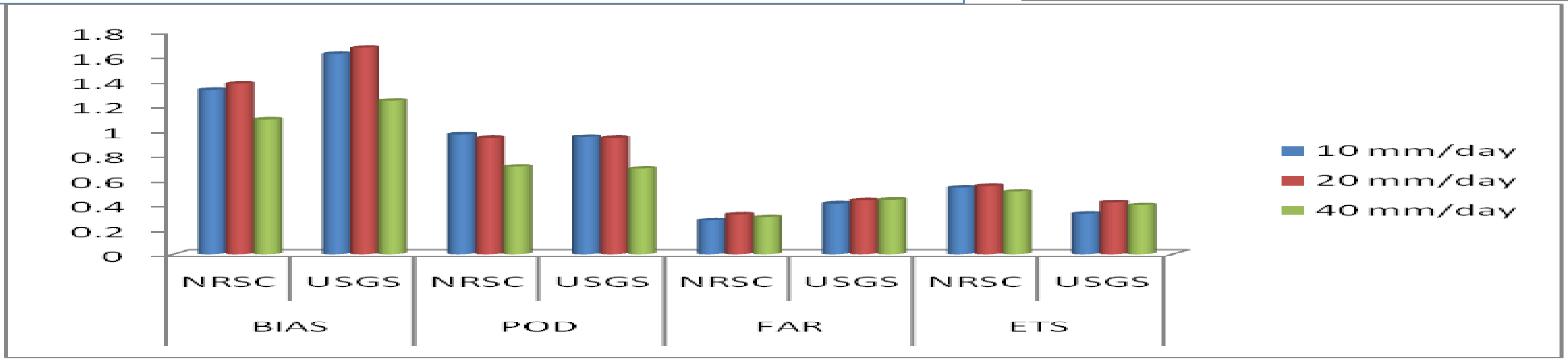
WRF model: Sensitivity Analysis



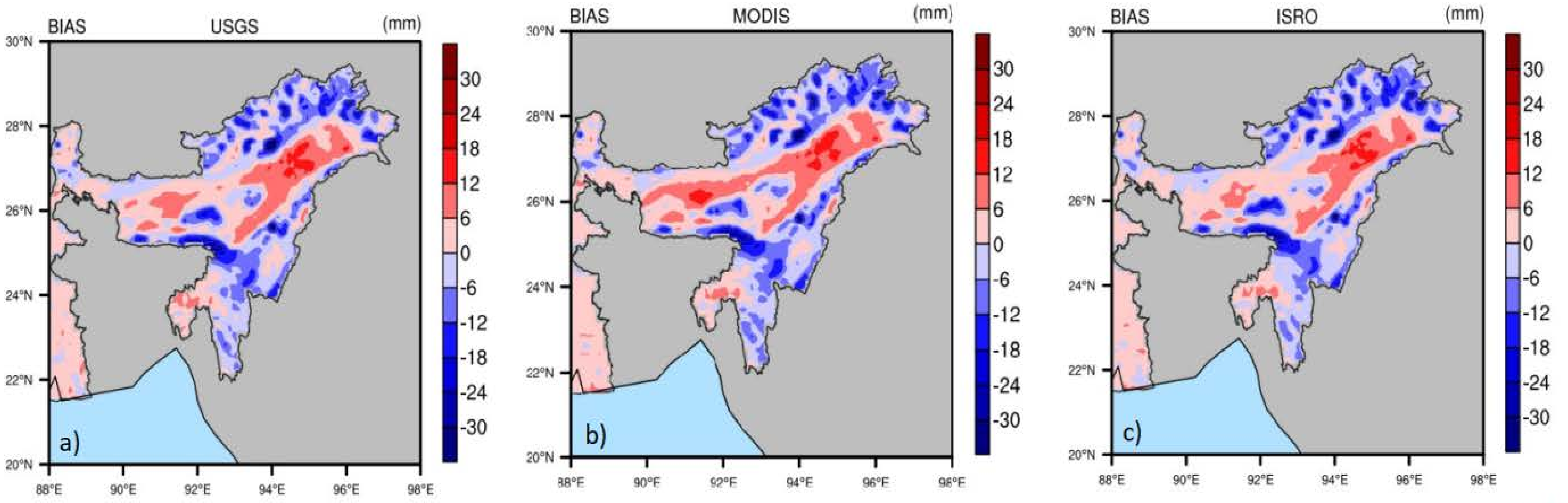








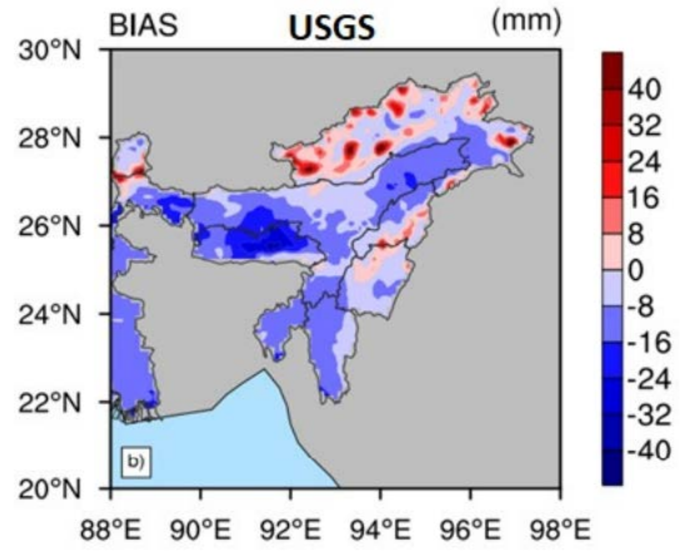
Impact of Satellite Based Geographical Data on Simulation of Rainfall over North Eastern Region of India Using a Limited-Area Model

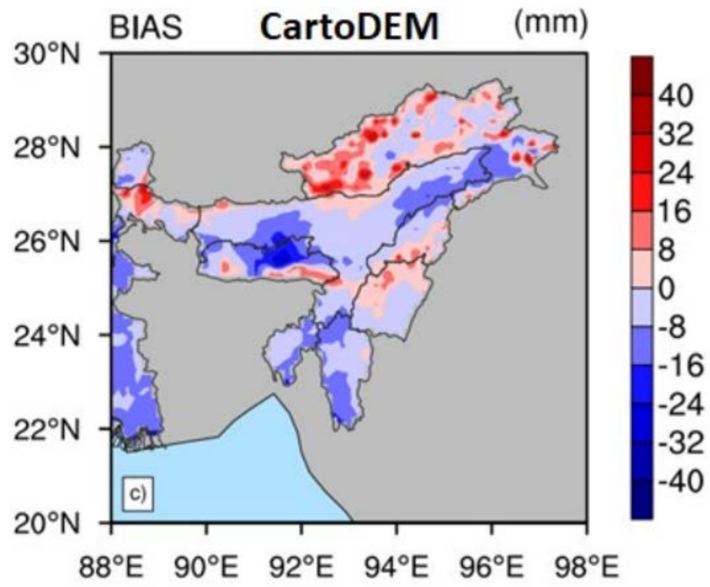


1. In this study, rainfall simulations are conducted using Weather Research and Forecasting (WRF) model for the monsoon season in the year 2018 at 9 km resolution. Three sets of LULC data are taken from USGS, MODIS and ISRO.
2. The ISRO experiment shows lower Bias in precipitation as compared to the rest of the experiments, mainly over central and the western Assam covering the Brahmaputra valley. Significant wet bias is observed in MODIS simulations.

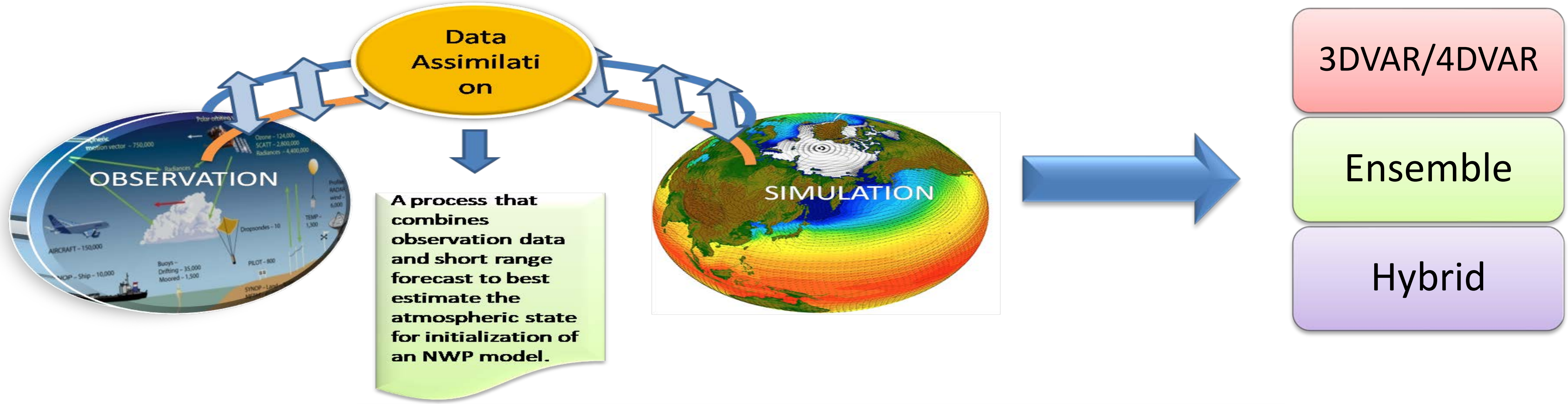
Impact of Terrain Data on Simulation of Rainfall over North Eastern Region of India Using a Limited-Area Model

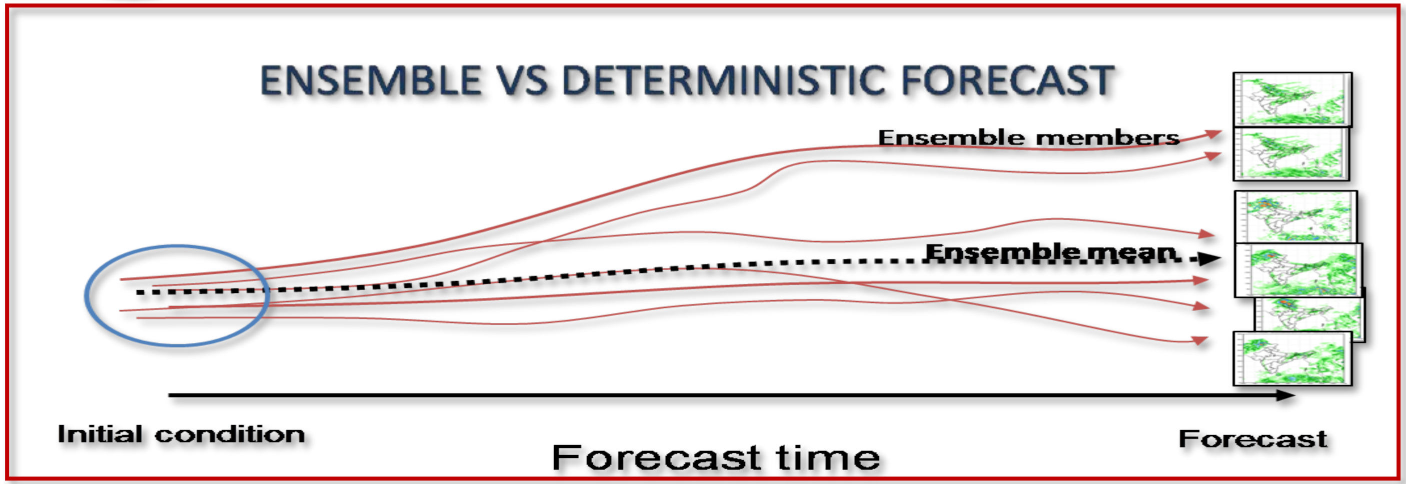
1. In another case study, two set of terrain data are used namely, WRF default **USGS** and **CartoDEM**.
2. The simulations are conducted at 9 km and 3 km resolution.
3. For incorporating the CartoDEM in the WRF model, QGIS platform is used and also, a python code has been developed to convert the data to binary format.
4. The results reveal that the underestimation observed in USGS simulation over western and eastern Assam, Tripura and Mizoram is significantly improved in CartoDEM simulation at 3km resolution.



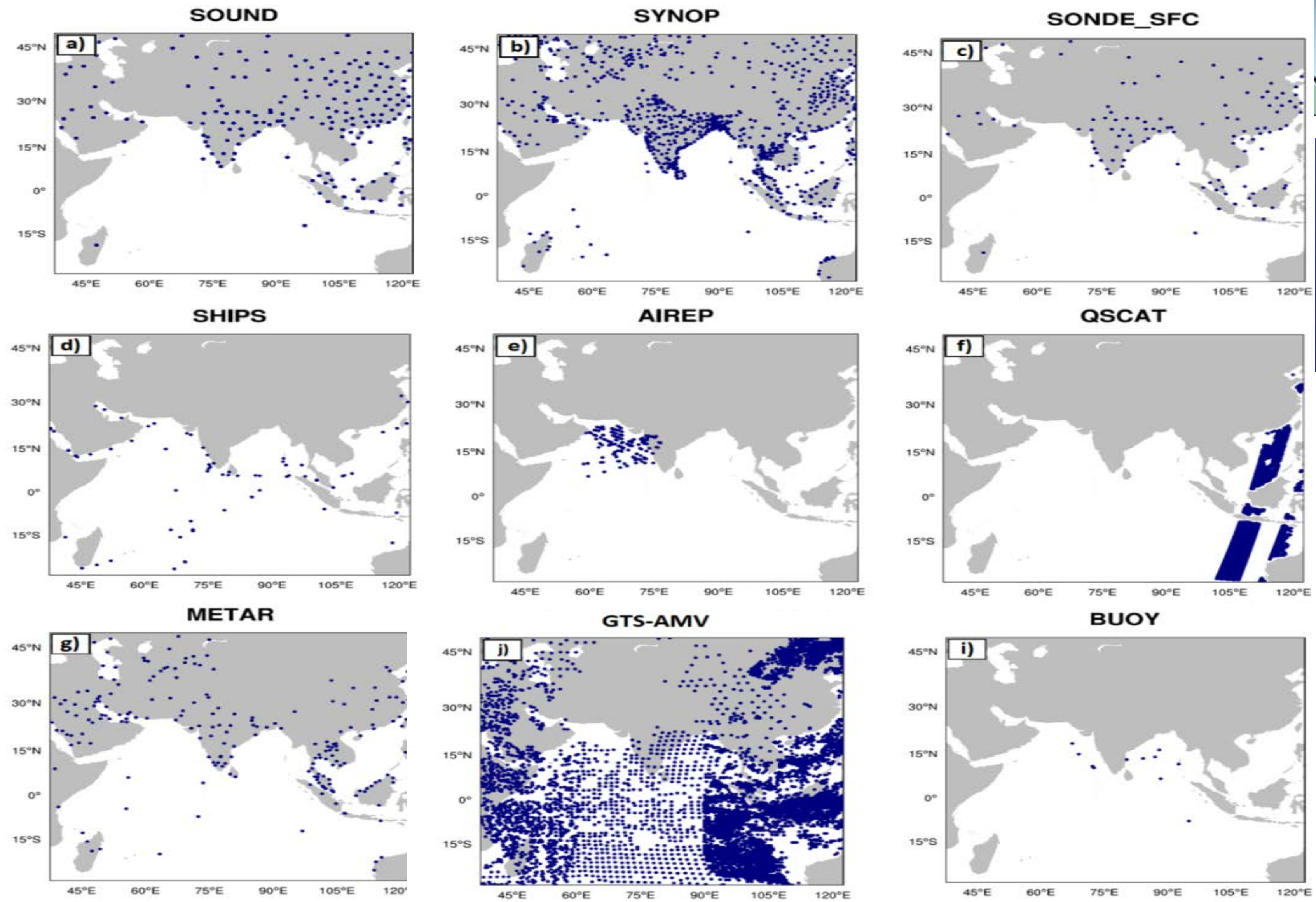


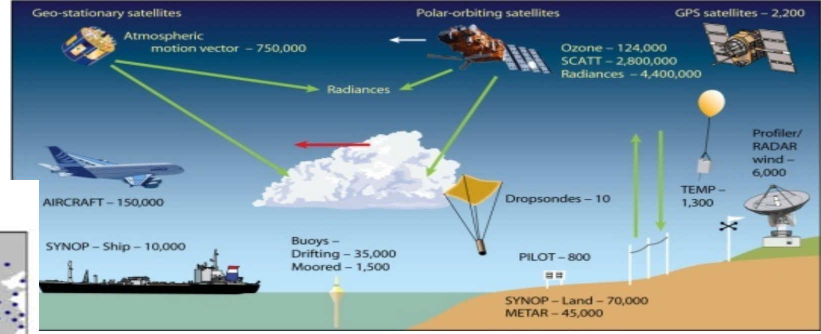
Data Assimilation is a process that combines observed data with model short-range forecast to generate a much accurate initial conditions.



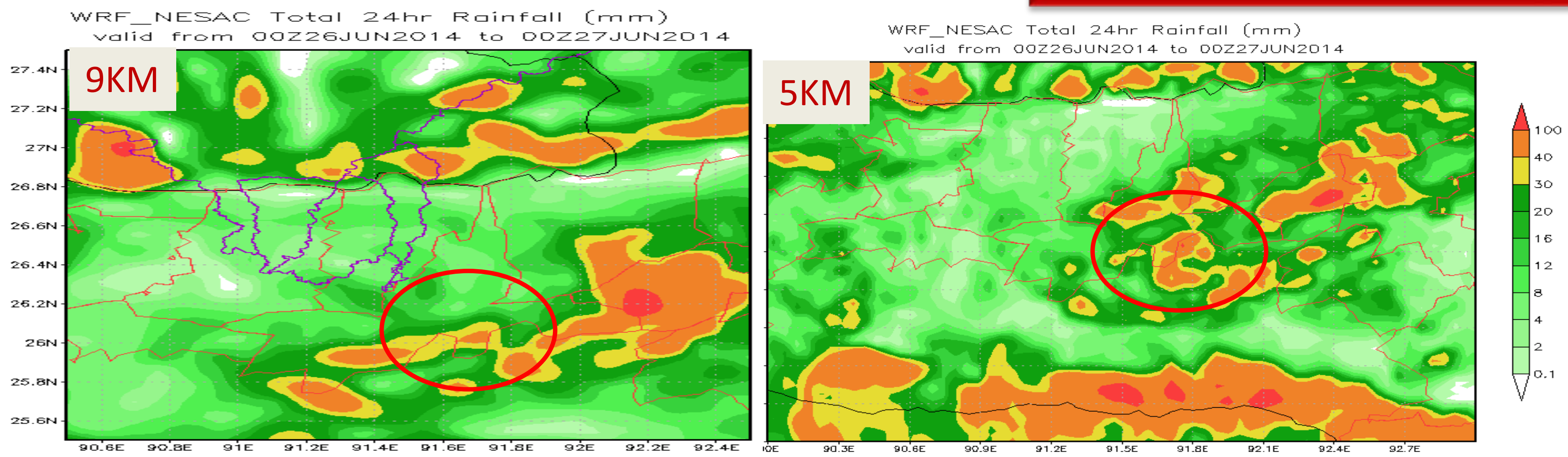


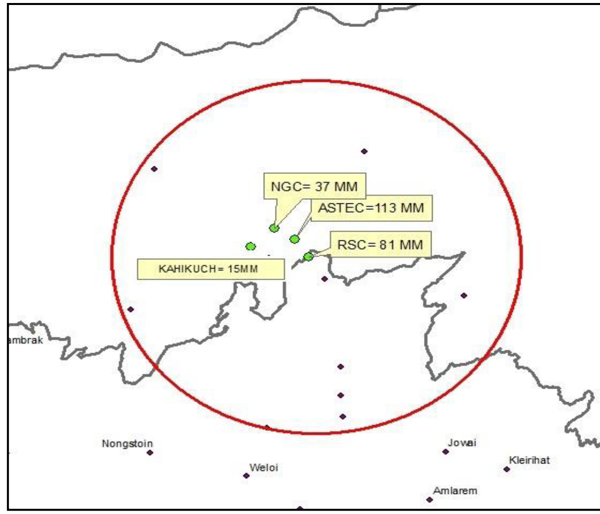
Observed Data Used for Data Assimilation





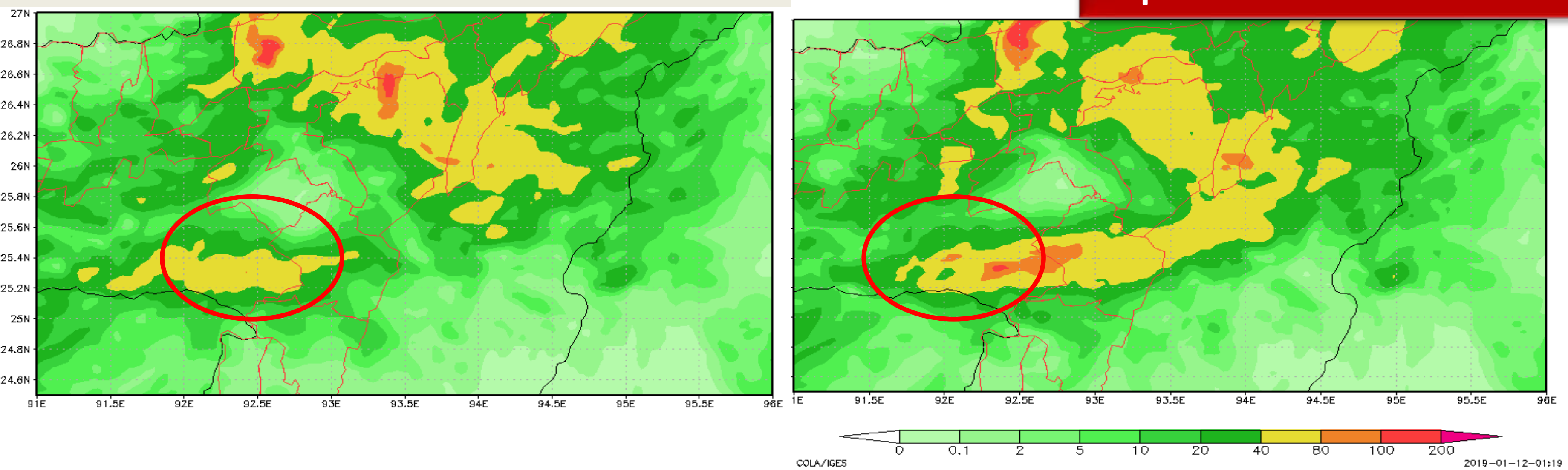
Improvement with increased model resolution

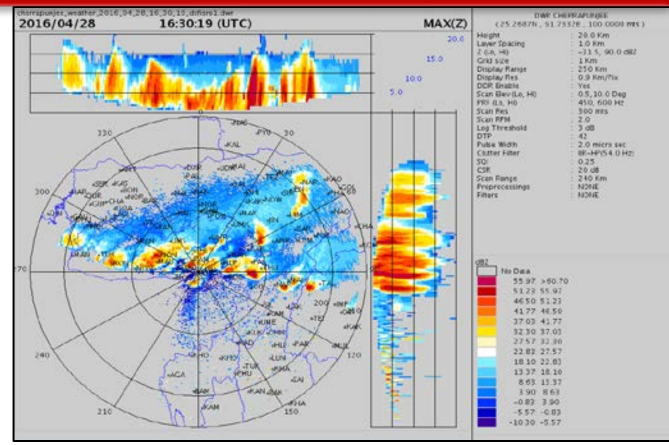




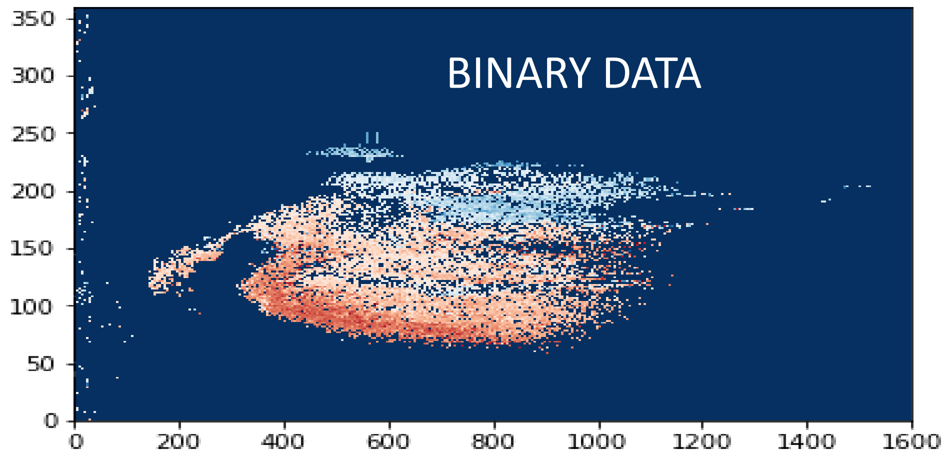
Total rainfall (mm) from 16UTC to 21UTC 28 April2016

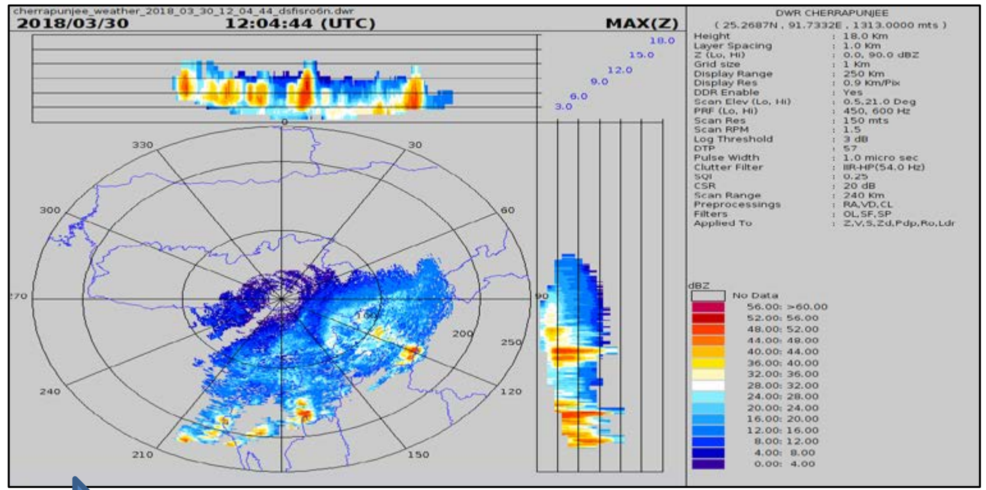
Improvement with DWR data assimilation

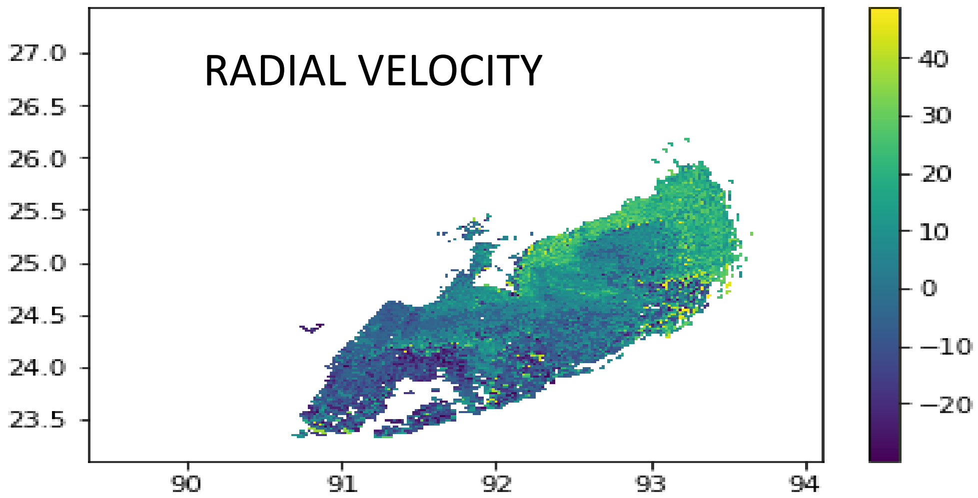


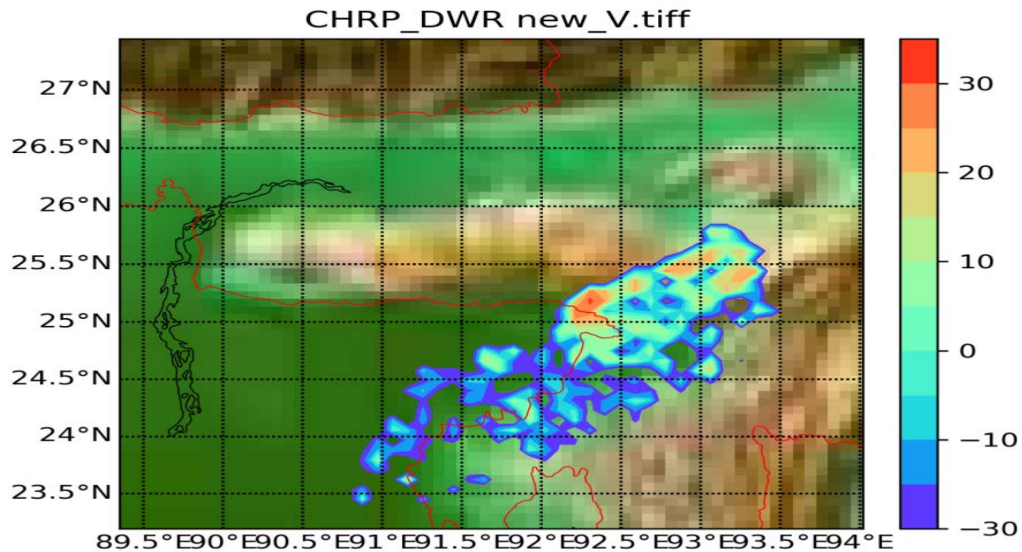


RADAR DATA ASSIMILATION

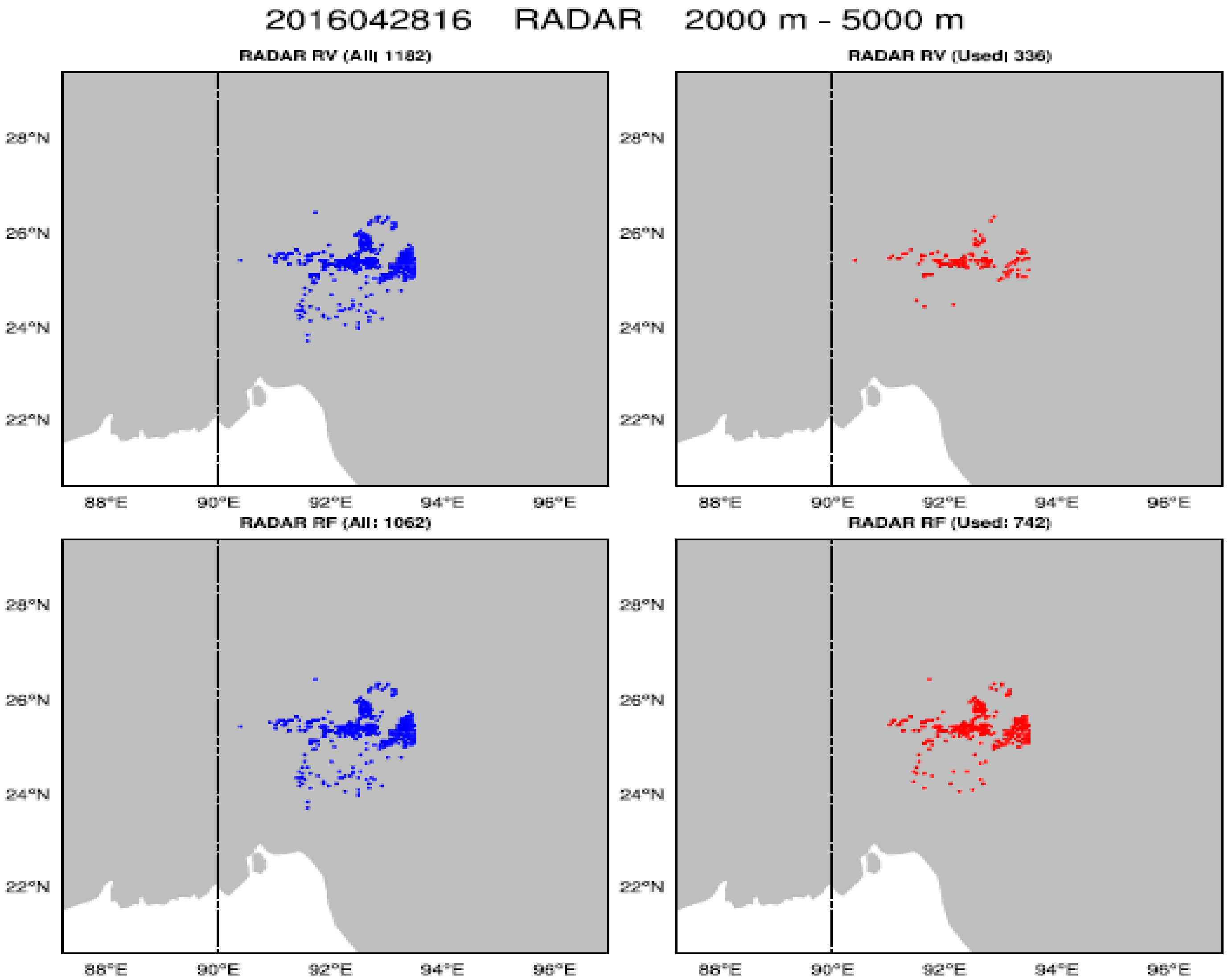








RADAR DATA ASSIMILATION



RMSE of DWR observations at model initial time of 1600 UTC for Case 1

Var	O-B	O-A
RF	6.24	5.99
RV	2.70	2.15

Data used in DA system	Experiment
GTS	CTRL
GTS + Reflectivity	DWR_RF
GTS + Rain water and Water Vapor derived from reflectivity	DWR_Q

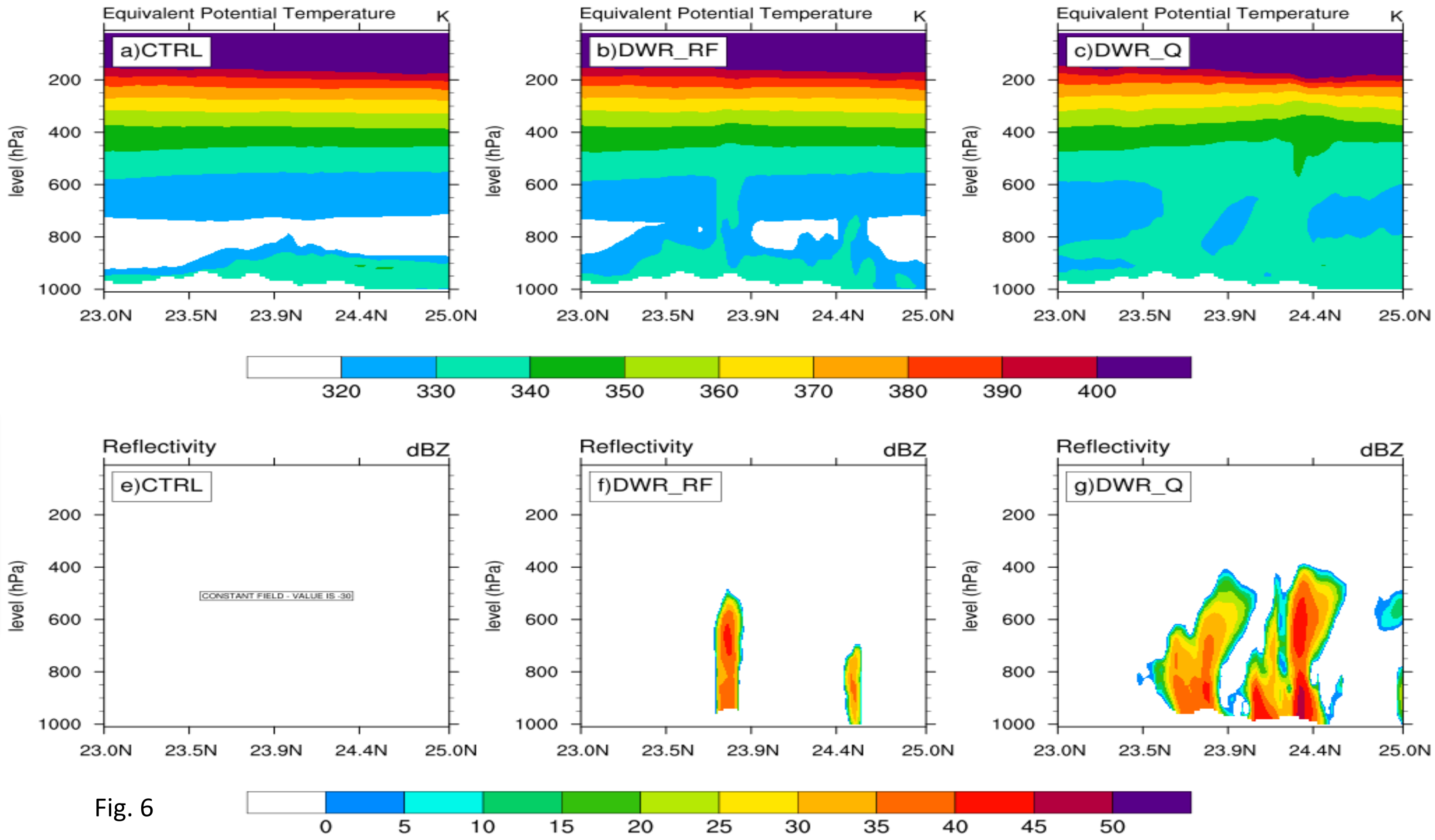
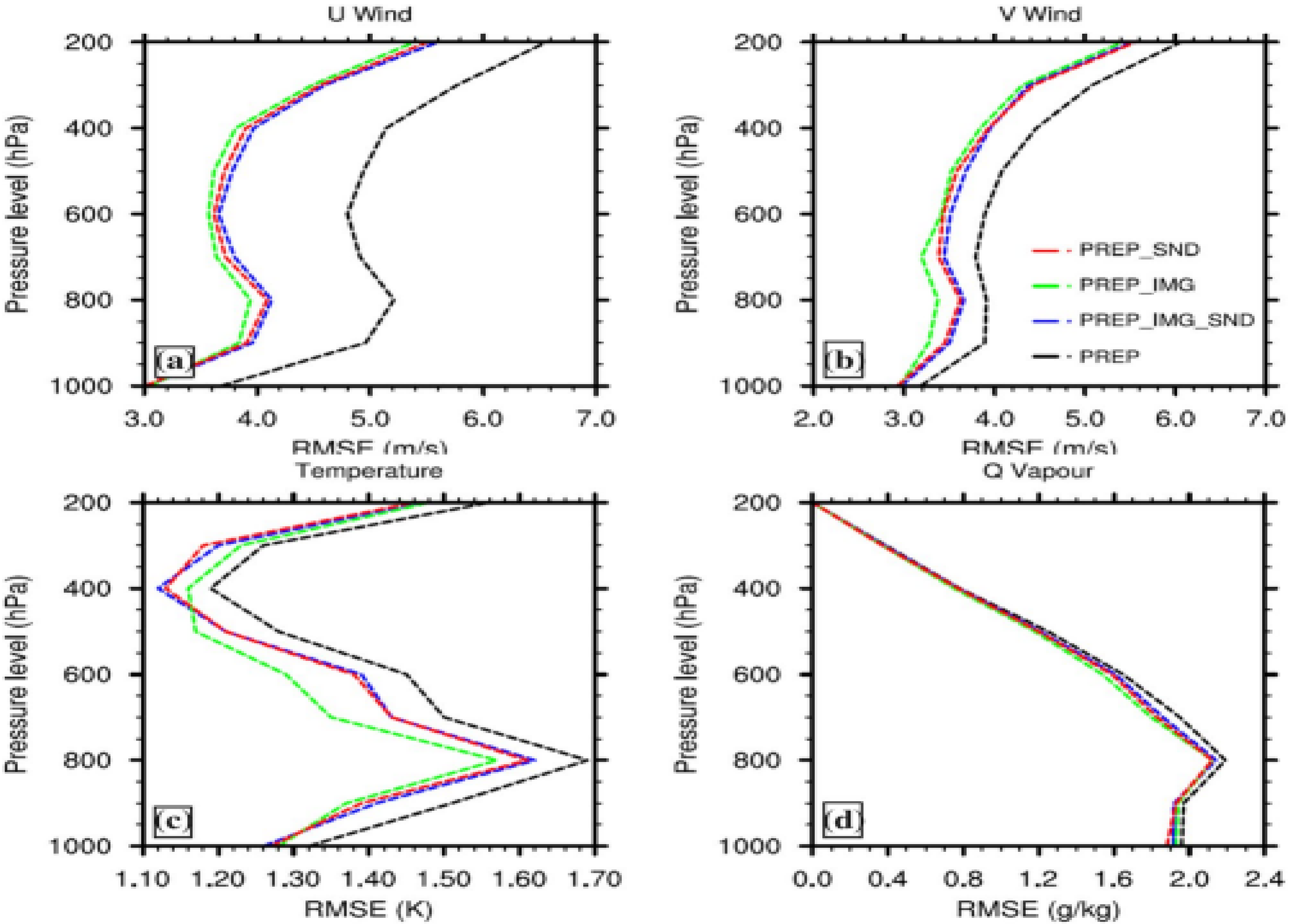


Fig. 6

Cherrapinji Radar Data has been assimilated for the first time both in direct and indirect way for simulation of thunderstorm over NER

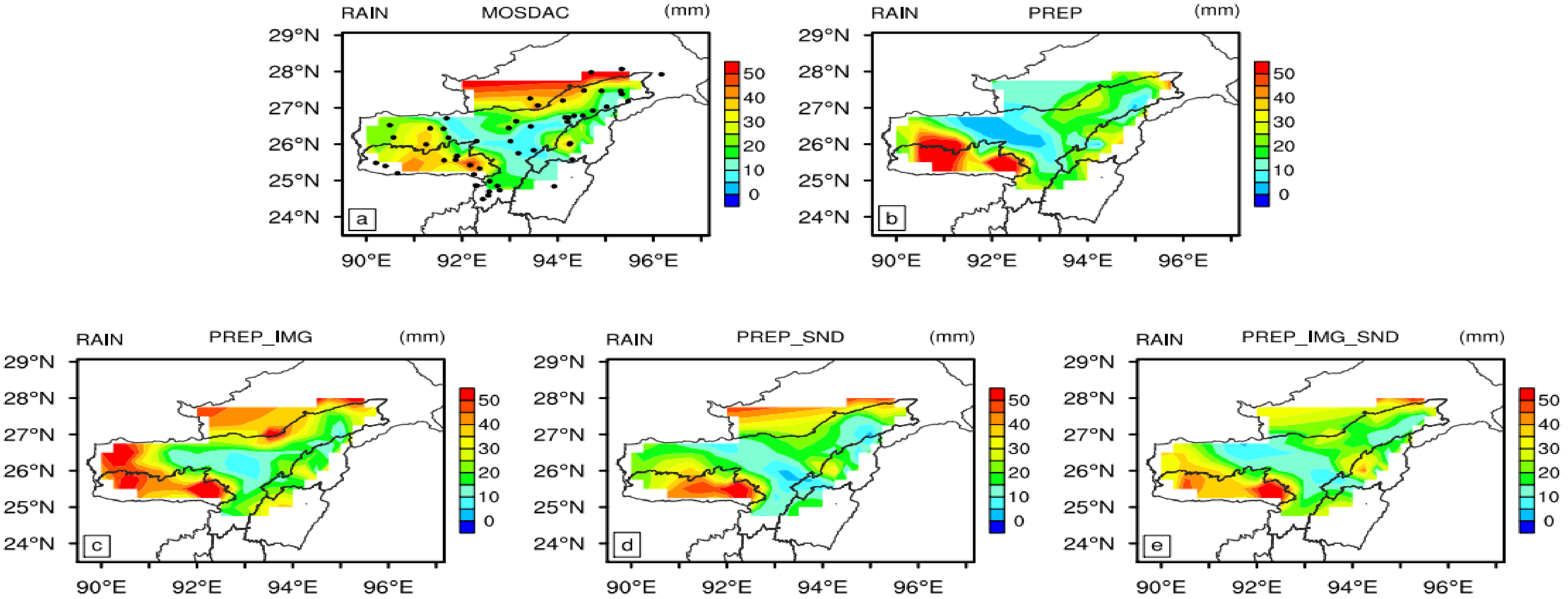
- ➢ The simulated thermodynamic indices and the meteorological field such as equivalent potential temperature, reflectivity, vertical velocity are compared between CNTL, DWR_RF and DWR_Q.
- ➢ Vertical cross sections are taken through the thunderstorm core area at 24° N and 93° E for the analysis. It is observed that DWR experiment reveals the presence of moist warm core (Figure 6 b-c)) corresponding to strong updraft (figure not shown) that further enhances the instability to build up the thunderstorm.
- ➢Figure 6(f-g) depicts the tall cloud favorable for severe thunderstorm which is missing in the CTRL experiment. However the severity of the thunderstorm is better simulated by DWR_Q where reflectivity is assimilated indirectly.

IMPACT OF INSAT-3D RADIANCE DATA ASSIMILATION

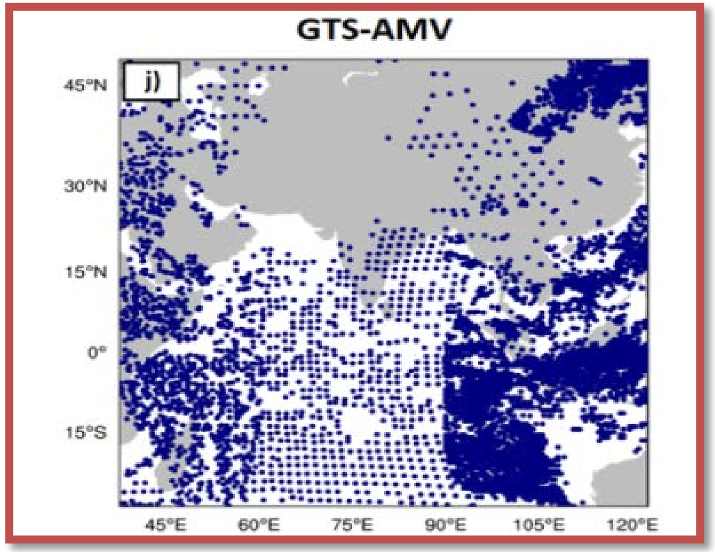


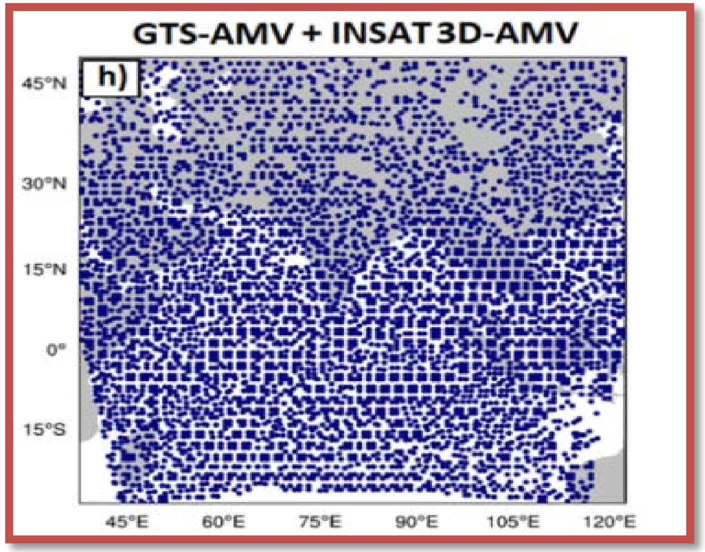
Vertical profiles of root mean square error for 24 h forecasts against radiosonde observations for experiments

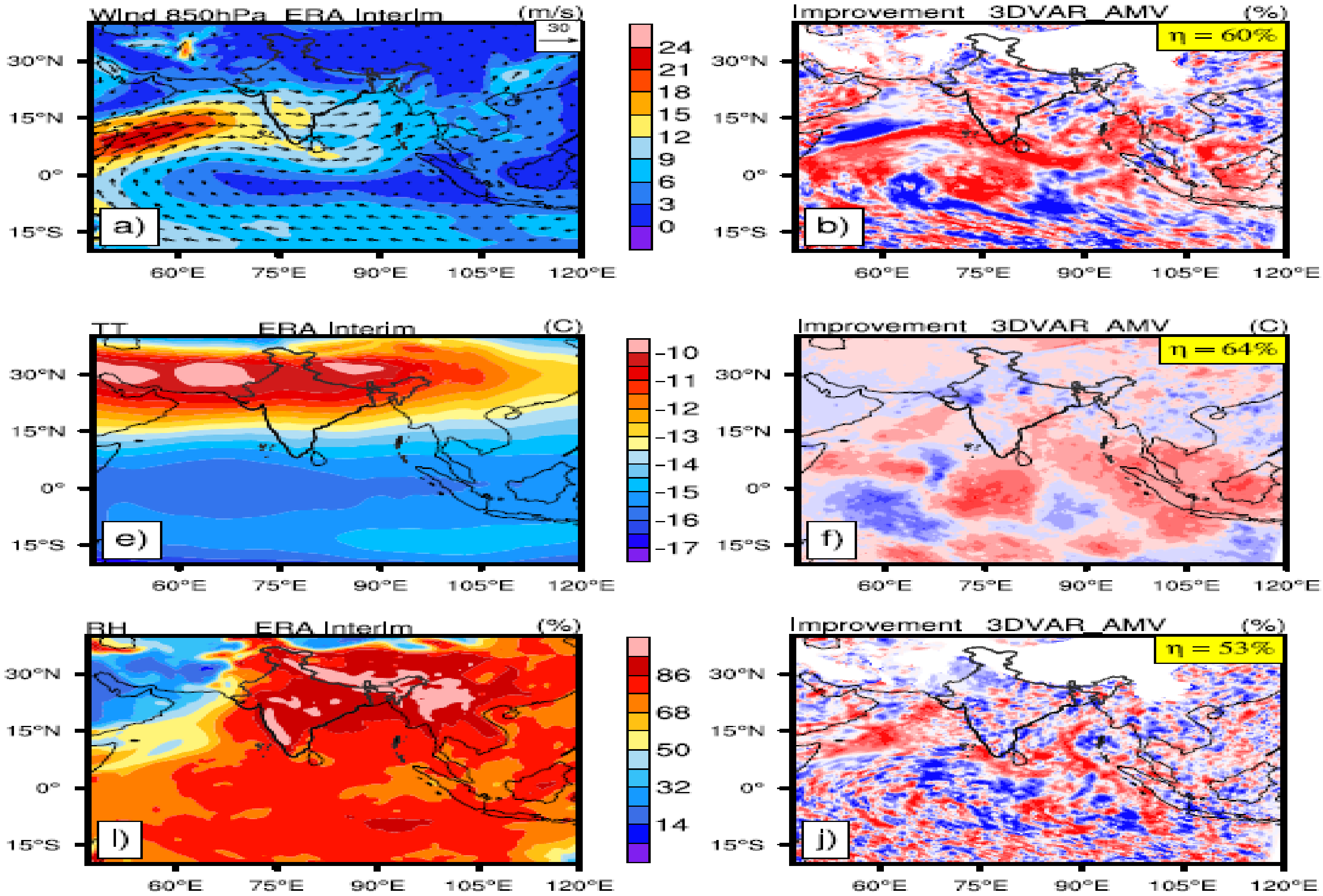
IMPACT OF INSAT-3D RADIANCE DATA ASSIMILATION



Improvement in simulation of various weather parameters using INSAT-3D AMV:



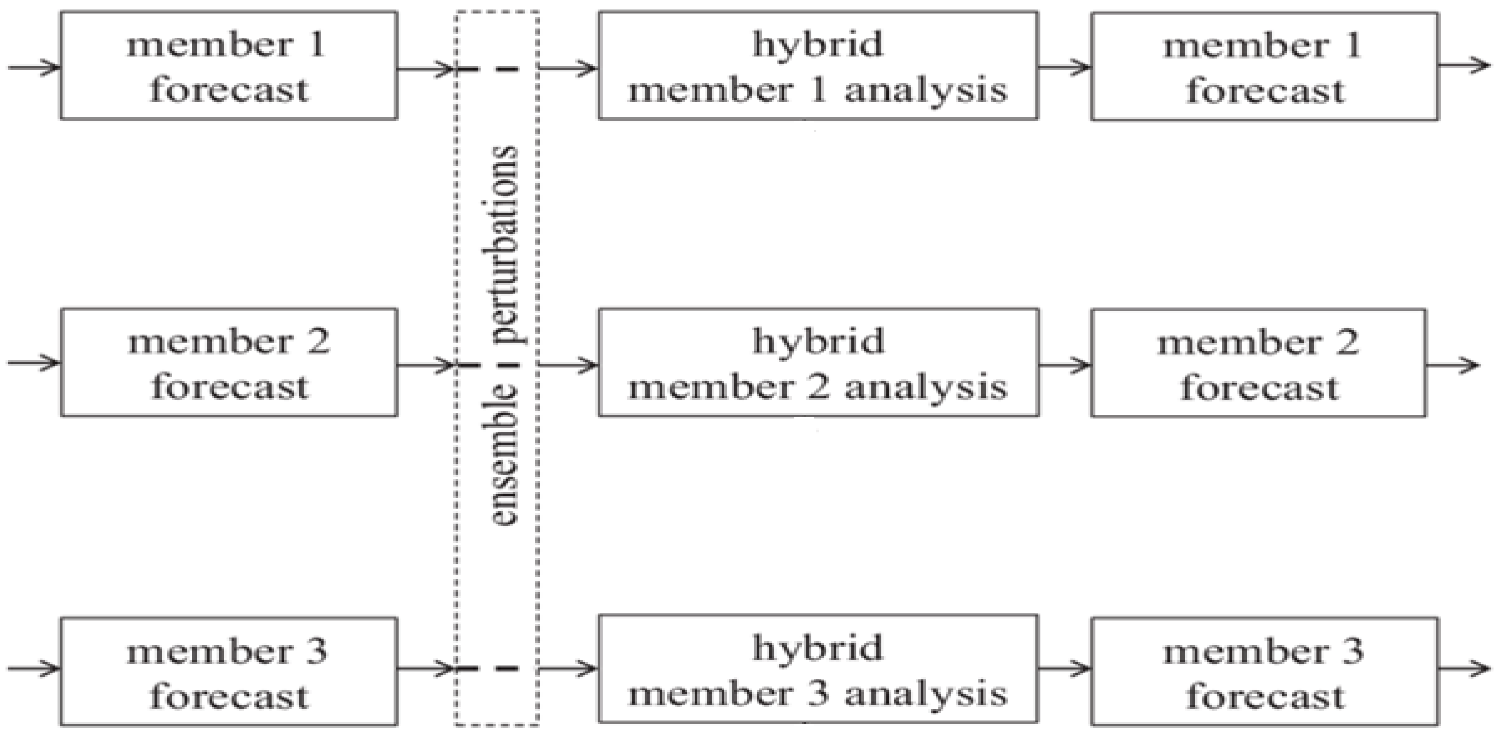


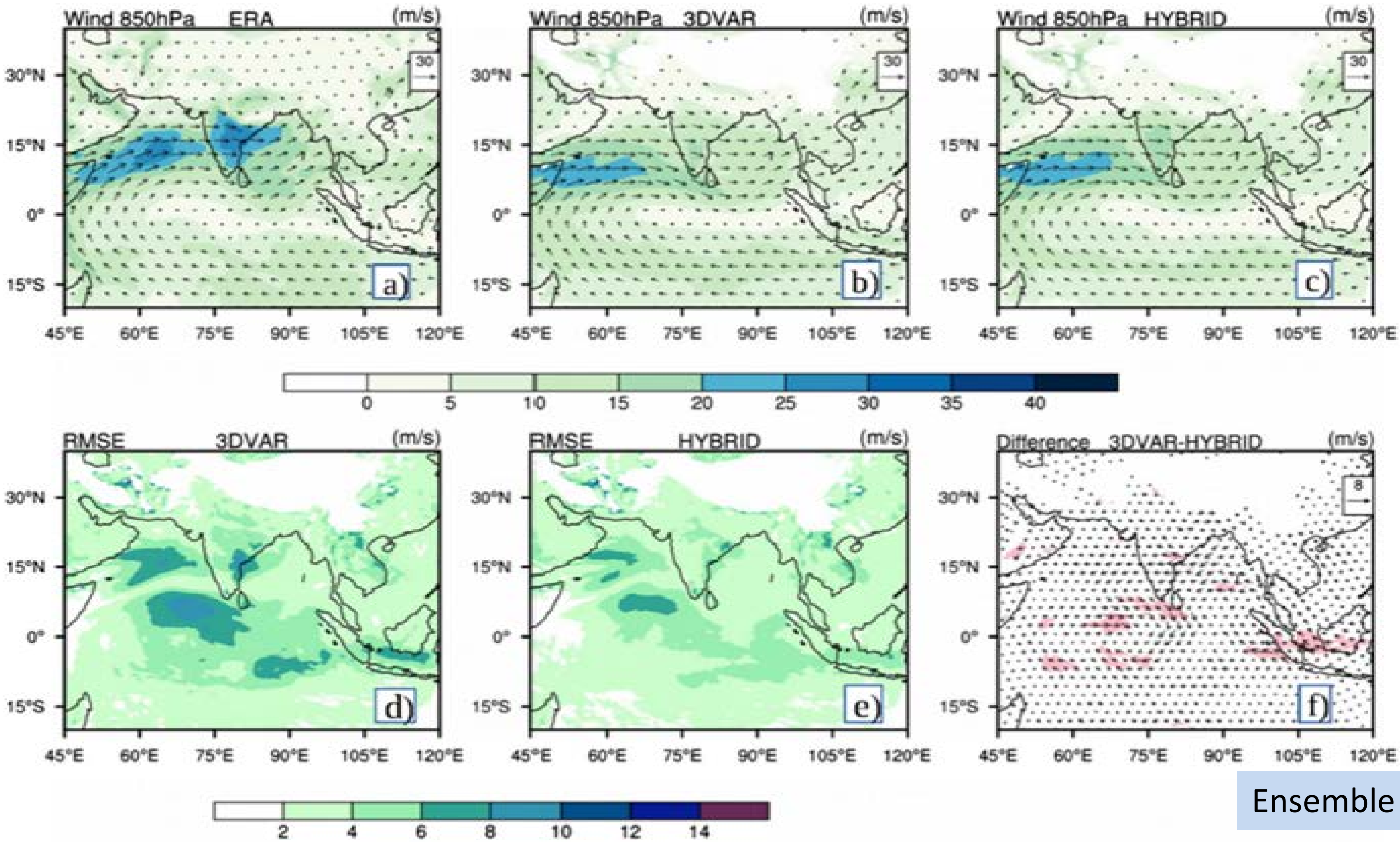


Ensemble-Based Forecast

- NWP model : WRF-ARW
- DA Technique : WRFDA 3DVAR, ETKF/EAKF-3DVAR (Hereafter HYBRID)

The ensemble perturbations are updated using either the ensemble adjustment Kalman filter (EAKF) or Ensemble Transform Kalman Filter (ETKF) available in the DART module. The EAKF DA system updates the forecast ensemble perturbation.



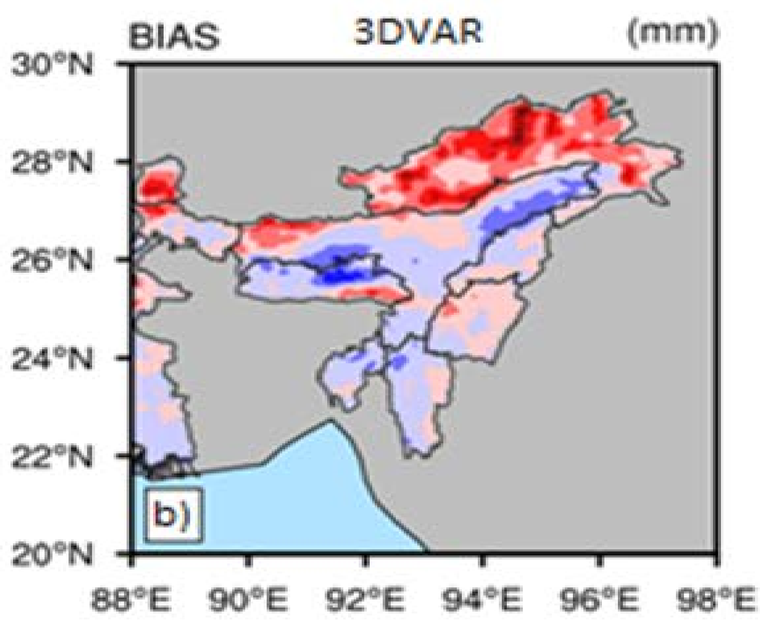


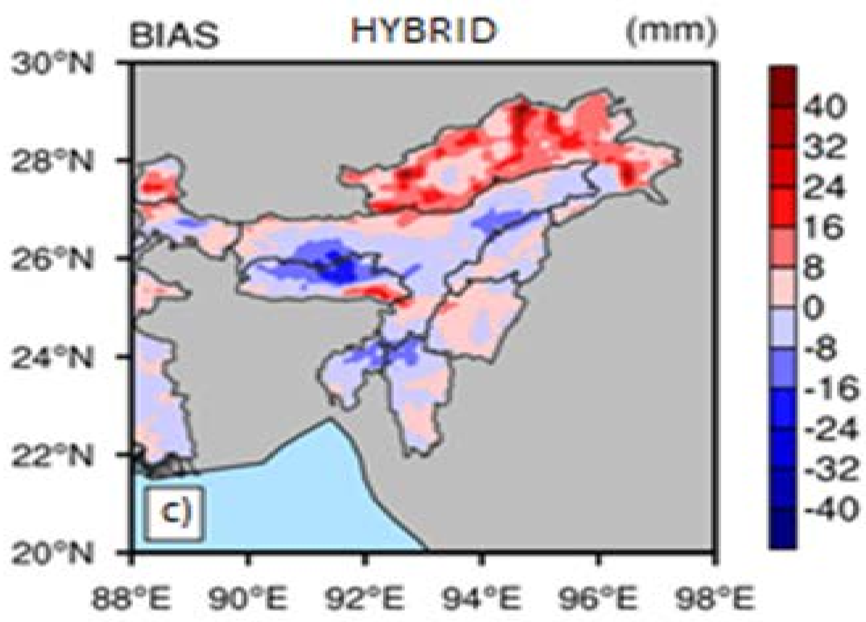
Ensemble Member: 50

- The magnitude of westerly wind over the peninsular Indian landmass in 3DVAR is considerably lower than that in Hybrid experiments. This could be the reason for enhanced dry bias observed over the Indian landmass in 3DVAR experiments as compared to Hybrid experiments.

- RMSE in simulated wind fields is generally higher in the 3DVAR than the Hybrid experiments.

Validation of Rainfall over NER



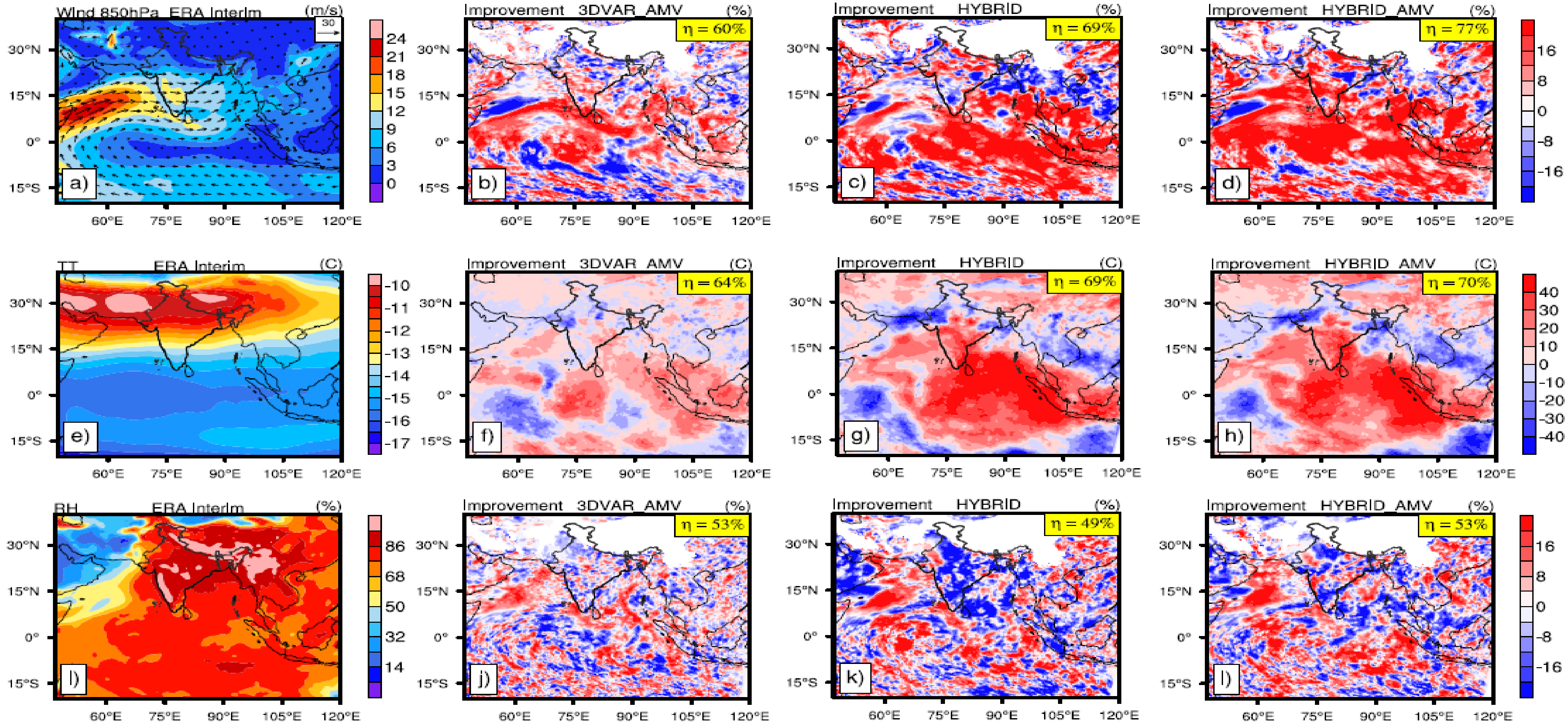


- Figure shows Bias of monthly averaged (July) 24-h forecasted rainfall (mm/day) at 9 km resolution with respect to GPM rainfall
- The significant wet bias of the model simulated 24-h rainfall forecast with respect to GPM rainfall observed in 3DVAR for NER of India is considerably reduced in HYBRIID experiment mainly in western Assam and slightly reduced over Arunachal Pradesh
- Hybrid experiments have shown better skills in quantitative precipitation forecast (QPF) both at regional-scale and convective-scale during the ISM

OBJECTIVE : Identifying the difference in the impact of INSAT-3D Atmospheric Motion Vectors when ensemble error covariance is used in 3DVAR framework on the forecasts of Indian summer monsoon rainfall

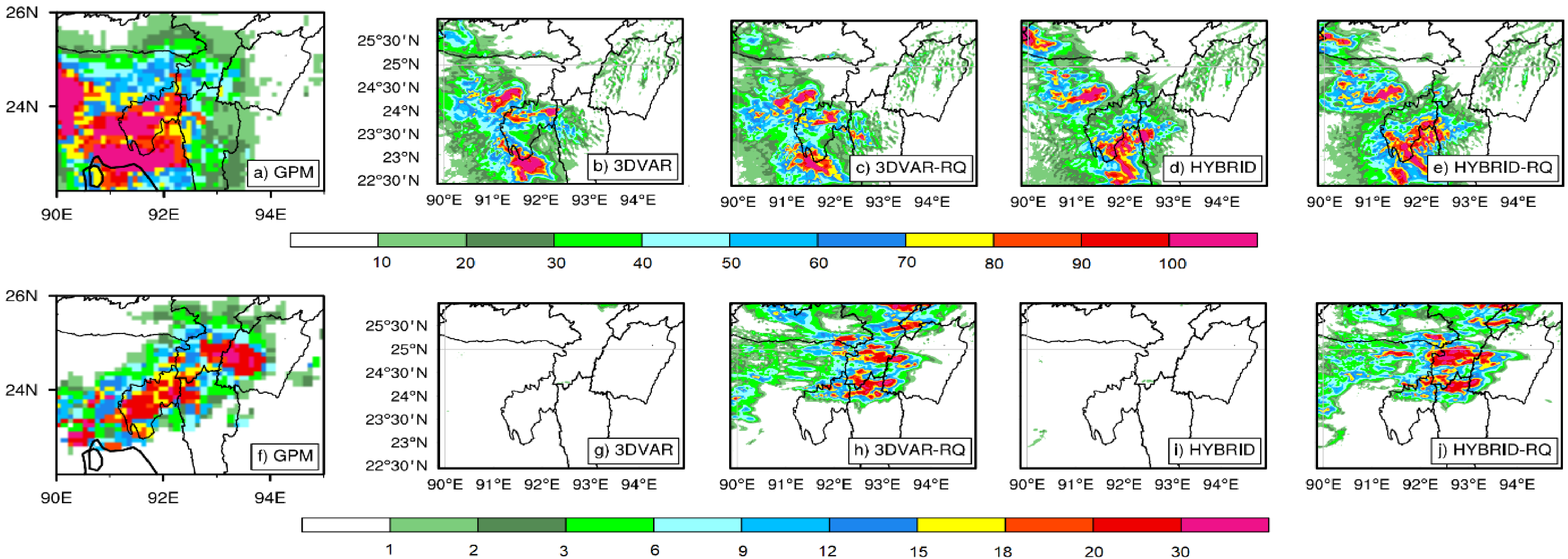
Model Configurationc	
Model Grid	350x350
Resolution	27 km
Microphysics scheme	WRF single-moment five-class (WSM5)
Cumulus Parameterization Scheme	Kain-Fritsch
Longwave radiation	Rapid Radiative Transfer Model (RRTM)
Shortwave radiation	Dudhia
Planetary Boundary Layer	Yonsei scheme

DA method	Data used in DA system	Experiment name
3DVAR	GTS	3DVAR
3DVAR	GTS + INSAT-3D AMV	3DVAR_AMV
HYBRID	GTS	HYBRID
HYBRID	GTS + INSAT-3D AMV	HYBRID_AMV



- The AMV observations show a larger relative impact in HYBRID than in 3DVAR and the relative improvement in comparison to 3DVAR is 77% for wind and 70 % for tropospheric temperature.

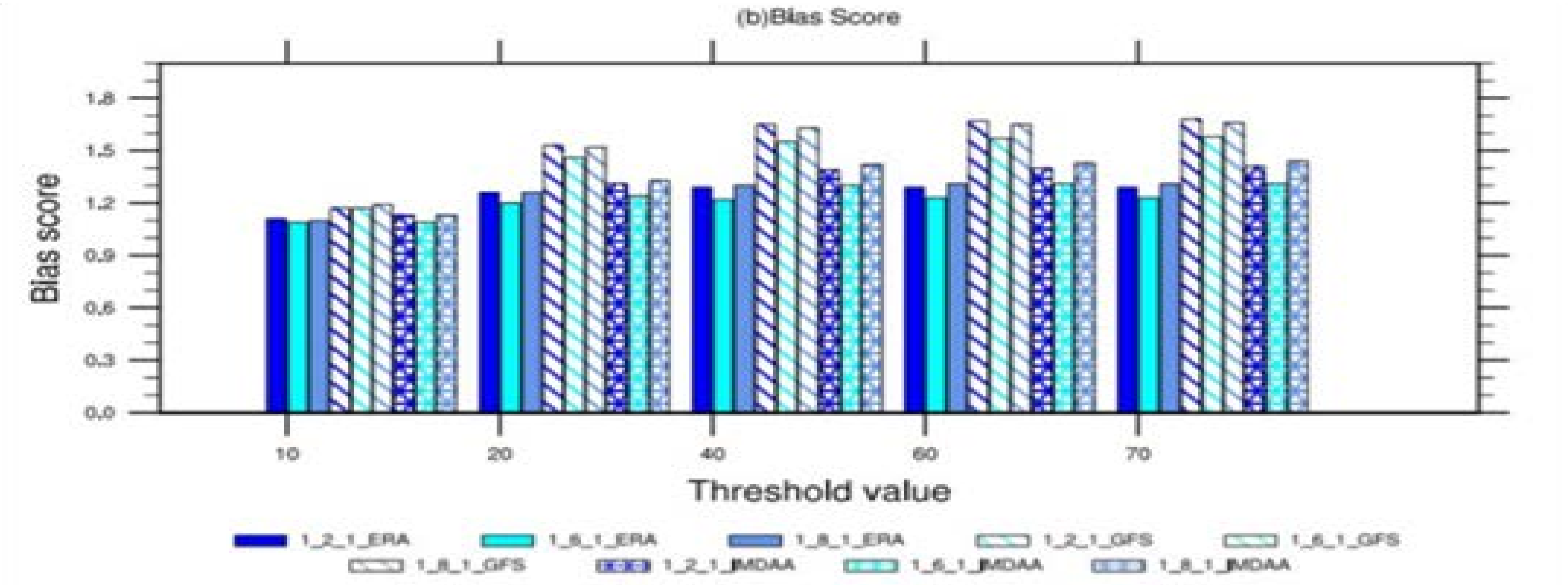
Understanding the role of ensemble error covariance in convection-permitting resolution using Radar data assimilation for heavy rainfall forecasts



a) Accumulated rainfall calculated from GPM data; Model simulated rainfall forecast from b) 3DVAR, c)3DVAR-RQ, d) HYBRID and e) HYBRID-RQ valid from 20170419 12 UTC to 20170420 00 UTC. f) Accumulated rainfall calculated from GPM data; Model simulated rainfall forecast from b) 3DVAR, c)3DVAR-RQ, d) HYBRID and e) HYBRID-RQ valid from 20180330 12 UTC to 20180330 15 UTC. RQ reprents indirect assimilation of radar data

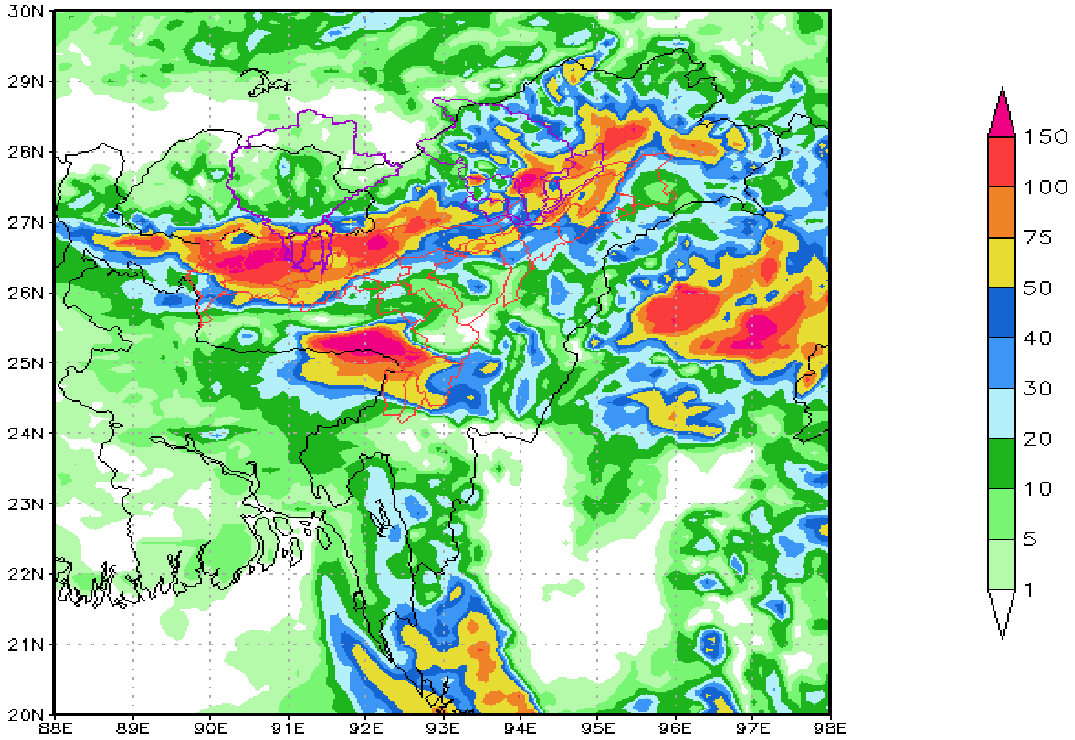
Impact of Initial Condition

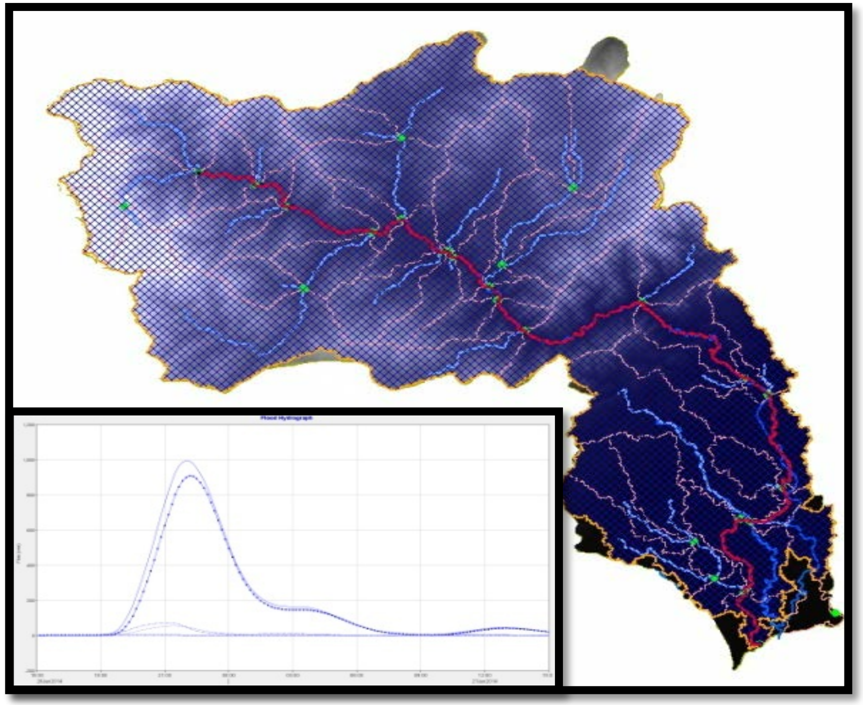
To assess the performance of WRF model using three different reanalysis data for simulation of rainfall over NER : ERA, GFS and IMDAA



GFS shows significant overestimation and relatively poor performance skill compared to ERA and IMDAA.

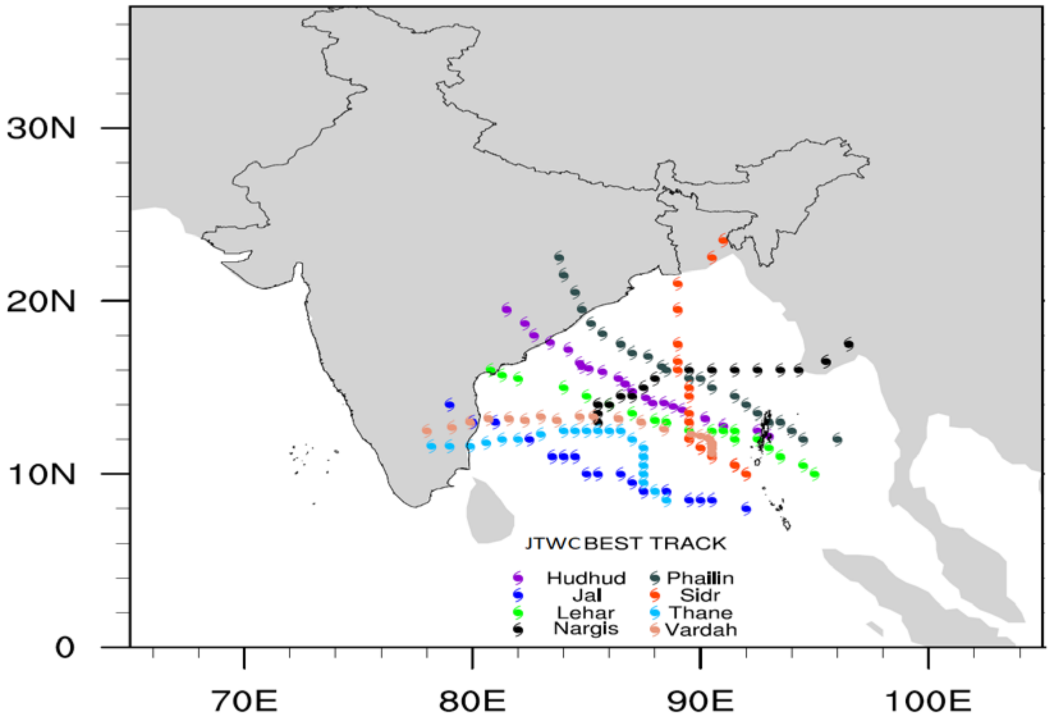
Flood Early Warning System (FLEWS)

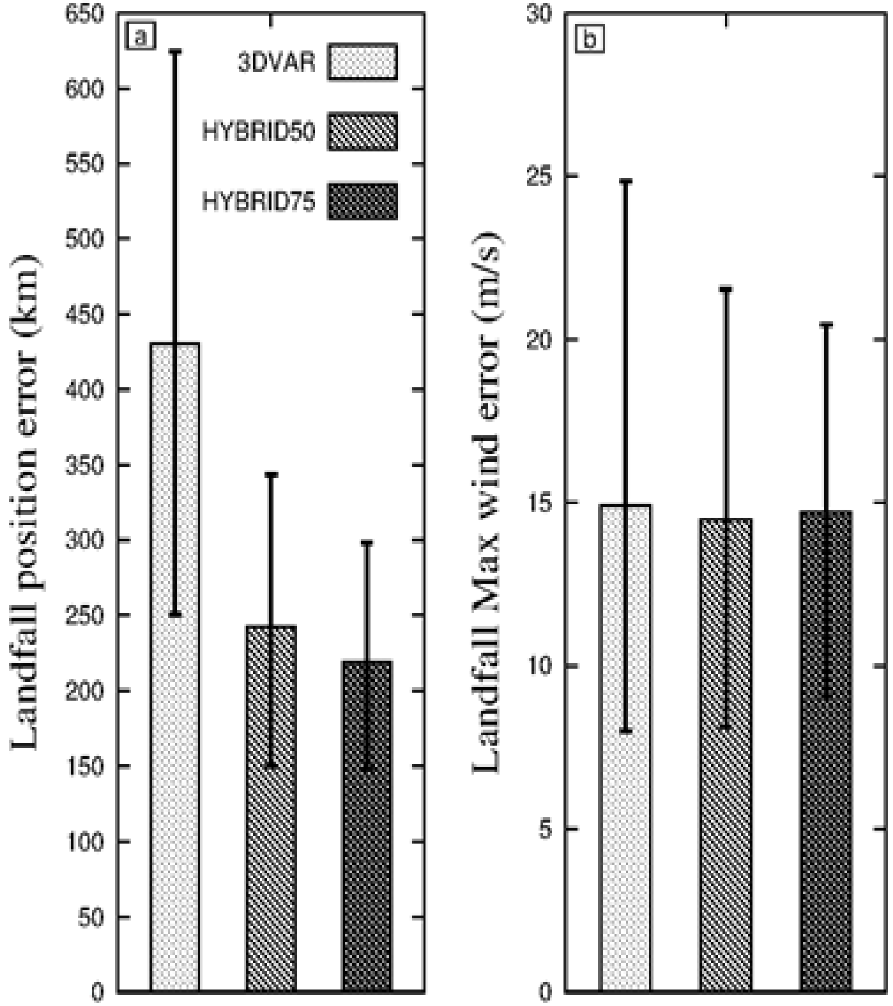




WRF Forecasted Rainfall as an input to Hydrological Model

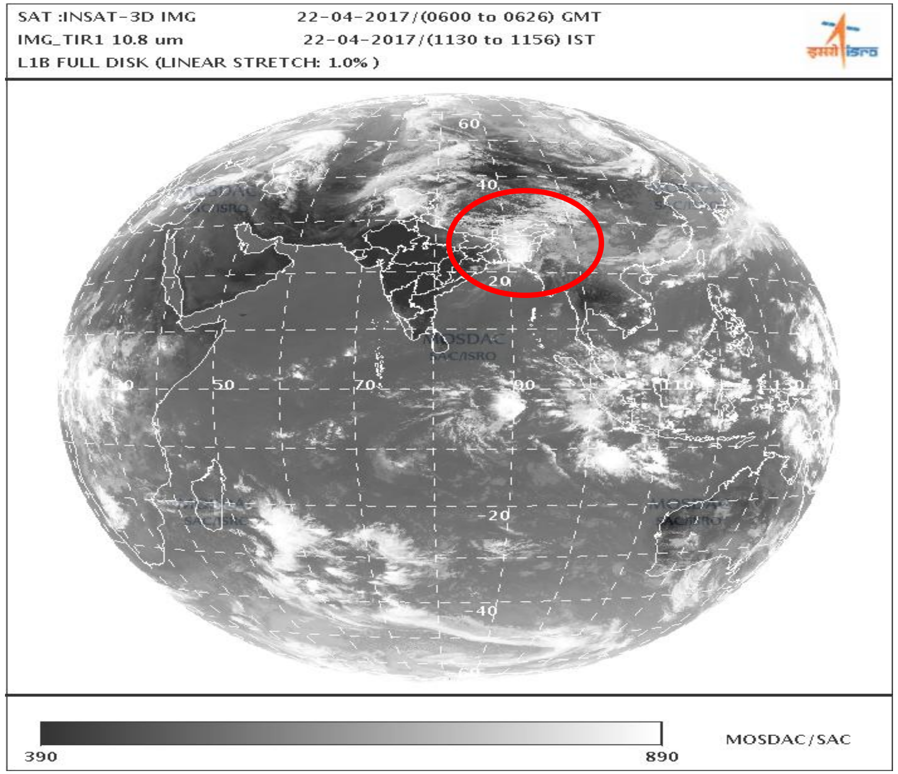
OBJECTIVE : **Quantifying the Impact of flow-dependent ensemble error covariance on the forecast of land-falling tropical cyclones formed over the Bay of Bengal**

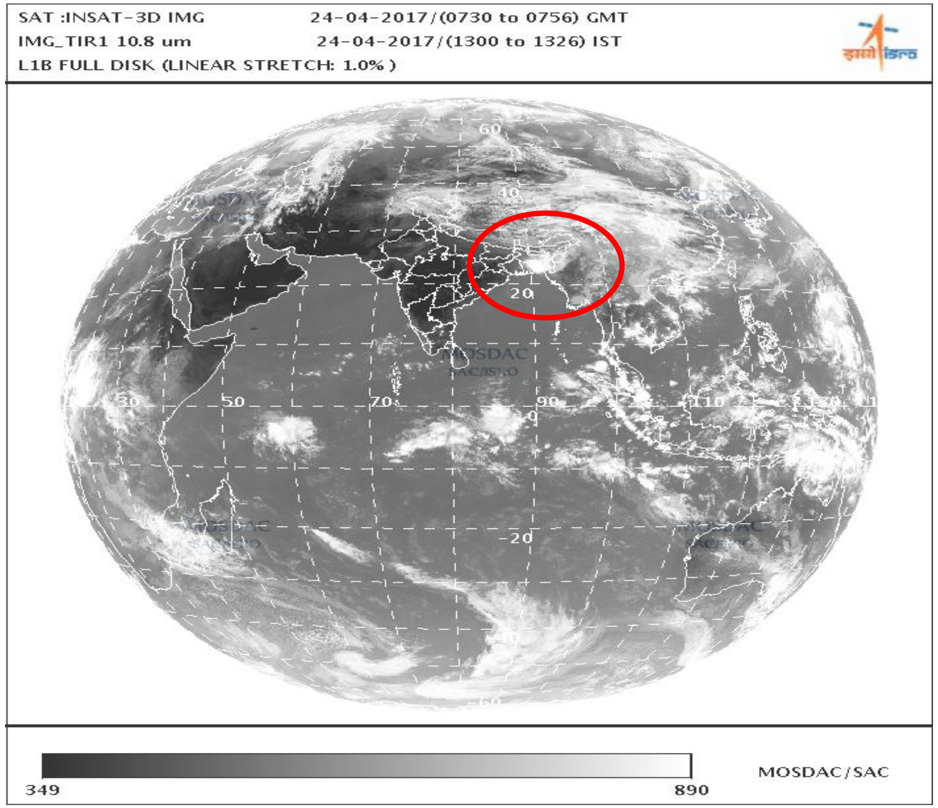




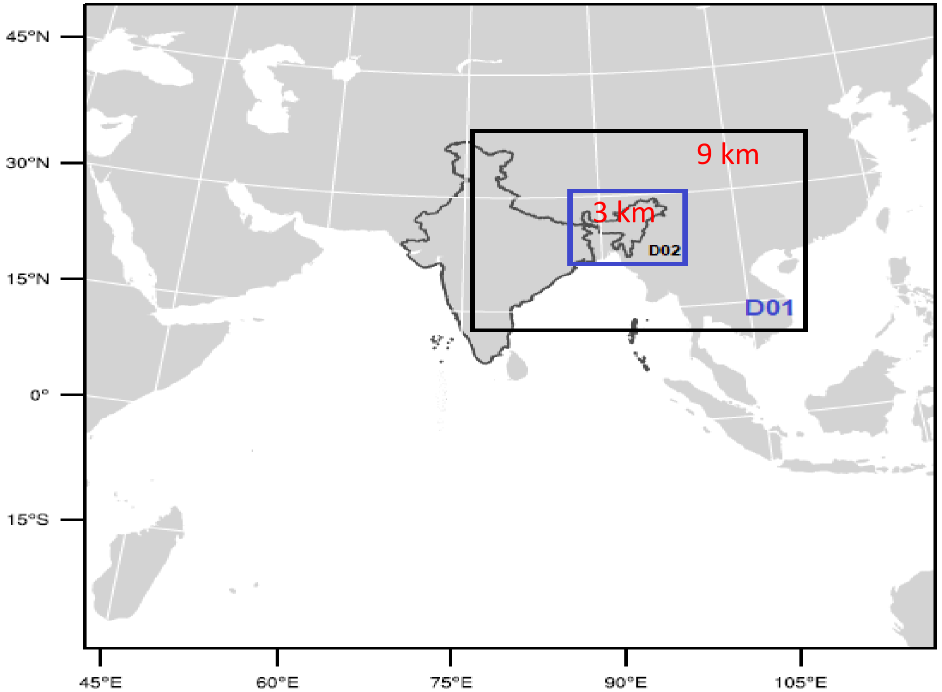
Performance Evaluation of Flow-Dependent error covariance in 3DVAR Data Assimilation system in the Simulation of Pre-monsoon Thunderstorm event over NER

Thunderstorm events occurred over NER during 22nd April 2017 and 24th April 2017 respectively





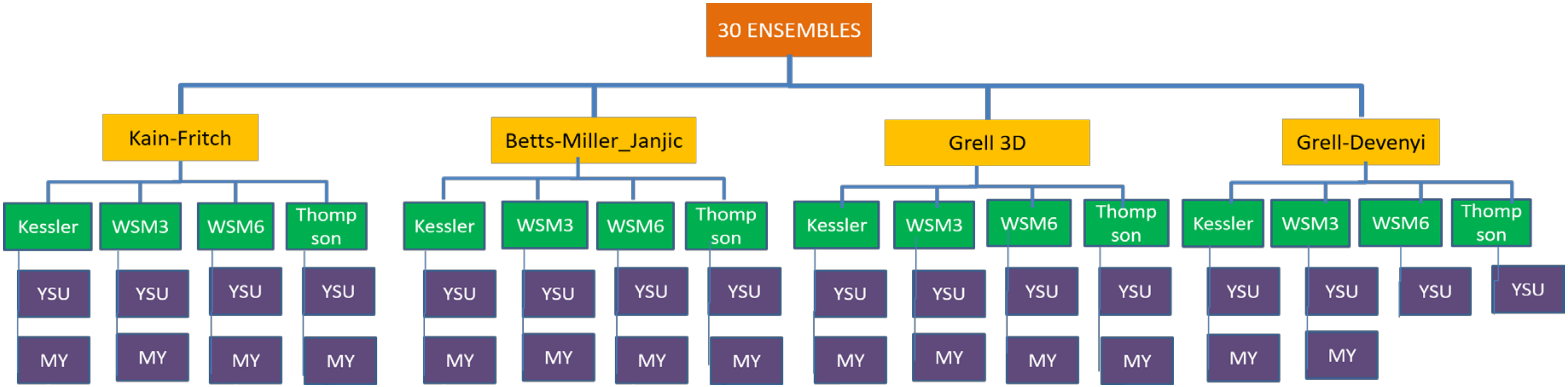
The first experiment conducted was the Hybrid-Single, which is the main experiment conducted to find out how much better is the hybrid data assimilation scheme compared to the conventional 3DVAR scheme with a single set of parameterization schemes



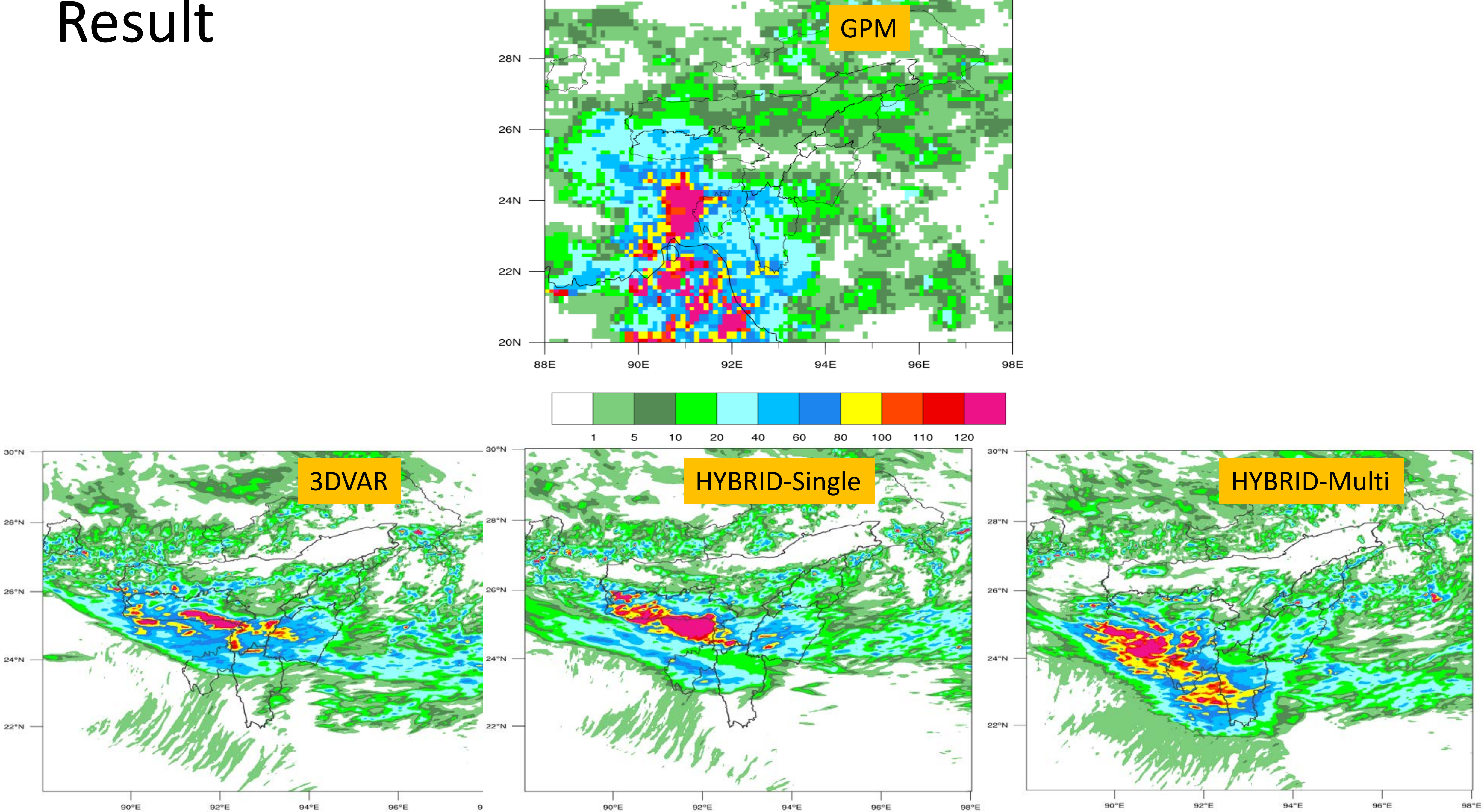
Model Configuration	
Model Grid	346x262,415x367
Resolution	9, 3 km
Microphysics scheme	WRF single-moment six-class (WSM6)
Cumulus Parameterization Scheme	Kain-Fritsch
Longwave radiation	Rapid Radiative Transfer Model (RRTM)
Shortwave radiation	Dudhia
Planetary Boundary Layer	Yonsei scheme

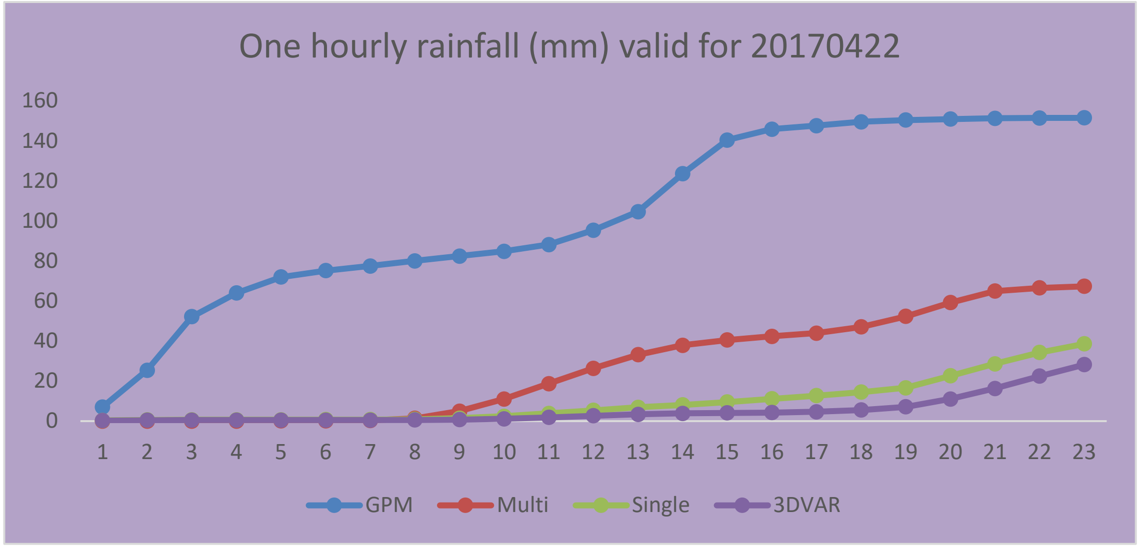
To avoid the spin-up issues, the ensembles are initialized at 1800UTC 21 April 2017, 6 h prior to the first analysis time, by adding 30 random perturbations from WRF 3DVAR

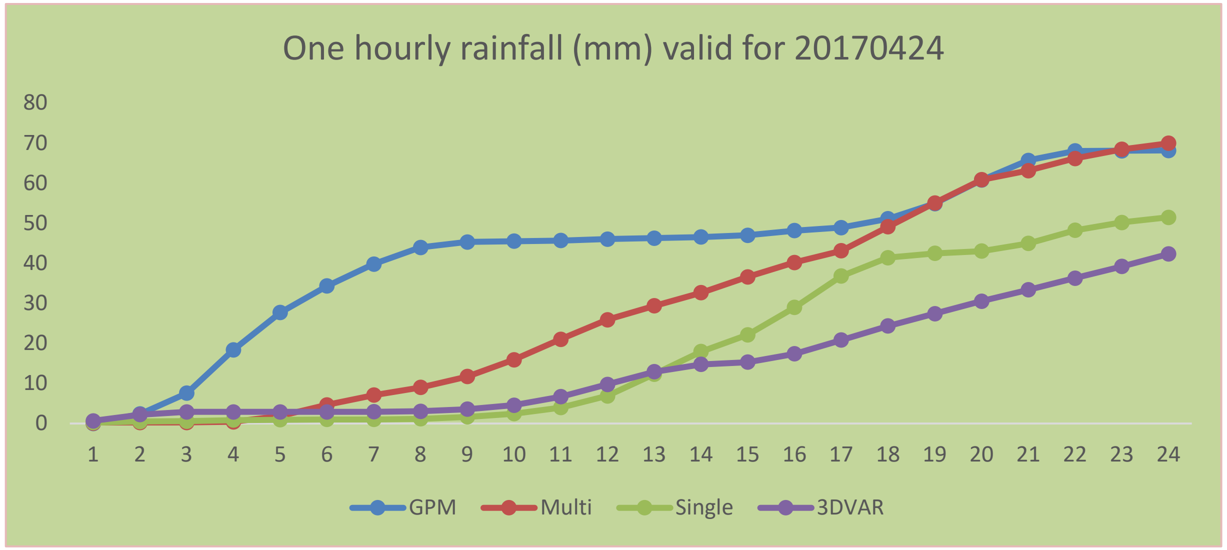
The experiment Hybrid-Multi is called so because the ensembles use different parameterization schemes for forecast from one point to another. Each ensemble will have a unique set of Microphysics, Cumulus and Planetary boundary layer (PBL) schemes.



Result

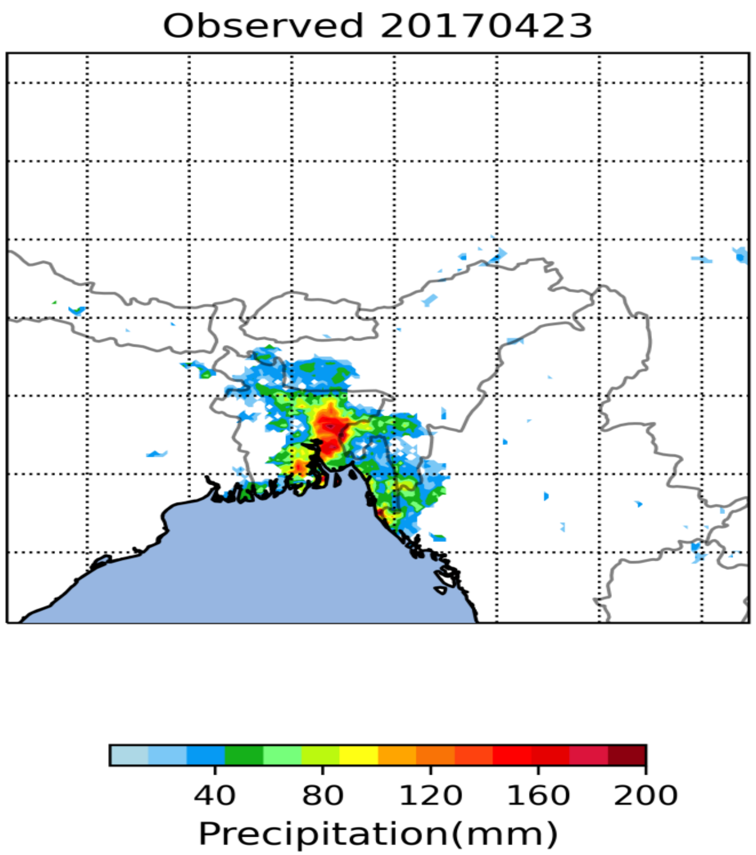

GPM
28N
26N
24N
22N
20N
88E
90E
92E
94E
96E
98E
1
5
10
20
40
60
80
100
110
120
3DVAR
HYBRID-Single
HYBRID-Multi
30°N
28°N
26°N
24°N
22°N
90°E
92°E
94°E
96°E
98°E

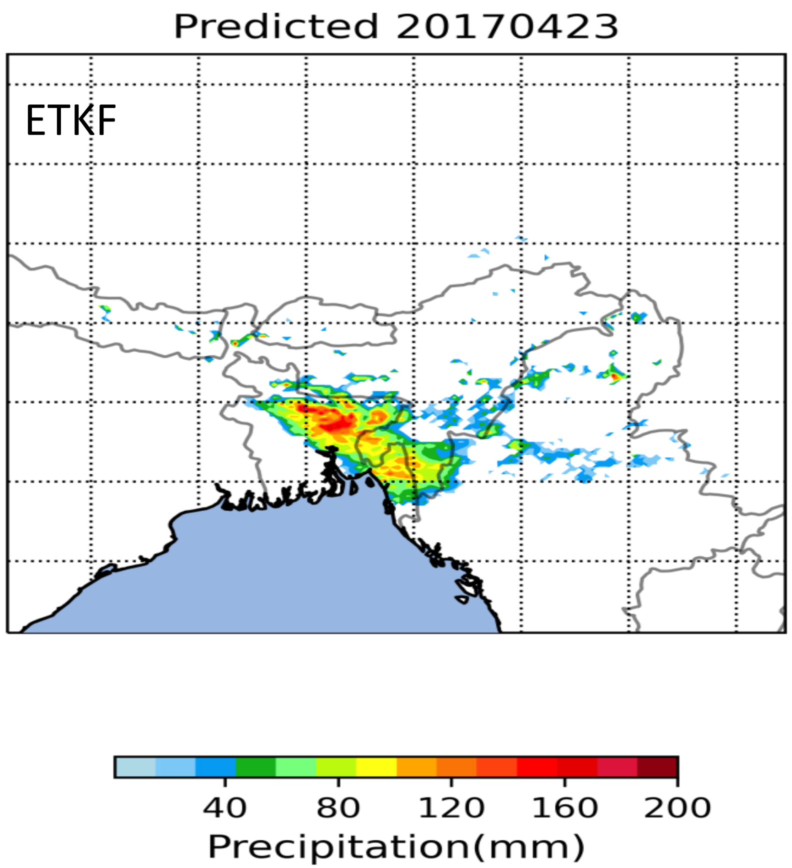


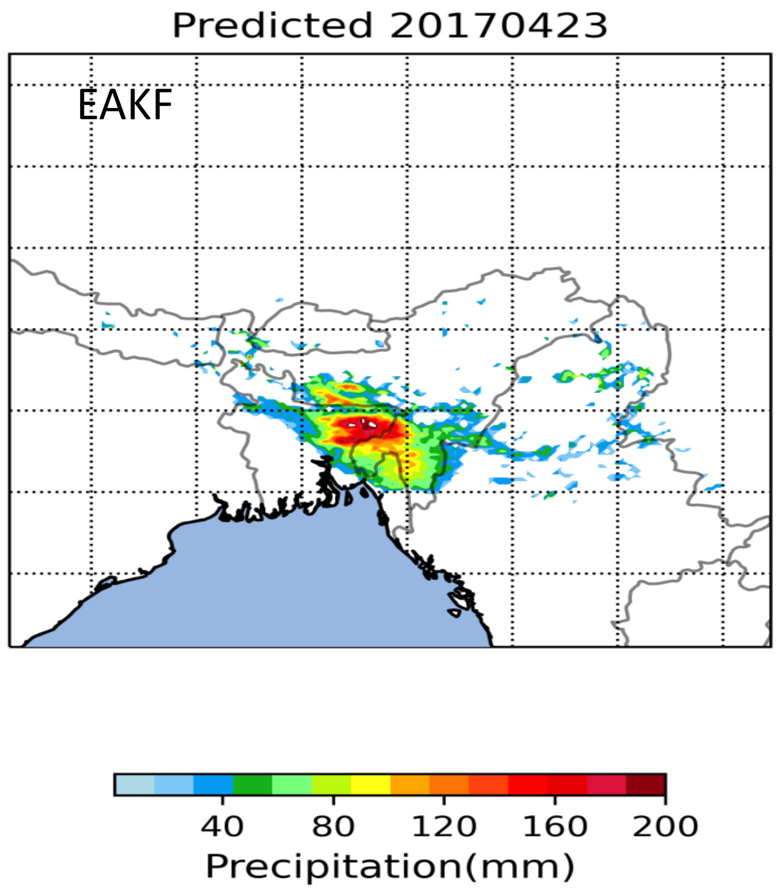


- The assimilation experiments reveal superior performance of HYBRID in comparison to 3DVAR
- Further, inclusion of model error improves the HYBRID rainfall forecast.
- One hourly rainfall forecast shows significant improvement using multi-physics schemes for ensemble generation in comparison to single-physics scheme based ensembles.
- The early hour rainfall prediction is very crucial for thunderstorm forecast. However, not a single experiment could predict the early hour rainfall. Assimilation of radar data may improve the result
- One significant difficulty with high resolution model simulation is the scarcity of observed data for one to one validation

Comparison between WRF-ETKF and EAKF

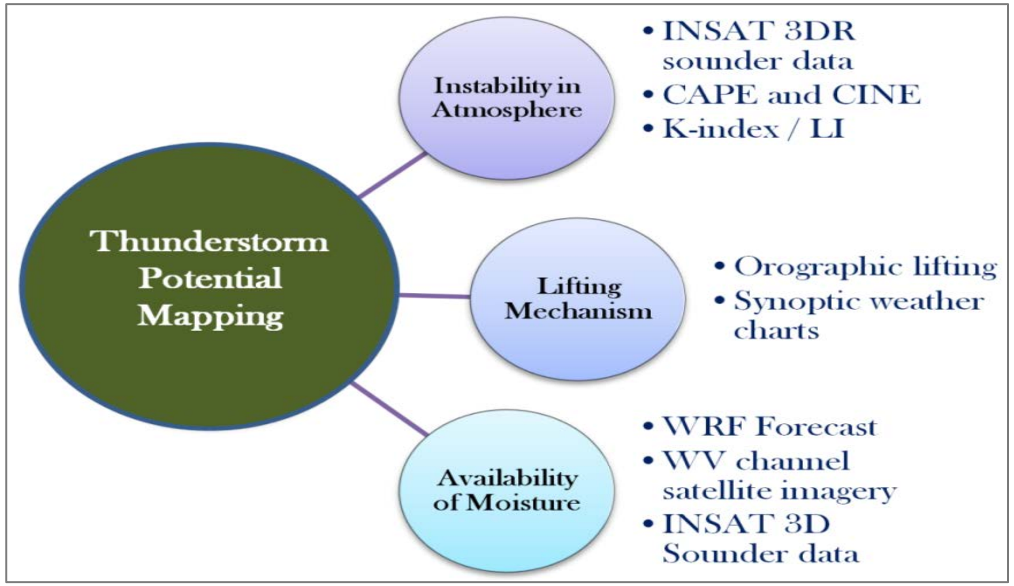


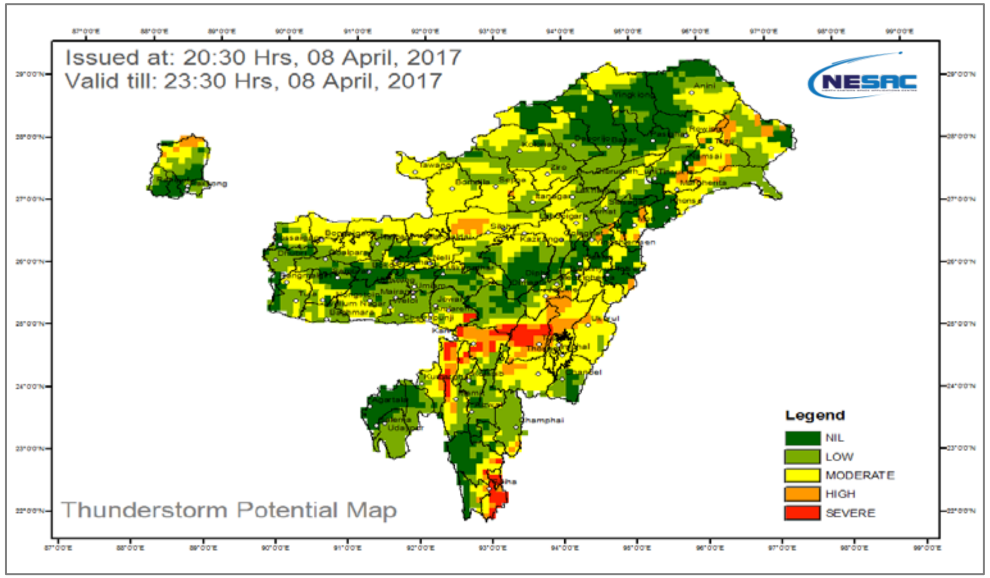




Thunderstorm nowcasting for NER at NESAC

Thunderstorm nowcasting is done for the entire NER of India using the DWR, Satellite, and AWS data supported with WRF forecast.

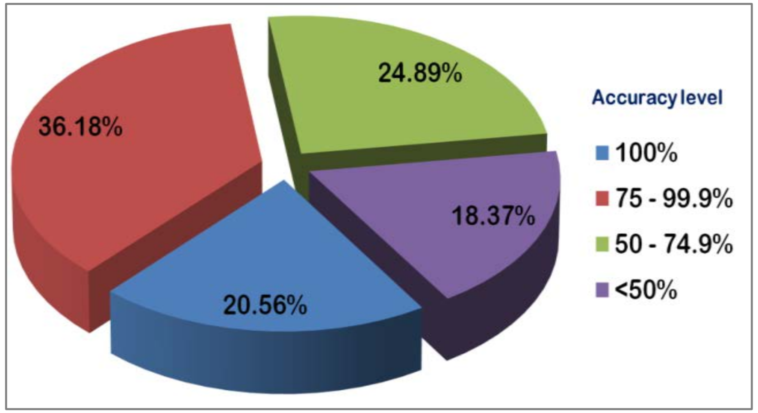


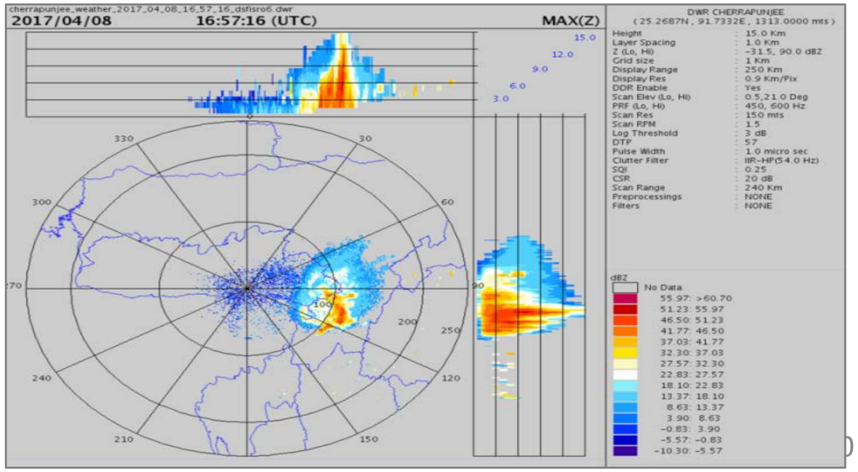


Thunderstorm Potential map prepared on 8 April, 2017.

A severe thunderstorm developed over the southern Assam region and travelled to Manipur as seen in the DWR image

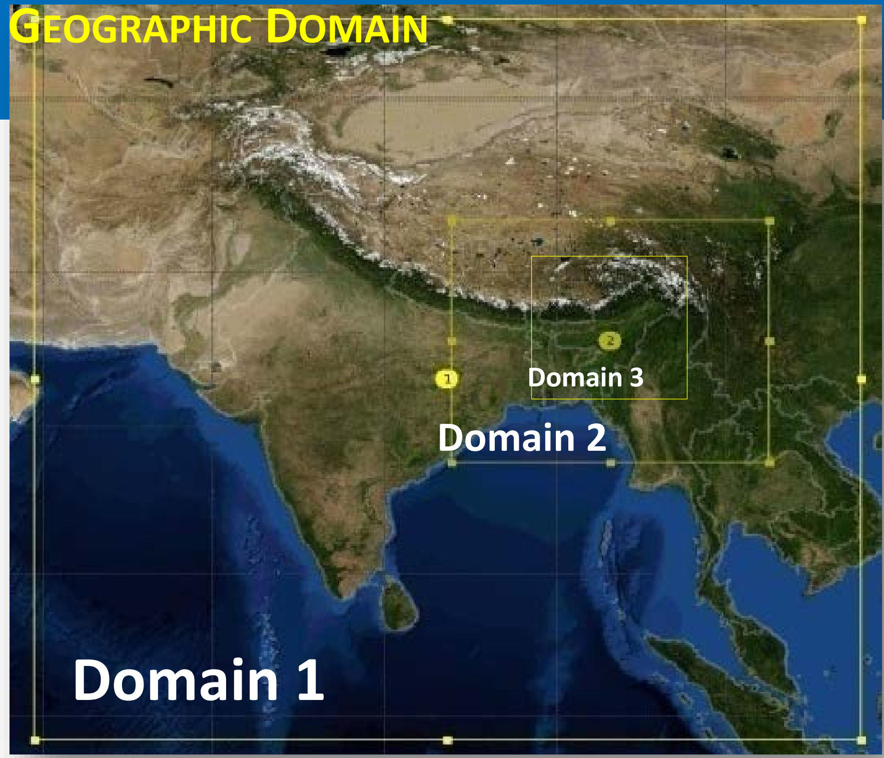
- o 3 maps daily. 3 hrs lead time.
- o March 15 – June 15 period
- o Communication to SDMA, DC
- o Probability of detection: 0.89
- o False alarm ratio: 0.46





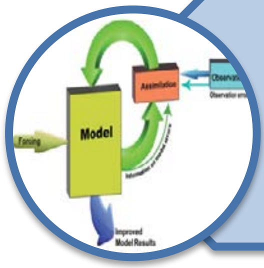
Lightning nowcasting over NER using NWP model

- Numerical Weather and Lightning Prediction over NER of India is done using the WRF-ARW and WRF-ELEC model.
- The lightning data from IITM lightning detection network is assimilated in the WRF-ELEC model.



Increased Resolution

- 27:9:3 km (planned for 1 km)
- 1 hour time integration
- 12/6 hours forecast



Data Assimilation

- AWS, Satellite, **Lightning data**
- 3DVAR, 4DVAR technique
- Ensemble Kalman Filter

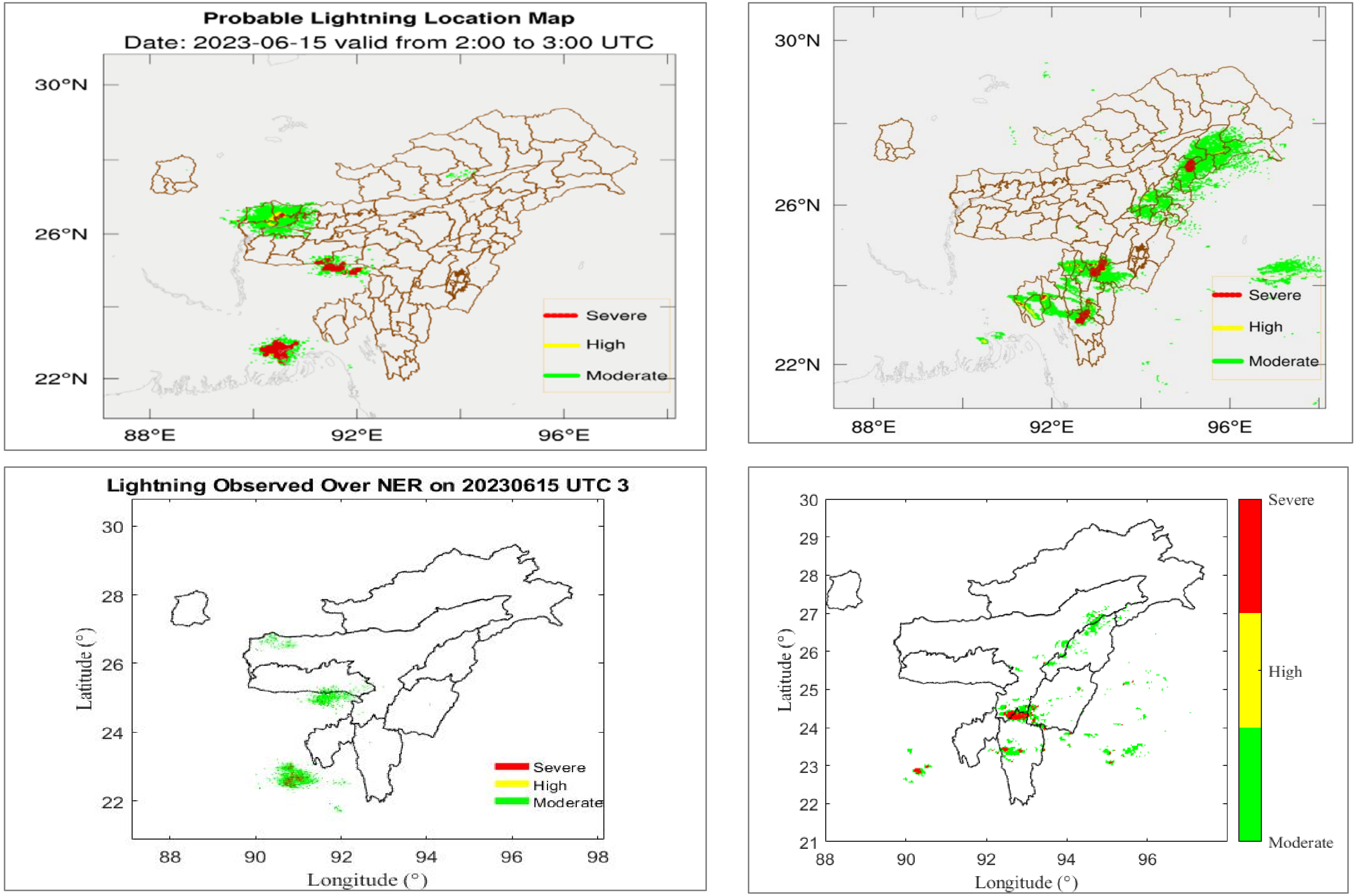
Validation

- IITM, NRSC and WWLLN data.
- AWS data, INSAT 3D/3DR, GPM
- DWR data

Table 1 Configuration details to run the E-WRF with WRF-ARW

Horizontal resolution	27 km, 9 km, and 3 km
Number of vertical levels	35
Time steps	30 s
Simulation duration	18 h
Planetary boundary layer scheme	MYJ (Janjic 1994)
Long-wave radiation scheme	RRTM (Mlawer et al. 1997)
Shortwave radiation scheme	Dudhia (Dudhia 1989)
Microphysics scheme	NSSL two-moment microphysics scheme (Mansell et al. 2010)

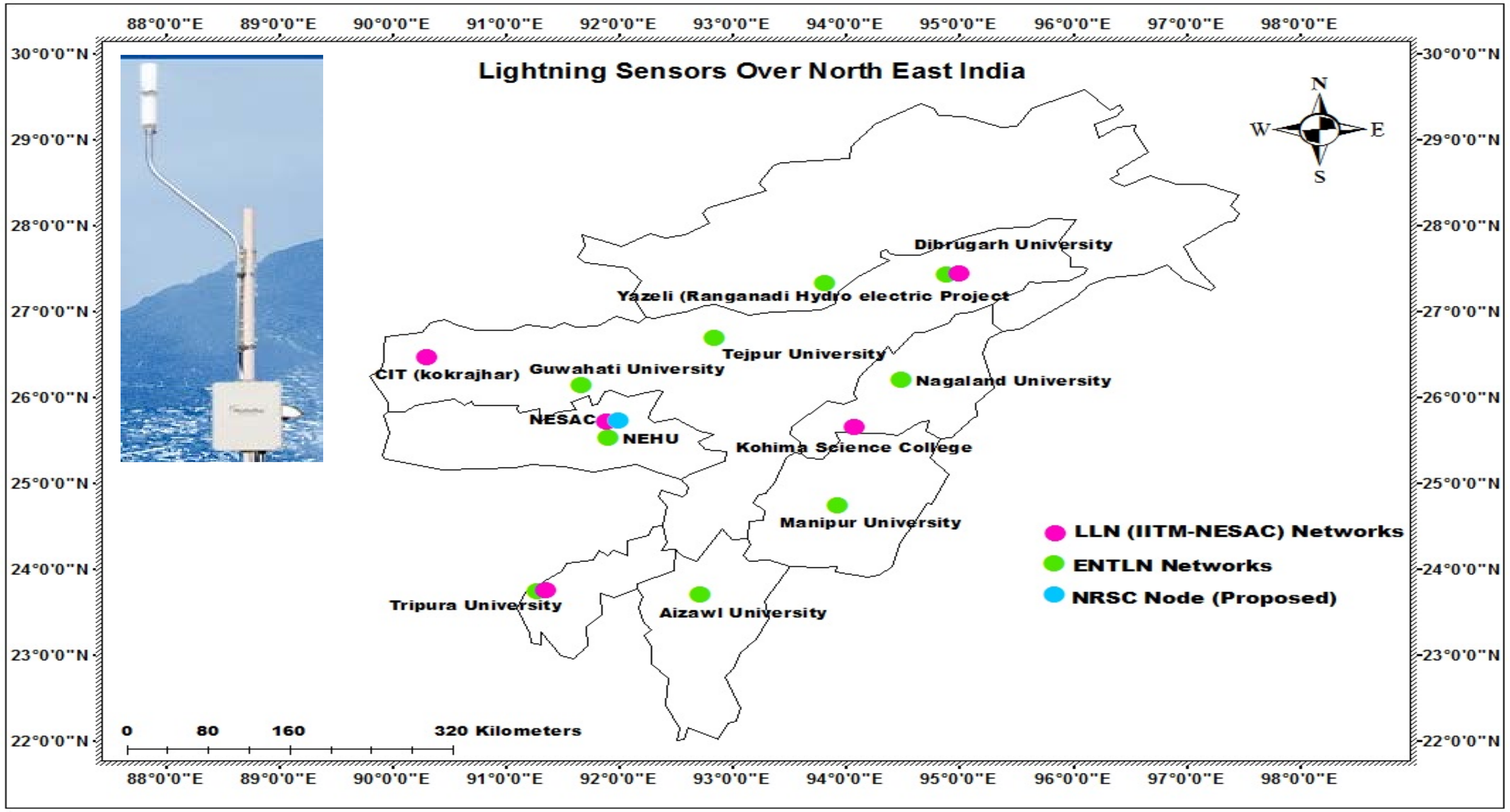
WRF-ELEC based forecast and comparison with observation



- The lightning patches are forecasted well using the WRF-Elec model and by assimilating the ground based lightning data in the model.
- The accuracy is actionable upto 4 hours

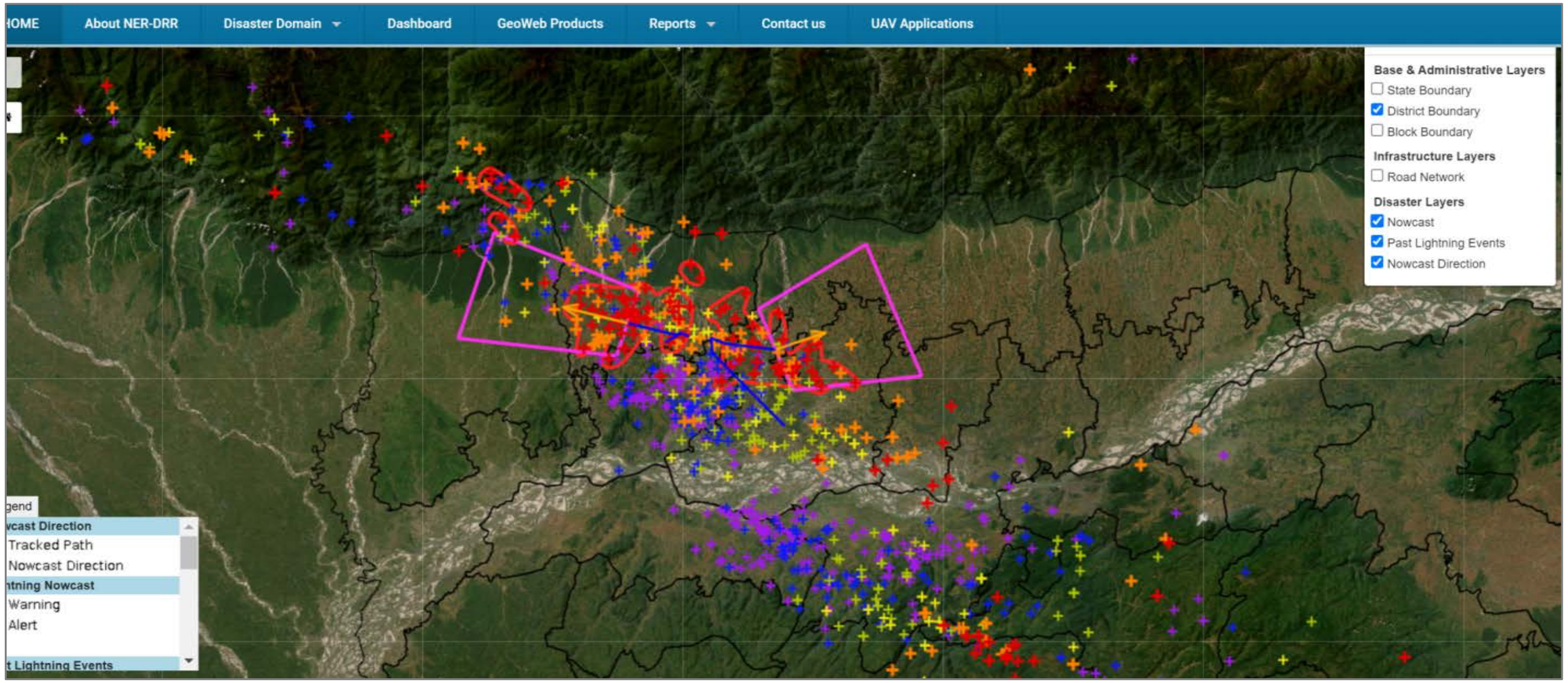
Ground based Lightning detectors

- Lightning detectors have been set up in NER by the IITM, Pune and NRSC, Hyderabad with support from NESAC.
- NESAC utilizes the data from IITM as well as NRSC network for developing early warning systems.
- The data from lightning detectors and Doppler Weather Radars when assimilated in numerical weather forecasting models, could improve the lightning and severe storm early warning over India



Development of location based lightning nowcasting system for NER of India

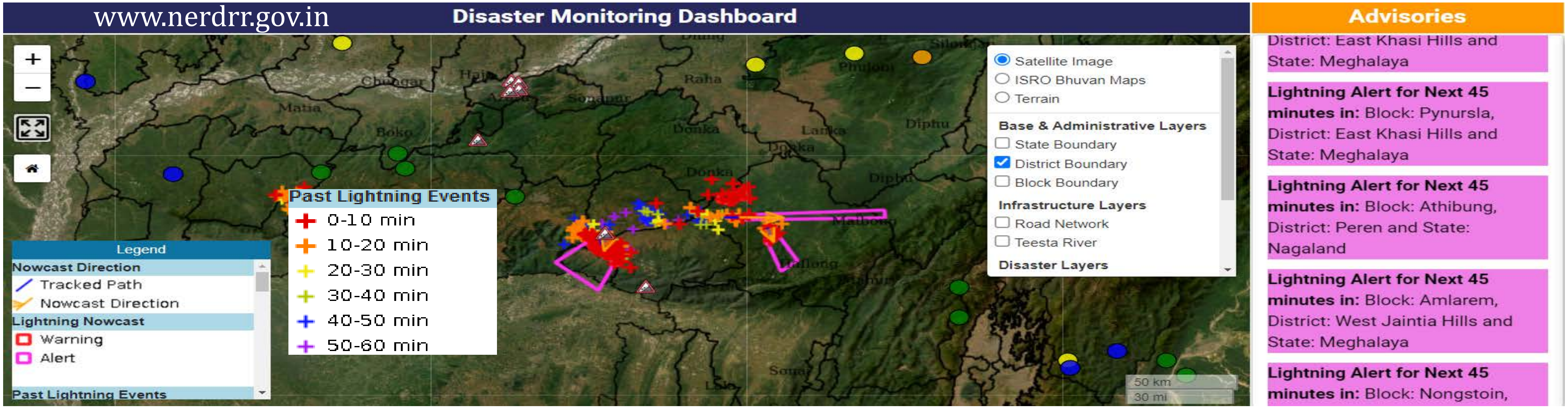
- The lightning data from IITM-LLN has been used to develop an algorithm to identify severe convective systems and tracking them.
- All storm cells are tracked and their movement is forecasted for next 45 minutes.
- Efforts are being made to forecast the list of villages that will be affected by severe storm and lightning with 45 minutes lead time.
- The system is refreshed every 5 minutes

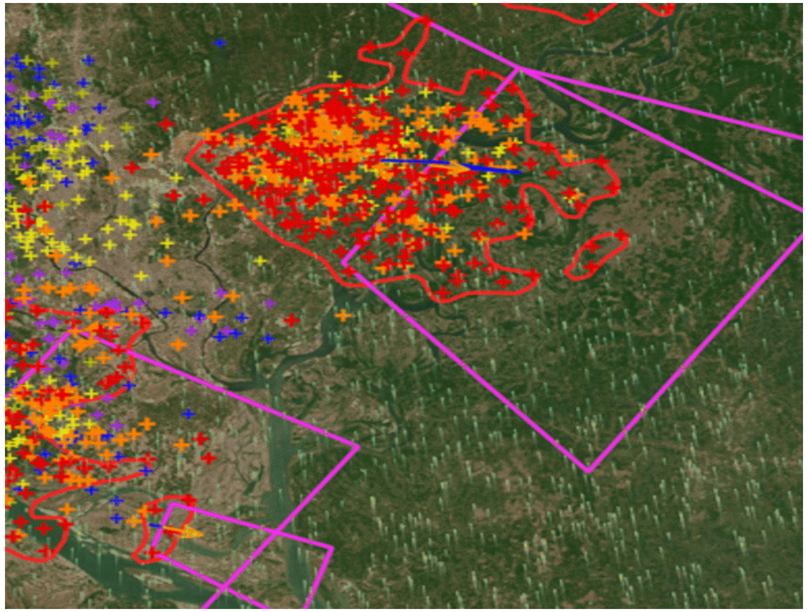


The severe weather tracking system in NER-DRR webportal

Thanks to IITM for sharing of real time data

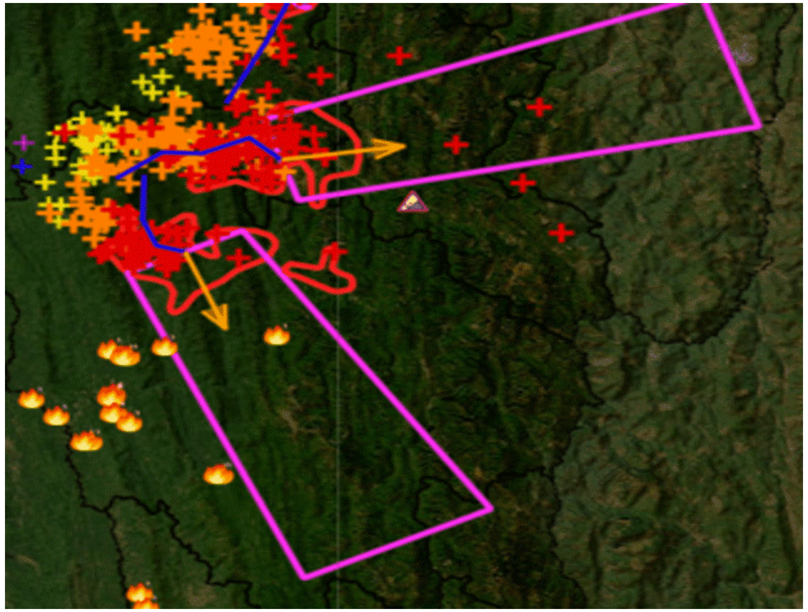
Development of location based lightning nowcasting system for NER of India



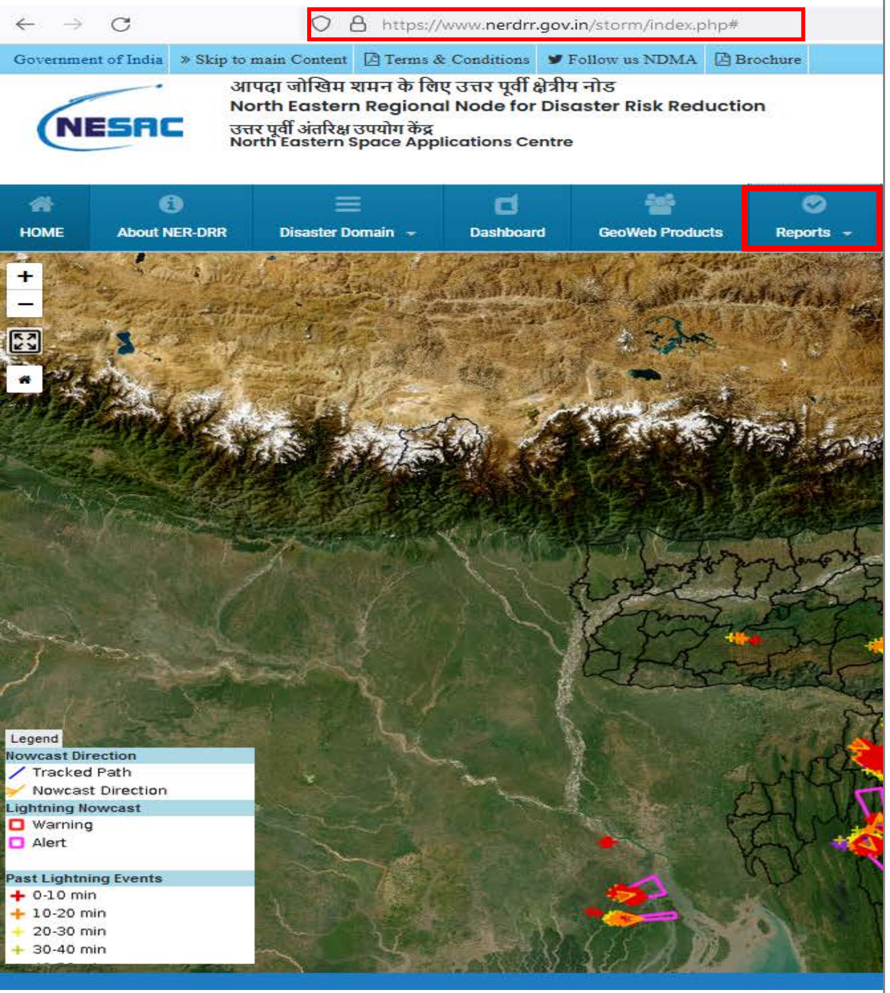


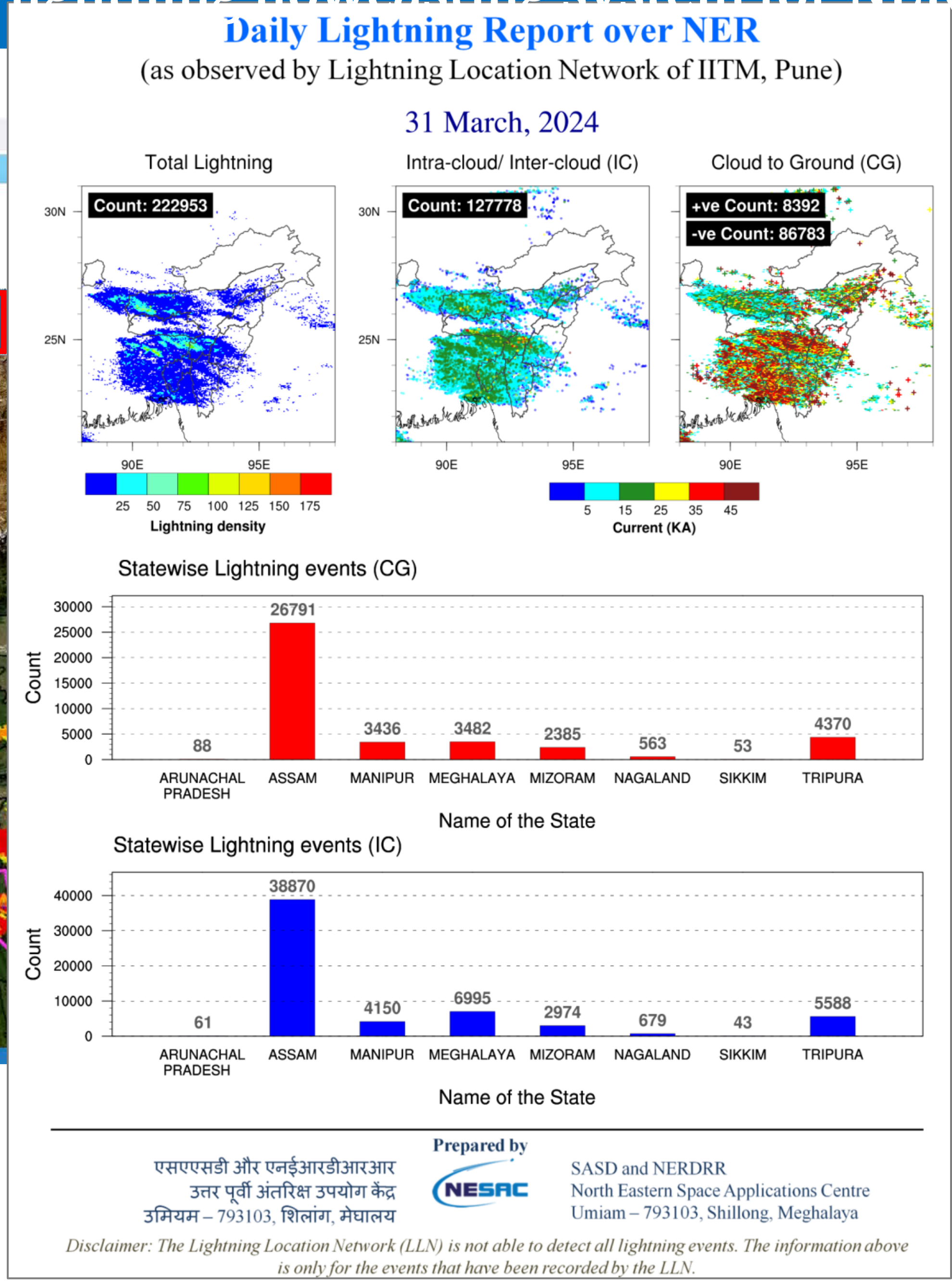
Silent Features

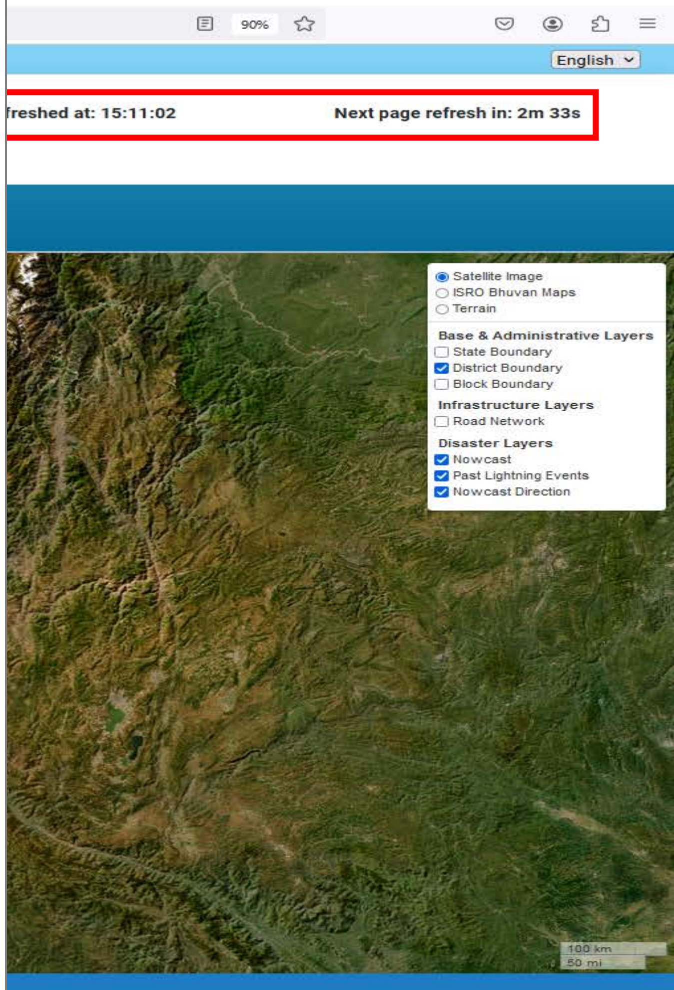
- Real time display of lightning locations
- Capable to quickly identify thunderstorm cell merging and splitting
- 45 minutes lead time
- Block level alert
- Daily Lightning Report



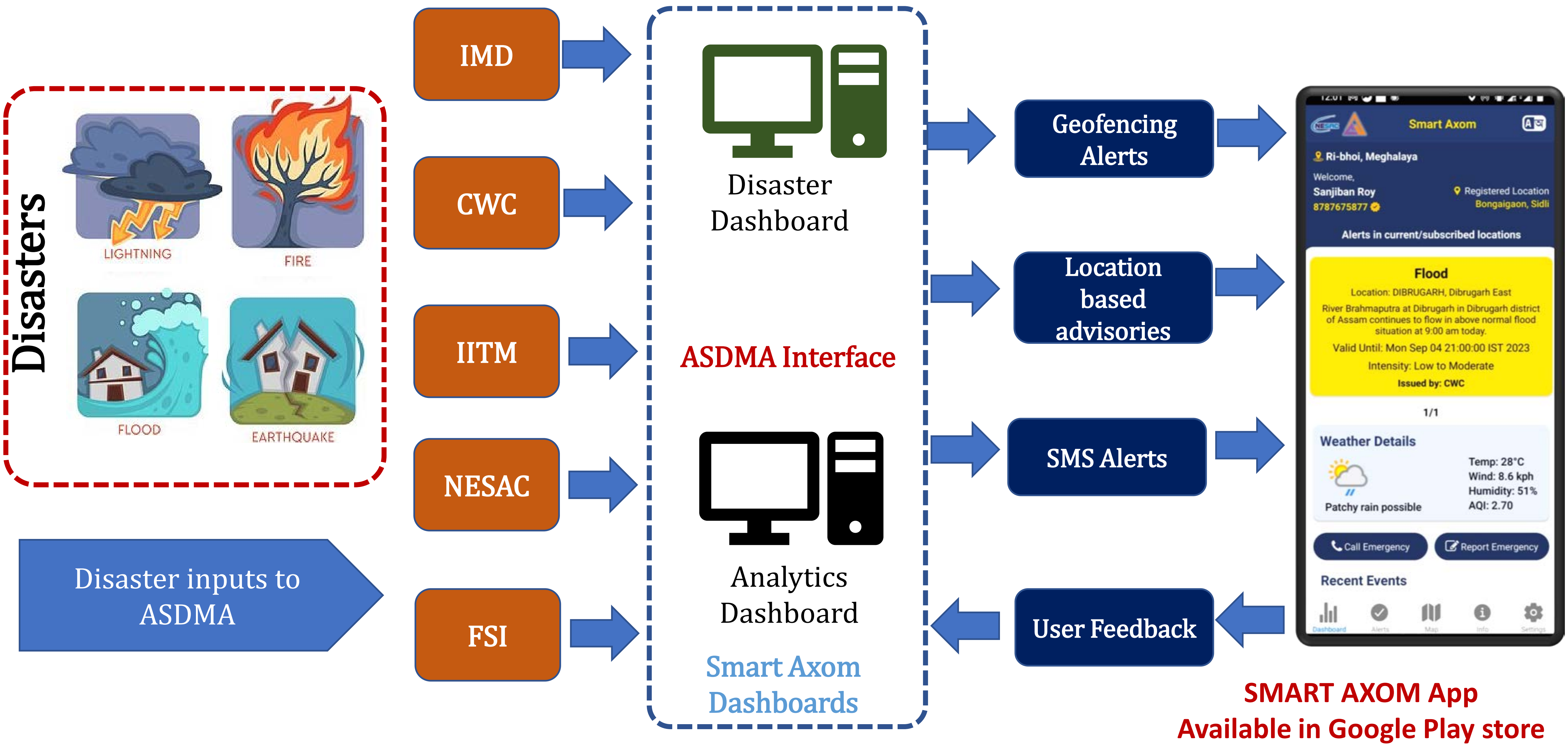
Development of location based lightning nowcasting system for NER of India







SMART AXOM - Integrated Platform for dissemination of early warnings



PUBLICATION

1. Journal papers (Recent publications)

- Gogoi, R. B., Kutty, G., Rakesh, V., & Borgohain, A. (2020). Comparison of the Performance of Hybrid ETKF-3DVAR and 3DVAR Data Assimilation Systems on Short-Range Forecasts during Indian Summer Monsoon Season in a Limited-Area Model. Pure and Applied Geophysics, 177(10), 5007-5026.

- Gogoi, R. B., Kundu, S. S., & Raju, P. L. N. (2021). Impact of INSAT-3D radiance data assimilation using WRF 3DVAR on simulation of Indian summer monsoon and high-resolution rainfall forecast over hilly terrain. Natural Hazards, 109(1), 221-236.

- Gogoi, R. B., Kutty, G., & Borgohain, A. (2021). Impact of INSAT-3D satellite-derived wind in 3DVAR and hybrid ensemble-3DVAR data assimilation systems in the simulation of tropical cyclones over the Bay of Bengal. Modelling Earth Systems and Environment, 1-11.

- Gogoi, R. B., Kutty, G., & Boroghain, A. (2021). Intercomparison of the impact of INSAT-3D atmospheric motion vectors in 3DVAR and hybrid ensemble-3DVAR data assimilation systems during Indian summer monsoon. Theoretical and Applied Climatology, 145(1), 585-596.

- Chakravorty, A., Gogoi, R. B., Kundu, S. S., & Raju, P. L. N. (2021). Investigating the efficacy of a new symmetric index of agreement for evaluating WRF simulated summer monsoon rainfall over northeast India. Meteorology and Atmospheric Physics, 133(3), 479-493.

- Banik, T., Thandlam, V., De, B. K., Kundu, S. S., Gogoi, R. B., Raju, P. L. N., & Guha, A. (2021). Understanding dynamics of tropical cyclones in the Bay of Bengal using lightning data. Meteorology and Atmospheric Physics, 133(5), 1505-1522.

- Srivastava, Abhay, Dongxia Liu, Chen Xu, Shanfeng Yuan, Dongfang Wang, Ogunsua Babalola, Zhuling Sun, Zhixiong Chen, and Hongbo Zhang. 1 (2022). Lightning Nowcasting with an Algorithm of Thunderstorm Tracking Based on Lightning Location Data over the Beijing Area. Advances in Atmospheric Sciences 39, no.: 178-188.

- Kutty, G., Gogoi, R., Rakesh, V., & Pateria, M. (2020). Comparison of the performance of HYBRID ETKF-3DVAR and 3DVAR data assimilation scheme on the forecast of tropical cyclones formed over the Bay of Bengal. Journal of Earth System Science, 129(1), 1-14.

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Overall Supervision:

Dr. Shyam S Kundu, Scientist ‘SG’ and Head,
Space and Atmospheric Science Division

Thank You Very Much