Weather and Climate Modelling Efforts at MoES

M Rajeevan

Ministry of Earth Sciences

New Delhi

secretary@moes.gov.in

Major Weather and Climate Prediction Activities

- IMD is supported by NCMRWF and IITM Pune for modelling activities.
  - Short to medium range prediction
  - Extended Range Prediction
  - Seasonal Forecasts
  - Modelling of Water Cycle
  - Fog Prediction efforts
  - Air Pollution Emergencies
- Two modelling frameworks are being used:
  - NCEP GFS and CFS models
  - UK Met Office Unified Models
  - Seamless prediction

Models being used for operational work at MoES

- Short to Medium Range
  - GFS Model T1534 (12 Km) – Deterministic
  - GFS Model T 574 - Ensemble (20 Members)
  - UKMO UM N768 (17 Km) Deterministic
  - UKMO UM N400 (33 Km) Ensemble – 44 Members
  - UKMO UM Regional Model- 4 km
- Extended Range
  - CFS/GFS Model T126 – Original and bias corrected
  - CFS/GFS Model T382 - Original and bias corrected

44 Members

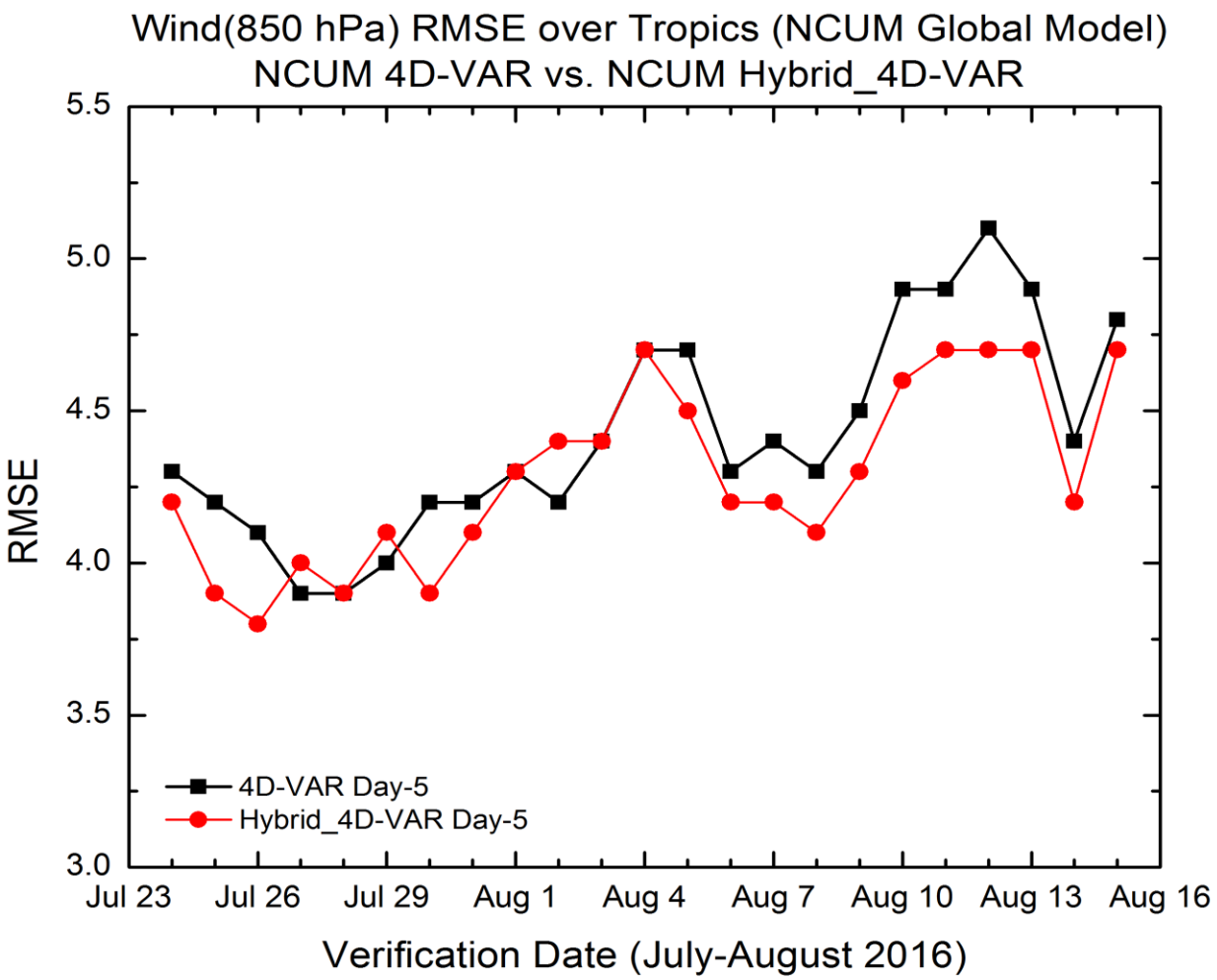
- Seasonal Forecasts
  - CFS Model T382- 40 Ensembles
- Climate Change Projections- Earth System Model
  - CFS Model -T62

Satellite Observations Used in NCUM DA System

Observation Type	Satellite
AMSU/MHS radiances	NOAA , MetOp Satellites
HIRS clear radiances	NOAA , MetOp Satellites
IASI and AIRS radiances	MetOp satellites (IASI), Aqua (AIRS)
ATMS & CrIS radiances	Suomi NPP
MT-SAPHIR radaiances	Megha-Tropiques
Geo Imager – cloud clear IR radiances	Meteosat , GOES Satellites
Geo Sounder – cloud clear IR Radiances	INSAT-3D
GPS RO bending angles	COSMIC, MetOp/GRAS, GRACE
GPS ZTDs	Global observations (various locations)
Satellite Atmospheric Motion Vectors	INSAT-3D, Meteosat-7& 10, GOES-E& W, Himavari-8, AQUA, NOAA & MetOp Satellites
Scatterometers : Sea-surface winds	MetOp Satellites (ASCAT)
Surface soil moisture/wetness	MetOp Satellites (ASCAT)
Aerosol Optical Depth (for dust)	AQUA , INSAT-3D (experimental)

Comparison of NCMRWF 4D-VAR with Hybrid 4D-VAR DA System

(Hybrid 4D-Var system uses 44 member Ensemble forecast of NCMRWF)



Recent improvements in Data Assimilation (DA) System at NCMRWF

NCMRWF is providing required initial atmospheric conditions for both GFS/CFS and UKMO UM.

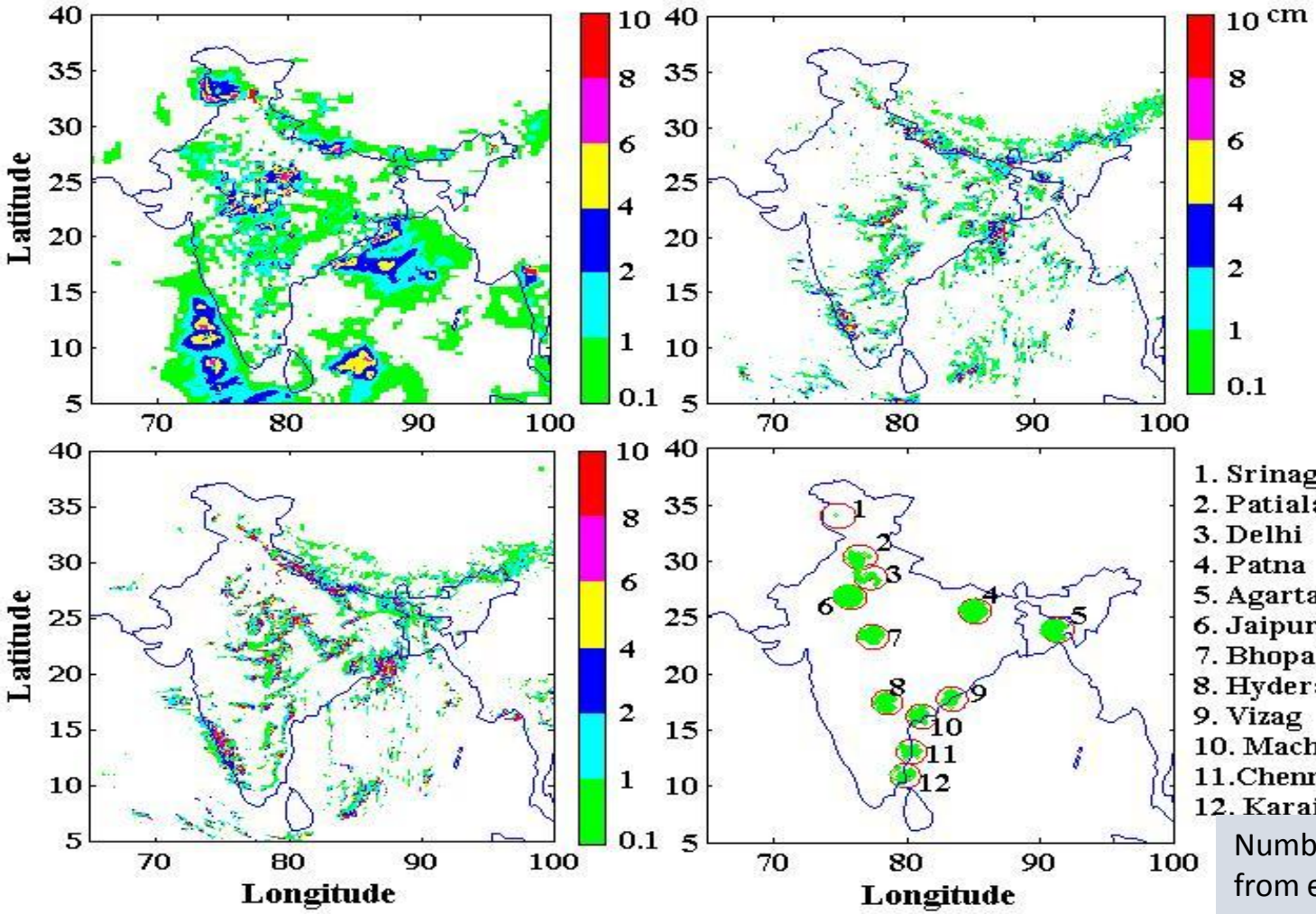
Hybrid 4D-VAR replaced the 4D-VAR Data Assimilation system at NCMRWF in Sept-2016

Radar Data Assimilation in 4 km NCUM Regional Model

Verification of Rainfall forecast

Rainfall Observation (IMD-NCMRWF)

24 hr forecast: DA with GTS+Satelite Obs



DWR Radial Wind Assimilation in Regional NCUM DA system

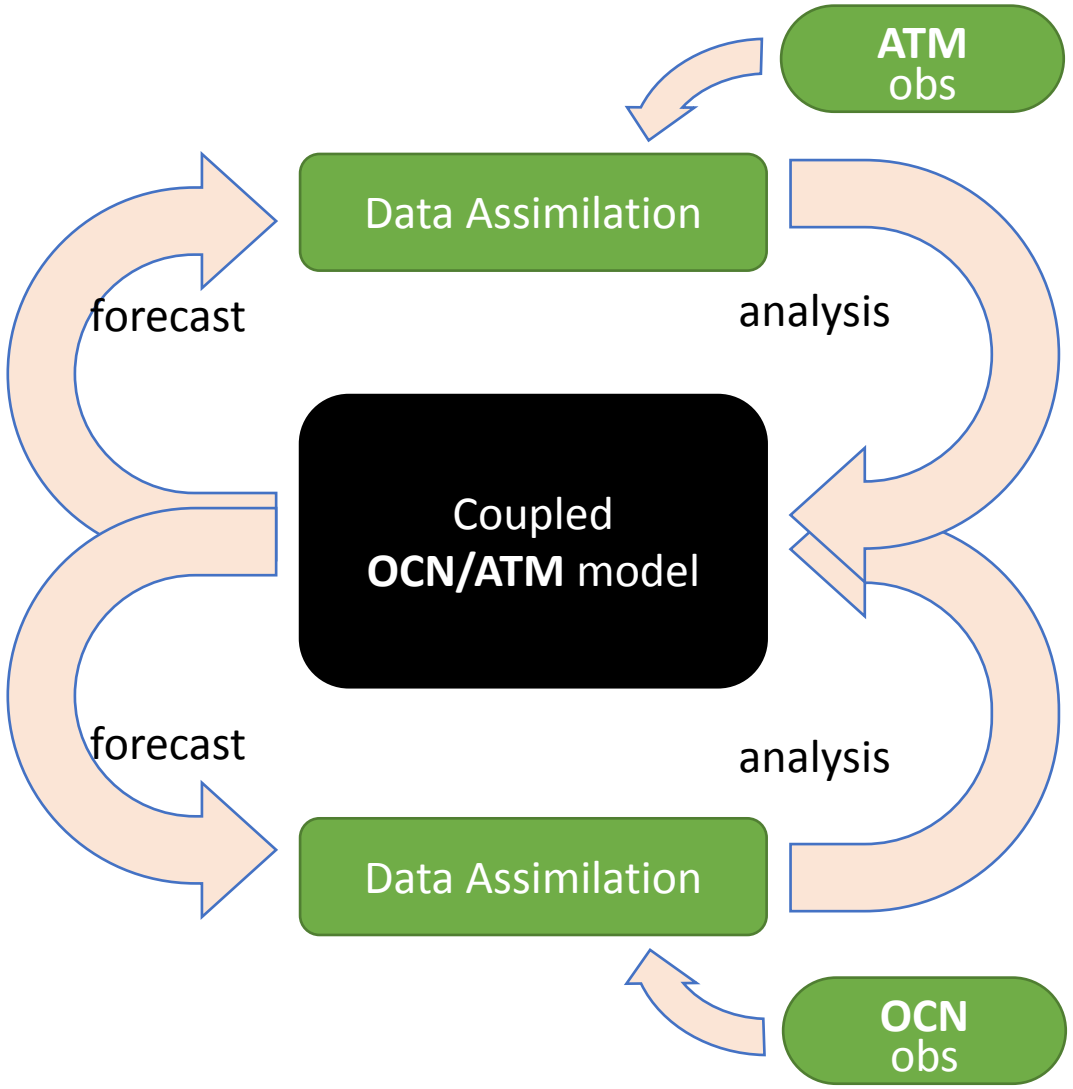
Rainfall valid at 00 UTC 27-July-2016
(24 hr forecast based on 00 UTC 26-July-2016 initial condition)

Number of DWR radial wind observations used in DA from each radar is given in the brackets

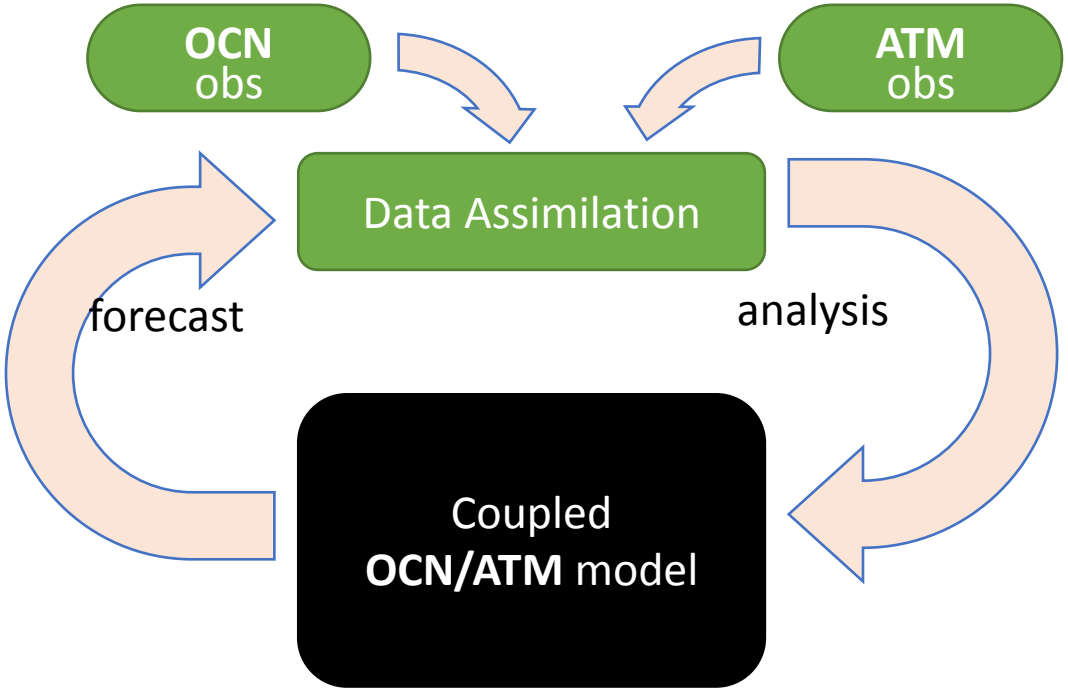
24 hr forecast: DA with GTS+Satellite+Radar

DWR wind observations used in DA

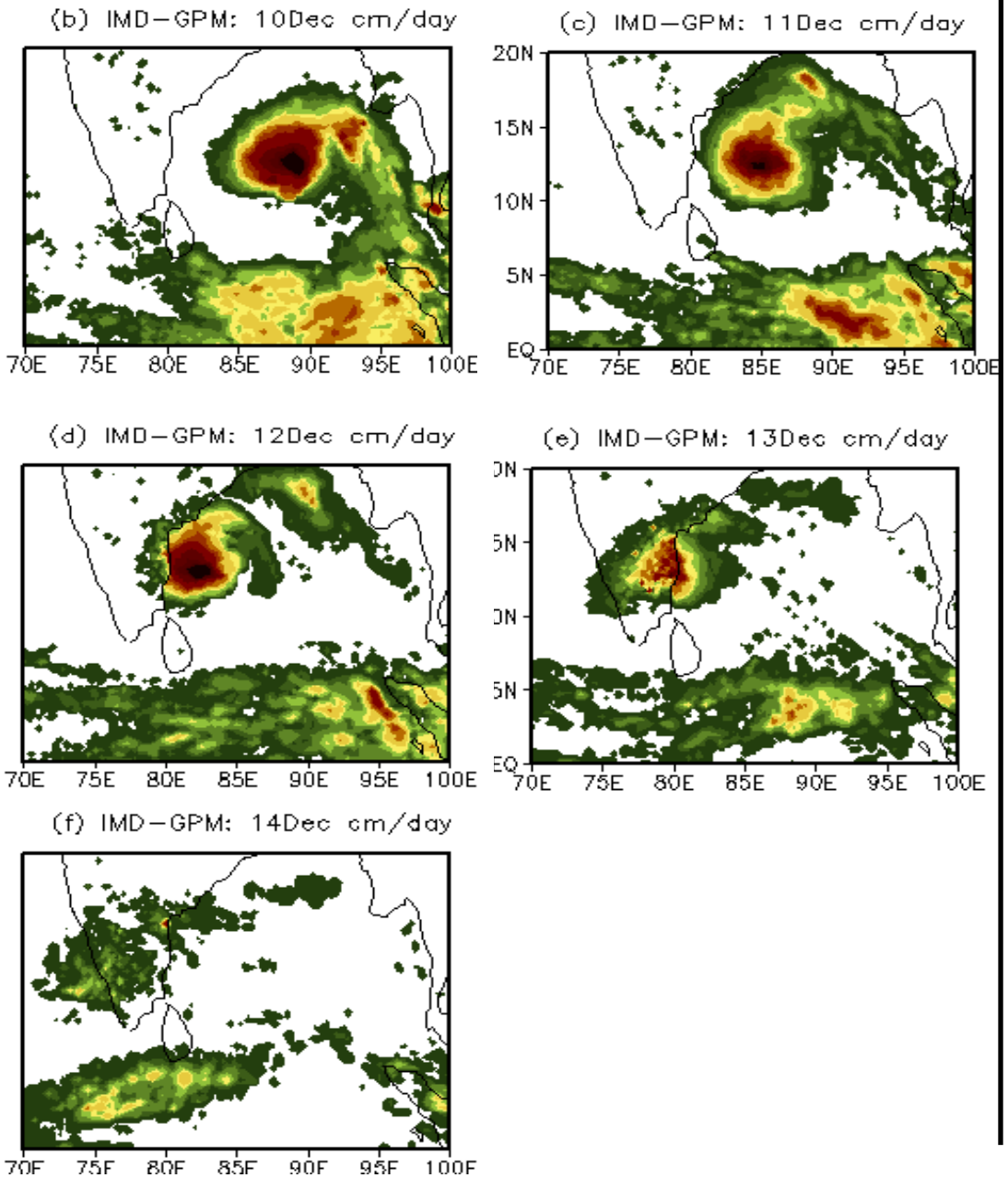
Weakly Coupled DA



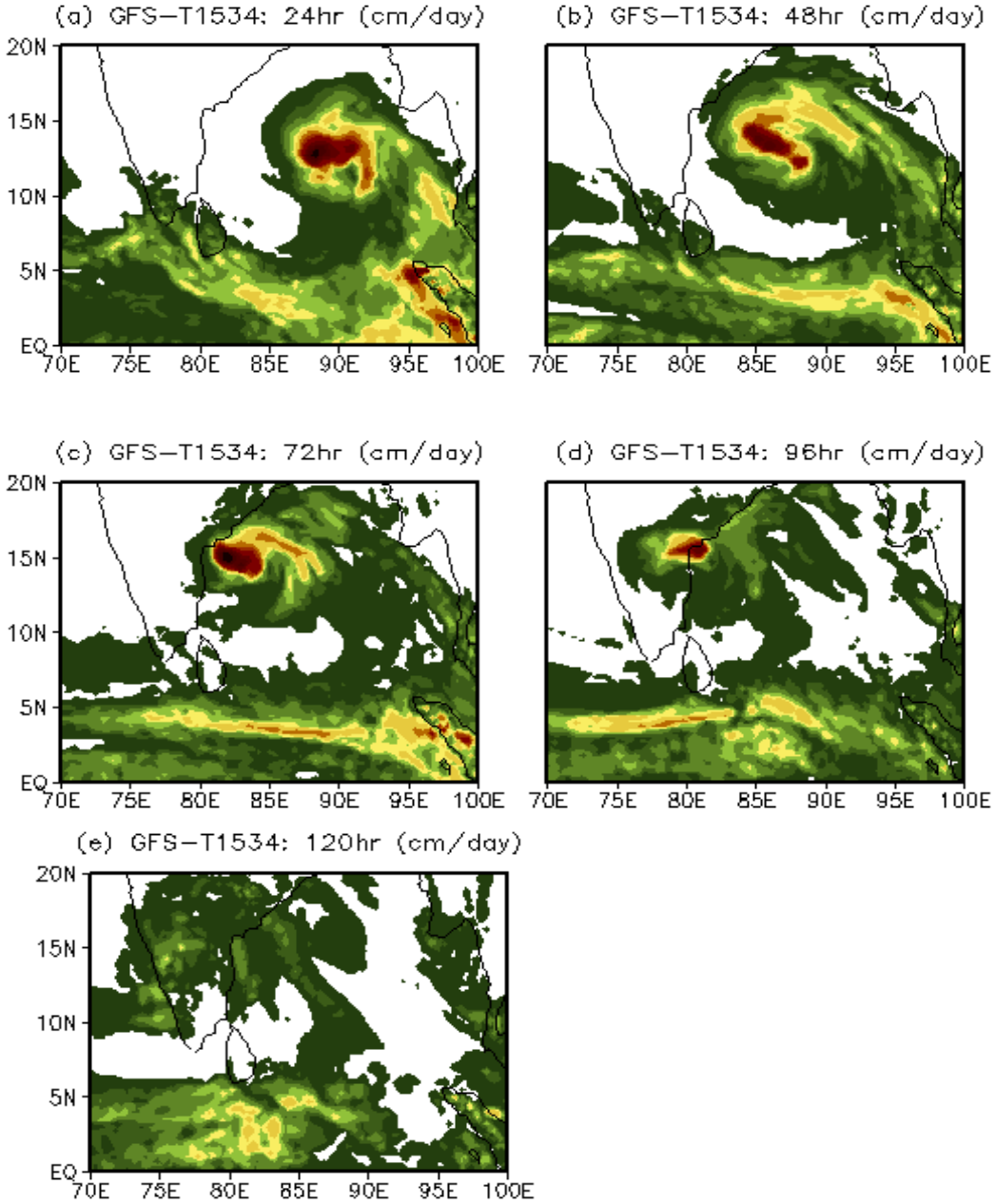
Strongly Coupled DA



IMD-GPM (cm/day)



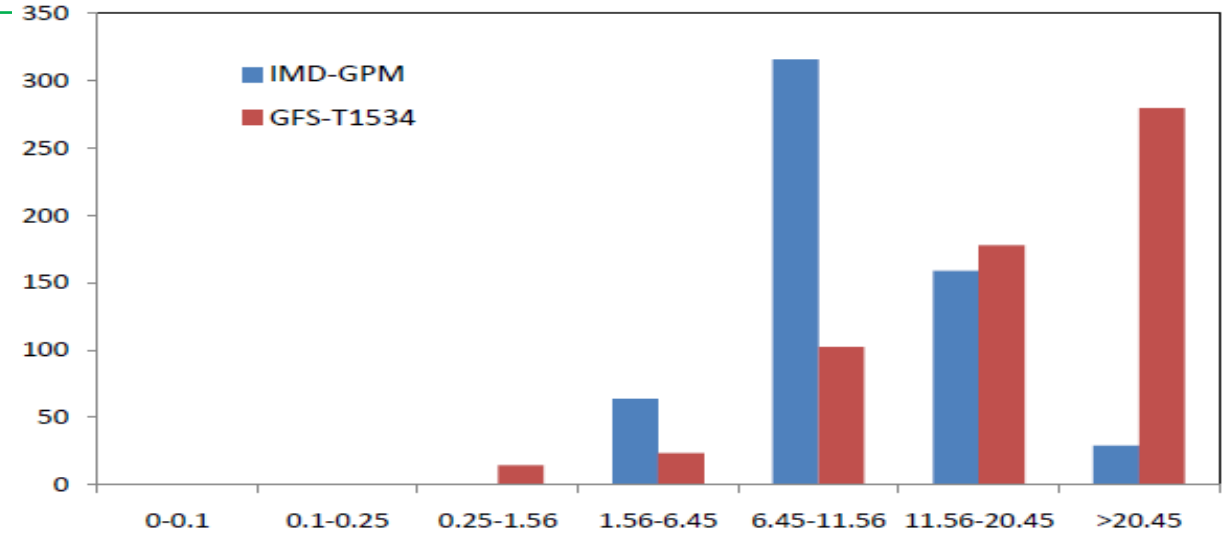
GFS-T1534: 09th December IC



(cm/day)

11DEC-IC

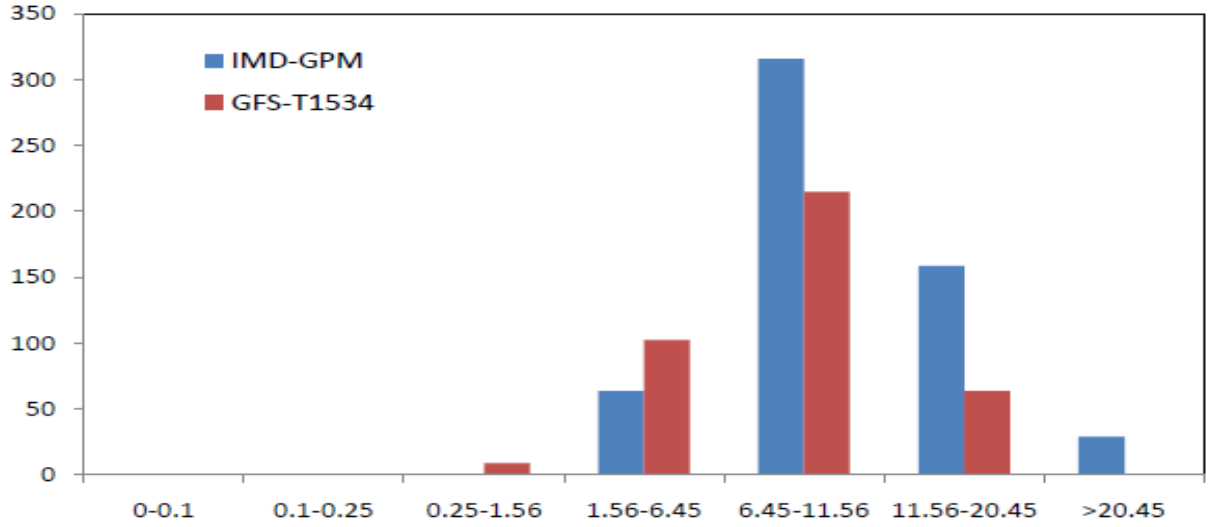
Forecast valid for 0300UTC of 13-Dec



Total rainfall (cm) over 12-14N, 79-80.5E contributed from various categories (cm/day)

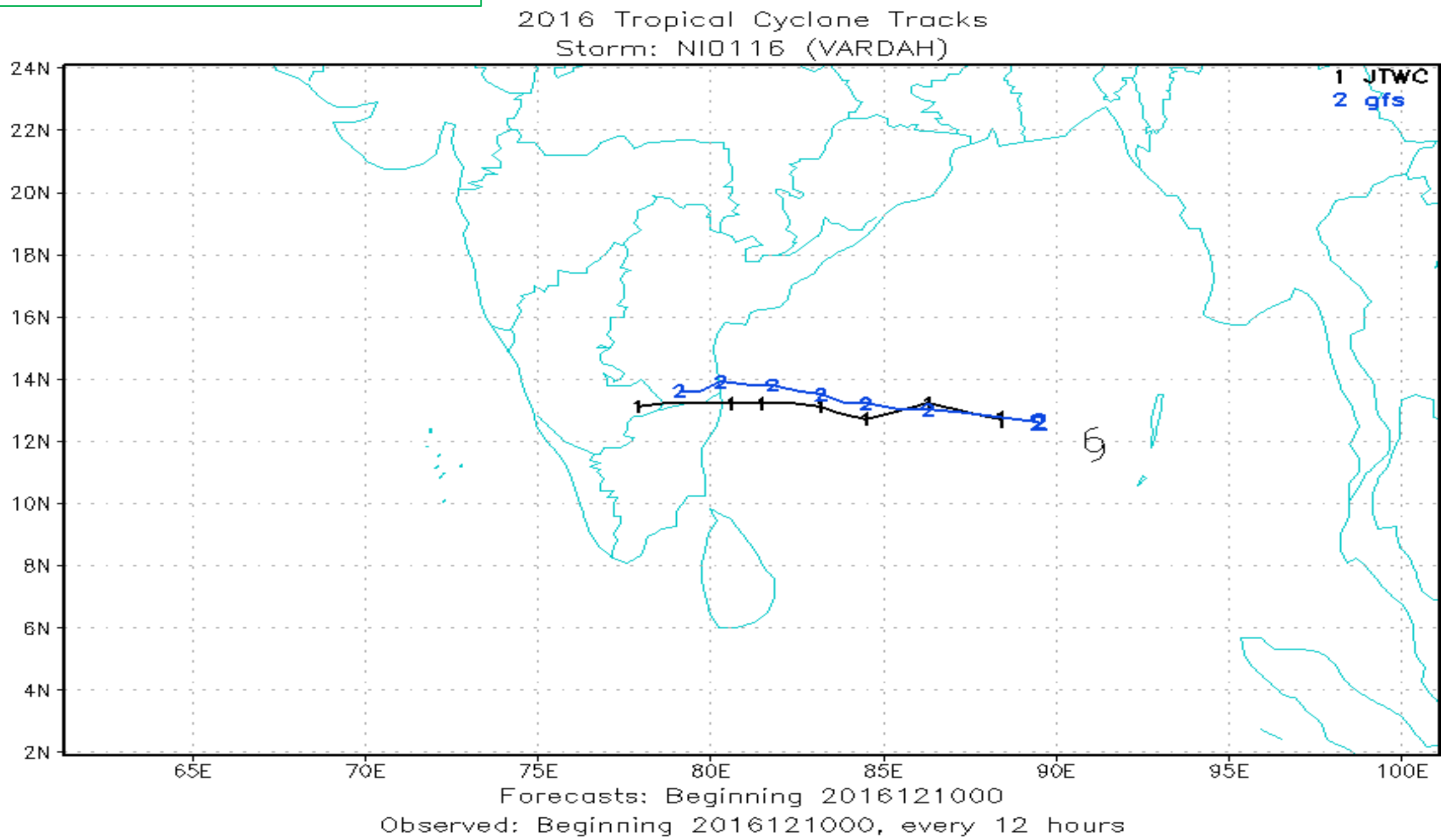
12DEC-IC

Forecast valid for 0300UTC of 13-Dec



X axis: rainfall bins
y axis: rainfall (cm)

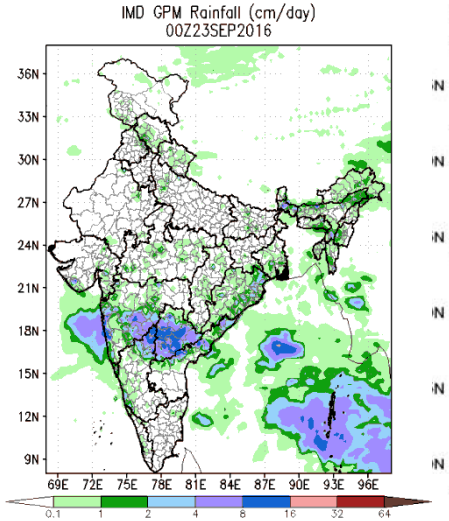
Based on 10 Dec IC

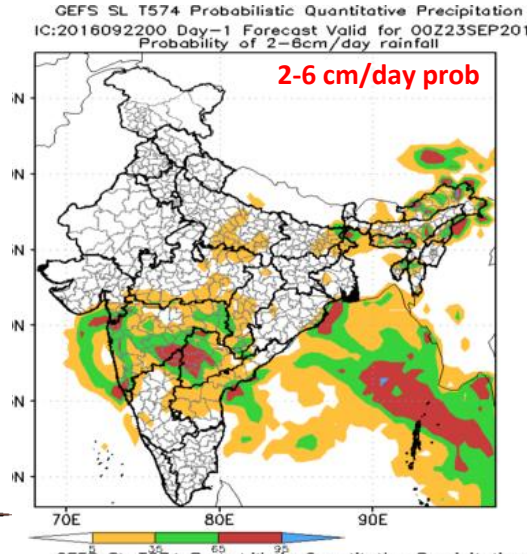


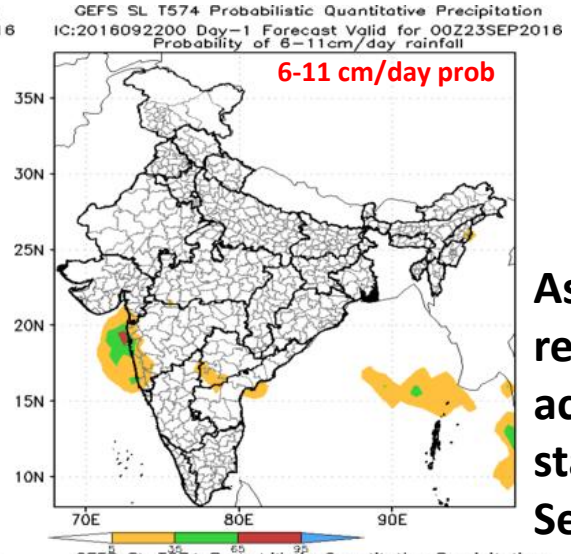
Recent very heavy rainfall over west coast predicted by GEFS T574 (30 km) with the probability

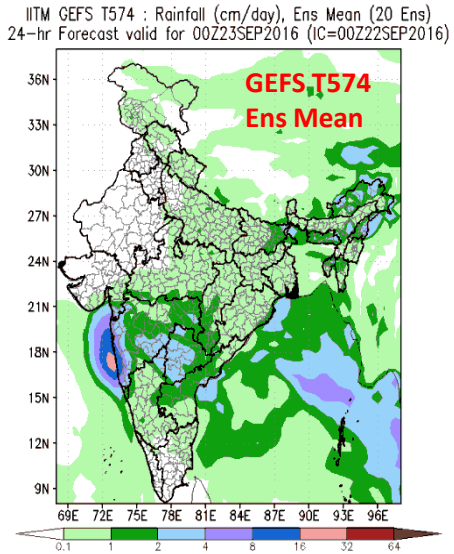
Forecast Valid for 23 Sept 2016 IC:22 Sept 2016

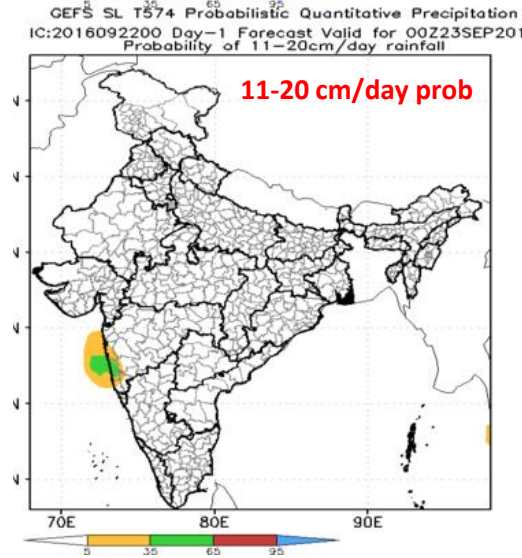
OBSERVATION

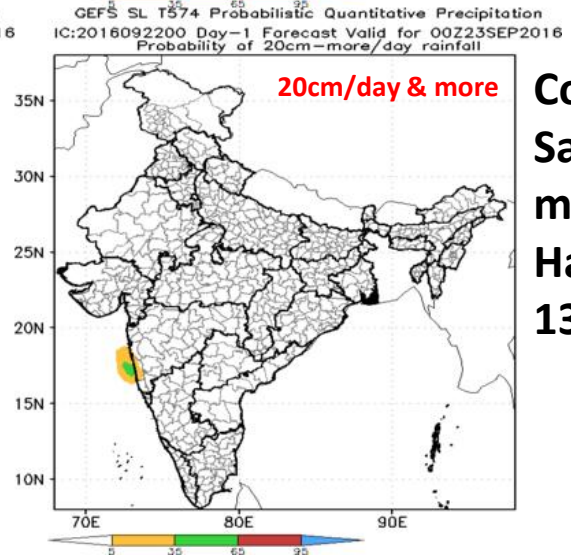








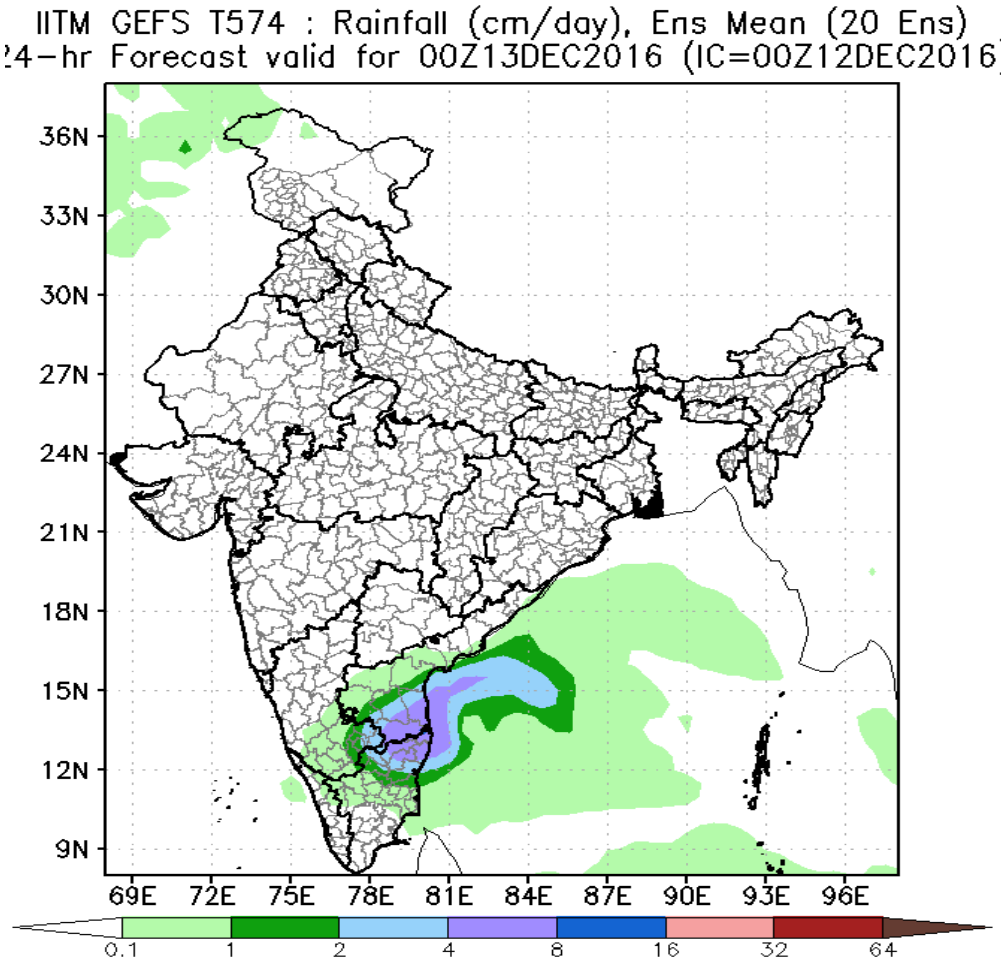




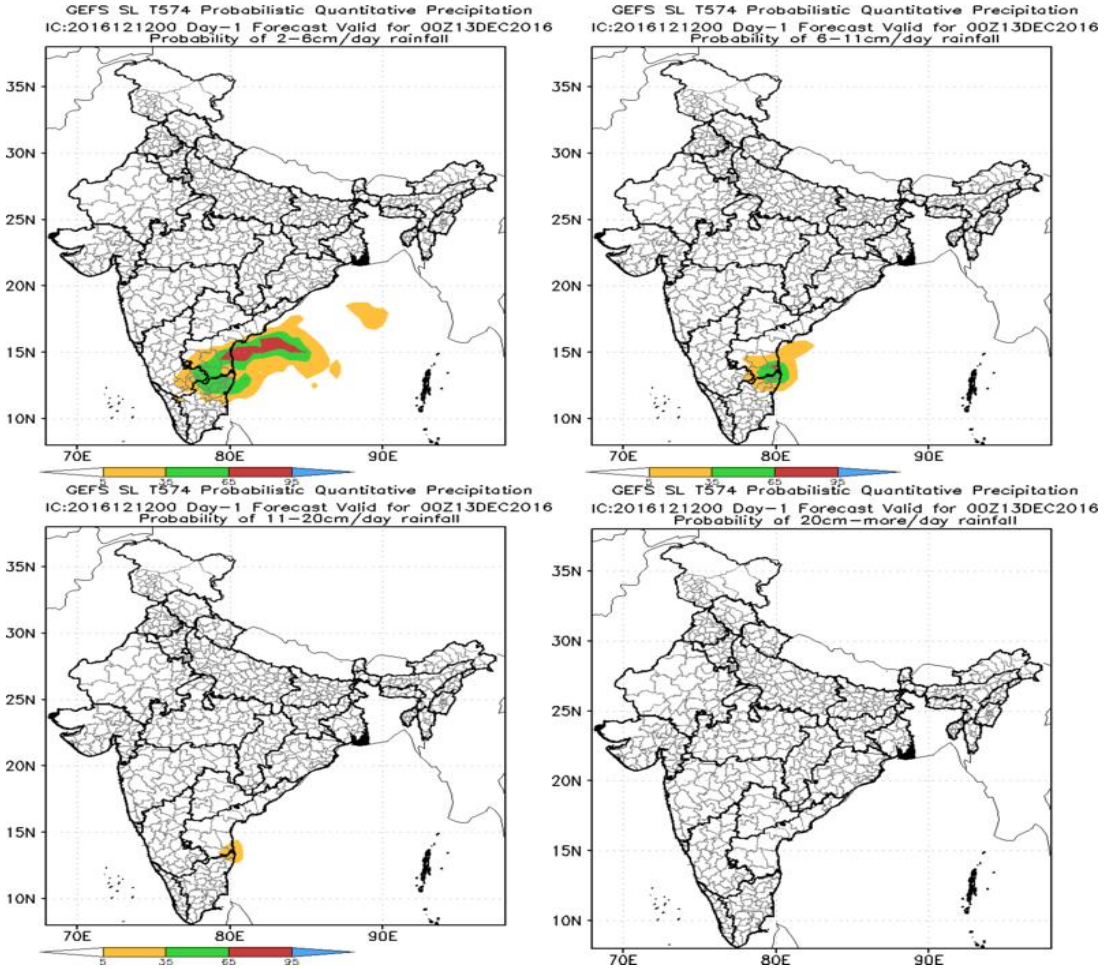
As per the IMD records, the 24 hr accumulated station rain on 23 Sep 2016 over Colaba:45mm; SantaCruz: 40 mm; Harnai, Goa: 136.7 mm

Probabilistic Prediction of Heavy rain over Chennai associated with Cyclone VERDAH 12 Dec 2016

Forecast valid for 00Z13Dec2016



IC: 00Z12Dec2016



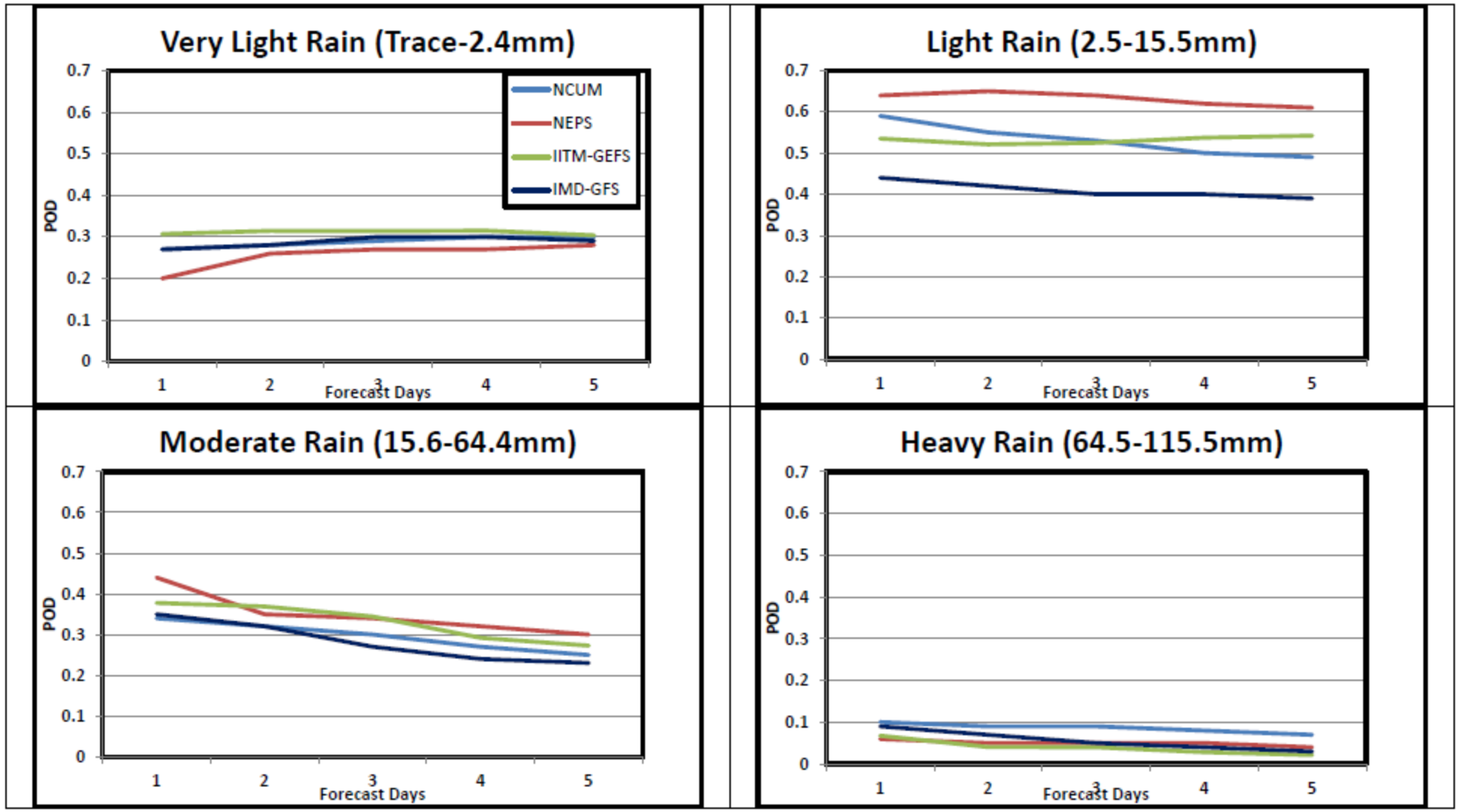


Figure 10. POD for Day-1 to Day-5 forecasts of the MoES models for four different rainfall categories namely (a)Very Light Rain, (b) Light Rain, (c) Moderate Rain and (d) Heavy Rain

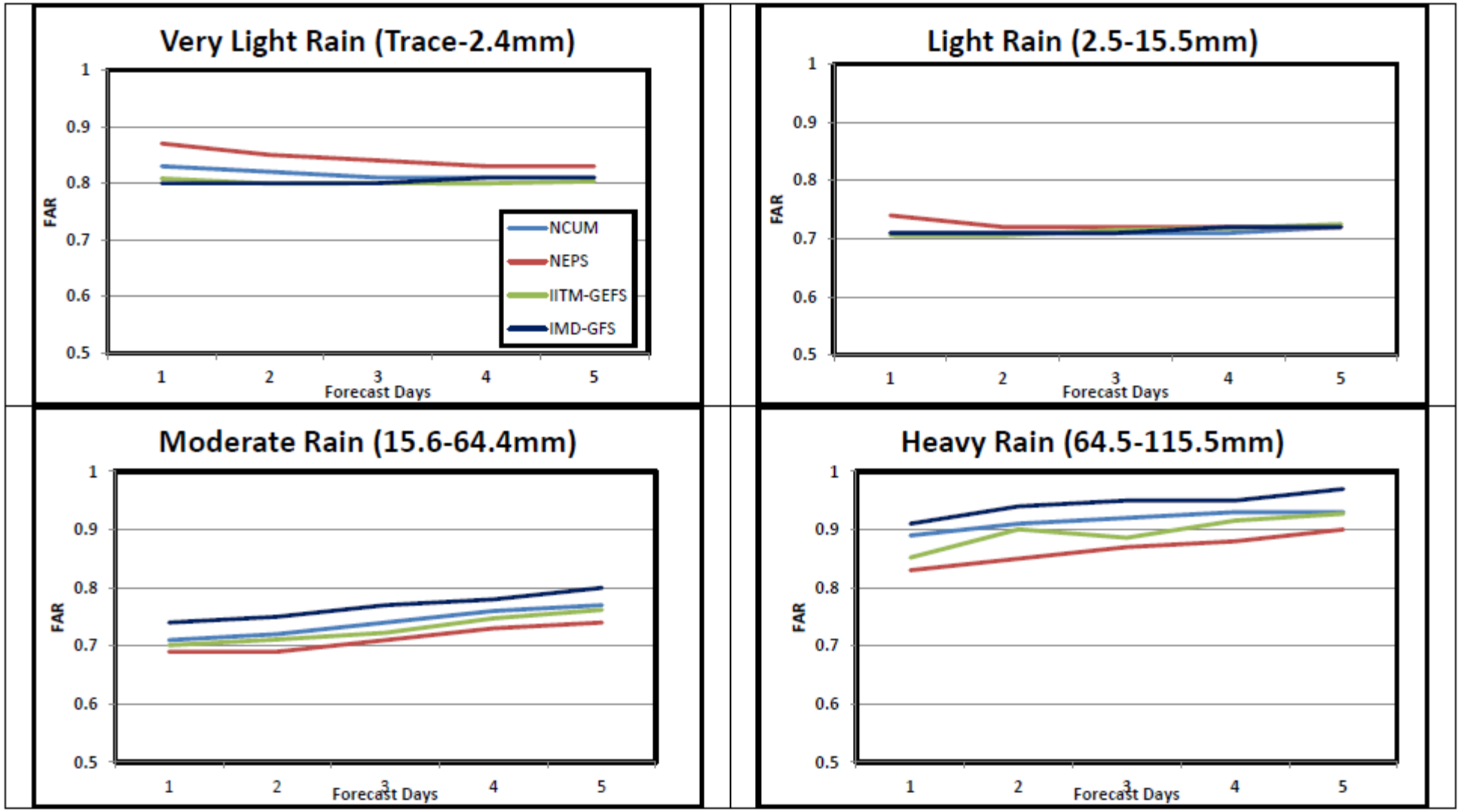
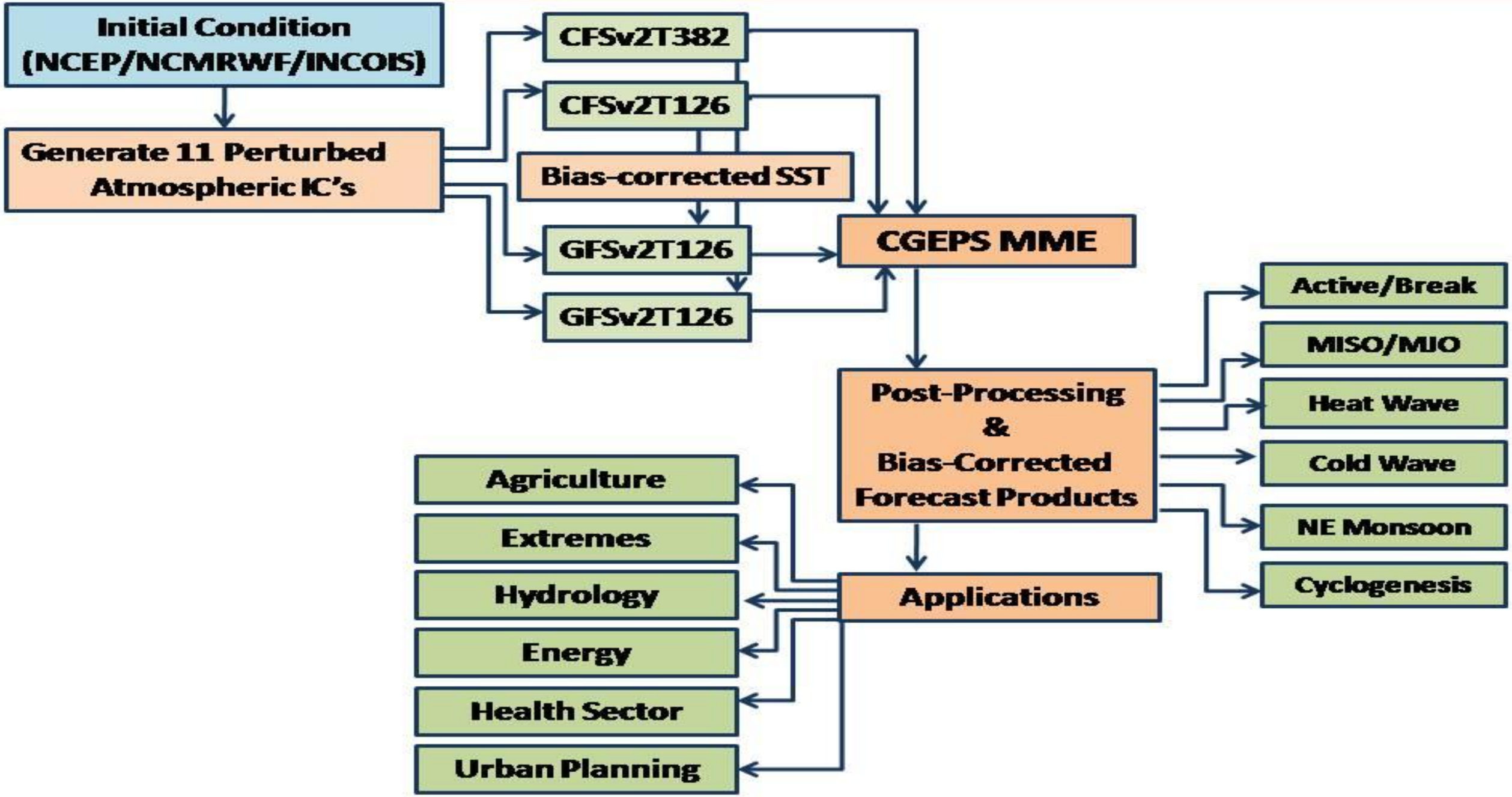


Figure 11. FAR for Day-1 to Day-5 forecasts of the MoES models for four different rainfall categories namely (a)Very Light Rain, (b) Light Rain, (c) Moderate Rain and (d) Heavy Rain

Extended Range Forecasts

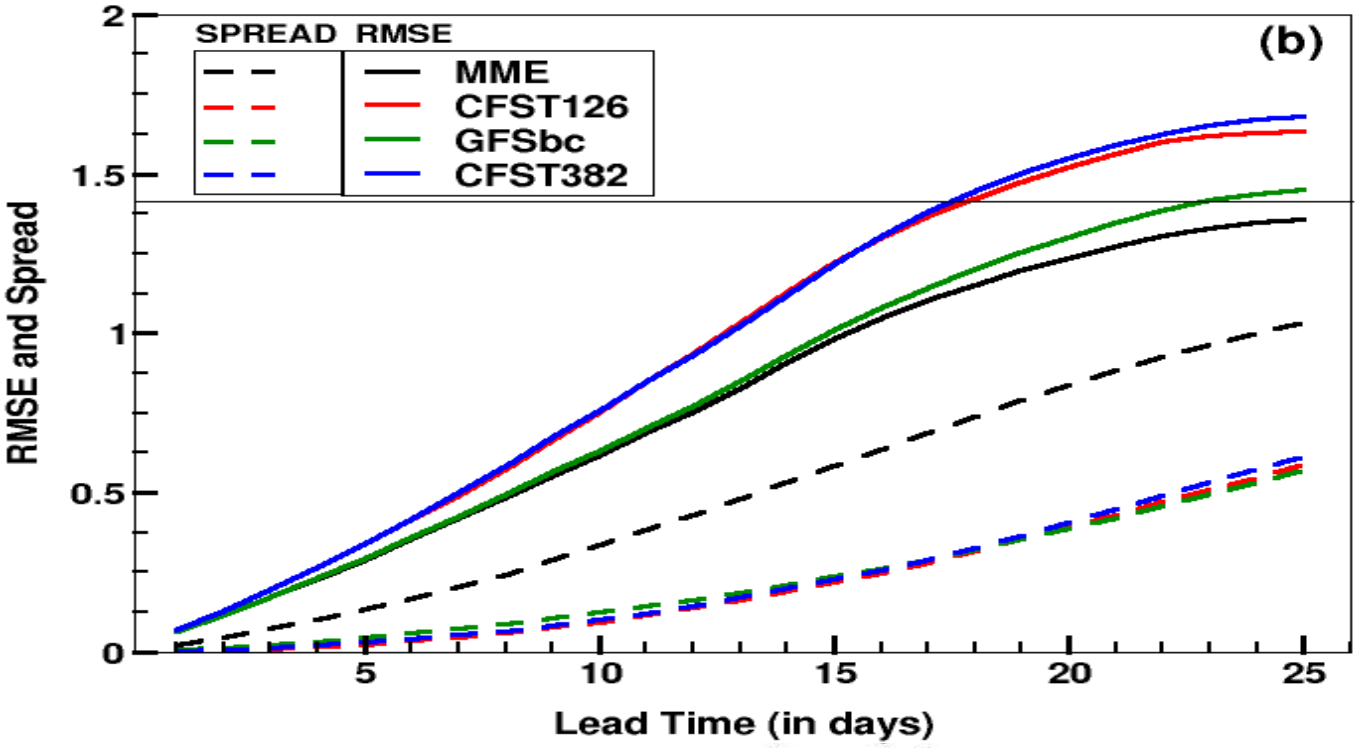
End-to-End Extended Range Prediction and Dissemination System



Gain through CGEPS MME system:

1. Improved spread and Reduction in RMSE

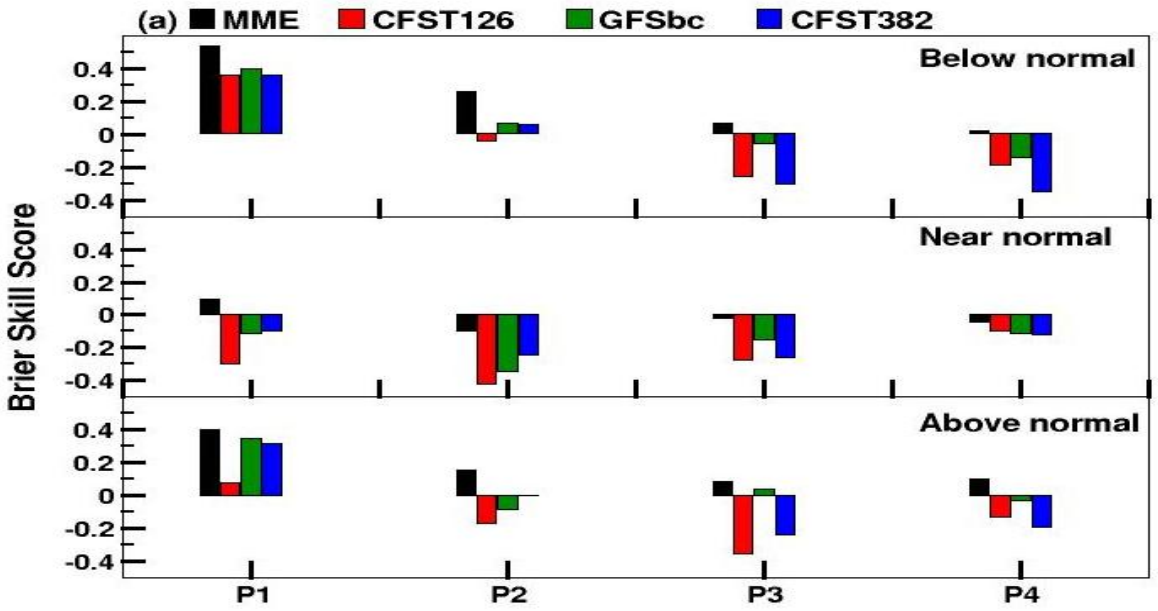
2. Improvement in Probabilistic forecast Skill



Bivariate RMSE: RMSE w.r.t. observation

Bivariate Spread: Std. Dev of iindividual models w.r.t. Ensemble mean

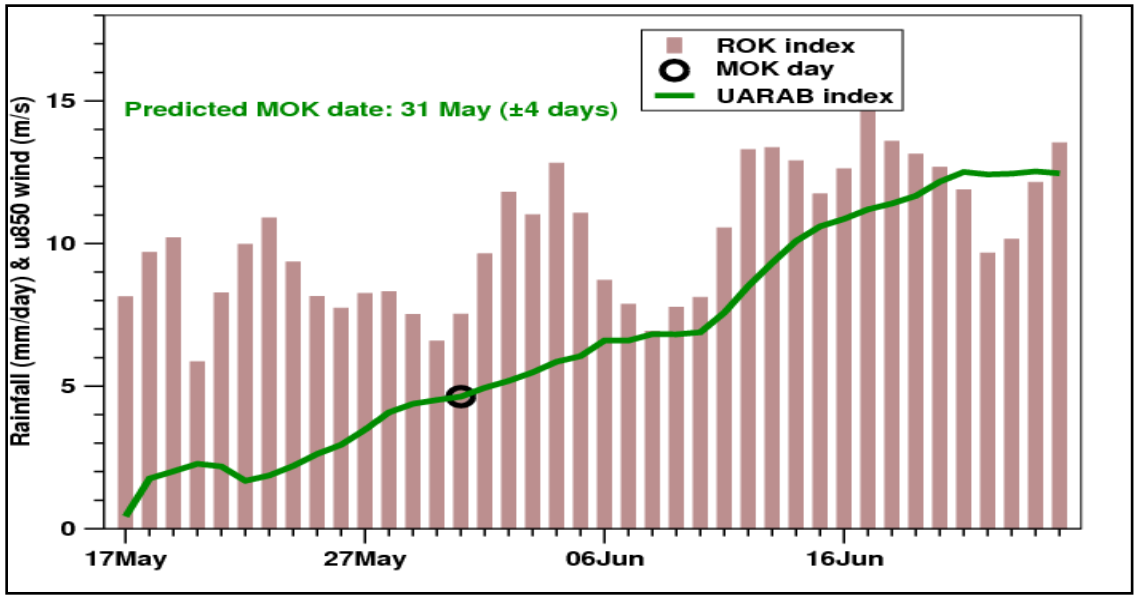
Probabilistic Prediction Skill



Considerable improvement in MME is contributed from the increased spread, which overcomes the under-dispersive nature of the individual models in EPS.

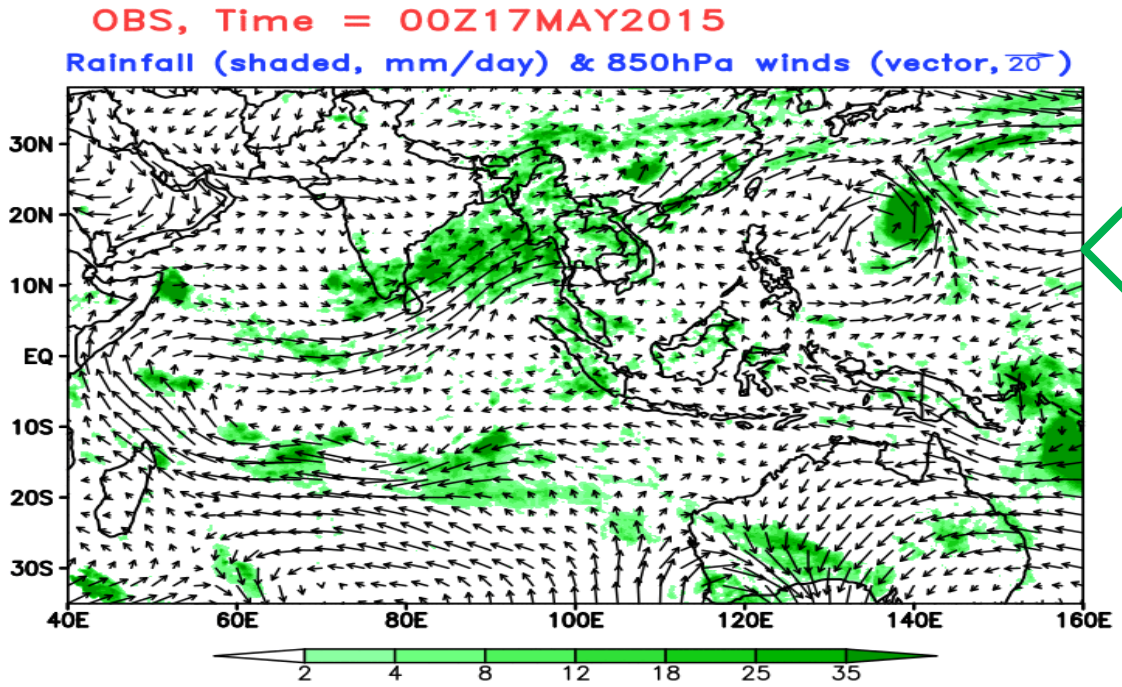
Abhilash et al. 2015, JAMC; BAMS

Prediction of MOK during 2015 monsoon



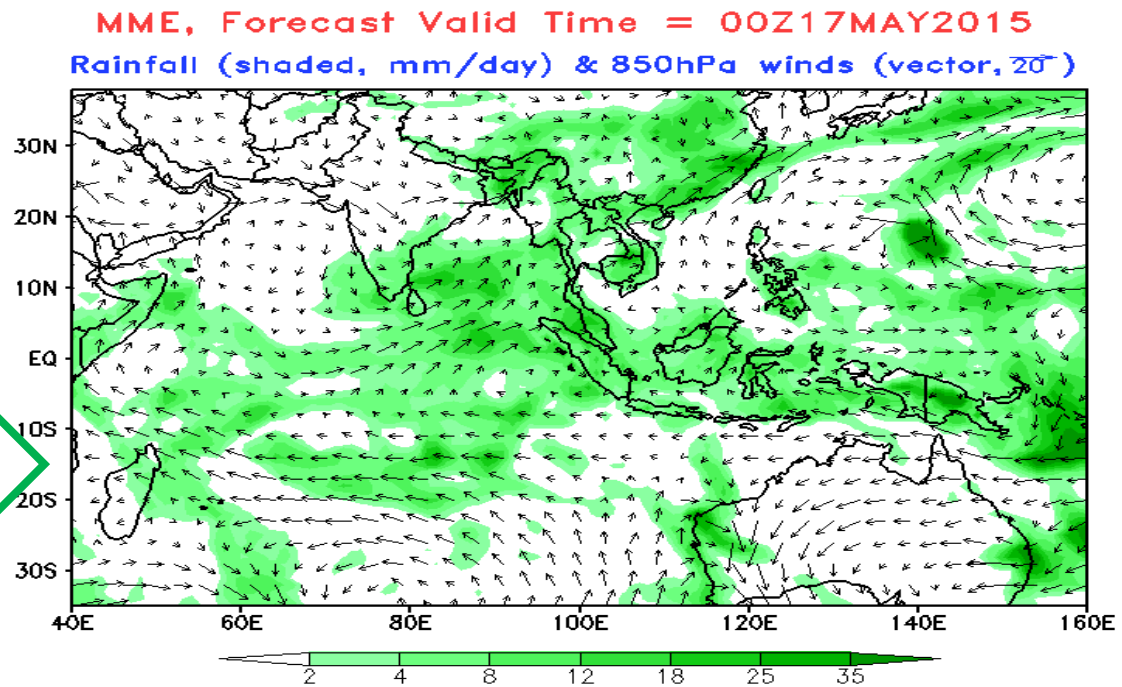
MOK date has been calculated for all 44 members of CGEPS and the mean of all of them is given as the final predicted MOK date.

IC: 16 May



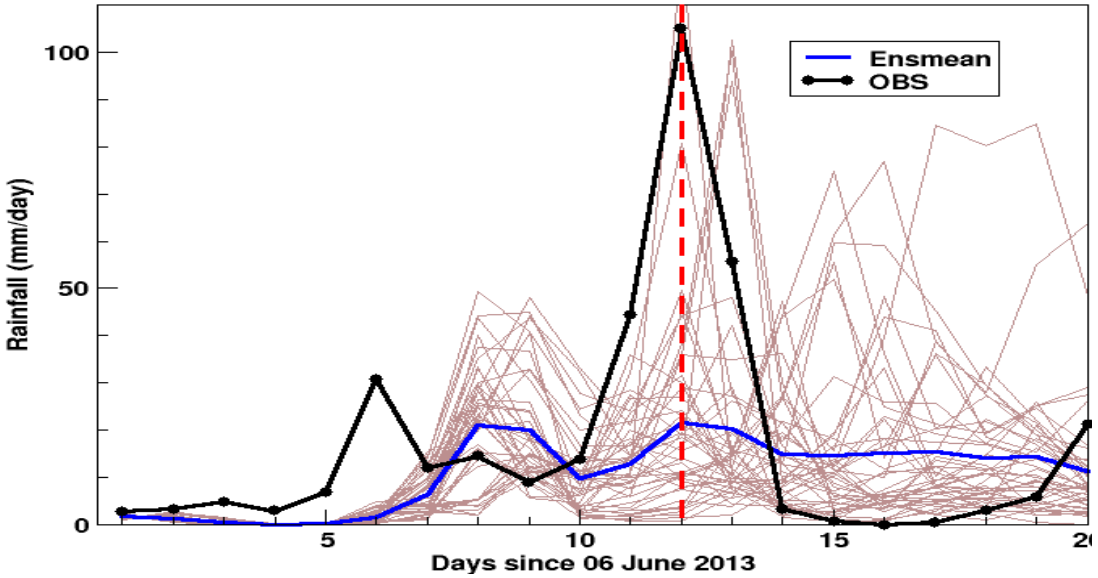
OBS

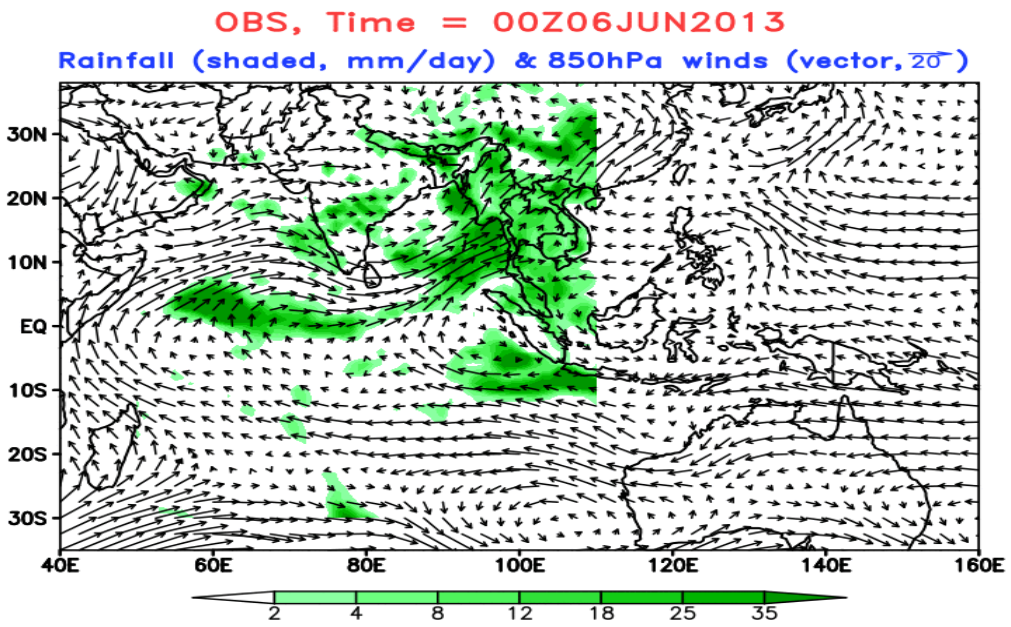
MME



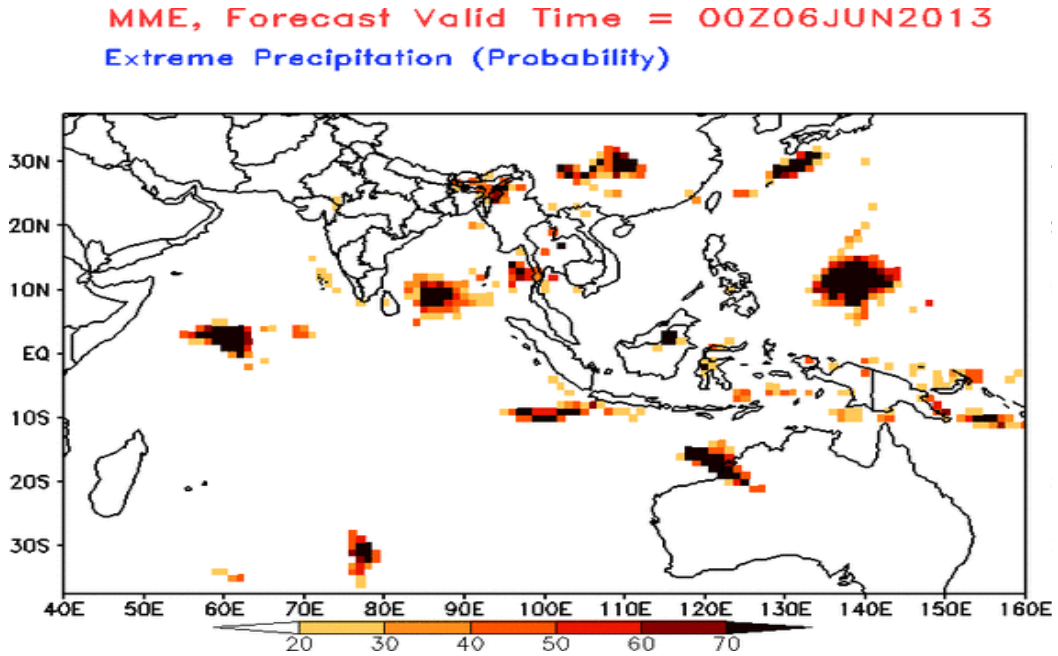
Prediction of Heavy Rainfall Events

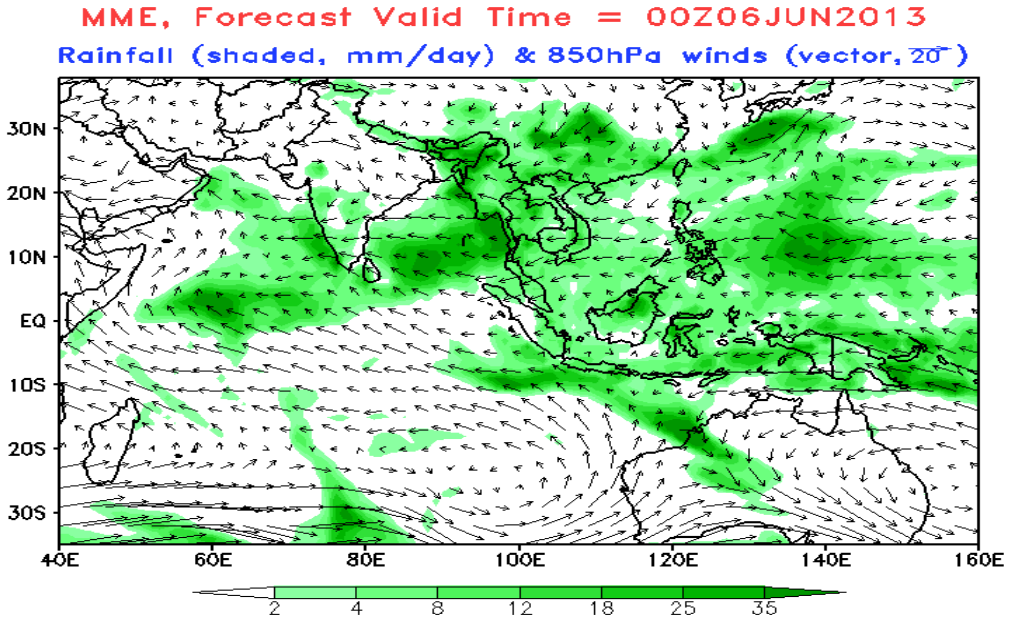
Uttarakhand event in June 2013 (IC: 0605)





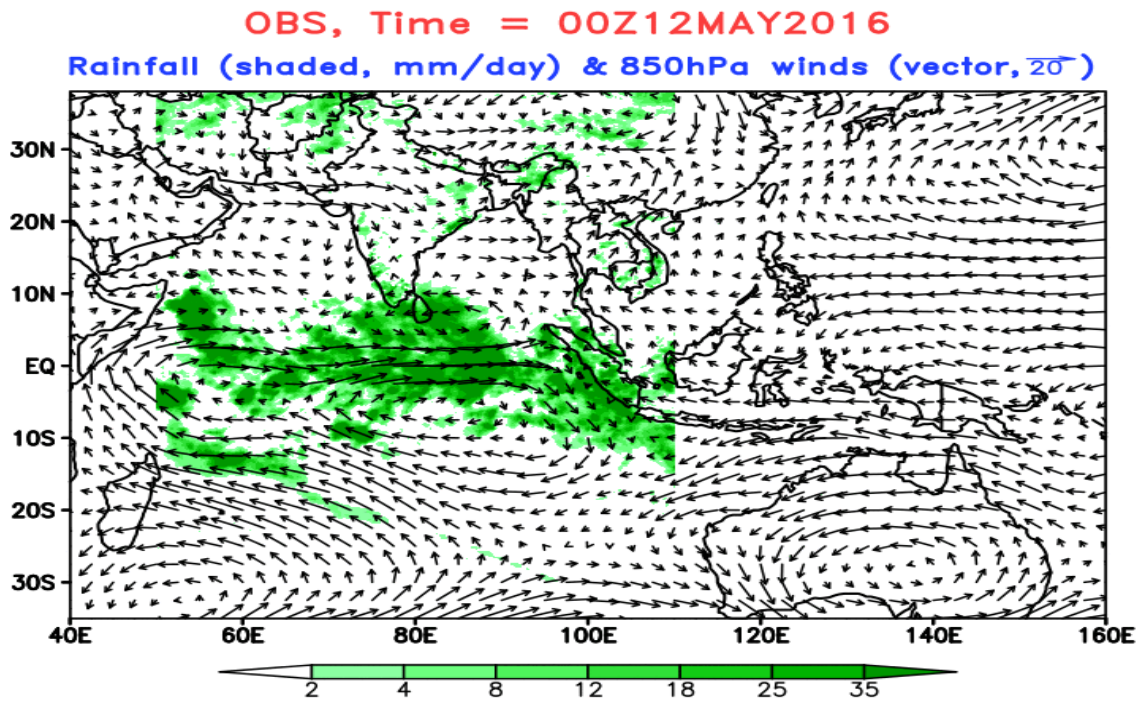
OBS

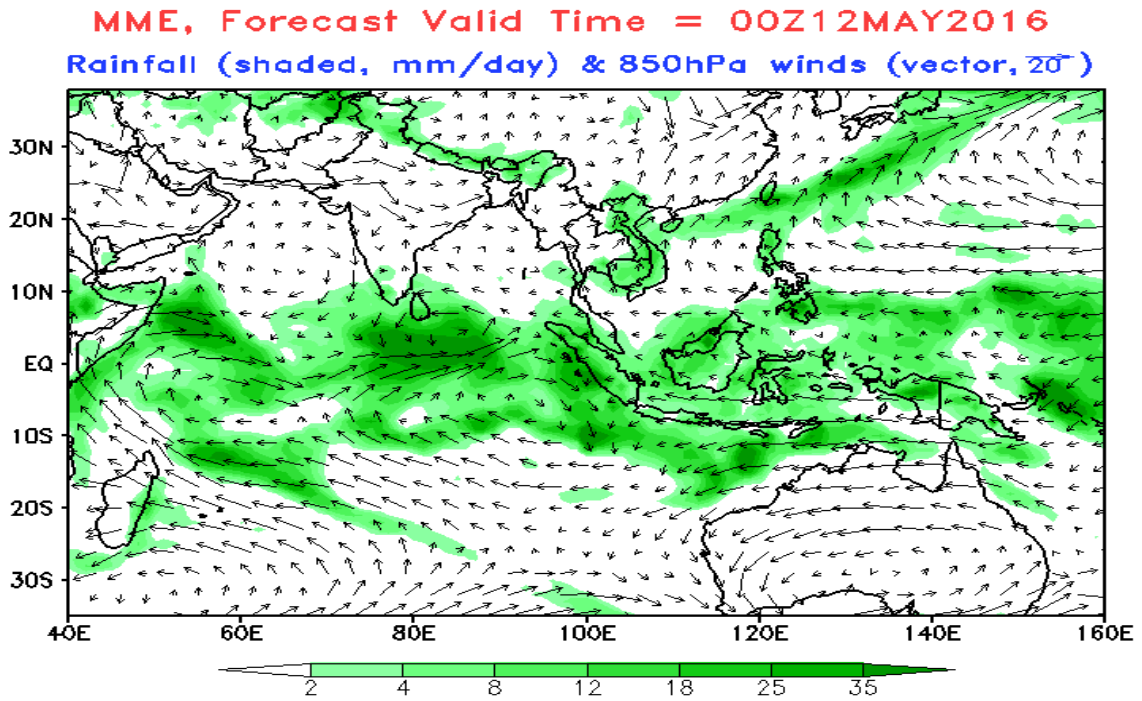




MME

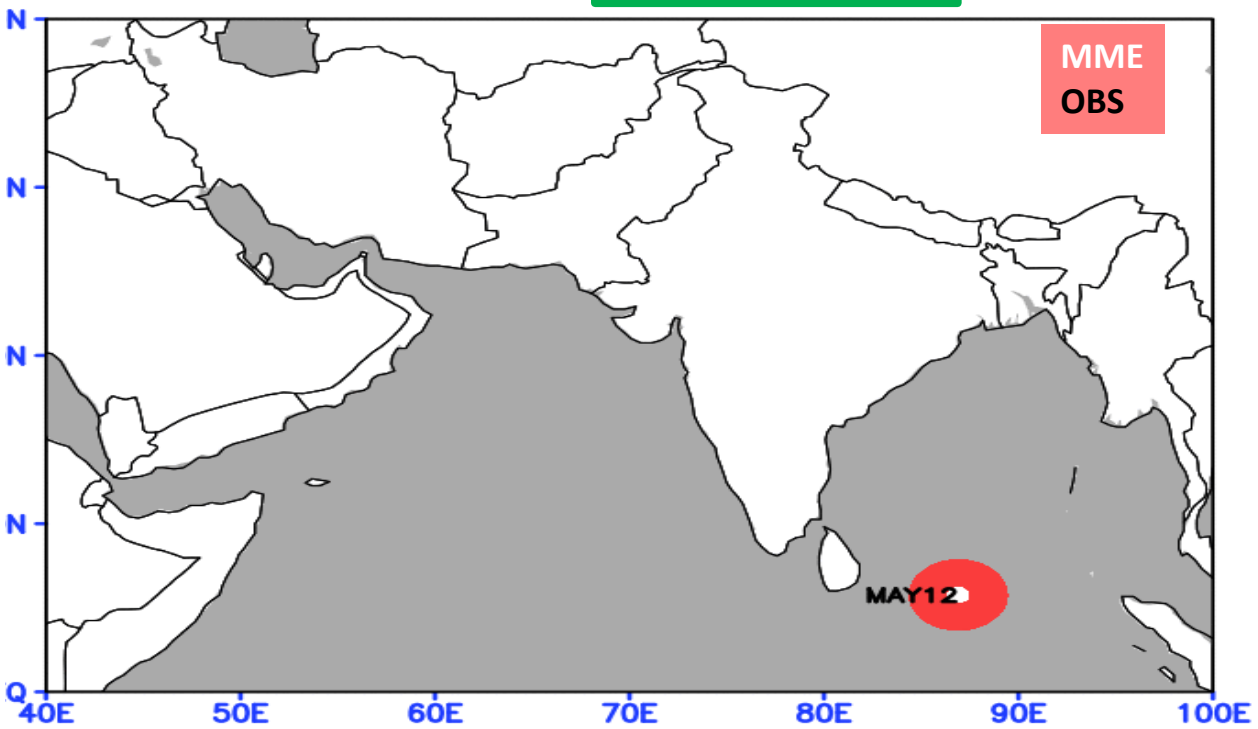
Prediction of Cyclogenesis



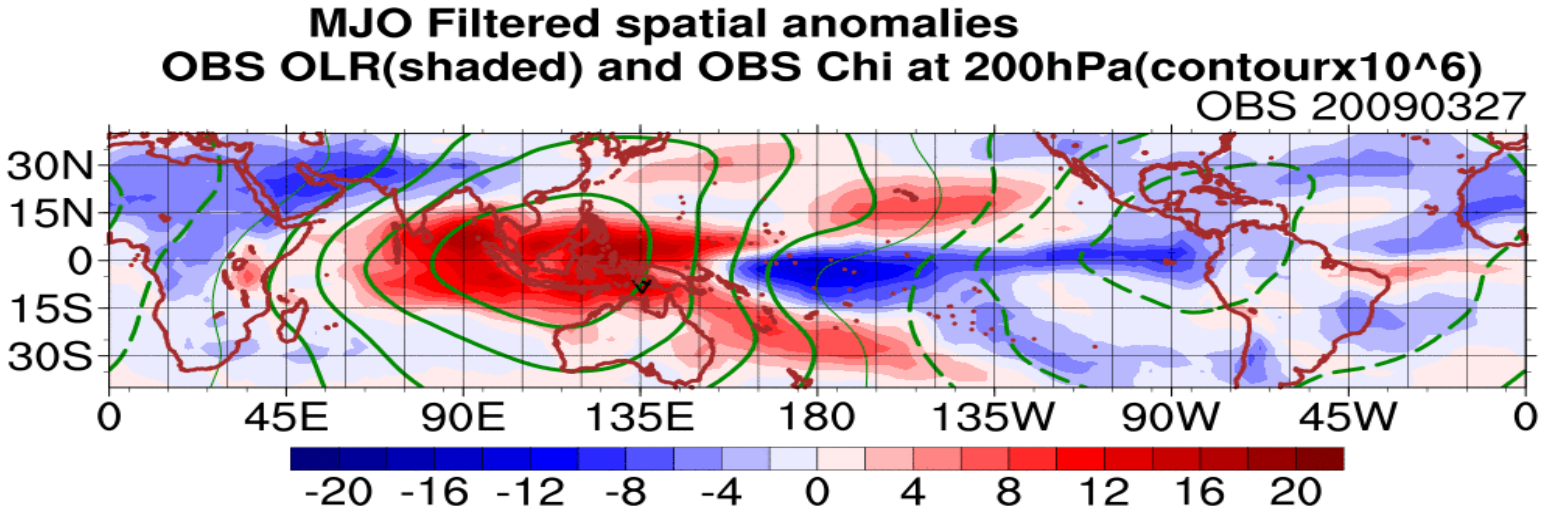


Cyclone Roanu in May 2016

IC: 11 May

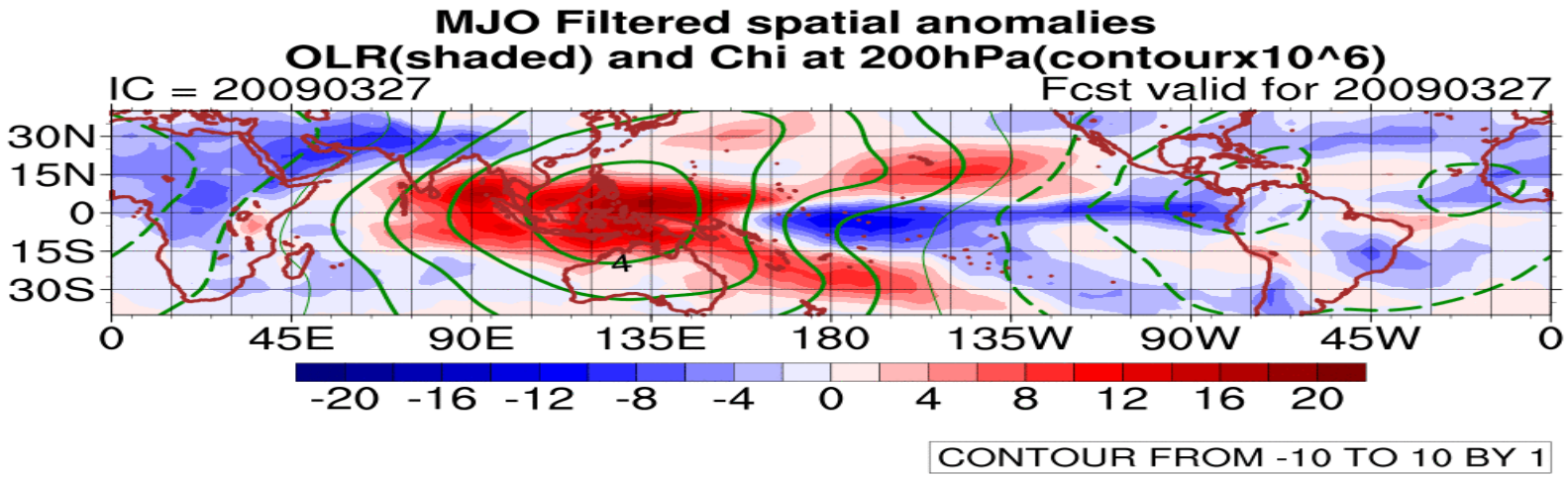


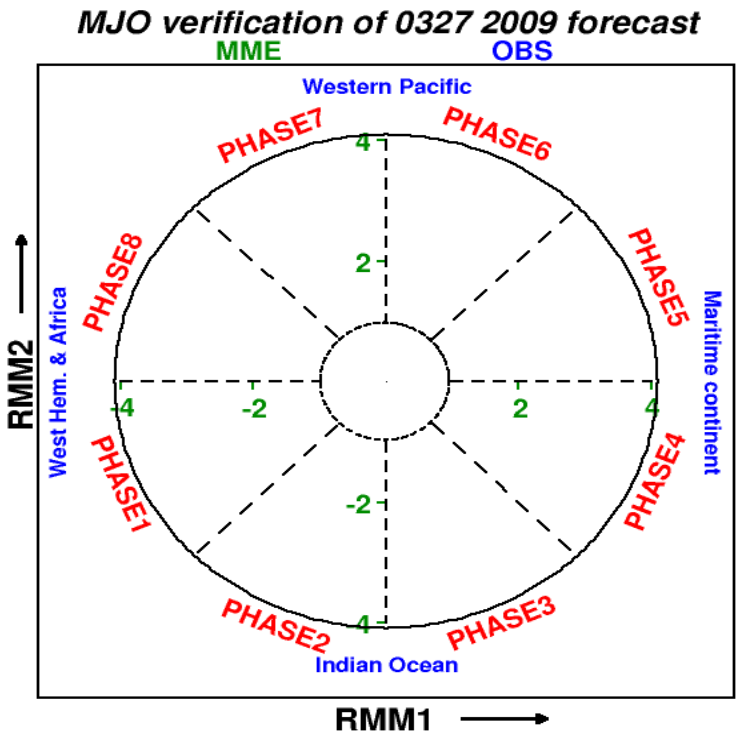
MJO Reconstruction March-April 2009 period



OBS

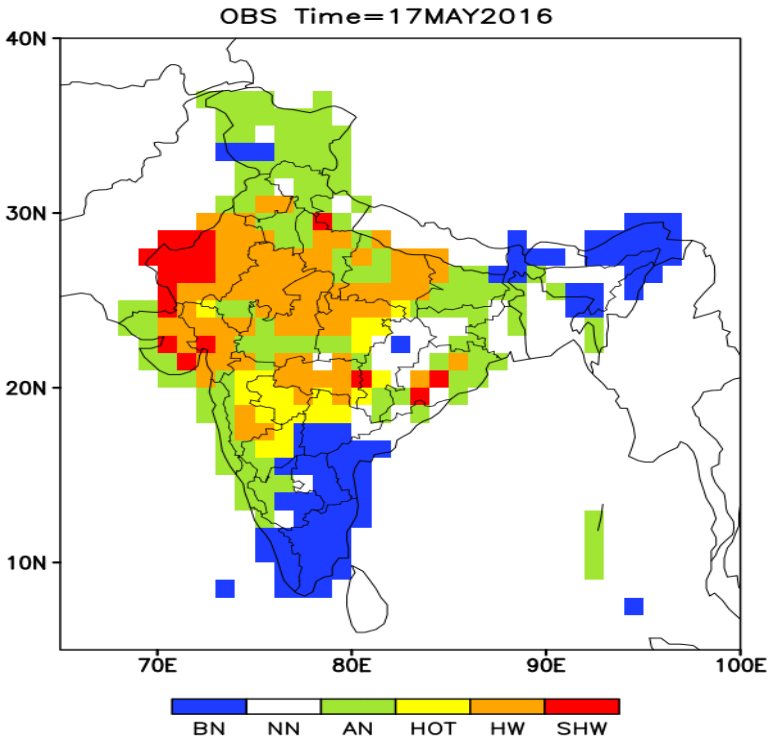
model





Prediction of Heat Waves

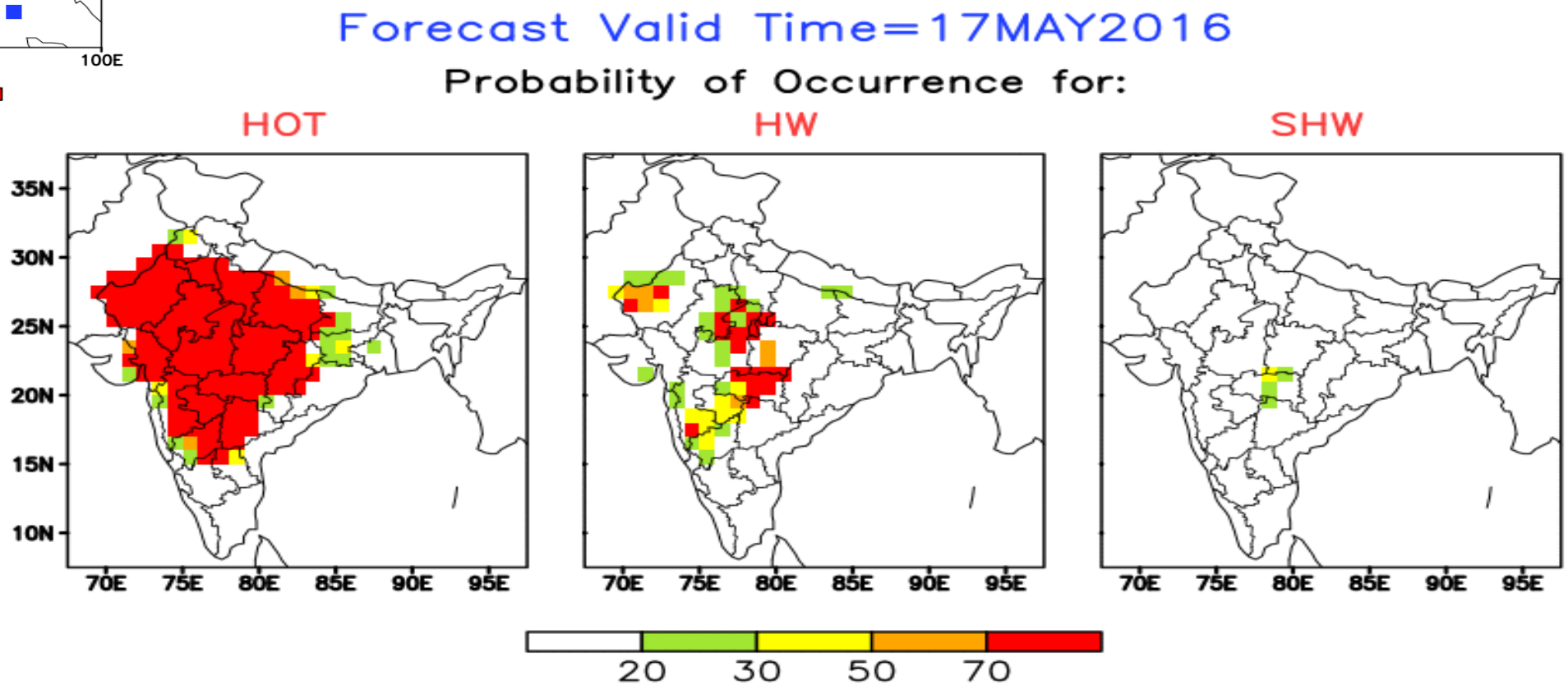
Heat Wave in May 2016



Observed Heat Index

Predicted Heat Index

IC: 0516

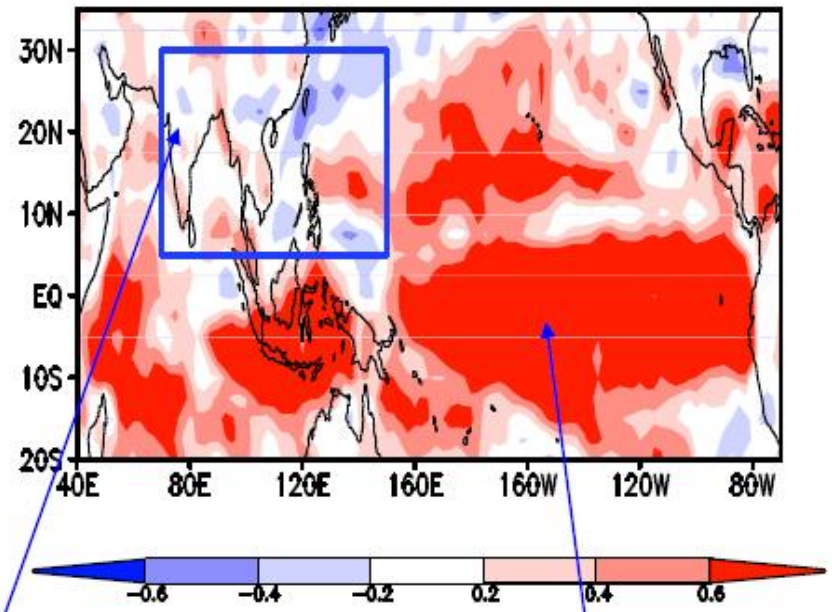


Seasonal Forecasts

STATE OF THE ART COUPLED MODELS PREDICTION SKILL (Correlation between observed and Predicted) OF TROPICAL PRECIPITATION (Prior to Monsoon Mission)

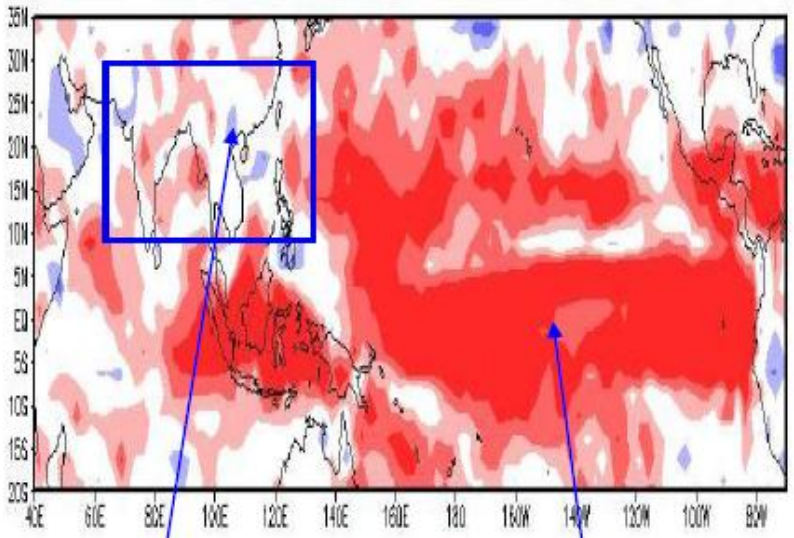
Earlier version models

1979-1999



Latest models (ENSEMBLES)

1979-1999



Poor skill

High skill

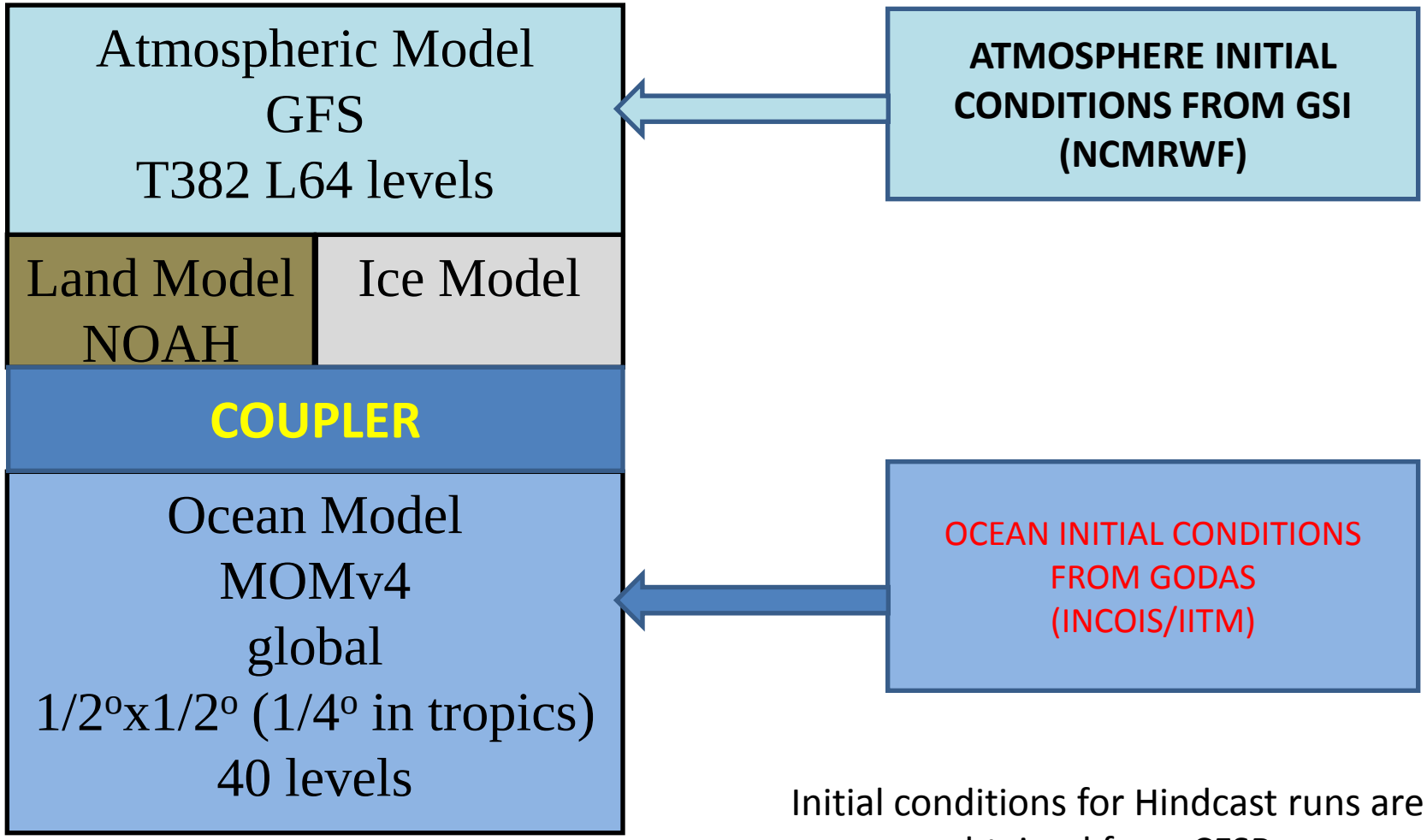
Improved skill

High skill

Preeti et al., (2009)

Rajeevan et al., (2011)

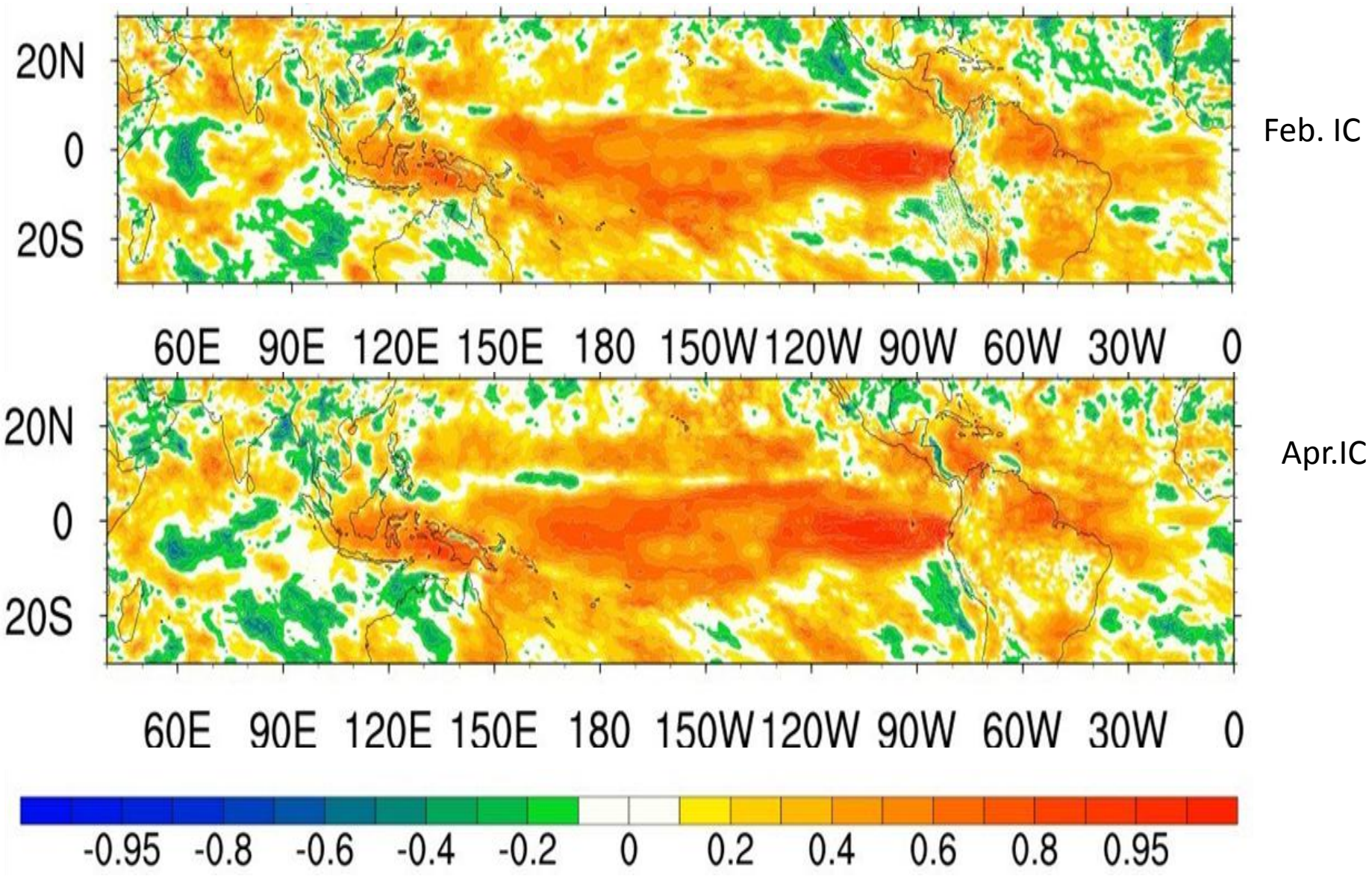
IITM CFS Model: Seasonal Prediction



Initial conditions for Hindcast runs are obtained from CFSR

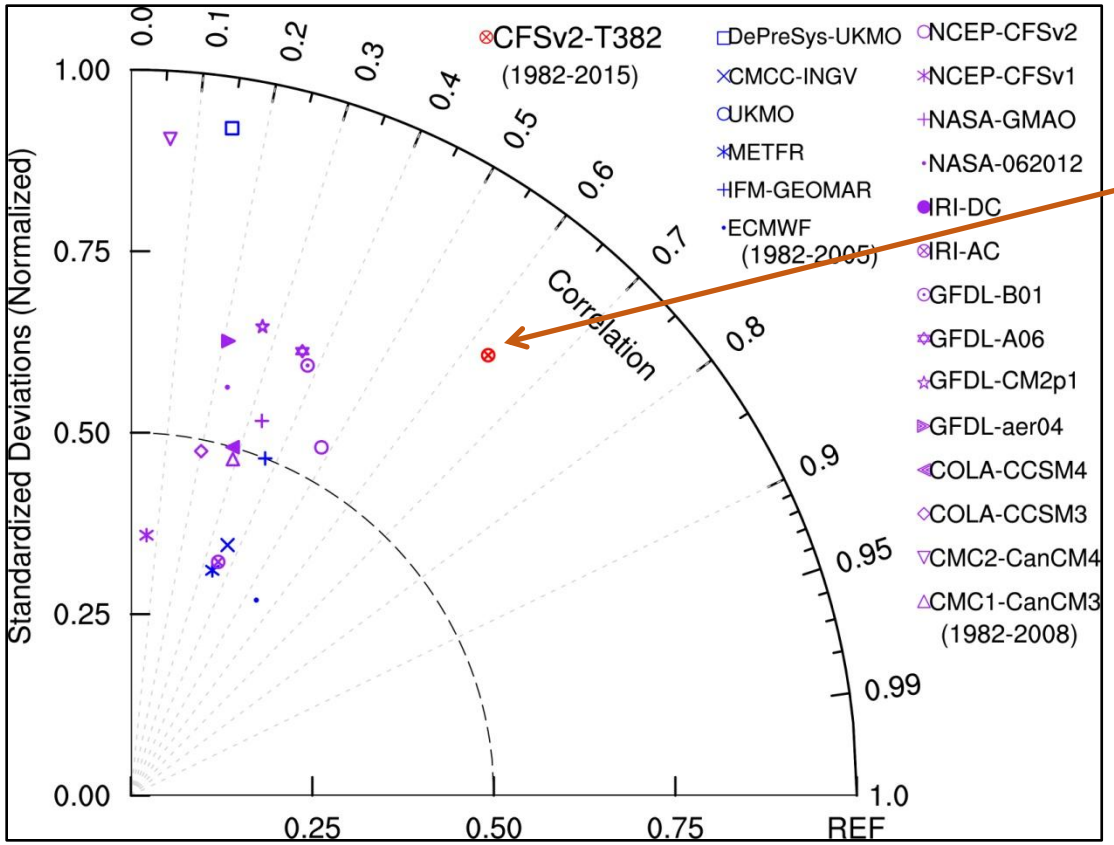
(Original model is adopted from NCEP)

Anomaly Correlation Between Observed and Predicted (Rain: 1982-2008)

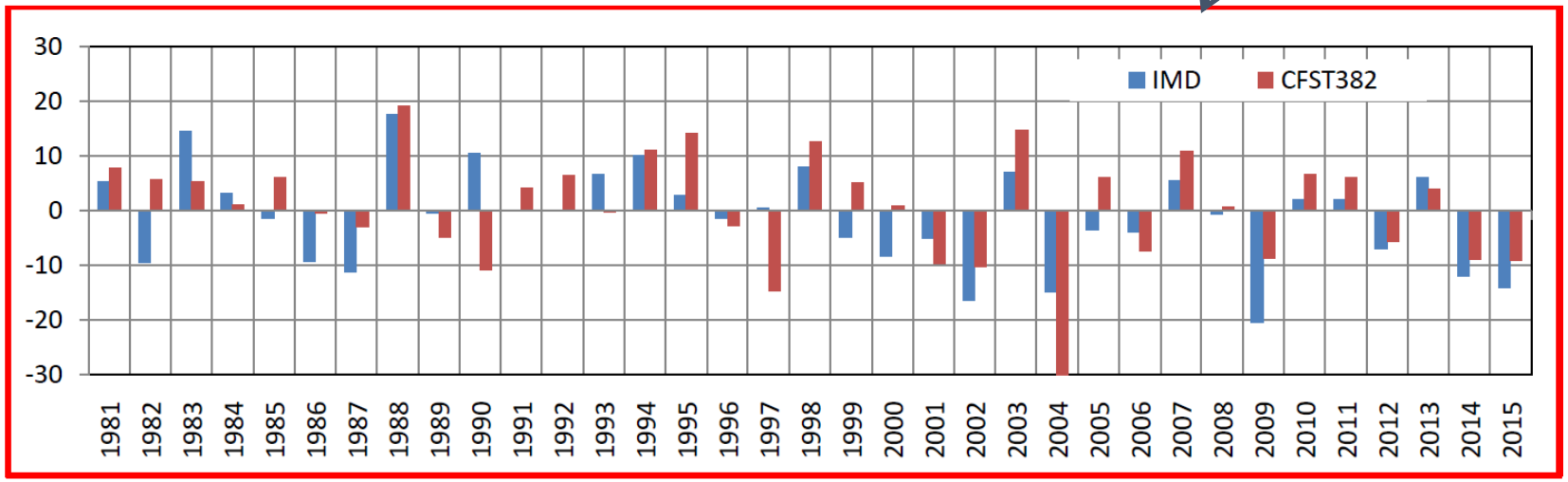


Feb. IC

Apr.IC

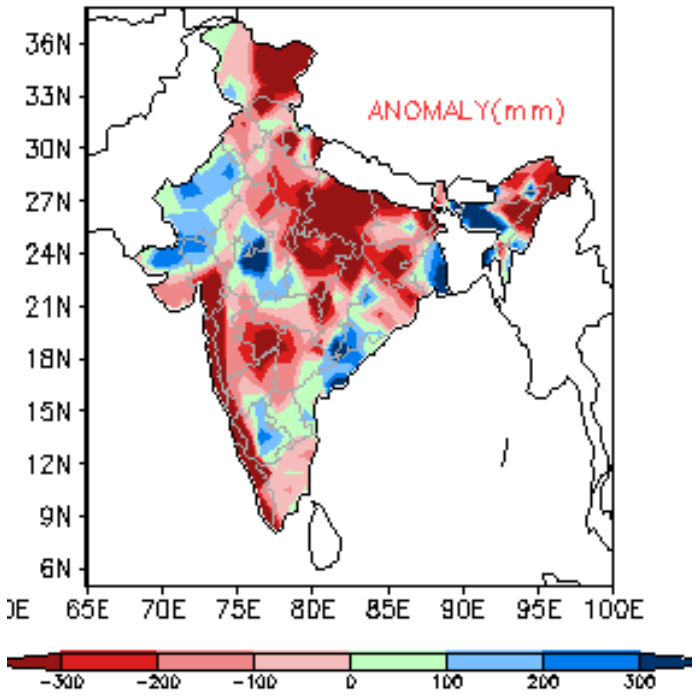


Monsoon Mission Model Performance (Prediction Skill as well as interannual variance) is better than other models for Indian Monsoon.

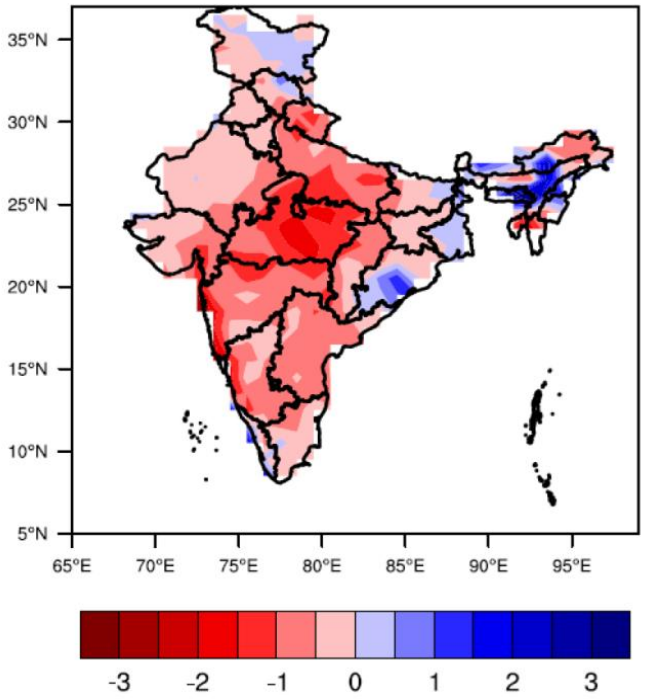


Forecast Verification for 2015 Summer Monsoon IITM CFS T382

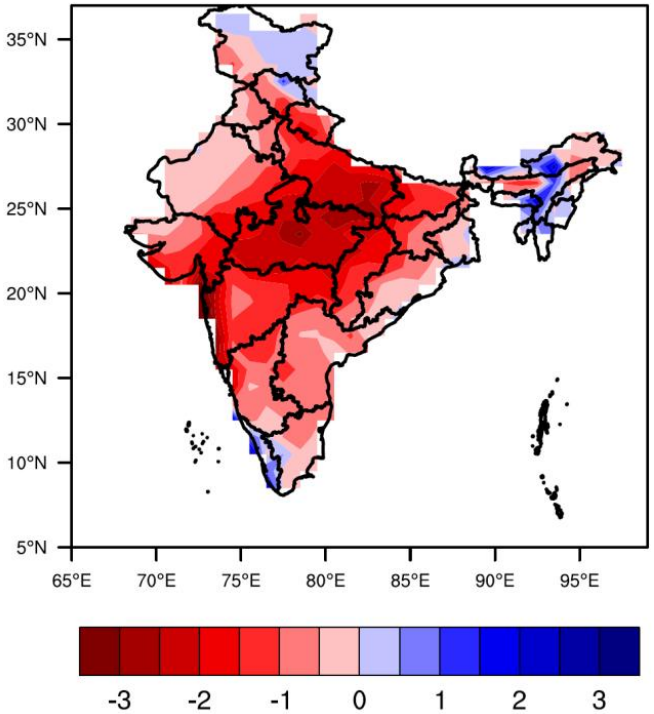
Observed, 84%



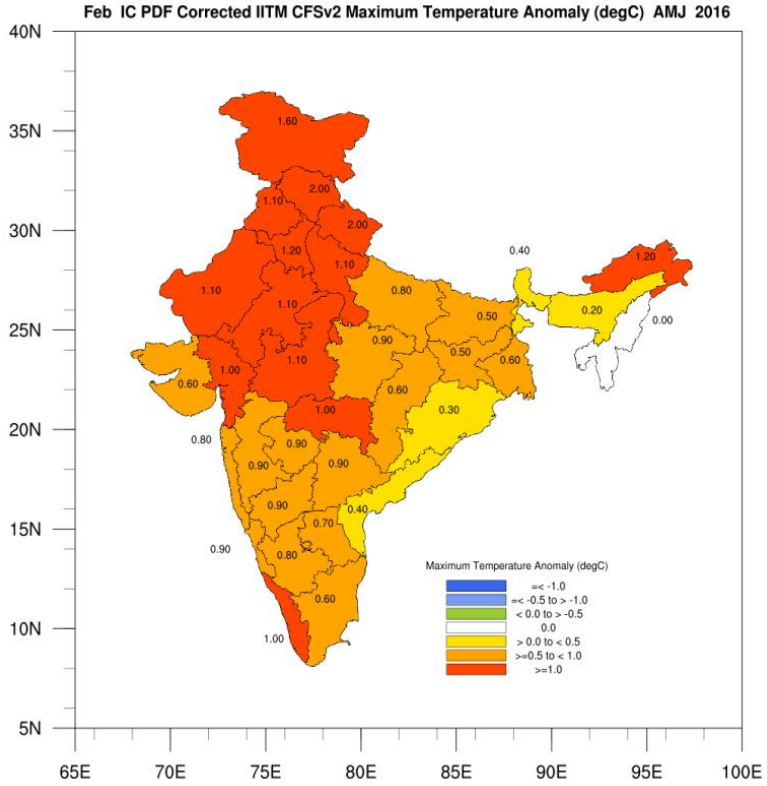
Feb. IC, 91%

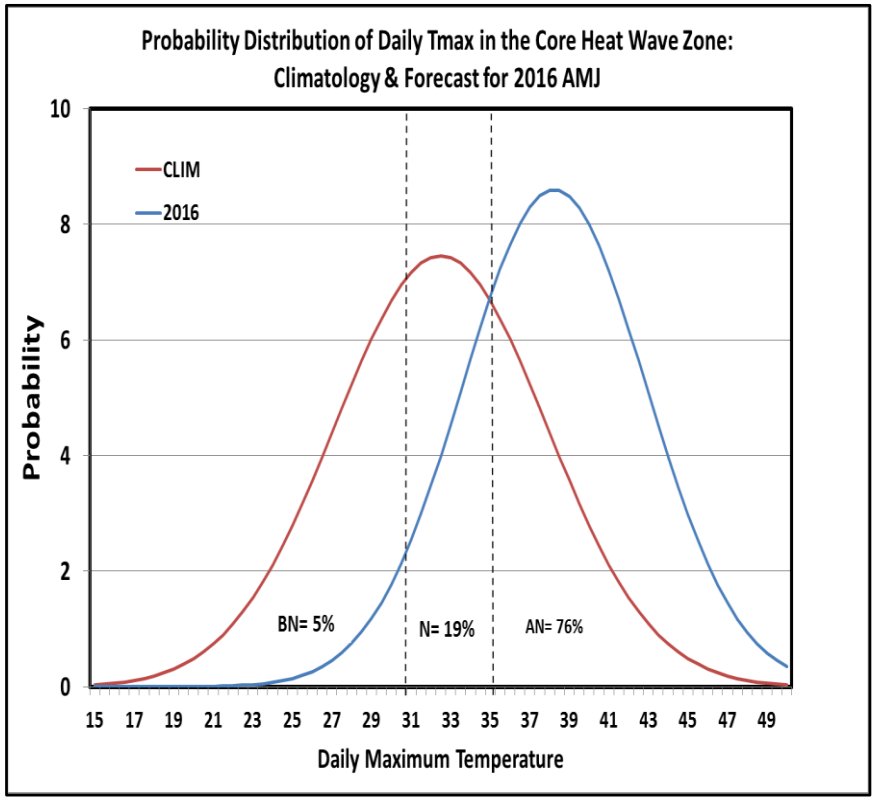


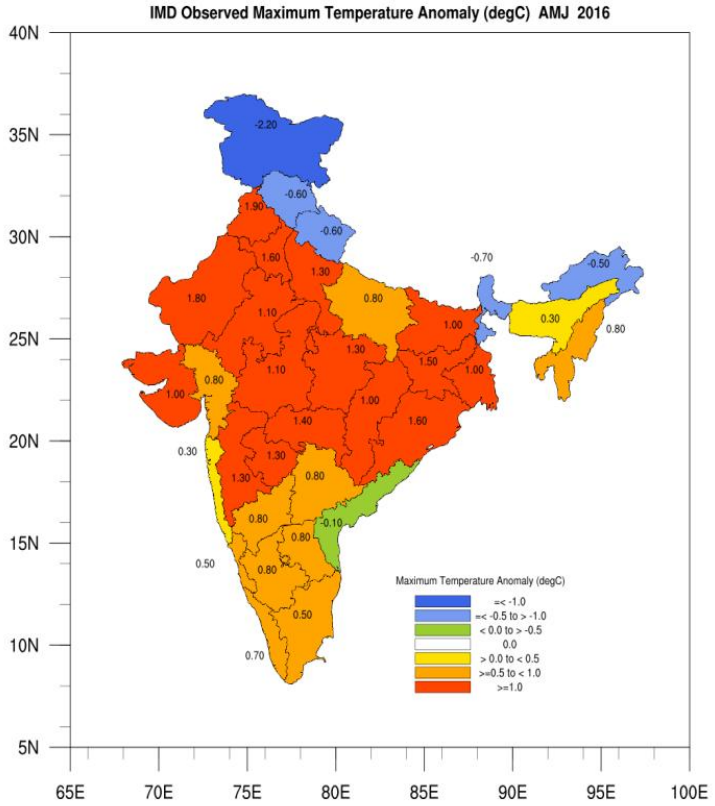
Apr. IC , 84%



Hot Season Seasonal Forecasts



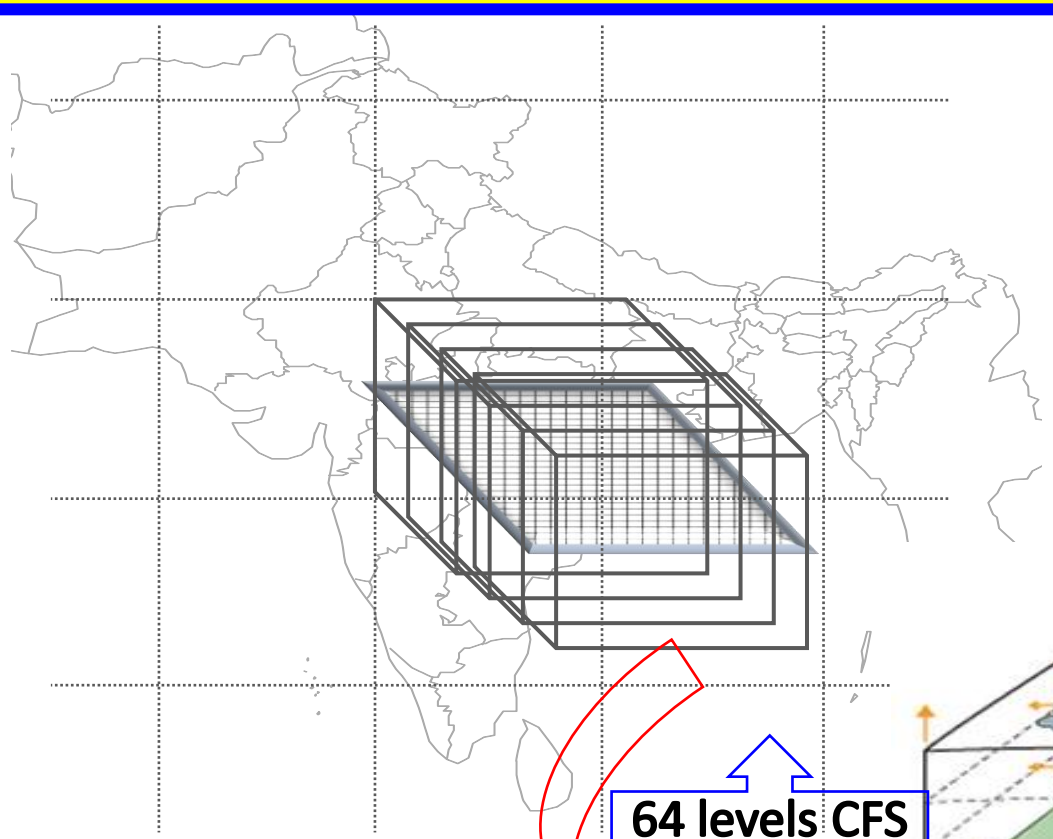




For the first time, IMD issued a seasonal forecast for hot weather season, which has become a very successful.

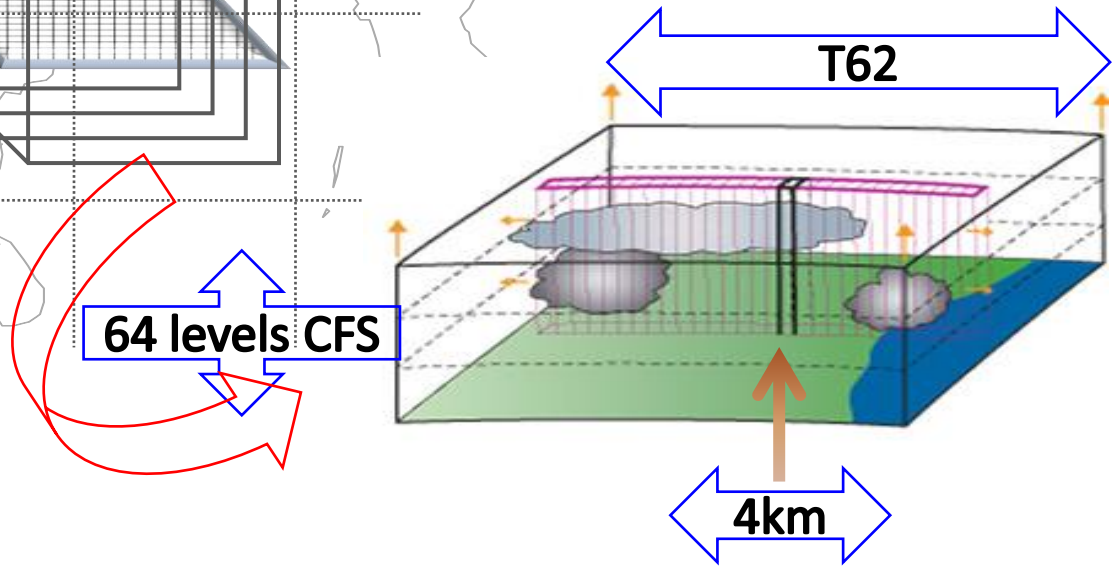
Cloud Resolving Models

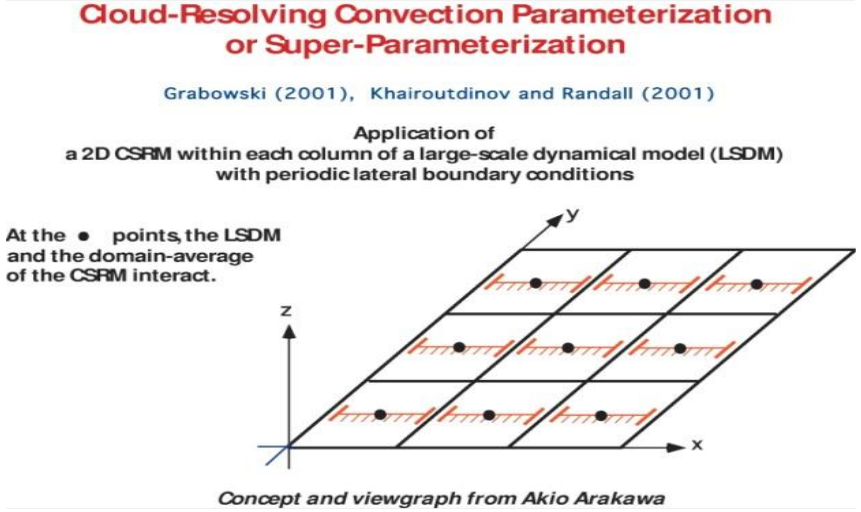
Superparameterized CFSv2-T62 (SPCFS) Analyses of 6.5 year free run



Convective tendencies are explicitly simulated with a **C**loud **R**esolving **M**odel running in each GCM grid column which replaces the traditional cumulus parameterization of the GCM.

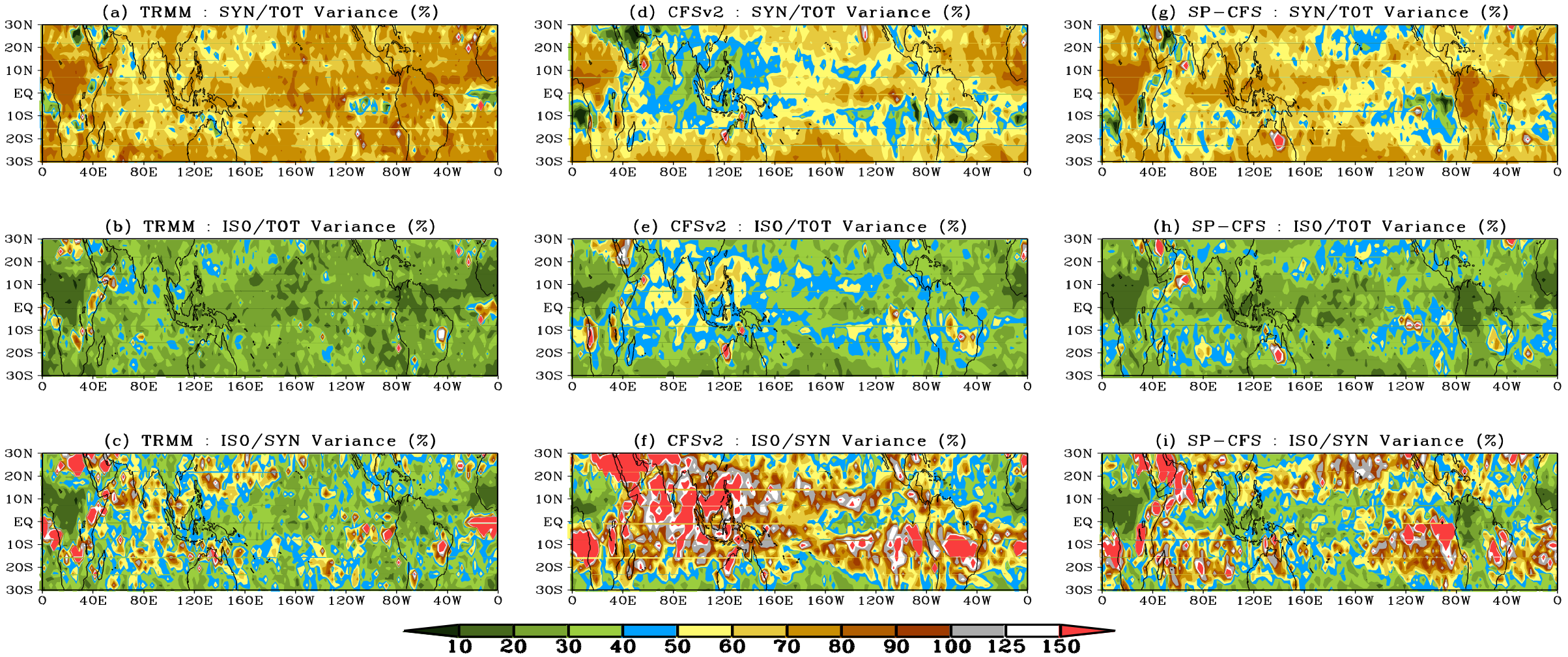
- Model integrated for 6.5 years and five years are analyzed





Bidyut B. Goswami, R. P. M. Krishna, P. Mukhopadhyay, Marat Khairoutdinov, and B. N. Goswami, 2015: Simulation of the Indian Summer Monsoon in the Superparameterized Climate Forecast System Version 2: Preliminary Results. J. Climate, 28, 8988–9012

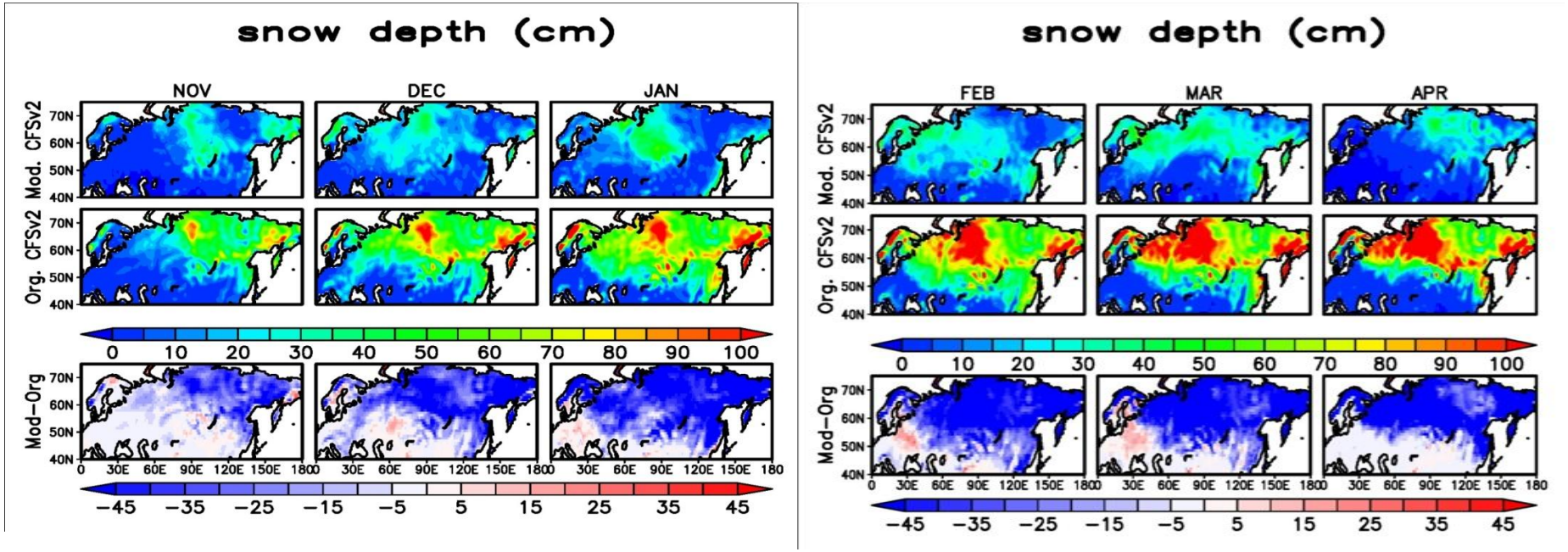
Ratio of Synoptic to ISO variance.



SP-CFS has improved the bias in synoptic and ISO variance

Improvement in Land Surface Modelling

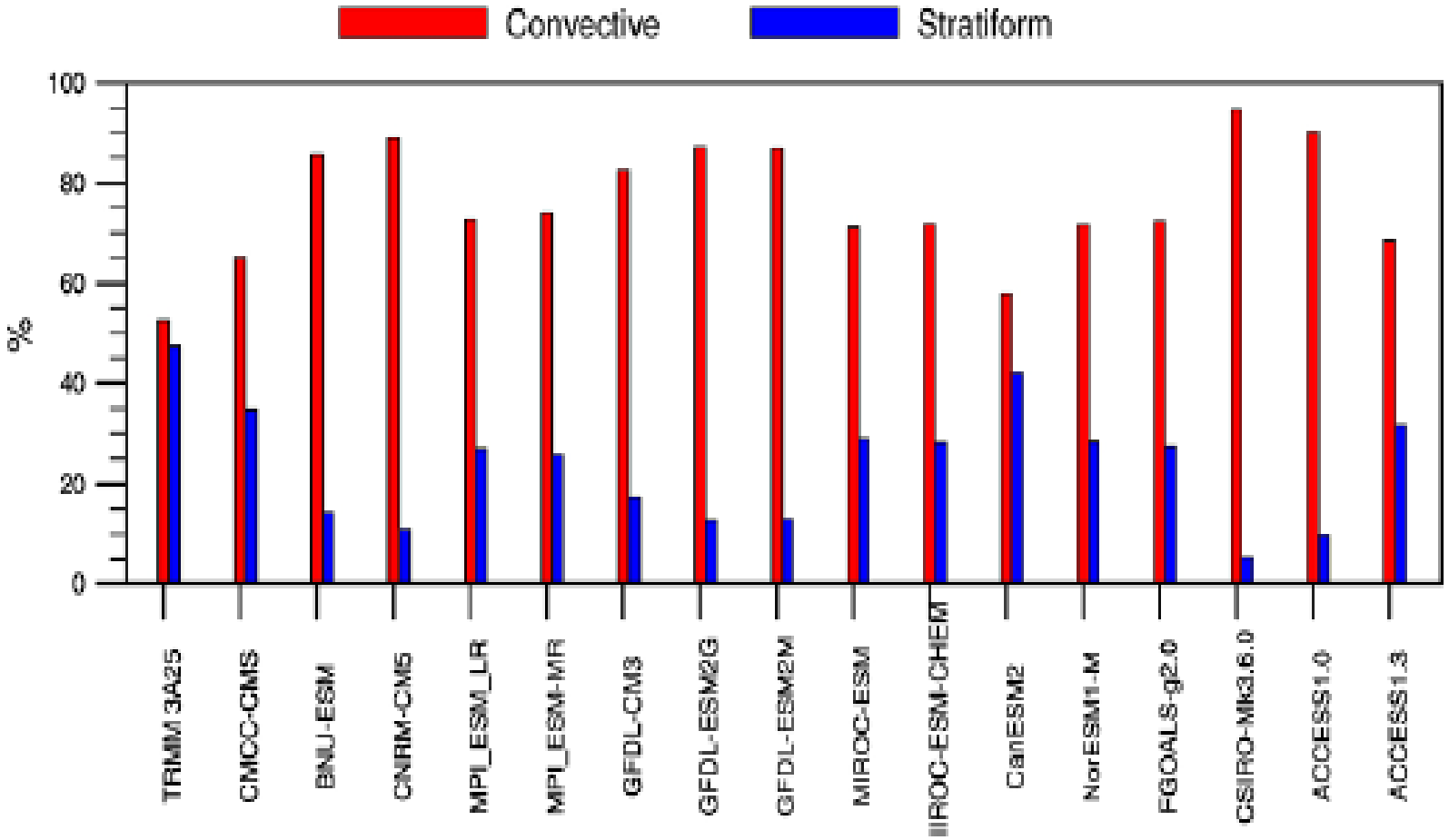
ILS is incorporated in CFSv2, which involves incorporation of five prognostic variables into ESMF, initial conditions, restart file



- **A preliminary result from the simulation of one year it is evident that amount of snow is much reduced in new version of CFSv2**

- **There is further scope to improve snow depth simulation using new schemes (continuing)**

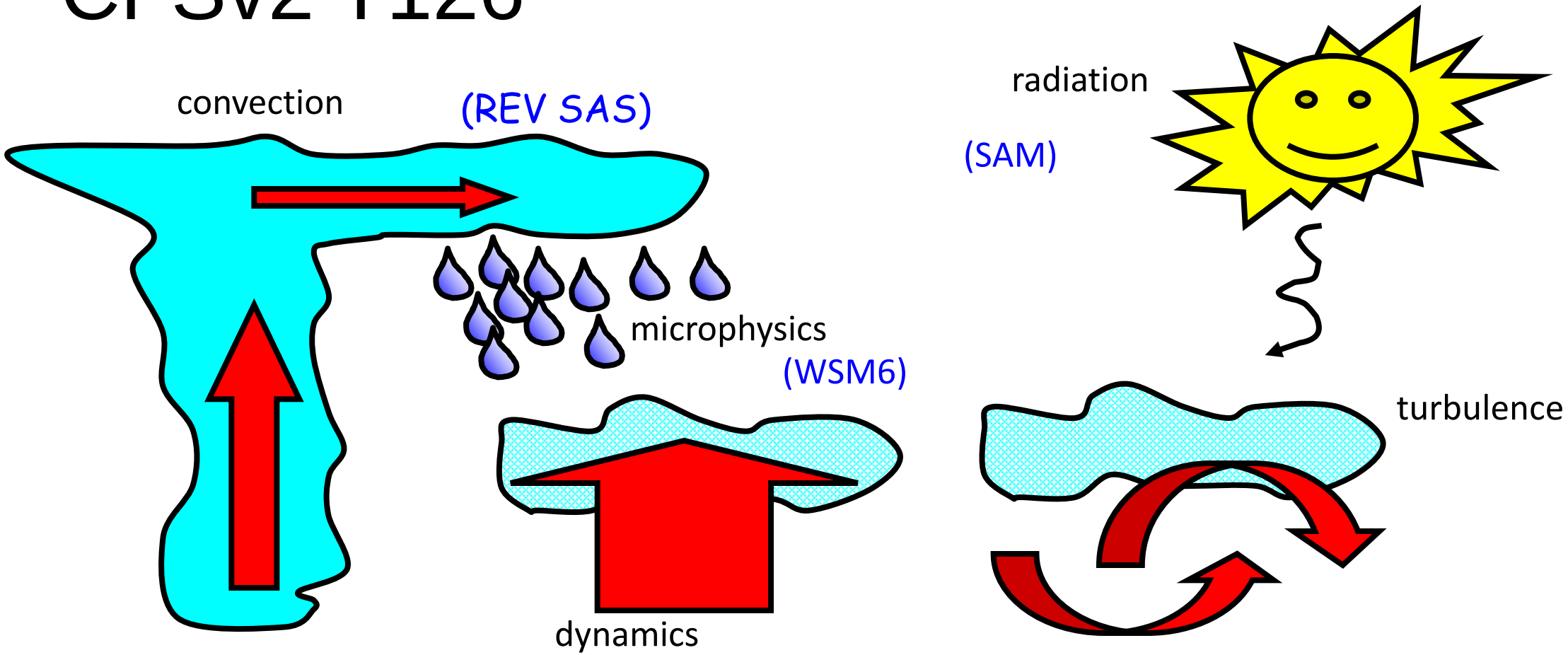
Fig. 8 Percentage of precipitation (averaged over SAM region, 10°N–30°N and 70°E–100°E) explained by convective (*red bars*) and stratiform (*blue bars*) types in the historical simulations of the 16 CMIP5 models along with that from observations (TRMM)



Most of the models produce ~80-90% convective rain and 10~20% stratiform rain as against 55% convective and 45% Stratiform rain in reality

Sabeerali et al. 2015

Revised Cloud-Convective-Radiation in CFSv2 T126



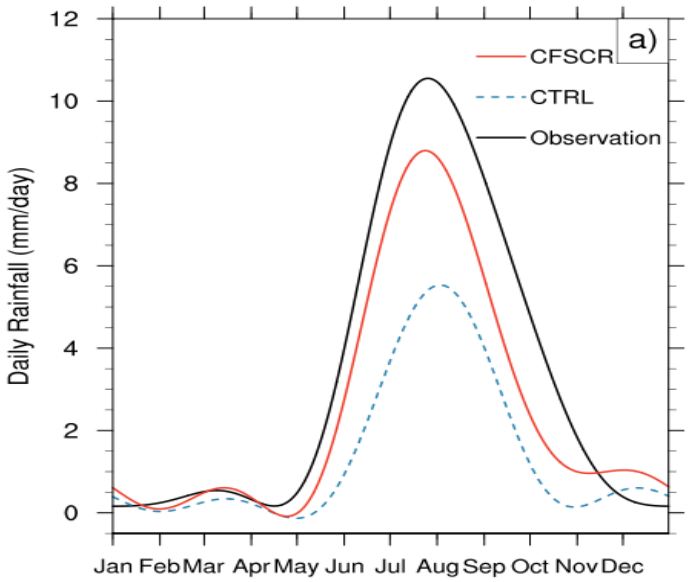
Clouds are the result of complex interactions between a large number of processes

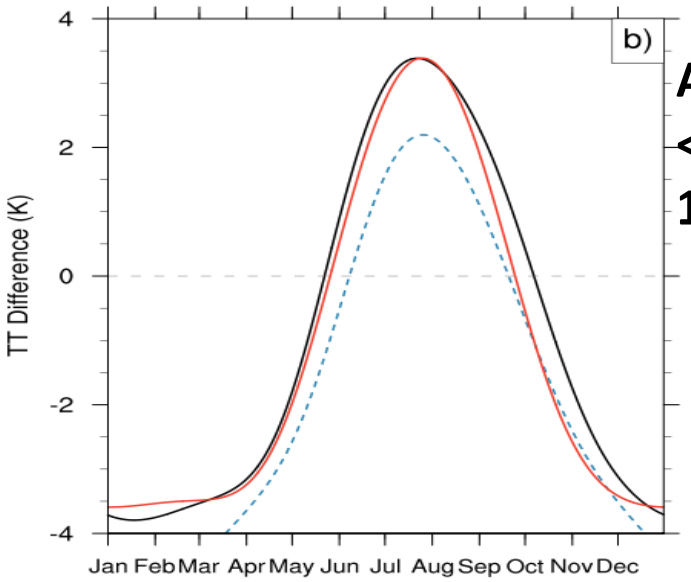
SAM: System of Atmospheric Model

Courtesy: Partha

Revised convection, modified microphysics and radiation is able to improve the mean state and Intra-seasonal variability of CFSv2T126

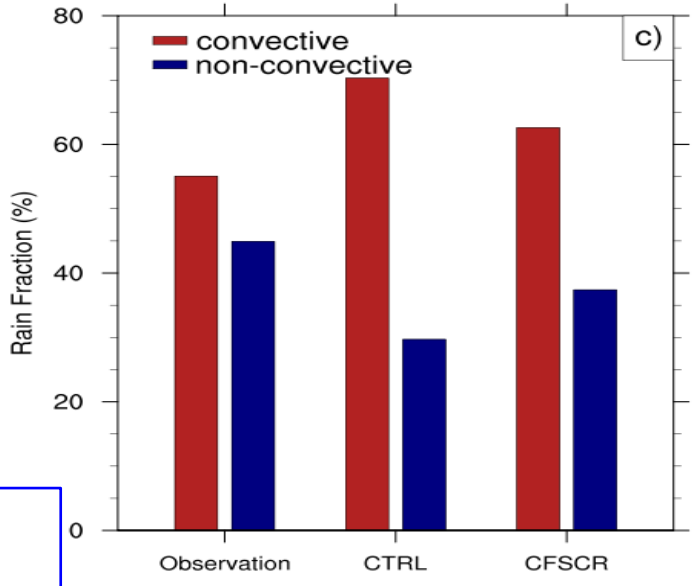
Annual Rainfall Cycle
<73°-85°E,15°-25°N>

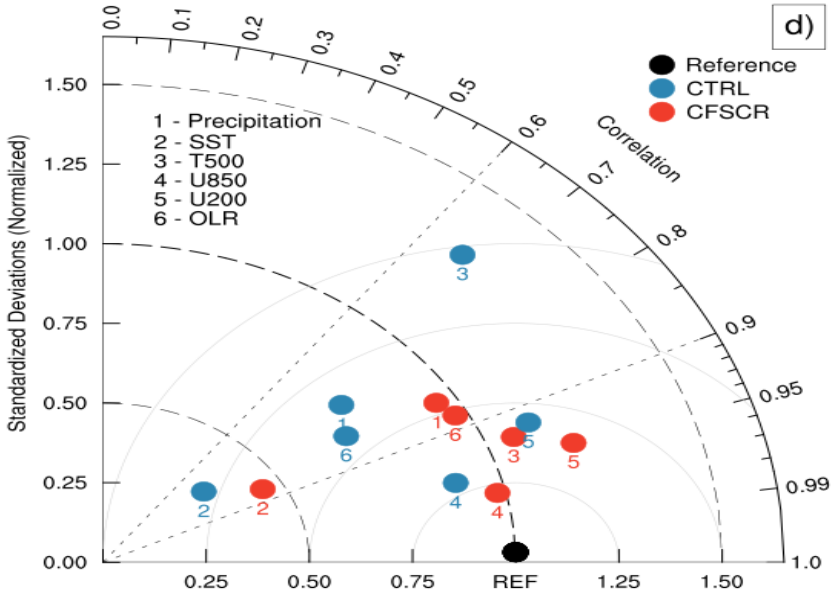




Annual TT Difference
<40°-100°E,5°-35°N> - <40°-100°E,15°S-5°N>

<40°-120°E, 15°S-30°N>

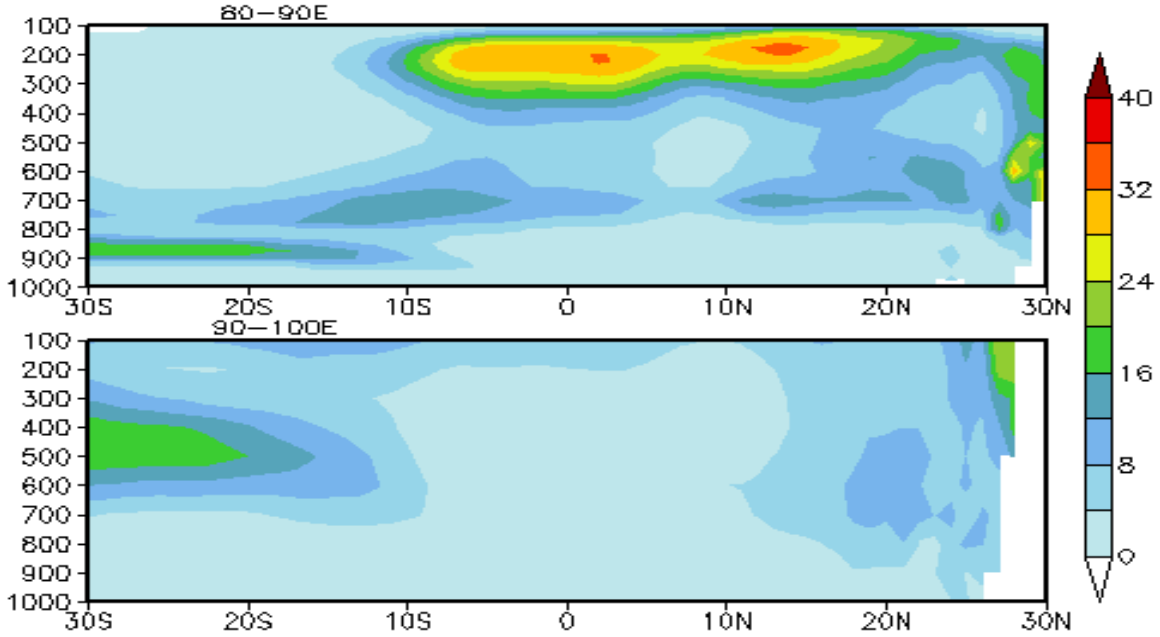




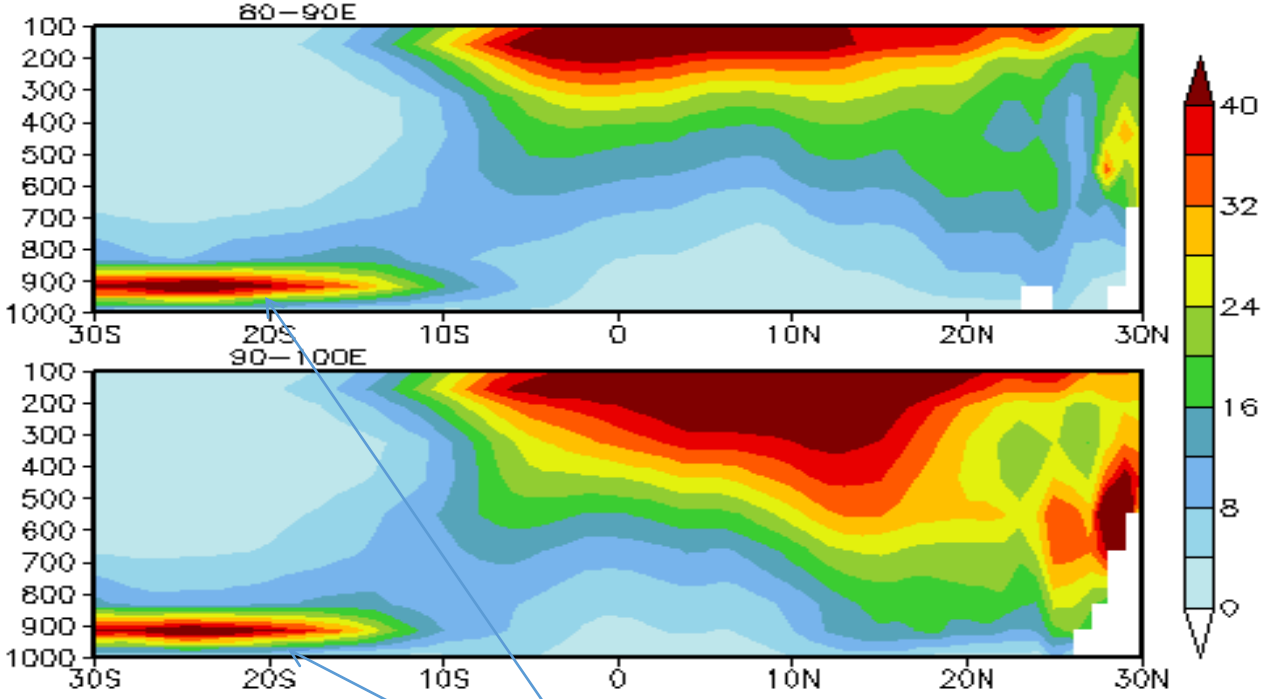
Abhik et al. (under revision)

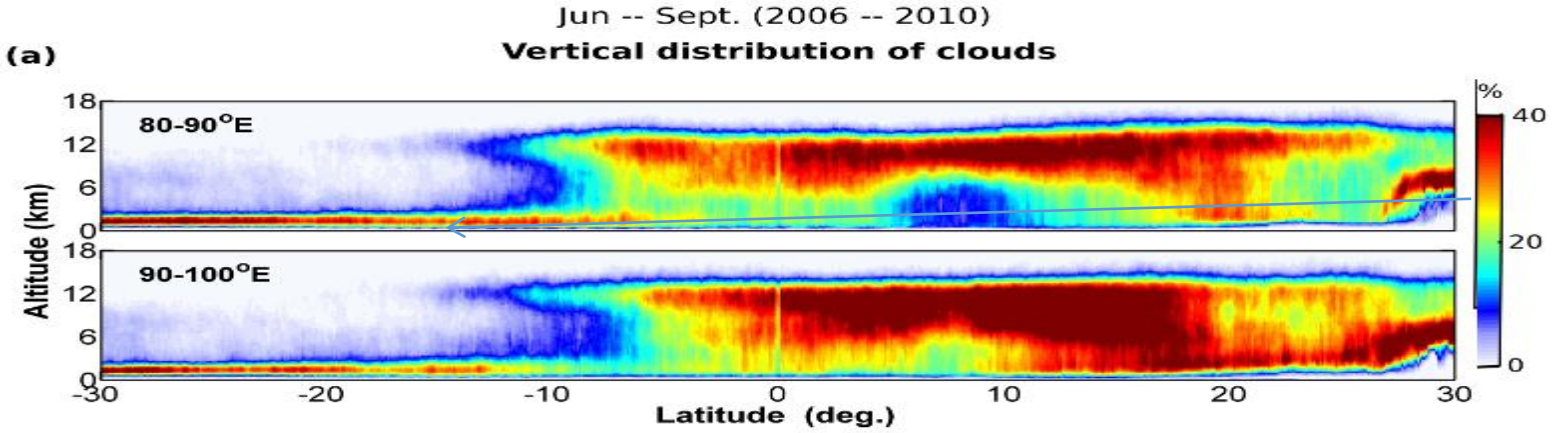
Vertical distribution of clouds (JJAS) averaged over 80-90E and 90 to 100E

CFS



CFS-CR



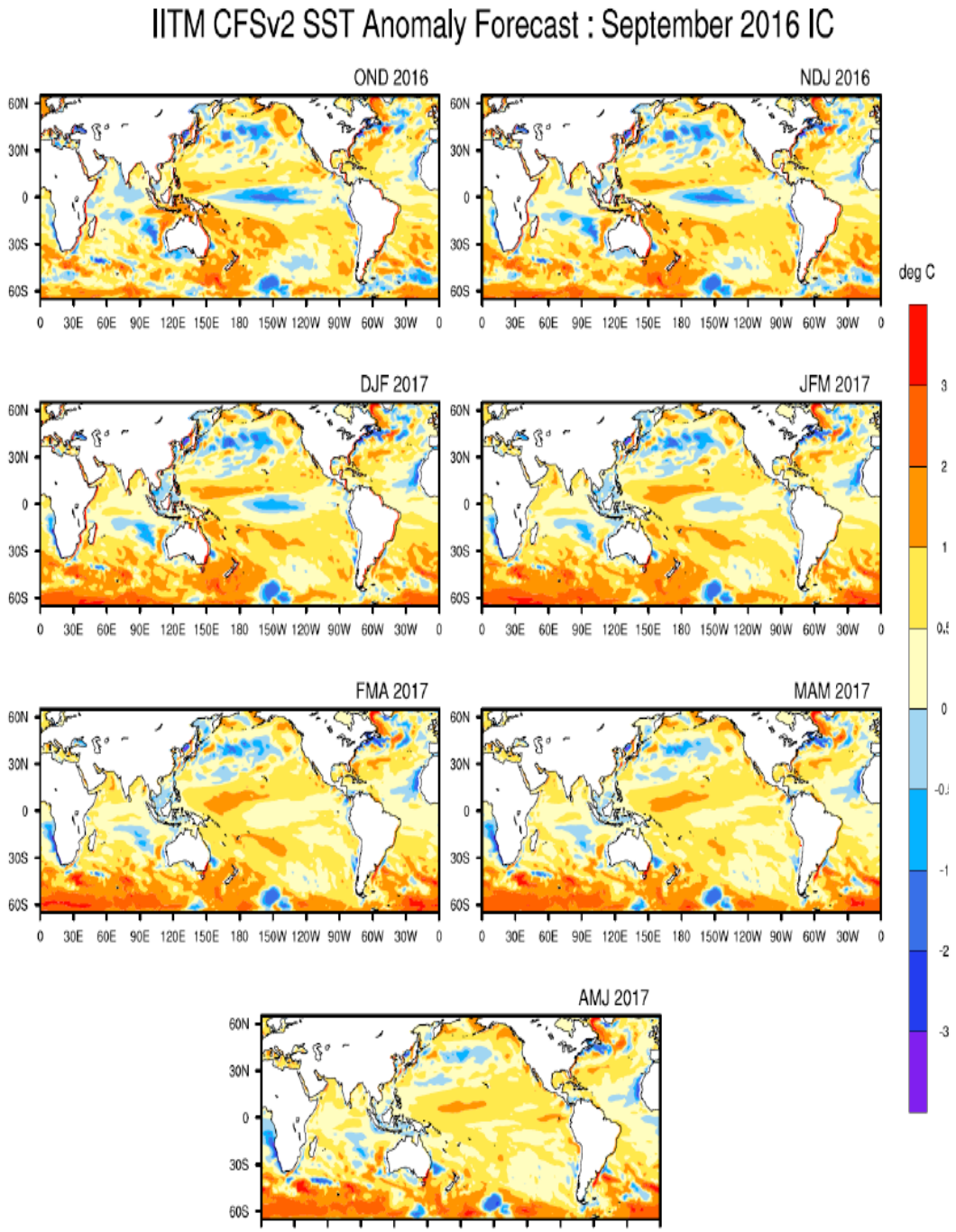


Low Cloud captured by CFS-CR as seen in CloudSat observations. CFSv2 does not capture

Courtesy: Dr Partha, IITM

T. Narayan Rao, Aneeshkumar et al.

Regional Climate Services



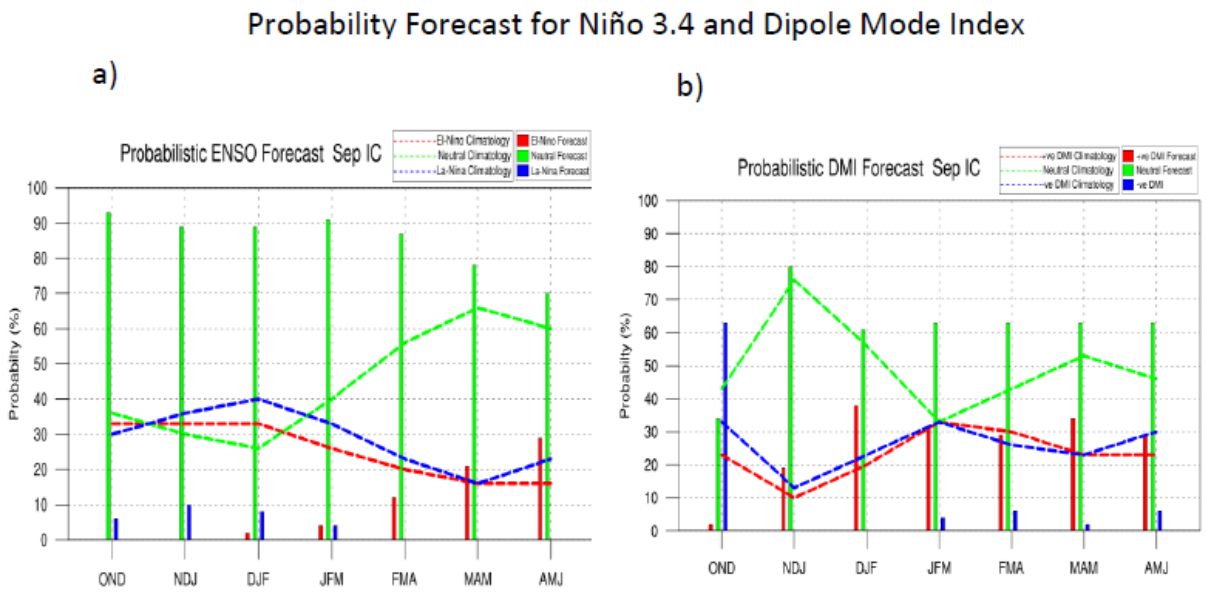


Fig.5: Probability forecast along with climatological probability of **(a)** Niño 3.4 and **(b)** Indian Ocean Dipole Mode Index from high resolution CFSv2. Data source for Climatology probabilities: NOAA Extended Reconstructed SST V3b. Criteria used for Probabilistic ENSO Forecast: ≤ -0.5 La Niña, >0.5 to <-0.5 neutral, ≥ 0.5 El Niño. Criteria used for Probabilistic DMI Forecast: ≤ -0.2 negative DMI, >0.2 to <-0.2 neutral, ≥ 0.2 positive DMI.

IMD Pune now has been recognized by WMO as the Regional Climate Centre to provide regional climate services

www.imdpune.gov.in

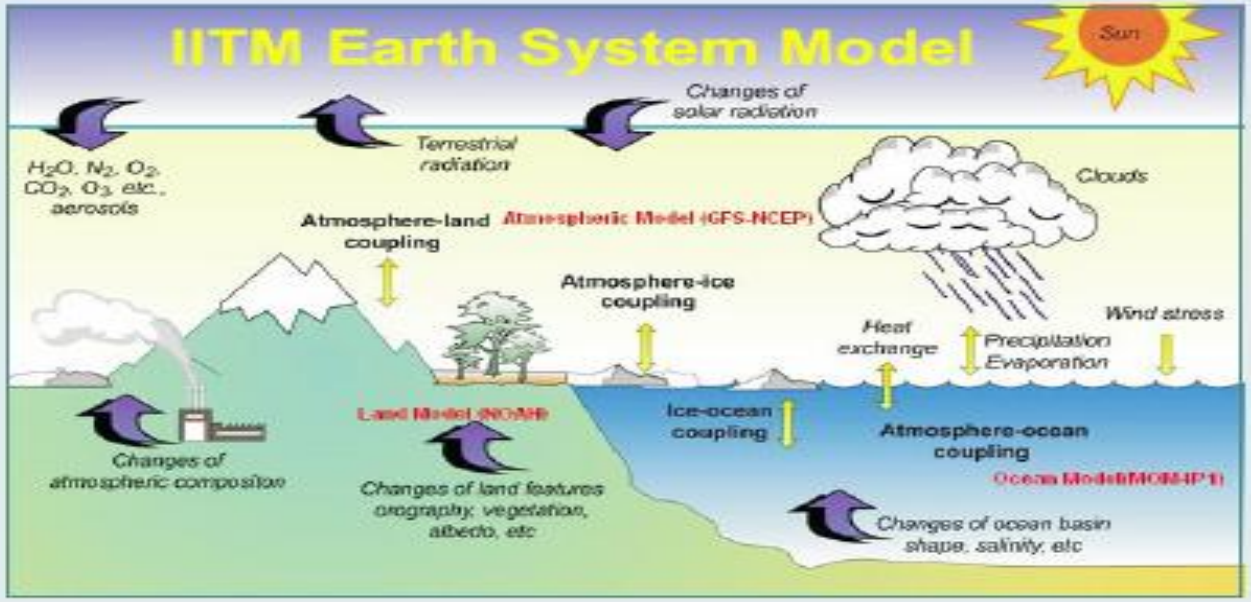
Climate Change Modelling

THE IITM EARTH SYSTEM MODEL

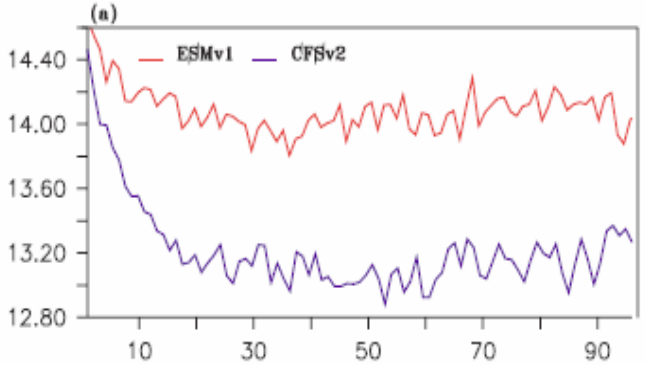
Transformation of a Seasonal Prediction Model to a Long-Term Climate Model

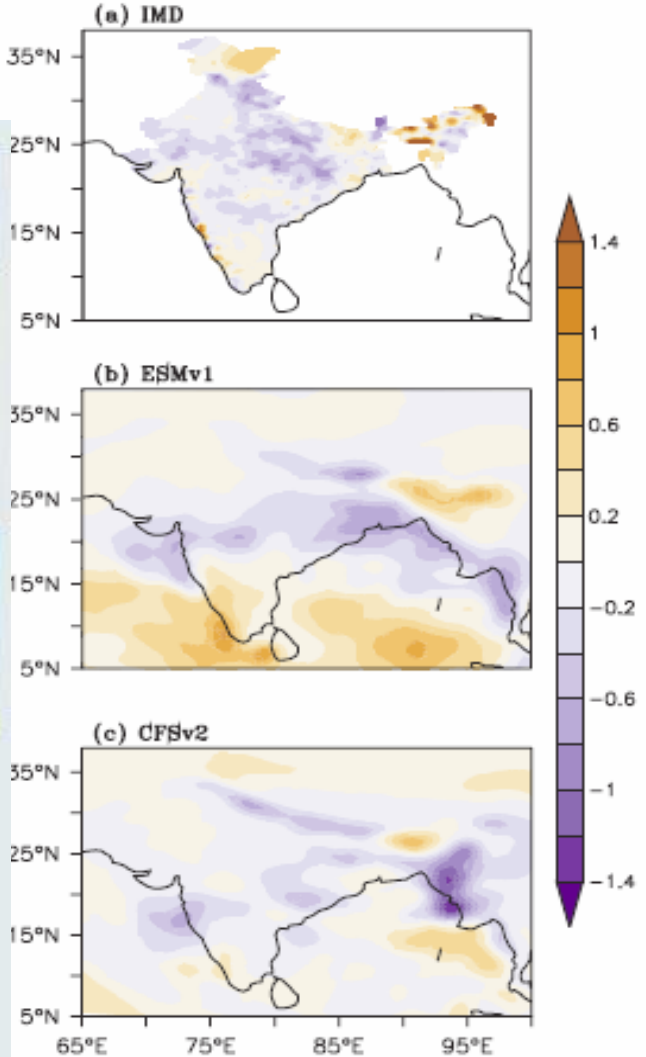
BY P. SWAPNA, M. K. ROXY, K. APARNA, K. KULKARNI, A. G. PRAJEESH, K. ASHOK, R. KRISHNAN, S. MOORTHI, A. KUMAR, AND B. N. GOSWAMI

This work documents the fidelity of the newly developed Indian Institute of Tropical Meteorology climate model simulations and demonstrates its suitability to address the climate variability and change issues relevant to the South Asian monsoon.



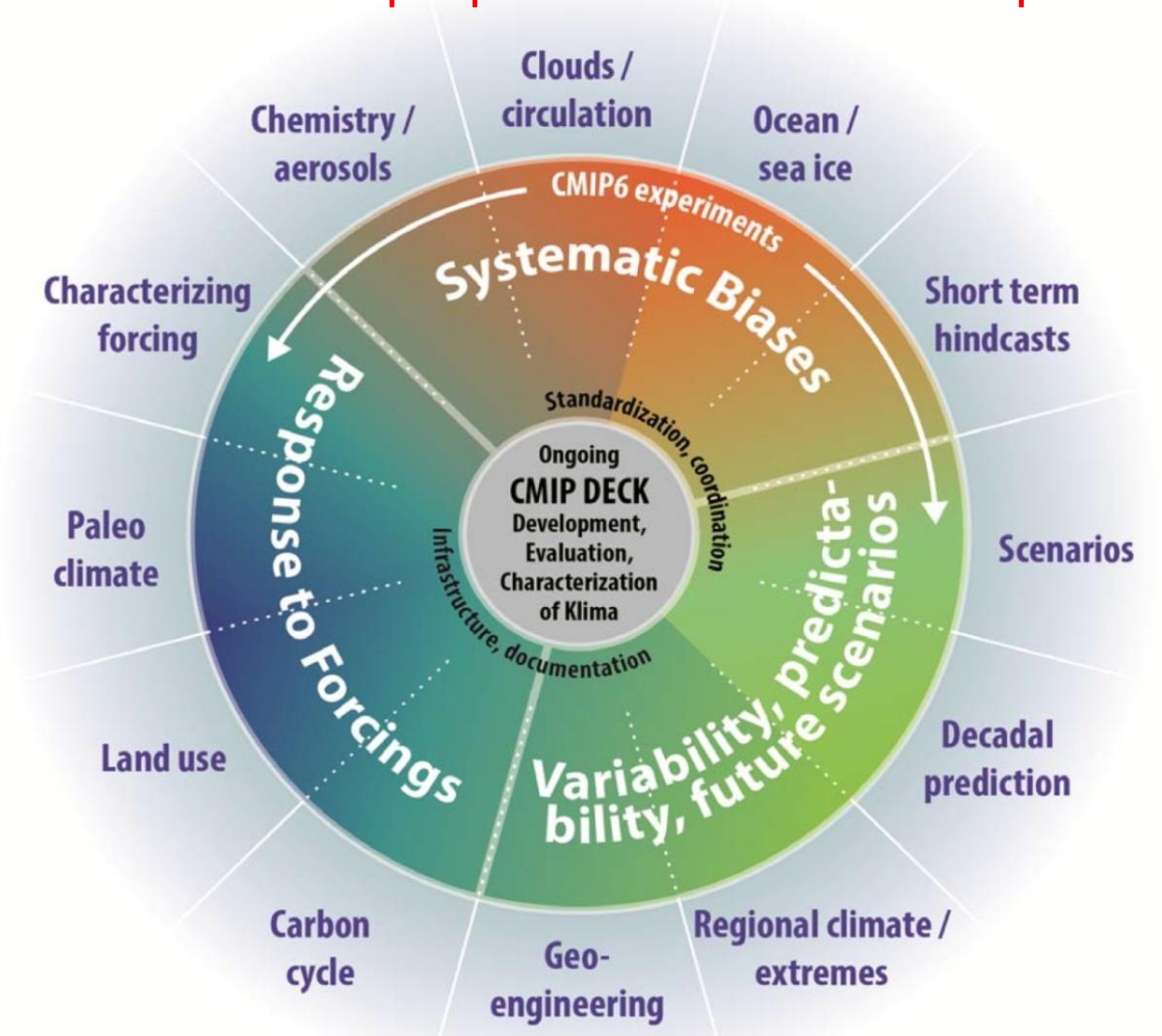
The coupled ocean-atmosphere-land model with interactive ocean bio-geochemistry developed at CCCR, IITM to study the long-term changes in Climate with special emphasis on Asian Monsoon. The components of IITM ESM are Atmosphere (NCEP GFS, Ocean (MOM4p1, GFDL) and Land (NOAH) model.





CMIP6 Schematic: Participation in the 6th Intergovernmental Panel for Climate Change (IPCC)

Initial proposal for the CMIP6 experimental design has been released



CMIP6 Concept: A Distributed Organization under the oversight of the CMIP Panel

IITM ESM will participate in the climate modeling CMIP6 experiments for the IPCC 6th Assessment Report

Time-varying aerosol distributions in IITM ESM from CMIP

(Courtesy: Ayantika Dey Choudhury; Data source: Stefan Kinne, Bjorn Stevens, Max Planck)

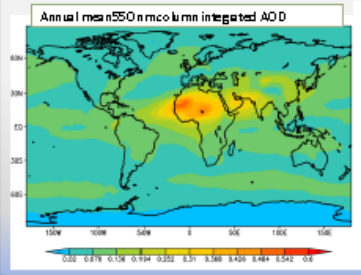
To understand the impact of natural tropospheric aerosols on climate: as observed in IITM-ESM

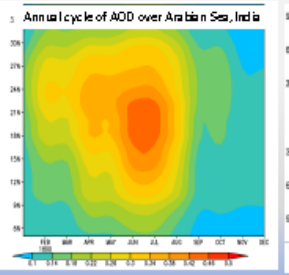
Sensitivity experiments : 50yrs model integration
1) Pre-Industrial aerosols 2) No aerrosols (Clean Environment)

Pre-Industrial model setup

•PI Aerosols

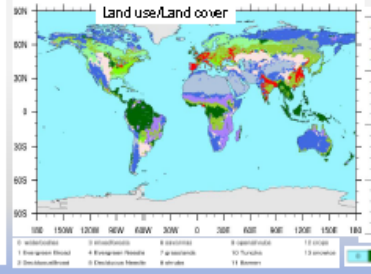
- MAC-V2 aerosol data (1°x1° AOD, SSA,ASY and 20layer EXT) (Max Planck Institute Aerosol Climatology V2, update of MAC-v1, Kinne et al 2013)
- The 3D (T62L64) AOD, SSA, ASY for IITM ESM-V2 is constructed by weighting the aerosol properties with the vertical profile of aerosol extiction data.
- Natural aerosols for 1850 are representative of Pre-Industrial era and implemented on monthly timescales

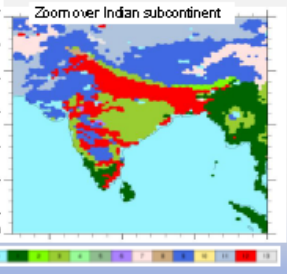




•PI Land use/ Land cover

- UNH transient historical crop and pasture dataset (.25 x .25)(Hurtt et al. (2015) for the period1870-2015)
- Crop area in IITMESM-v2 set to UNH data. Reduction of anthropogenic area implies proportional increase in all natural vegetation types for the cell. The most abundant vegetation type is set as dominant for that cell
- This method is used to derive the Pre-Industrial land use/land cover at T62 grid





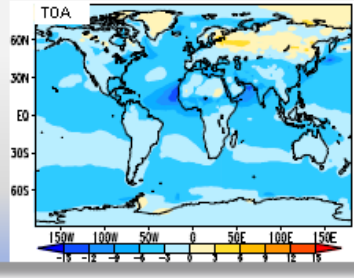
Aerosol Direct Radiative Forcing

Aerosol Radiative Forcing (ΔF=Faer-Fclean)

Faer is the net flux in the presence of natural aerosols
Fclean is the net flux reference atmospheric condition (clean)

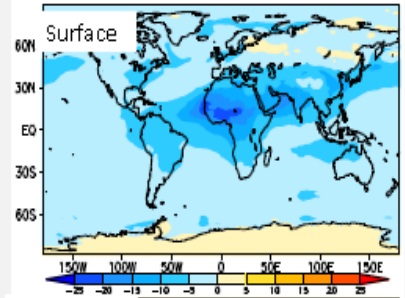
ARF		Clear Sky (W/m²)	Total Sky (W/m²)
TOA	Net Total Radiation (SW+LW)	-2.63	-0.45
	Net Solar Radiation (SW)	-3.49	-0.89
ATM	Net Total Radiation (SW+LW)	2.47	2.39
	Net Solar Radiation (SW)	1.65	1.52
SFC	Net Total Radiation (SW+LW)	-5.11	-2.84
	Net Solar Radiation (SW)	-5.15	-2.39

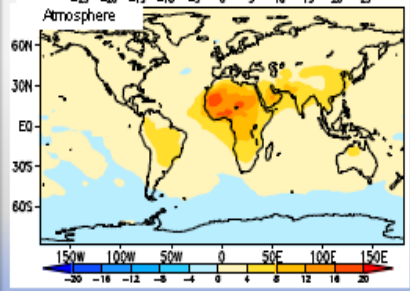
Solar Radiative forcing for clear sky



Aerosol Direct Radiative Forcing

Solar Radiative forcing for clear sky

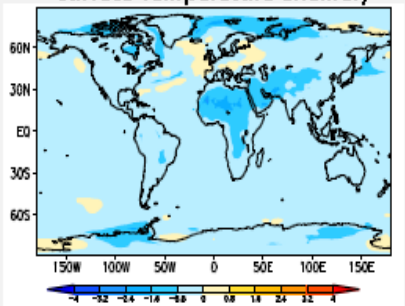




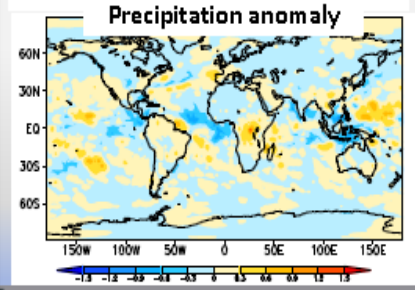
- ✓TOA direct solar radiative flux for clear sky conditions indicate negative forcing over tropics
- ✓The Surface radiative forcing show considerable decrease over regions with high natural aerosol loading
- ✓The atmospheric radiative forcing show an increase in absorption of solar energy over high aerosol regions

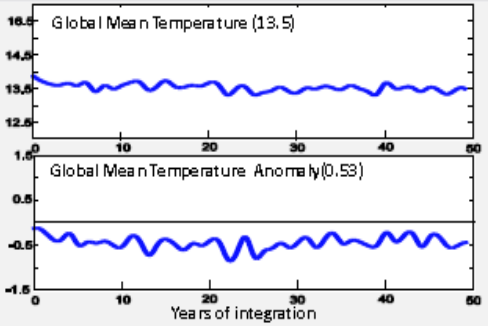
Surface Temperature & Precipitation Change

Surface Temperature anomaly



Precipitation anomaly

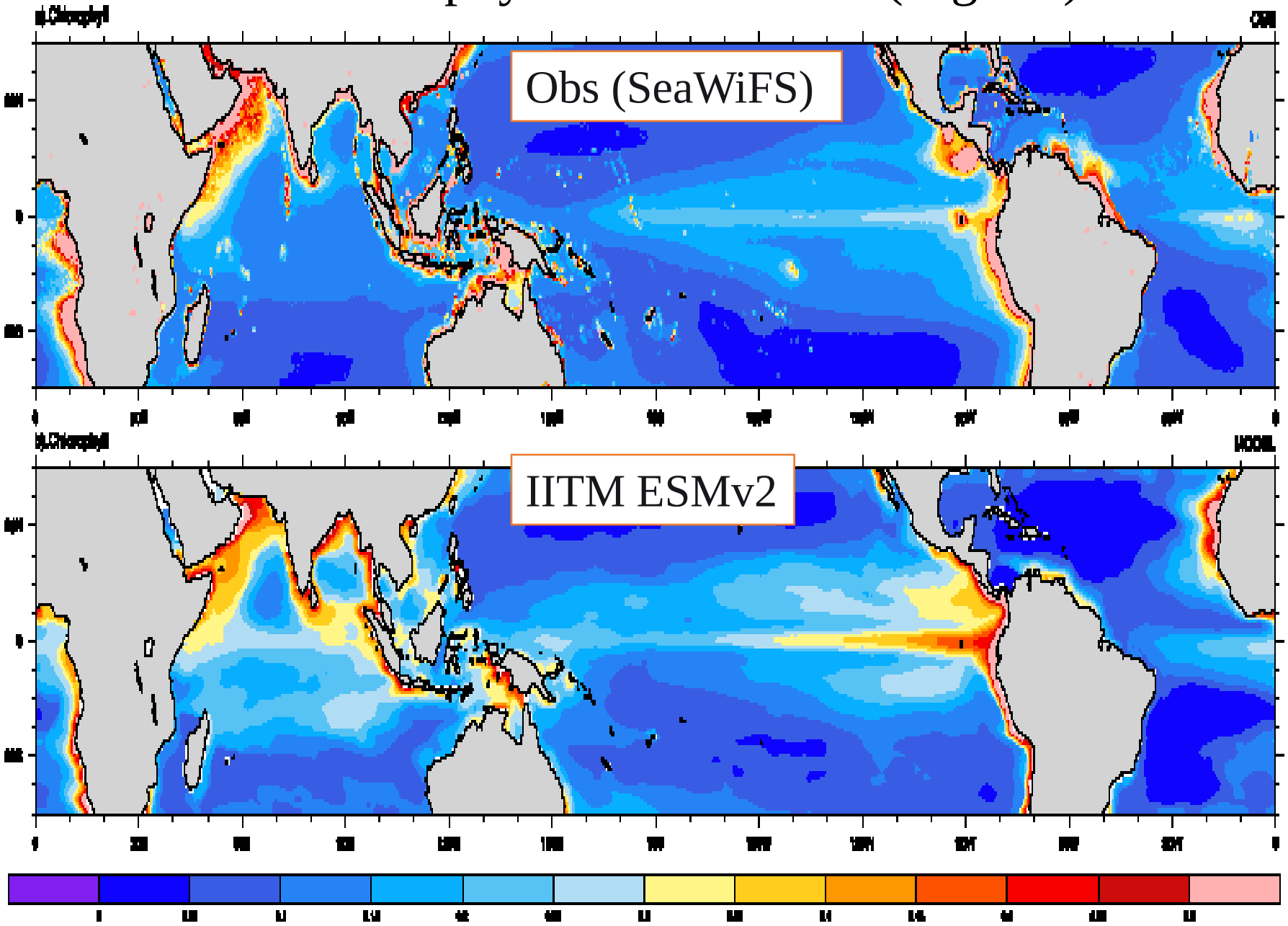




Global	Tropics
Temperature Change ~-0.48° C	Precipitation Change 0.06mm/day

- ✓Surface temperature response indicates cooling over almost entire globe, specially over northern hemispheric continents
- ✓Precipitation anomaly shows a reduction over various tropical region s like South Asia and equatorial Atlantic

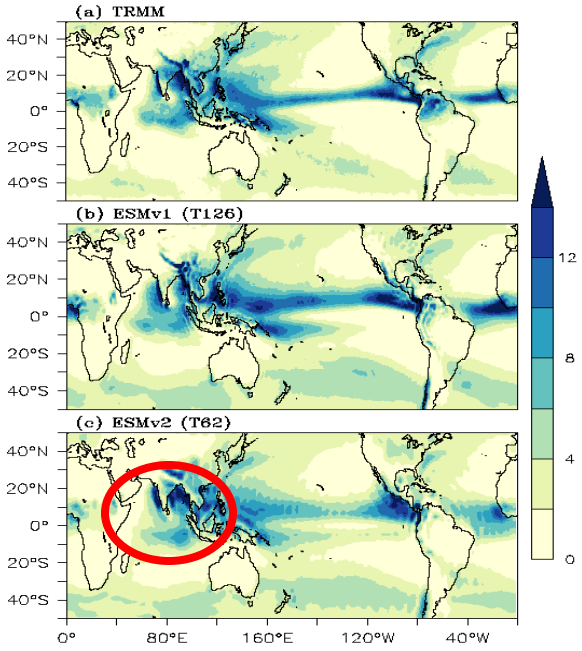
Chlorophyll Concentration (Mg m^{-3})



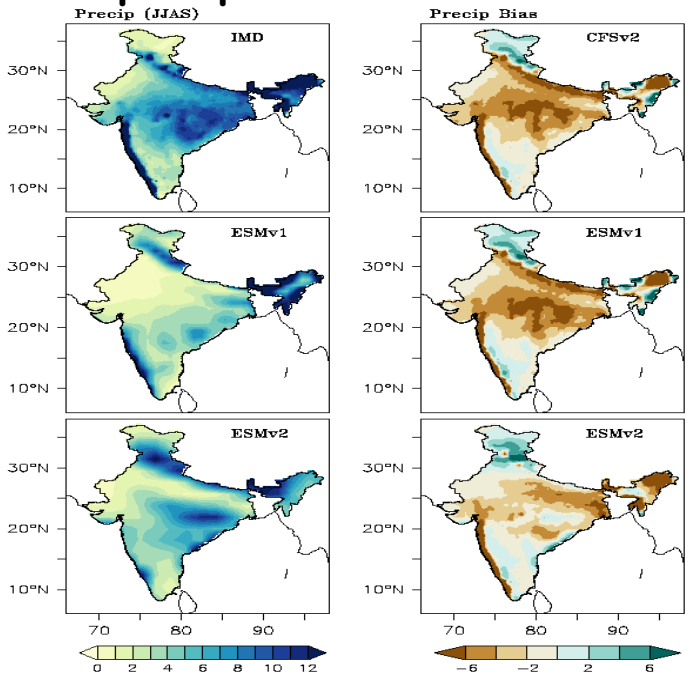
Courtesy: Sandeep, CCCR

Improvements in IITM ESMv2 Mean Monsoon Characteristics

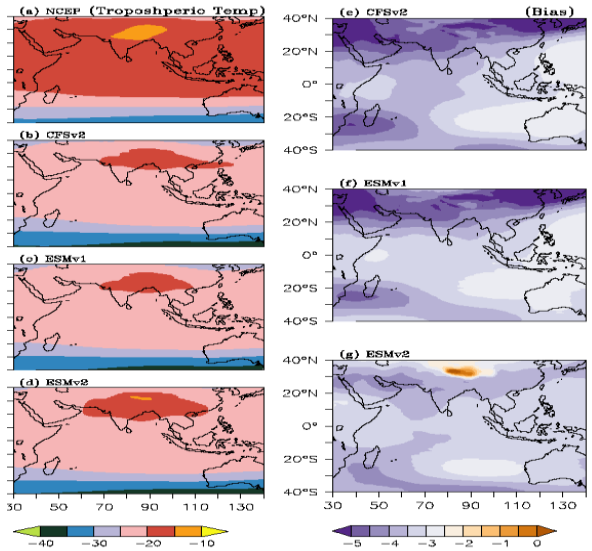
(mm day^{-1})



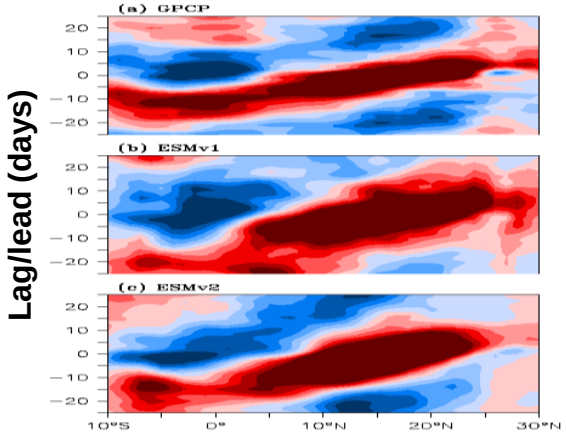
Significant reduction in precipitation bias



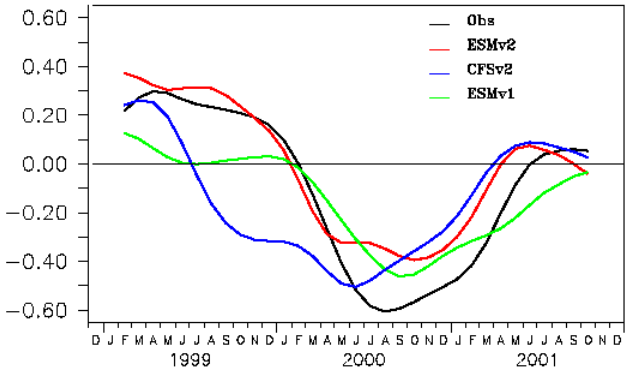
Reduced bias in JJAS Tropospheric Temperature (°C, 200-500 hPa)



JJAS ISO northward propagation speed similar to observed of 1 ms^{-1}



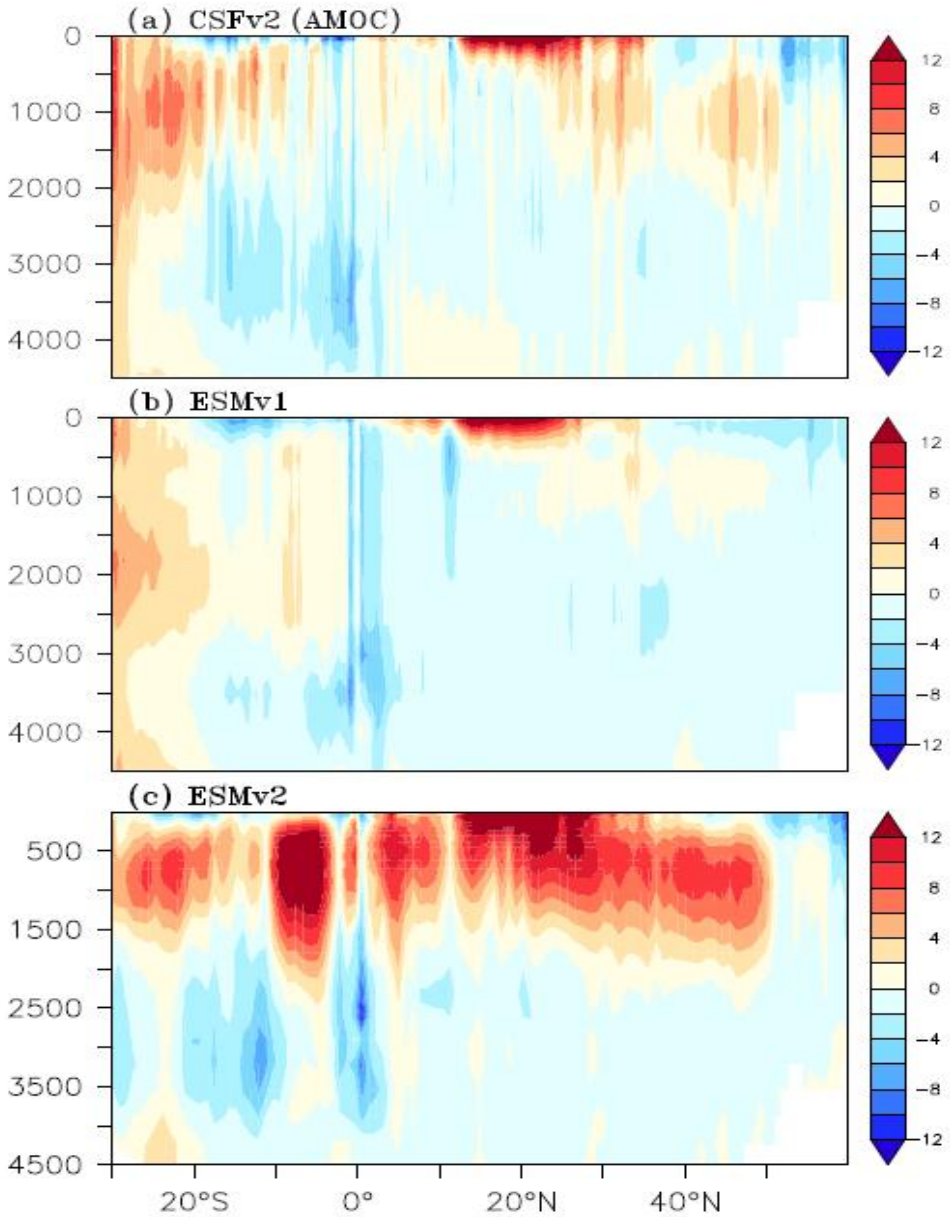
Lead/lag correlation between ISMR and monthly Nino 3.4 Index



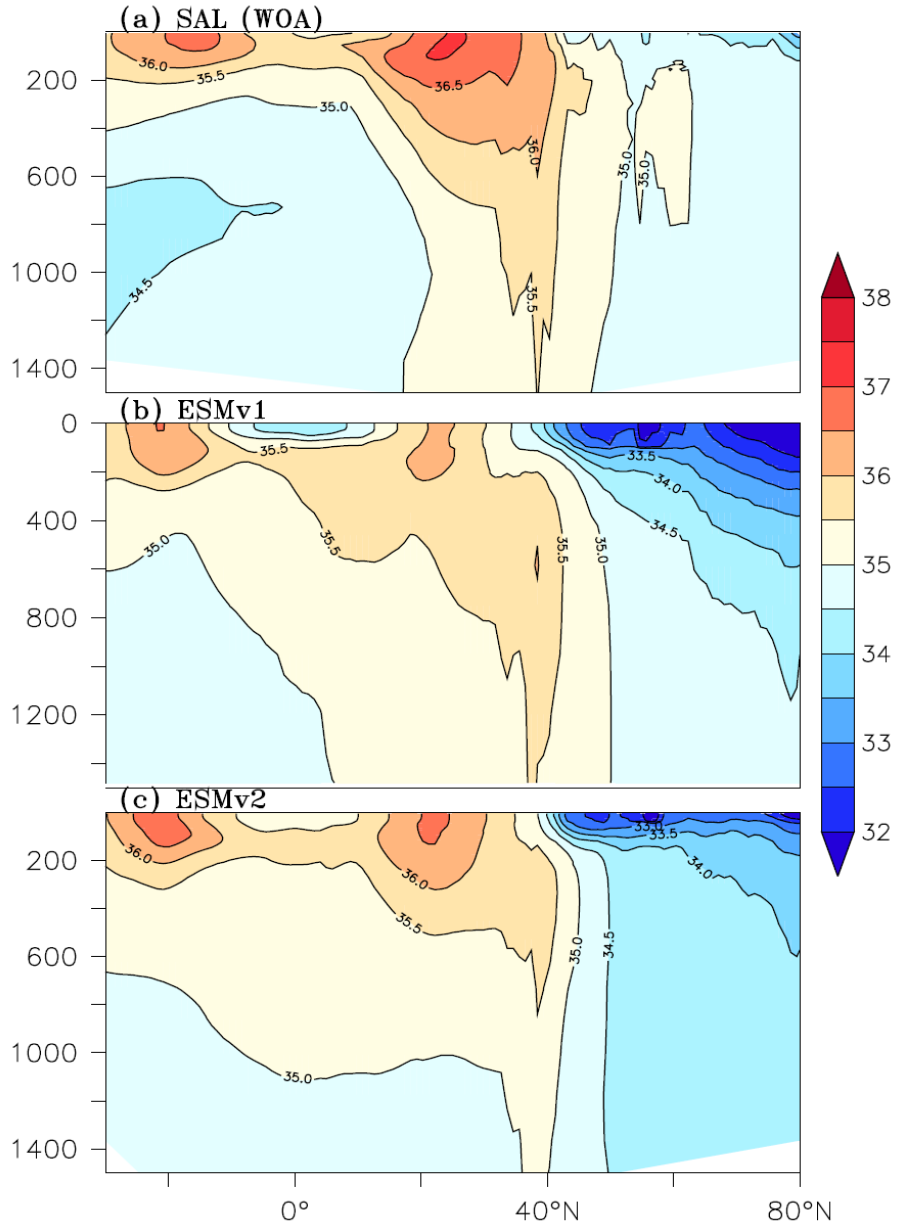
Courtesy: Swapna, CCCR

Large scale ocean overturning circulation - AMOC

Streamfunction (AMOC)



Salinity

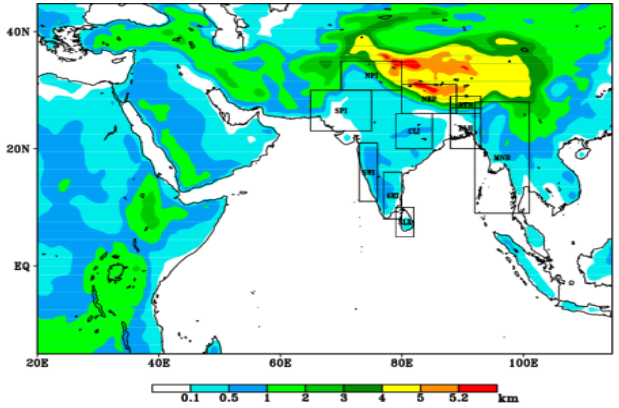


Coordinated Regional Climate Downscaling Experiment (CORDEX): Sponsored by the World Climate Research Programme , WMO

The CORDEX vision is to advance and coordinate the science and application of regional climate downscaling through global partnerships

CORDEX South Asia Co-ordination @ CCCR, IITM, Pune

- **Development of multi-model ensemble projections of high resolution (50km) regional climate change scenarios for South Asia**
  - Generation of regional climate projections at CCCR-IITM
    - LMDZ variable grid global climate model
    - RegCM4 regional climate model
  - Co-ordination with partner institutions for multi-model ensemble projections – SMHI, IAES, CSC, CSIRO, ICTP…
- **Development of an Earth System Grid (ESG) node at CCCR-IITM for CORDEX South Asia**
  - Archival, Management, Dissemination of CORDEX South Asia data
- **Evaluation of regional climate projections over South Asia**
  - For reliable regional climate change information for effective harnessing of science-based climate information by Vulnerability, Impact Adaptation (VIA) community
- **Development of regional capacity for assessment of regional climate change**



ESG Data Node @ CCCR, IITM

http://esg-cccr.tropmet.res.in/esgf-web-fe/

CORDEX South Asia (WAS-44) Datasets Published on Earth System Grid Federation (ESGF)

Downscaling RCMs

Driving AOGCMs

Updated: 10/Sep/2016

	ERA-INTERIM	ACCESS1-3	CanESM2	CCSM4	CNRM-CM5	CSIRO-Mk3-6-0	EC-EARTH	GFDL-ESM2M	HadGEM2-ES	IPSL-CM5A-MR	MIROC5	MPI-ESM-LR	NorESM1-M	MPI-ESM-MR	IPSL-CM5A-LR	ACCESS1-0	GFDL-CM3
IITM-RegCM4-4	published	control RCP2.6 RCP4.5 RCP8.5	published published published		finished finished finished	finished finished finished		finished finished finished	finished finished finished					finished finished finished	finished finished finished		
SMHI-RCA4	published		finished finished finished		published published published	finished finished finished	published published published published	published published published	finished finished finished finished	published published published	published finished published published	published published published published	finished finished finished finished				
MPI-CSC-REMO2009												published published published published					
IITM-RegCM4-1	published							finished running									
IITM-LMDZ4															finished finished		
CSIRO-CCAM	finished			finished finished finished	finished finished finished							finished finished finished	finished finished finished			finished finished finished	finished finished finished
CLMcom-CCLM4-8-17												finished finished					

Published:

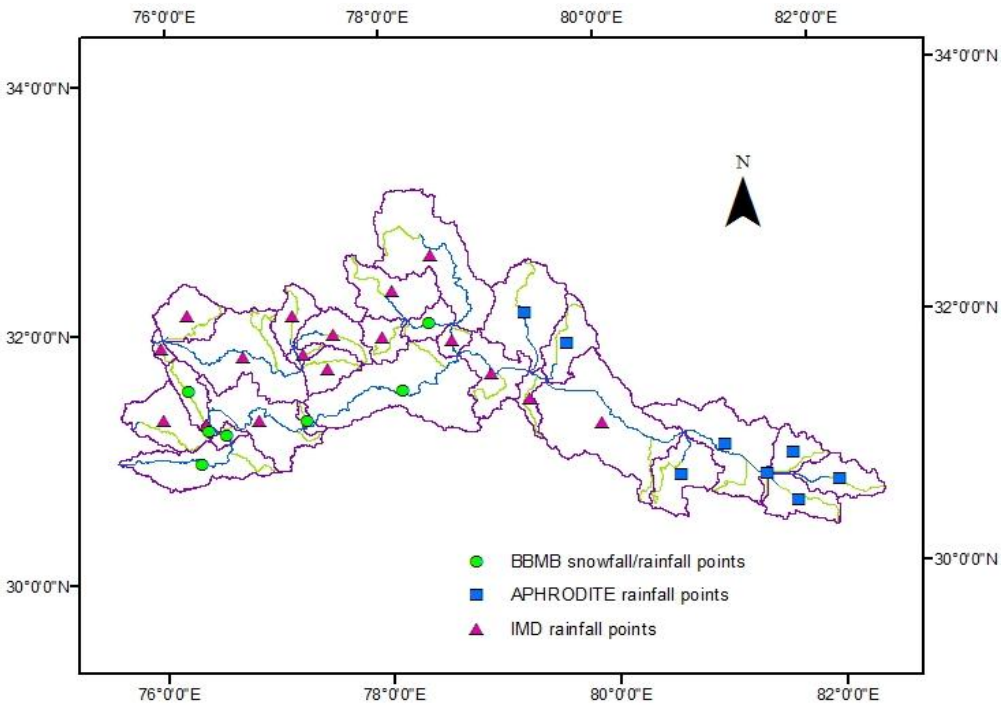
- **Control(1951-2005):8 RCP2.6(2006-2100):3 RCP4.5(2006-2100):8 RCP8.5(2006-2100):8**

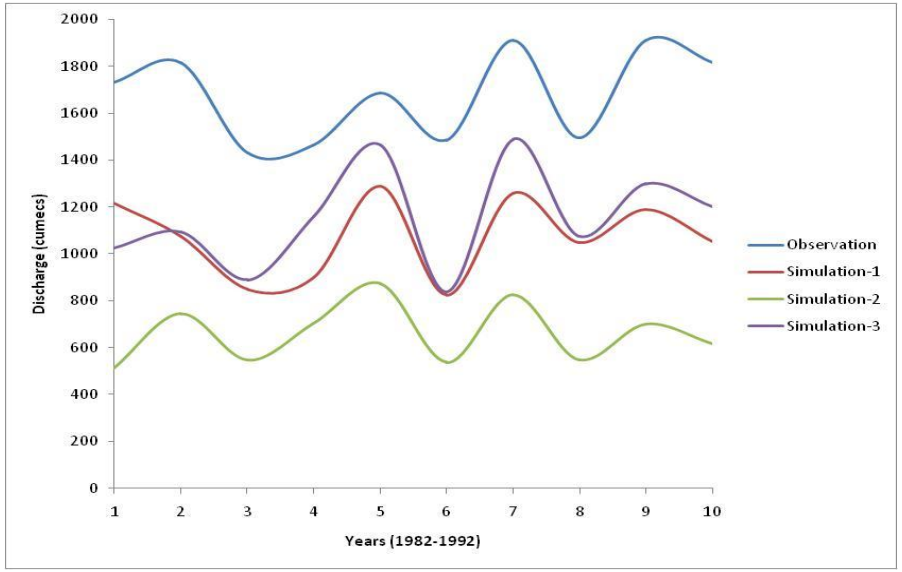
Finished:

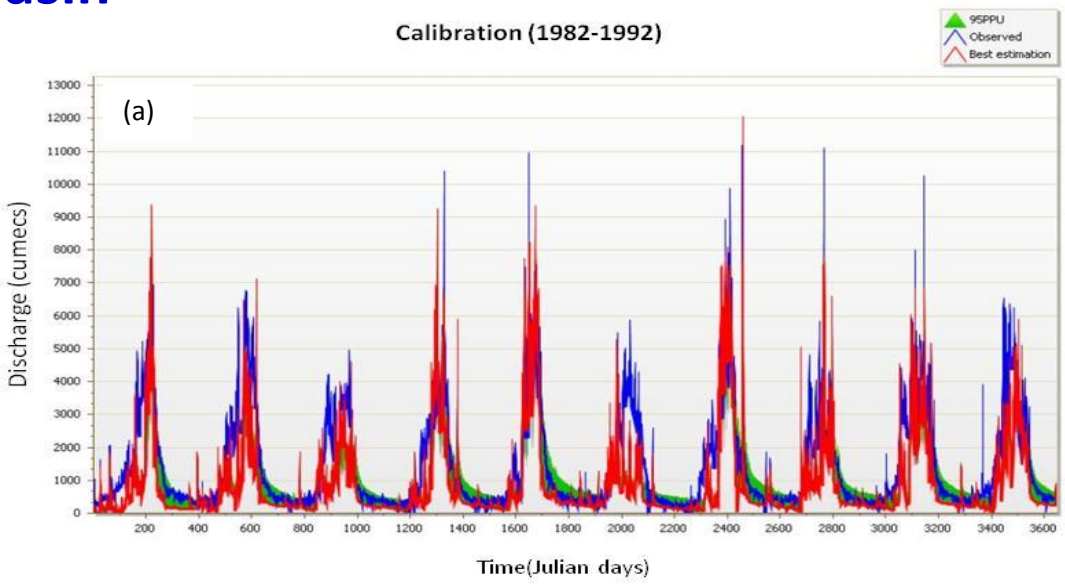
- **Control(1951-2005):19 RCP2.6(2006-2100):3 RCP4.5(2006-2100):18 RCP8.5(2006-2100):16**

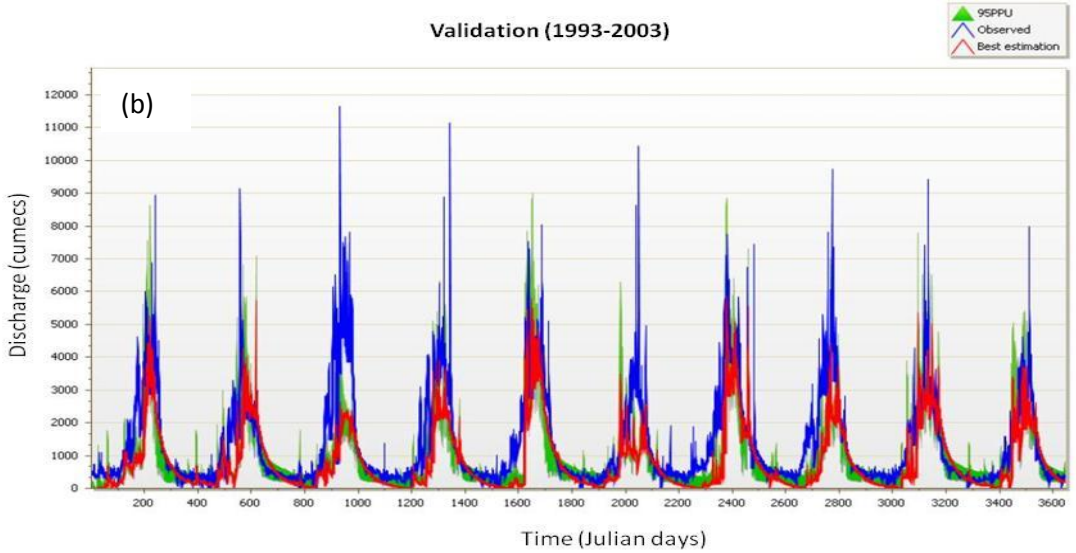
Modelling of Water Cycle

Satluj basin









Simulated Discharge using various types of Input datasets

Sarita Tiwari et al (2016) HSJ, under review

Prediction of Fog

WIFEX 2016-2017 (IGI Airport, New Delhi)

(32 scientific equipment to monitor:
Ground and surface properties, Surface layer meteorology, Radiation fluxes, aerosol and fog microphysics, optical properties,

Atmospheric profiles (102 meter high resolution T&Rh)

Nano size particle measurements
(Secondary aerosols, CCN, water partitioning in system, visibility parameteriziation)

- Fog microphysics
- Chemical analysis of aerosols (PILS)
- 102 meter high resolution Rh & T profile
- New flux measurements at Hisra
- Experimental forecast: IITM GFS (12km) and WRF (2 km)

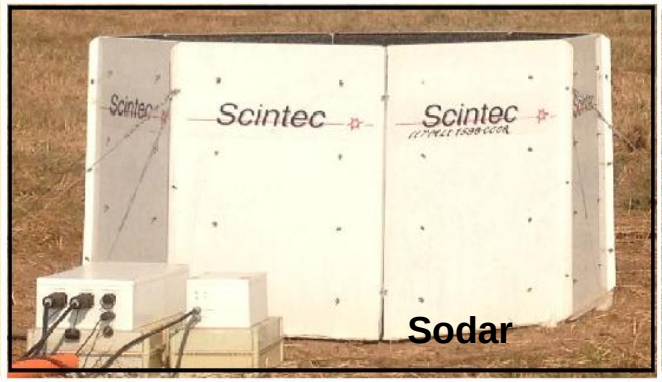

102 meter Rh & T profile


Ramdas Layer


Celiometer


CDP


Fog sampler, PM2.5 collector

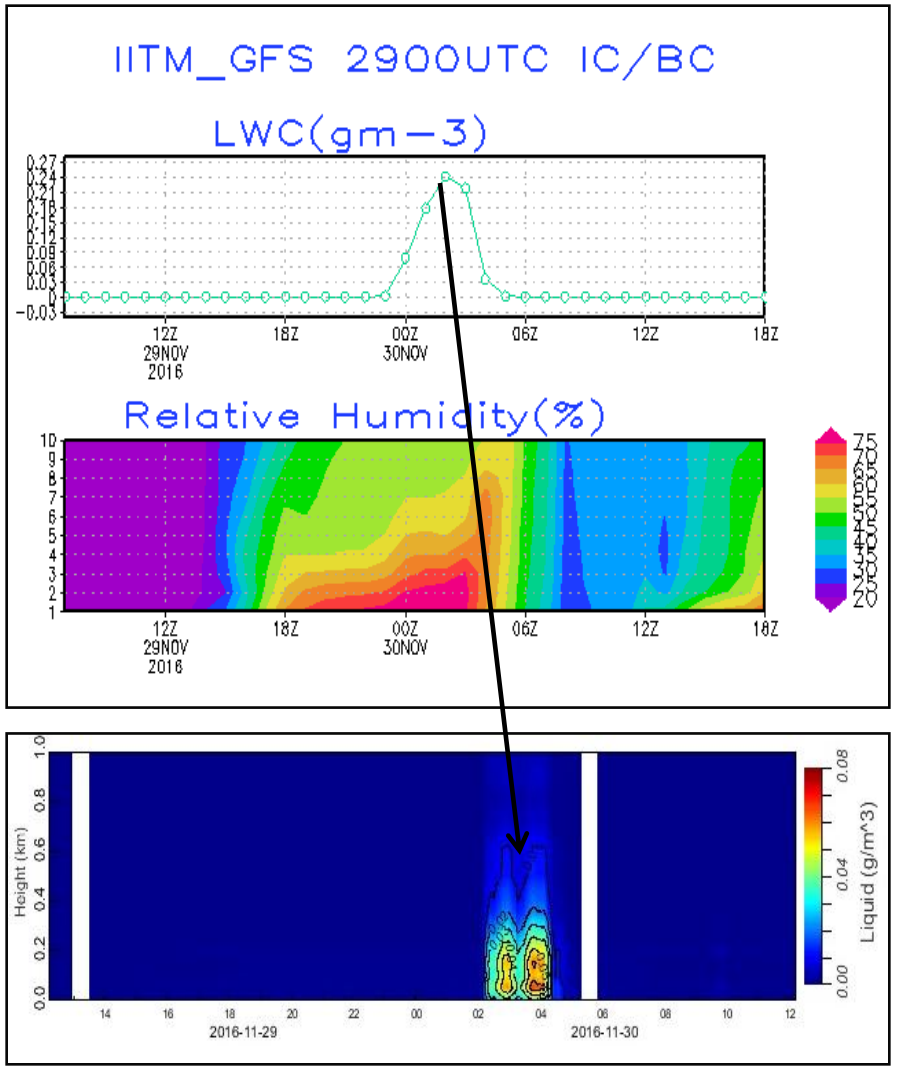

Scintec
Scintec
Sodar


Fog Collector
Fog collector

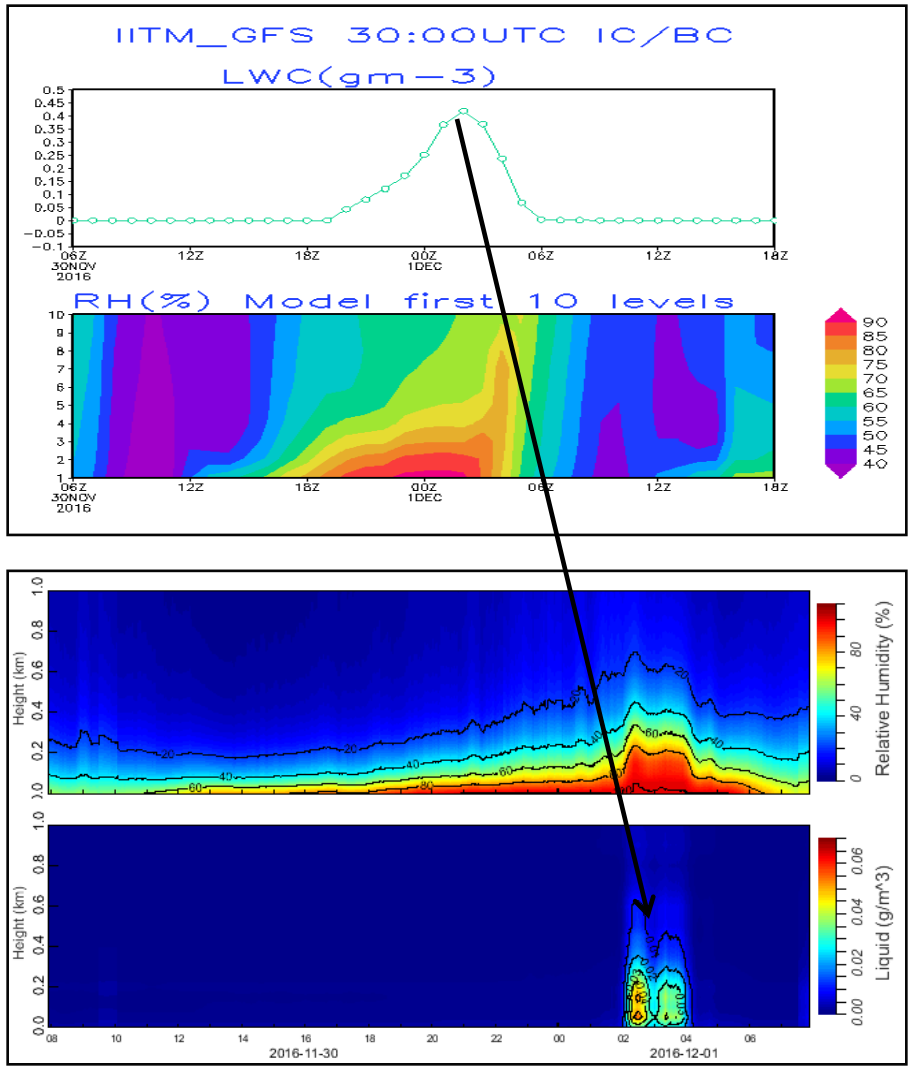

Electric field mill

18h Forecast Generated using IITM GFS (12 km) and IITM-WRF (2 km) for recent fog event

30 November



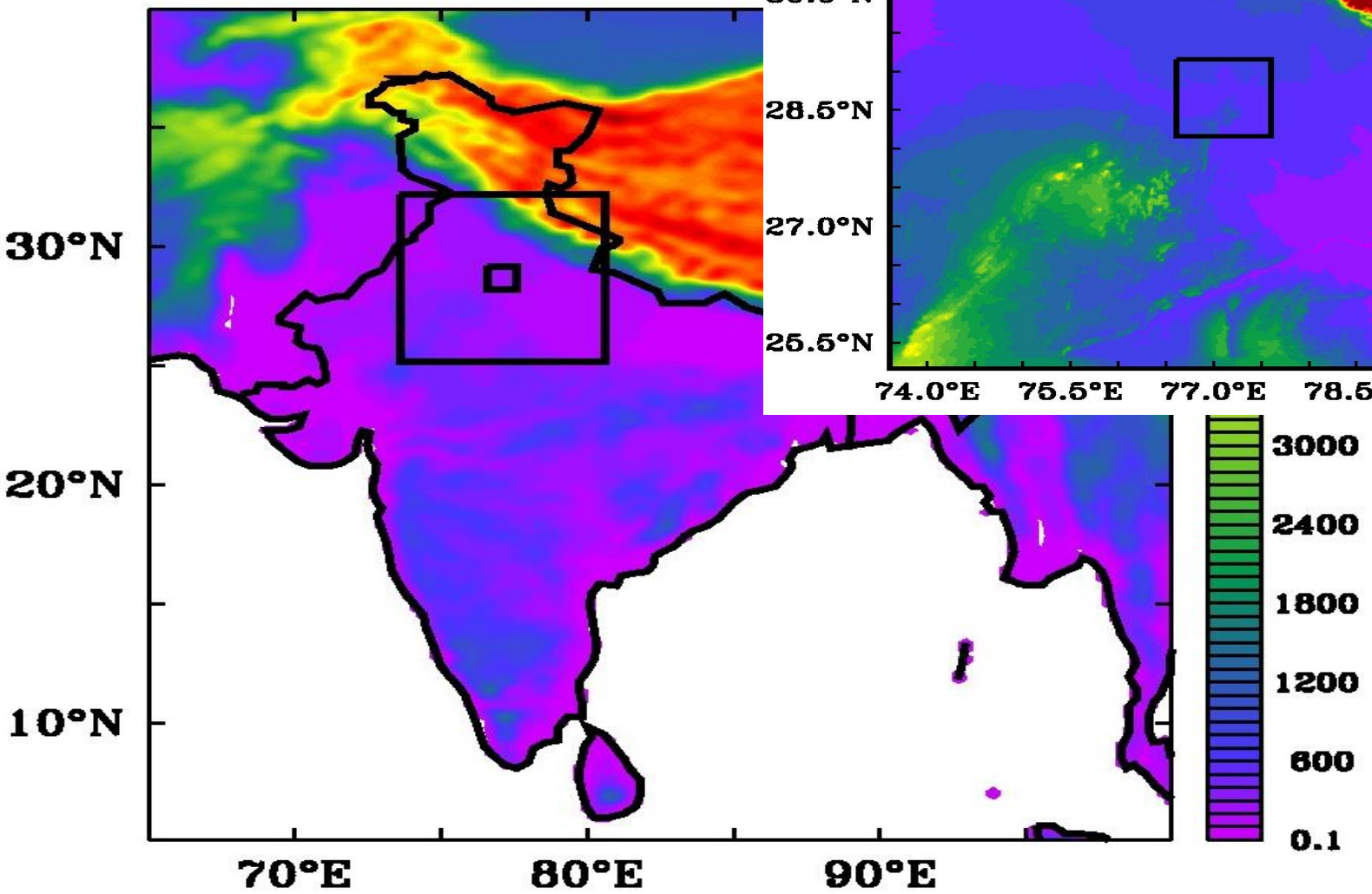
1st December



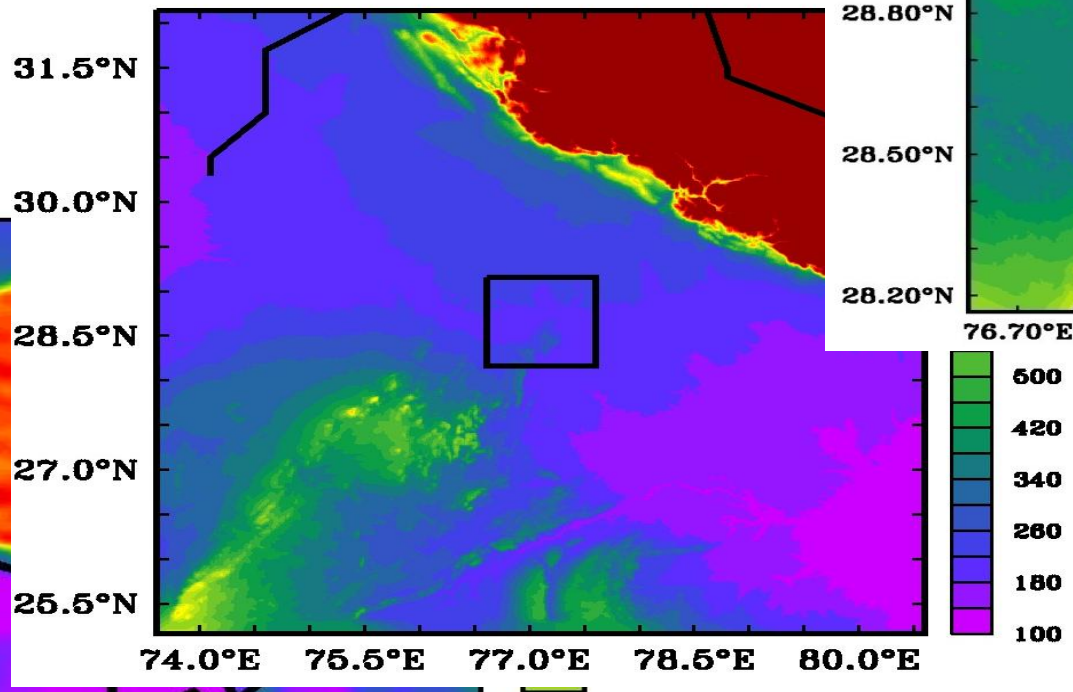
NCMRWF

ESSO

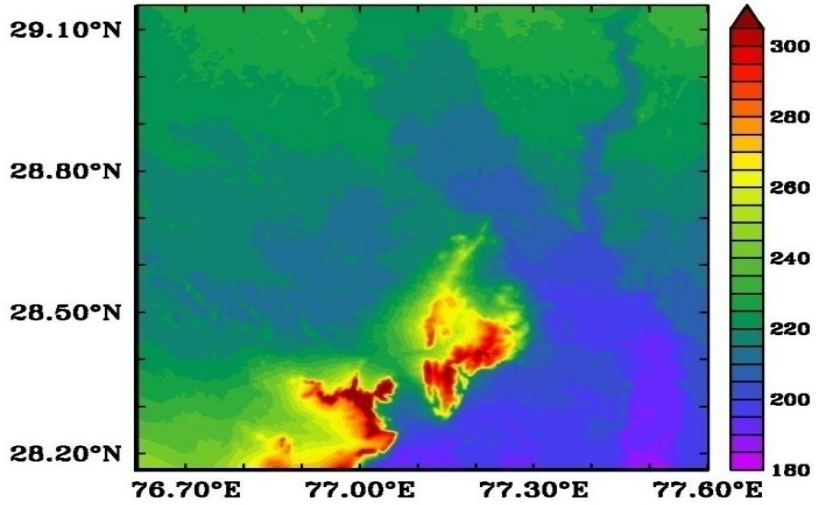
GL-17km

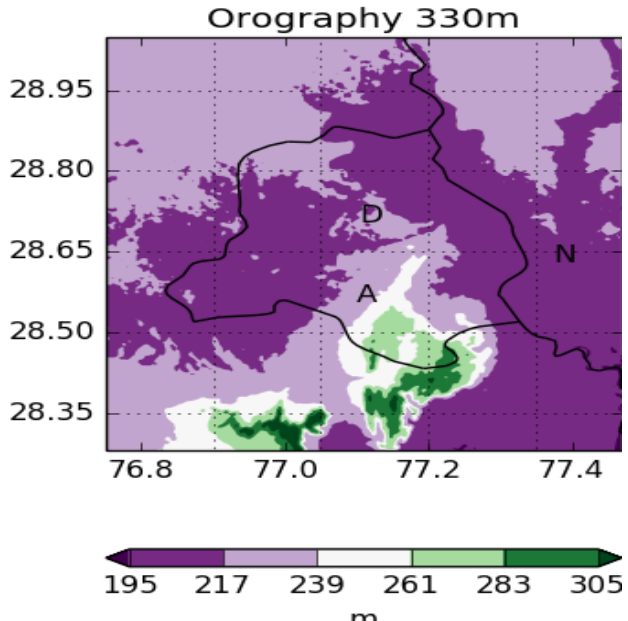


NCUM IND-1.5km

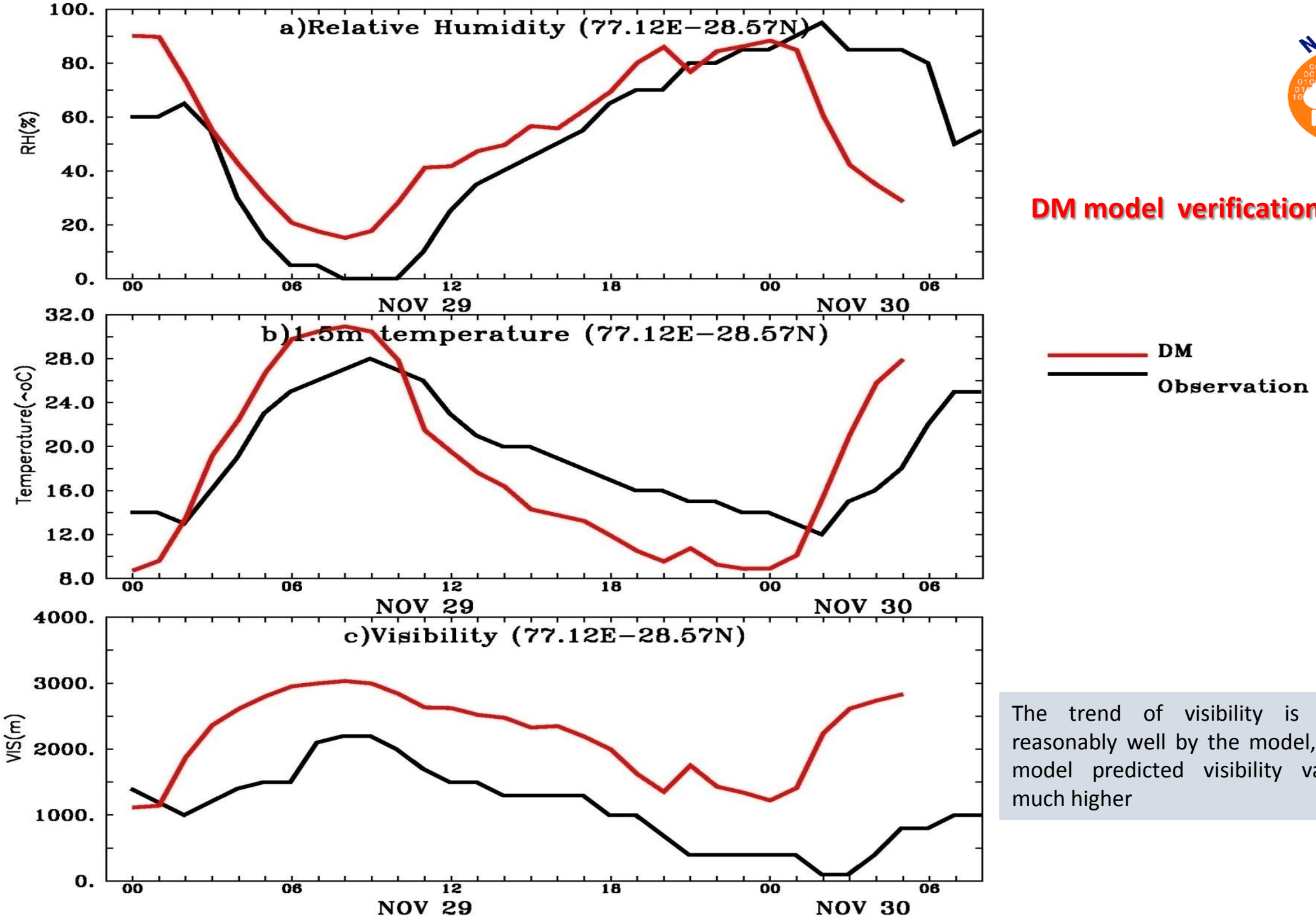


DM-330m





DM model verification



The trend of visibility is predicted reasonably well by the model, however, model predicted visibility values are much higher

Future Strategy for next 3-7 years

- Global Ensemble High Resolution Weather Forecasting System (10-12 Km resolution).
  - Probabilistic forecasts of severe weather events
  - Nowcasting systems (Radar/Satellite and Model based)
  - Urban Meteorology
  - Services to Energy Sectors (wind and solar)
- Multi Model Ensemble Extended Range Forecasting system
  - All the seasons, heat and cold waves,
  - More applications (Hydrology, Agriculture, Health).
- Multi-Model Seasonal Forecasting System
  - All the seasons, more applications, Regional climate services
- Hydrometeorological Forecasting system-
  - QPF for Flood Warnings, Urban and Flash Floods
- Prediction of Fog, Air Pollution Emergencies

Observations and Services

- Augmentation of regional meteorological observational network
  - Ideally 25 X 25 km surface and 100 X 100 km upper air, supplemented by satellite, RADARs, lightning sensors, LIDARs, Radiometers etc
- Improved Agro-meteorological Services
  - Block Level Forecasts through 660 District Centres
- Research Testbeds
  - Fog Prediction- at IIG Airport, Delhi
  - Monsoon Convection- At Sagar University, Madhya Pradesh, Bhubaneshwar
- Climate Reference Stations
  - Climate Change Monitoring
  - To start with 50 Pristine locations
- Special Observational network over NW Himalayas and North-eastern States.

Thank you