From Observations and Coupled NWP to Impacts: Advancing Tropical Weather and Monsoon Forecasts over the Indian Subcontinent



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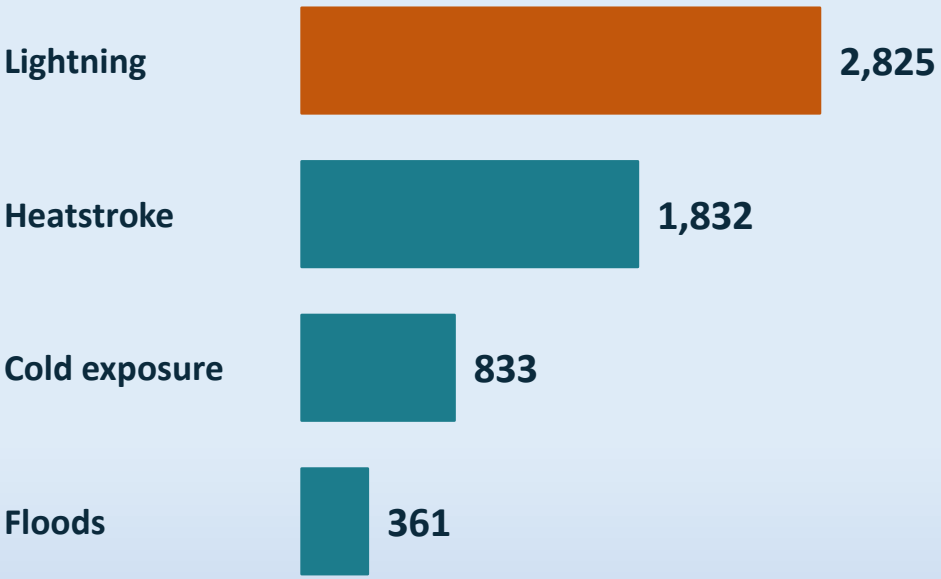
Outline of the Presentation

- Basic Monsoon Concepts
- Numerical Study of Impact of Desertification on Indian Monsoon Region
- Coupled modeling system, Data Assimilation, Land-surface Data Assimilation for NWP
- Methodological Advances in the Ensemble system
- sEKF based ASCAT Soil Moisture Assimilation
- INSAT-3D Land Surface Temperature Assimilation
- NCMRWF Operational Services

WHY IMPACTS MATTER

Recurring hazards dominate the toll

Deaths in India, 2024



- Lightning alone caused 35.7% of natural-force deaths
- Heatstroke deaths reached a record in 2024
- Headline disasters get attention, but these hazards recur every season

Source: NCRB, Accidental Deaths and Suicides in India 2024 (police-recorded; may under-count floods). Heatstroke figure per Dataful analysis of NCRB.

TROPICAL CYCLONES

Cyclones: lives saved, assets lost

Odisha 1999

~10,000

deaths from a 30-hour storm; surge swept about 20 km inland

Fani 2019

1.2 M

people moved to ~4,000 shelters in 24 h; deaths in the tens, not thousands

Amphan 2020

~US$13 B

state-estimated damage; 1.5 M+ houses hit; Kolkata trees and power down

Amphan deaths came mostly from house collapse and electrocution. Warnings provided on impacts, not wind speed alone.

Sources: NDRF and Reuters (Fani 2019); Reuters (Amphan 2020). Amphan loss is a state-official estimate.

MONSOON RAINFALL EXTREMES

Rain extremes: cities and hillsides

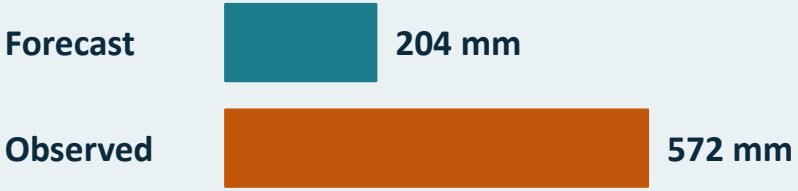
Mumbai, 26 July 2005

944 mm

in 24 h, a single-day record for India

- 500+ deaths across Mumbai, Thane, Raigad
- Airport shut 30+ h; rail and road paralysed
- No heavy-rain forecast for 26-27 July

Wayanad, 30 July 2024 (48-h rain)



- 400+ dead: Kerala's deadliest landslides
- Struck after midnight; many victims were estate workers
- Early moves to relief camps cut the toll

Sources: Deccan Herald (Mumbai 2005); Reuters, Wikipedia and Kerala state figures (Wayanad 2024). Death tolls vary by source.

CONVECTIVE AND HEAT HAZARDS

Lightning and heat: quiet killers

Lightning

2,825 deaths in 2024

- Mostly rural: farm workers caught in open fields
- Bihar: 33 killed in two days, July 2025

Heatstroke

1,832 deaths in 2024, a record

- ~750 a year in 1995-2004; 1,000+ a year since 2005
- Top natural killer in 53 megacities (27.6%)

Both can be flagged hours to days ahead, and most of these deaths are preventable with targeted warnings.

Sources: NCRB 2024 via ETV Bharat and Dataful; AFP (Bihar, July 2025); IITM lightning studies.

SYNTHESIS

Who and what gets hit

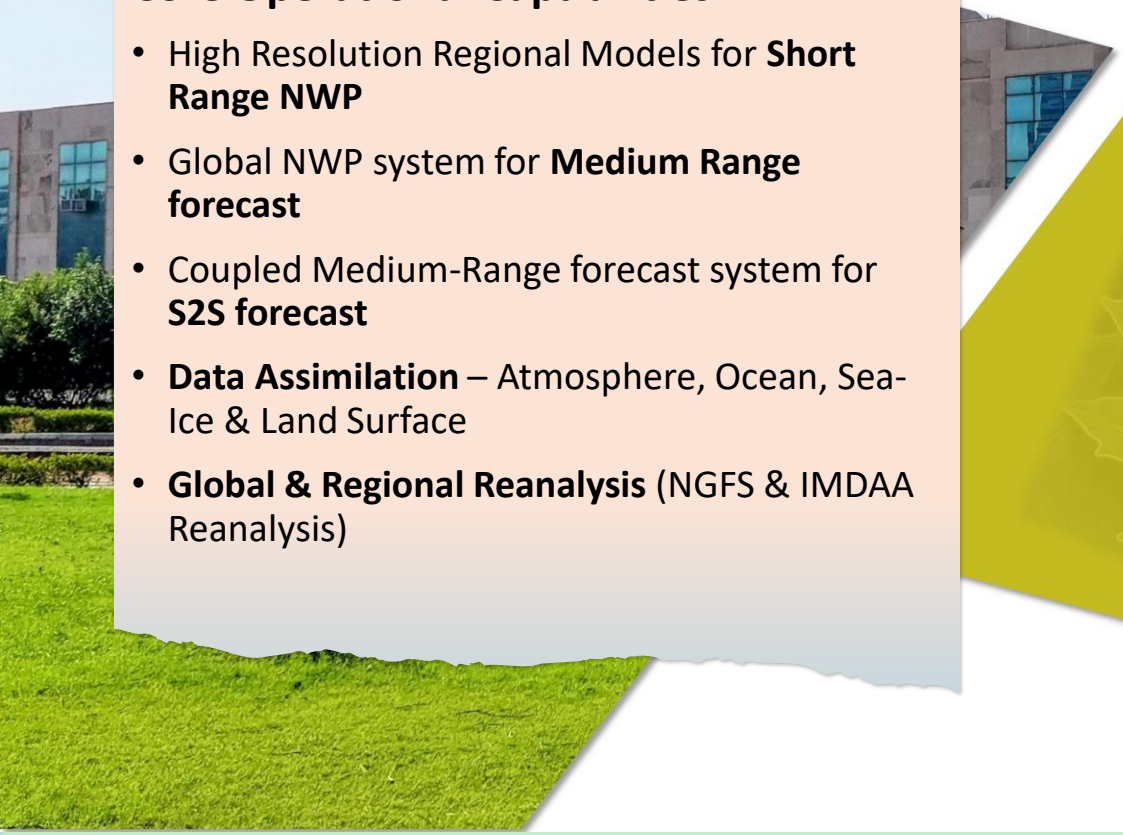
Hazard	People	Infrastructure	Economy and livelihoods
Tropical cyclone	Kutcha homes collapse; electrocution	Power and telecom lines, trees on roads	Fisheries, saline farmland, large state losses
Urban flood	Stranded commuters; disease after	Rail, roads, airport closures; drains overwhelmed	Markets and offices shut for days
Cloudburst, landslide	Night-time burial; estate workers	Roads and bridges cut; villages isolated	Plantations, tourism, long rehabilitation
Lightning	Farm workers in open fields	Local power faults	Outdoor work stops in storm season
Heatwave	Outdoor labour, urban poor	Peak power demand, water stress	Lost work hours, crop stress

Indicative synthesis from the cases in this talk; not an exhaustive damage taxonomy.

National Centre for Medium Range Weather Forecasting (NCMRWF)

Core Operational Capabilities:

- High Resolution Regional Models for **Short Range NWP**
- Global NWP system for **Medium Range forecast**
- Coupled Medium-Range forecast system for **S2S forecast**
- **Data Assimilation** – Atmosphere, Ocean, Sea-Ice & Land Surface
- **Global & Regional Reanalysis** (NGFS & IMDAA Reanalysis)

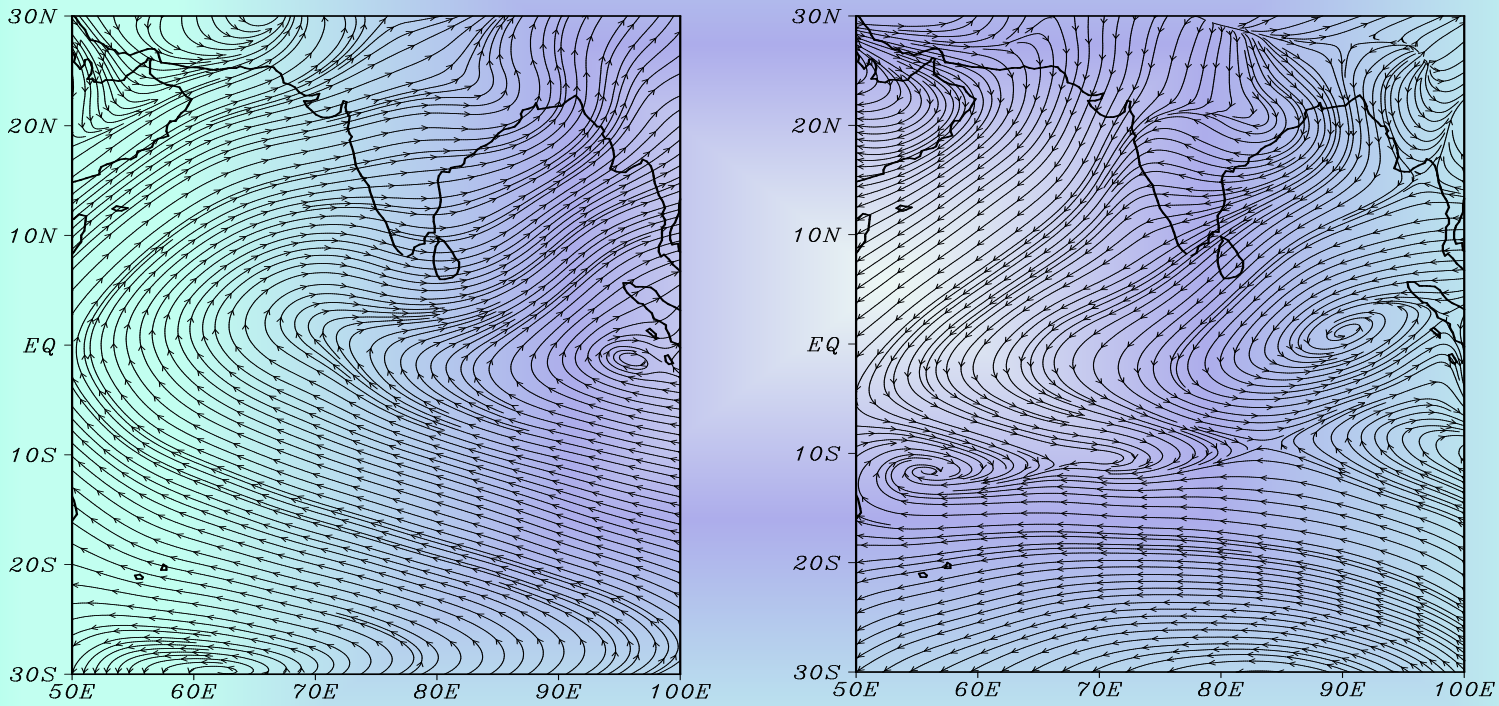


NCMRWF Mission

"continuously develop advanced NWP systems, with increased reliability and accuracy over India and neighboring regions through research, development, and demonstration of new and novel applications, while maintaining the highest level of knowledge, skill, and technical expertise"

Definition : Monsoons

The monsoons of the world are defined through the seasonal reversal of large-scale surface winds. The best place to see an illustration of this phenomenon is in the domain of the **Indian Monsoon** where the southwesterly surface winds of the summer monsoon get replaced by the northeasterly surface winds of the winter monsoon.



(a) (b)

Fig Climatological 925mb streamlines over the Indian Monsoon region for the month of a) July, and b) January.

Domain of Monsoons, Reversal of Surface Wind Directions

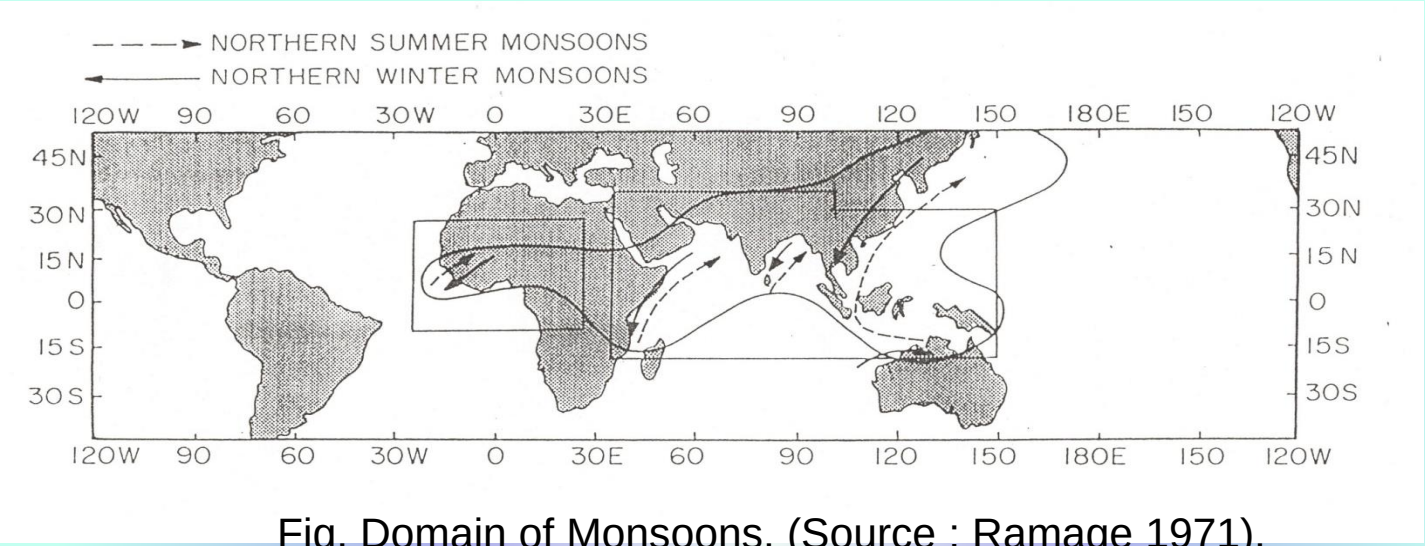


Fig. Domain of Monsoons. (Source : Ramage 1971).

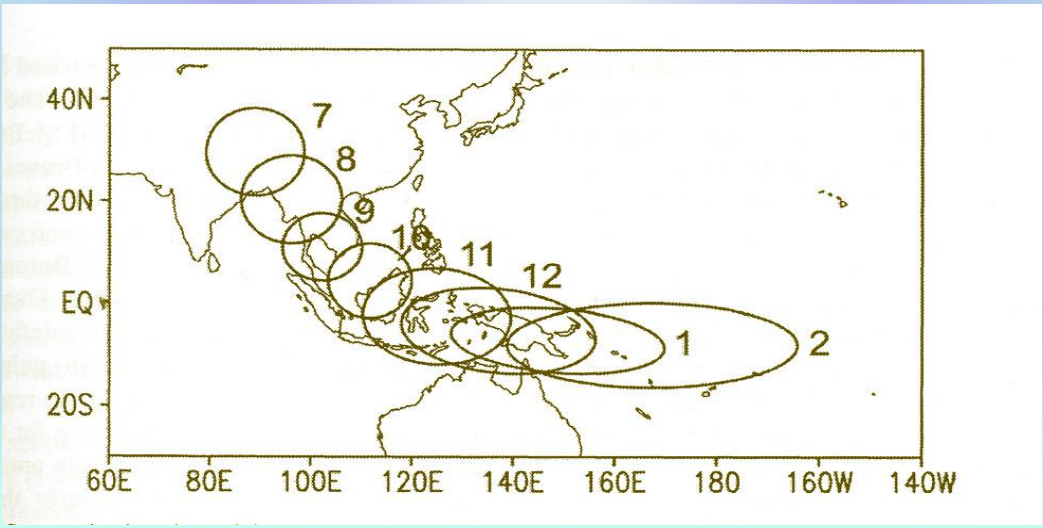


Fig. Propagation and extent of the monsoonal heat sources between the months of July (marked by a 7) and February (marked by 2) (Source: Chang 2005).

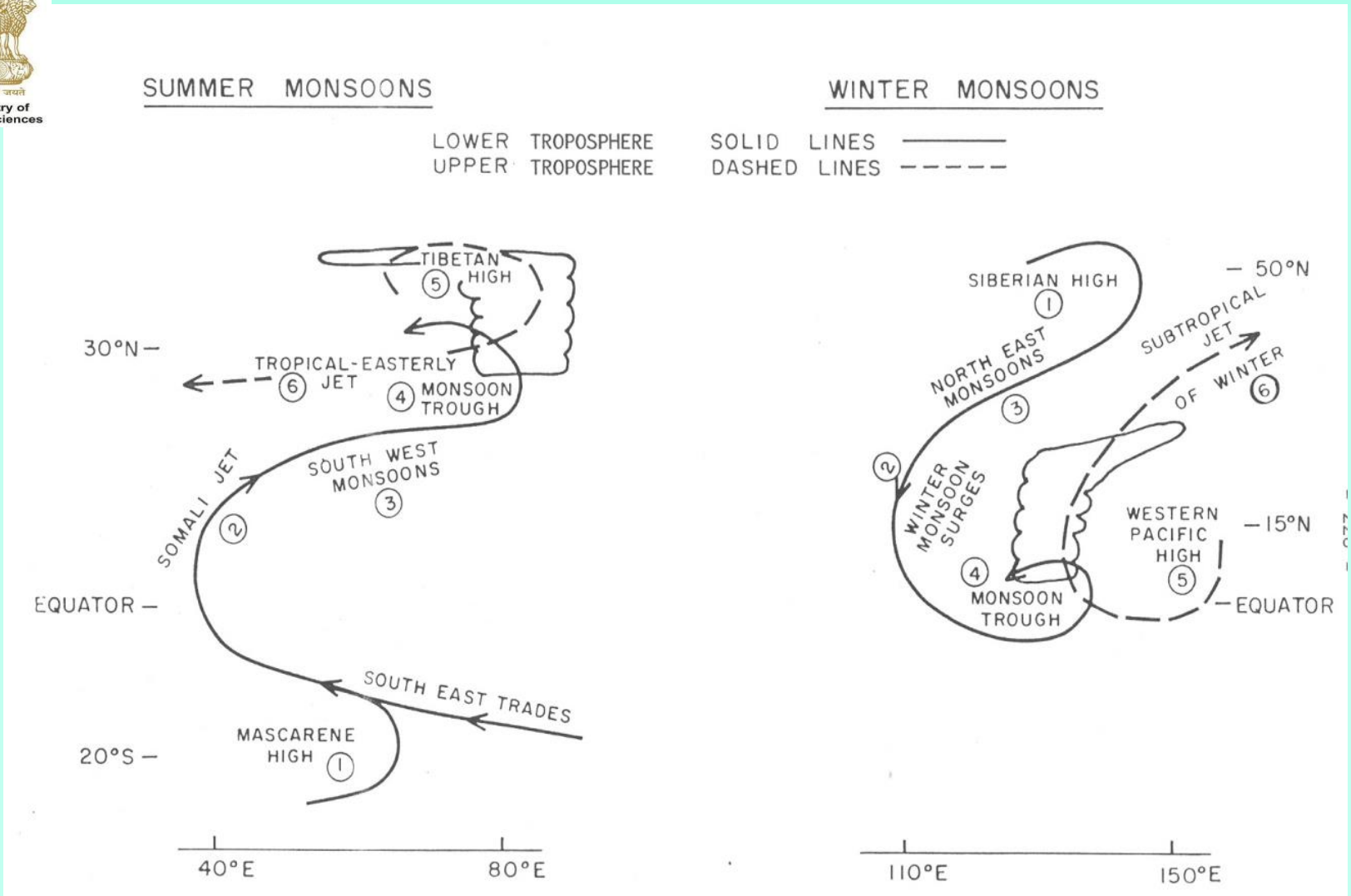


Fig. Schematic diagram of the Summer (left) and Winter (right) Monsoon complex. Solid lines indicate lower tropospheric flow, dashed lines indicate upper tropospheric flow.

Main Features of Summer Monsoon

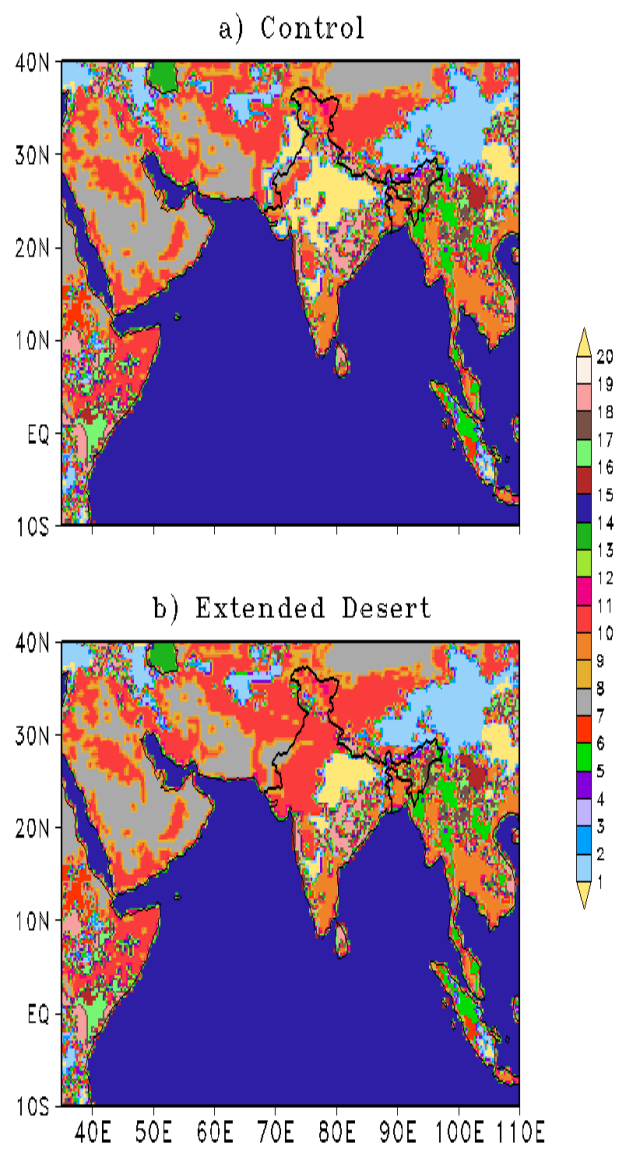
- The **Mascarene high** of the Southern Hemisphere located near 30°S and 60°E.
- The southeast trade winds of the Southern Indian Ocean extending into a counterclockwise flow around the Mascarene high.
- The cross-equatorial flow along the Arabian Sea shores of Kenya, east of the Kenya highlands, with southerly winds on the order of $10ms^{-1}$.
- The Somali Jet. This is a continuation of the cross-equatorial low-level flow as it exits to the east of the Horn of Africa. The Somali Jet is a major element of the Asian Monsoon. It carries westerly winds (as strong as $50ms^{-1}$ on certain days) offshore from Northern Somalia over the Arabian Sea at an altitude of about 1km above the ocean. The climatological seasonal mean winds of the Somali Jet are in excess of $15ms^{-1}$.
- The southwesterly monsoonal flow over the Arabian Sea. This is a major element of the Asian Summer Monsoon. This southwesterly flow has two branches – one along 15°N and another one moving south towards the Central Arabian Sea and Southern India.
- The Monsoon trough of North-Central India between 15°N and 25°N. The southwesterly winds carrying moist air from the Arabian Sea and the Bay of Bengal flow counterclockwise around this trough.
- The heavy rains of the Indian Monsoon. The monsoonal precipitation is strongly influenced by the orography of the region. The heaviest rains occur along the eastern foothills of the Himalayas and at the western slopes of the Western Ghats that lie along the west coast of India.
- The Tibetan high. This is a major thermal high pressure system located in the upper troposphere above the Monsoon trough. Between the Monsoon trough at the surface levels and the Tibetan high of the upper troposphere resides a warm troposphere that is largely maintained by deep cumulus convection of the heavy monsoon rains and the heating of the Tibetan Plateau
- The tropical easterly jet (TEJ) located near 10°N over the southern flanks of the Tibetan high.

Main Features of Winter Monsoon

The counterpart to the Summer Monsoon described above is the Winter Monsoon system where the following features are of importance:

- **The Siberian high pressure system.** This is a counterpart to the Mascarene high of the Summer Monsoon. Climatologically, the Siberian high is located near 50°N and 125°E. This is a region of significant heat sink in the troposphere of the northern hemisphere during winter.
- The **northeasterly lower tropospheric flow**. This can be regarded as a counterpart to the southeast trades of the Summer Monsoon
- Wind surges carried by the northwesterly monsoonal flow seen along the western shores of the South China Sea. The winds in these surges can be as strong as $15ms^{-1}$, and are normally associated with cyclonic disturbances in the central part of the South China Sea. These winds are not quite as strong as those of the Somali jet.
- The Monsoon trough, located north of the equator in December and south of the equator in the months of January and February. The Monsoon trough is the locale of the heavy rains of the Winter Monsoon over Northern Australia, Southern Peninsular Malaysia and Borneo.
- The West Pacific high. This is a counterpart to the Tibetan high. It resides over the region of heavy monsoon rains and is strongest near the 200mb level.
- The subtropical jet stream of winter (STJW). This is one of the strongest wind systems of the troposphere. It is located near the northern flanks of the West Pacific high, south of Japan.

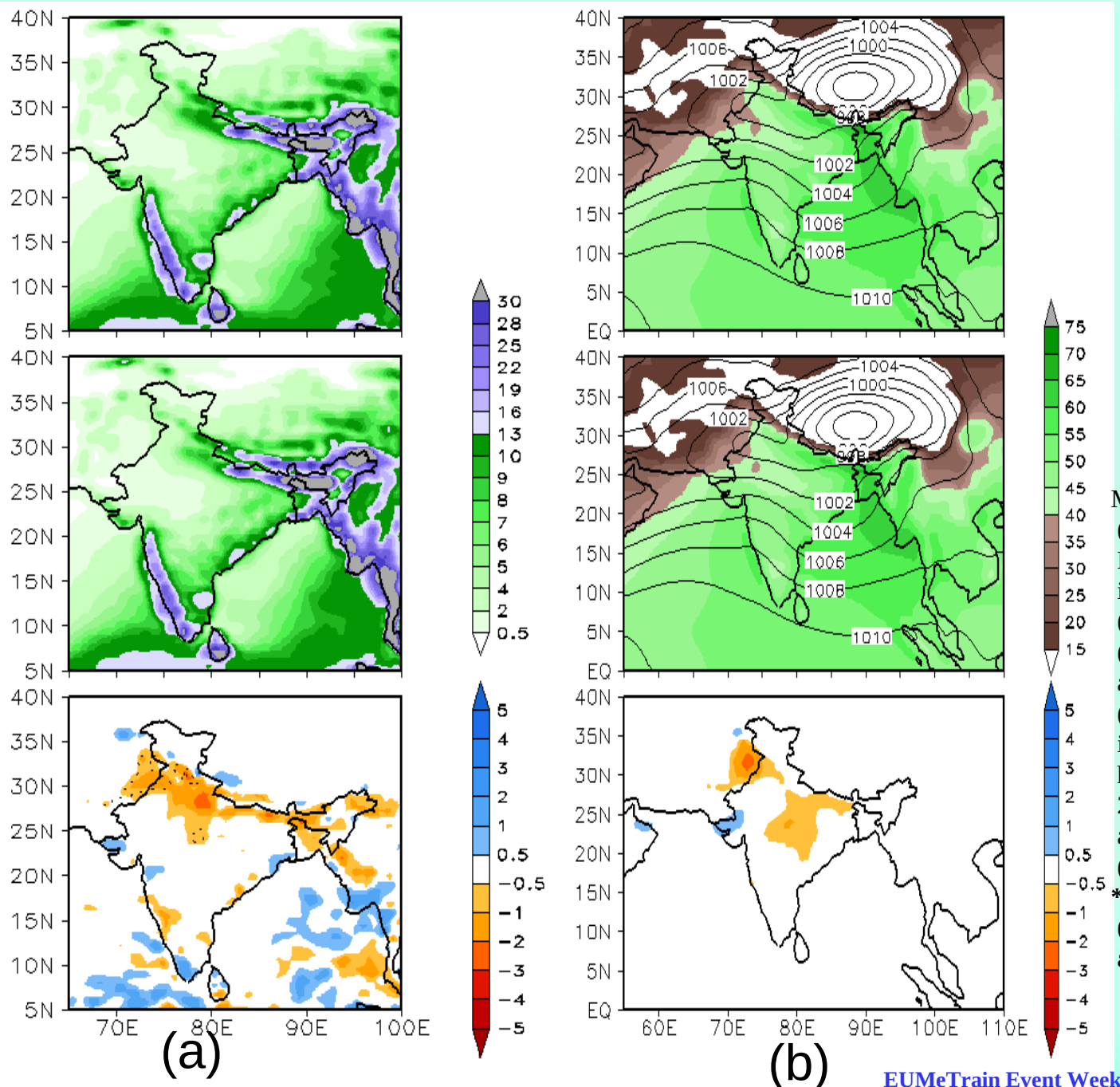
Modeling the Impacts of LULCC: Extended Desertification over the Indian Region



Experiment name and it's acronym	Model Domain, Grid spacing and region of prescribed vegetation change	Land-surface condition and duration of simulation run	Details of Parameterization schemes used
1. RegCM4.4.5.10-CONTROL	17°E-123°E, 16°S-40°N, (166 x 108 x 18); ~ 60km resolution; None	00UTC of 1st October 1999 to 00UTC of 1st January 2011 (simulation length is 98640 hours).	Emanuel over land and Grell over ocean with Arakawa Schubert (AS) 1974 closure and Holtslag PBL scheme.
2. RegCM4.4.5.10-EXTENDED DESERT	17°E-123°E, 16°S-40°N, (166 x 108 x 18); ~ 60km resolution Extended desert	Expanded Thar Desert experiment representing land degradation 00UTC of 1st October 1999 to 00UTC of 1st January 2011 (simulation length is 98640 hours).	- same as above -

(a) Control landuse map in the baseline experiment using RegCMv4.4.5.10 model; (b) modified land use map for extended desert experiment (extensive desertification over Thar Desert of north-western regions of Indian sub-continent).

Results : Extensive Desertification



Mean and anomaly (**design-control**) for RCM-DES design experiment illustrated though JJAS (2001-2010) composite of (a) precipitation (mm/day) and (b) precipitable water (kgm^{-2}) [vertically integrated specific humidity from 950 to 275hPa, shaded, contours are of sea level pressure], **(p<0.01)**

**** (top) CONTROL exp , (middle) DESIGN exp ; and (bottom) Difference .**

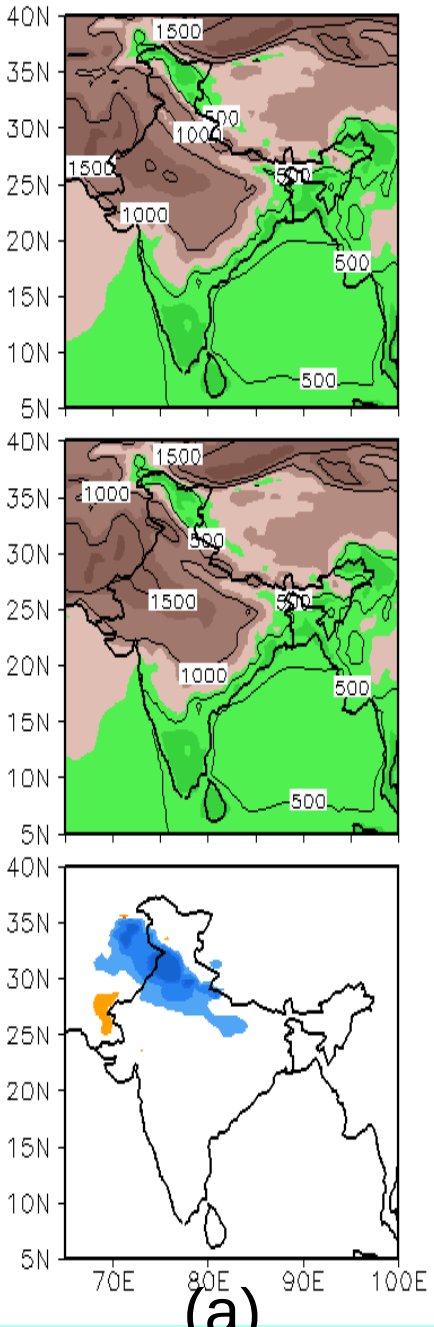
Results : Extensive desertification ..... continued

Ministry of Earth Sciences

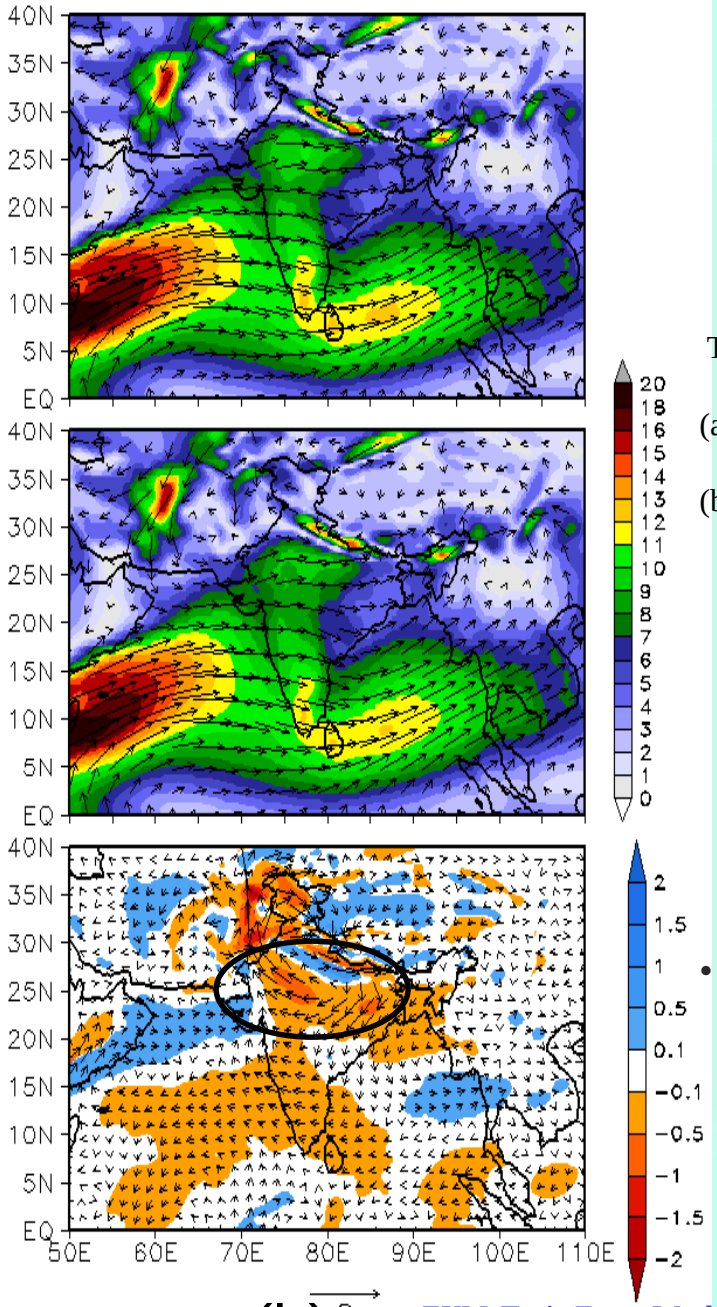
CONTROL

DESIGN (EXTENDED DESERT)

DESIGN – CONTROL



(a)



(b)

The JJAS (2001-2010) composite of

(a) Lifting condensation level (m)

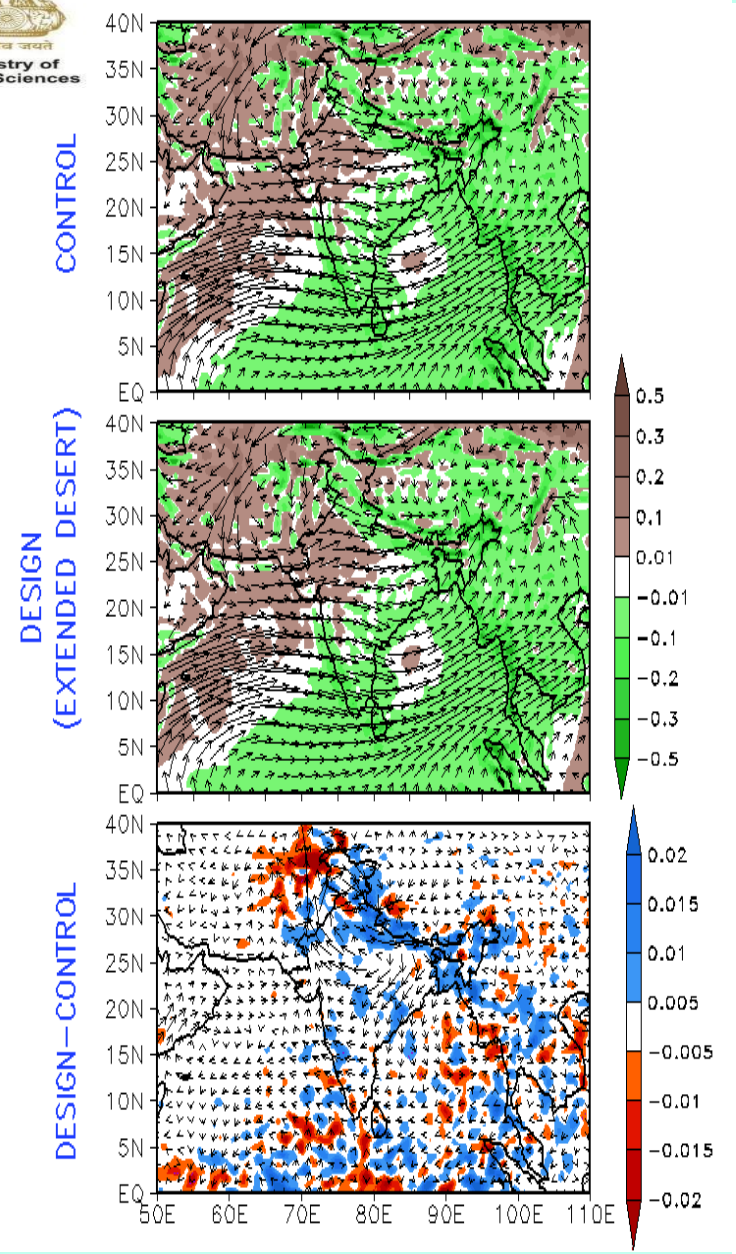
(b) wind (m/sec) and direction change at 850 hPa anomaly (**design-control**) for extended desert design experiment **(p<0.01)**

**** (top) CONTROL exp , (middle) DESIGN exp ; and (bottom) Difference**

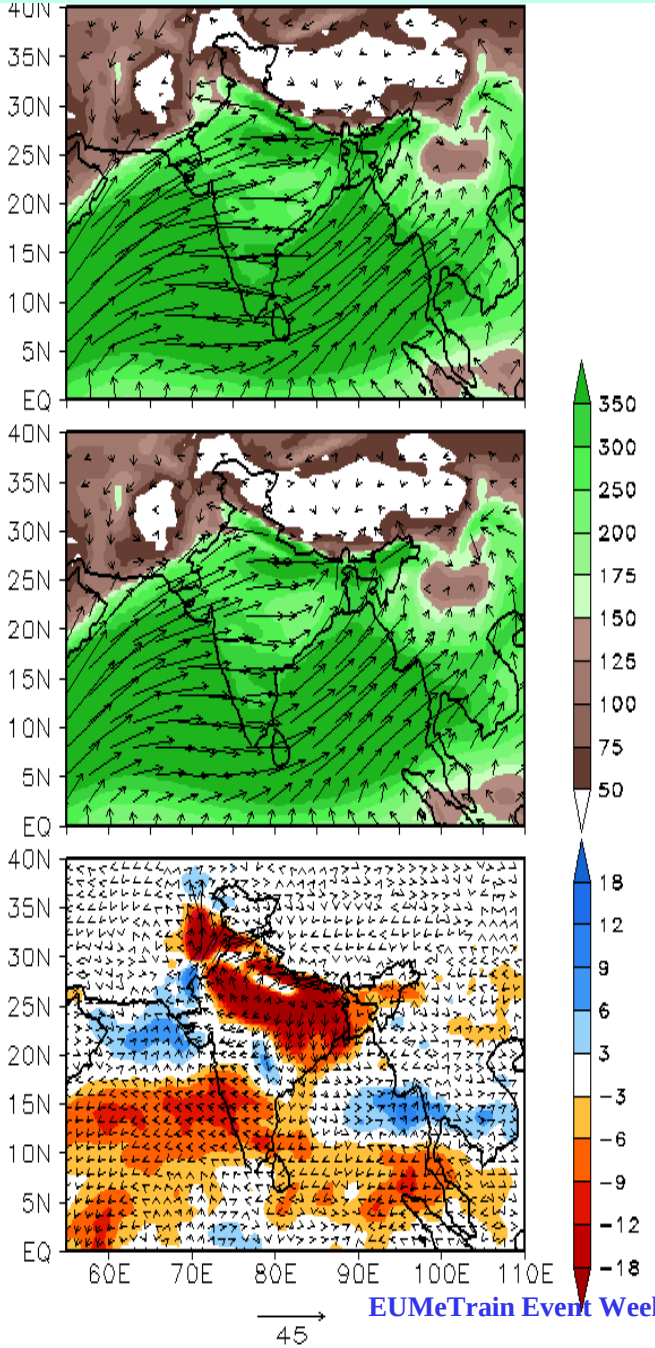
- **Due to extended desertification there is a formation of anti-cyclone over North India.**

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(a) Vertical velocity



(b) VIMT upto 300hPa



(a) The JJA 850-hPa wind (m /sec) and 500-hPa vertical velocity (x 10^{-2} hPa /sec; shaded positive values representing subsidence): (top) [shaded region are 500-hPa vertical velocity]

(b) The JJAS (2001-2010) composite of vertically integrated moisture transport upto 300hPa, anomaly (design-control) for extended desert design experiment.

**** (top) CONTROL exp , (middle) DESIGN exp ; and (bottom) Difference .**

Conclusions – Extended Desert Exp.

- Increase in desertification over northwest India → Decrease in soil moisture → Decrease in precipitable water (column integration of specific humidity), recycling ratio, precipitation efficiency → Decrease in convergence of vertically water vapor → Decrease in low level winds with formation of anti-cyclonic circulation→ Decrease in VIMT → Increase in 2-metre and surface temperature /ground temperature → Decrease in Monsoon Hadley index and land–sea temperature contrast → Decrease in JJAS precipitation over NWP and CI (statistically significant) ***(Lodh 2021).***

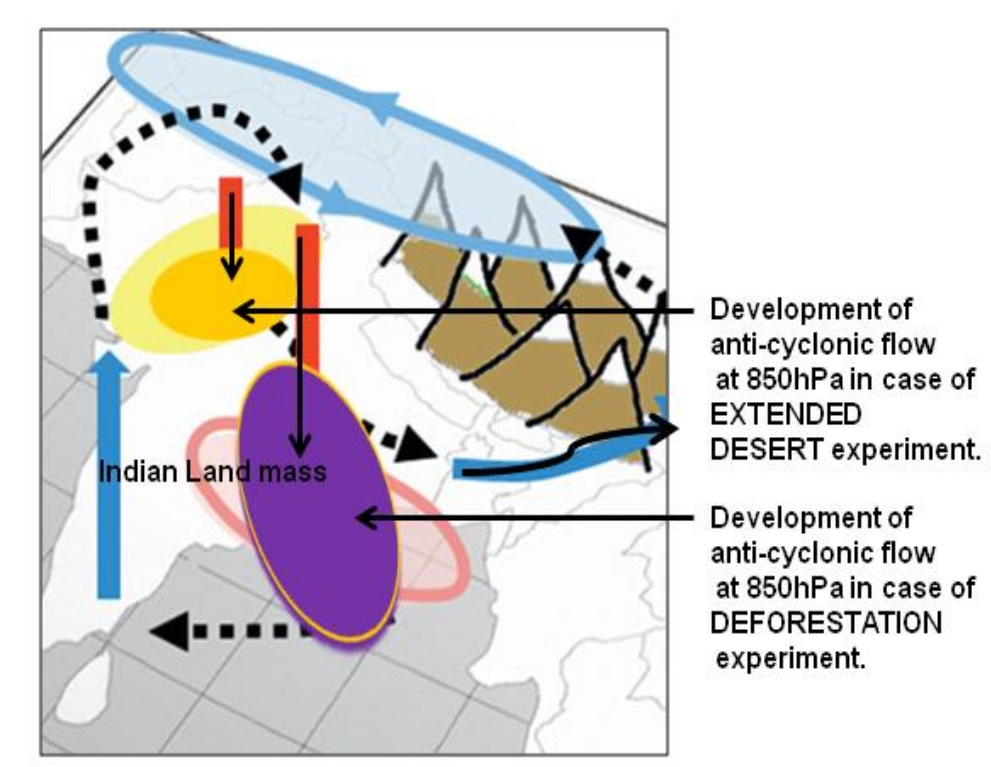
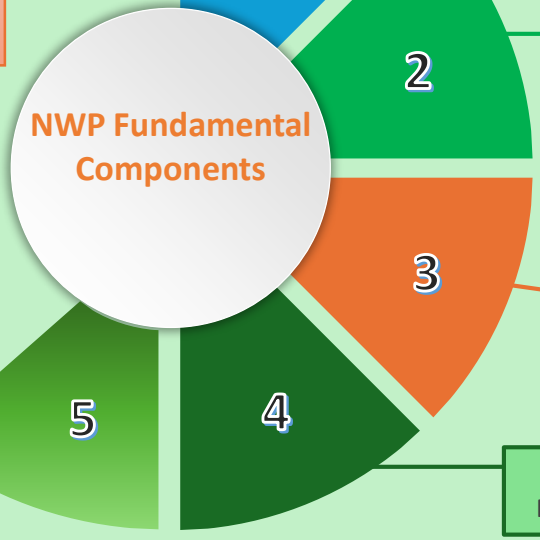


Figure : A schematic picture (**Bollasina et al., 2011**) of the atmospheric processes over the Indian subcontinent potentially induced by extensive desertification and deforestation.

Numerical Weather Forecasting (NWP)

Numerical Weather Prediction (NWP) models are complex computer programs that simulate (i.e., mimic) the Earth's atmosphere to forecast future weather conditions.

These models include various components that work together to make accurate predictions.



Key Components of the NWP Model

Initialization

This stage involves collecting real-world observational data from various sources, such as weather stations, satellites, and radars.

Data Assimilation

In data assimilation, we incorporate observational data into the initial conditions of NWP models. By doing so, any discrepancies between the predictions made by the model and actual observations can be corrected. This technique helps to make the model's starting point more accurate.

Numerical Integration

NWP models use mathematical equations to simulate the behavior of the atmosphere over time. These equations describe the conservation of mass, momentum, and energy in the atmosphere.

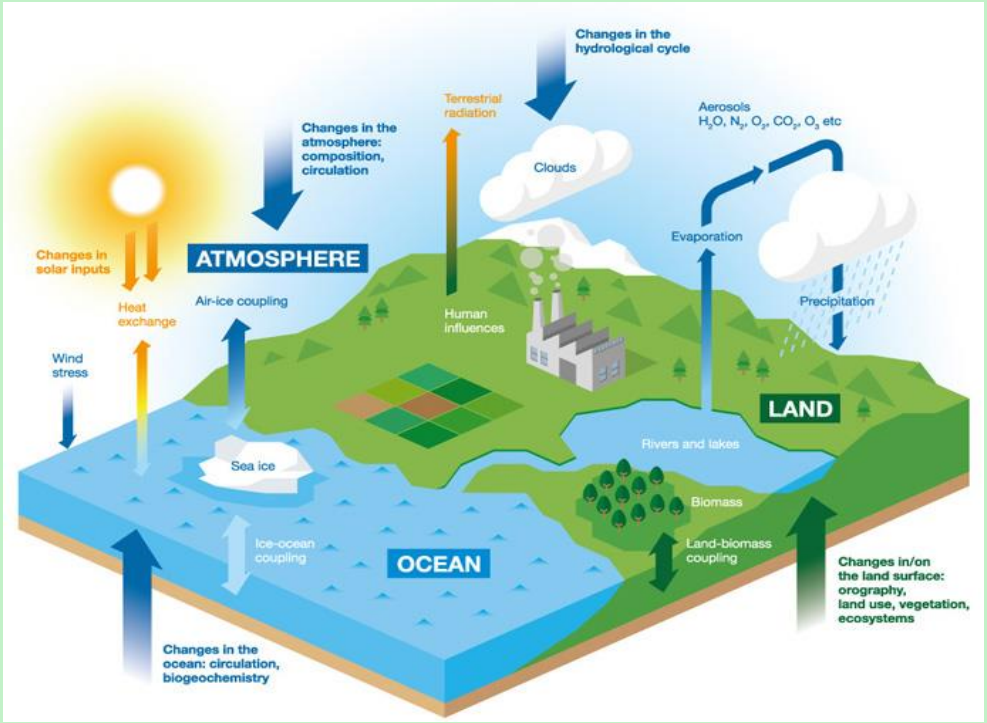
Post-processing

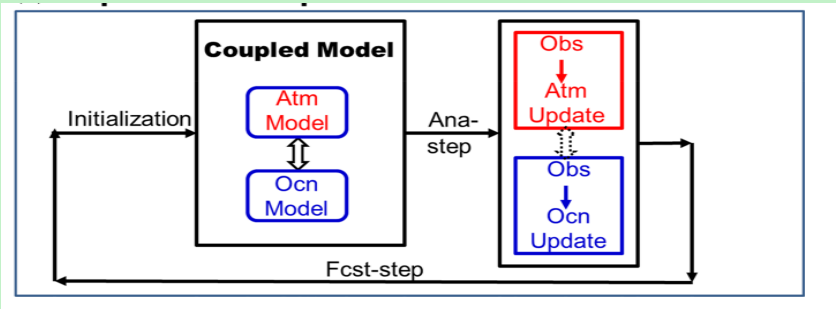
After the model has run, the output data often requires post-processing to generate user-friendly weather forecasts. Post-processing may involve converting the model output into weather variables—such as temperature, wind speed, and precipitation—as well as creating forecast maps and graphics.

Ensemble Techniques

Some NWP models utilize ensemble techniques by running multiple simulations with slightly different initial conditions or model physics. This approach helps assess forecast uncertainty and provides probabilistic forecasts.

How Coupled modeling system is important ?





ESM weather: Represent the complex interactions between different Earth system components: **Atmosphere, Oceans, Land, and Sea-ice**

Forecast accuracy: Crucial for improving weather forecast accuracy, especially in **Medium and Extended-range time scales.**

Global transition: Leading NWP centres, including ECMWF and UKMO, have adopted a coupled modelling approach.

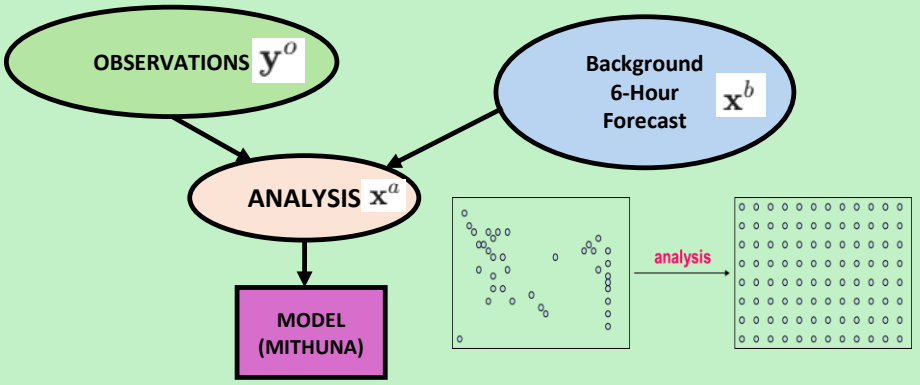
NGMS: Setting the Benchmark for the Next-Generation Modelling System (NGMS) under Mission Mausam/Vision 2047

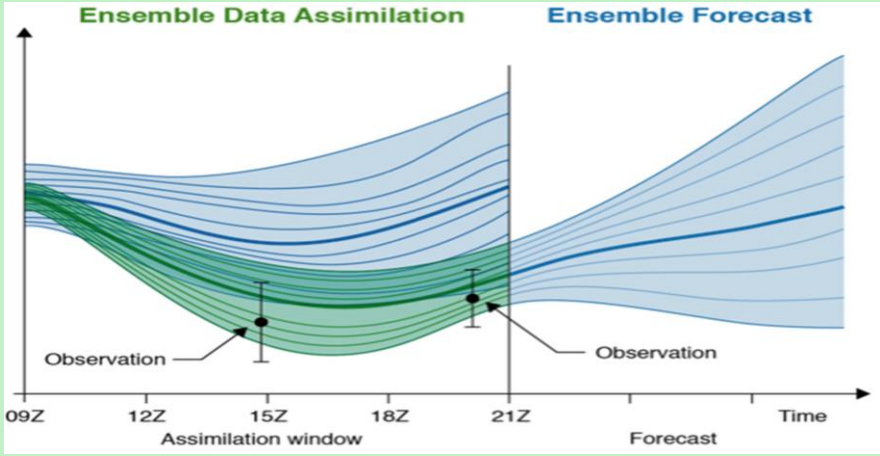
Data Assimilation

- Data assimilation is an analysis technique in which the observed information is accumulated into the model state by taking advantage of consistency constraints with laws of time evolution and physical properties.

- This integration is performed to rectify any discrepancies or anomalies that may exist between the model's predictions and actual observations and hence improve weather forecasts.
- In essence, the aim is to produce a regular, physically consistent, four-dimensional representation of the state of the atmosphere from a heterogeneous array of in-situ and remote instruments which sample imperfectly and irregularly in space and time

- This cycle continues iteratively to improve the accuracy of the background and analysis. Since B (background uncertainty) and A (analysis uncertainty) can be very large, scientists often employ Ensemble Data Assimilation techniques to estimate B and A.



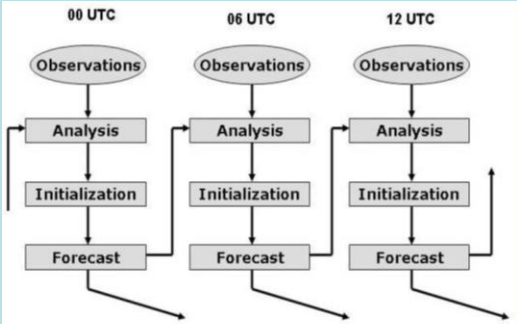


Ensemble Data Assimilation (EDA) – Ensemble of Atmospheric 4D-Vars with Perturbed Observations and Forcing Fields

Source : ECMWF

Assimilation methods

- **Empirical methods**
  - Successive Correction Method (SCM)
  - Nudging
  - Physical Initialisation (PI), Latent Heat Nudging (LHN)
- **Statistical methods**
  - Optimal Interpolation (OI)
  - 3-Dimensional Variational data assimilation (3DVAR)
  - 4-Dimensional VARiational data assimilation (4DVAR)
- **Advanced methods**
  - Extended Kalman Filter (EKF)
  - Ensemble Kalman Filter (EnFK)



Typical 6-hour analysis cycle.

- In the variational assimilation algorithm, one scalar function is defined for any model solution over the assimilation period. It measures the "distance" or "misfit" between the model solutions and the available observations. That is called objective function or cost function.
- The cost function is a sum of squared difference between the observations and the corresponding model values with weight function.

Surface Analysis System for Mithuna

Surface Analysis

Soil Moisture Analysis:

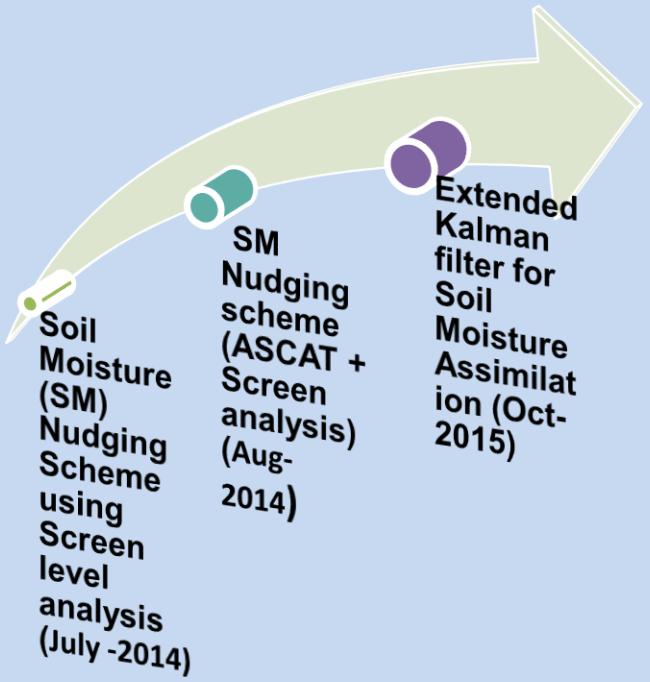
Method: **Extended Kalman Filter**

Analysis time: 00, 06, 12 and 18 UTC

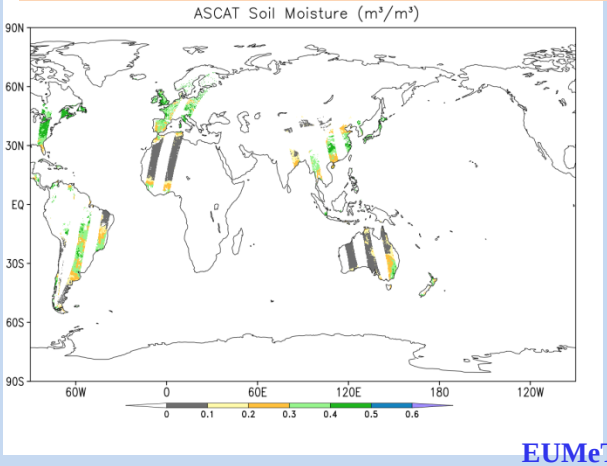
Observations assimilated: ASCAT soil wetness observations, Screen level Temperature and Humidity (pseudo observations from 3D-Var screen analysis)

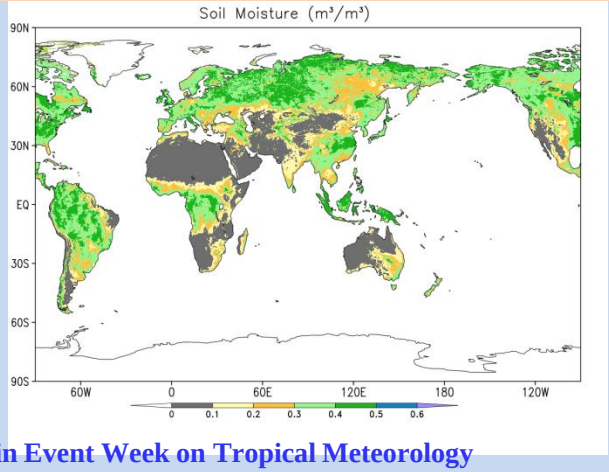
Sea Surface Temperature Analysis: Updated at 12 UTC DA cycle with OSTIA based SST and sea-ice analysis

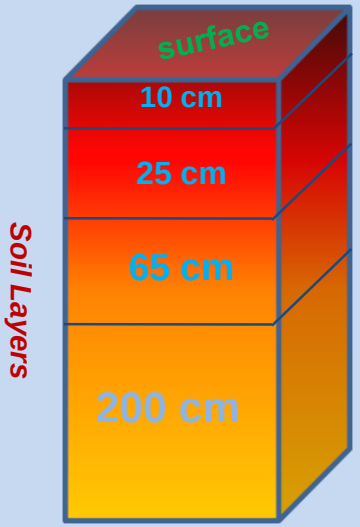
Snow Analysis: Satellite-derived snow analysis. Updated at 12 UTC DA cycle



12 UTC 07 Nov 2018: ASCAT Observation & SM Analysis

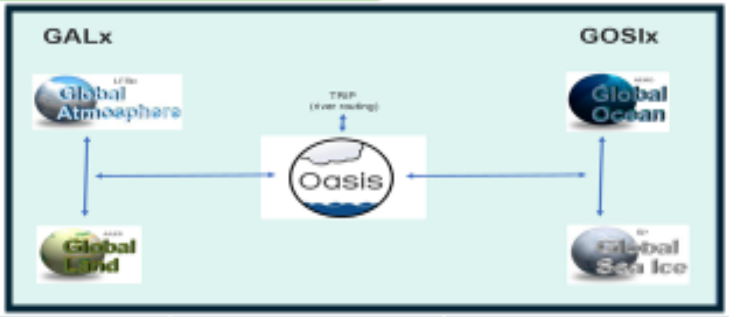






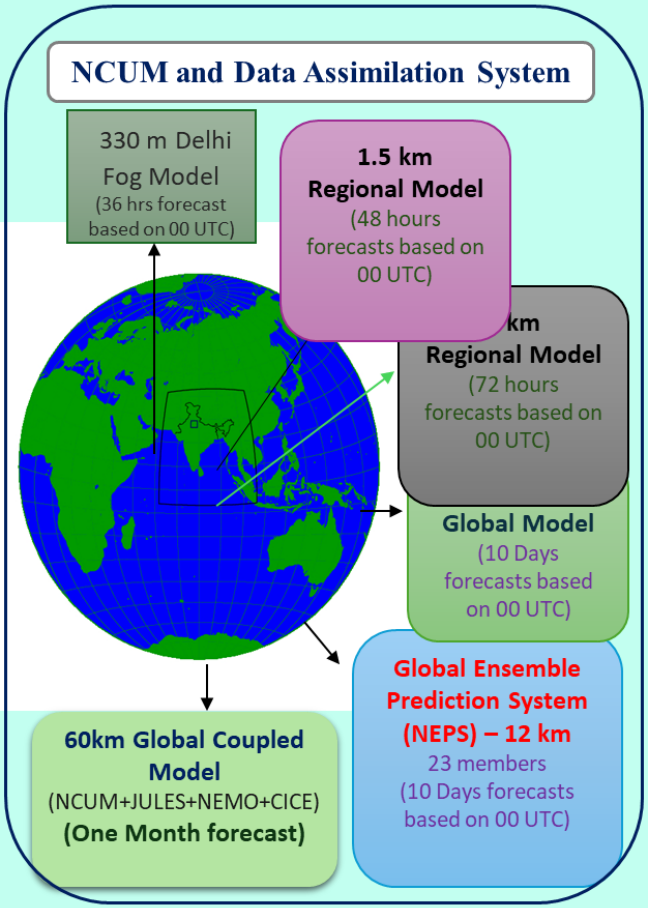
Operational/Research Coupled Suites

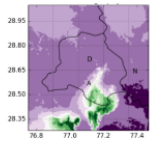
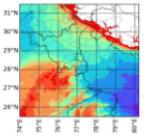
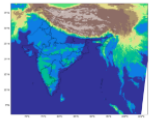
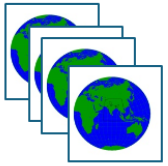
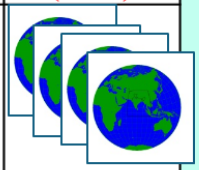
	Global Coupled Medium Range
Domain	
Horizontal resolution	Atmosphere ~12 km Ocean ~25 km Ensemble ~20 km
Fcst length (IC)	Deterministic 10 days 6hr (00, 12 UTC) 2 days 6hr (06, 18 UTC) Ensemble 7 days (00, 12 UTC)
Ensemble size	(long fcst 22 members 00, 12 UTC) 44 Members Initial Condition Perturbation
Initial conditions	Coupled Global DA Atmosphere IC: Hybrid-4DEnVar Ocean & Sea Ice IC : NEMOVAR
SST Conditions	Predicted SST in the fully coupled model
Main Products	Both Atmospheric and marine operational products



Items	Current operational (GAL7)	Upgraded version (GC5)
Cluster type	Cray XC40 Intel Haswell/Broadwell 36 cores/node Cray compiler	Bull Sequana XH2000 AMD Epyc Rom 96 cores/node HPCX (NVIDIA) OpenMPI Build with Intel Compiler(X86_64)
Science Configuration	Global Atmosphere (GA7) Global Land (GL7) Classic aerosol	Global Atmosphere (GA9) Global Land (GL9) Global Ocean and ICE (GOSI9 NEMO4 SI3) Glomap mode aerosol

Operational NWP Systems at NCMRWF

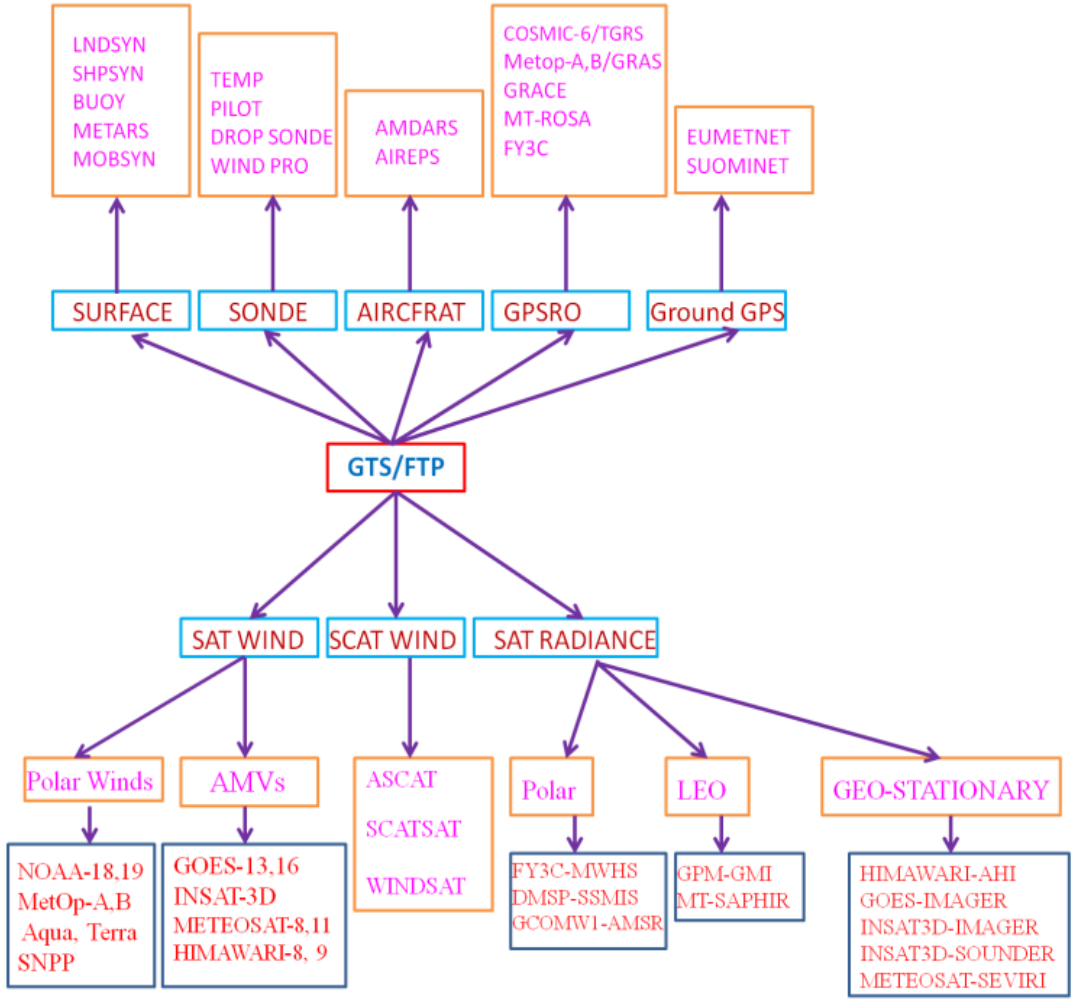


	Urban Model (DM-Chem)	Meso-scale Model (1.5 km)	Regional UM (NCUM-R) (4km)	Global UM (NCUM-G) (12km)	Global EPS (NEPS) (12km)	Coupled UM (CNCUM) (60km)
Domain						
Horizontal resolution	330m	1.5km	4.4 km	12km	12km	Atmosphere: approx. 60 km Ocean: approx. 25 km
Fcst length (IC)	48 hours	48 hours	75 hours(00UTC & 12UTC)	10 days (00,12 UTC)	10 days (00,12 UTC)	1 month (ERP) 3 Months- Seasonal
Ensemble size	-	-	-	-	23	ERP:16 Seasonal: 55 (Only atmosphere)
Initial conditions	Downscaled IC from 1.5km domain	Downscaled IC From NCUM-G	Regional DA (4-D Var)	Global DA (Hybrid 4-D Var)	Global DA Pert: ETKF+SKEB+SP	Atmosphere: Global DA Ocean: NEMOVAR
SST Conditions	Downscaled	Downscaled	OSTIA SST Analysis (EKF)	OSTIA SST Analysis (EKF)	OSTIA SST Analysis (EKF)	Coupled model
Main Products	Visibility/fog AQI Surface weather	Visibility/Fog AQI Surface weather	Precipitation Lightning Wind gust Surface weather	Precipitation Wind TC track and intensity Severe weather	Precipitation Wind TC track and intensity EFI	Various Monthly and seasonal forecast products

Observations (Atmos) Assimilated in the NCMRWF Global DA System

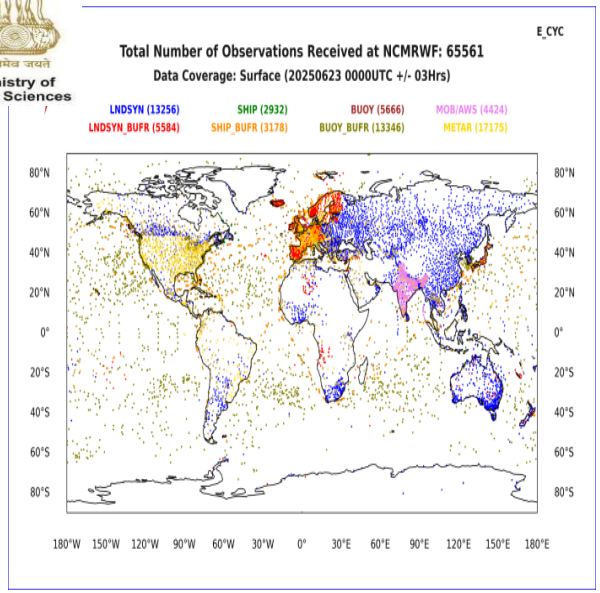
Conventional Observations	Surface (GTS)			**LAND SYNOP (TAC, BUFR), SHIP (TAC, BUFR), BUOY (TAC, BUFR), METAR, TC BOGUS, AWS**
	Upper Air (GTS)			**PILOT, RS/RW (TAC and BUFR) , Wind Profiler, Drop sonde, Indian DWR VAD Winds**
	Aircraft (GTS)			**AMDAR, AIREP**
Satellite Observations	HLOS Wind		LEO	**ALADIN (Aeolus) (Mie Cloudy and Rayleigh Clear)**
	Satellite Winds	AMVs	GEO	**INSAT-3D & 3DR, Meteosat-9 , Meteosat-11, Himawari-9, GOES-16, GOES-18**
			LEO	**MetOp-B & C, NOAA-18, NOAA-19, SNPP, NOAA-20, AQUA, TERRA, Dual MetOp**
		Scatterometer winds	LEO	**ASCAT (MetOp-B), ASCAT (MetOp-C), OSCAT-3 (Oceansat-3)**
	Satellite radiances	IR	GEO	**INSAT-3D Imager, INSAT-3DR Sounder, SEVERI (Metosat-9 & 11), AHI (Himawari-9), ABI (GOES-16 & 18)**
		IR (Hyper Spectral)	LEO	**IASI (MetOp-B, C), AIRS (AQUA), CrIS (SNPP & NOAA-20)**
		MW	Sounder	**AMSU-A (MetOp-B, -C, NOAA-15, 18, 19) , MHS (MetOp-B, C, NOAA-19), ATMS (SNPP & NOAA20) SSMIS (DMSP-F17), MWHS-2 (FY3-C, D), MWTS-2 (FY3-C,D), Microsat-2B (EOS-07)**
			Imager	**AMSR-2 (GCOM-W1), MWRI (FY3D), GMI (GPM)**
	GPSRO	Bending angle	LEO	**GRAS-(B & C), TanDEM-X, TerraSAR-X, FY-3D, COSMIC-2, Spire, PAZ, KOMPSAT-5, GeOptics, GRACE (C & D), PlanetIQ, Sentinel-6**

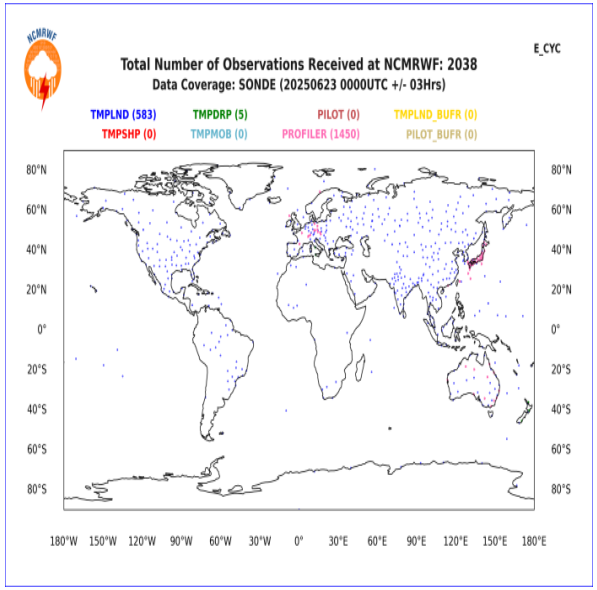
Pre-processing and Quality Control of Atmospheric and Ocean Observations

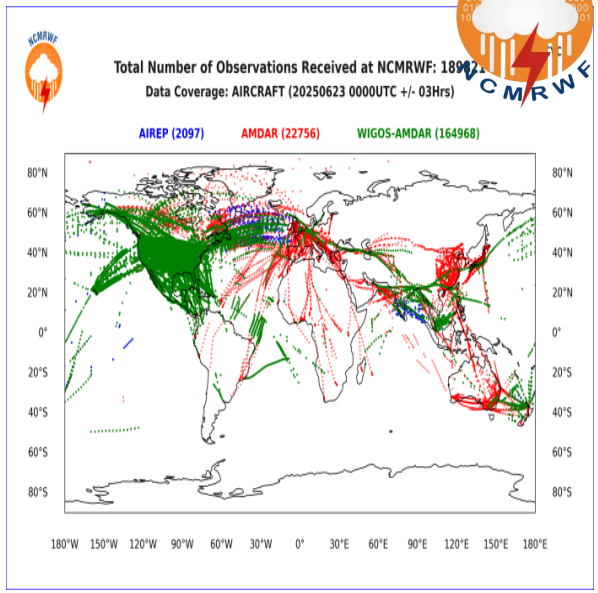


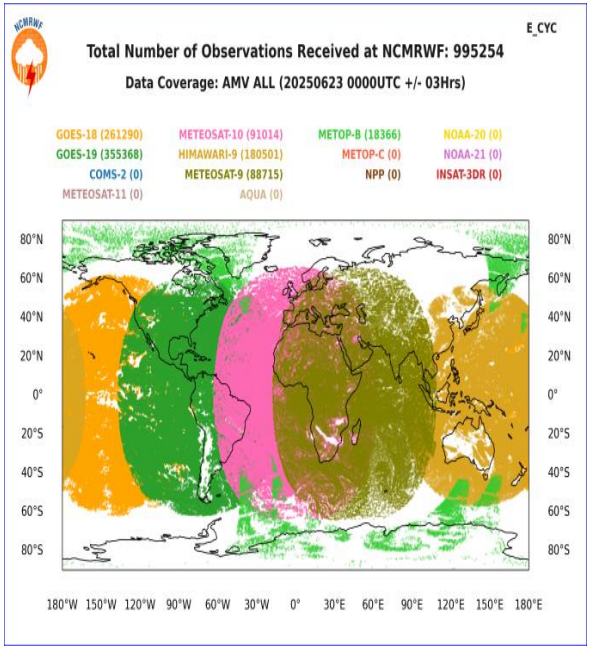
Sr. No	Observations	Sensors/Satellite
1	Sea Surface Temperature (Satellite & In-situ)	GHRSST observations (METOP-B, NOAA AVHRR, Sentinel 3A/3B) Ship observations, Drifter, and Moored buoy
2	T/S profiles	ARGO, TESAC, XBT, and Moored Buoys
3	Sea level anomaly	Sentinel 3A/3B, Sentinel 6, SARAL Altika
4	Sea Ice Concentration	AMSR2, and SSMIS

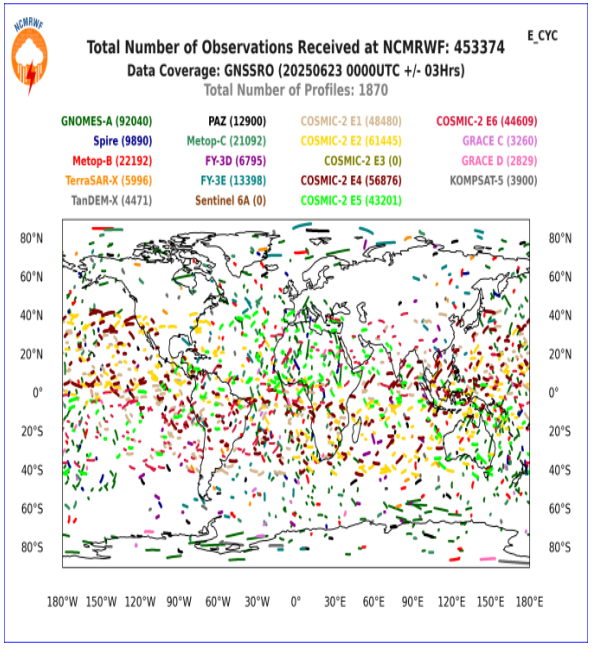
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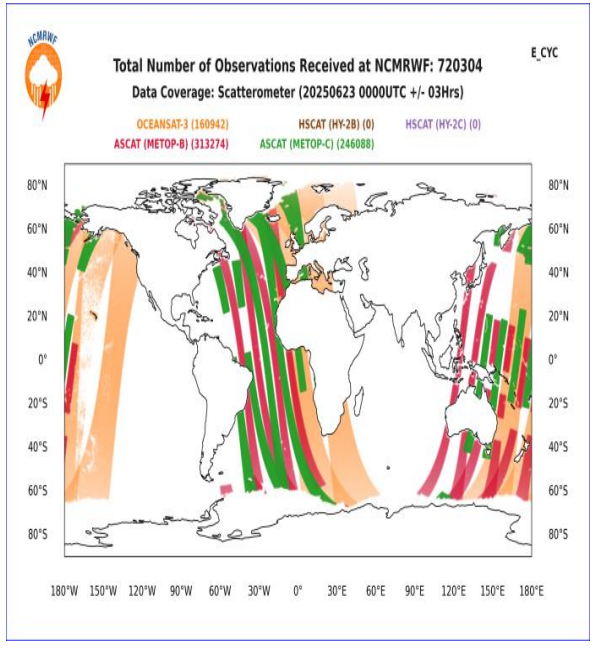










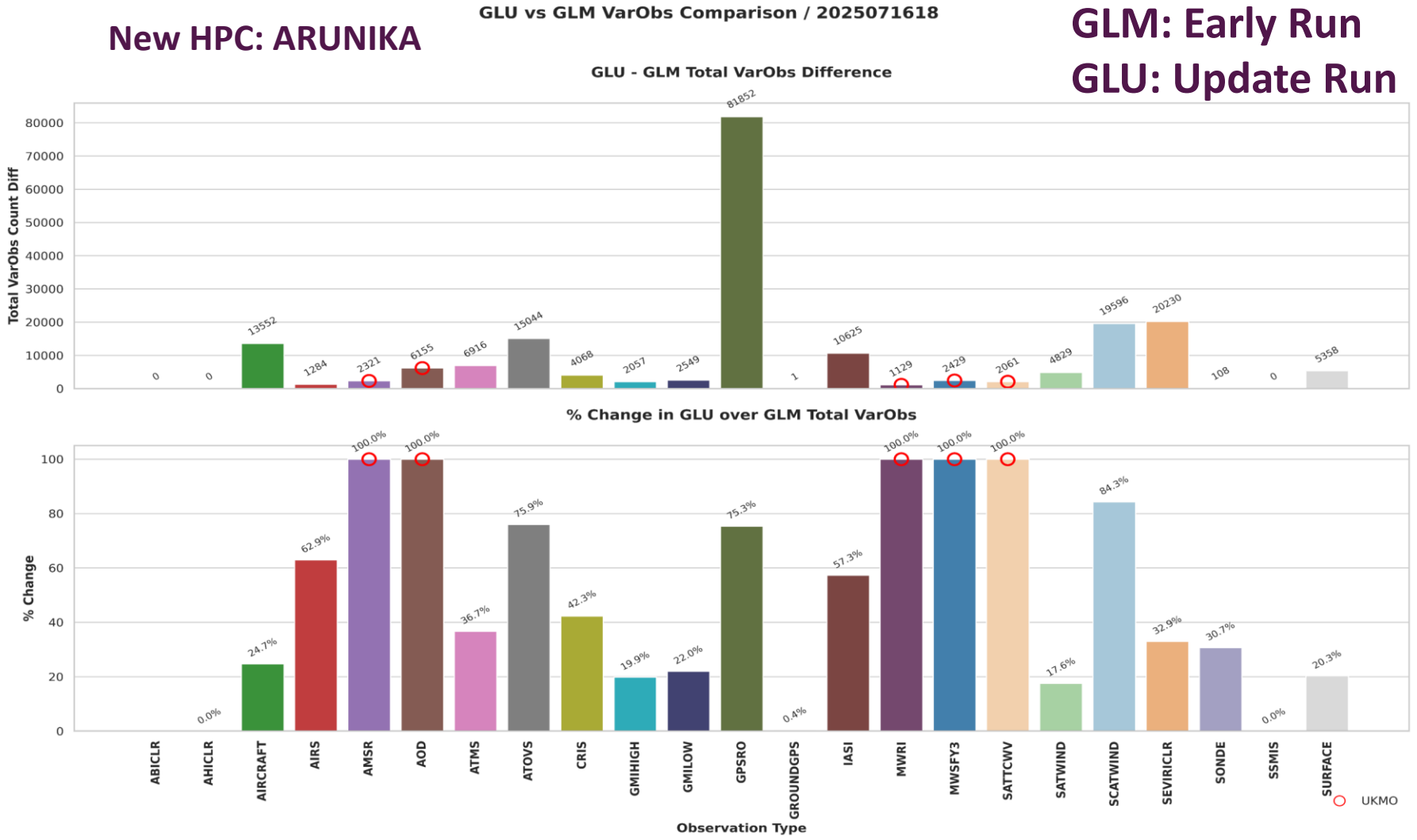


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New HPC: ARUNIKA

GLM: Early Run

GLU: Update Run

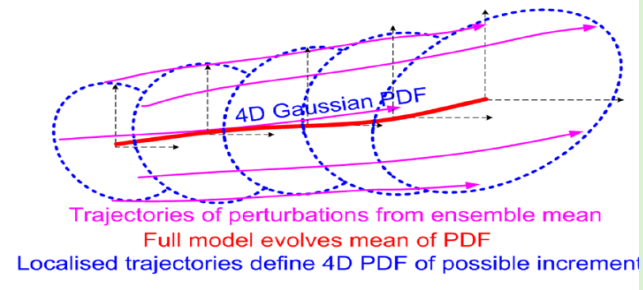


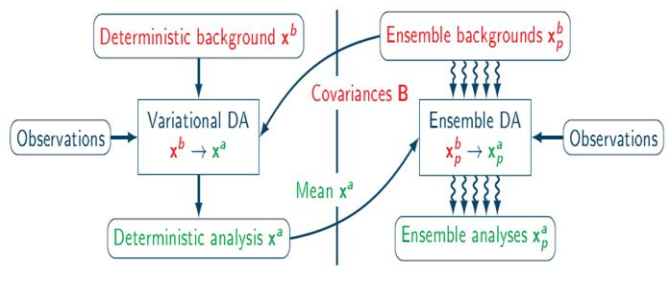
Methodological Advances in Ensemble System

En4DEnVar (Ensemble 4D Ensemble Variational) replaces the need for explicit model linearization by using an ensemble of nonlinear forecasts to approximate model error covariances and the 4D model evolution. Instead of building tangent linear and adjoint operators, En4DEnVar uses ensemble perturbations to estimate the sensitivity of model outputs to initial conditions. So, for example:
Each ensemble member is run forward with the full nonlinear model.
The differences between members implicitly capture the linearized model dynamics.
Gradients and covariance structures are approximated statistically from the ensemble.

ETKF-based ensemble: Transforms background ensemble perturbations using information from the latest observations
- Sophisticated adaptive inflation scheme,
- Localisation.

4DEnVar-based ensemble: Performs data assimilation for each member using VAR code.
- Sophisticated Localisation, sasier to maintain and opportunity to assimilate more observations
- Closer to operational deterministic DA system (hybrid covariances)
- Cheaper than an ensemble of Incremental 4DVar

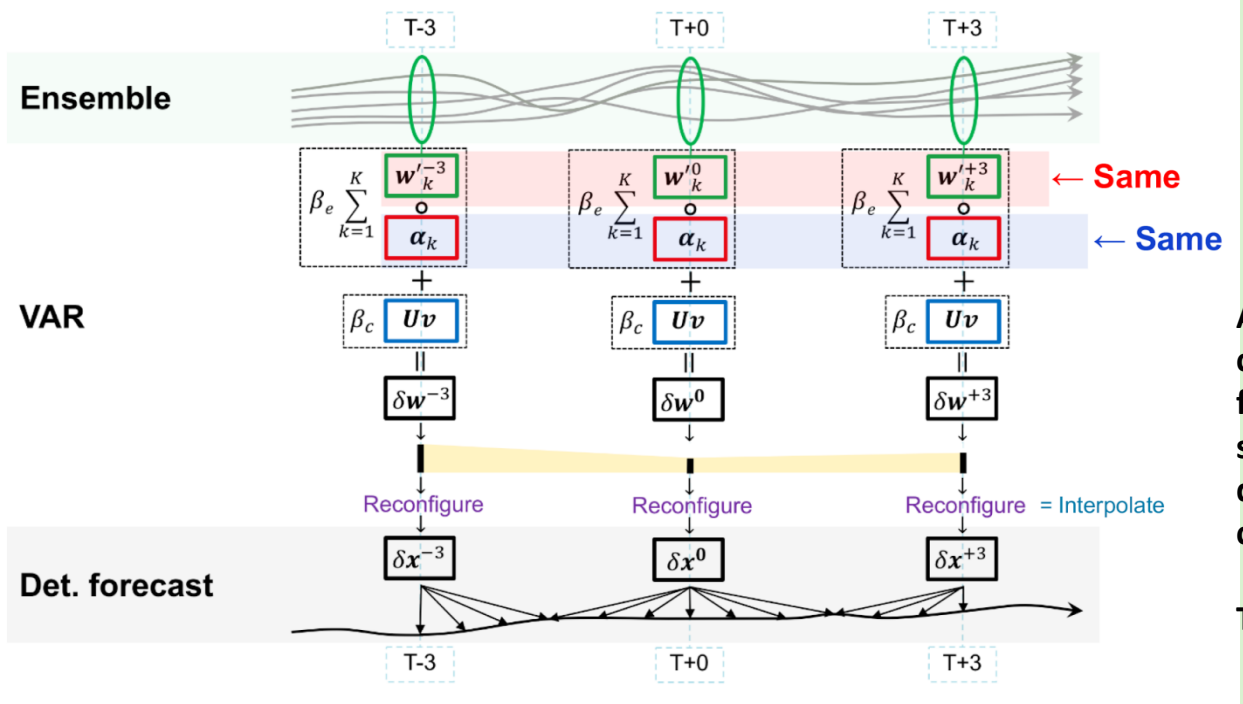




Variational DA **Ensemble DA**

Source : Benjamin (MET NORWAY)

Over all Hybrid-4DEnVar schematic



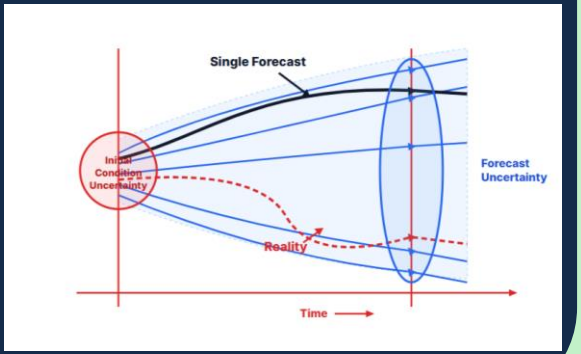
A common approach is to linearly combine the ensemble-based covariance from 4DEnVar with a climatological or static covariance from 4DVar to dynamically estimate background error covariances

This will avoid expensive adjoint models

Details in: Clayton et al (2013) *Q.J.R. Meteorol., Soc.*, https://doi.org/10.1002/qj.2054

Ensemble Forecasting

An ensemble runs the forecast many times, using different member initial states and/or model physics representations.



Quantifying NWP Uncertainty

Accounts for chaotic sensitivity, initial condition errors, and physical parameterization limitations.

Control + Perturbed Members

Integrates unperturbed control analysis along with multiple perturbed initial states forward in time.

Probabilistic Decision Support

Generates range of potential outcomes, extreme event probabilities, and confidence bounds.

Provides better guidance on both the expected weather and its uncertainty.

How the Ensemble Members Are Generated

NEPS-G compared with the upgraded MFS-ENS configuration

EARLIER NEPS-G

Atmosphere–land | ~12 km | 1 control + 22 perturbed

Initial conditions	ETKF perturbations added to the deterministic hybrid 4D-Var analysis
Model physics	SKEB + Random Parameters (RP); surface perturbations included
Lagged ensemble	11 members from current 00 UTC + 11 from previous-day 12 UTC + control

UPGRADED MFS-ENS

Coupled Earth system | ~20 km | 1 control + 44 perturbed

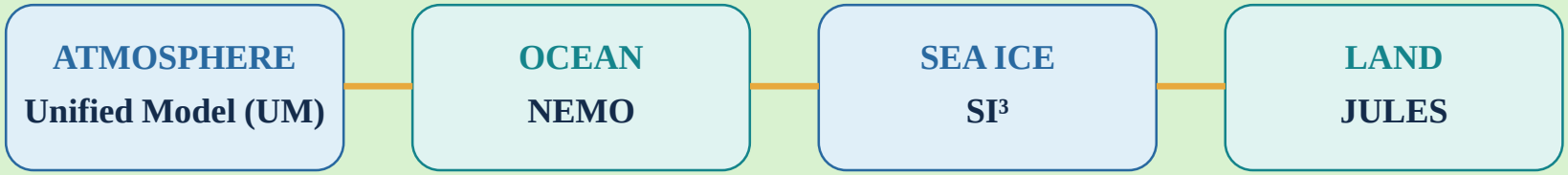
Initial conditions	Hybrid En4DEnVar framework; member-specific initial perturbations
Model physics	SKEB + Stochastic Physics Perturbation Tendencies (SPT)
Spread maintenance	RTPP + RTPS + analysis-increment-based additive inflation
Lagged ensemble	22 members from 00 UTC + 22 from 12 UTC across successive cycles + control

Main change: updated ensemble DA + stochastic physics + explicit spread maintenance, within the new coupled forecasting framework.

System Upgrade: NEPS-G → MFS-ENS

The transition from atmosphere–land modelling to a fully coupled global forecasting system

MFS exchanges heat, momentum and moisture across Earth-system components



Coupled interactions matter for SST evolution, monsoon variability, tropical cyclones and heavy-rainfall environments.

NEPS-G

Model: Atmosphere–land, ~12 km

Members: 1 control + 22 perturbed; lagged ensemble

Perturbations: ETKF; SKEB + RP

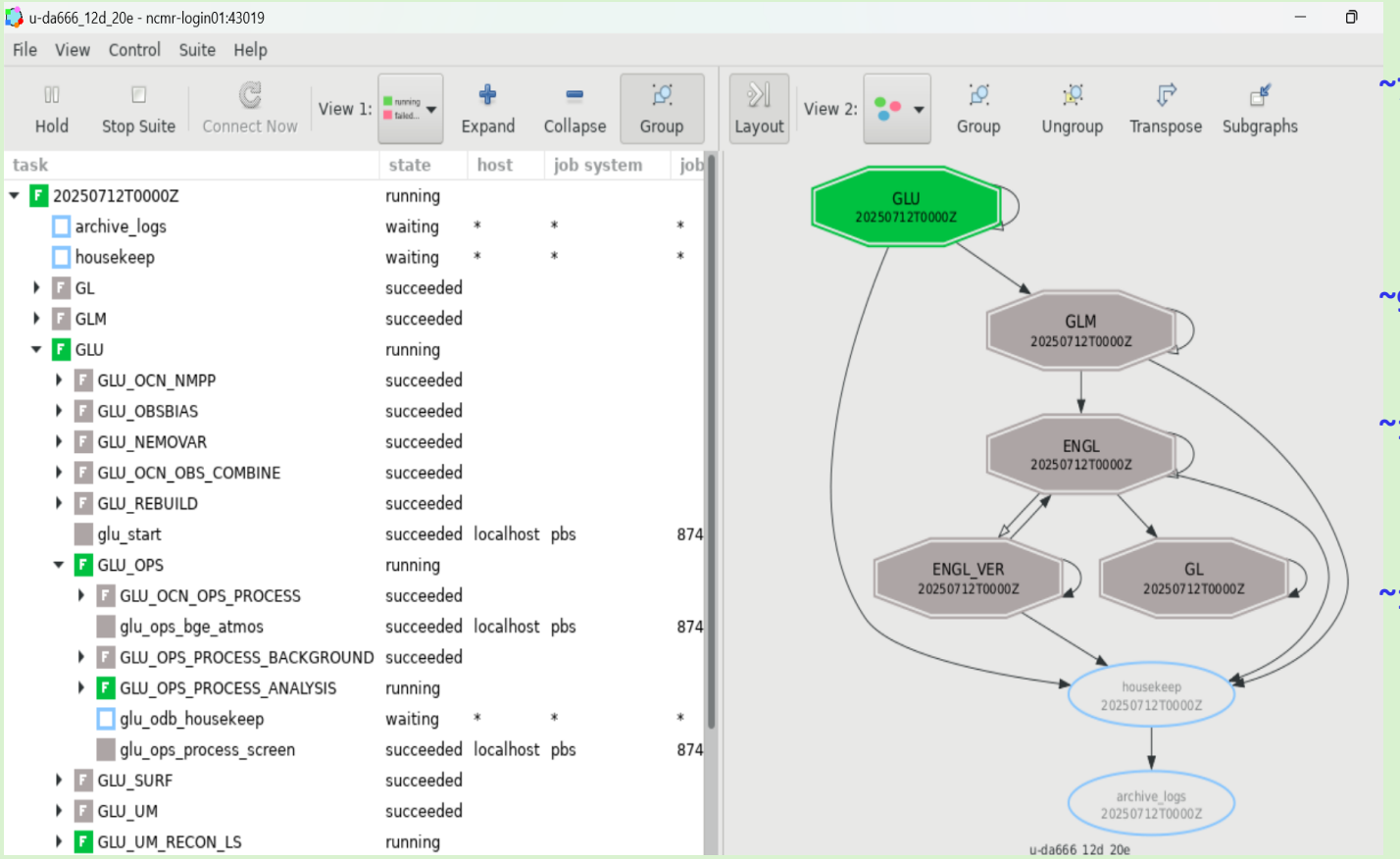
MFS-ENS

Model: Coupled atmosphere–ocean–land–sea ice, ~20 km

Members: 1 control + 44 perturbed; lagged ensemble

Perturbations: En4DEnVar; SKEB + SPT; RTPP/RTPS + additive inflation

/home/ncmrwf/prod/umprod/cylc-run/u-da666_12d_20e



~7.45am suite starts

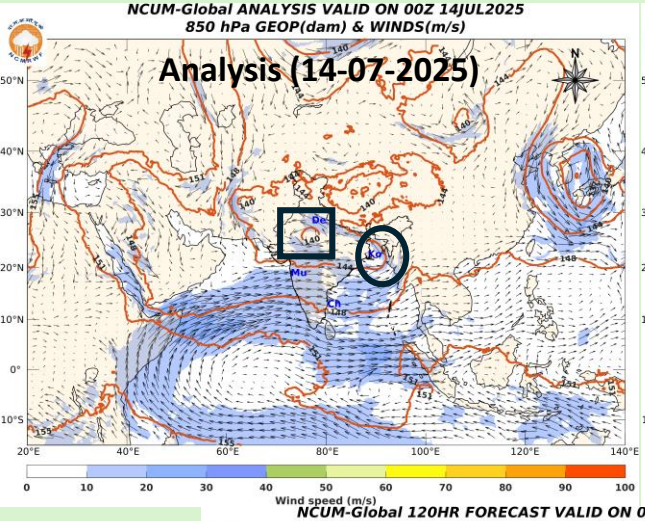
~9.43am Deterministic finish

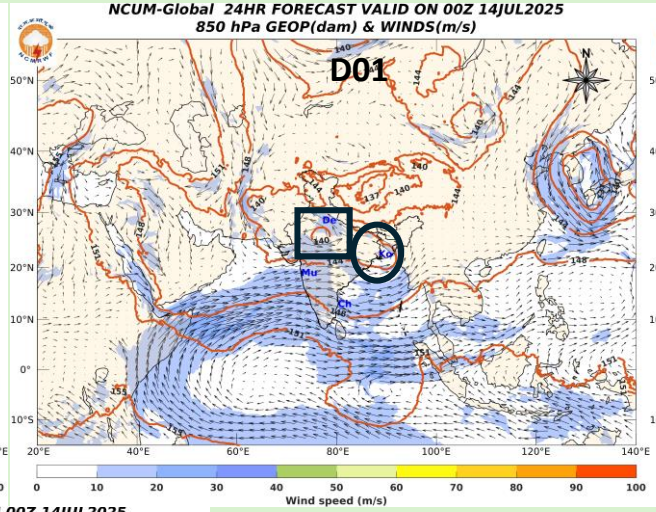
~11.15am Ensemble finish

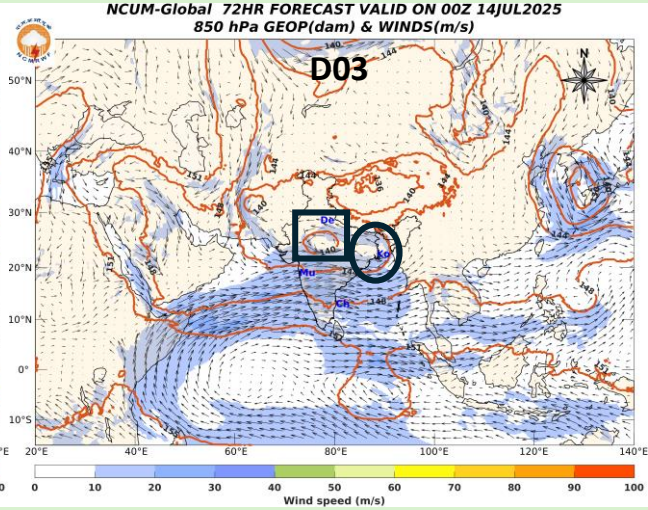
~12.15pm Updated run starts

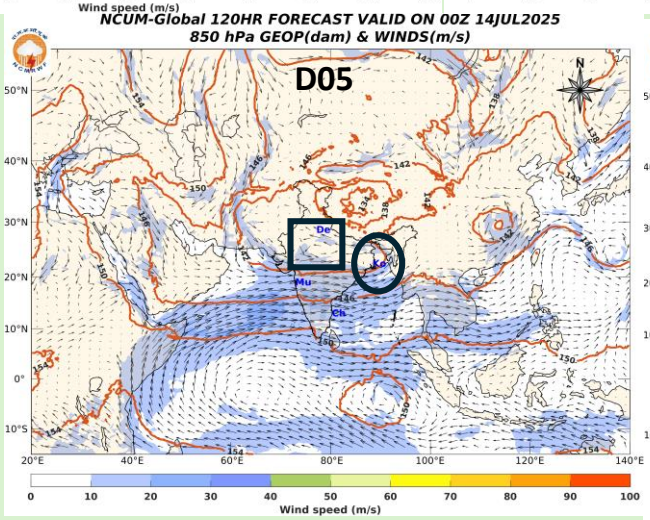
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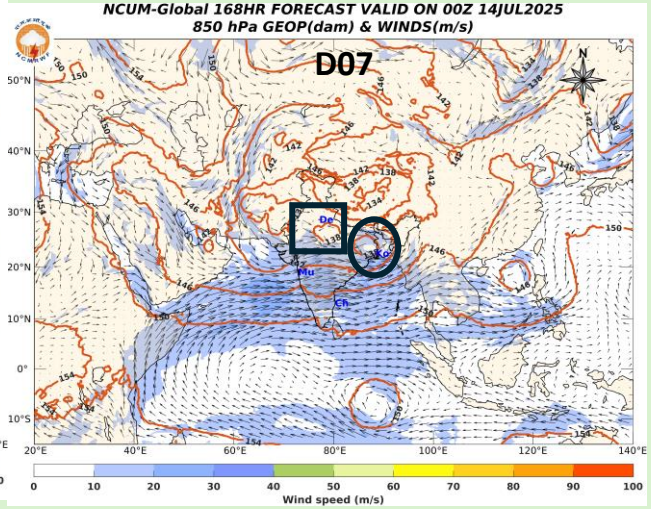
850 hPa Wind analysis and Day-1, 3, 5 and 7 forecasts valid on 14th July 2024 (coupled model)





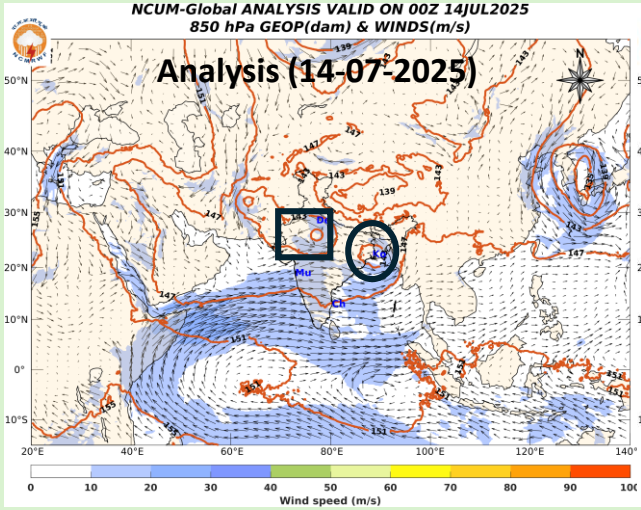


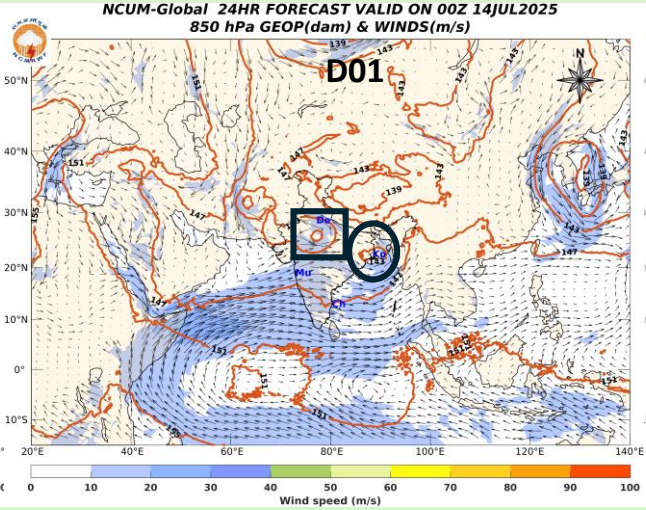


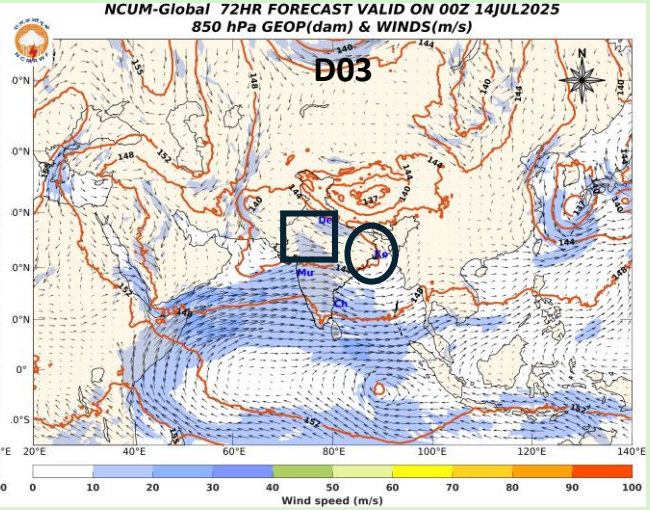


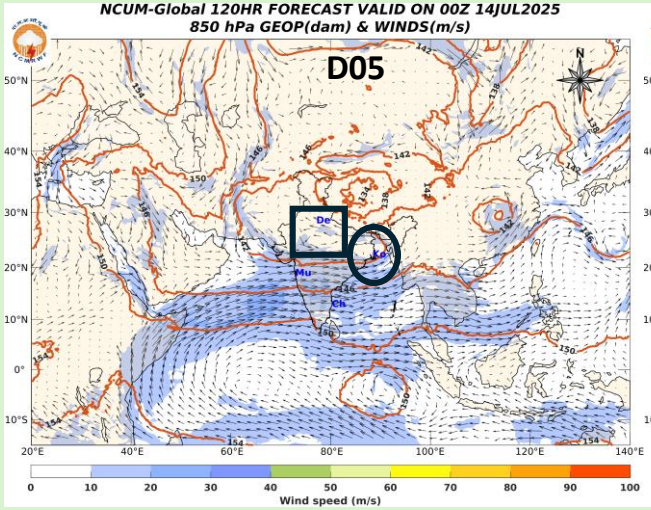
Both systems are predicted by the coupled model till day 7 lead time as seen in the 850 hPa wind forecasts

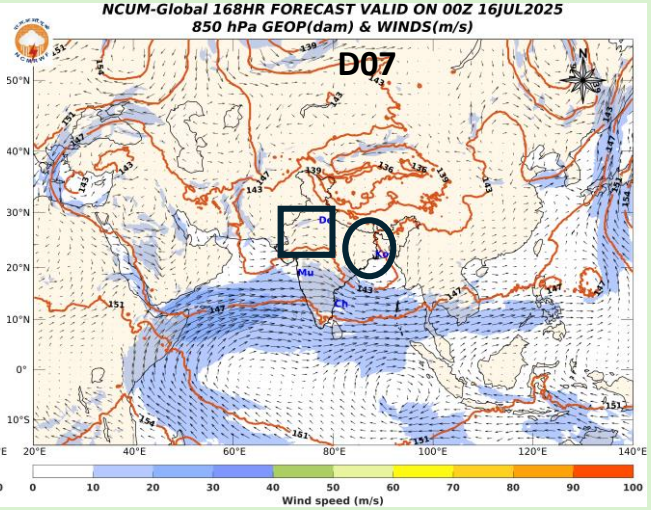
850 hPa Wind analysis and Day-1, 3, 5 and 7 forecasts valid on 14th July 2024 (atmosphere only model)







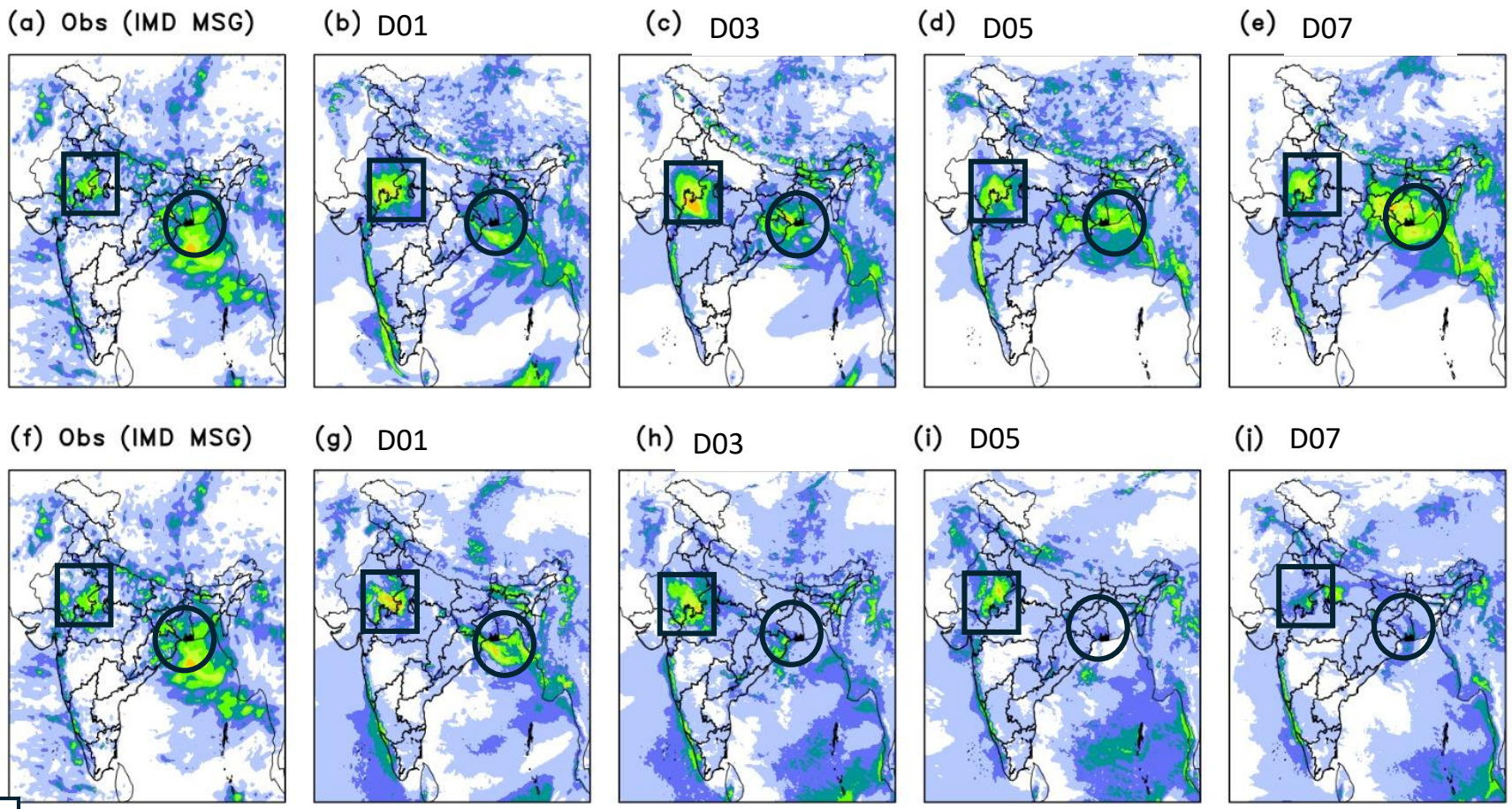




Beyond day 3 lead time the NCUMG model is not able to predict the systems as seen in the 850 hPa wind forecasts

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OBS & Model RAINFALL(cm) FCST FOR 14Jul2025

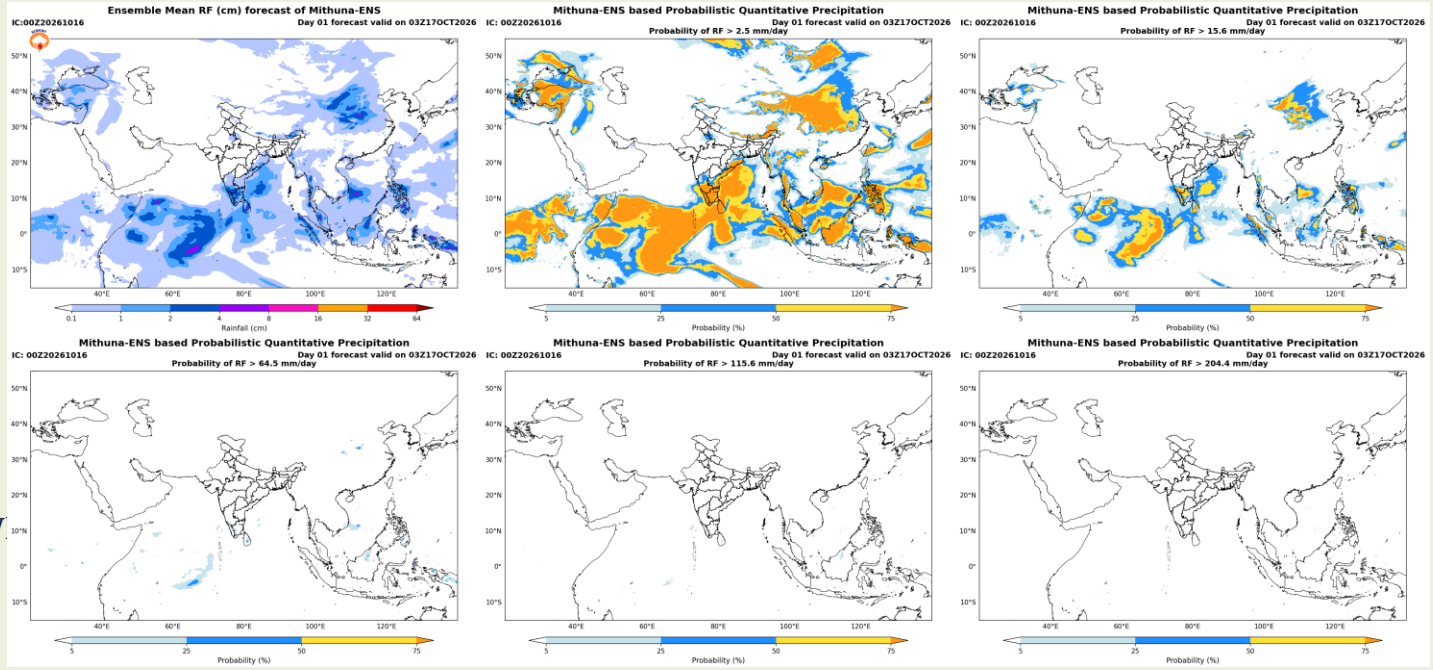


The rainfall due to the depression over East Rajasthan and MP is well predicted in the coupled model with 7-day lead time (only 5-day lead time in NCUMG)

The rainfall due to system over eastern India is not predicted by NCUMG beyond Day-3 lead time.

Probabilistic Quantitative Precipitation Forecast (PQPF)

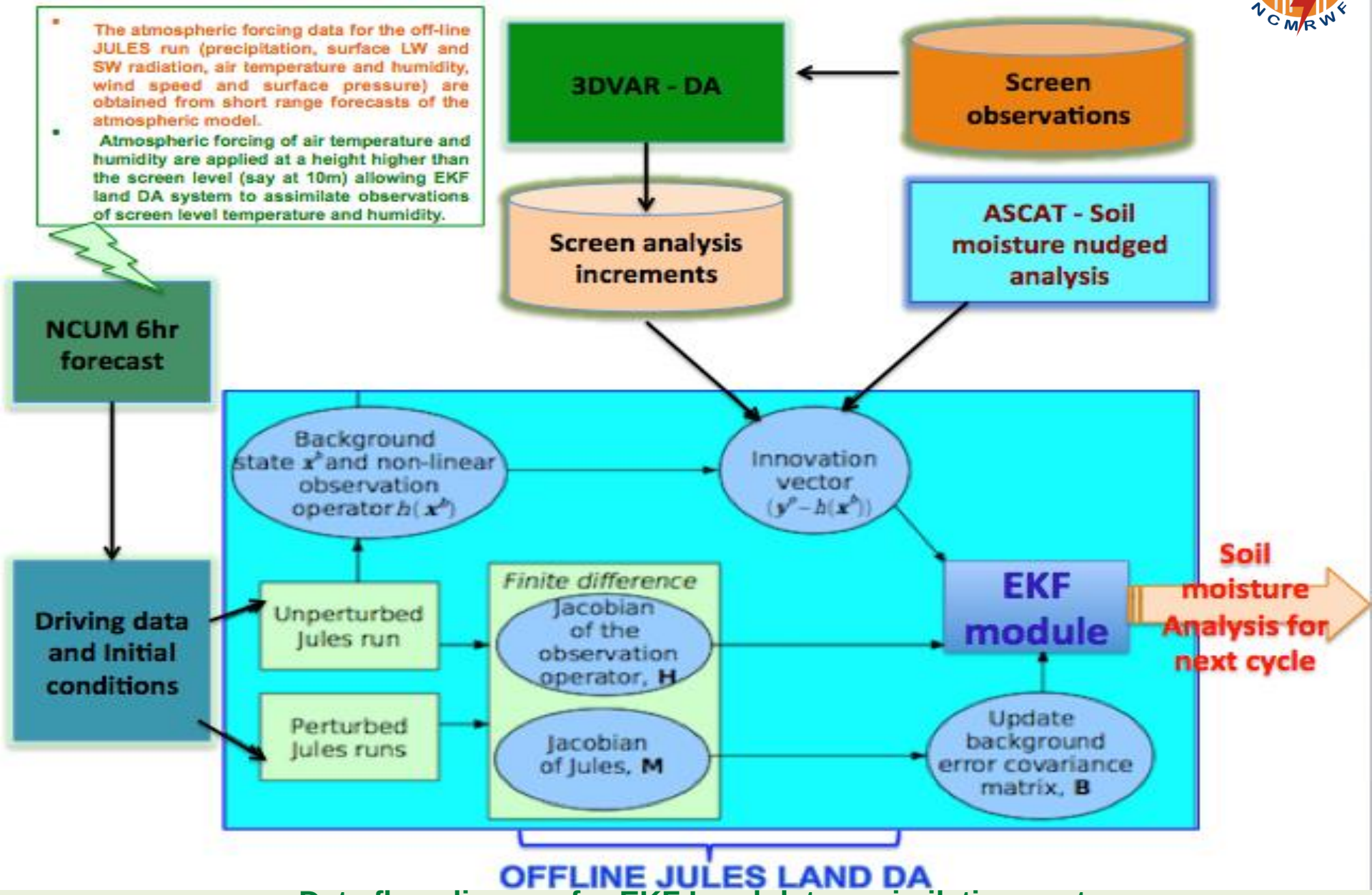
Probability that 24-hour accumulated rainfall exceeds a specified threshold



- **Locate risk**: shows where rainfall thresholds may be exceeded.
- **Support warnings:** helps prioritise areas for monitoring.
- **Communicate likelihood:** provides probabilities, not just one rainfall amount.
- **Plan for impacts:** supports flood preparedness and response.

PQPF translates ensemble forecasts into actionable information about the likelihood of heavy and extreme rainfall.

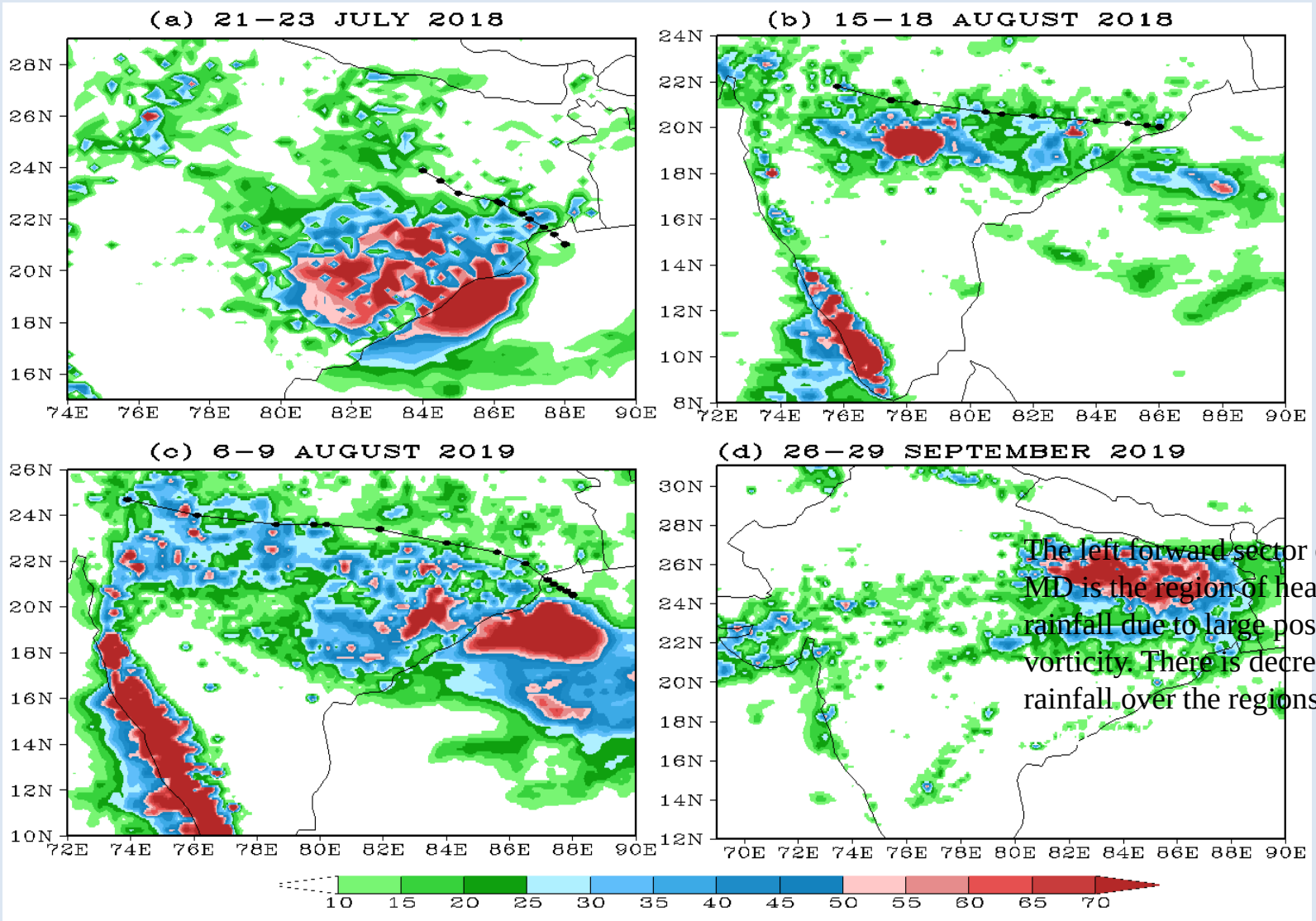
sEKF based ASCAT Soil Moisture Assimilation in Mithuna NWP System



Data flow diagram for EKF Land data assimilation system

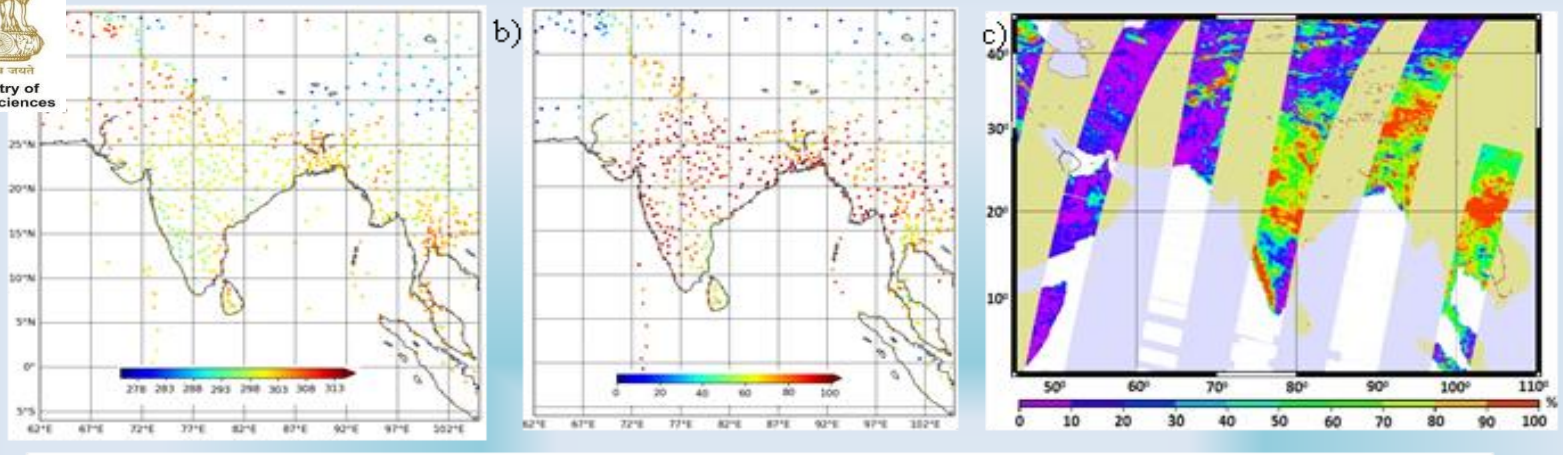
Sl. No.	Experiment Name	Observations used in LDAS	Initialization and forecast length
1	CTL	No ASCAT soil moisture data is used in the LDAS. Only screen level analysis increments of humidity and temperature (pseudo observations) are used.	NCUM-R 72 hour forecasts based on 06UTC initial condition (analysis) from • 19th – 21th July 2018 • 12th -14th August 2018 • 4th-6th August 2019 • 25th-28th September 2019 (Total two simulations each for CTL and ASCAT experiments). Soil moisture analysis at 06 UTC is used in all simulations.
2	ASCAT	Both ASCAT soil moisture observations and screen level analysis increments of humidity and temperatures are used.	

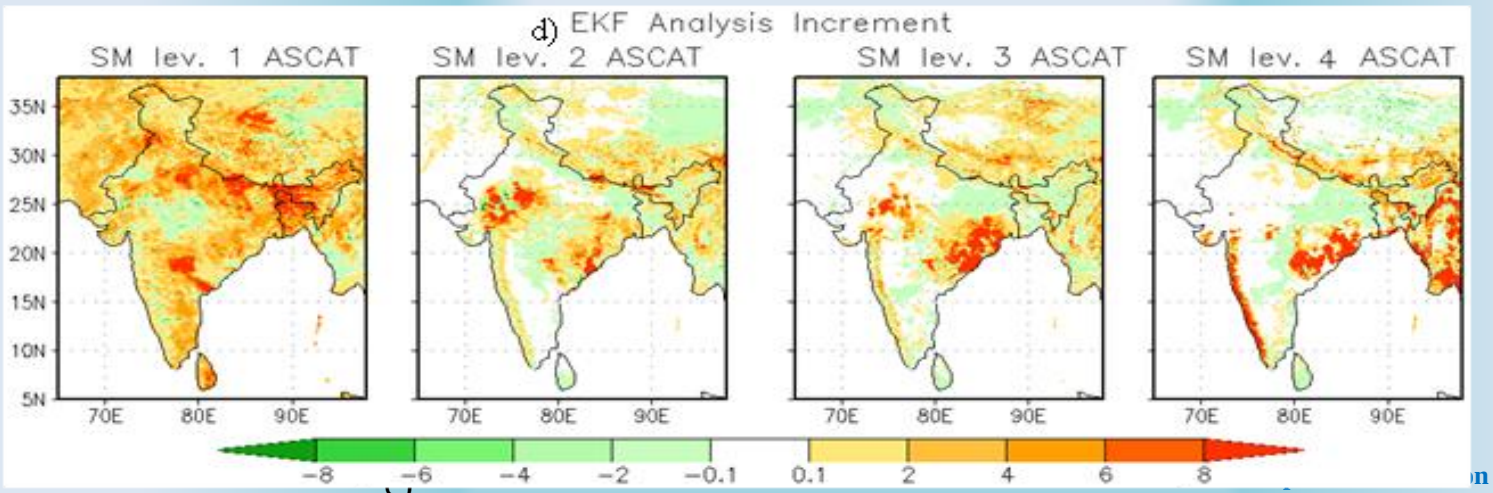
- The NCUM regional analysis-forecast system is used to conduct CTL and ASCAT sensitivity experiments (without and with assimilation of ASCAT soil moisture in LDAS).
- NCUM-R forecast run with updated analysis is given to simulate the monsoon depression during (a) 06UTC, 15th August to 06UTC, 17th August 2018 , over Coastal Odisha (b) 06UTC, 25th September 2019, to 06UTC, 27th September 2019, over east India (c) 4th-6th August 2019 and (d) 25th-28th September 2019 , to simulate the monsoon depressions and lows over India.

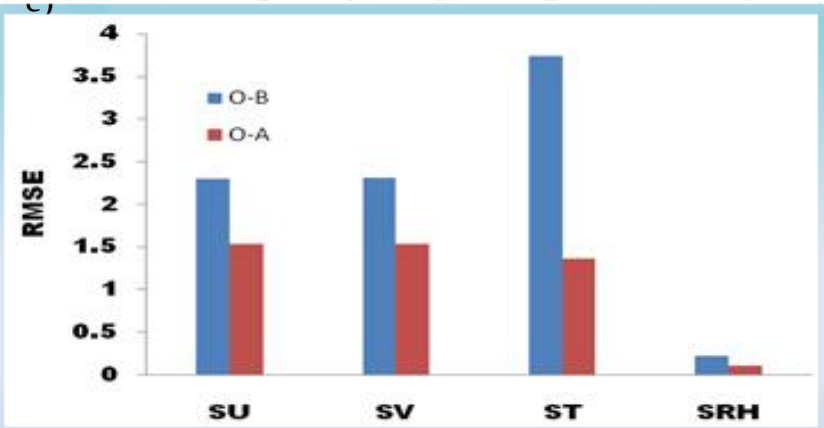


The left forward sector of a MD is the region of heavy rainfall due to large positive vorticity. There is decrease in rainfall over the regions lying

Time averaged (life span of MD) IMD-NCMRWF satellite-rain gauge merged rainfall (cm; shaded) for a) Case 1; b) Case 2; c) Case 3 and d) Case 4 with superimposed observed (IMD) MD tracks except for Case 4.





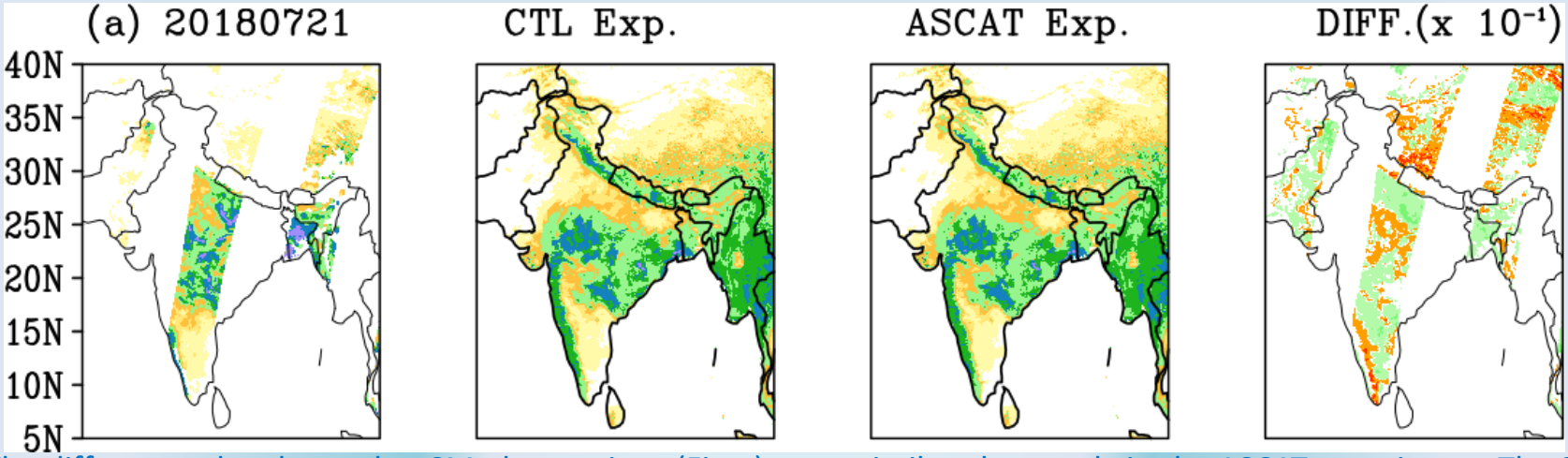


n of a) 2m-temperature (K); b) Relative humidity (%) at near-surface level from SYNOP observations and c) Soil moisture (SM) from ASCAT satellite of Case 1 valid at 06 UTC 21st July 2018. d) Analysis increment of SM (kg/m^2) obtained from the EKF driven by screen level and SM from ASCAT satellite observations valid at 06 UTC 21st July 2018.

e) Mean (four cases) RMSE of O-B and O-A of surface zonal/meridional (SU/SV; m/s) wind, surface temperature (ST; °K) and near-surface humidity (SRH; × 10^2 %).

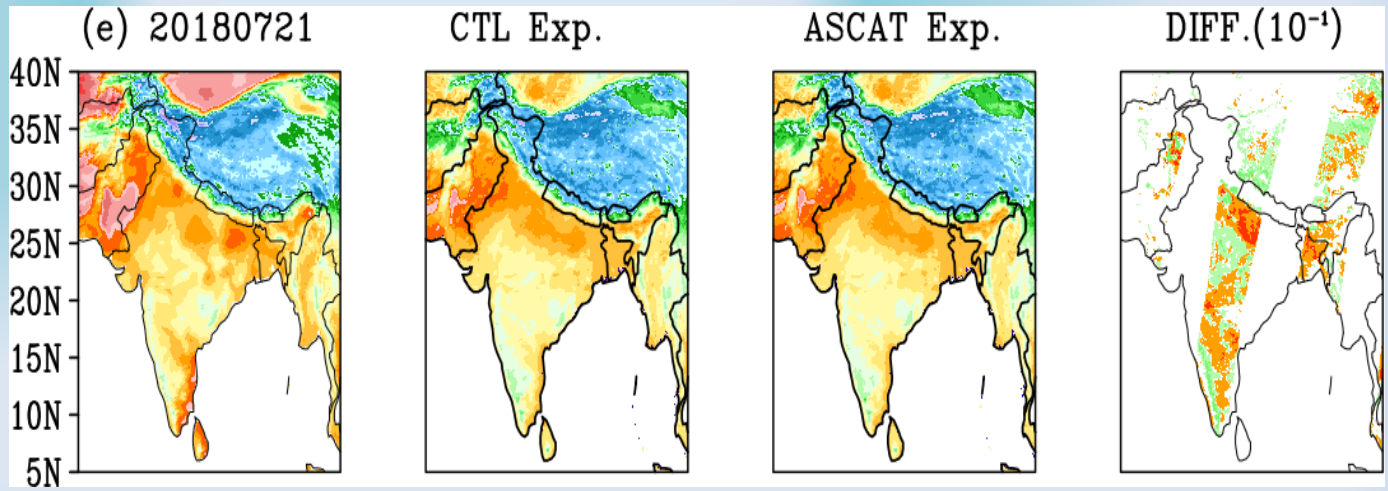
Impact of initial ASCAT soil moisture assimilation on initial soil moisture analysis (m^3/m^3)

(06UTC, 21st July 2018)

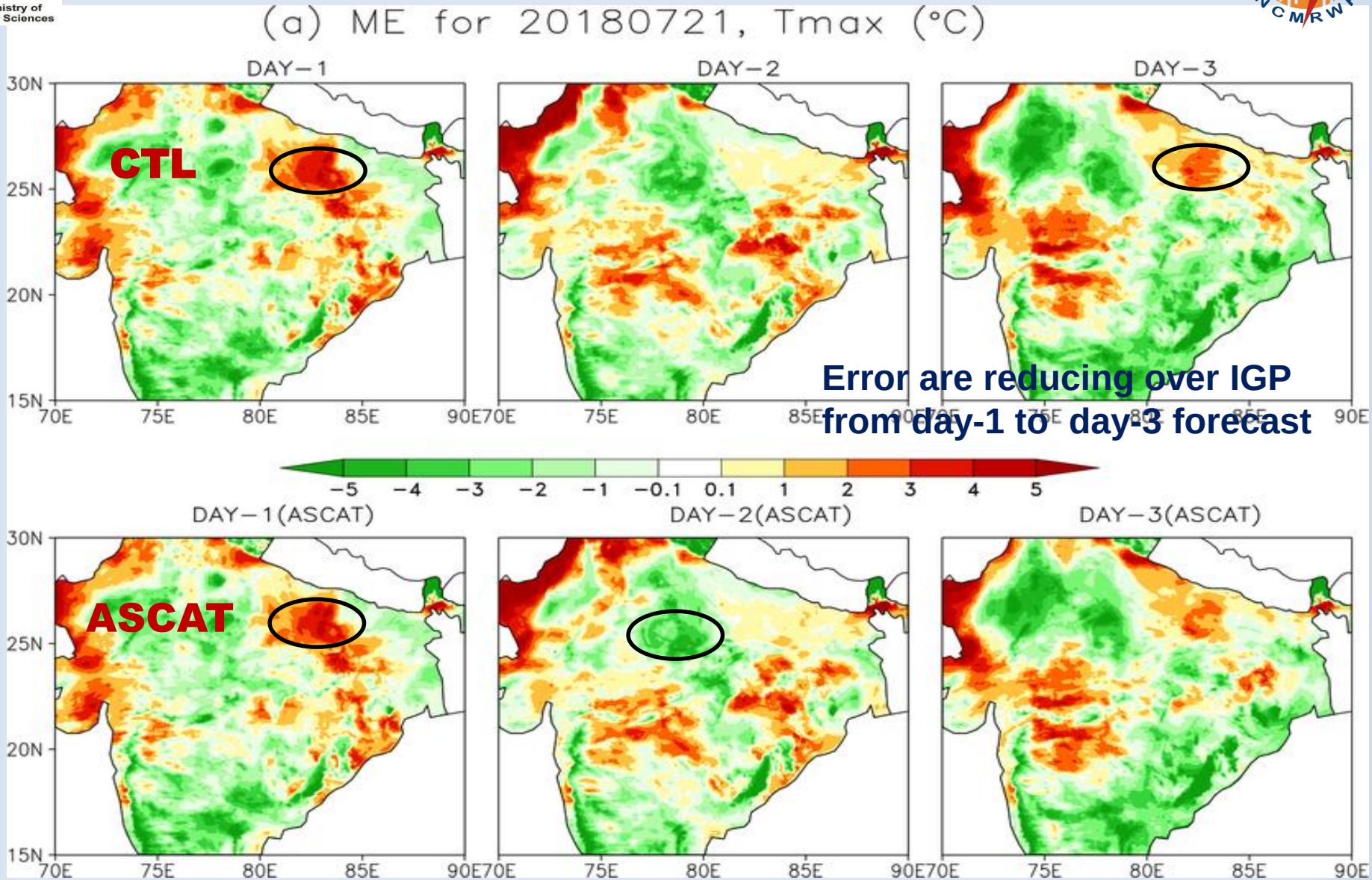


- The difference plot shows that SM observations (Fig-a) are assimilated properly in the ASCAT experiment. The SM values are increased (decreased) over Maharashtra and Uttar Pradesh regions in ASCAT experiment after assimilation of the SM. It is clearly depicted that the SM values are modified, wherever the satellite SM observations are available

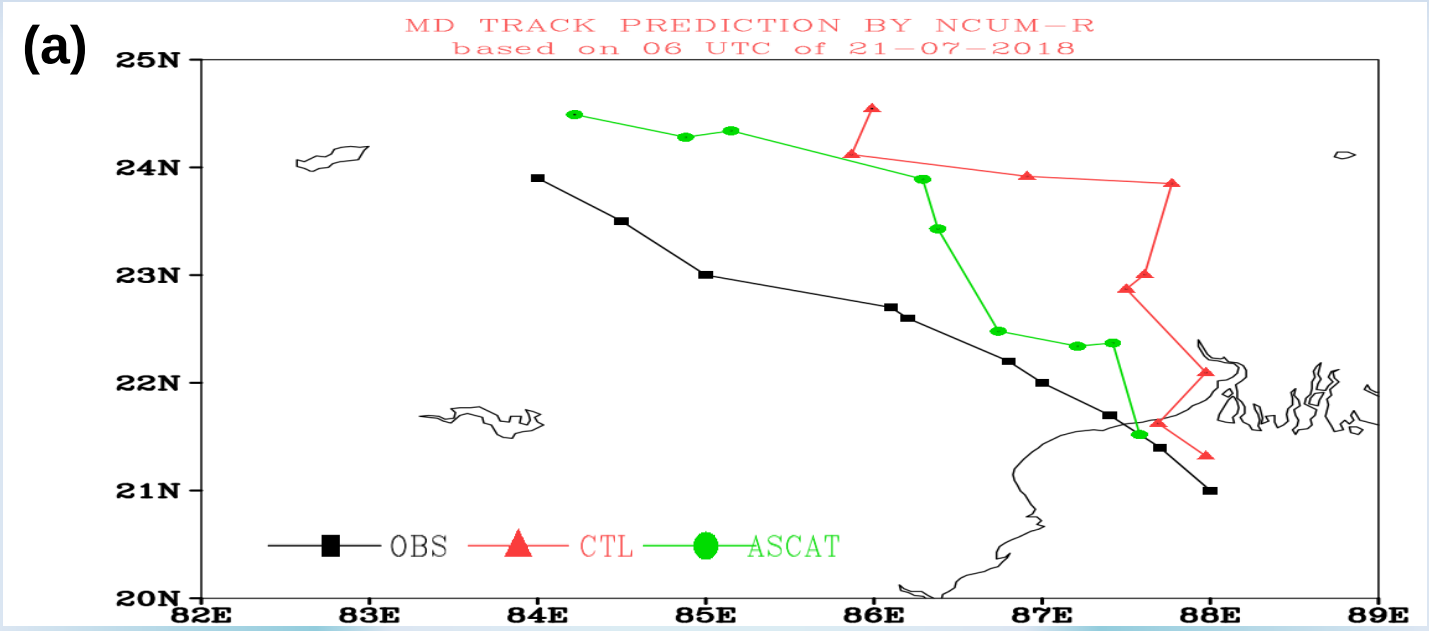
- **Change in LST due to ASCAT soil moisture assimilation**

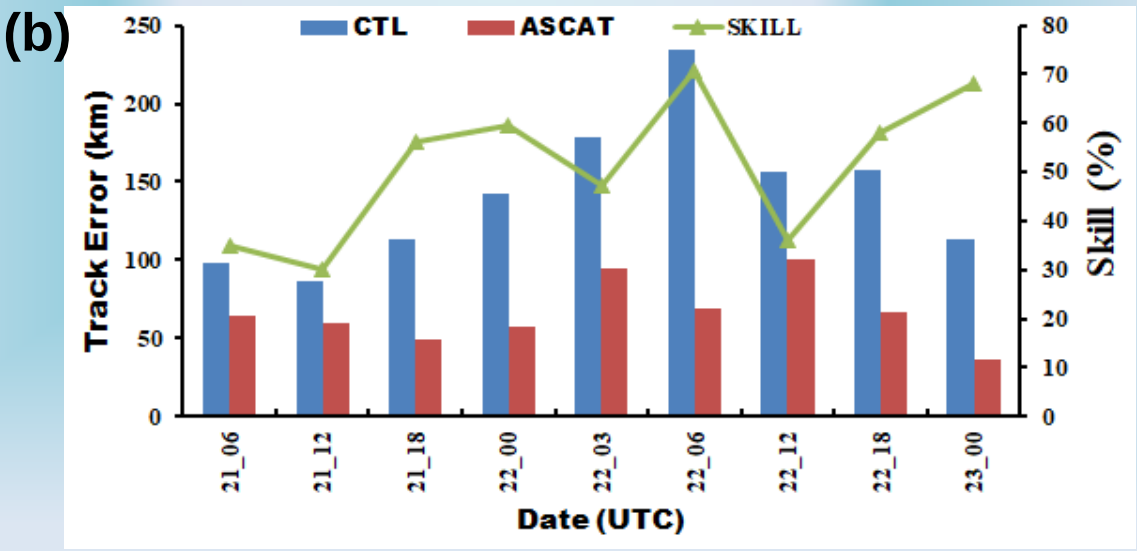


Impact of ASCAT soil moisture assimilation on minimum temperature forecast (06UTC, 25th September 2019)



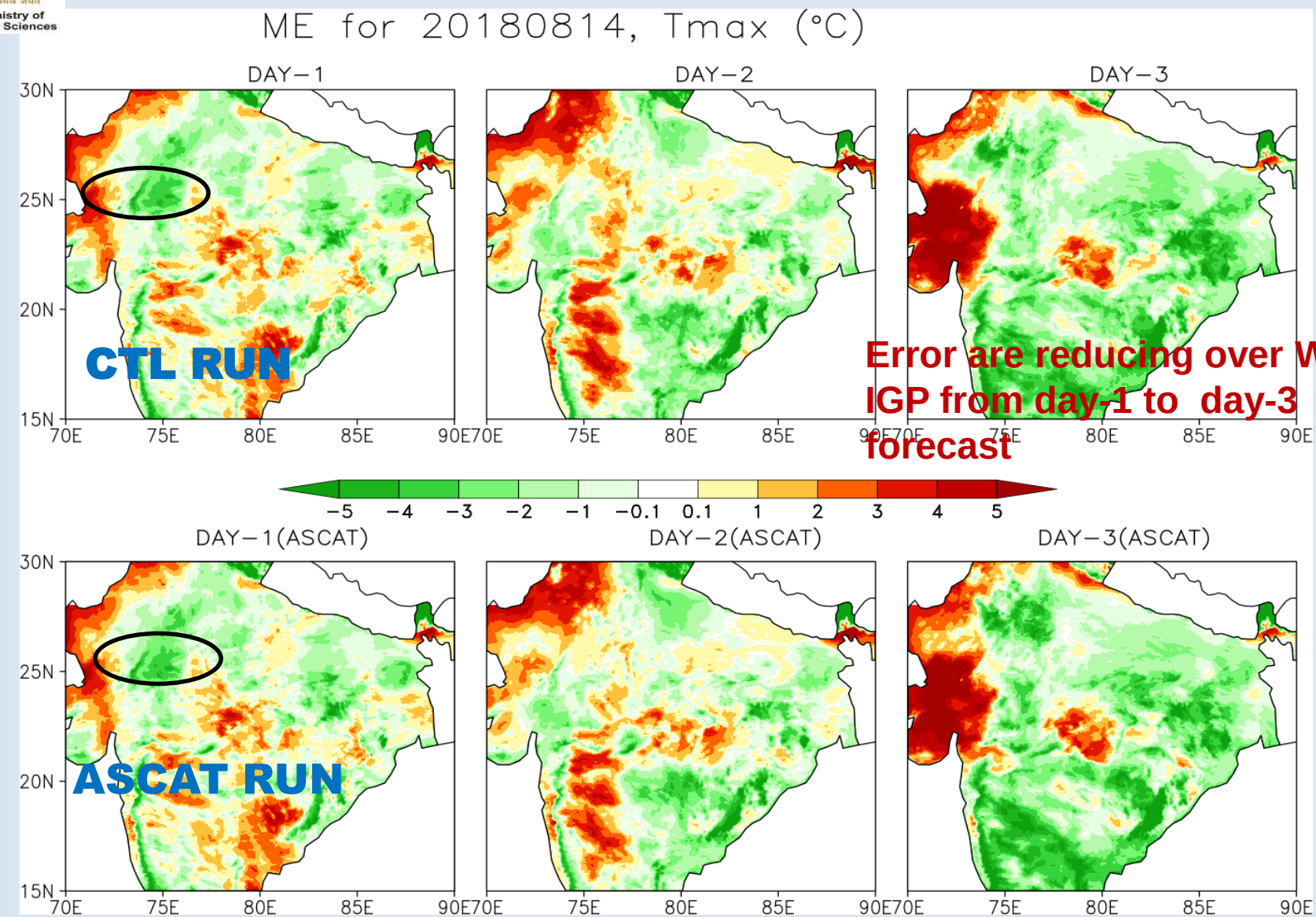
Spatial map of MEAN ERROR in minimum temperature forecast based on 06UTC, 20180721 for (a) CONTROL experiment and (b) for ASCAT sensitivity experiment.



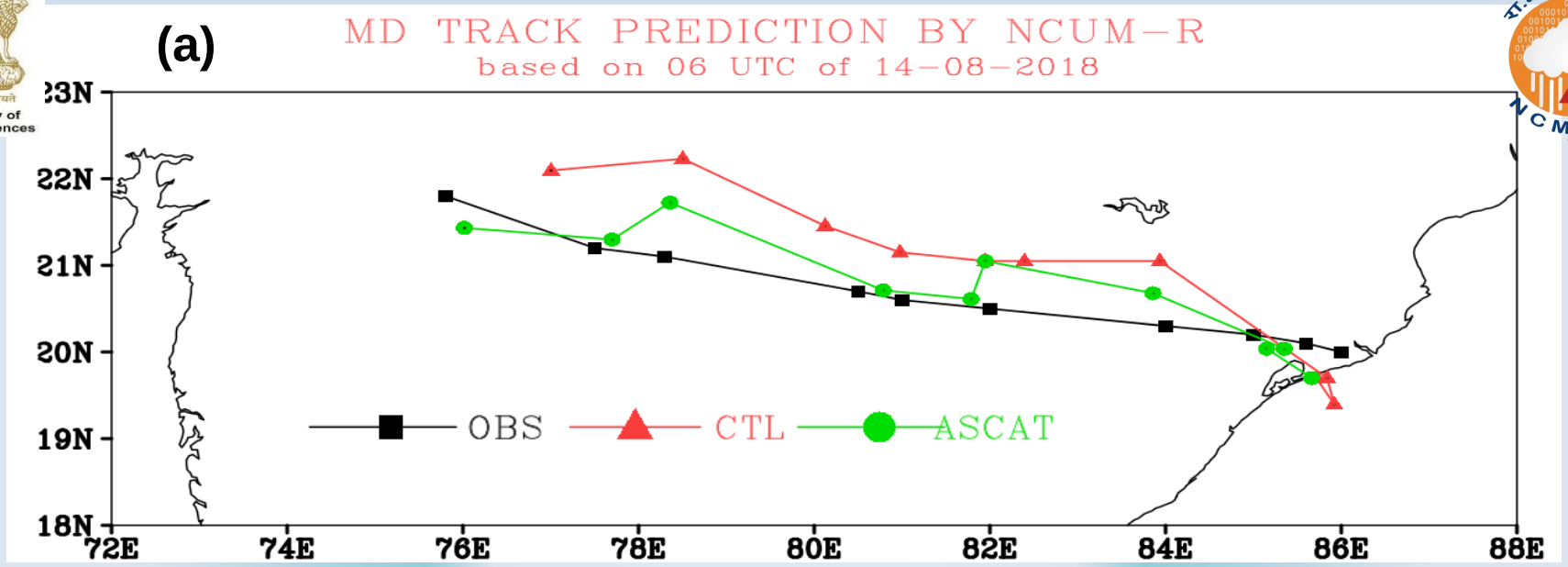


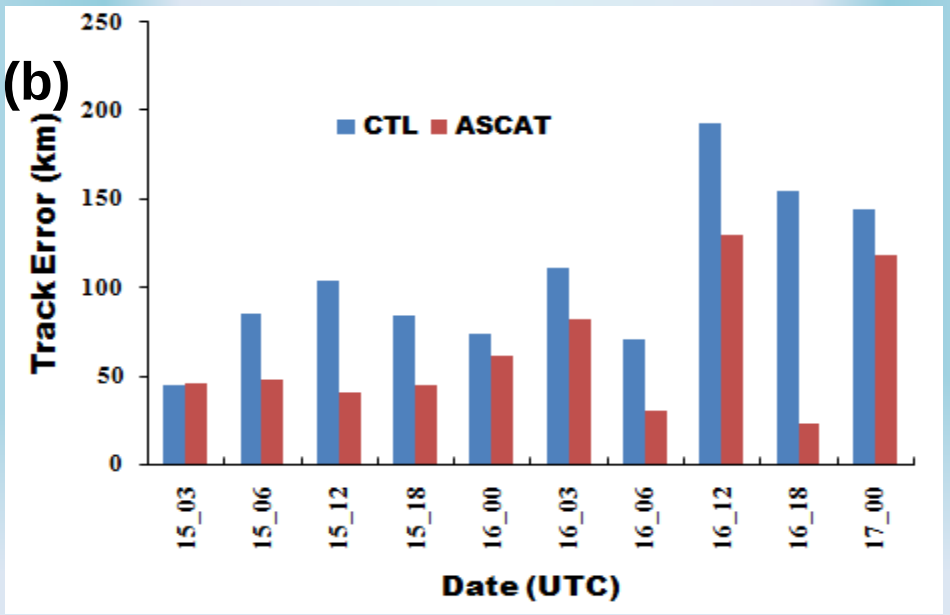
(a) IMD Observed, CTL and ASCAT experiment Monsoon Depression tracks (b) Track errors of monsoon depression over coastal Odisha during 21st to 23rd July, 2018 based on initial condition 06 UTC of 21st July 2018.

Impact of ASCAT soil moisture assimilation on minimum temperature forecast (06UTC, 25th September 2019)

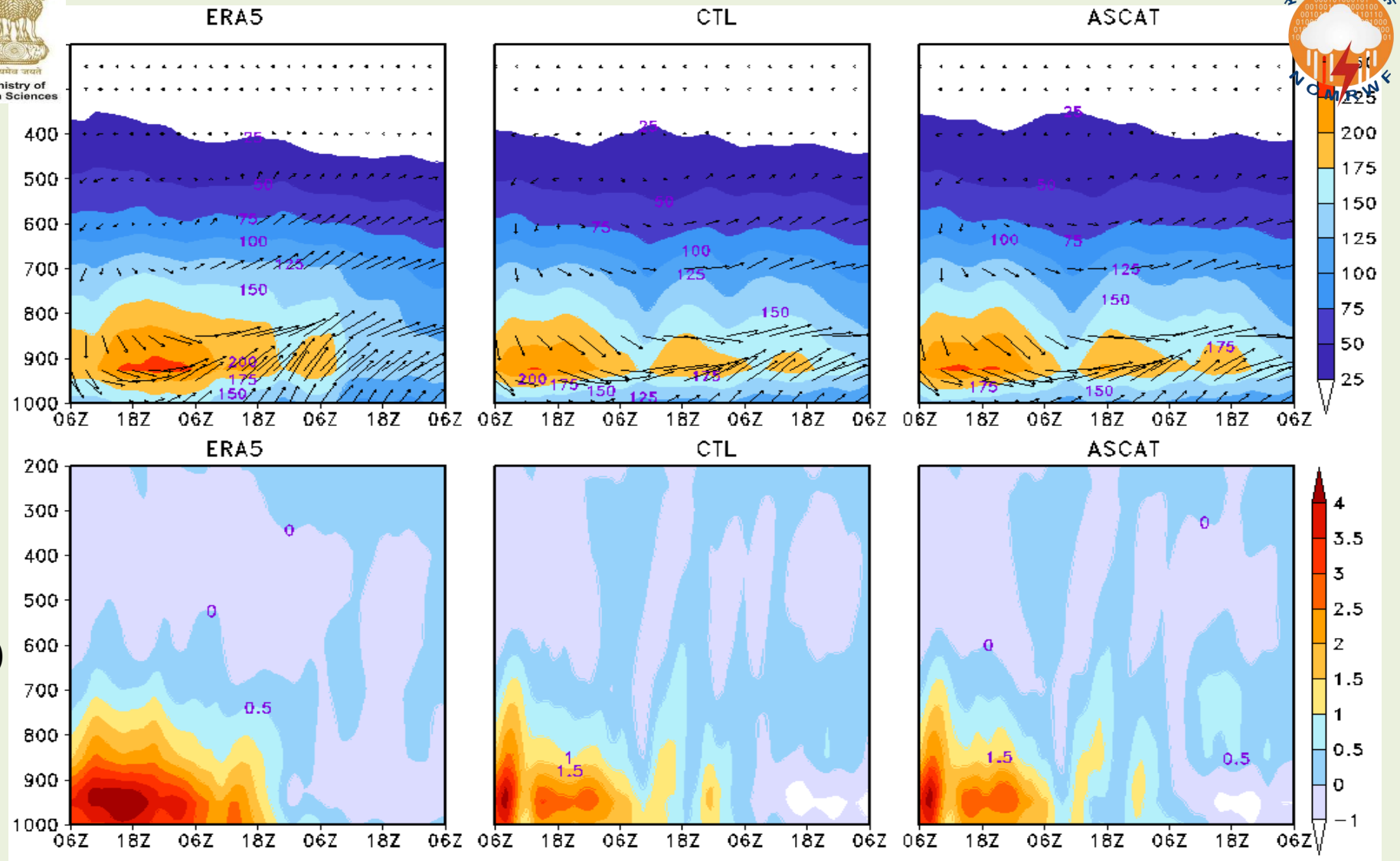


Spatial map of MEAN ERROR in maximum temperature forecast based on 06UTC, 20180814 for (a) CONTROL experiment and (b) for ASCAT sensitivity experiment.



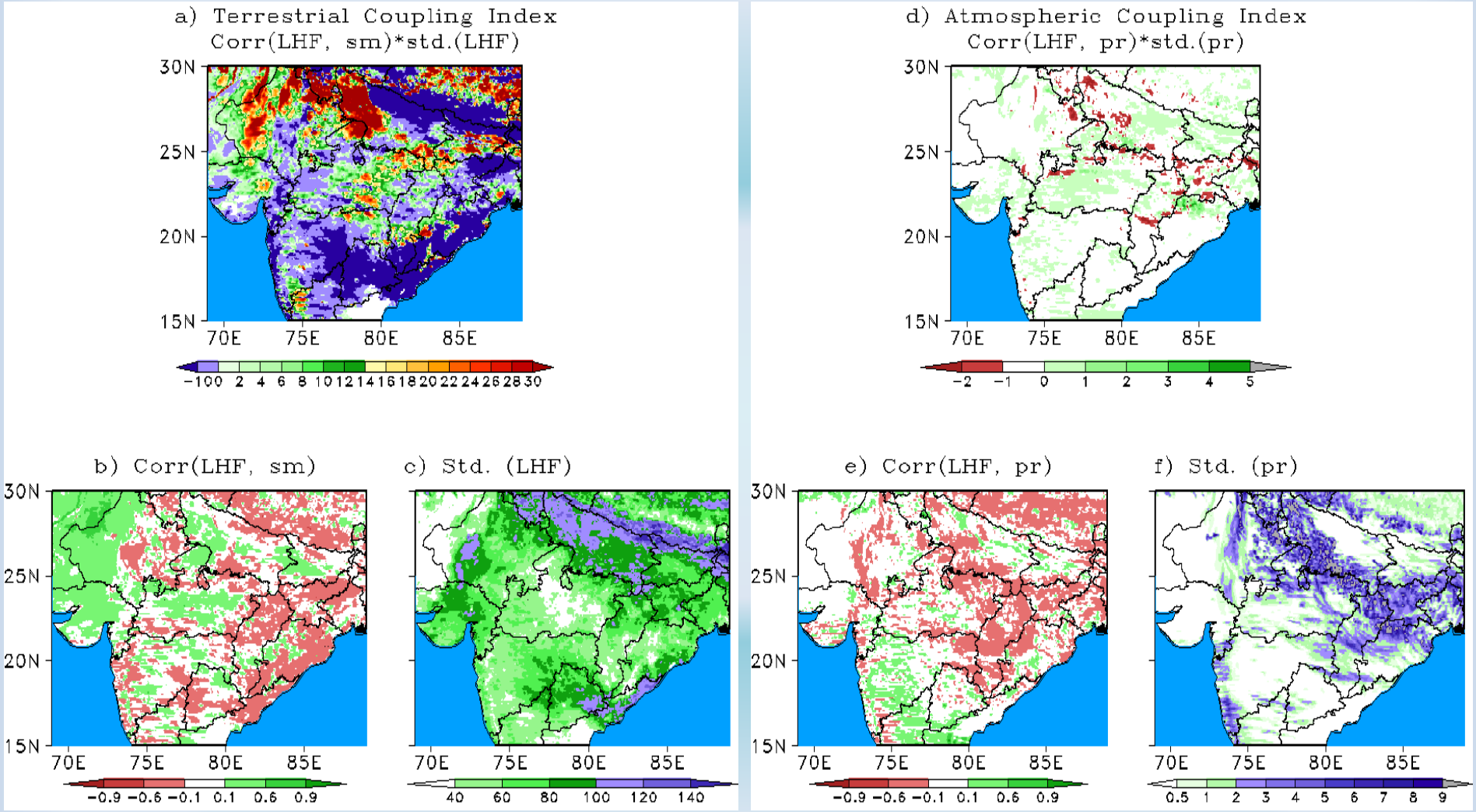


IMD Observed, CTL and ASCAT experiment Monsoon Depression tracks (b) Track errors of monsoon depression over coastal Odisha during 15th - 17th August, 2018 based on initial condition 06 UTC of 14th August 2018.

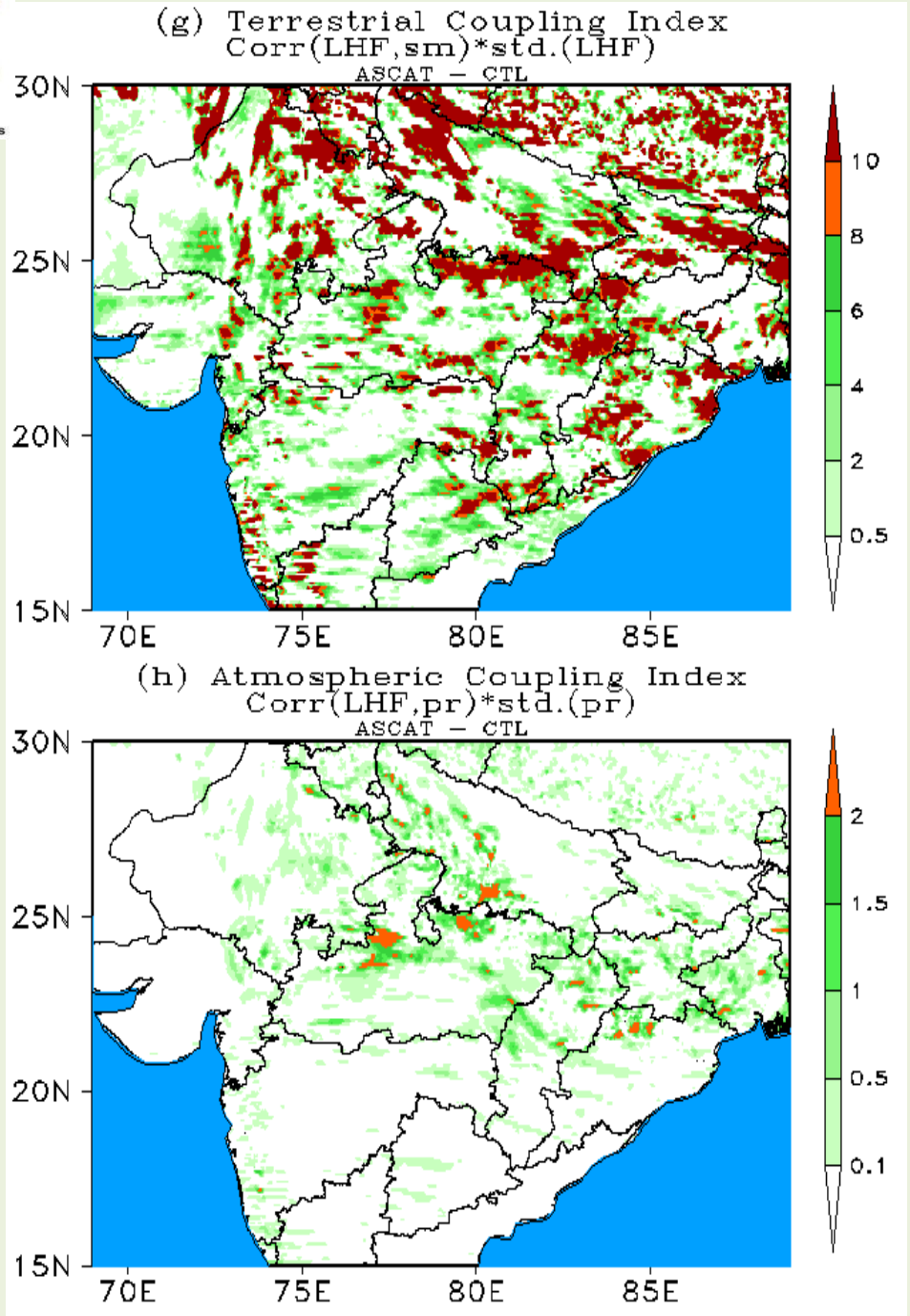


Time-pressure cross section of (a) moisture transport (g. kg^{-1}. m. s^{-1}), (b) moisture convergence ($\times 10^{-4}$ g·kg^{-1}. s^{-1}) averaged between 19-24° N and 84-88° E from ERA5 (top panel); CTL (middle panel) and ASCAT (bottom panel) for Case 1 during (06 UTC 21st July 2018 to 06 UTC 24th July 2018).

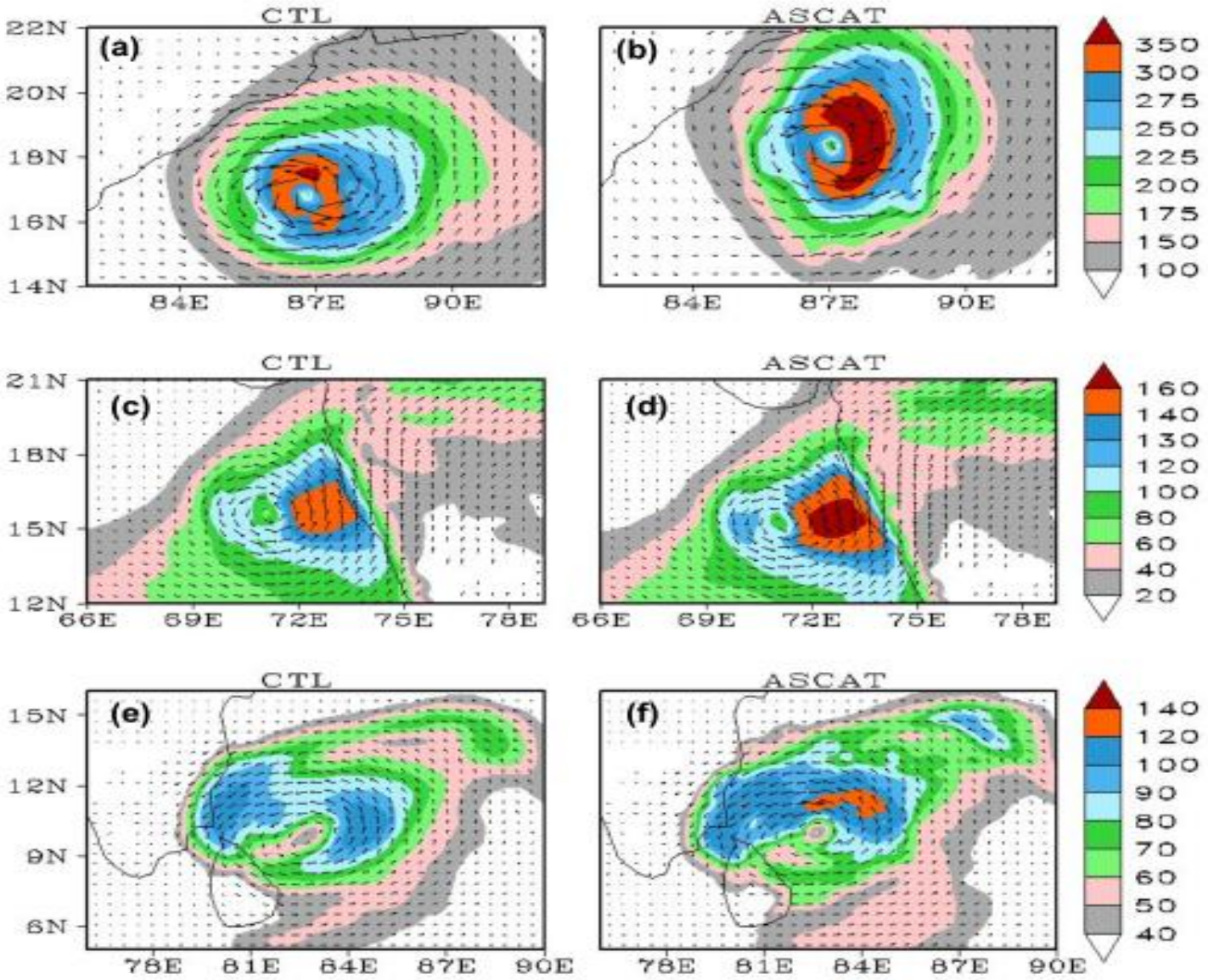
Land-Atmosphere Interactions: Dirmeyer's Indices



(a) Terrestrial coupling (LHF, sm) index of soil moisture (unit: $W.m^{-2}$) (b) correlation (LHF, sm) (c) standard dev. (LHF) (d) atmospheric coupling (LHF, pr) index of precipitation (unit: mm/day) (e) correlation (LHF, pr) (f) std. dev. (pr)) for the case 1 for the time period 06 UTC 21st July 2018 to 06 UTC 24th July 2018, (g)



Difference in terrestrial coupling (LHF, SM) index of soil moisture (unit: W m−2). (h) difference in atmospheric coupling (LHF, pr) index of precipitation (unit: mm/day) (results based on 06 UTC IC of 21st July 2018; significant at the 95 % confidence level)



AMPHAN

NISARGA

NIVAR

Vertically Integrated Moisture Transport (VIMT; $kg.m^{-1}.s^{-1}$; integrated up to 300 hPa) (a) CTL and (b) ASCAT for Case 1 valid at 06 UTC 19 May 2020 (model initial time). (c-d) and (e-f) are same as (a-b) but for Case 2 and Case 3 valid at 06 UTC 02 June and 24 November 2020, respectively.

Conclusions (Soil Moisture Assim.)

- ✓ **In the NCUM-R model, soil moisture analysis and forecasts are modified wherever satellite soil moisture observations (ASCAT) are available.**
- ✓ **Analysis of wind (zonal and meridional), surface temperature and surface humidity are more appropriate to the observations after assimilation of soil moisture.**
- ✓ **Track errors associated with monsoon depression cases under study reduces by ~ 50 km due to ASCAT soil moisture assimilation.**
- ✓ **The model simulated pattern of 2m-temperature and dew-point temperature are well simulated in both experiments throughout the forecast hours, however, the correlation coefficient and root mean square error has been improved significantly in the ASCAT experiment as compared to the CTL.**
- ✓ **Positive impact of assimilation of ASCAT soil moisture on the analysis and forecasts of near surface variables is observed.**
- ✓ **The vorticity tendency terms indicate that during the genesis time of MD, winds and vorticity are well represented in ASCAT experiments and MD is a bottom-up process.**
- ✓ **Studying the effects of soil moisture initialization on MDs in the NCUM-R model reports that increasing soil moisture in the monsoon trough region results in deeper inland penetration and a more developed structure of MDs and TCs**

•**Routray A., Lodh A., (2023)** "Influence of ASCAT Soil Moisture on Prediction of Track and Intensity of Landfall Tropical Cyclones", **International Journal of Remote Sensing , Taylor and Francis**, 44(1):341-380, DOI: 10.1080/01431161.2022.2164232

• **Lodh A., (2022)** "Improving the prediction of monsoon depressions by assimilating ASCAT soil moisture in NCUM-R modeling system", **Atmospheric Research, Elsevier**, https://doi.org/10.1016/j.atmosres.2022.106130





Reads the Control Information from name lists

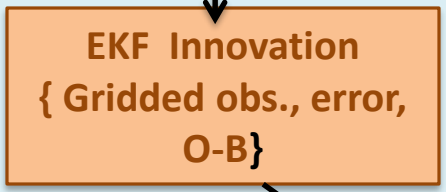


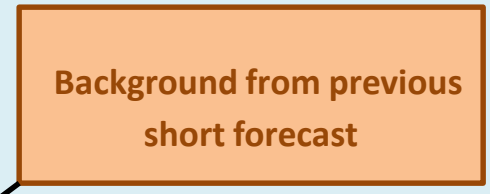
Reads the valid LST obs, allocates good obs after NC error and sanity check, obtain attributes











Flowchart of the INSAT-3D LST Experiment



Next cycle



Details of INSAT LST OSE Experiment

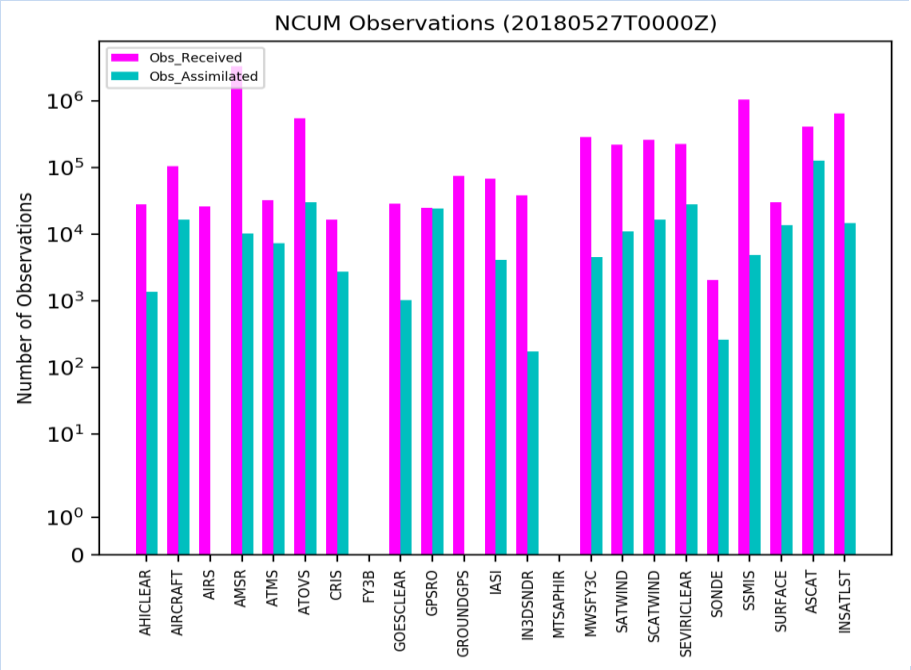
The NCUM analysis-forecast system (with assimilation of INSAT LST in LDAS) is run for the following periods to study the impact of INSAT LST assimilation on the global forecast. :

- 1st May 2018 to 7th June 2018
- 26th January 2019 to 28th February 2019

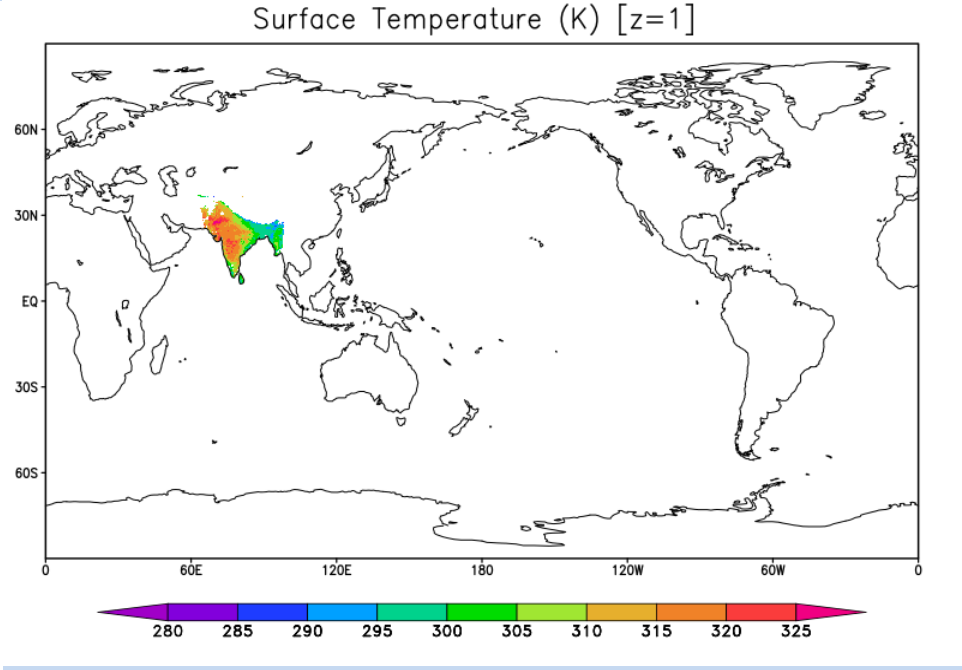
Forecast experiments (7-Day forecast), are performed at N1024 resolution (~12km) to study the impact of INSAT LST assimilation on the NCUM global forecast :

(a) CONTROL experiment (similar to operational run).

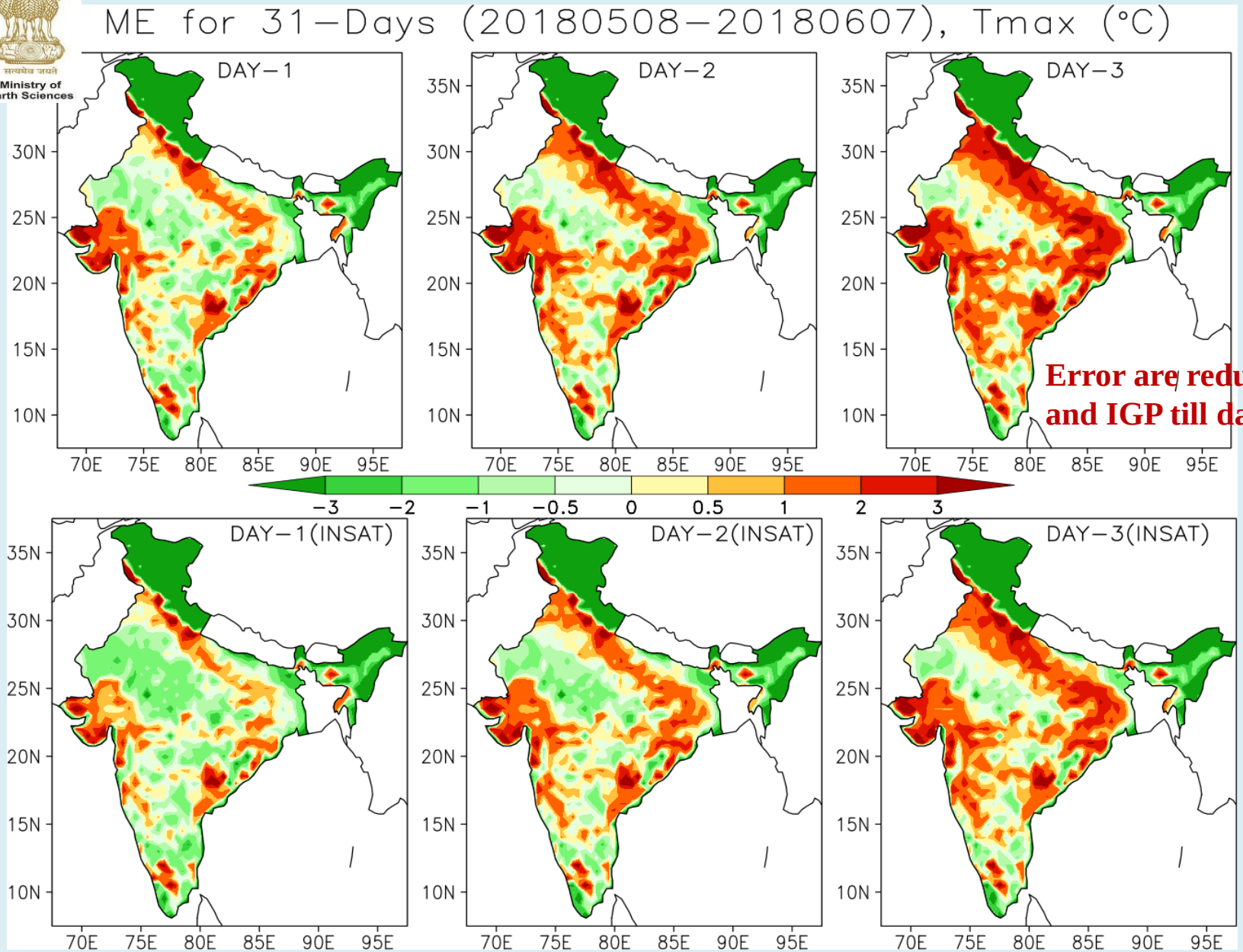
(b) INSAT -LST experiment (control + INSAT LST assimilation)



Bar Plots of the various observations included in INSAT LST assimilation



Gridded LST observations for a typical date, 20180501;12UTC



(a)

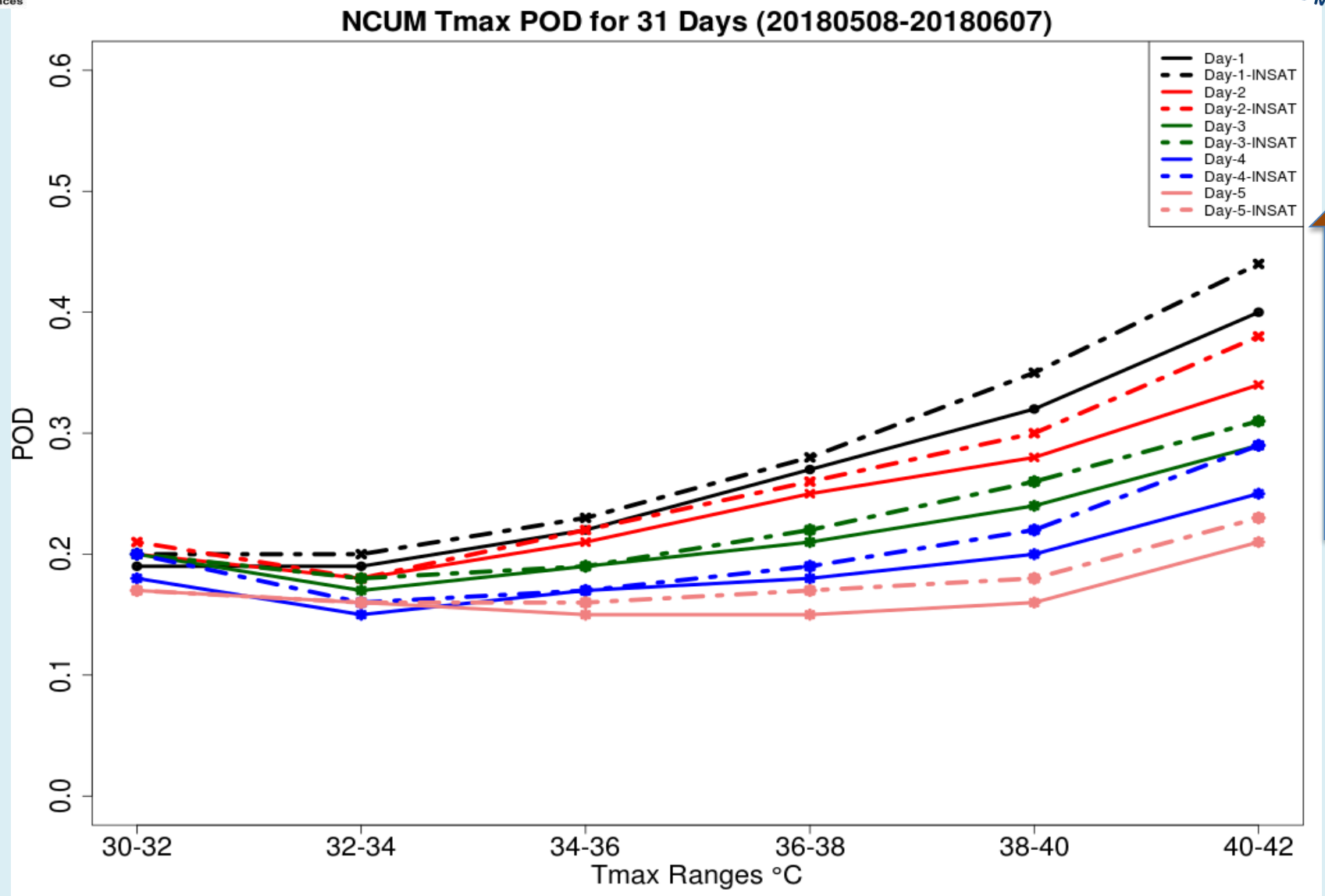
Error are reducing over NI and IGP till day-3 forecast

(b)

Spatial map of MEAN ERROR in maximum temperature for (a) CONTROL experiment and (b) for INSAT sensitivity experiment for 31 days from 20180508 to 20180608

Probability of detection (hit rate) =

$$POD = \frac{hits}{hits + misses}$$



POD for maximum temperature for (a) CONTROL experiment (straight line) snd (b) for INSAT sensitivity experiment (dashed line) (from 20180508 to 20180531).

Conclusions (INSAT-3D LST Assim.)

1. With assimilation of INSAT land surface temperature the mean error in maximum temperature forecasts (Day-1, Day-2 and Day-3 forecast) is reducing over India domain from during May and June 2018. For minimum temperature forecast, the mean error is reducing over north-west India only for the Day-1 forecast.
2. For the month of May – 2018, the verification metrics for maximum temperature viz. POD, ETS, CSI , SEDI and PSS is improving (by approx. 5%) for Day-1, Day-2 and Day-3 forecast for temperature ranges from 30-32 ^{o}C to 42-44^{o}C.
3. False Alarm Ratio is decreasing for T_{max} and T_{min} due to INSAT-3D LST assimilation for the month of May-2018 (Summer).
4. For the month of Feb-2019 (Winter), the mean error in maximum and minimum temperature forecasts (Day-1, Day-2 and Day-3 forecasts) is reducing over India domain.
5. The verification metrics for both maximum and minimum temperature is improving due to INSAT-3D LST experiment (by approx. 10%). False Alarm ratio decreasing for T_{min} forecasts.

•**Lodh A**., Routray. A, Dutta, D, Vivek Singh, John P. George (2024) "Impact of INSAT-3D land surface temperature assimilation via simplified extended Kalman filter-based land data assimilation system on forecasting of surface fields over India", **Meteorological Applications**, Wiley, https://doi.org/10.1002/met.70019

• **Lodh A.,** Gibies George, Harvir Singh, John. P. George and E.N. Rajagopal, Assimilation of INSAT-3D Land Surface Temperature in an EKF based Land Data Assimilation System", NCMRWF Technical Report, NMRF/TR/07/2019, May 2019.

FOR OPERATIONAL FORECASTERS

Turning forecasts into impact

Where modelling already helps

- Coupled model: depression rain captured at 7-day lead vs 5 days for atmosphere-only (NCMRWF)
- ASCAT soil-moisture assimilation: ~50 km smaller depression track errors
- Ensemble PQPF: chance that 24-h rain passes a threshold shows where to pre-position

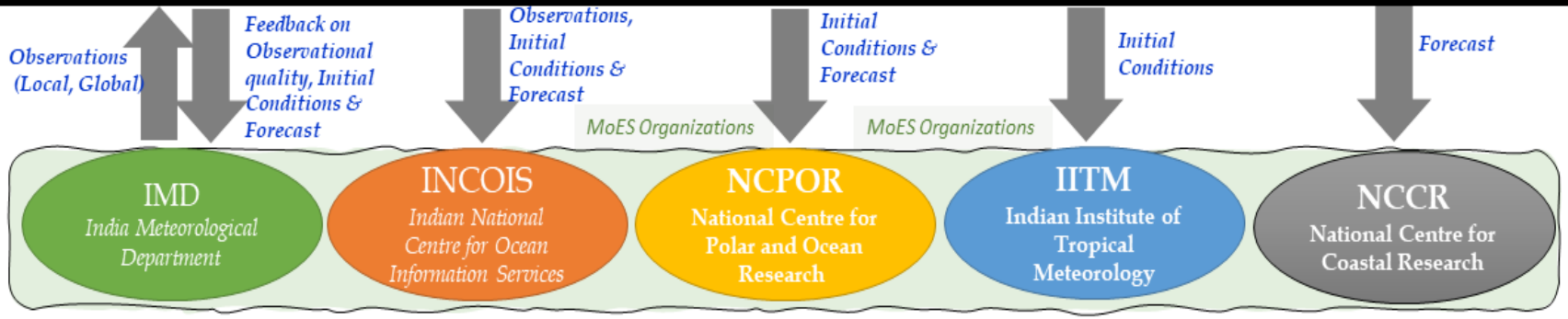
At the desk, ask: so what?

- Name the impact: homes, trees, power, roads, not wind speed alone
- Combine the rain class with wet ground and terrain
- Flag high tide plus heavy rain for coastal cities
- Night-time onset hits people asleep: warn early

Sources: NCRB 2024; Reuters, AFP, Al Jazeera, NDRF; Deccan Herald; Kerala state figures; NCMRWF / Lodh (2022, 2023).

Ministry of Earth Sciences

NCMRWF Operational Services



Central Government Agencies (Other than MoES)

- ✓Indian Armed Forces
- ✓Nuclear Power Corporation of India Limited (NPCIL)
- ✓Defence Research and Development Organisation (DRDO)
- ✓Indian Space Research Organisation (ISRO)
- ✓Central Water Commission(CWC)
- ✓Space Application Centre (SAC)
- ✓Indira Gandhi Centre for Atomic Research (IGCAR)
- ✓Bhabha Atomic Research Centre (BARC)
- ✓North Eastern Space Applications Centre (NESAC)
- ✓National Institute of Wind Energy (NIWE)
- ✓Ministry of Power
- ✓Defence Geoinfomatics Research Establishment (DGRE)
- ✓Geological Survey of India (GSI)

State Government Agencies

- ✓Nagaland Water Resource Department
- ✓Gujarat Urja Vikas Nigam Limited(GUVNL),
- ✓Krishna-Bheema Basin Study Division (KB-BSD), Govt. of Maharashtra
- ✓Tamilnadu State Disaster Management (TNSDMA)
- ✓Andrapradesh State Development Planning Society (APSDPS)
- ✓State Load Dispatch Centre(SLDC), Tamil Nadu
- ✓Kerala State Disaster Management Authority (KSDMA)
- ✓Telangana State Development Planning Society (TSDPS)
- ✓Karnataka State Disaster Management Authority (KSNDMC)

Private Agencies

- ✓ReConnect Energy
- ✓Manikandan Wind Power Ltd.
- ✓Energon Power Resources
- ✓KREATE Energy
- ✓Leap Green Energy
- ✓Greenko Energy Pvt Ltd
- ✓Utopus Insights India Pvt. Ltd
- ✓Climate Connect
- ✓Adani Green,
- ✓ PTC India Ltd.
- ✓RENew Power Ltd.,
- ✓Vena Energy,
- ✓Ayana Renewable Power Pvt. Ltd

International Contributions

- •Core member of the "UM Partnership" (other core partners include UK, Australia, New Zealand, Republic of Korea, and Singapore)
- •Operational Services to BIMSTEC Countries (Bangladesh, Bhutan, India, Mynmar, Nepal , Srilanka, Thailand)
- •Contributing to the TIGGE archive consists of ensemble forecast data from thirteen global numerical weather prediction (NWP) centres

धन्यवाद / THANK YOU

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