

Performance of GFS/GEFS forecast (at 12km resolution) and performance of experimental forecast of High resolution global forecast model (HGFM) at 6.5 km resolution for monsoon 2023

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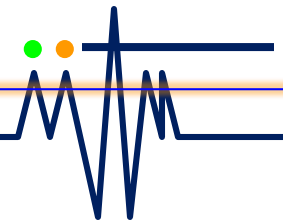
Indian Institute of Tropical Meteorology, Pune
([email:mpartha@tropmet.res.in](mailto:mpartha@tropmet.res.in))



Outline of the talk



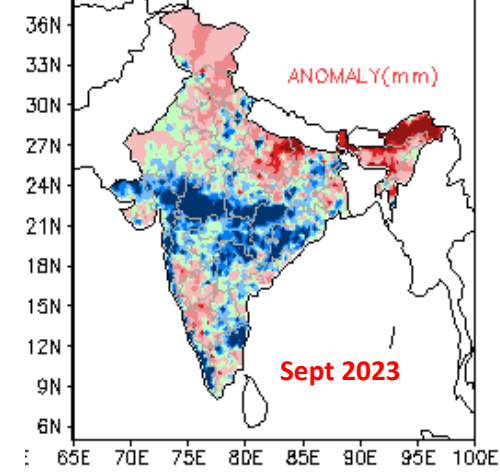
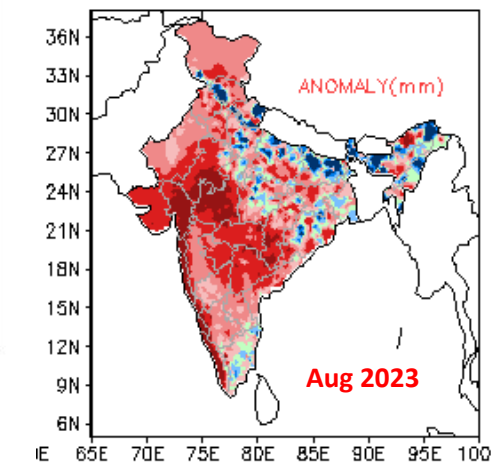
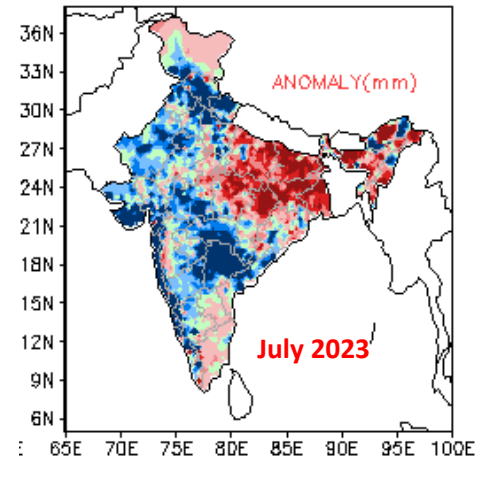
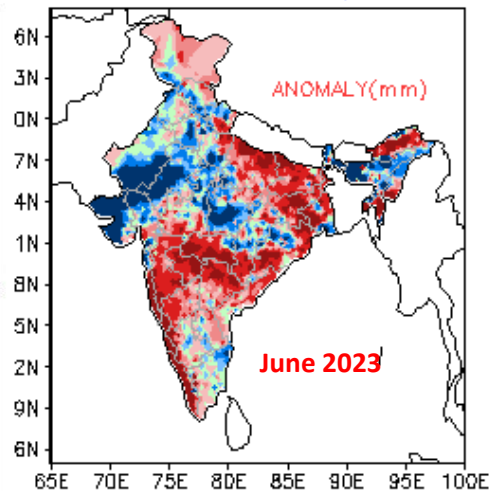
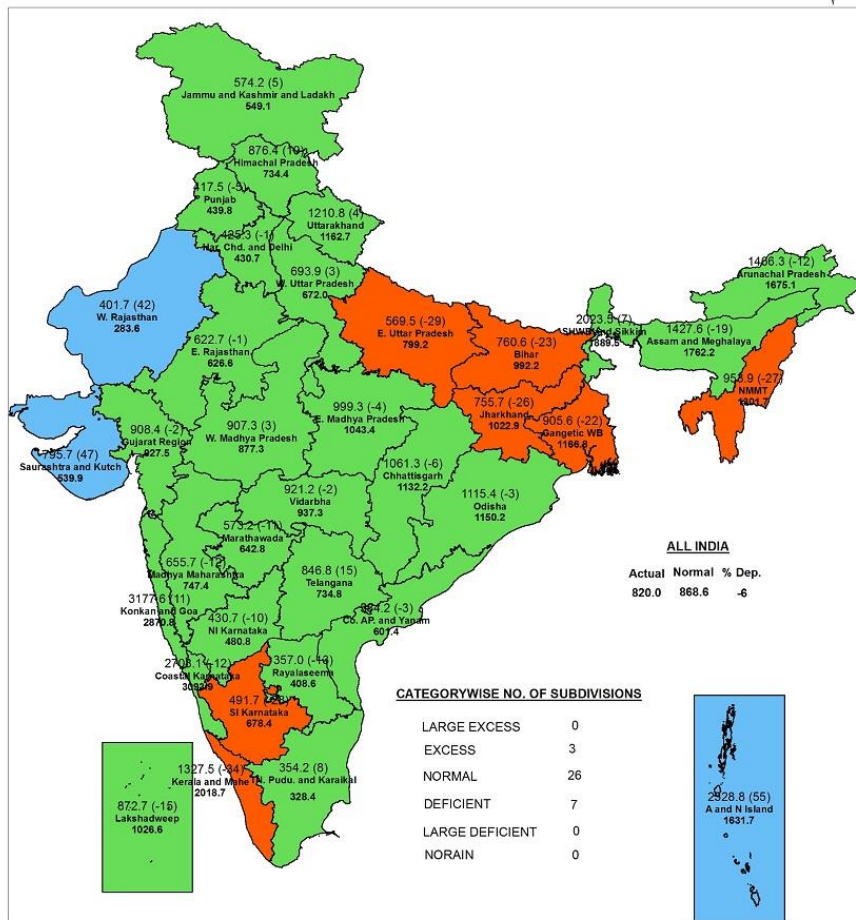
- Monsoon 2023 observation: Rainfall variability, transients
- Performance verification of GFS/GEFS prediction: Skill of the model
- Few cases: Prediction & verification
- Results from IITM HGFM (Tco 6.5km resolution)
- Summary





SUBDIVISION RAINFALL MAP

Period : 01-06-2023 To 30-09-2023



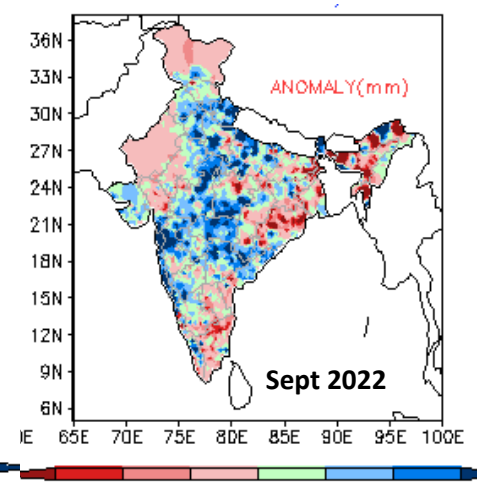
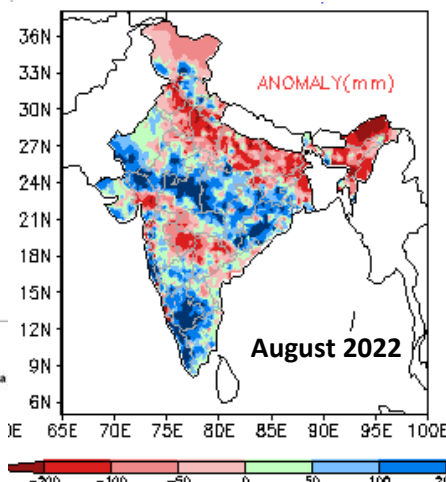
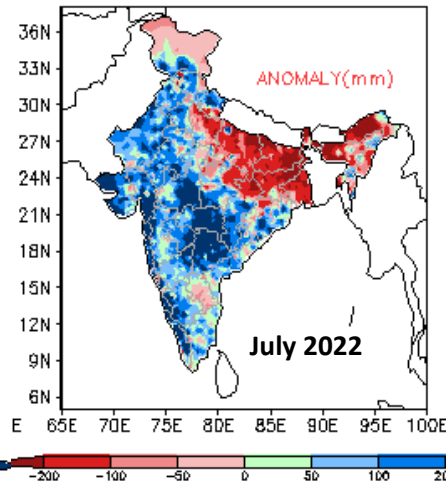
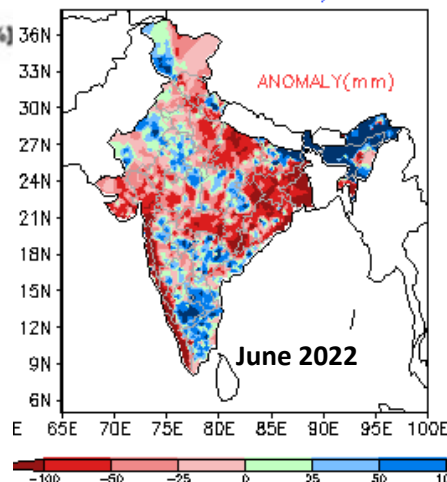
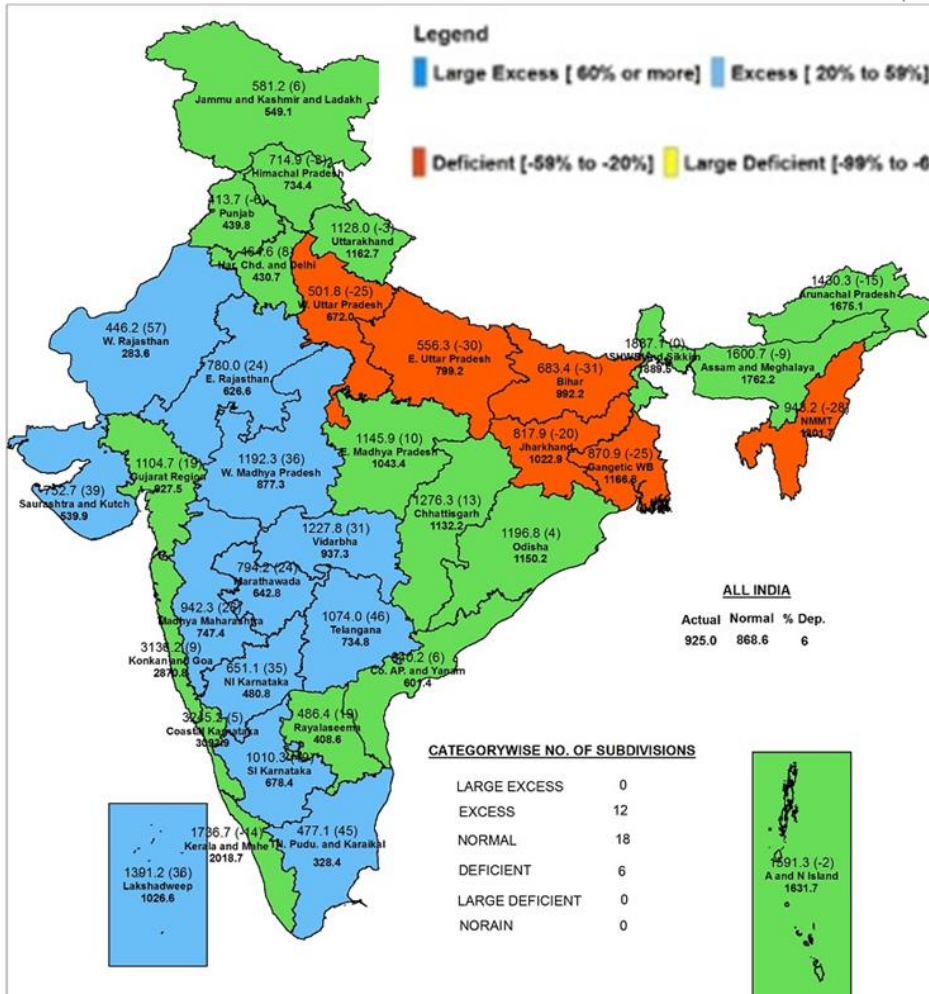
Legend
■ Large Excess [60% or more] ■ Excess [20% to 59%] ■ Normal [-19% to 19%] ■ Deficient [-59% to -20%] ■ Large Deficient [-99% to -60%] ■ No Rain [-100%] ■ No Data

NOTES :
a) RainFall figures are based on operation data.
b) Small figures indicate actual rainfall (mm), while bold figures indicate Normal rainfall (mm).
c) Percentage Departures of rainfall are shown in brackets.



SUBDIVISION RAINFALL MAP

Period : 01-06-2022 To 30-09-2022



Legend

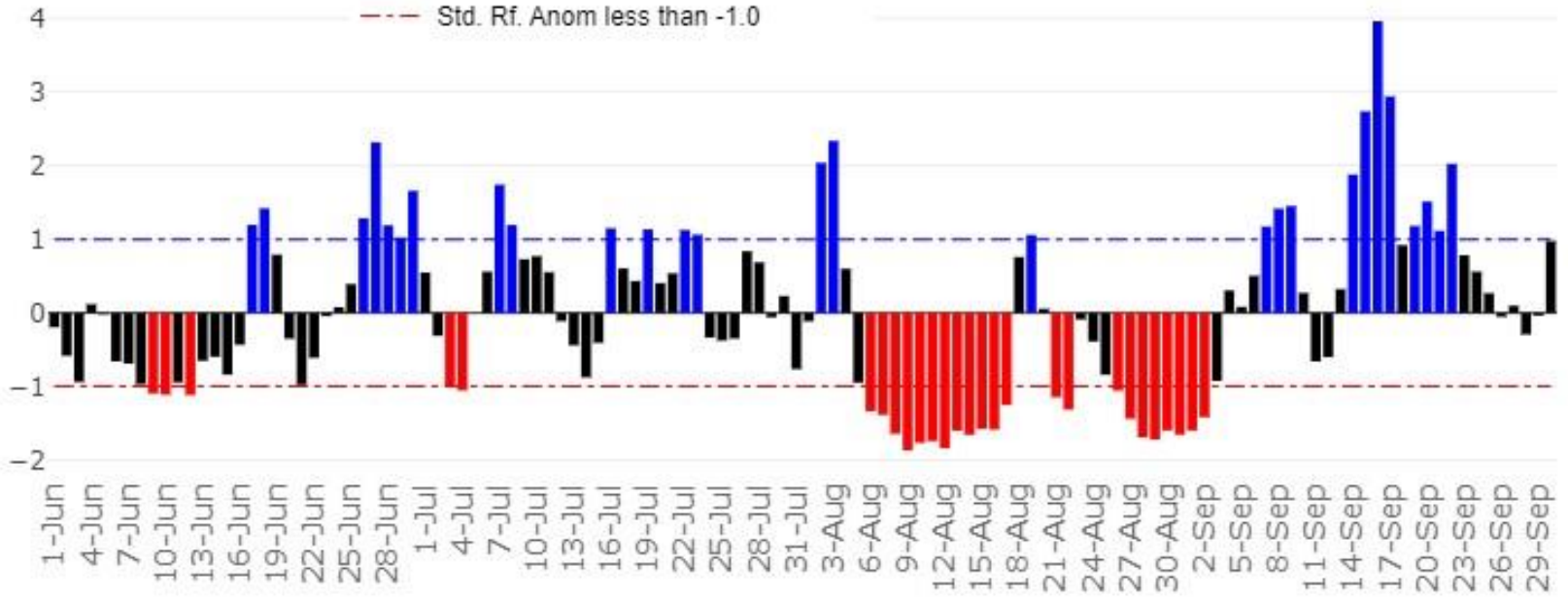
- Large Excess [60% or more]
- Excess [20% to 59%]
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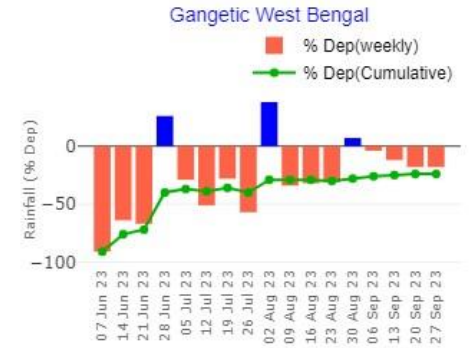
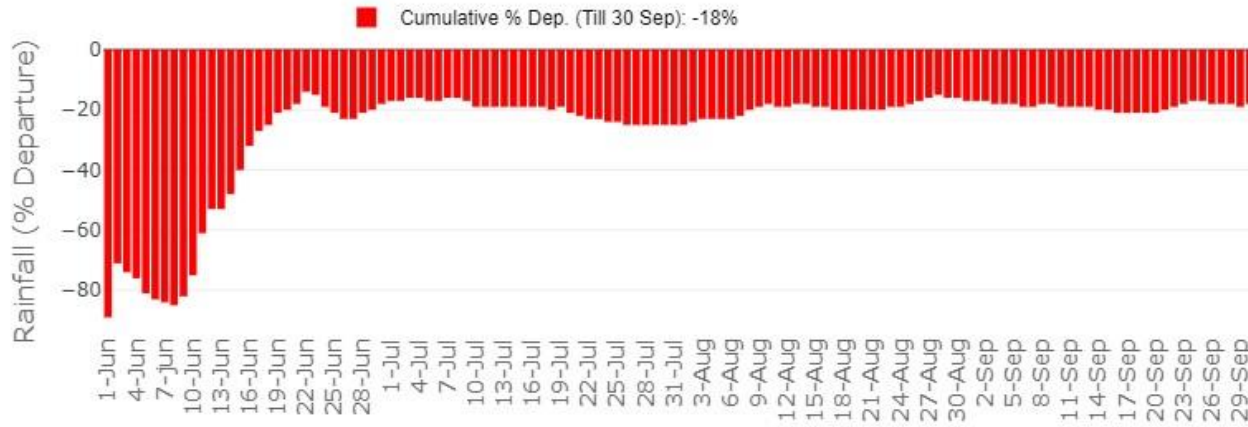
Standardized Rainfall Anomaly over the Core Monsoon Zone Region 2023

- Std. Rf. Anom between +1.0 and -1.0
- - - Std. Rf. Anom Greater than 1.0
- - - Std. Rf. Anom less than -1.0

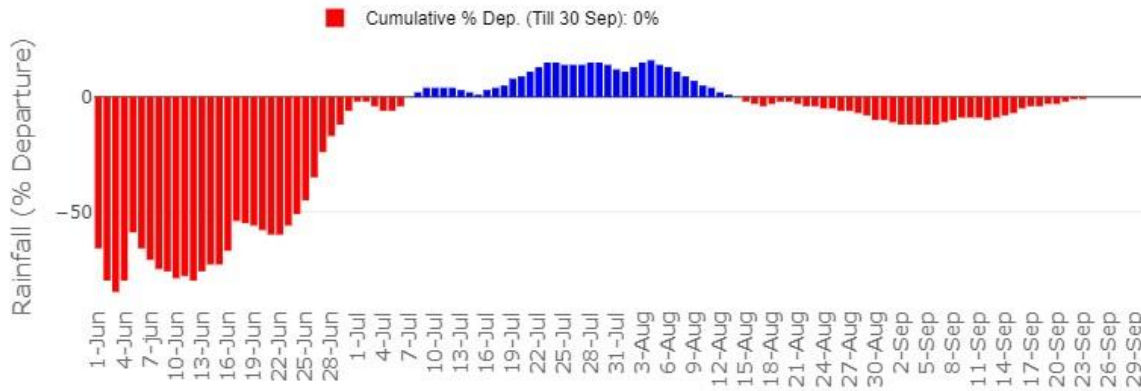
Standardized Rainfall Anomaly



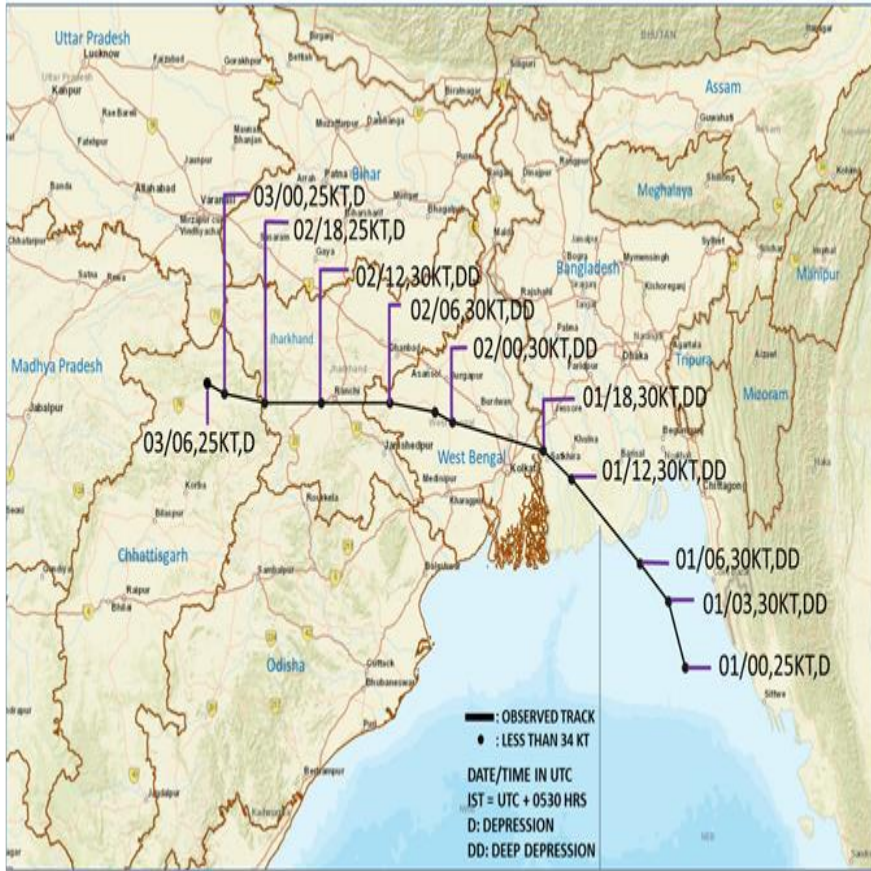
Cumulative Rainfall (% Departure) over East and North East India 2023



Cumulative Rainfall (% Departure) over Central India 2023



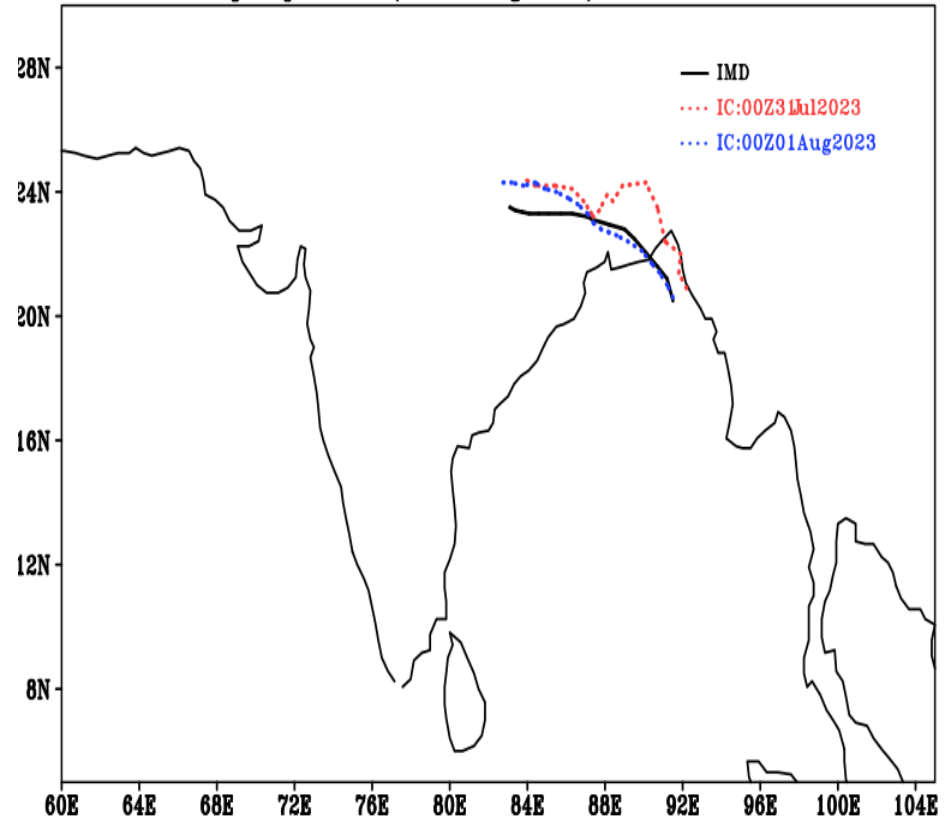
Depression 1-3 Aug 2023



Observed track of Deep Depression over Northeast Bay of Bengal

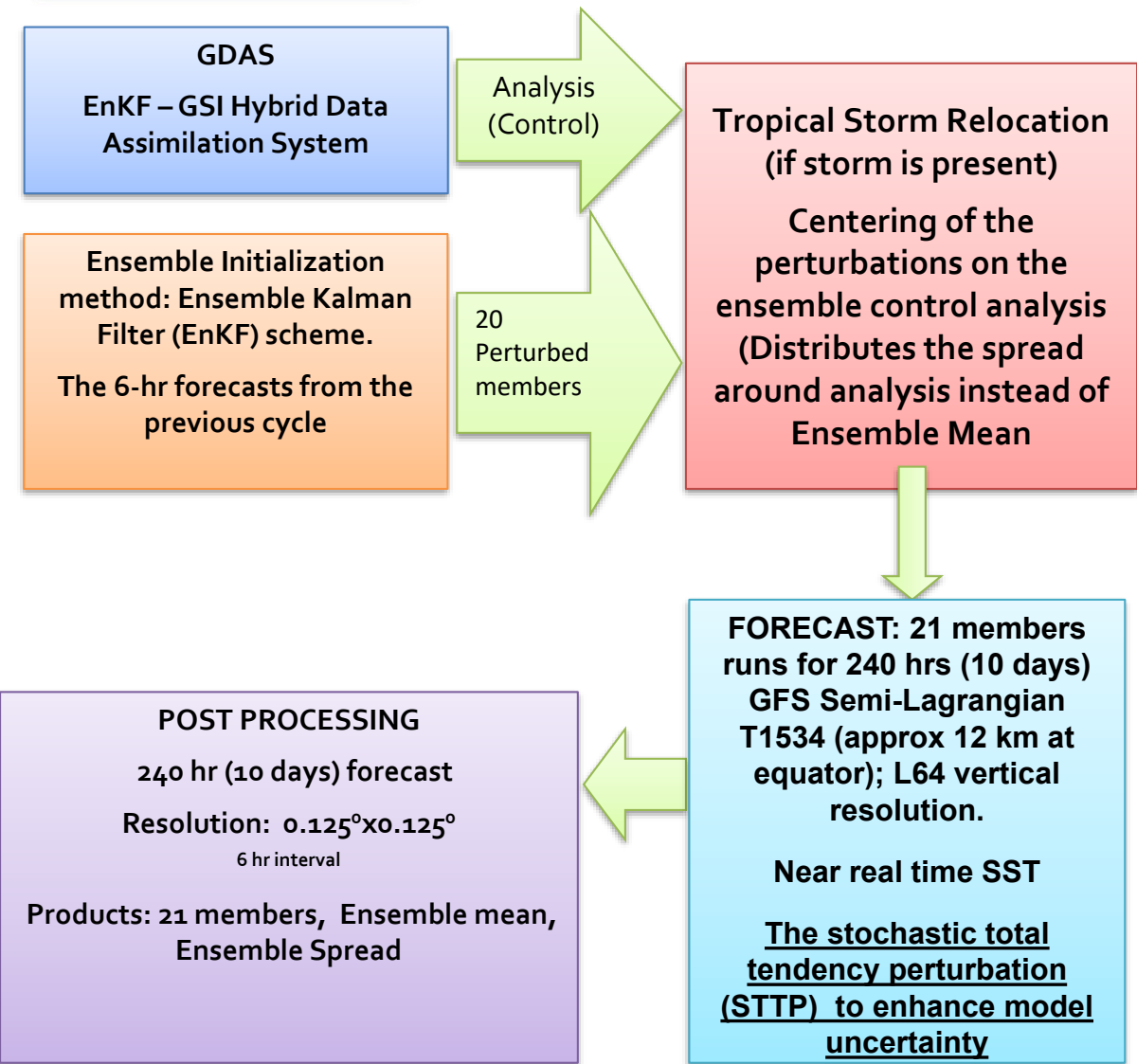
GFST1534 Forecast

Deep Depression (01-03 Aug 2023)



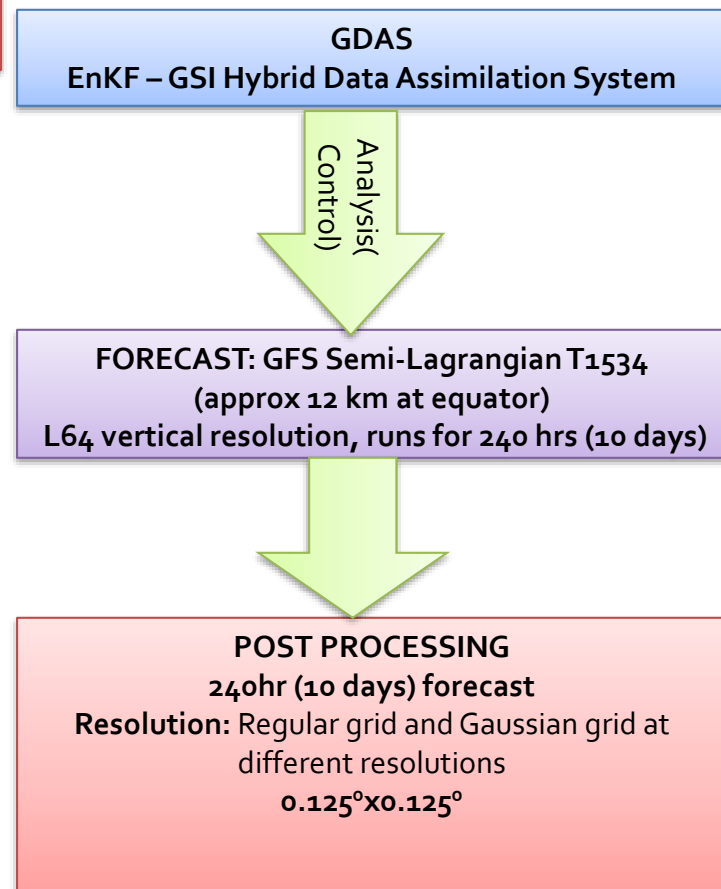
ICs: 00Z 31Jul, 00Z 01 Aug

Flowchart of GEFS



The Global (Ensemble) Forecast Model

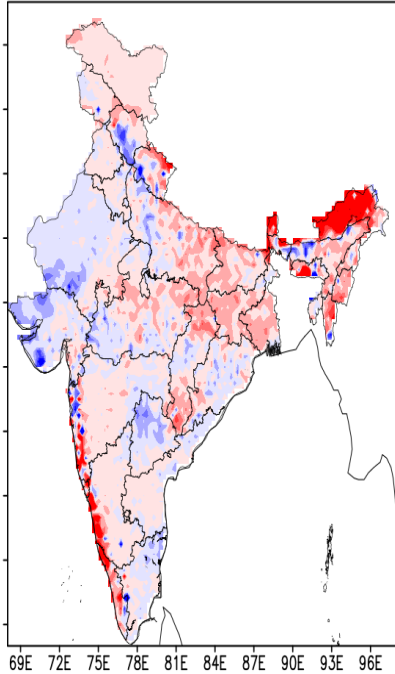
Flowchart of deterministic GFS



Anomalous rainfall (mm/day) during JJAS 2023 from Obs and GFS T1534

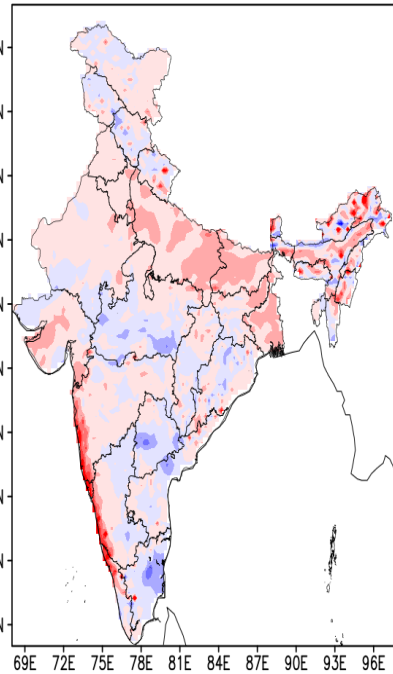
IMD-GPM

Observed Rainfall (mm/day) Anomaly during JJAS 2023



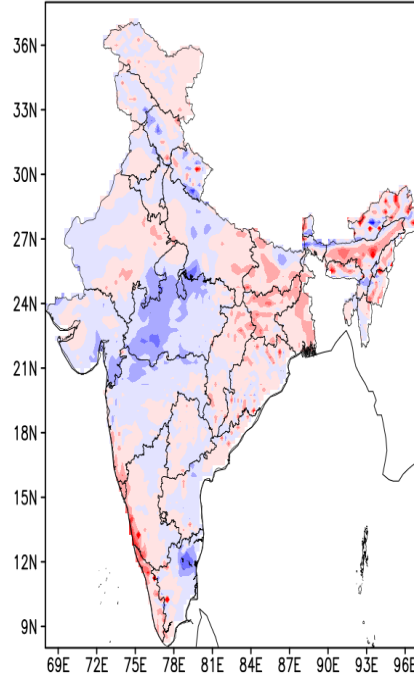
Day-1

GFST1534 Rainfall (mm/day) Anomaly during JJAS 2023, Day-1



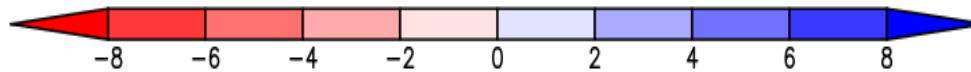
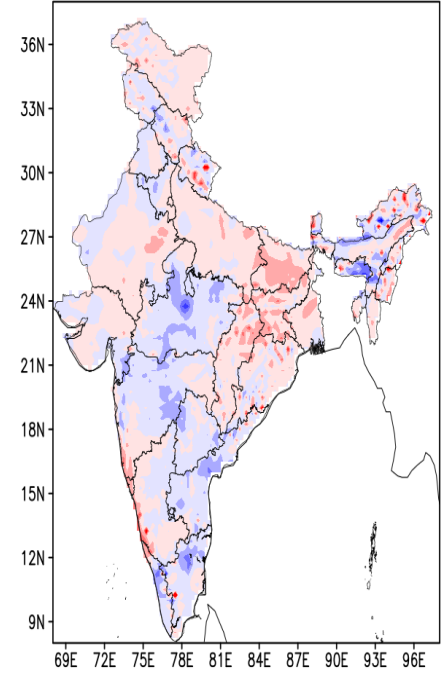
Day-3

GFST1534 Rainfall (mm/day) Anomaly during JJAS 2023, Day-3



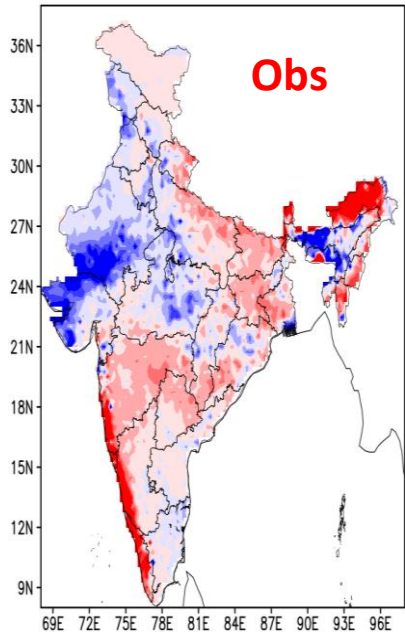
Day-5

GFST1534 Rainfall (mm/day) Anomaly during JJAS 2023, Day-5

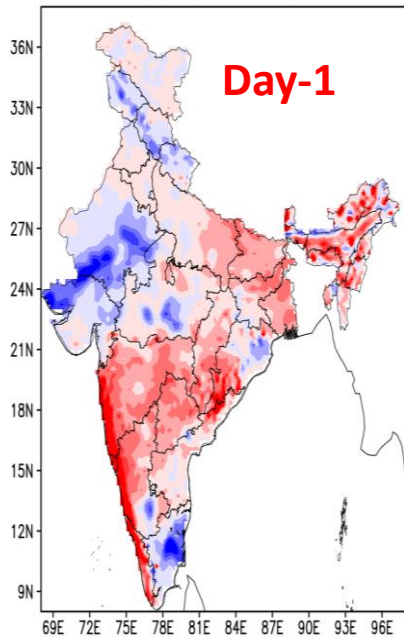


IMD clim: 1961-2020
GFS clim: 1999-2020

Observed Rainfall (mm/day) Anomaly during JUNE 2023

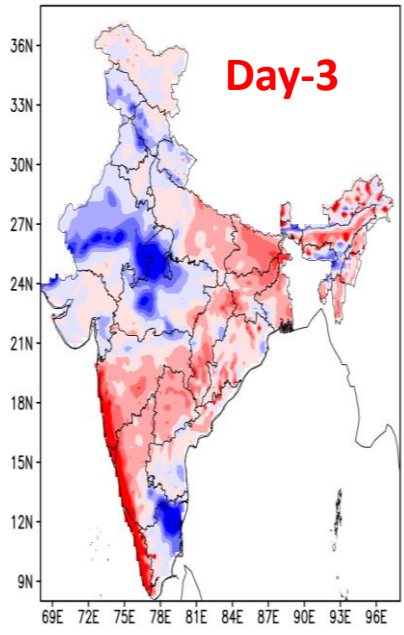


GFST1534 Rainfall (mm/day) Anomaly during JUNE 2023, Day-1

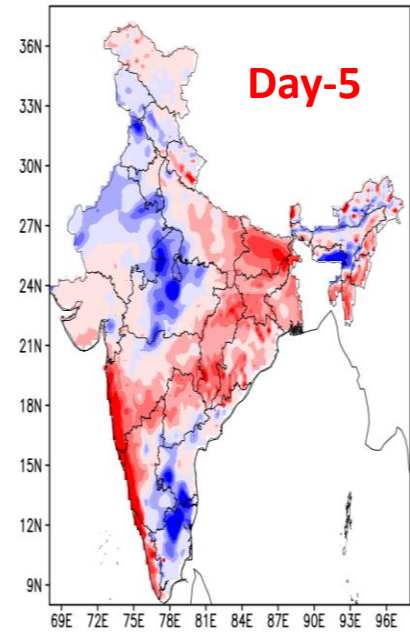


JUNE

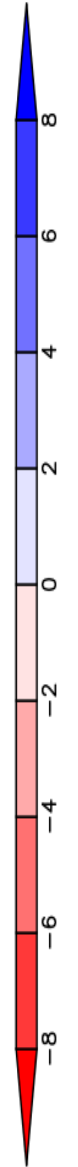
GFST1534 Rainfall (mm/day) Anomaly during JUNE 2023, Day-3



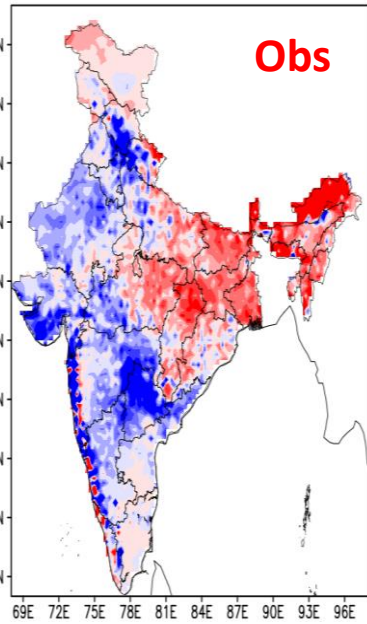
GFST1534 Rainfall (mm/day) Anomaly during JUNE 2023, Day-5



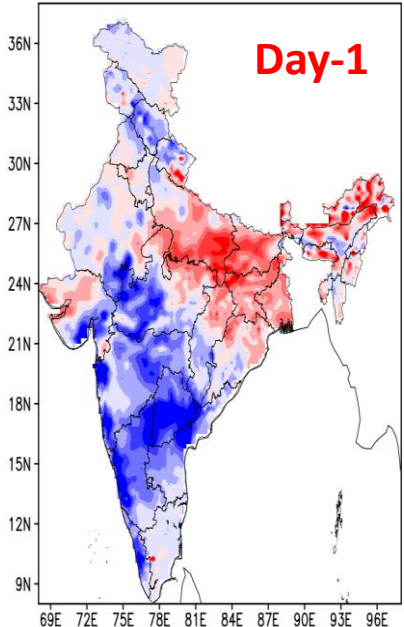
Rainfall Anomaly (mm/day)



Observed Rainfall (mm/day) Anomaly during JULY 2023

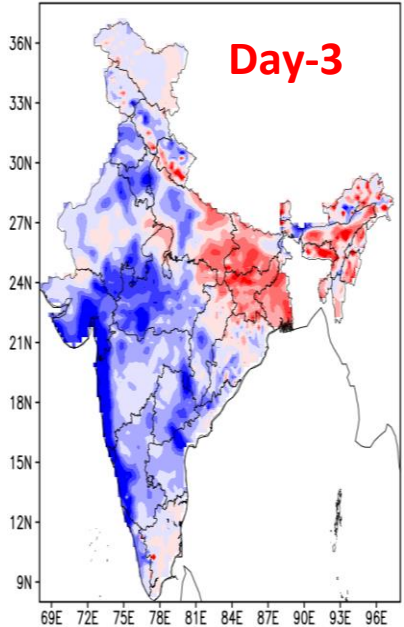


GFST1534 Rainfall (mm/day) Anomaly during JULY 2023, Day-1

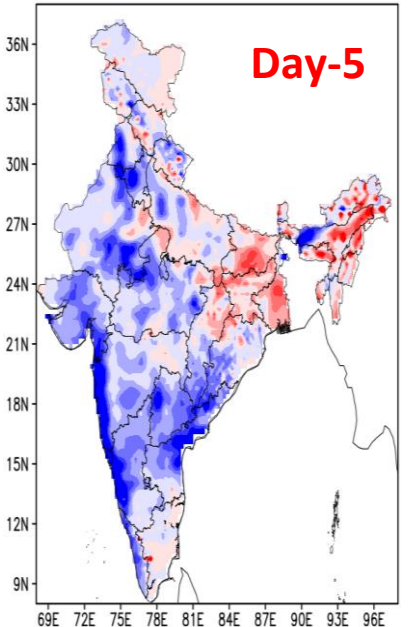


JULY

GFST1534 Rainfall (mm/day) Anomaly during JULY 2023, Day-3



GFST1534 Rainfall (mm/day) Anomaly during JULY 2023, Day-5



AUGUST

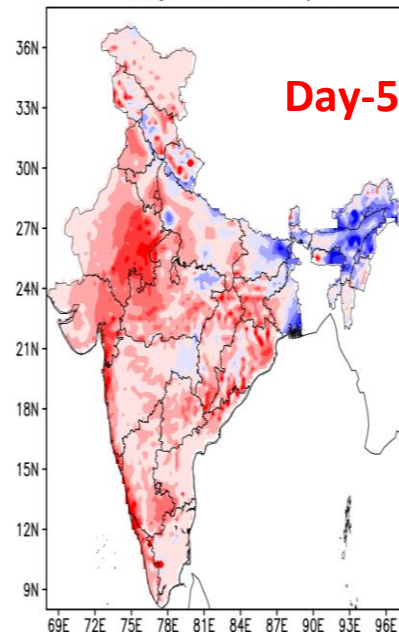
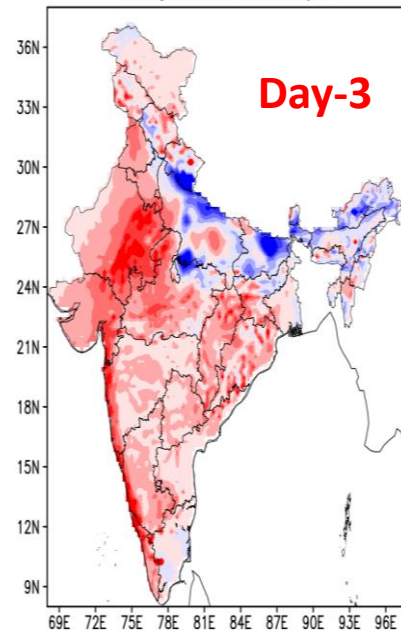
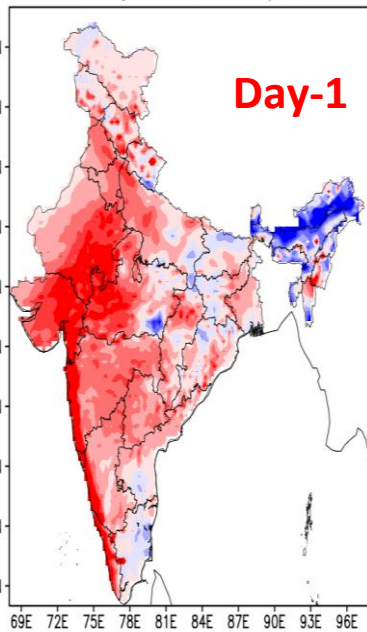
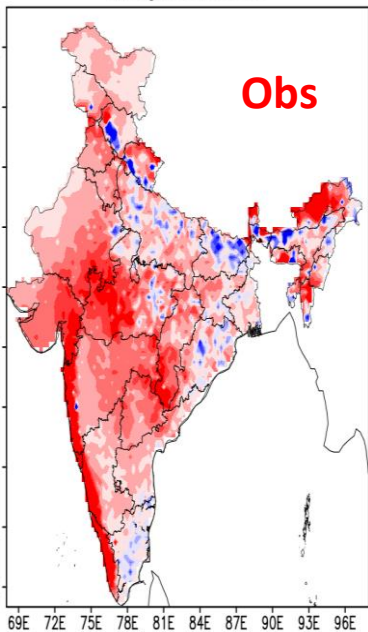
Observed Rainfall (mm/day) Anomaly during AUGUST 2023

GFST1534 Rainfall (mm/day) Anomaly during AUGUST 2023, Day-1

GFST1534 Rainfall (mm/day) Anomaly during AUGUST 2023, Day-3

GFST1534 Rainfall (mm/day) Anomaly during AUGUST 2023, Day-5

Rainfall Anomaly (mm/day)

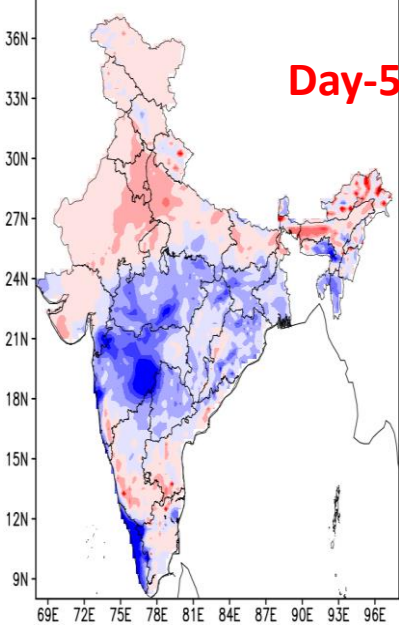
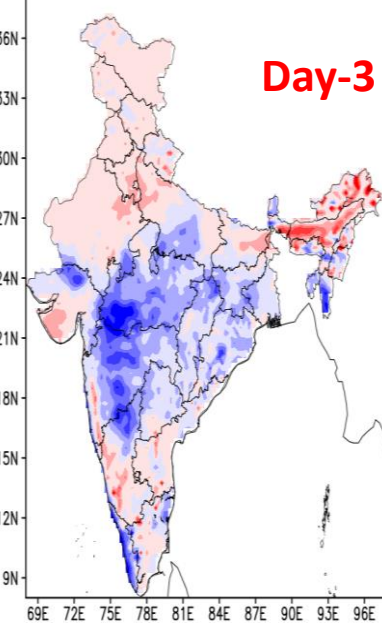
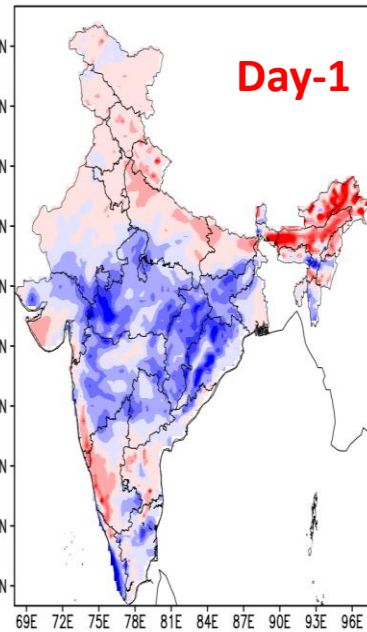
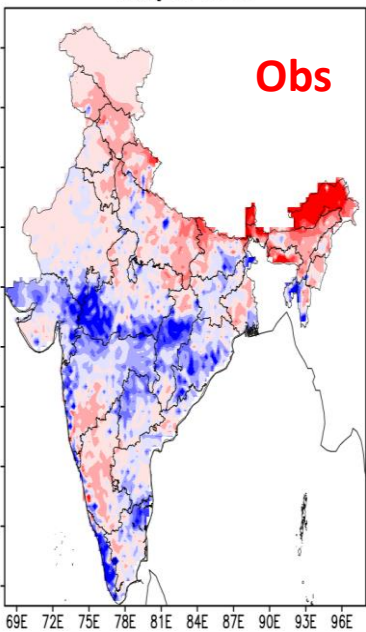


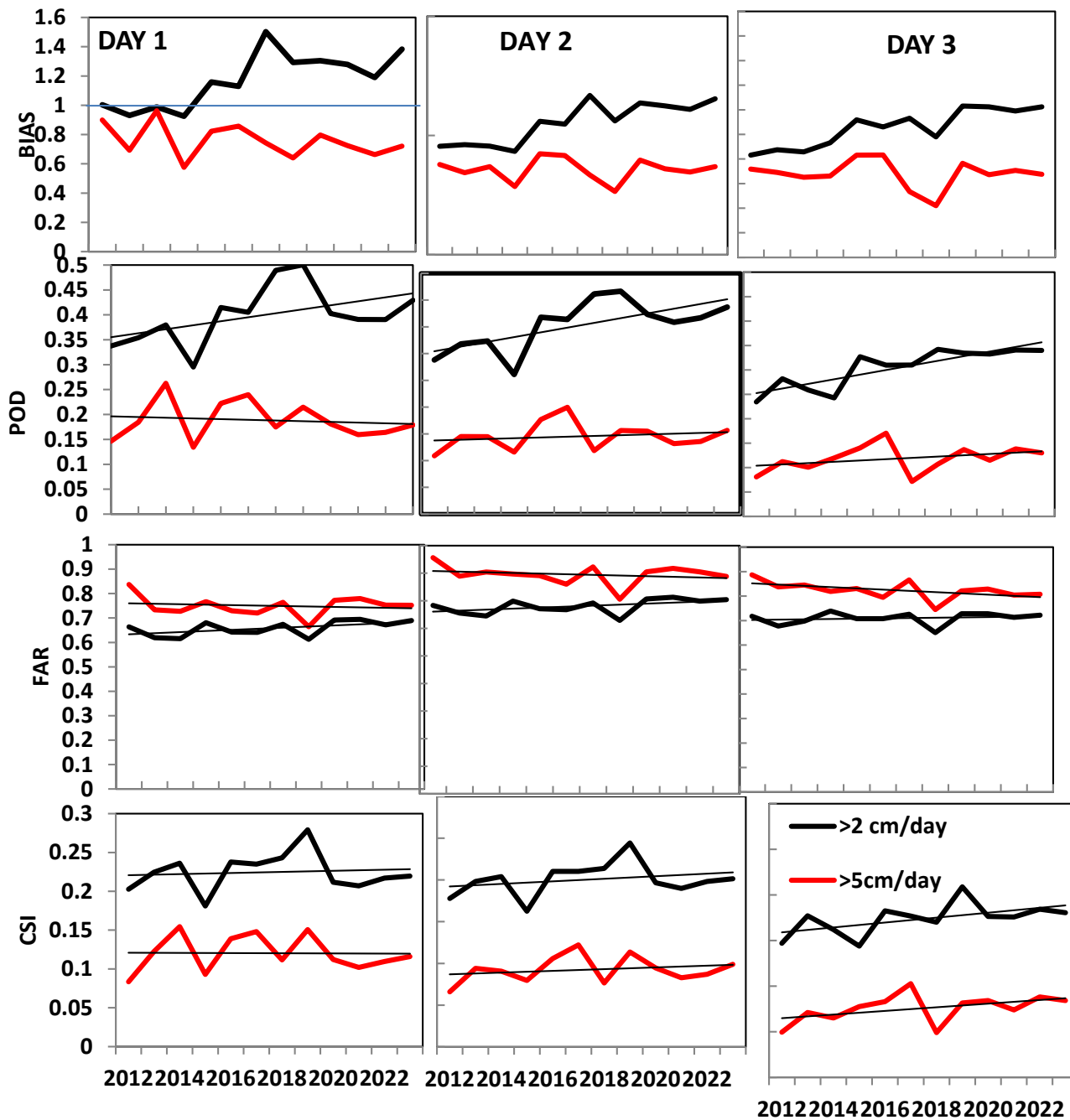
Observed Rainfall (mm/day) Anomaly during SEPT 2023

GFST1534 Rainfall (mm/day) Anomaly during SEPT 2023, Day-1

GFST1534 Rainfall (mm/day) Anomaly during SEPT 2023, Day-3

GFST1534 Rainfall (mm/day) Anomaly during SEPT 2023, Day-5





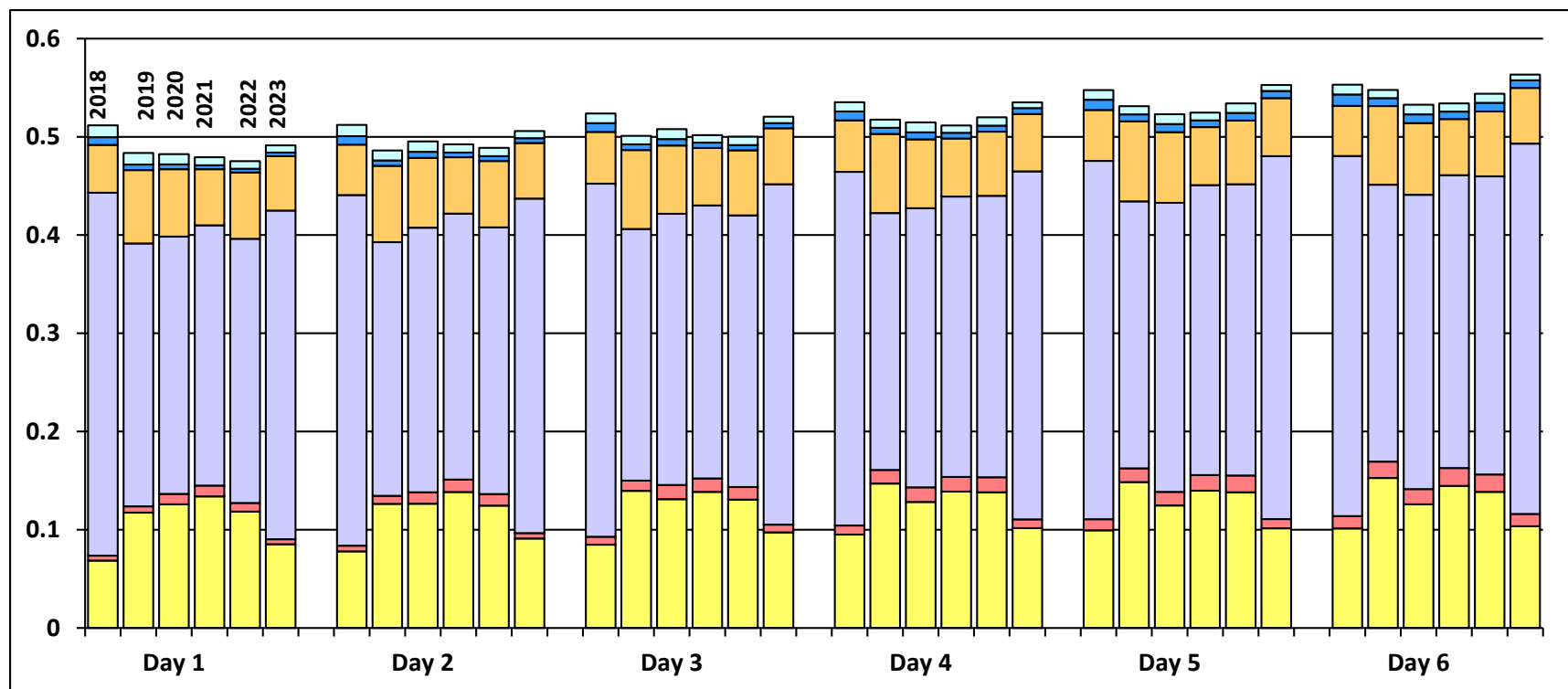
Skill scores for
the rainfall
forecast from
GFS T1534 for
JJAS 2023

Thin black
lines indicate
the trend

SEEPS for GFS T1534 (JJAS) for Indian land points only



Stable Equitable Error in Probability Space (SEEPS) score for GFS T1534 JJAS 2018-2023 for Indian land points only. It is an error score which uses the categories 'dry (D)', 'light precipitation (L)', and 'heavy precipitation (H)' based on the climatological cumulative precipitation distribution.



GFS T1534 forecast valid for 09th July

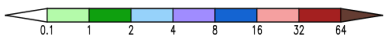
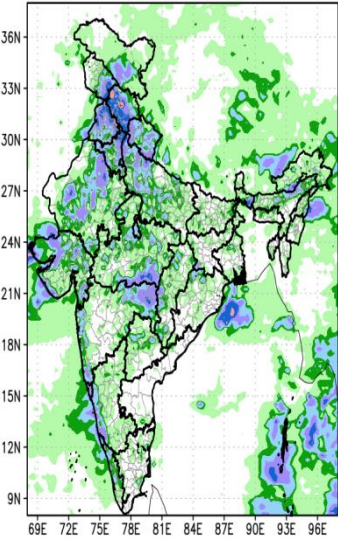
Day-1

Day-2

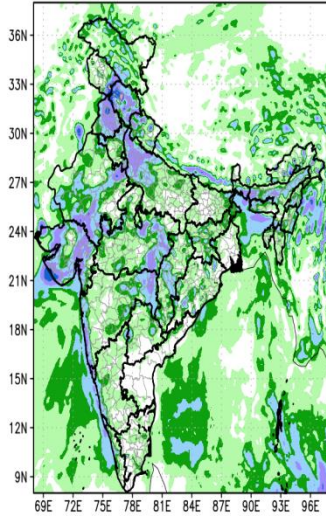
Day-3

Observed rainfall (cm day⁻¹) 09th July

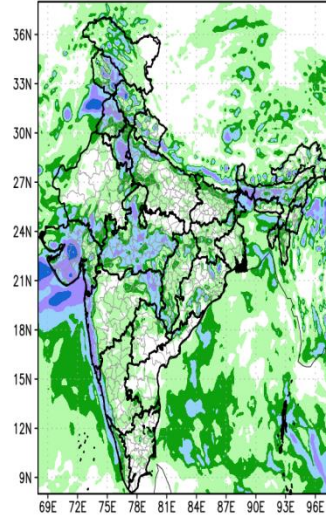
IMD GPM Rainfall (cm/day)
09JUL2023



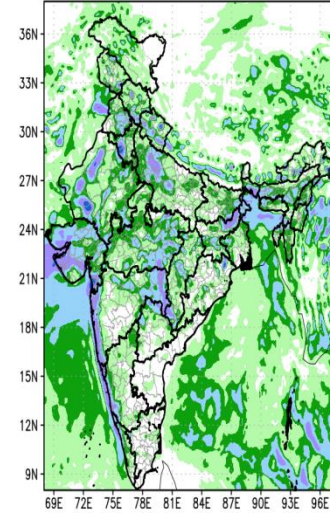
IITM GFS T1534 : Rainfall (cm/day)
Forecast valid for 03Z09JUL2023 (IC=00Z08JUL2023)



IITM GFS T1534 : Rainfall (cm/day)
Forecast valid for 03Z09JUL2023 (IC=00Z07JUL2023)



IITM GFS T1534 : Rainfall (cm/day)
Forecast valid for 03Z09JUL2023 (IC=00Z06JUL2023)



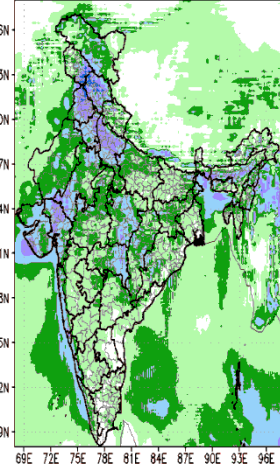
GEFS T1534 forecast valid for 09th July

Day-1

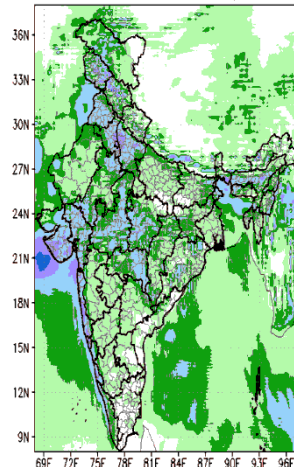
Day-2

Day-3

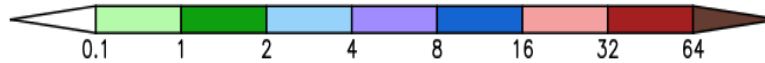
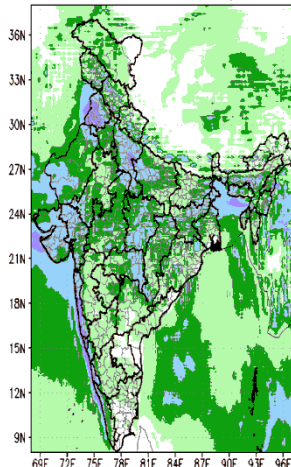
GEFS T1534 : Rainfall (cm/day), Ens Mean (20 Ens)
24-hr Forecast valid for 03Z09JUL2023 (IC=00Z08JUL2023)



GEFS T1534 : Rainfall (cm/day), Ens Mean (20 Ens)
48-hr Forecast valid for 03Z09JUL2023 (IC=00Z07JUL2023)

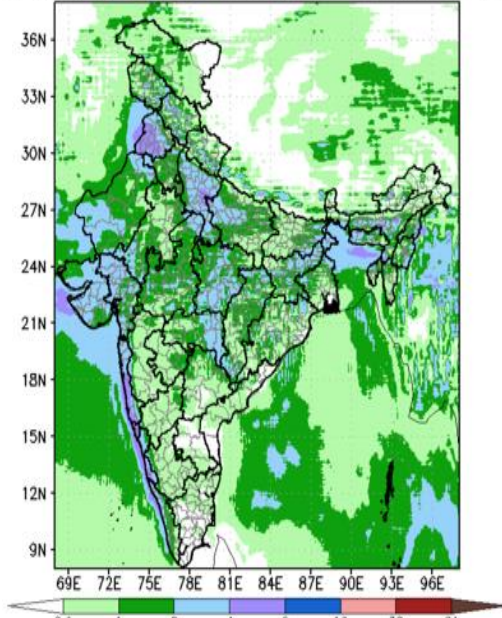


GEFS T1534 : Rainfall (cm/day), Ens Mean (20 Ens)
72-hr Forecast valid for 03Z09JUL2023 (IC=00Z06JUL2023)

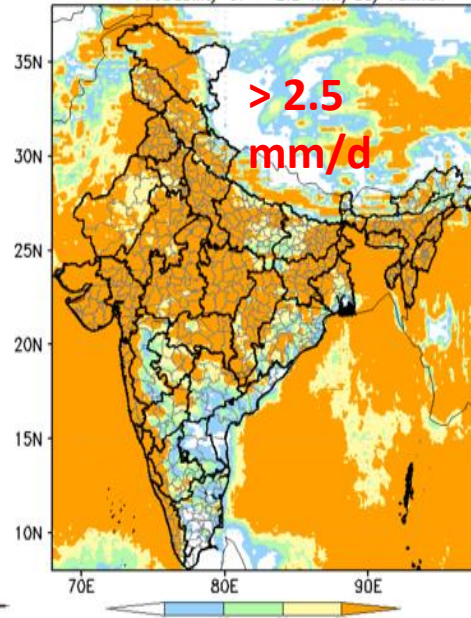


**GEFS T1534
Probabilistic
rainfall
forecast based
on 6th July IC
valid for 9th
July**

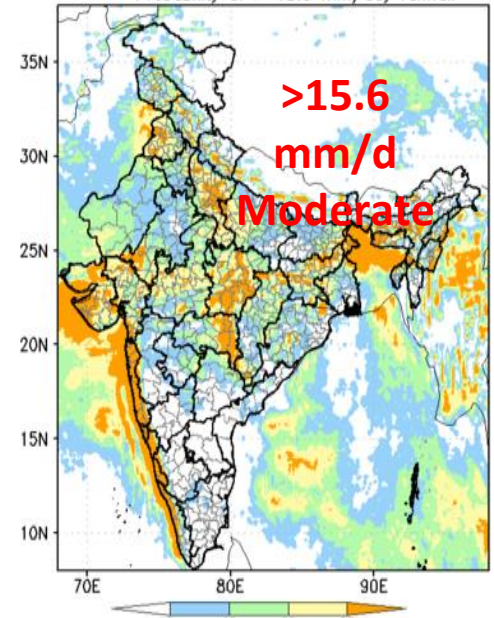
GEFS T1534 : Rainfall (cm/day), Ens Mean (20 Ens)
72-hr Forecast valid for 03Z09JUL2023 (IC=00Z06JUL2023)



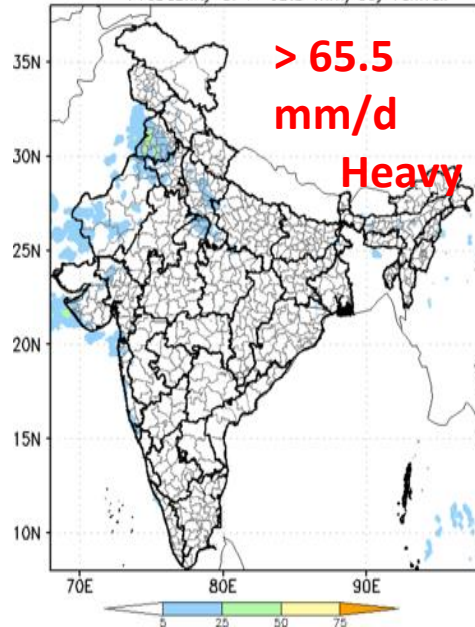
GEFS SL T1534 Probabilistic of Exceedance Precipitation
IC:2023070600 Day-3 Forecast Valid for 03Z09JUL2023
Probability of > 2.5 mm/day rainfall



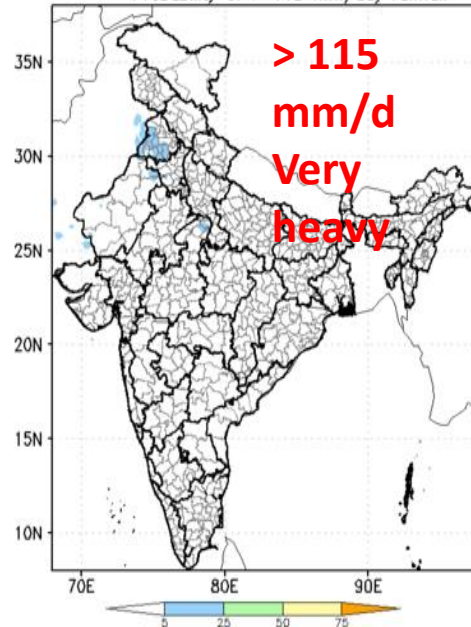
GEFS SL T1534 Probabilistic of Exceedance Precipitation
IC:2023070600 Day-3 Forecast Valid for 03Z09JUL2023
Probability of > 15.6 mm/day rainfall



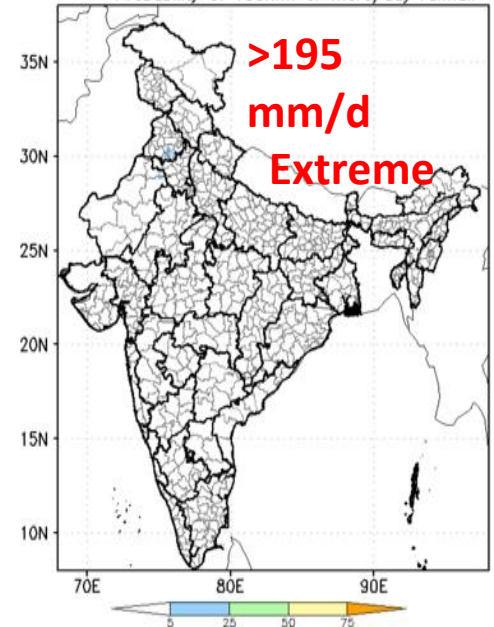
GEFS SL T1534 Probabilistic of Exceedance Precipitation
IC:2023070600 Day-3 Forecast Valid for 03Z09JUL2023
Probability of > 65.5 mm/day rainfall



GEFS SL T1534 Probabilistic of Exceedance Precipitation
IC:2023070600 Day-3 Forecast Valid for 03Z09JUL2023
Probability of > 115 mm/day rainfall



GEFS SL T1534 Probabilistic of Exceedance Precipitation
IC:2023070600 Day-3 Forecast Valid for 03Z09JUL2023
Probability of 195mm or more/day rainfall

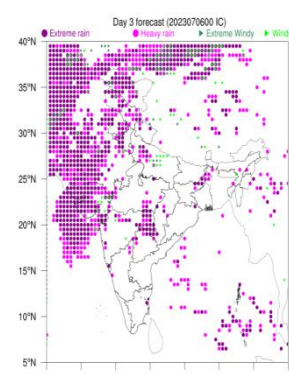
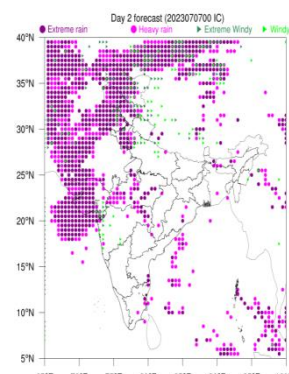
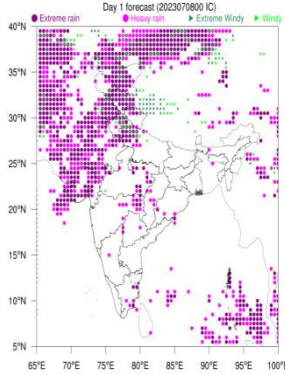


Percentile based forecast based on GFS valid for 09th July

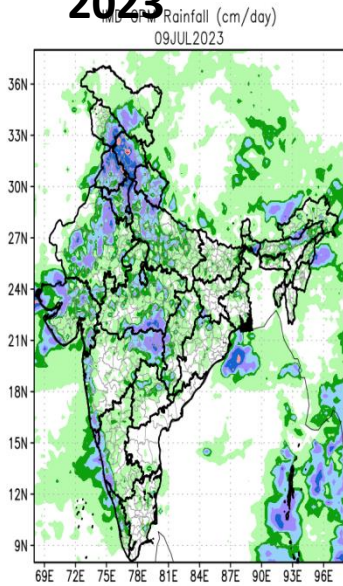
Day-1

Day-2

Day-3

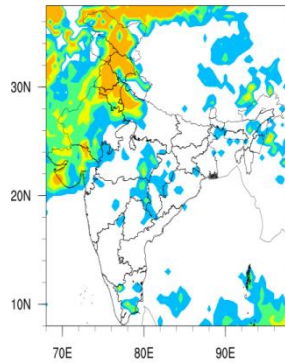


**Observed
rainfall
(cmday⁻¹)
09th July
2023**

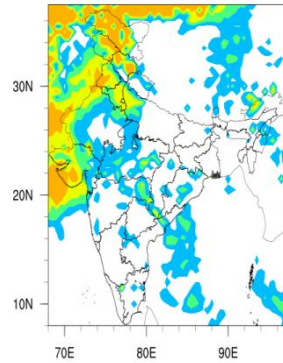


Percentage probability of 95th Percentile based forecast based on GEFS

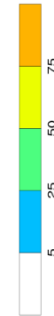
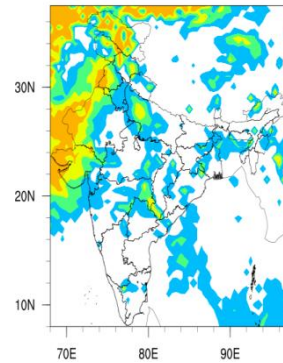
Probability > 95th percentile Day 1 FCST



Probability > 95th percentile Day 2 FCST

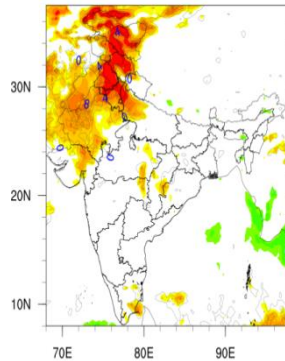


Probability > 95th percentile Day 3 FCST

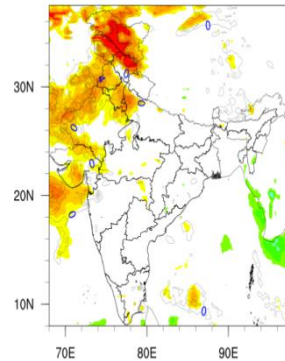


Extreme Forecast Index (EFI) based on GEFS valid for 09th July

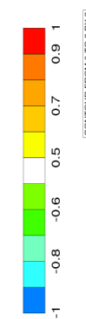
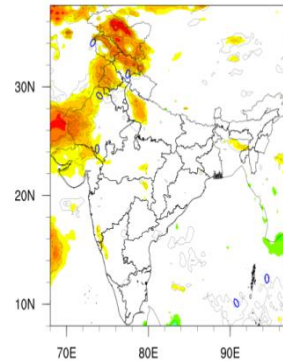
Day 1 forecast (2023070800 IC)



Day 2 forecast (2023070700 IC)



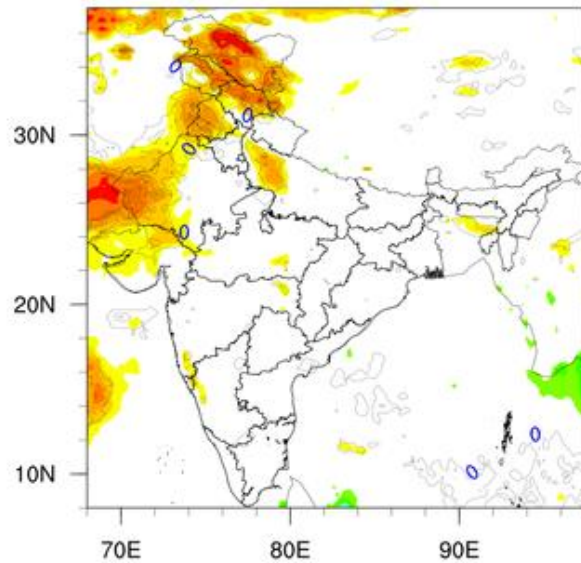
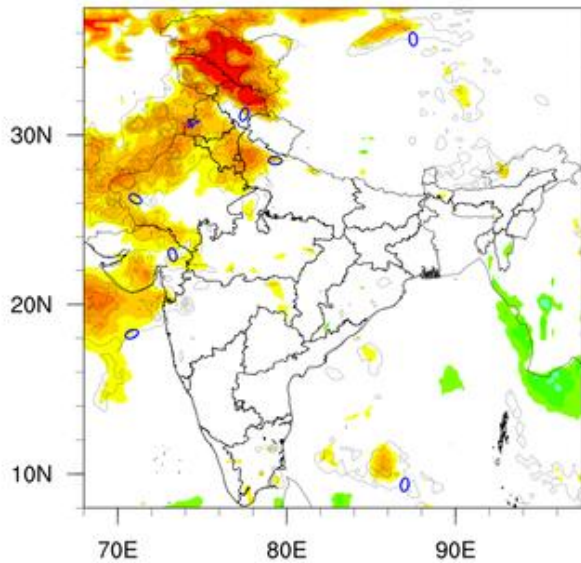
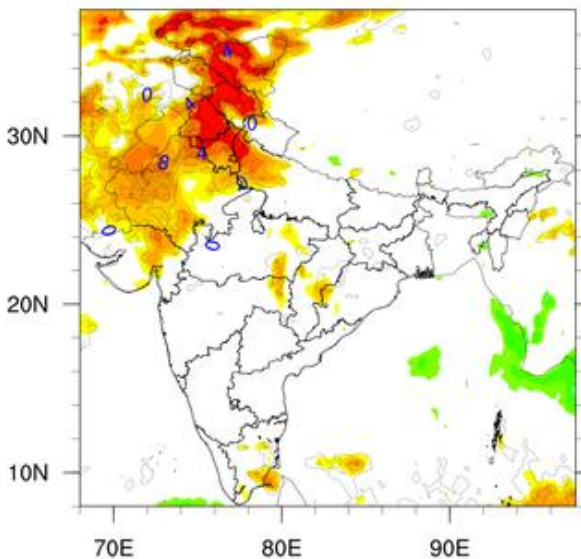
Day 3 forecast (2023070600 IC)



Day 1 forecast (2023070800 IC)

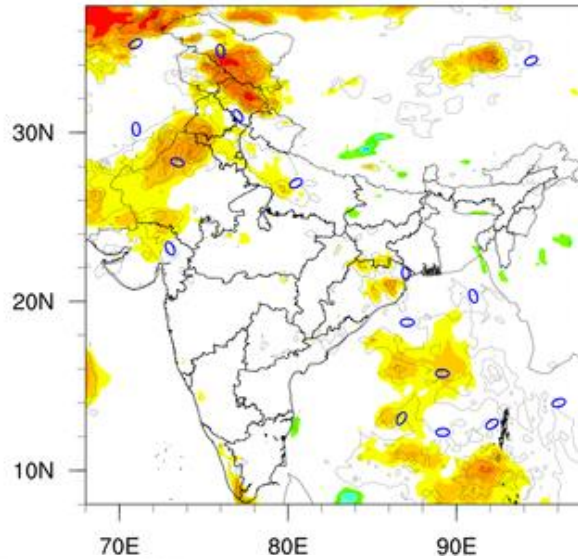
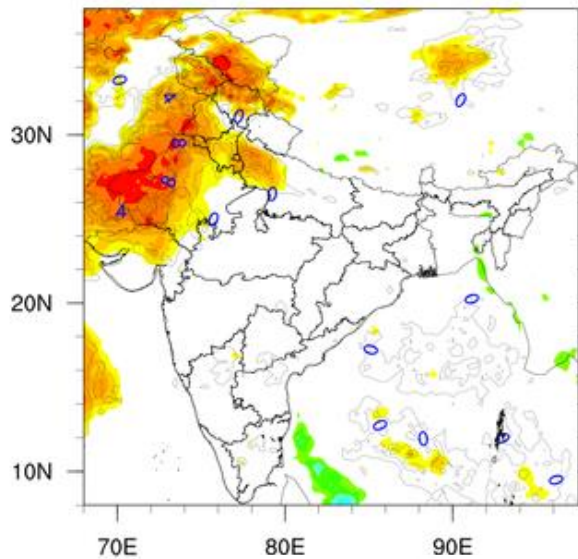
Day 2 forecast (2023070700 IC)

Day 3 forecast (2023070600 IC)

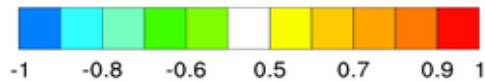


Day 4 forecast (2023070500 IC)

Day 5 forecast (2023070400 IC)



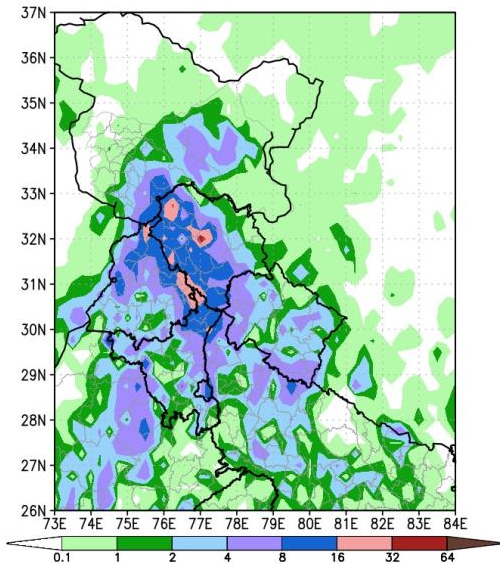
Day 1 to 5 EFI and SOT valid for the 9 July 2023 event



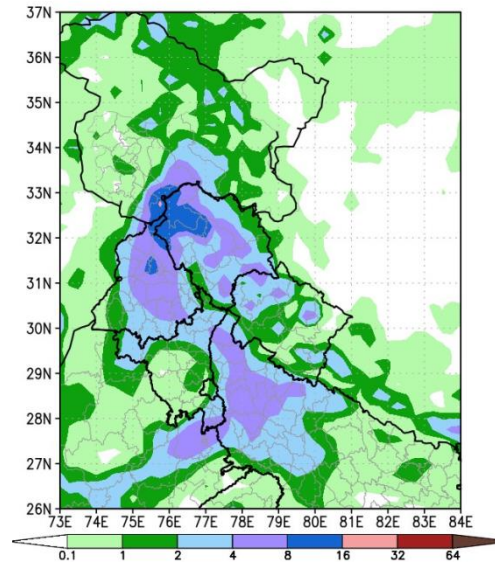
CONTOUR FROM 0 TO 8 BY 2

Spatial Forecast Verification: Contiguous Rain Area

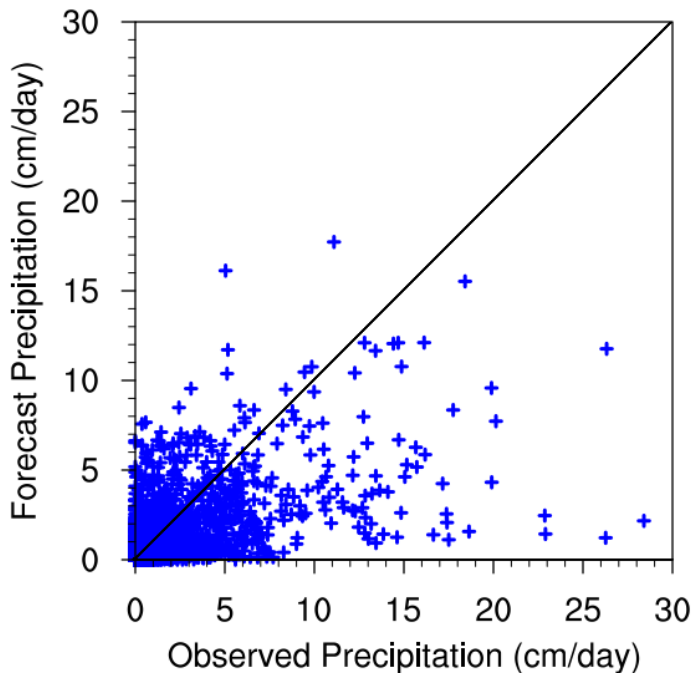
IMD GPM Rainfall (cm/day) on 03Z09JUL2023



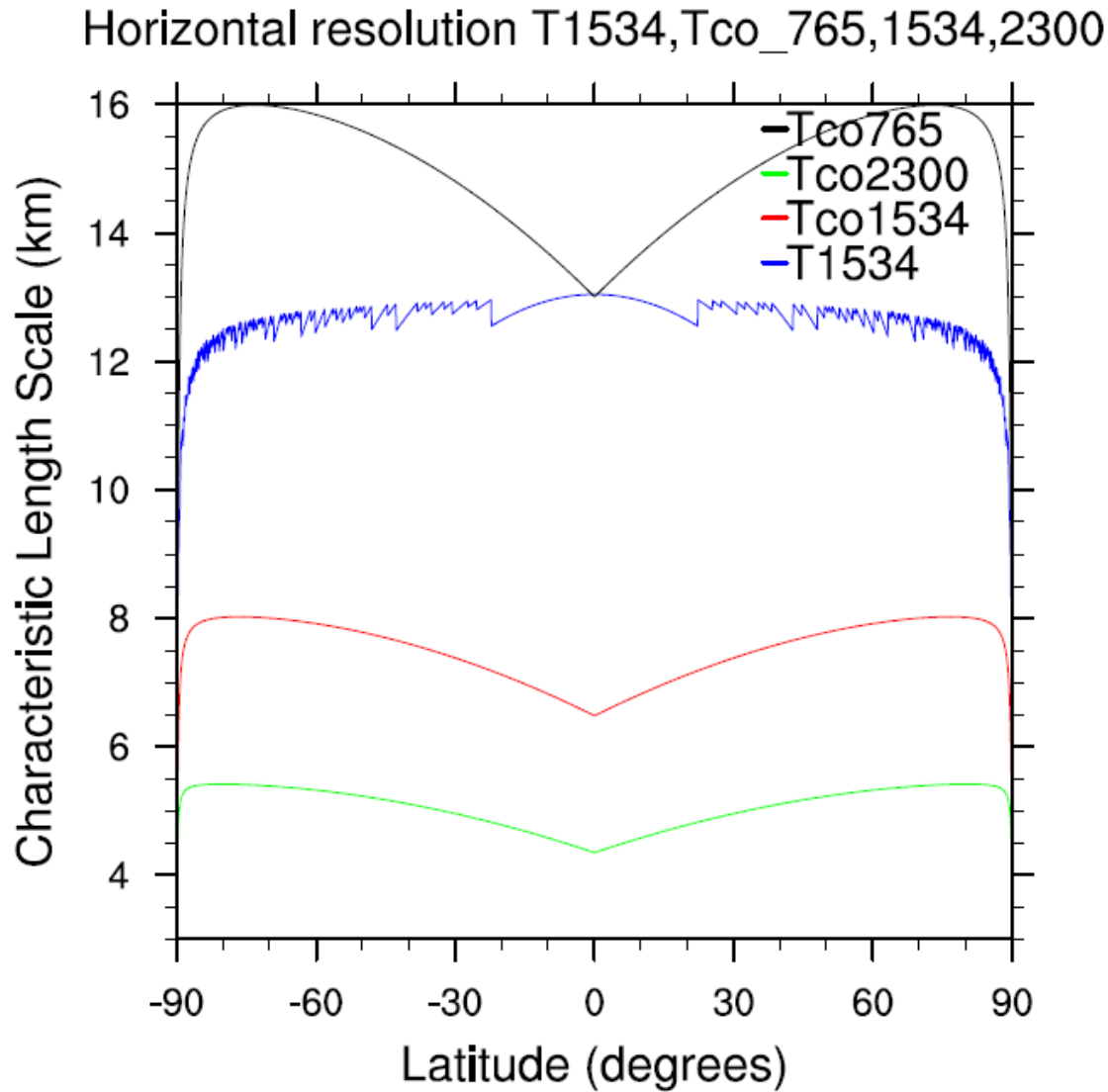
GFS T1534 Rainfall (cm/day)



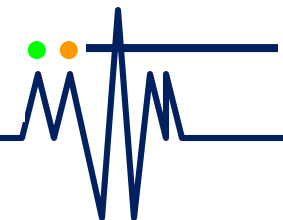
Extremely Heavy rainfall over north Indian region on 9 July 2023



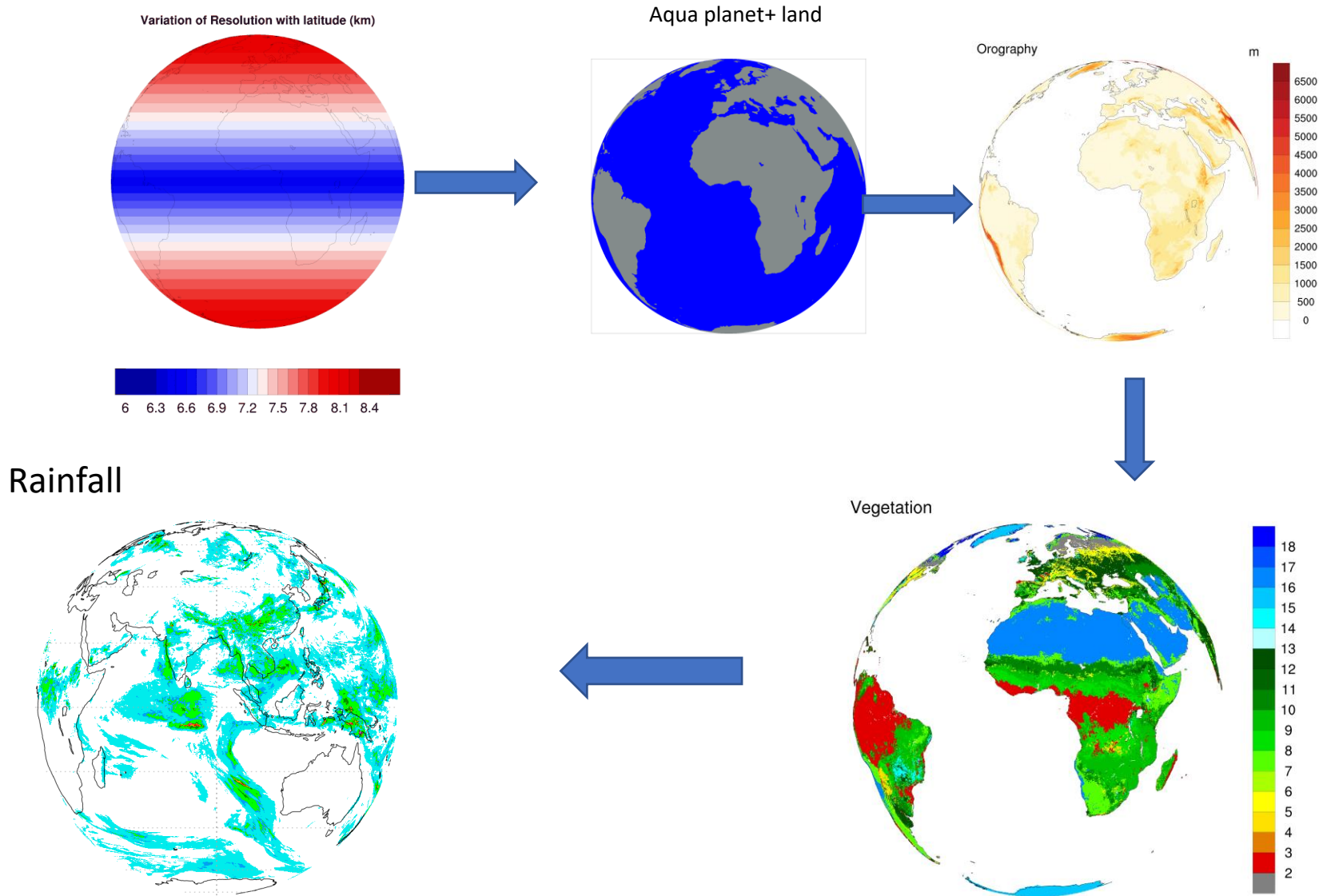
For 24hr **GFS forecast**
CRA threshold 6 cm/day for area 26°-37°N, 73°-84°E
Total no. of grid points=37*37=1369
No. of grid points with ≥ 6 cm/day
Observed=73, Forecast=54
Maximum Rain (cm/day)
Observed=29.6, Forecast=35.2
Displacement (E,N) = (-2.5, 1.85)
RMSE (cm/day) = 2.7
Error Decomposition
MSE_{displacement} = 0.1 %
MSE_{volume} = 2.6%
MSE_{pattern} = 97.3%



Improvement
in dynamic
computation
~7-8%%

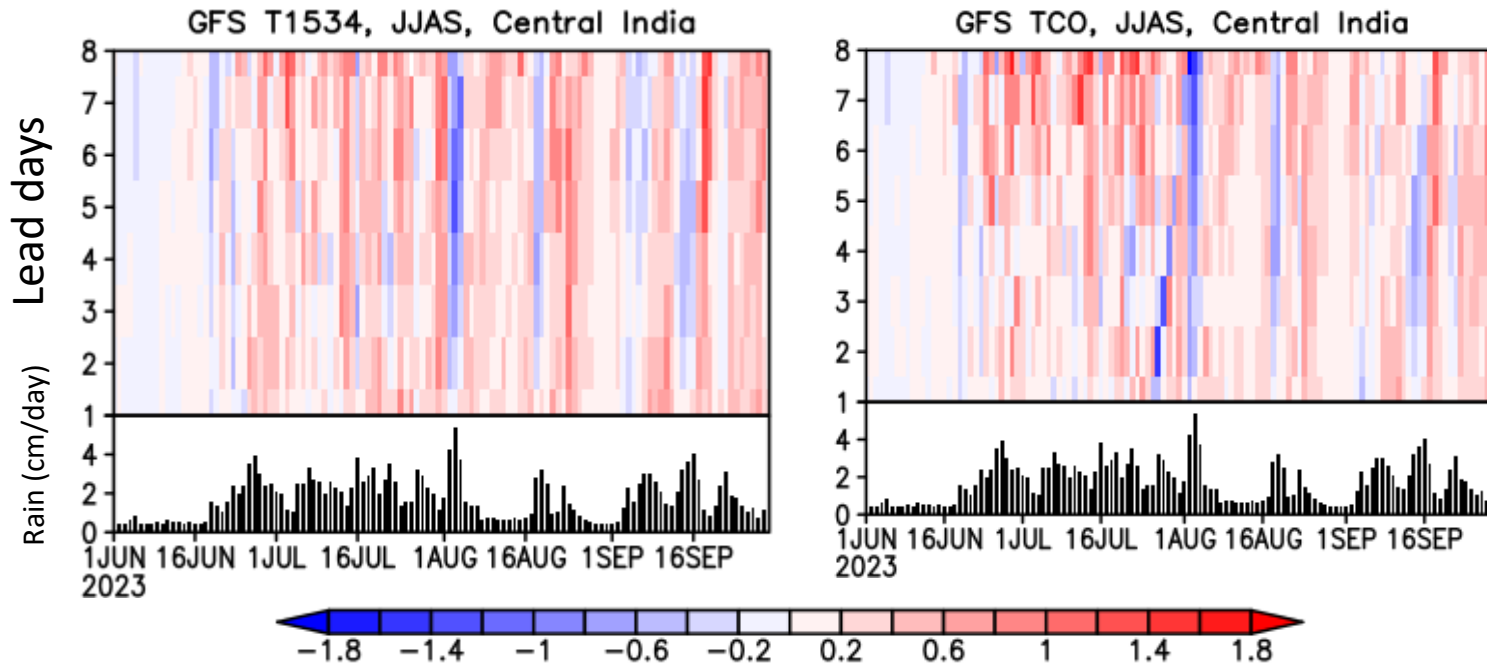


Sequence of IITM HGFM Development



[Link for a film on the development of the model https://youtu.be/dxacESa28bY](https://youtu.be/dxacESa28bY)

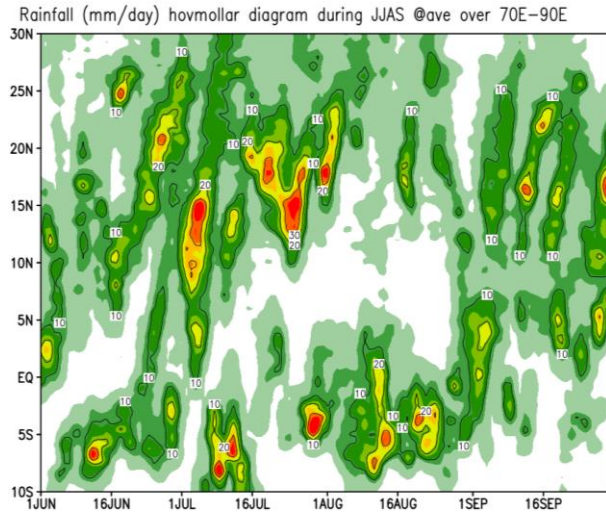
Chiclet diagram (Carbin et al., 2016; Wang et al., 2017)



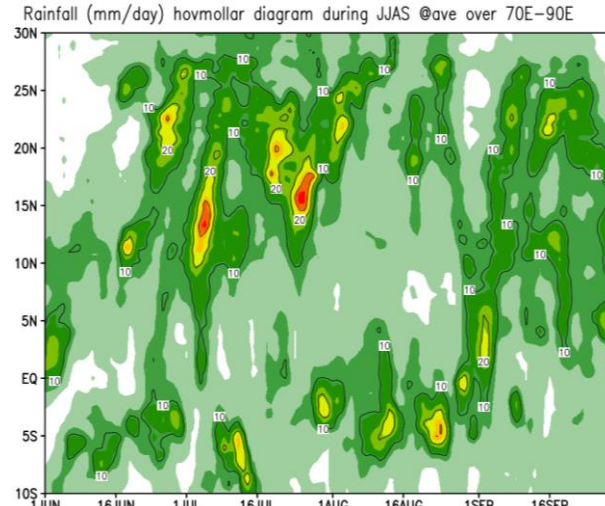
Chiclet diagram of daily precipitation bias (cm/day; model-obs) forecasts from the model as a function of the verification date (x axis) and lead time (y axis) over central India region. Time series of daily mean precipitation (cm/day) is plotted in the lower panel in each plot.

Rainfall (mm/day)
Hovmoller diagram
averaged over 70E-90E
during JJAS 2023

Observation

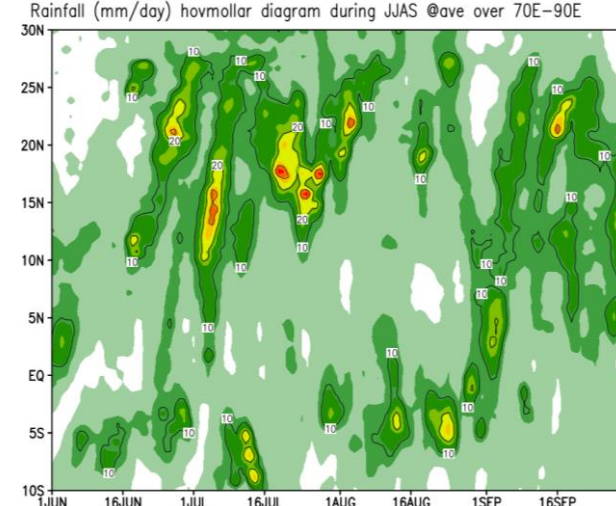


GFS T1534

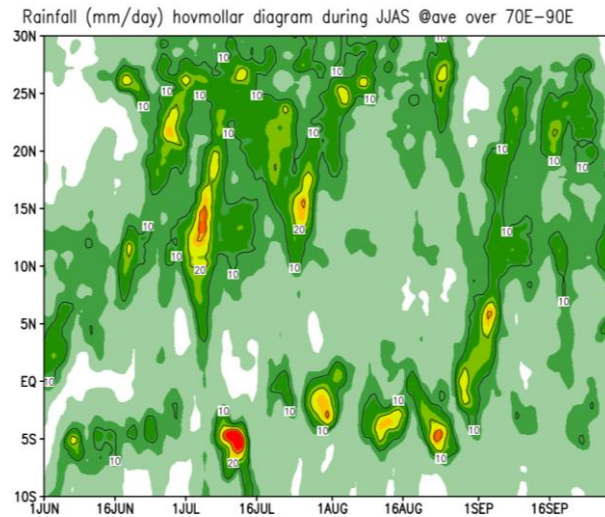


Day-1

GFS TCO

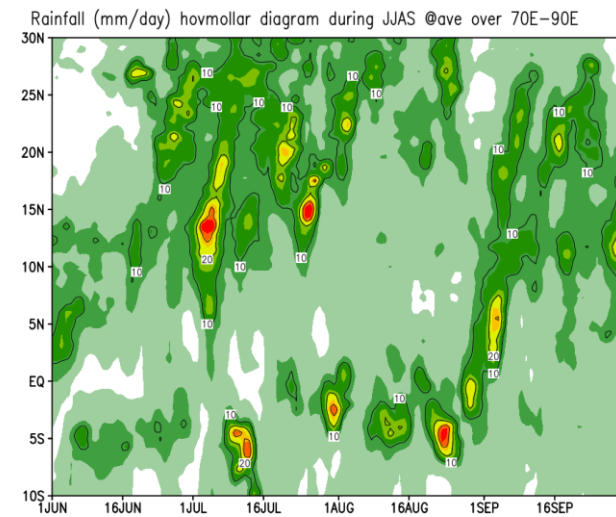


GFS T1534



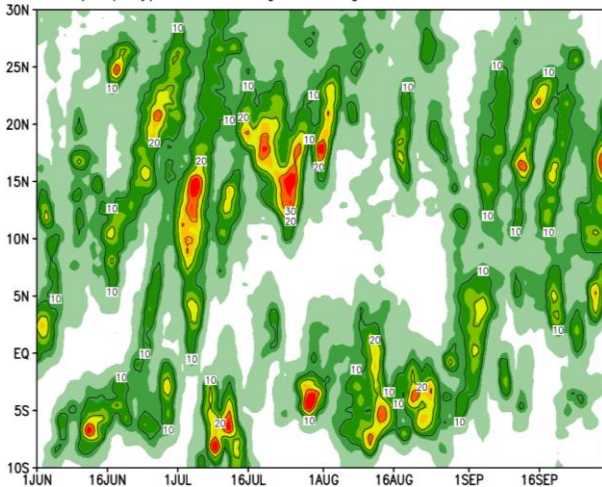
Day-3

GFS TCO



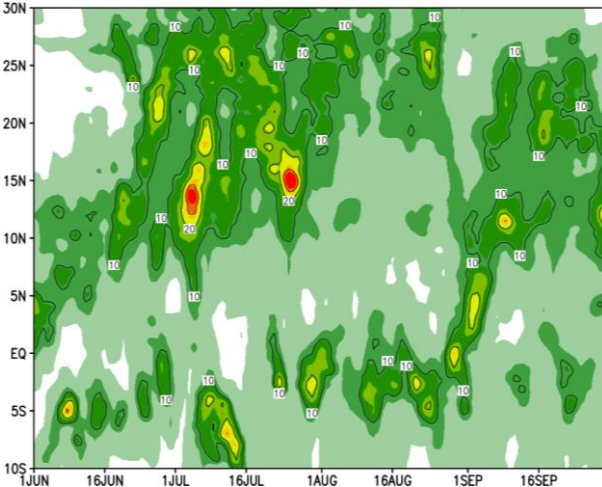
Observation

Rainfall (mm/day) hovmoller diagram during JJAS @ave over 70E-90E



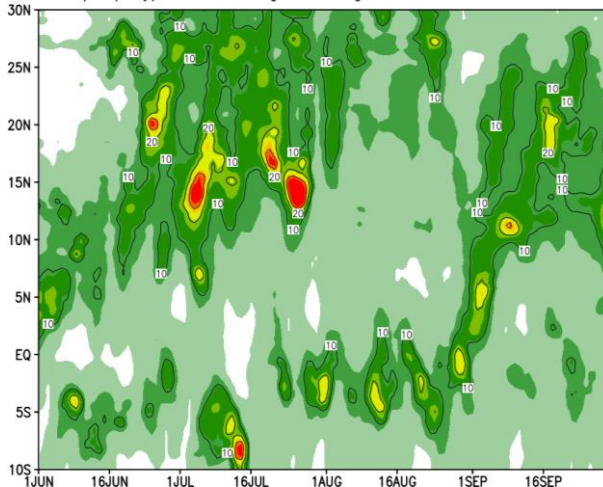
GFS T1534

Rainfall (mm/day) hovmoller diagram during JJAS @ave over 70E-90E



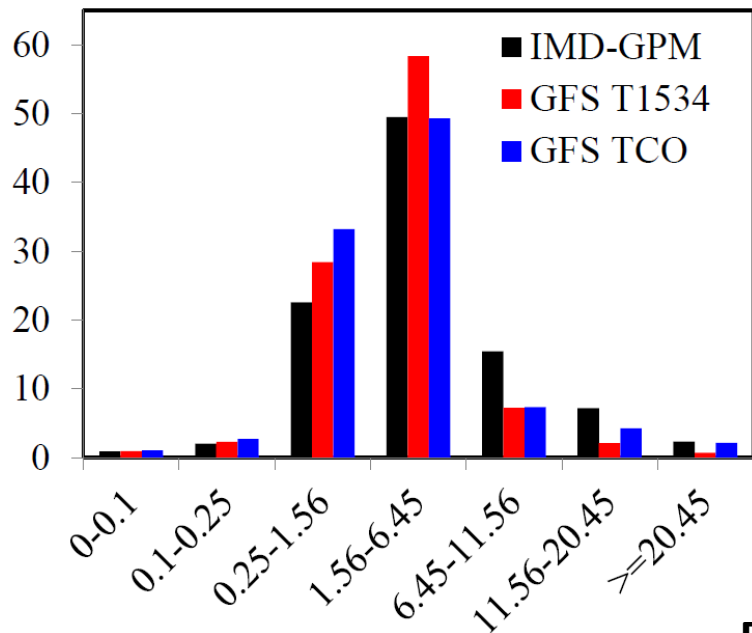
Day-5

Rainfall (mm/day) hovmoller diagram during JJAS @ave over 70E-90E

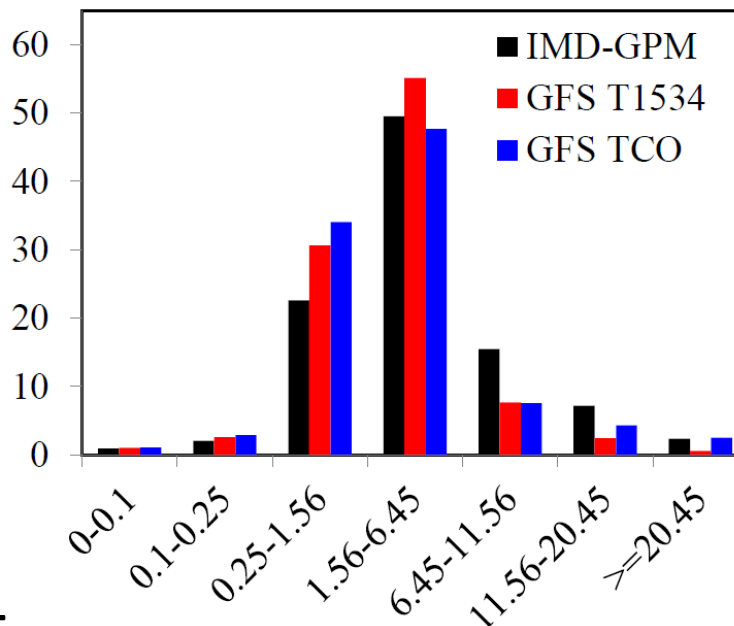


JAS rainfall PDF over continental India during 2023

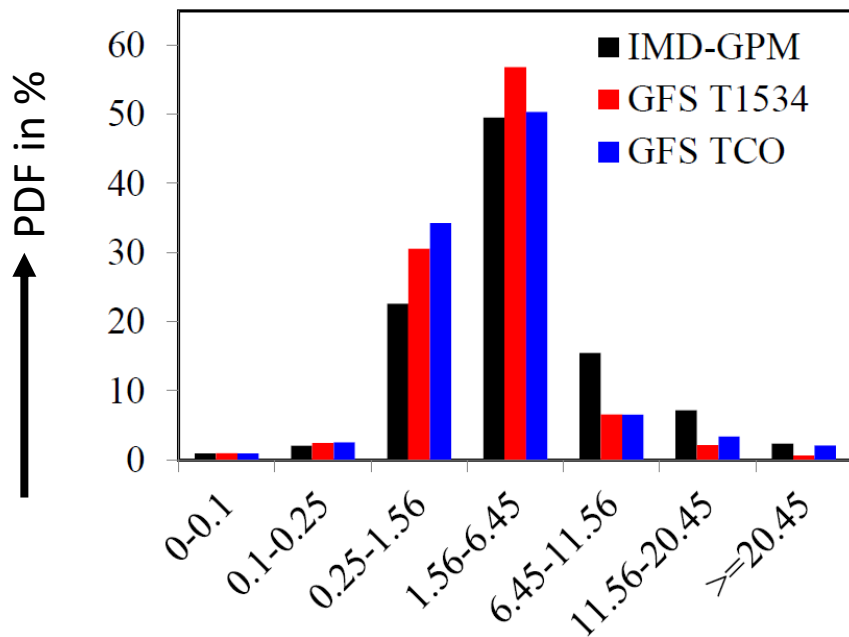
Day-1



Day-3



Day-5



PDF in %

Rainfall bins in cm/day

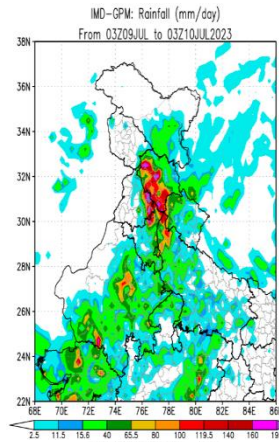
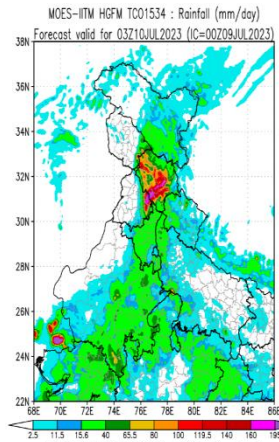
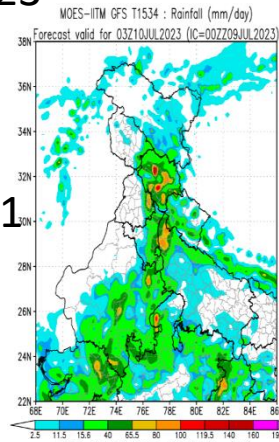
Rainfall event on 09 July 2023

GFS_T1534

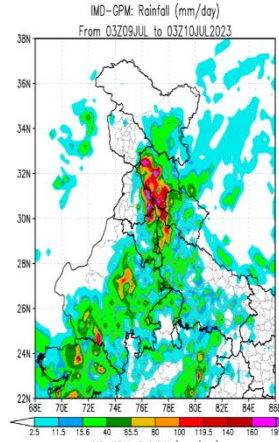
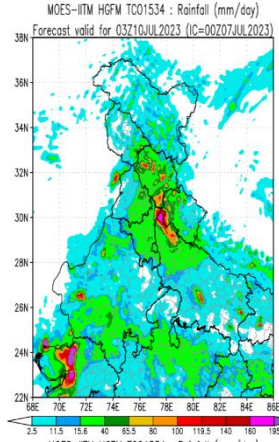
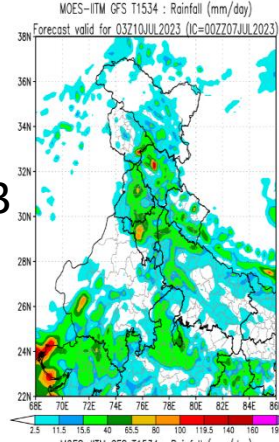
TCO_1534

IMD_GPM

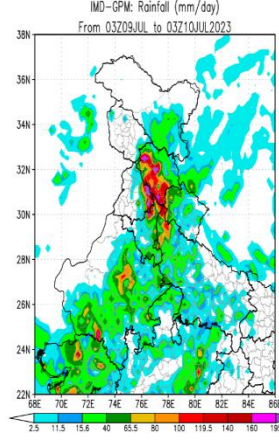
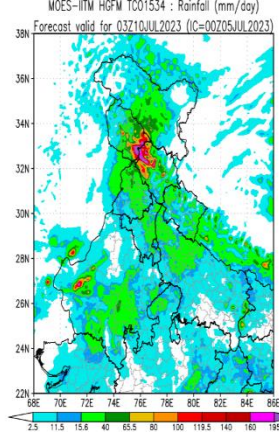
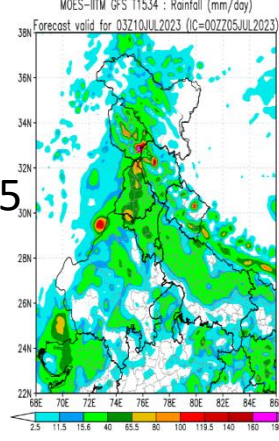
Day 1



Day 3



Day 5



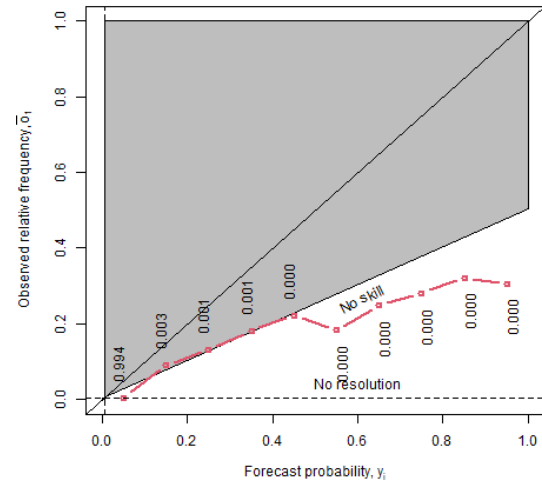
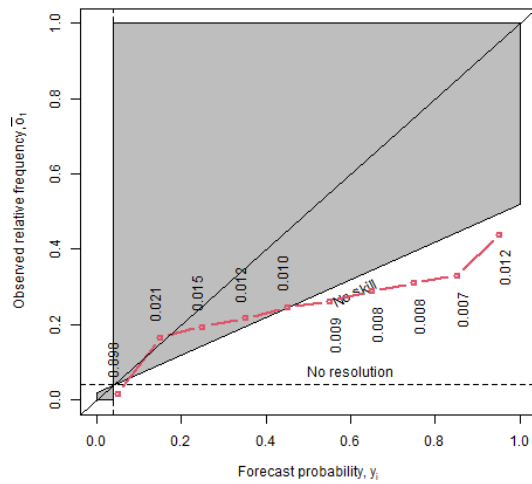
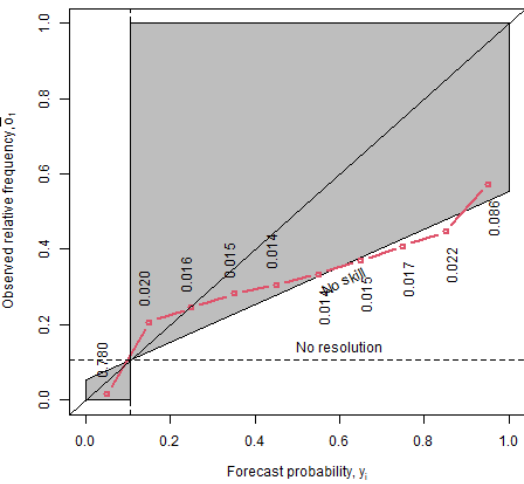
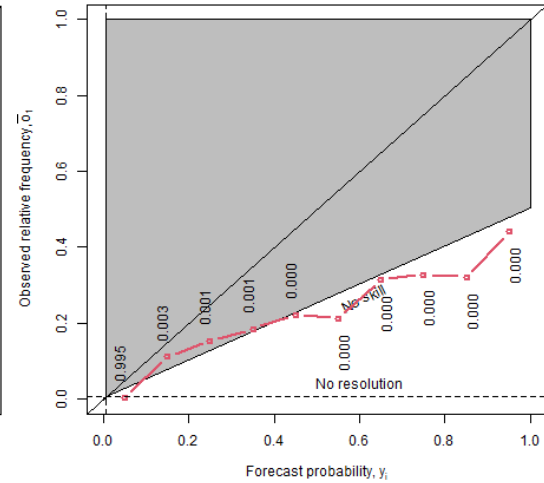
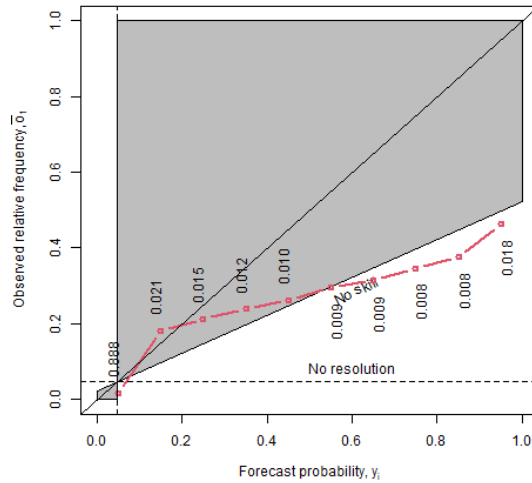
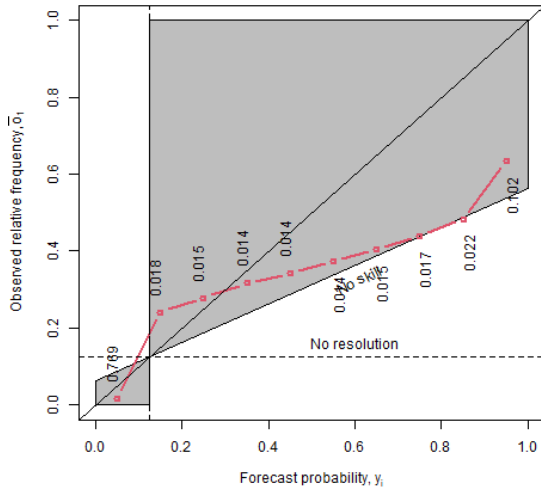
The Ensemble Skill

Threshold ≥ 2.5 mm/day

≥ 15.6 mm/day

≥ 65.5 mm/day

JJAS 2022
Day 2



JJAS 2023
Day 3

Relative Operating Characteristic (ROC) for rainfall forecast of JJAS 2023 from GEFS T1534

X-Axis-False Alarm Rate

Y-Axis-Hit Rate

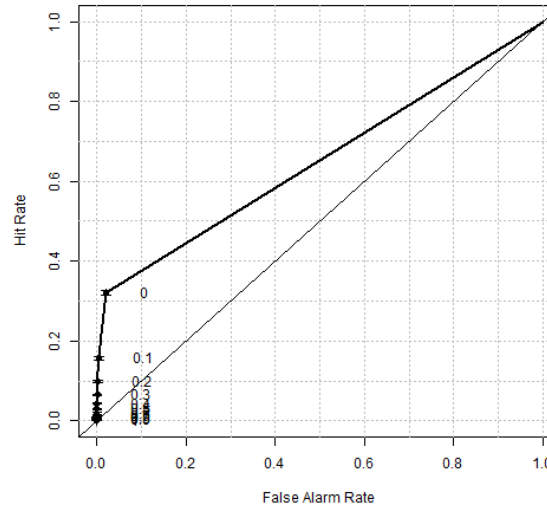
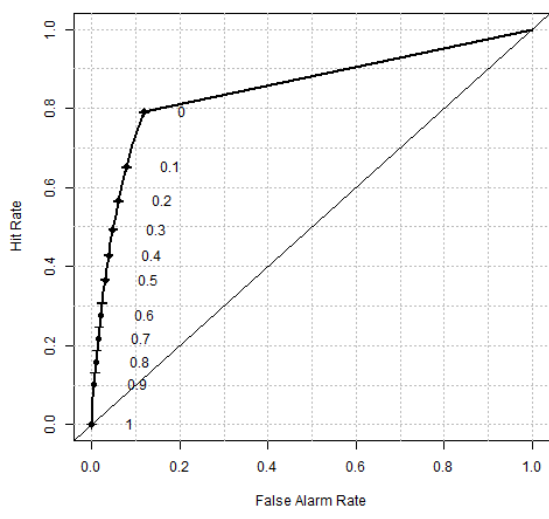
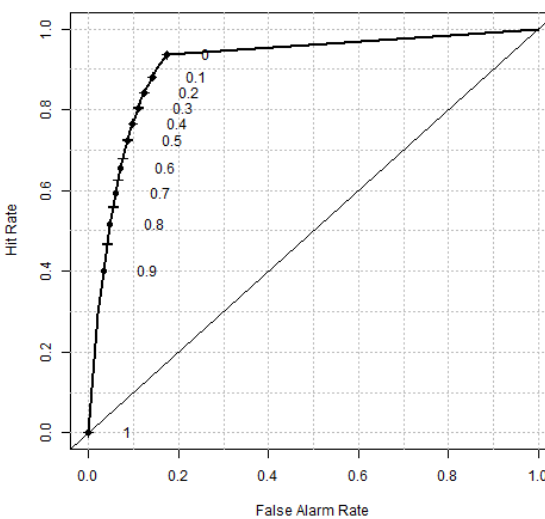
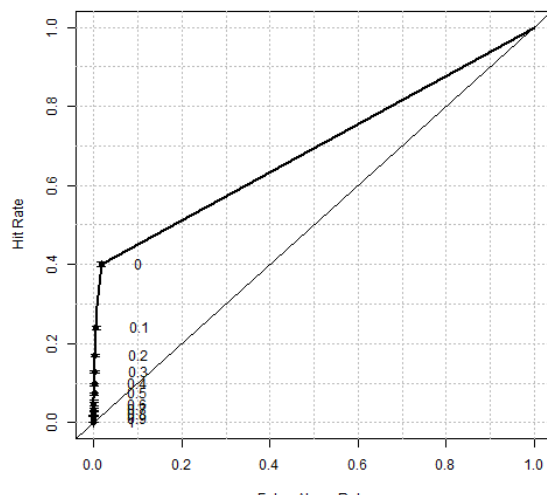
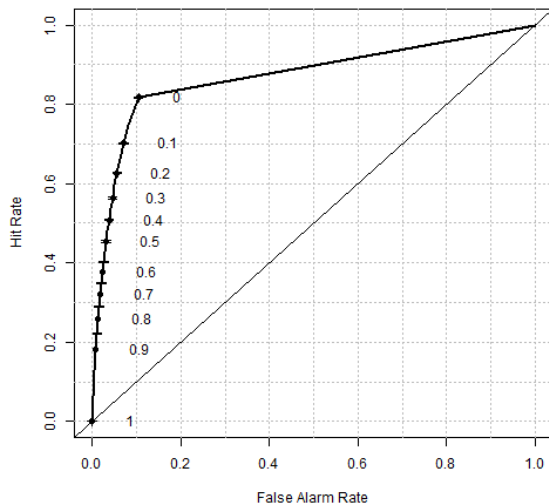
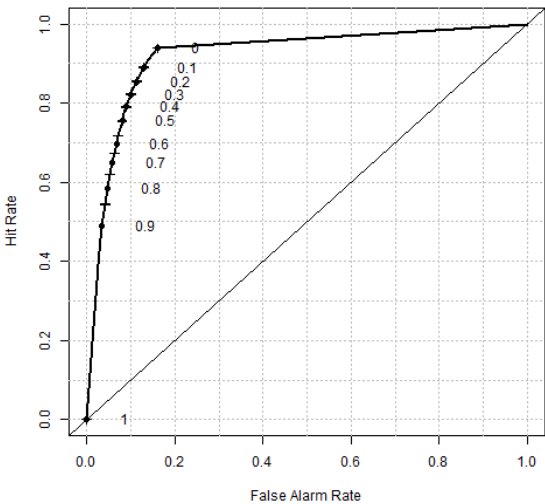
Threshold ≥ 2.5 mm/day

≥ 15.6 mm/day

≥ 65.5 mm/day

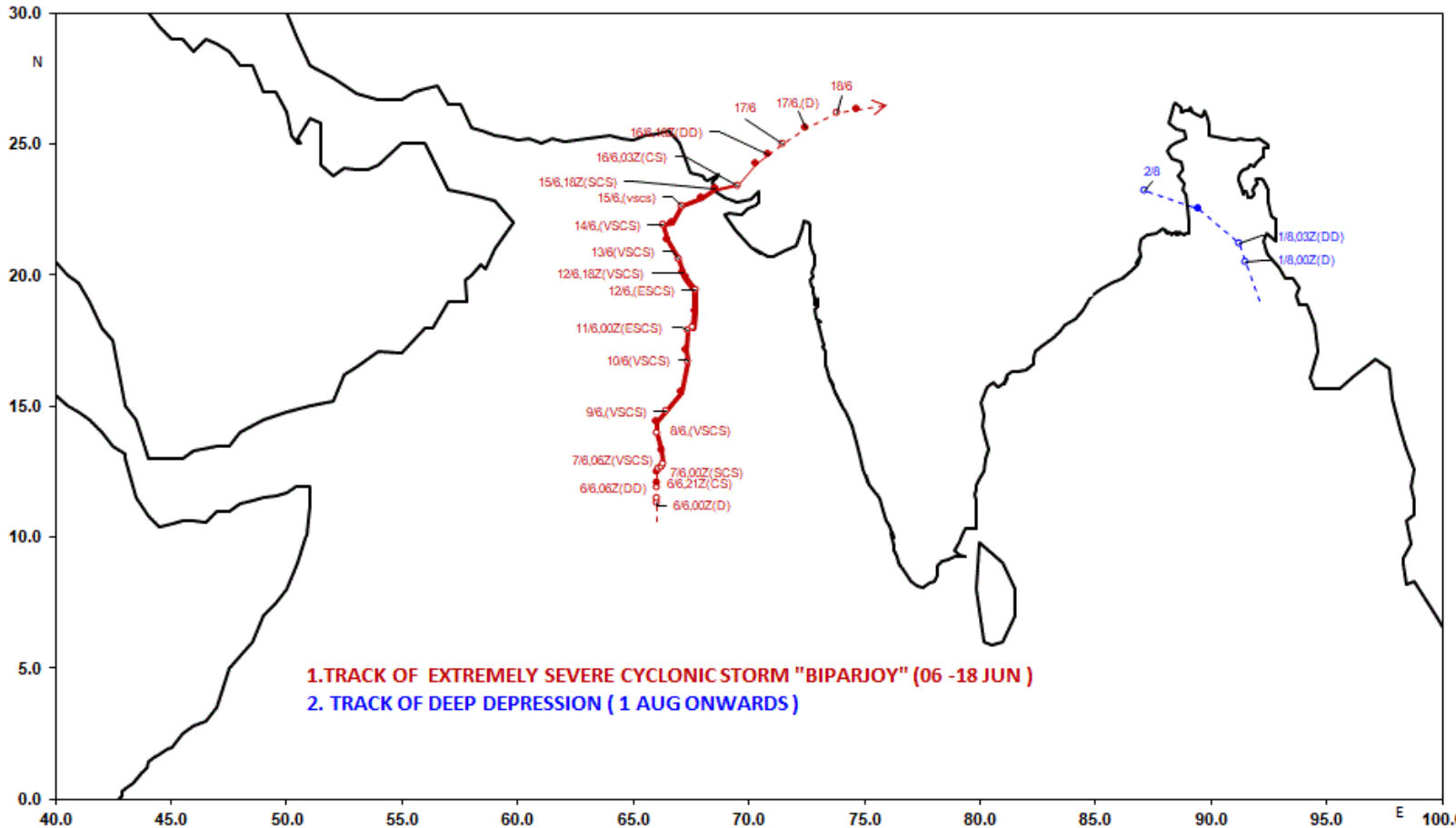
Day 1

Day 3



TRACK OF INTENSE LOW PRESSURE SYSTEM FORMED DURING MONSOON SEASON 2023

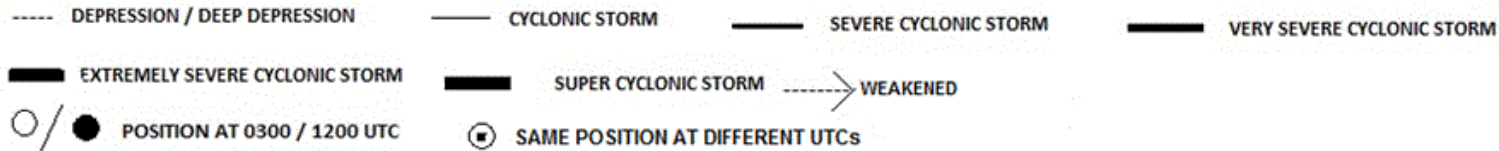
kindly visit www.rsmcnewdelhi.imd.gov.in for latest updates



1. TRACK OF EXTREMELY SEVERE CYCLONIC STORM "BIPARJOY" (06 -18 JUN)
 2. TRACK OF DEEP DEPRESSION (1 AUG ONWARDS)

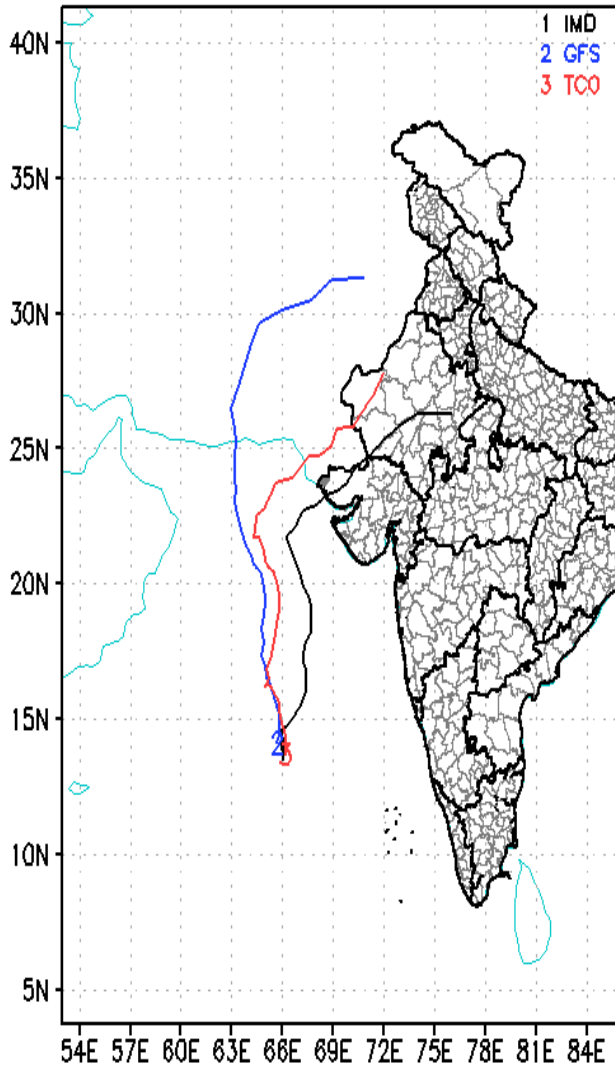
From D to VSCS in 30 hrs. Press drop from 3 mb to 21mb

From VSCS to DD dissipation 27 hr. Press filling from 21mb to 4 mb



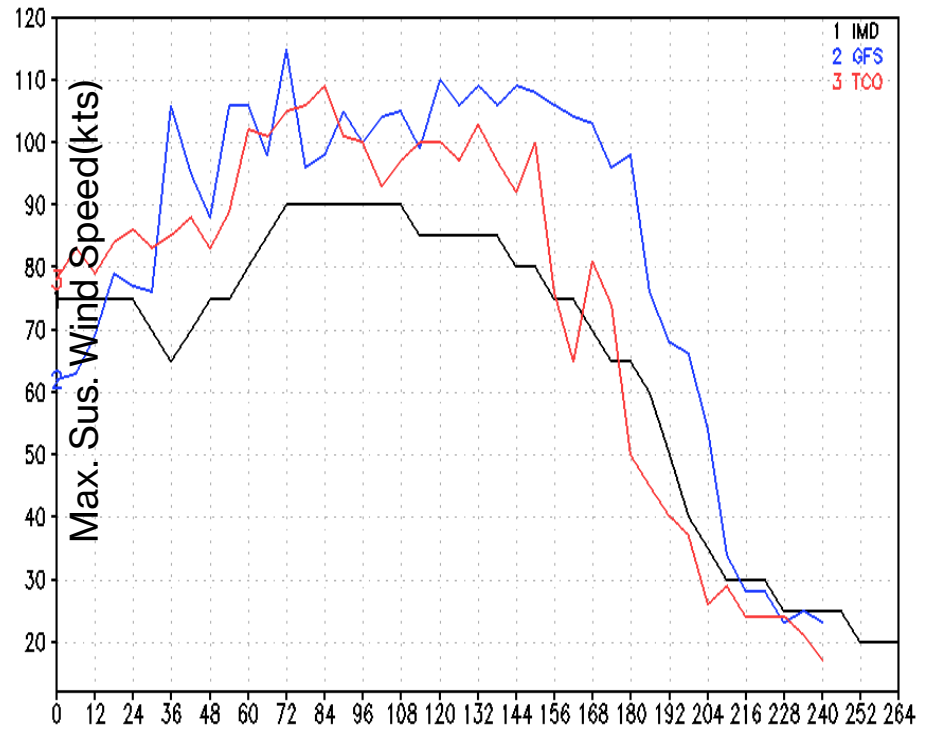
D on 6 June 00Z, DD 6 June 06Z, CS 6 June 12Z, SCS 7 June 00Z, VSCS 7 June 06Z remained VSCS 10 June 21Z, ESCS 11 June 00Z (press drop 40mb), remained ESCS 12 June 15Z, VSCS 12 June 15Z, remained VSCS till 15 June 15Z crossed the coastline, SCS 15 June 18Z, CS 16 June 03Z, DD 16 June 18Z, D 17 June 12Z, 18 June 03Z WML

2023 AS ESCS Biparjoy Tracks



Forecasts: Beginning 2023060800

2023 AS ESCS Biparjoy Intensity

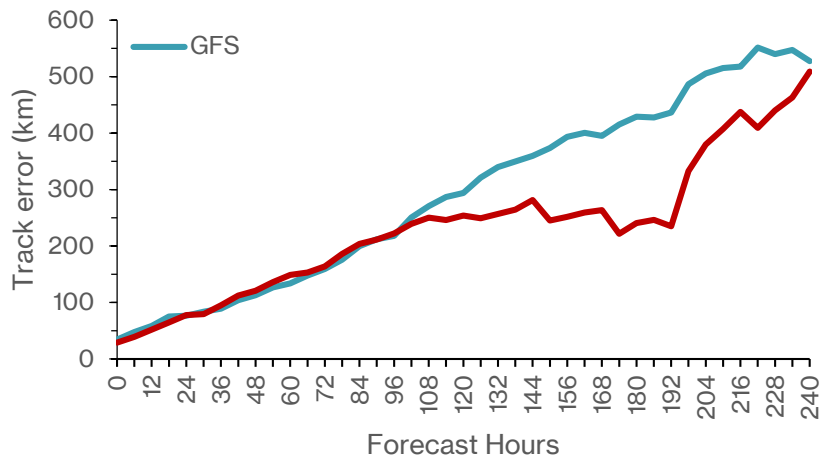


Forecasts: Beginning 2023060800

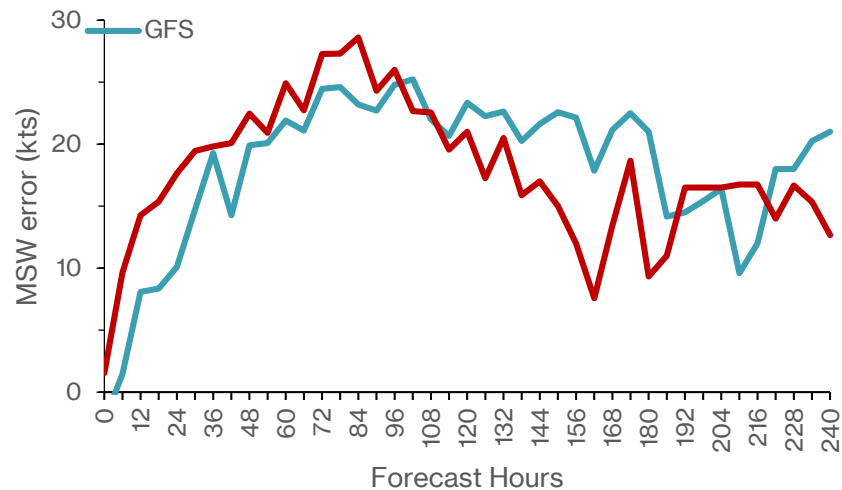
Forecast Hours

ICs considered : 00Z ICs from 6June to 15June 2023 for both GFS and TCO

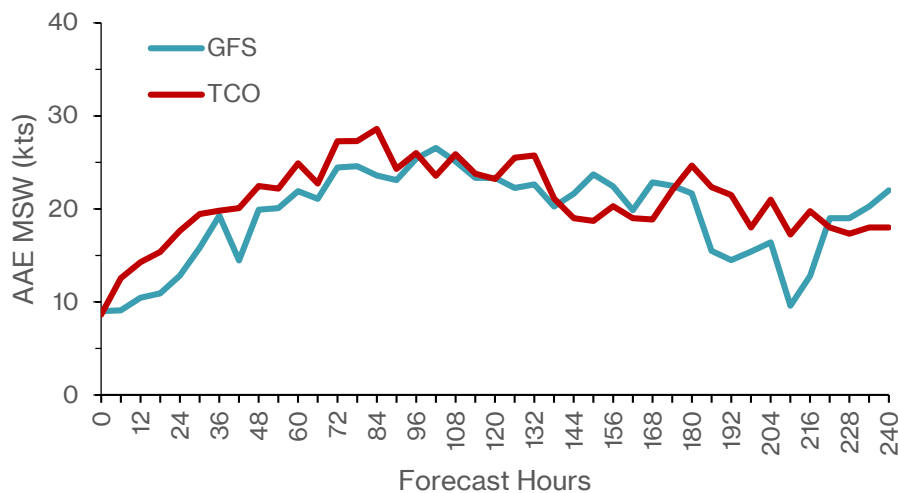
Average track Error



Average Intensity Error



AAE of MSW



Landfall Errors

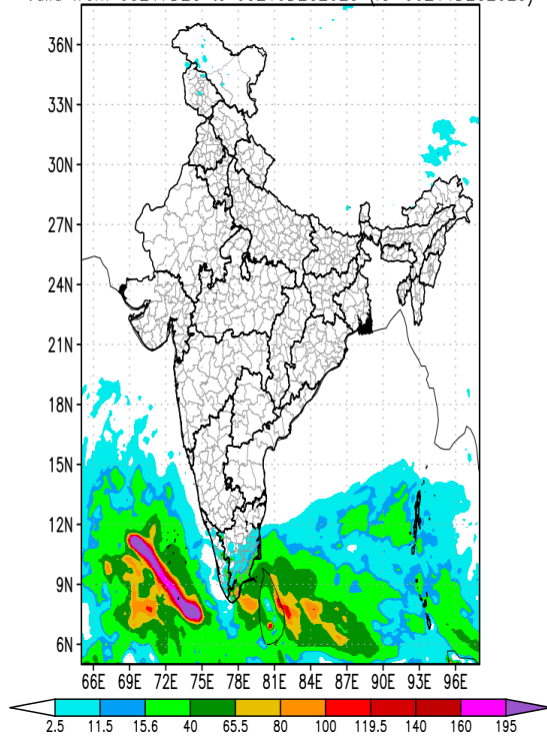
		GFS	TCO	GFS	TCO
Lead Hours	IC	positions error		Time Errors	
228hr	2023060600	298	57	0	-30
204hr	2023060700	No landfall			
180hr	2023060800	616	201	0	0
156hr	2023060900	349	197	12	12
132hr	2023061000	428	197	12	6
108hr	2023061100	197	7	6	-18
84hr	2023061200	279	123	12	12
60hr	2023061300	197	163	6	6
	2023061400				

ve (+ve) indicates early (late) landfall ³²

2days accumulated rainfall (mm/day) from 03Z17 Dec to 03Z19 Dec 2023

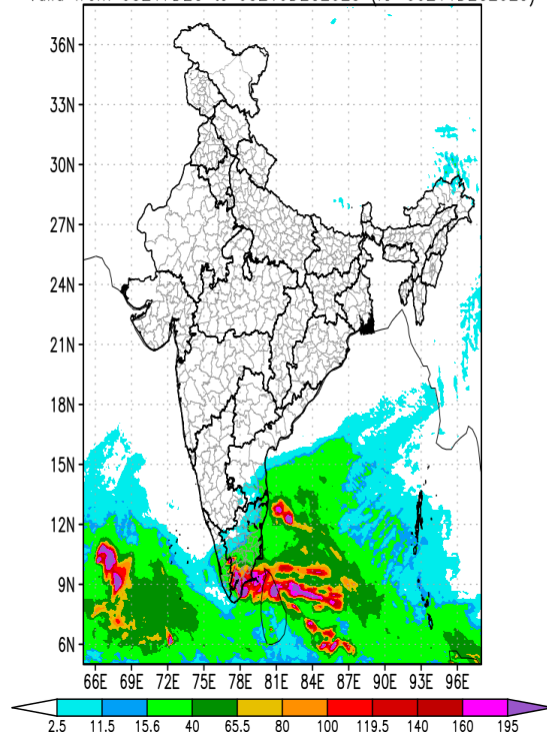
GFS_T1534

IITM GFS T1534 : Rainfall (mm/day)
valid from 03Z17DEC to 03Z19DEC2023 (IC=00Z11DEC2023)



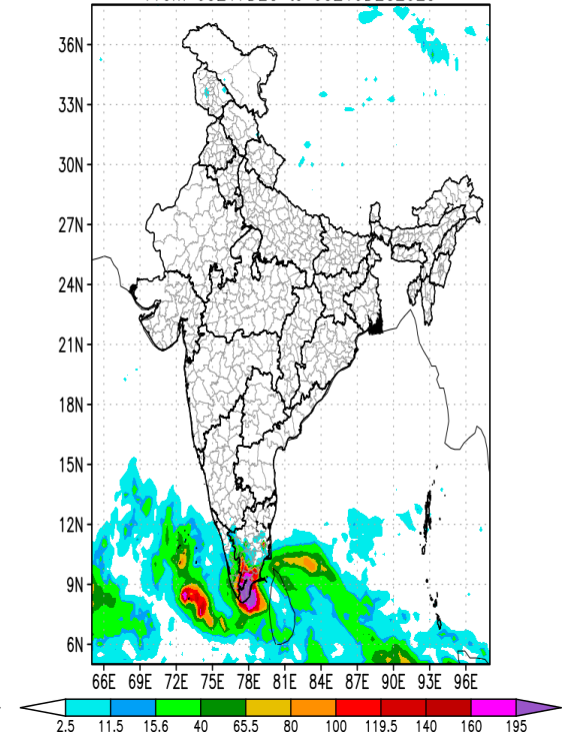
TCO_1534

MOES-IITM HGFM TCO1534 : Rainfall (mm/day)
valid from 03Z17DEC to 03Z19DEC2023 (IC=00Z11DEC2023)



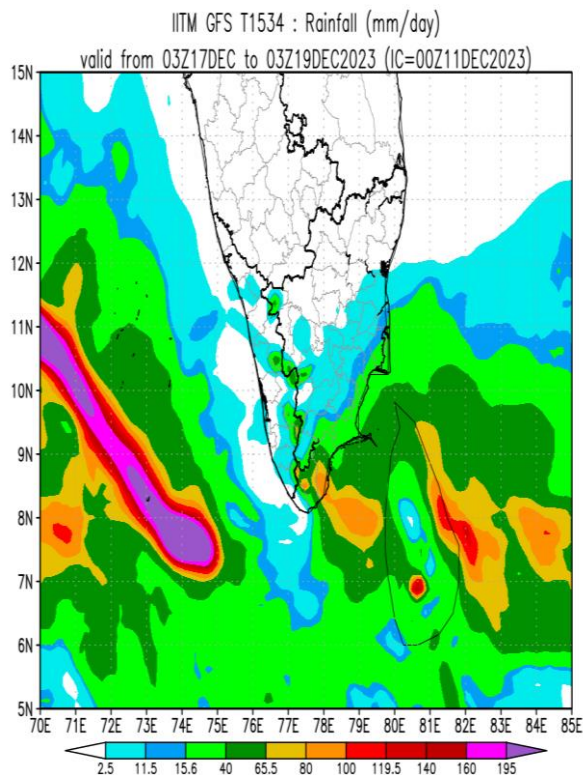
IMD_GPM

IMD-GPM: Rainfall (mm/day)
From 03Z17DEC to 03Z19DEC2023

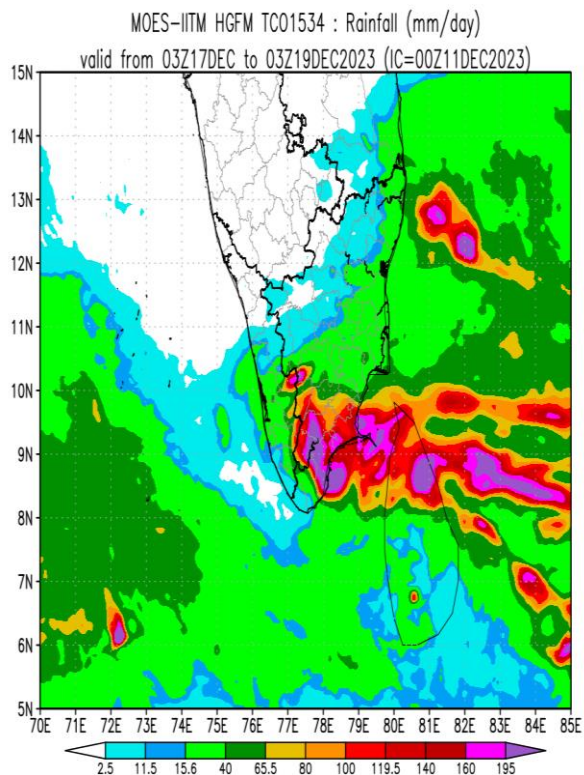


2days accumulated rainfall (mm/day) from 03Z17 Dec to 03Z19 Dec 2023

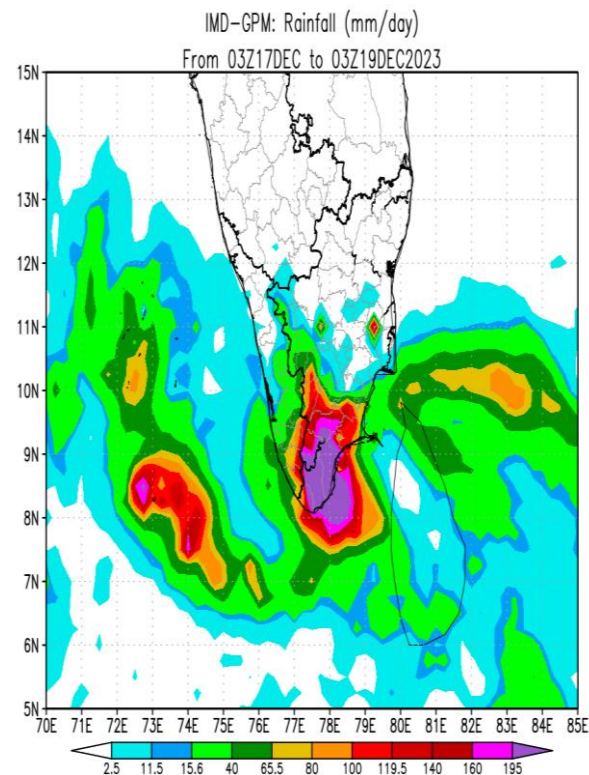
GFS_T1534



TCO_1534



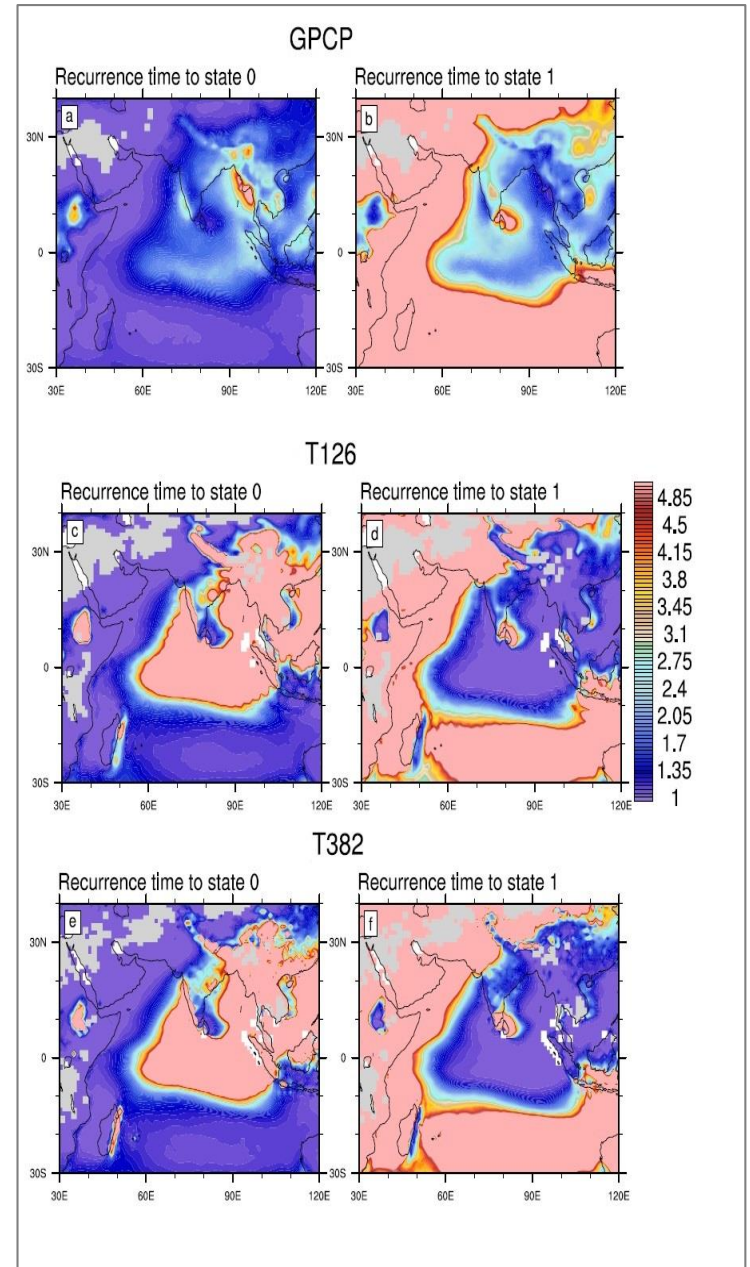
IMD_GPM



What else Markov Model convey?

Steady state probabilities calculation

$$\begin{bmatrix} S_0 & S_1 \end{bmatrix} \begin{bmatrix} p_{00} & p_{01} \\ p_{10} & p_{11} \end{bmatrix} = \begin{bmatrix} S_0 & S_1 \end{bmatrix}$$
$$T_i = \frac{1}{S_i}$$



Mean recurrence time

Common issue in most CMIP model

Model Description	CFSv2 T126	CFSv2T382
Truncation	126	382
Convective Parameterization	Simplified Arakawa Schubert (Pan and Wu, 1995)	Simplified Arakawa Schubert (Pan and Wu, 1995)

The tropical atmosphere does not obey CQE on temporal scales of day and shorter (Zhang, 2003)

Convective quasi-equilibrium (CQE)

$$\frac{\partial CAPE}{\partial t} = \left(\frac{\partial CAPE}{\partial t} \right)_{\text{largescale}} + \left(\frac{\partial CAPE}{\partial t} \right)_{\text{convection}}$$

$$\left(\frac{\partial CAPE}{\partial t} \right)_{\text{largescale}} \approx - \left(\frac{\partial CAPE}{\partial t} \right)_{\text{convection}}$$

$$dCAPE$$

$$= CAPE(\text{ at time } t + 1) - CAPE(\text{ at time } t) \left[\frac{J}{kgday} \right]$$

Arakawa and Schubert, 1974

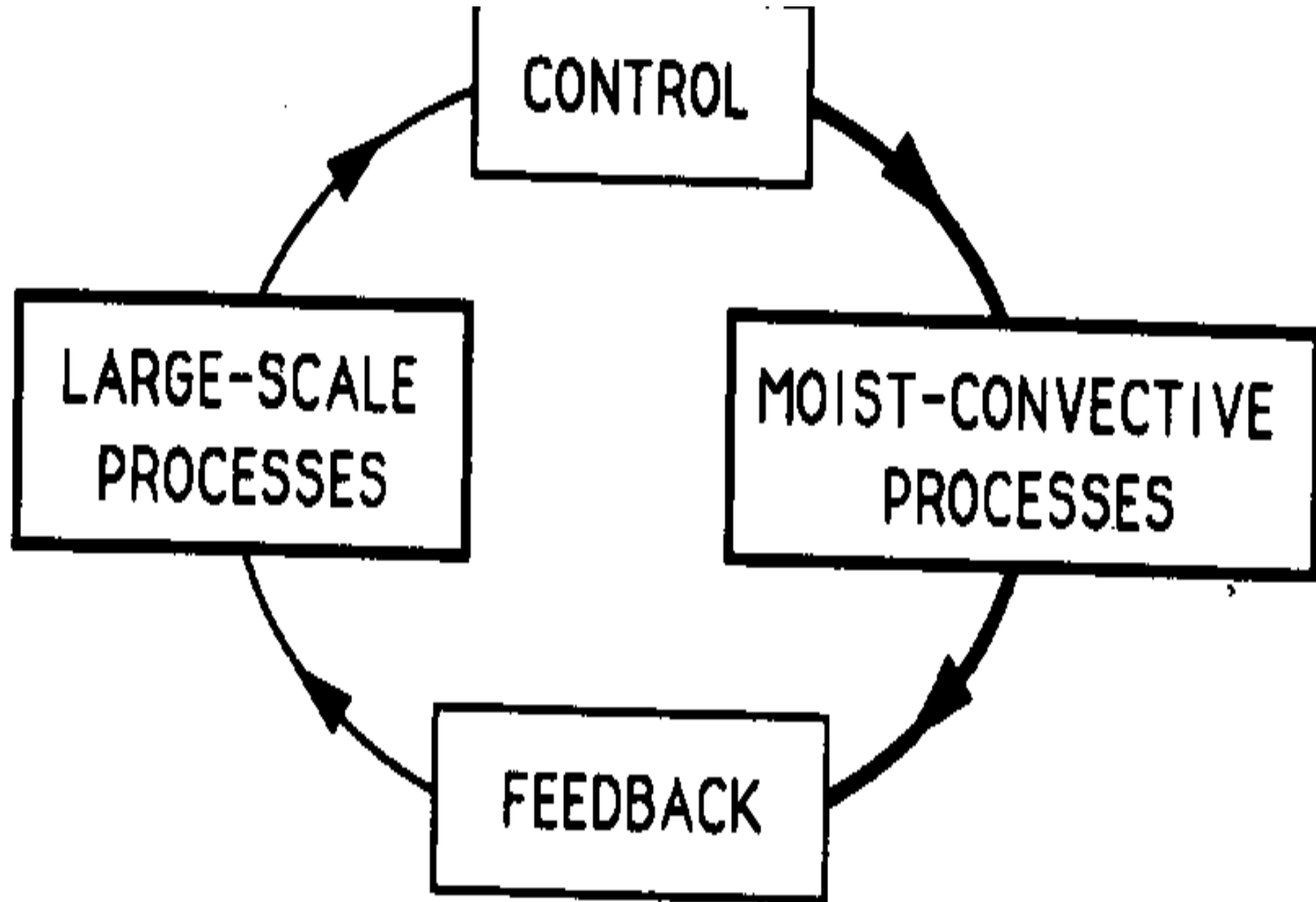
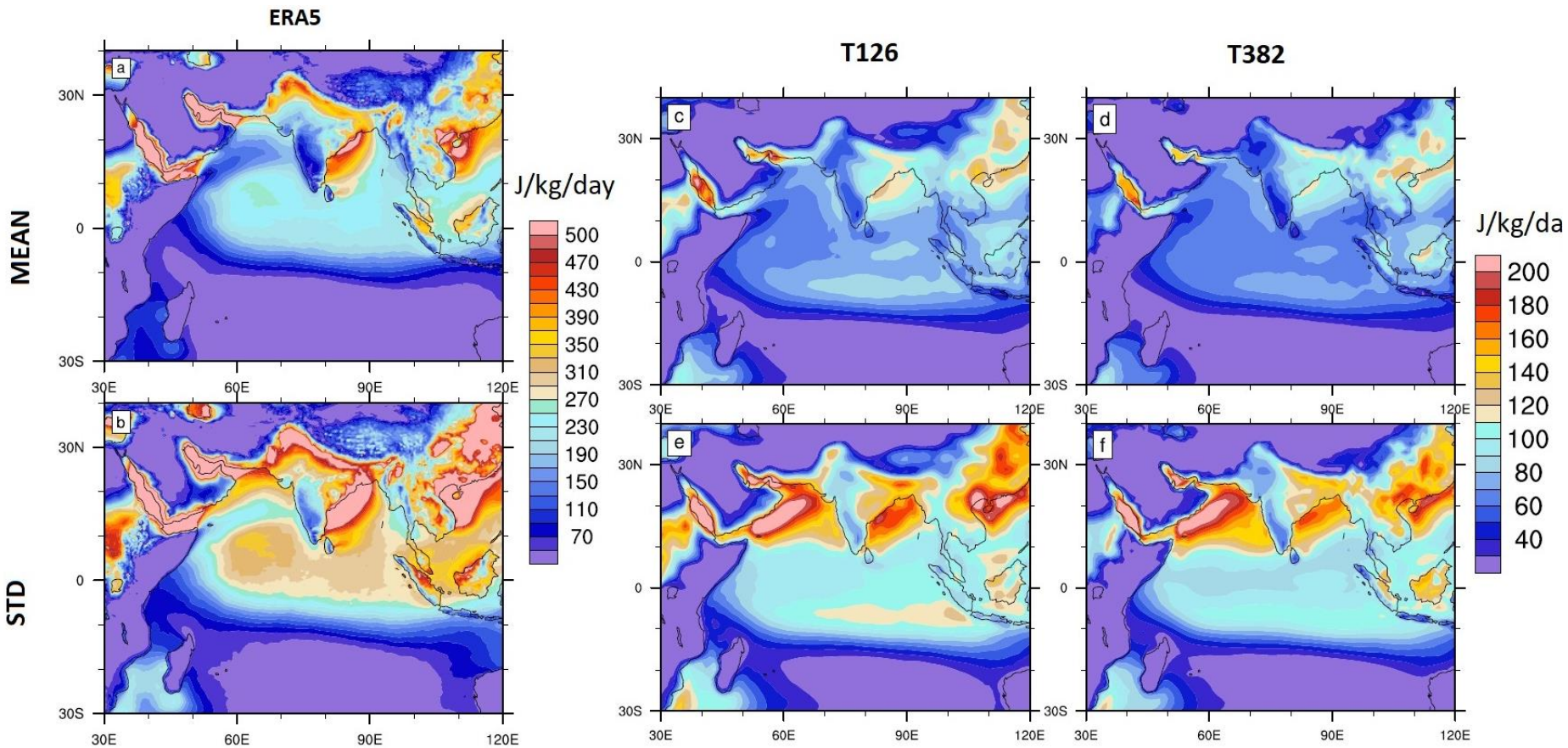


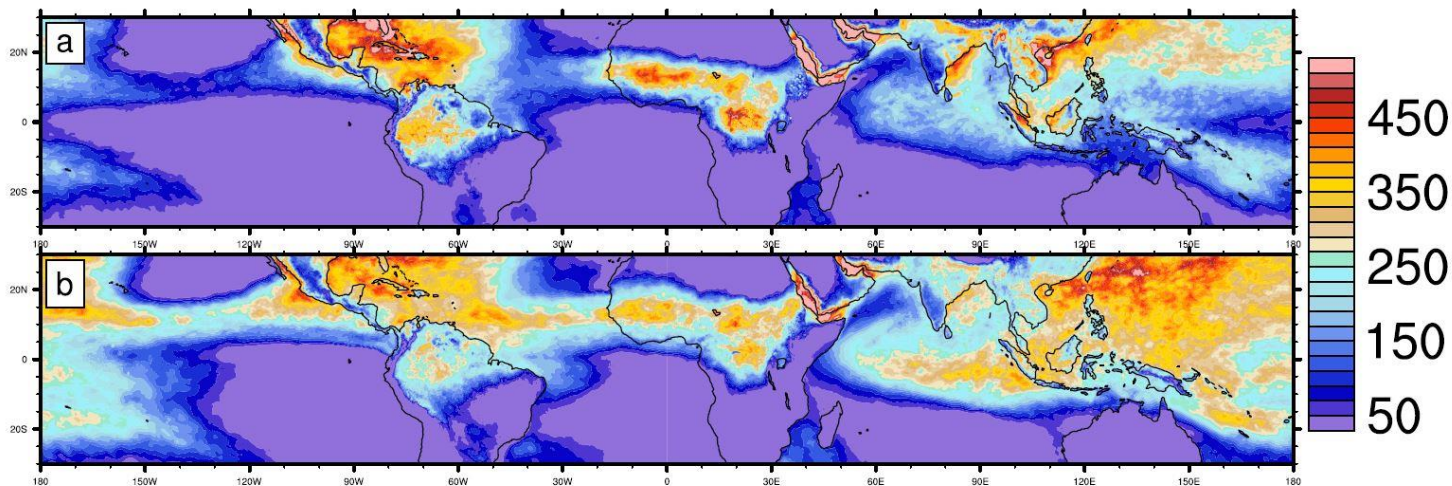
FIG. 1.1. A schematic figure showing the interaction between large-scale and moist-convective processes.

Convective quasi-equilibrium in CFSv2 models

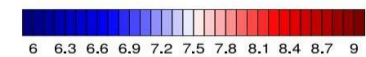
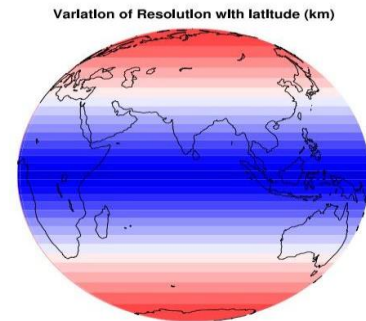
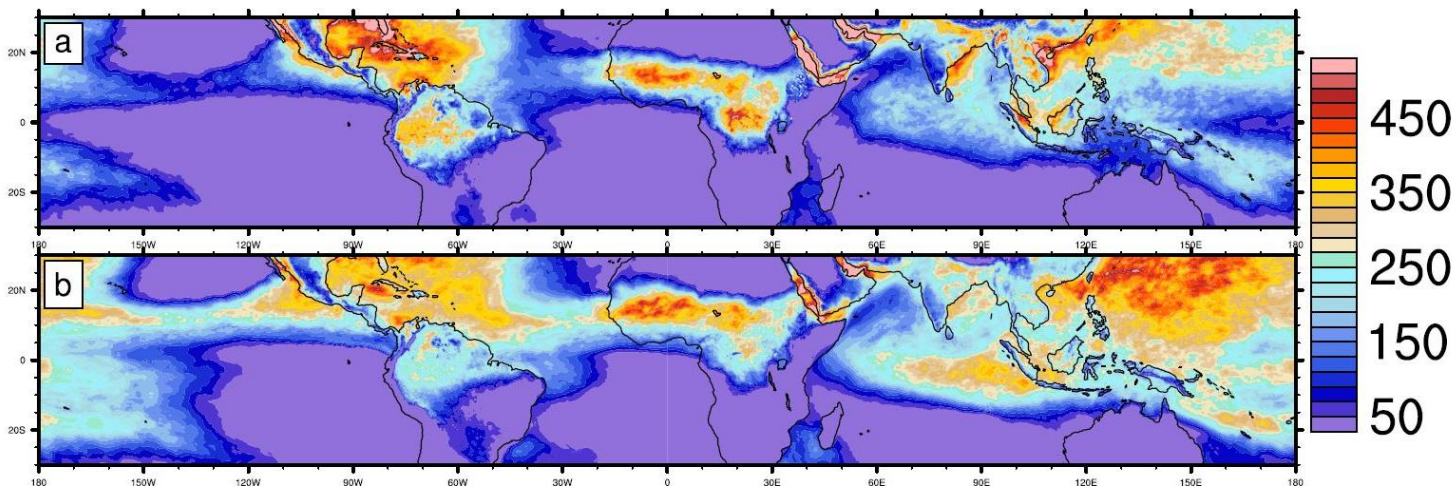


Mean of dCAPE ERA-5 & TCO-day1

(a) ERA-5
(b) TCO_1534



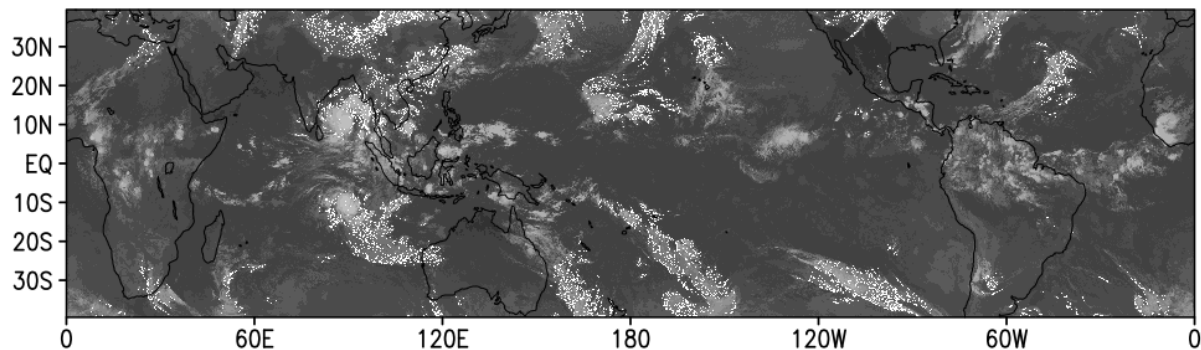
Mean of dCAPE ERA-5 & TCO-day3



Summary and Conclusion

- GFS forecast skill for 2023 appears to be marginally better than the season 2022
- GFS forecast captured Monsoon depression and also the tropical cyclone with good fidelity. However HGFM (Tco) shows better fidelity .
- The models tendency of producing more lighter rain persists (both Tco and GFS). Needs improvement. Possible through AI
- Skill of GEFS probabilistic forecast has improved for monsoon 2023. Typically Day 3 forecast skill of 2023 equivalent to Day 2 of 2022.
- Extreme Forecast Index and probability of percentile provide better skill for extreme with longer lead time.
- Tco shows higher skill in longer lead for Heavy rain forecasts and tropical cyclone forecasts and mostly resolves the spurious orographic rainfall issue.

Observation 00Z08MAY2022
Brightness Temperature (K)



TC ASANI

MOES-IITM HGFM TCO-1534 Forecast valid for 00Z08MAY2022 (IC=00Z07MAY2022)
Brightness Temperature (K)

Thank You !

