GEFS Based Ensemble Products in Medium Range

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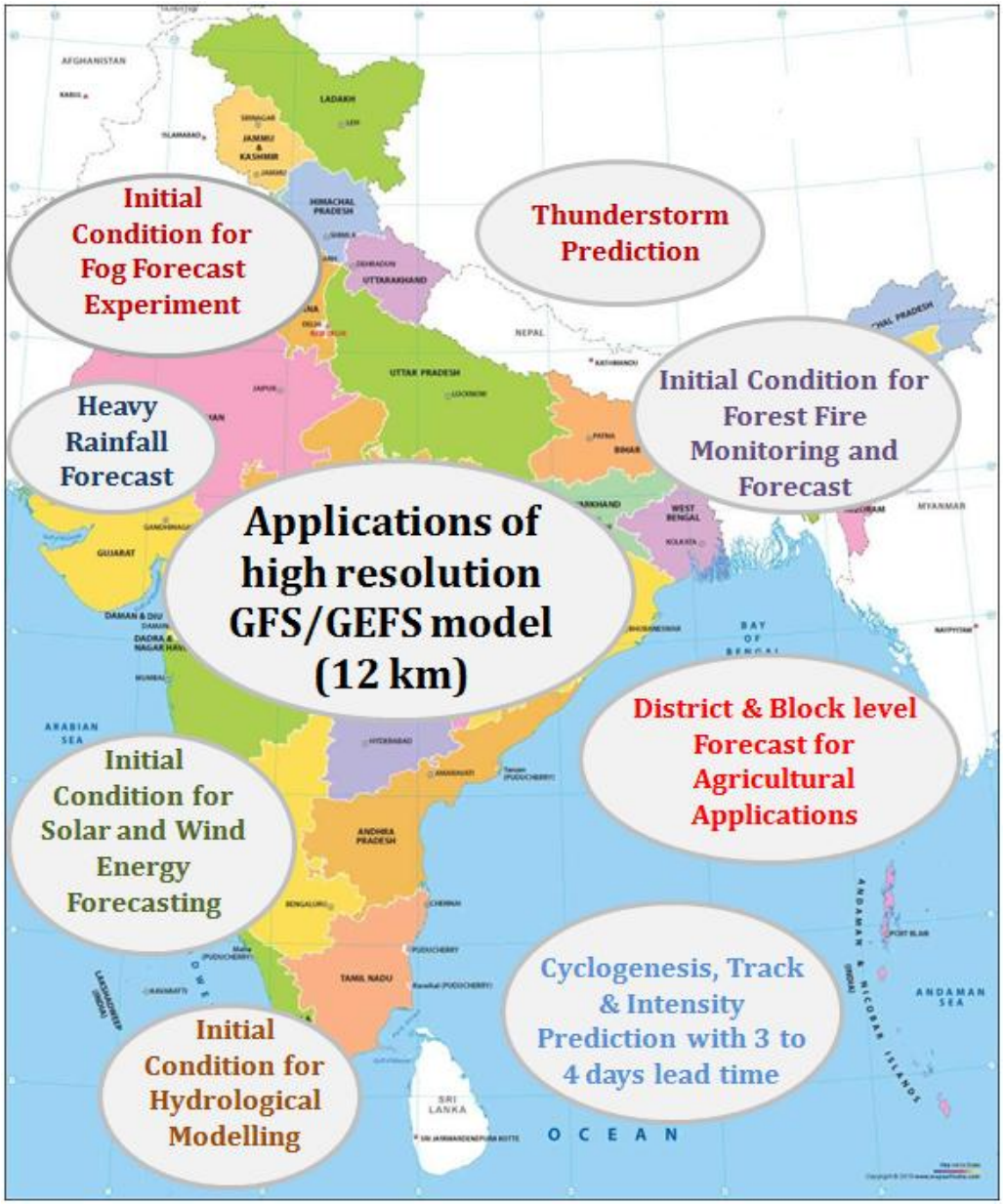
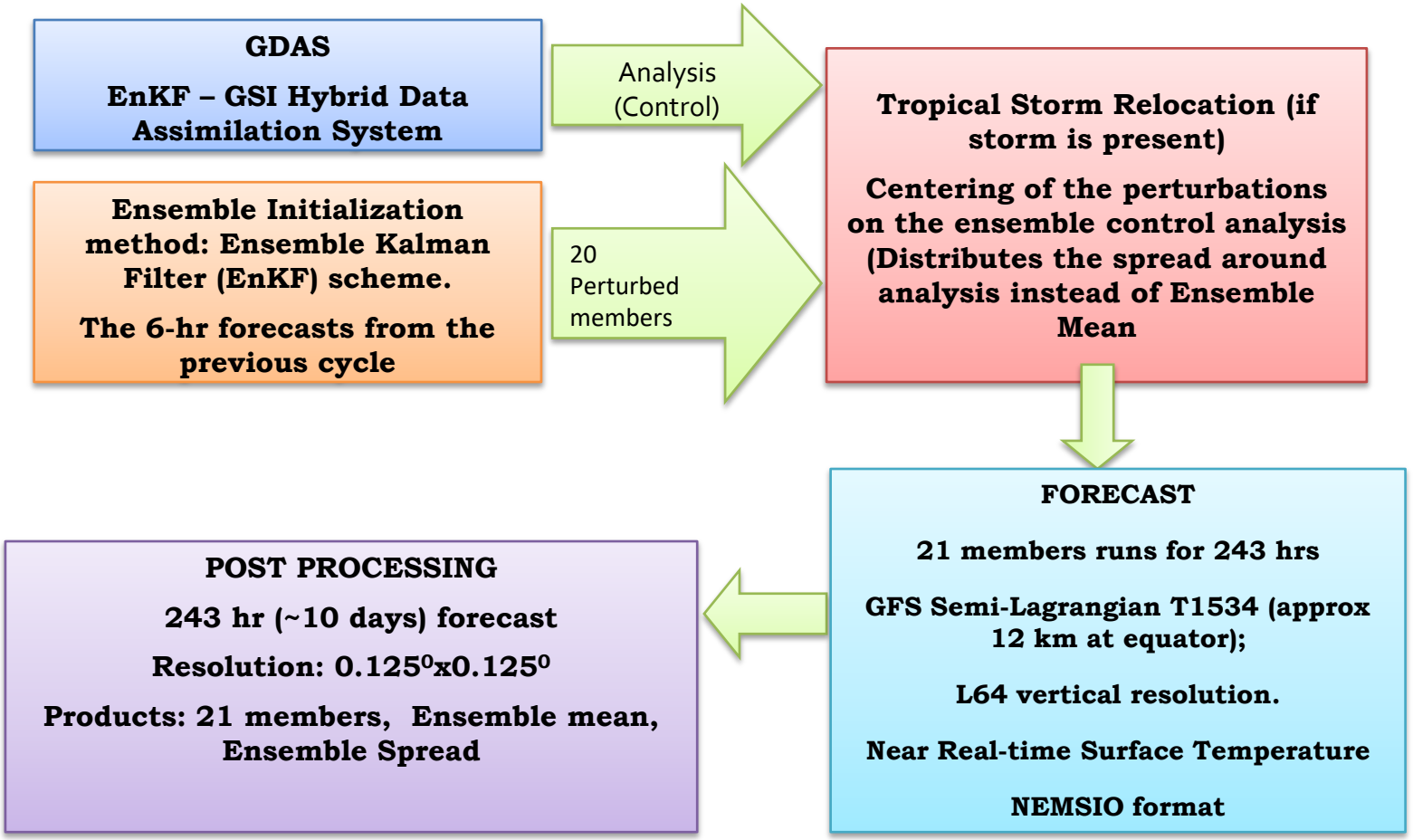
Outline

- About the GEFS Modeling System
- GFS/GEFS based products
- Fidelity of GEFS for synoptic weather systems (Tropical Cyclone and Low Pressure Area)
- Events: Heat wave, Thunderstorm, extreme Rainfall
- Summary

Application of GFS/GEFS products over Indian region



GEFS T1534

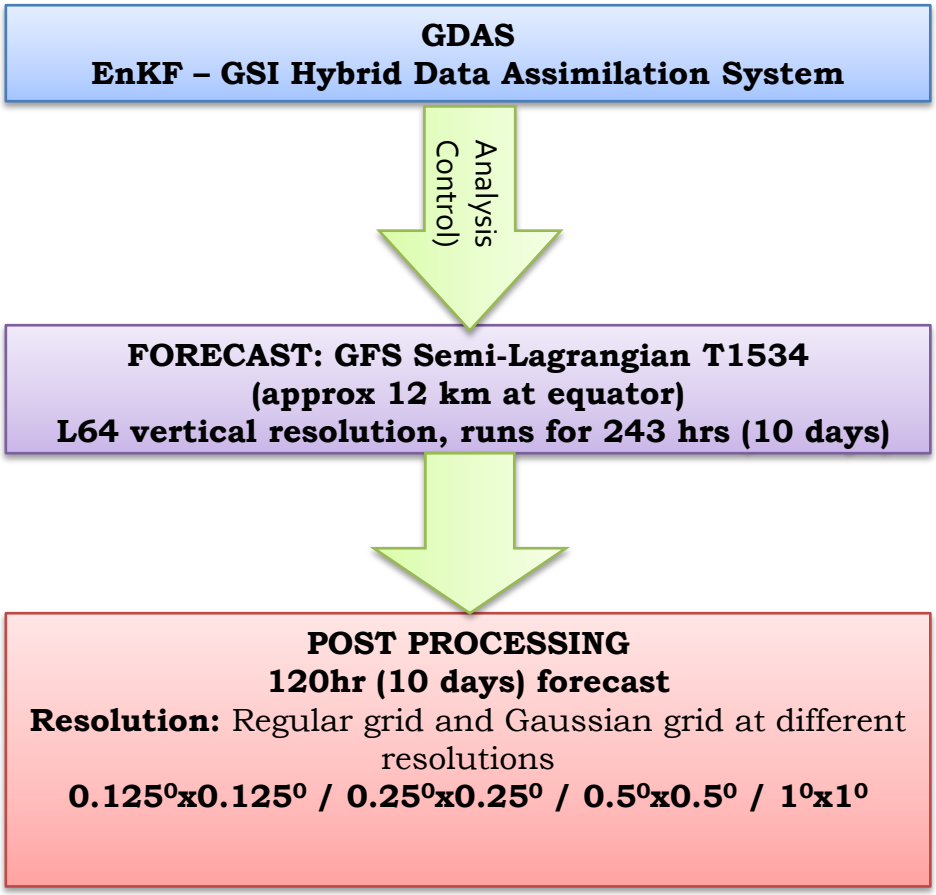


The GEFS is running operationally on Mihir HPCS at NCMRWF

The 21 member ensemble forecast takes nearly 90 minutes on 483 nodes

Plus, about 75 minutes for pre and post processing thus total of approximately 165 Minutes

GFS T1534 Version 14



The deterministic model (GFS v14) takes around 90 minutes on Cray XC-40 with 23 nodes.

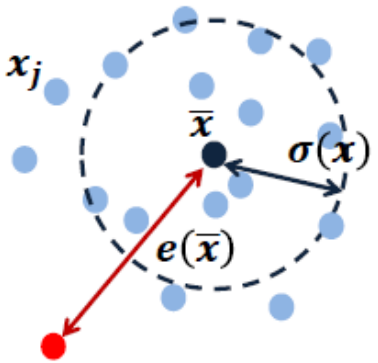
GFS/GEFS (T 1534) Model Physics for the operational setup

Physics	Description
Convection	Scale- & Aerosol-aware mass-flux shallow conv scheme Scale- & Aerosol-aware mass-flux deep conv scheme
Microphysics	Zhao-Carr-Moorthi microphysics scheme for Grid-scale Condensation, Evaporation and Precipitation
Gravity Wave Drag	Orographic gravity wave drag, mountain-drag and stationary convective gravity wave drag
PBL	New PBL Hybrid Eddy-diffusivity Mass-flux Scheme (Estimate Subgrid-scale vertical turbulent mixing in the PBL and above ; mass-flux approach to calculate the countergradient diffusion terms)
Radiation	LW and SW radiation parametrizations are optimized and modified (AER) by NCEP and uses unevenly distributed 140 g-points (quadrature) in 16-bands and 112 g-points in 14-spectral bands respectively. To represent statistically the unresolved sub grid cloud variability Monte Carlo Independent Column Approximation (McICA) is used. Cloud fraction for radiation is computed diagnostically from prognostic cloud condensate

Ensemble reliability

- In an **under**-dispersive ensemble,

$$e(\bar{x}) \gg \sigma(x)$$



Ensemble member

Ensemble mean

Observation

The small spread implies low uncertainty and hence, small errors:

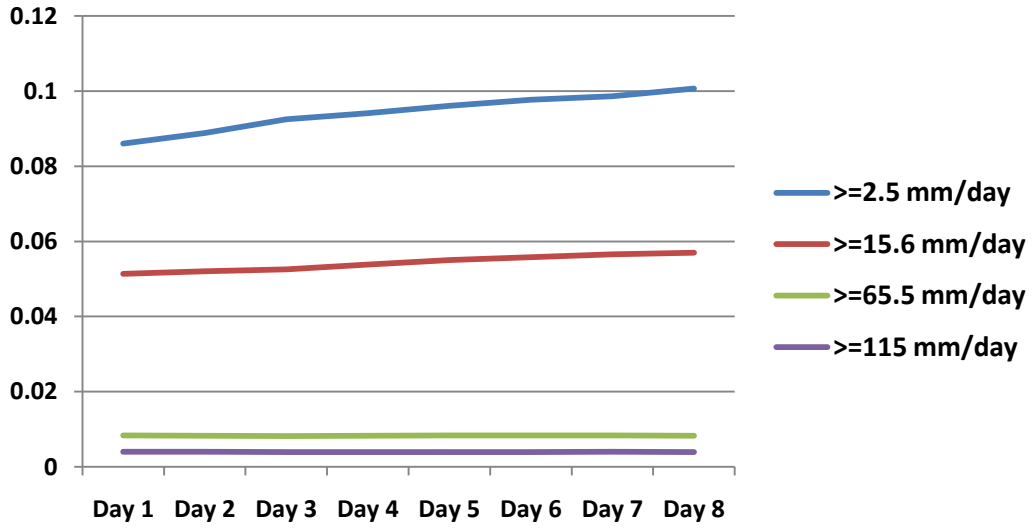
an "over-confident forecast"

Slide: Sarah-Jane Lock, ECMWF

Brier Score is a measures of mean squared error in probability space.
Being an error score, a value of 0 indicates perfect forecast.

$$BS = \frac{1}{n}\sum_{k=1}^{n}(y_k - o_k)^2$$

Brier Score for JJAS 2020 All India Land rainfall



The difference is between the forecast probabilities (y_k) and binary observations (o_k=1, event occurs and o_k=0, event does not occur).
The score ranges from 0 to 1 with 0 showing perfect forecasts.

Brier score is sensitive to the climatological frequency of an event
the more rare an event, the easier it is to get a good BS without having any real skill.

Reliability Diagram (JJAS Rainfall)

Measures agreement between predicted probabilities and observed frequencies

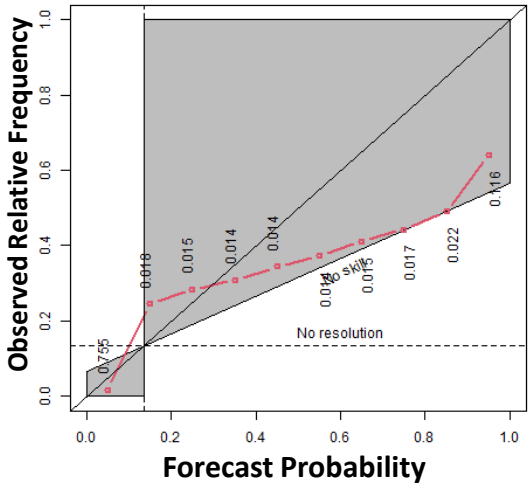
Diagonal indicates a perfect forecast

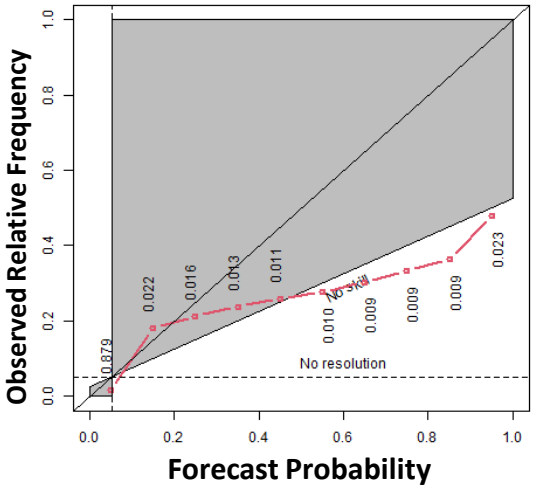
Threshold>=2.5 mm/day

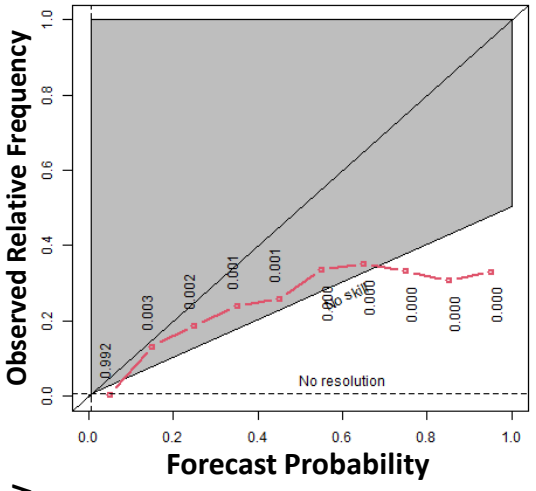
>= 15.6 mm/day

>= 65.5 mm/day

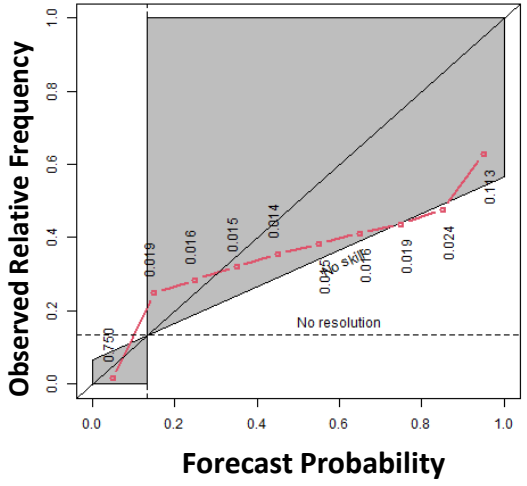
Day 1

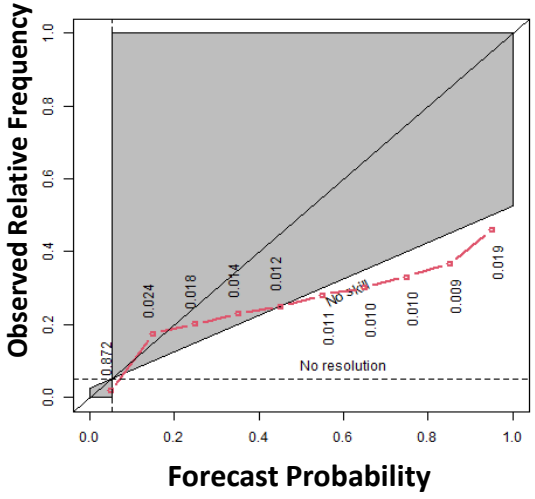


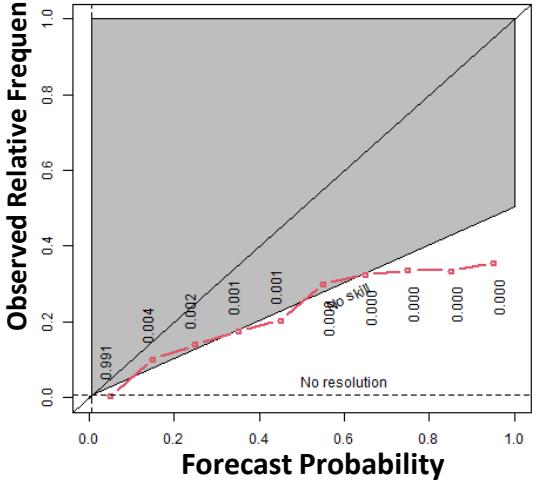




Day 2

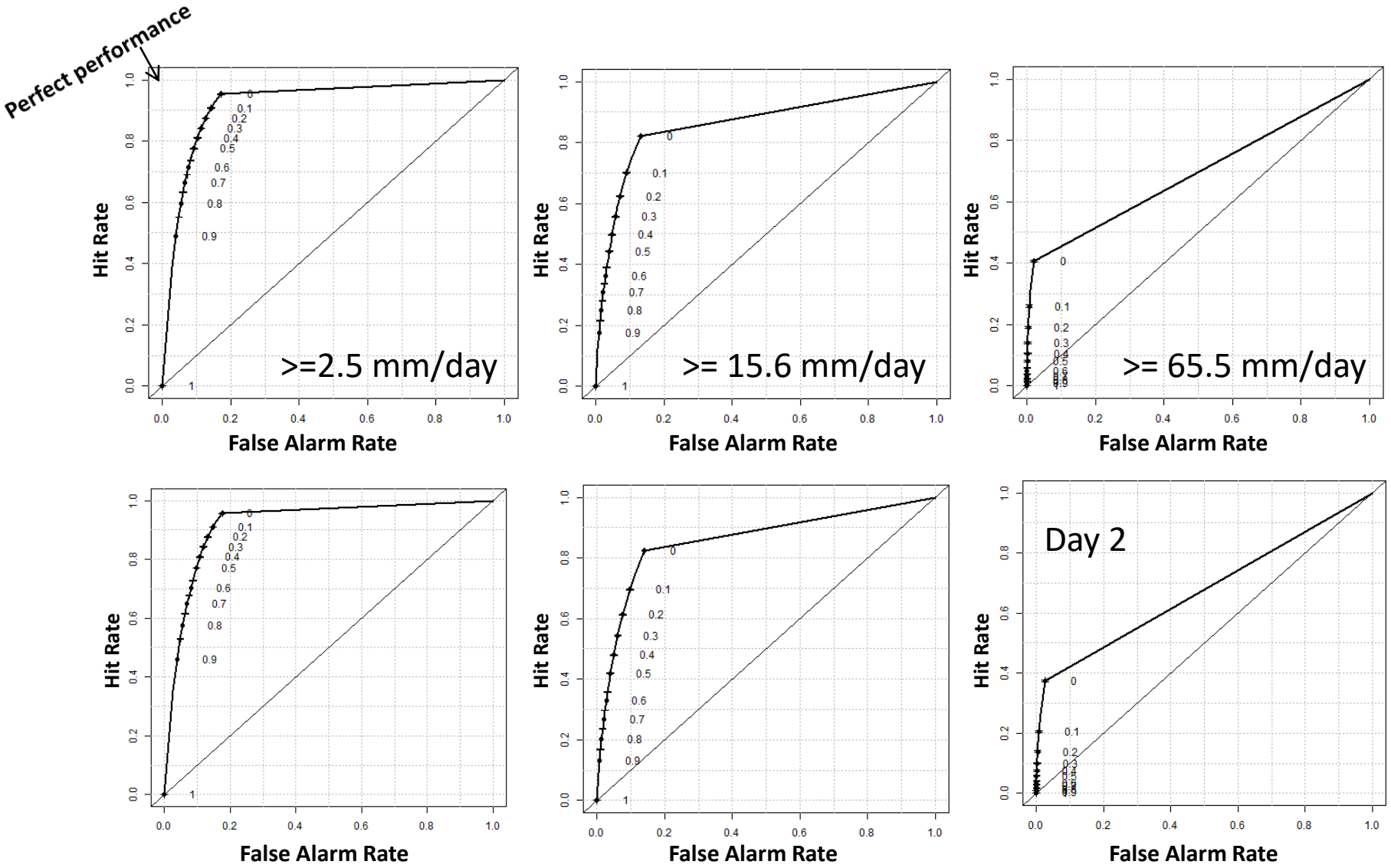






JJAS 2020 verification GEFS

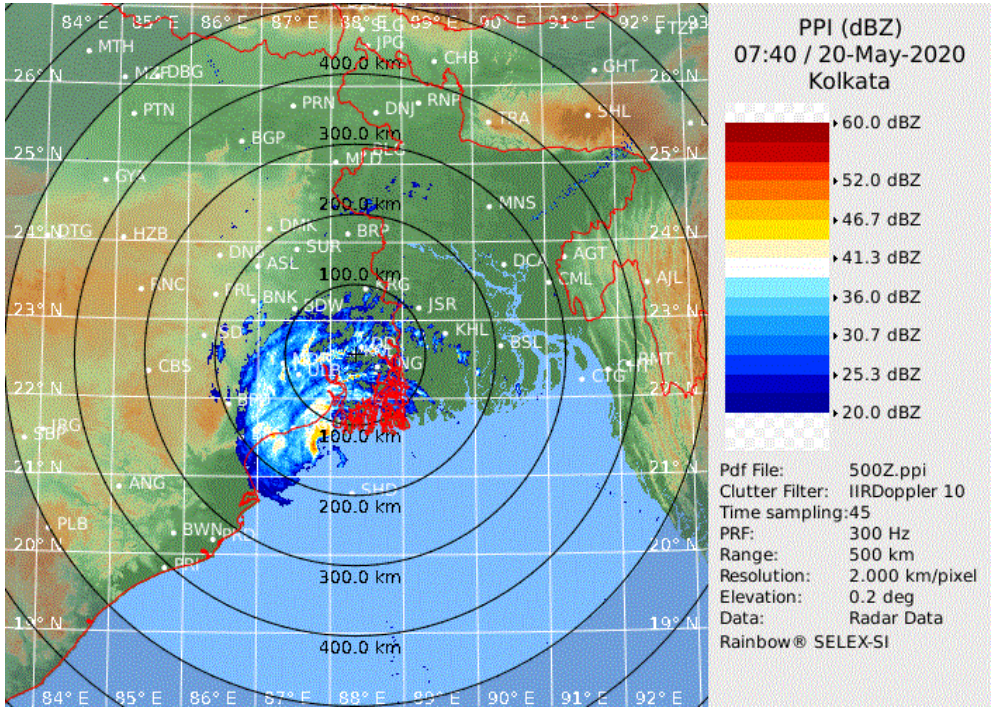
Relative Operating Characteristic (ROC): Measures discrimination. It is the Plot of hit rate against the false alarm rate using increasing probability thresholds to make the yes/no decision

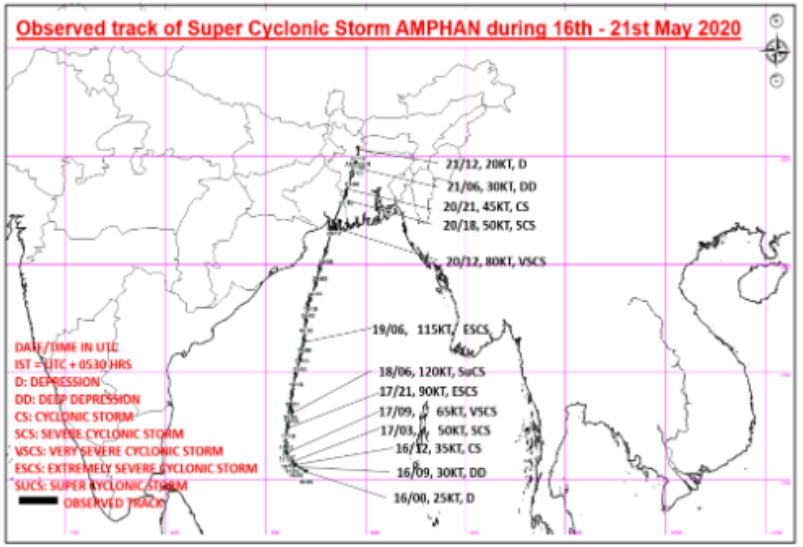


High resolution (high potential skill) for rainfall >=2.5 mm/day

Super Cyclonic Storm Amphan (16-21 May 2020)

The Summer Monsoon 2020 arrived over Andaman Sea on 17th May (5 days before the normal date, However its further advancement was hindered by the formation of SuCS AMPHAN over Bay of Bengal.





Observed track of SuCS 'AMPHAN' over the southeast Bay of Bengal May, 2020)

Originated as a LPA on 13th May

Concentrated into a depression on 16th May

It underwent Rapid Intensification and reached Super Cyclonic Storm Strength on 18th May.

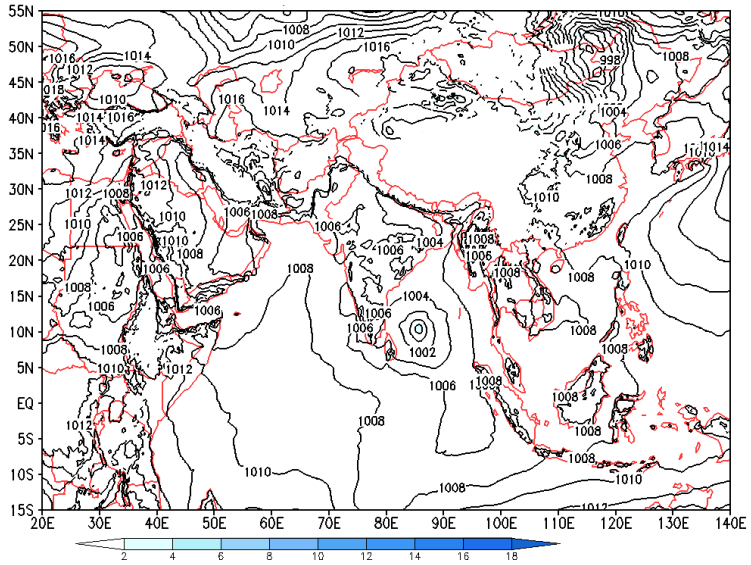
Weakened slightly and crossed West Bengal – Bangladesh coast as a VSCS on 20th May.

Source: **IMD**

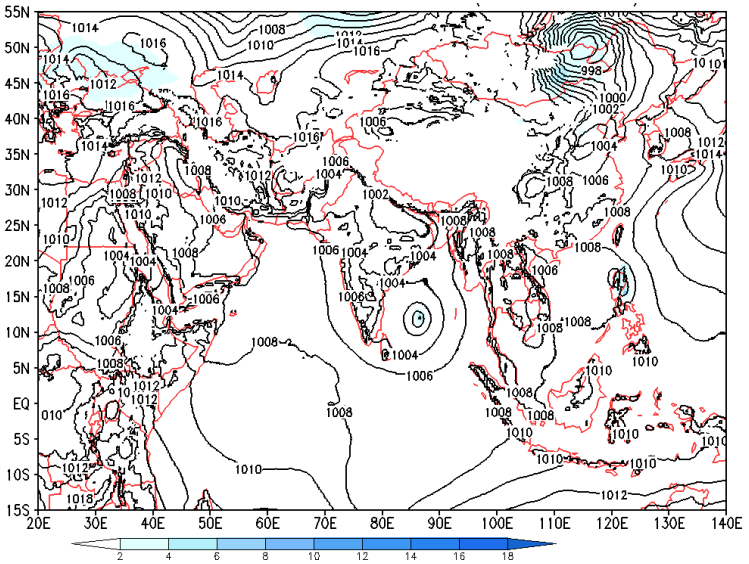
AMPHAN GENESIS

GEFS ENS mean (contour) and Spread (shaded) MSLP (hPa) valid for 16 May 2020

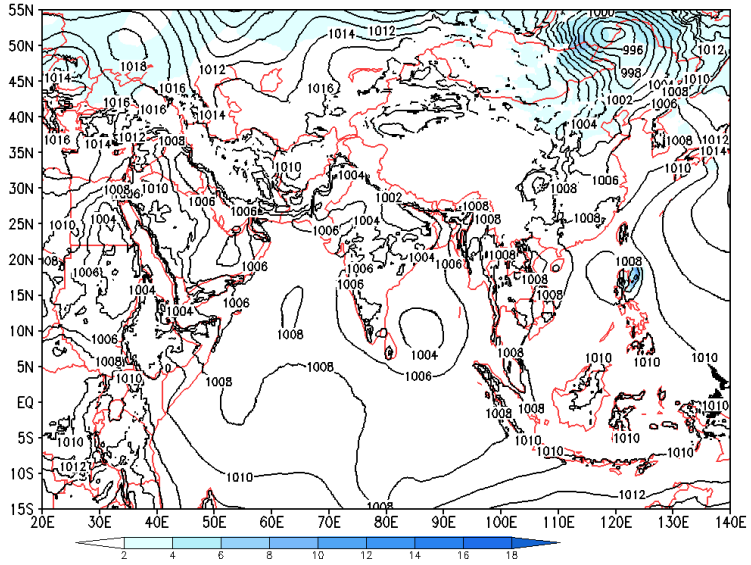
Analysis: 00Z 16 May 2020



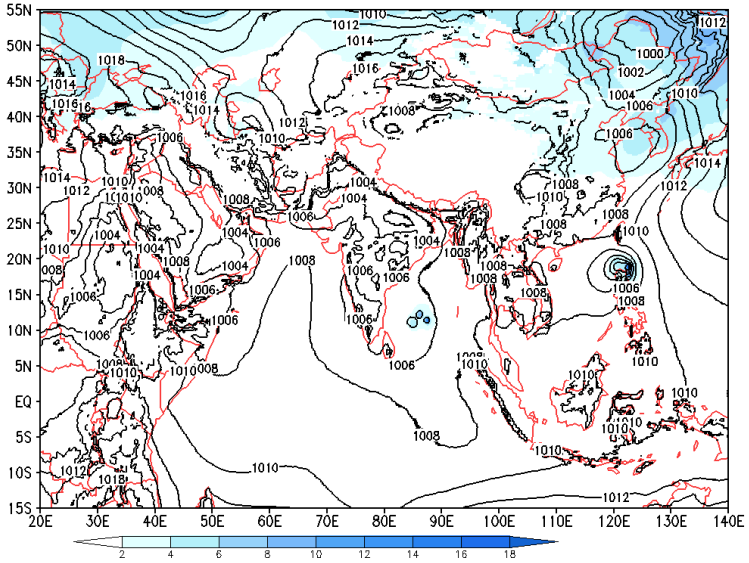
48 hr Forecast based on 00Z 14 May 2020



96 hr Forecast based on 00Z 12 May 2020



144 hr Forecast based on 00Z 10 May 2020



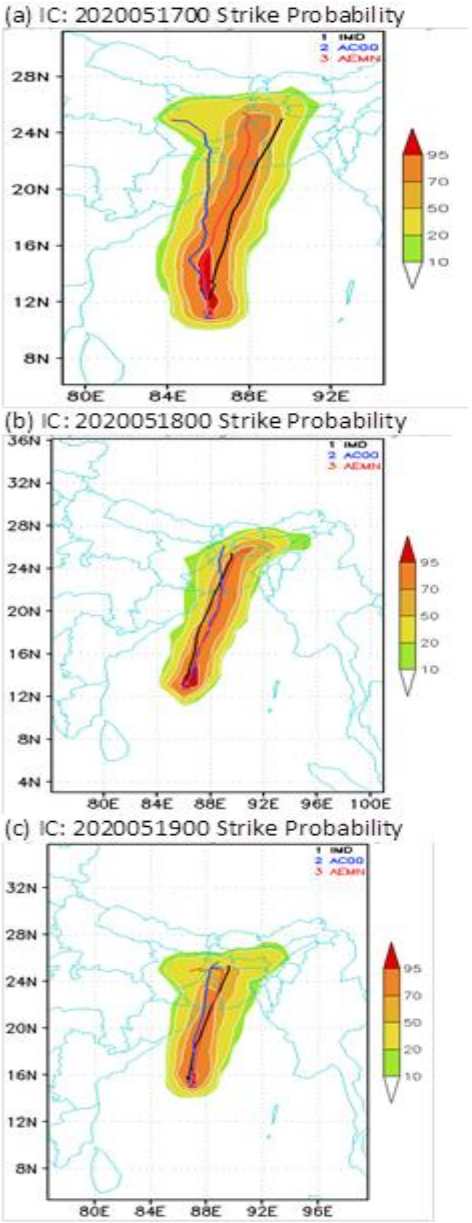
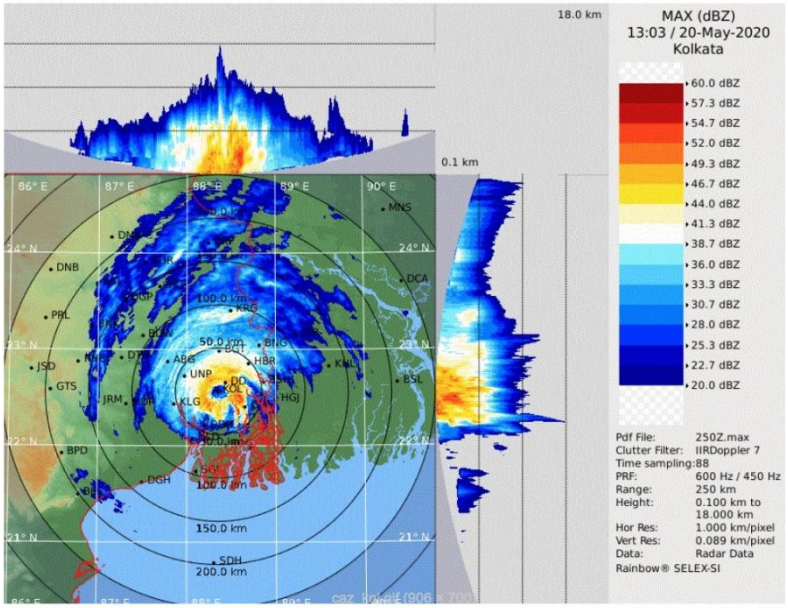
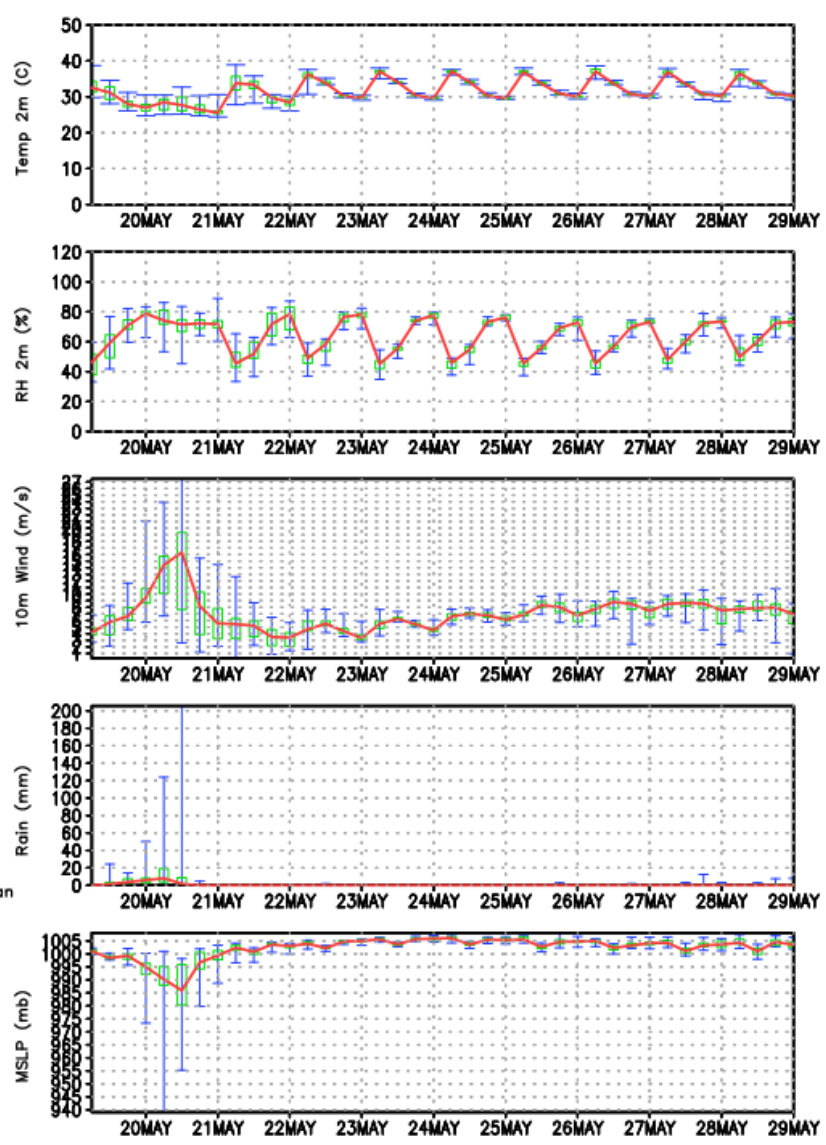


Figure 8: TC AMPHAN (a-c) strike probability, (d-f) Maximum Sustained Wind and Verification of the forecast of (g) track from all the ICs during the lifespan of the AMPHAN.





EPS Meteogram (EPSgram) is a probabilistic interpretation of the forecasts from the Ensemble Prediction System (EPS) for a given location. It displays the time evolution of the distribution of atmospheric variables in the ensemble forecast.

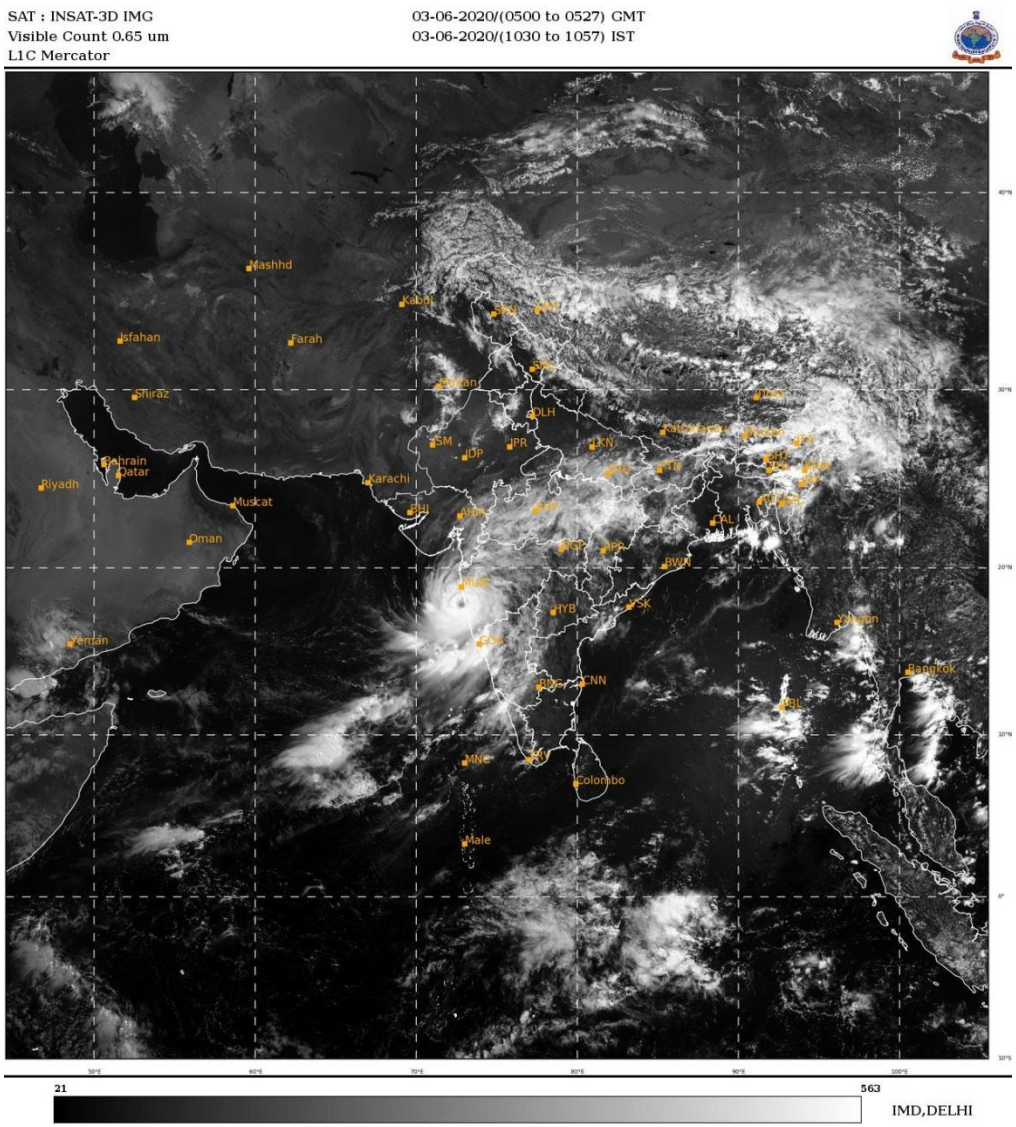
The red line is the median value from ensembles distribution

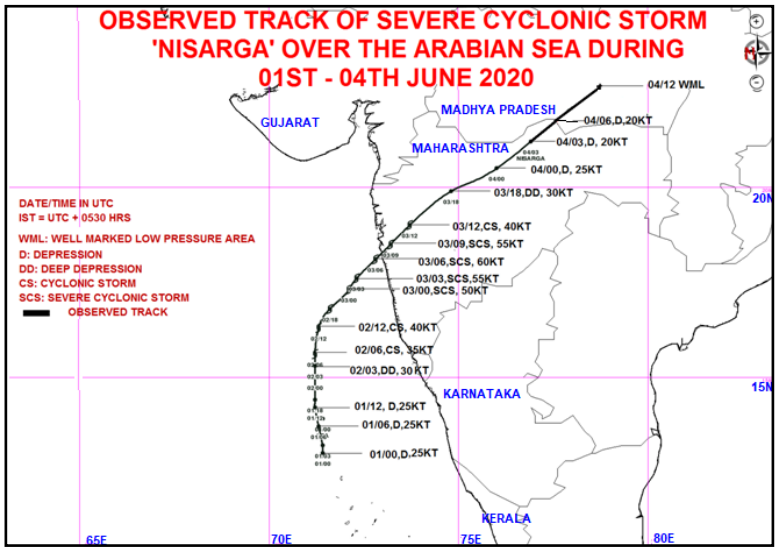
The top end of the blue line is the maximum value and lower end is the minimum value of the distribution

The green box shows the inner quartile range that is the values within bottom 25% and top 75% of the distribution.

AMPHAN crossed West Bengal – Bangladesh Coast across Sundarbans as VSSC at 21.65°N and 88.3 °E and between 10-12UTC (15:30 -1730 IST) of 20May 2020

Severe Cyclonic Storm Nisarga (1-4 June 2020)

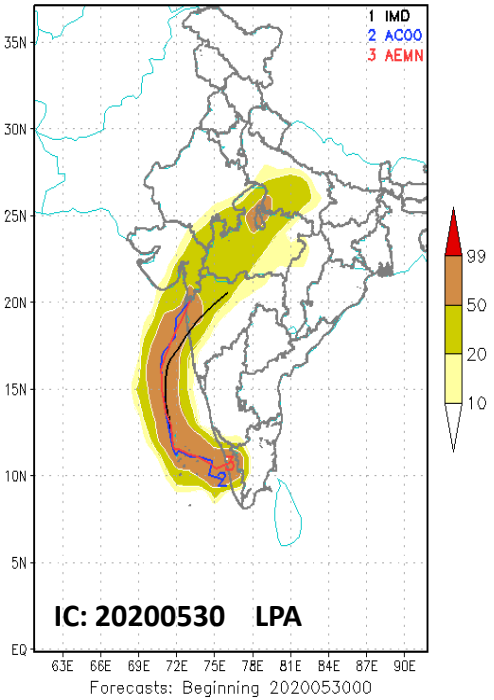


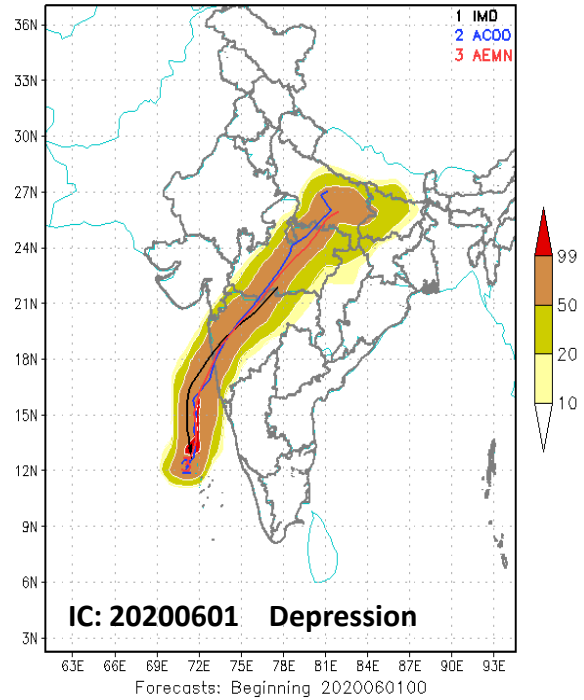


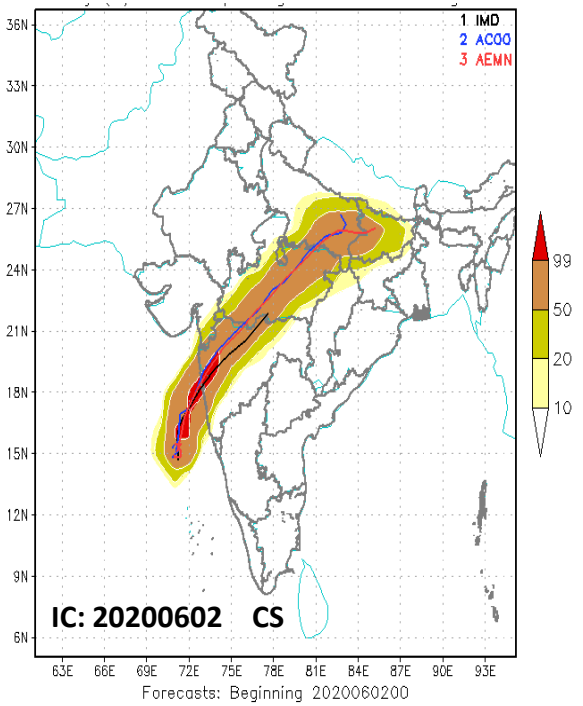
- It originated over Arabian Sea as a LPA on 31st May
- Concentrated into a Depression on 1st June
- Named as Nisarga on 2nd June.
- clockwise recurving track, mainly Steered by an mid-upper level anticyclone to the east of the system
- crossed Maharashtra coast close to south of Alibag as a SCS with a maximum sustained wind speed of 110-120 kmph gusting to 130 kmph during 0700-0900 UTC of 03rd June.

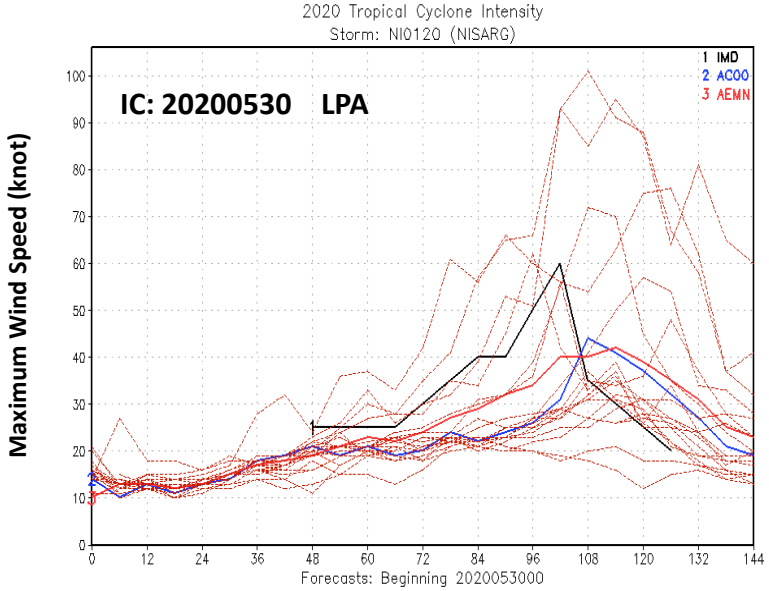
Source: **IMD**

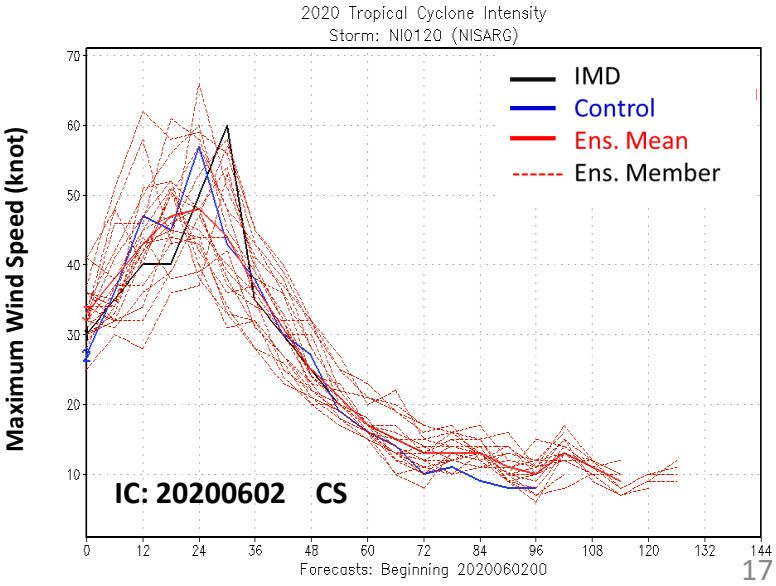
Severe Cyclonic Storm Nisarga Strike Probability







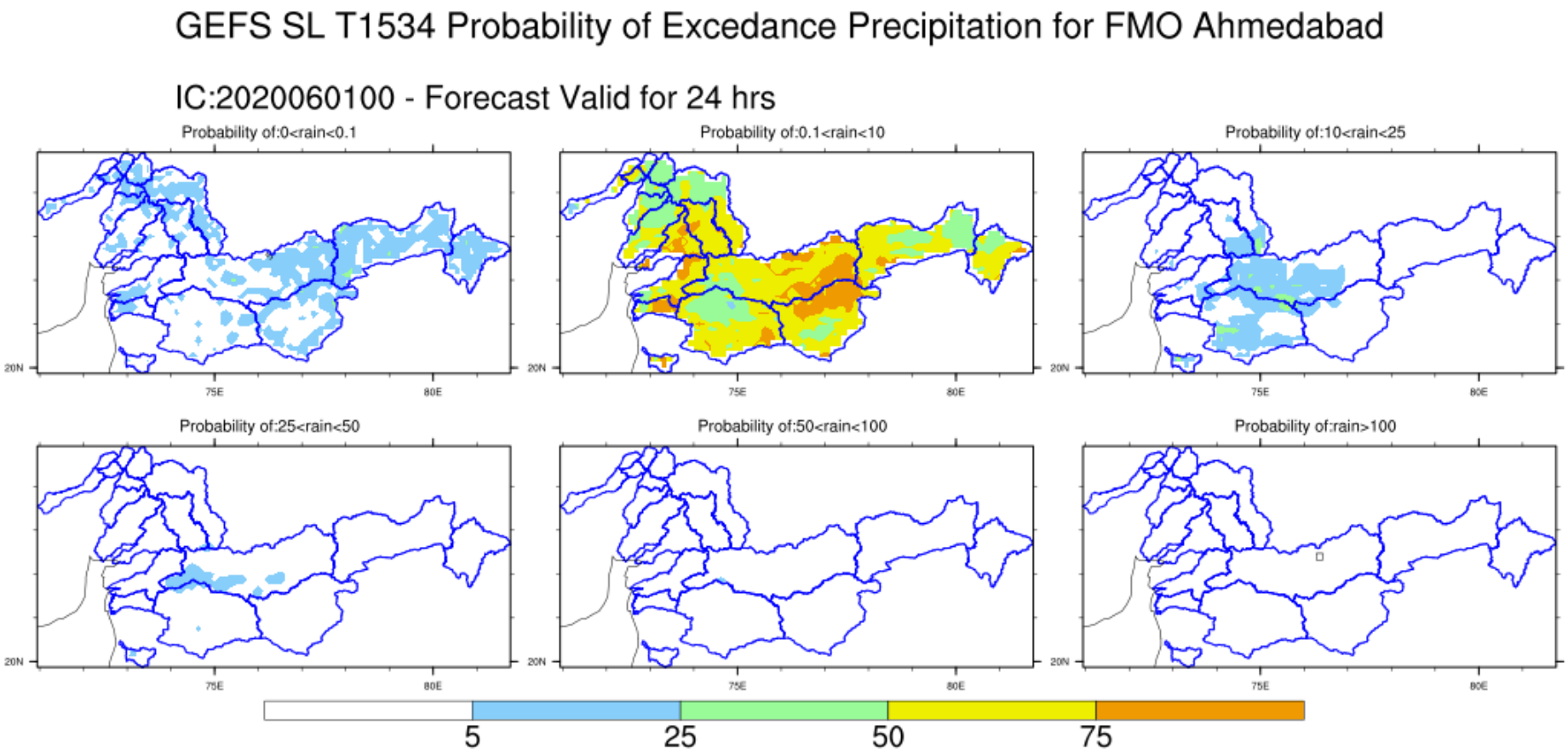




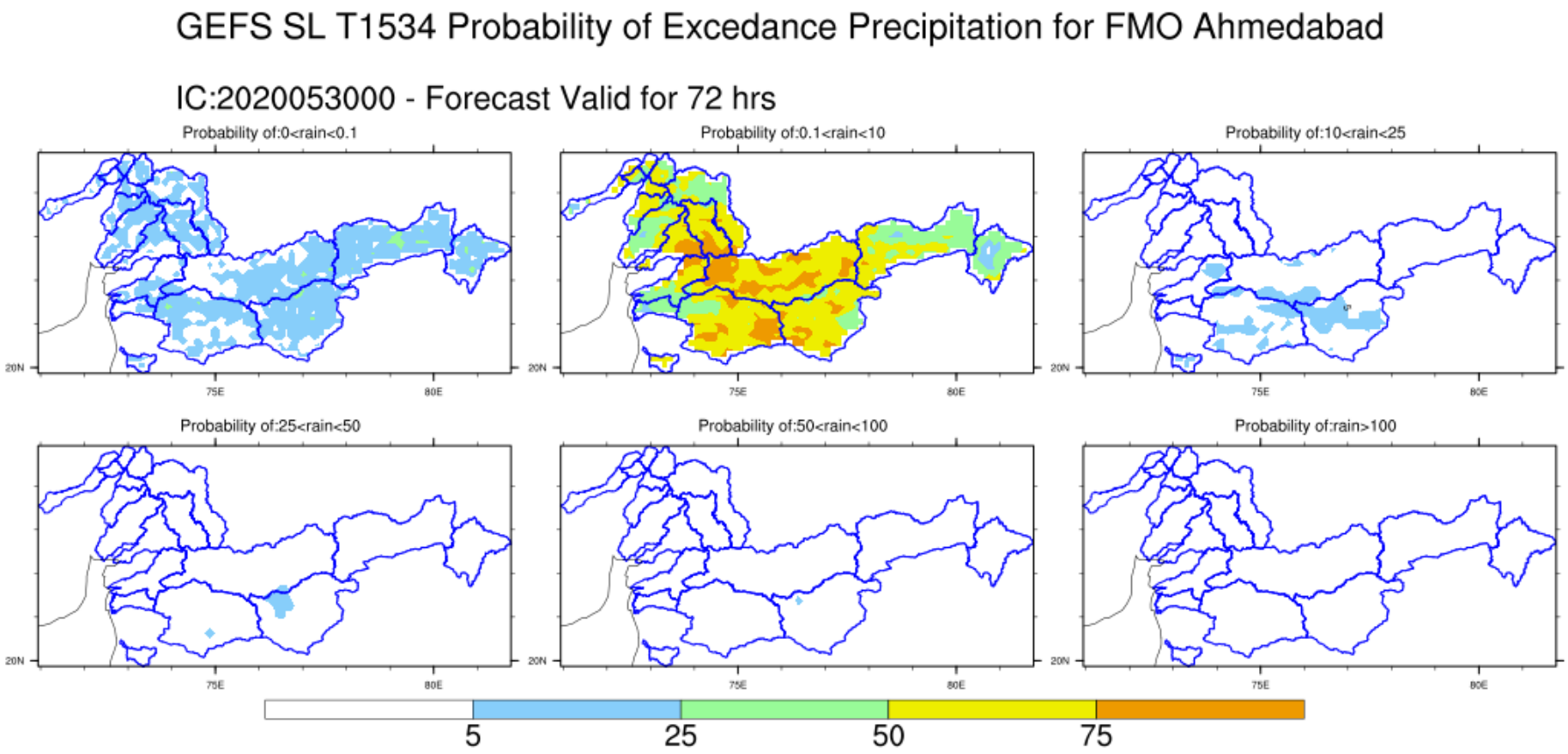
Landfall Errors for Cyclone Nisarga (From GEFS mean and control)

IC	Lat	Lon	landfall error(km)	landfall time	lat	lon	landfall error(km)	landfall time
	GEFS Mean				GEFS Control			
IMD	**18.35**	**72.95**	**--**	**bet 07-09Z03June**				
IC:00Z30May	21.27	72.09	**335**	06Z04June	19.57	72.71	**138**	bet 18-00Z 04June
IC:00Z31May	21.64	72.49	**365**	06Z04June	21.15	72.63	**310**	00Z04june
IC:00Z01June	18	73.05	**40**	bet 00-06Z03June	17.66	73.09	**77**	bet 00-06Z03June
IC:00Z02June	18.48	72.9	**15**	bet 00-06Z03June	18.73	72.84	**44**	bet 00-06Z03June

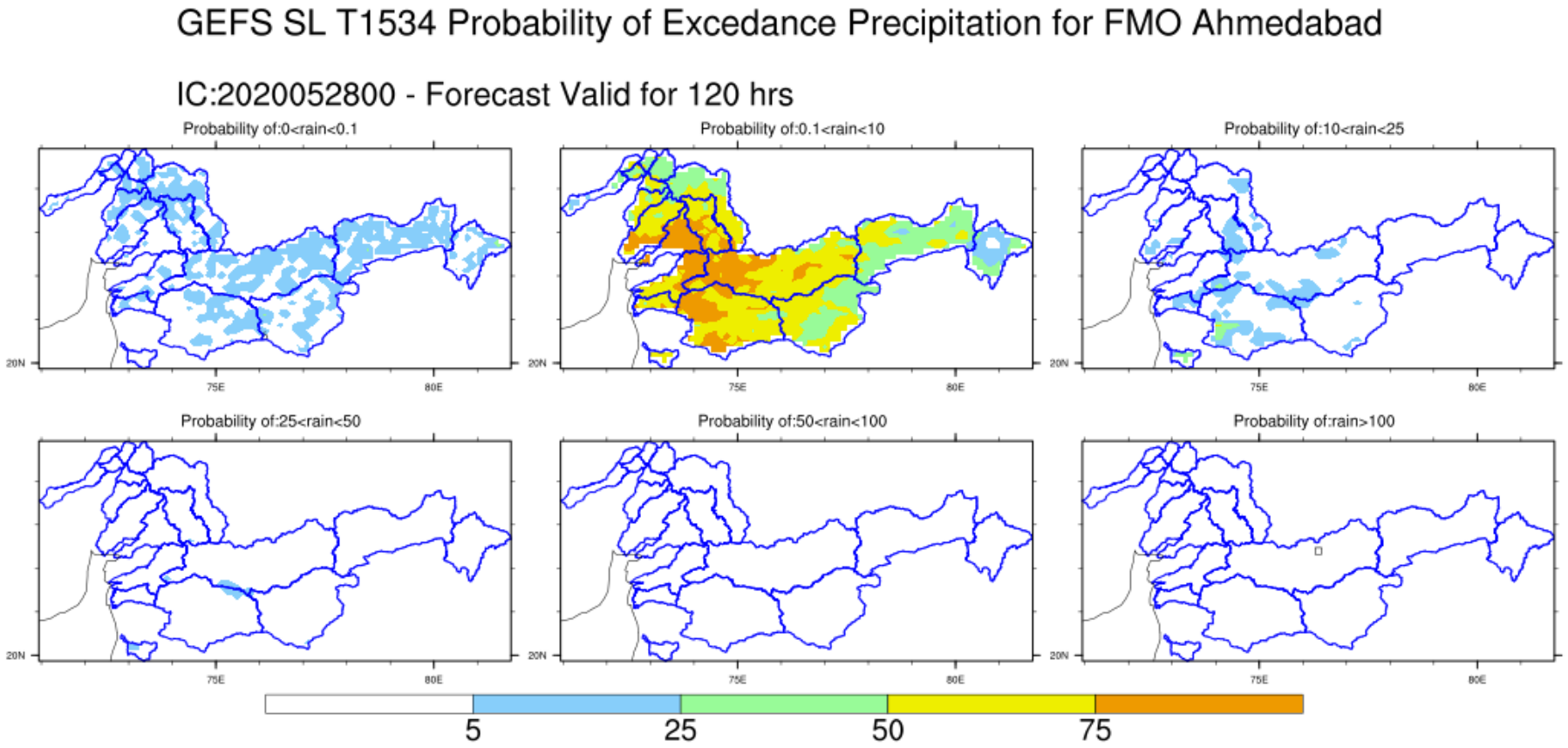
Day 1 forecast valid for 2nd June



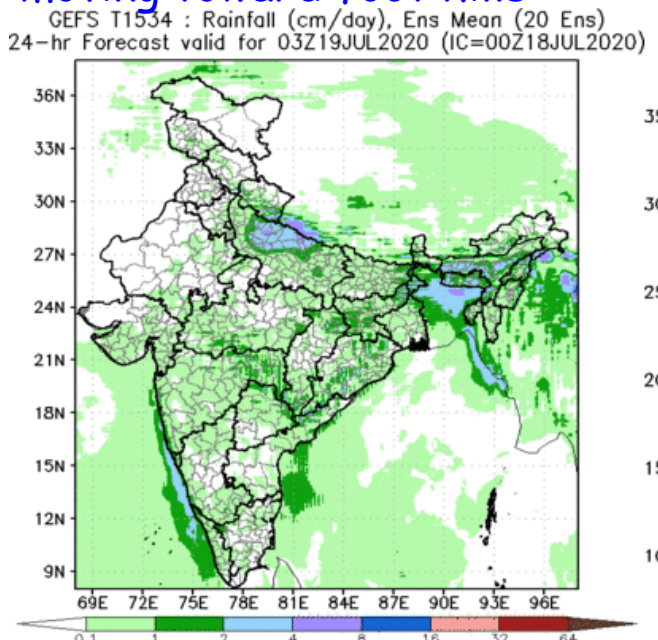
Day 3 forecast valid for 2nd June

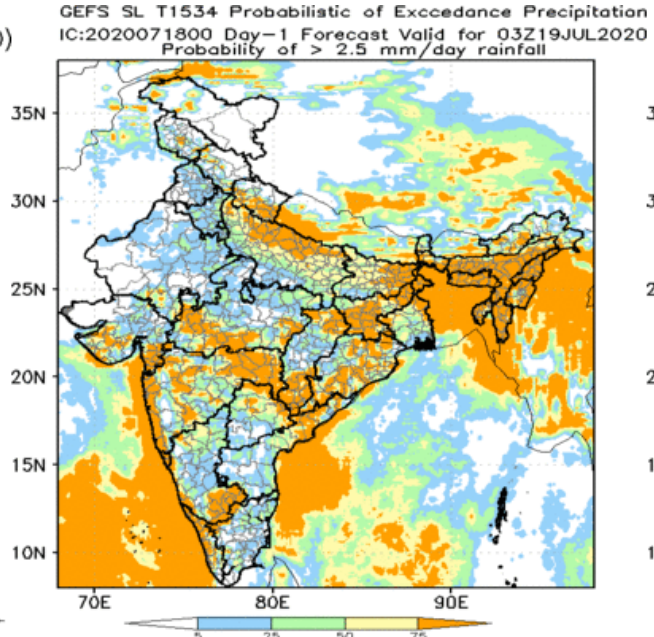


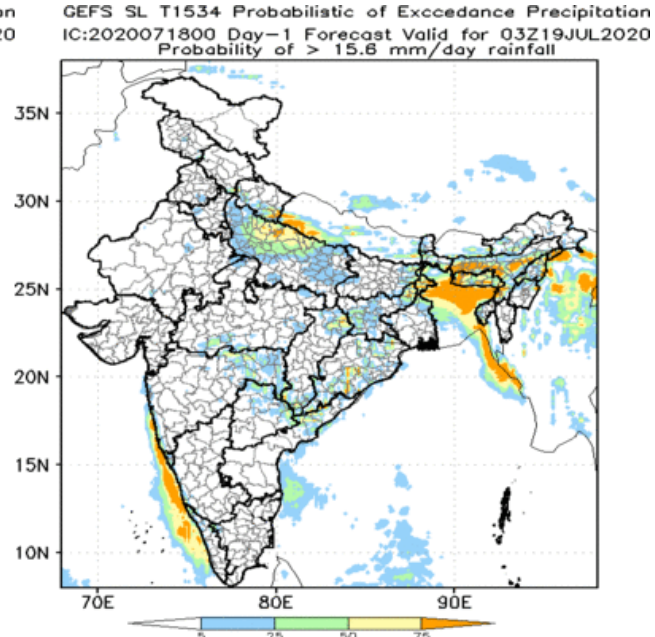
Day 5 forecast valid for 2nd June

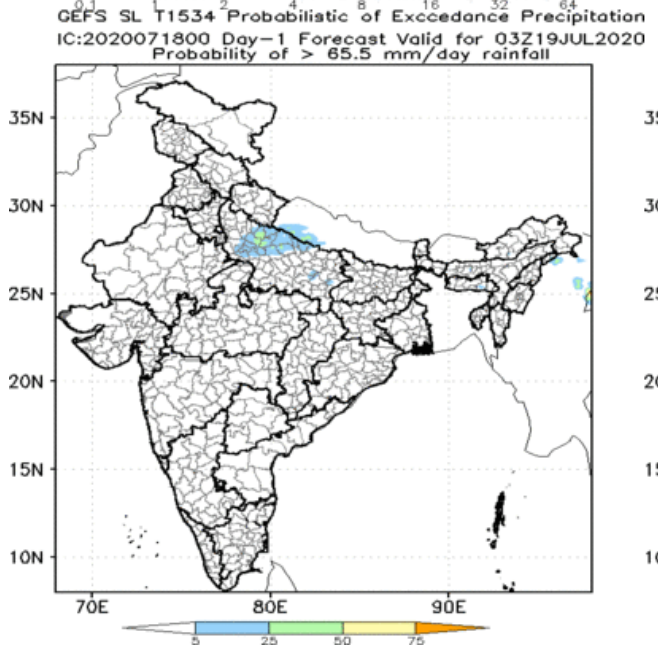


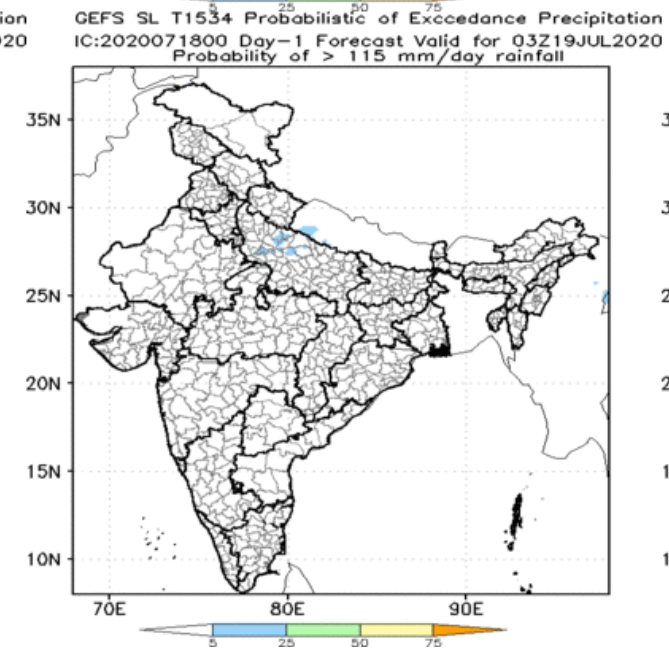
GEFS ensemble mean rainfall prediction and probability of rain with threshold 2.5, 15.6, 65.5, 115 and 195 mm day^{-1} based on 18 July 0000UTC IC. Monsoon trough moving toward foot hills

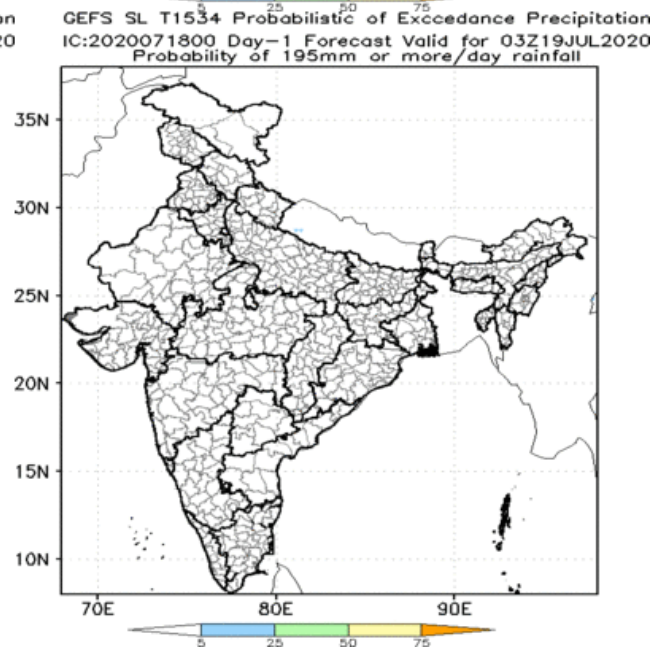




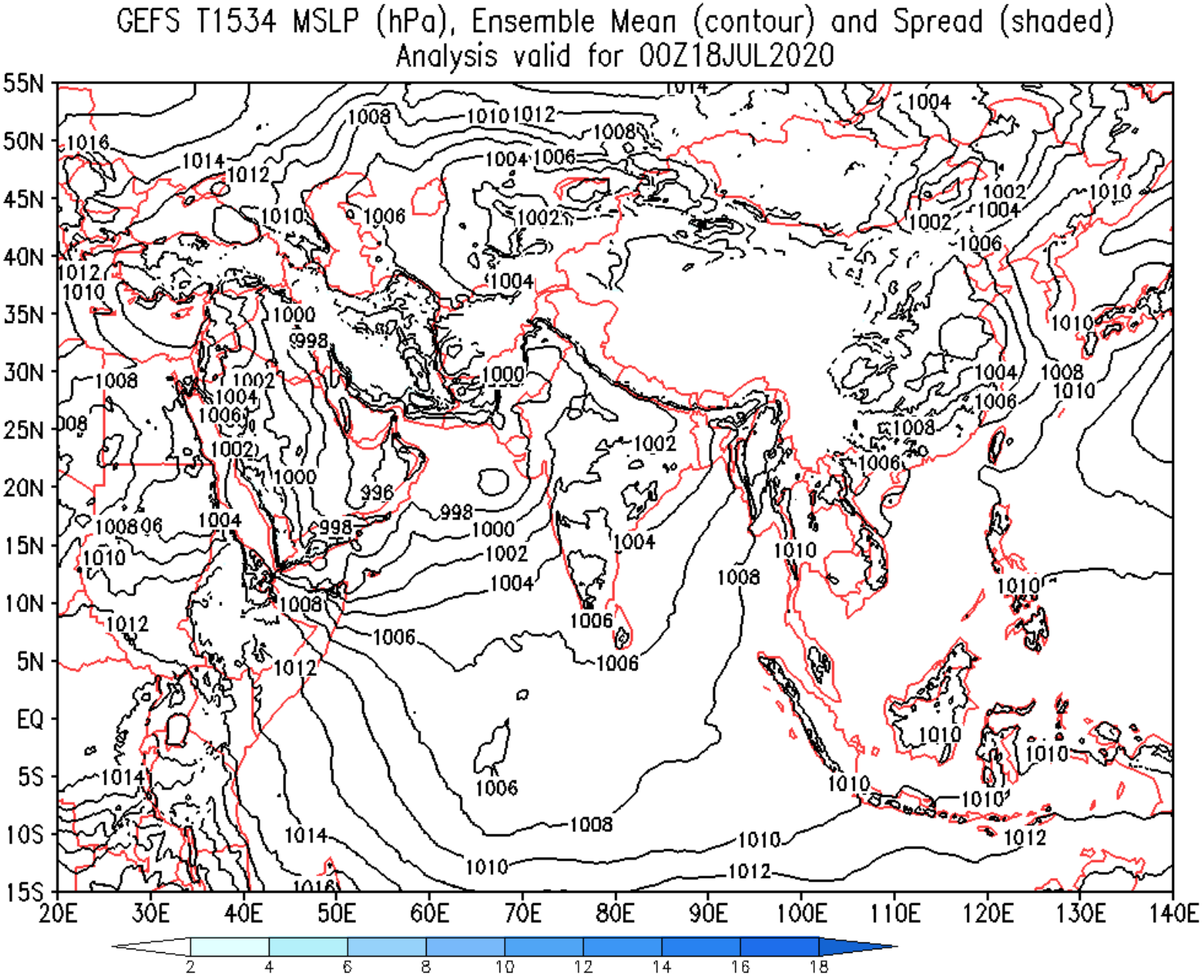








MSLP is showing lack of pressure gradient in the 10 days gefs forecast based on 00UTC 18 July 2020 ic



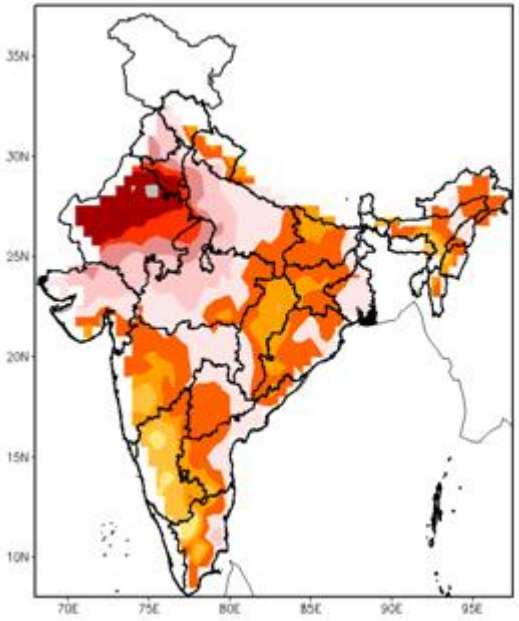
The Block level rainfall probability 5 day forecast over Assam Northeastern state of India based on 18July 2020 0000 UTC IC.

As the monsoon trough is shifting toward foot hills in GEFS 10 days forecast, the northeastern states are expected to get heavier spells which is reflected below.

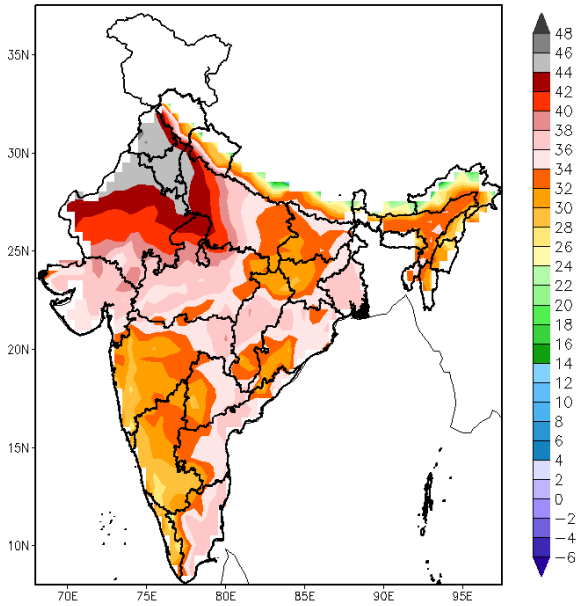
Rainfall threshold (mm day^{-1}) → 2.5 15.6 115 195

Dist	Block	>2.5	>15.6	>65.5	>115	>195	>2.5	>15.6	>65.5	>115	>195	>2.5	>15.6	>65.5	>115	>195	>2.5	>15.6	>65.5	>115	>195	>2.5	>15.6
BAKSA	BARAMA																						
BAKSA	BASKA																						
BAKSA	DHAMDHAMA																						
BAKSA	GORESWAR																						
BAKSA	JALAH																						
BAKSA	NAGRIJULI																						
BAKSA	TAMULPUR																						
BARPETA	BAJALI																						
BARPETA	BARPETA																						
BARPETA	BHABANIPUR																						
BARPETA	CHAKCHAKA																						
BARPETA	CHANGA																						
BARPETA	GOMAPHULBARI																						
BARPETA	MANDIA																						
BARPETA	PAKABETBARI																						
BARPETA	RUPOSHI																						
BISWANA	BAGHMARA																						
BISWANA	BEHALI																						
BISWANA	BISWANATH																						
BISWANA	CHAIDUAR																						
BISWANA	PUB-CHAIDUAR																						
BISWANA	SAKOMATHA																						
BONGAIG	BOITAMARI																						
BONGAIG	DANGTOL																						
BONGAIG	SRIJANGRAM																						
CACHAR	BANSKANDI																						
CACHAR	BINNAKANDI																						
CACHAR	BORKHOLA																						
CACHAR	KALAIN																						
CACHAR	KATIGORAH																						
CACHAR	LAKHIPUR																						
CACHAR	NARSINGPUR																						
CACHAR	PALONGHAT																						
CACHAR	RAJABAZAR																						
CACHAR	SALCHAPRA																						
CACHAR	SILCHAR																						
CACHAR	SONAI																						
CACHAR	UDHARBOND																						

IMD T_{max} on 20200630



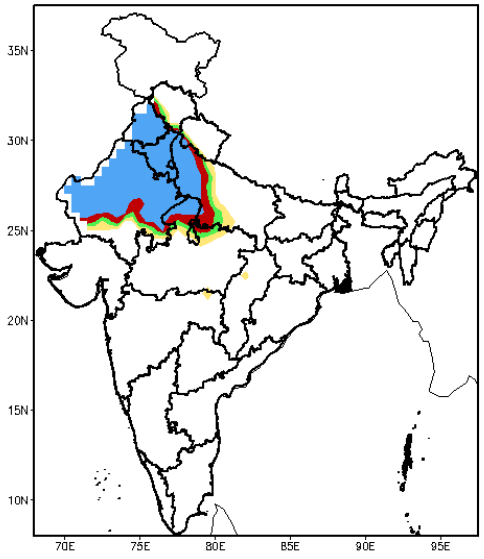
T_{max} Ens Mean



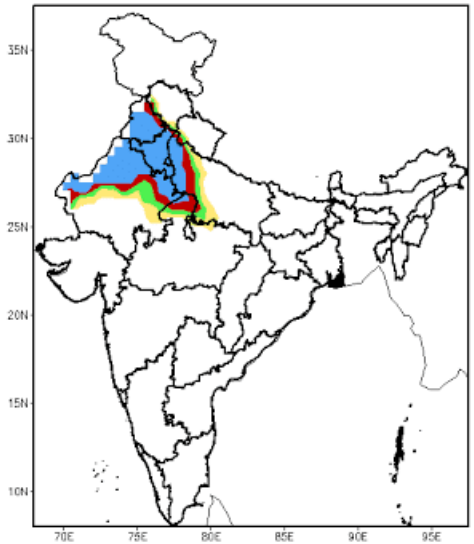
Day 1 FCST for 20200630

The highest maximum temperature of **45.0°C** had been recorded at **Bikaner (West Rajasthan) on 30th June 2020** over the plains of the country during the week.

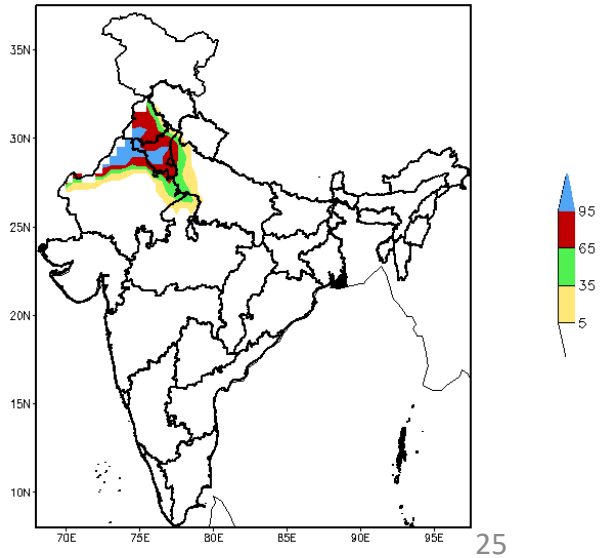
Day 1 Prob Tmax > 40 deg C



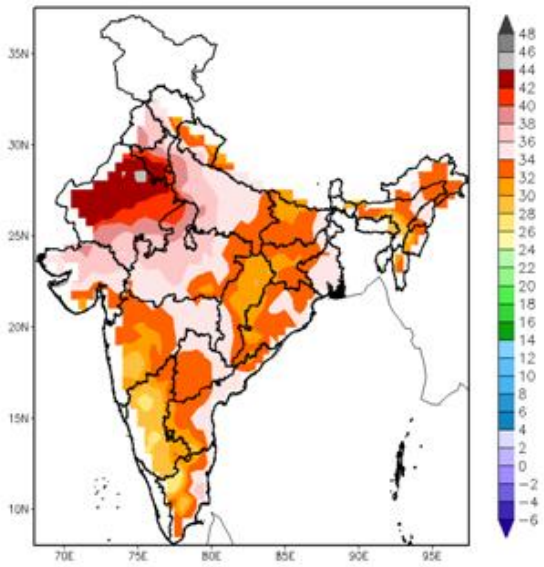
Day 1 Prob Tmax > 42 deg C



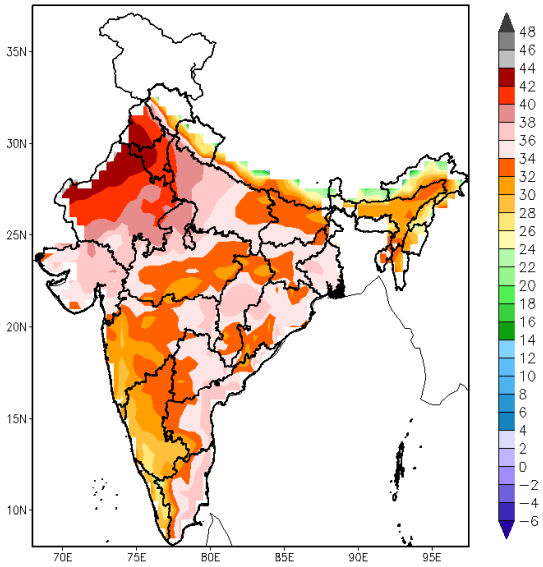
Day 1 Prob Tmax > 44 deg C



IMD T_{max} on 20200630

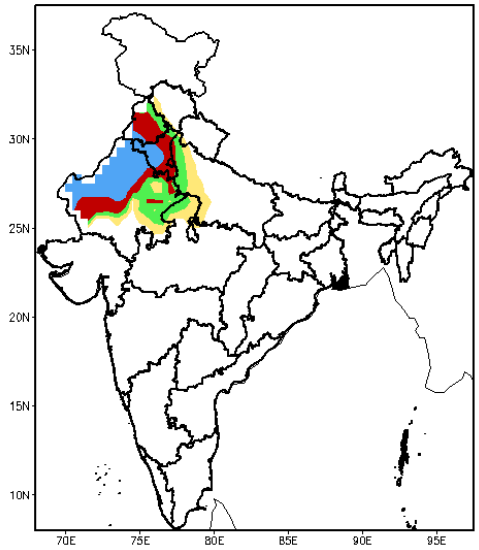


T_{max} EnsMean

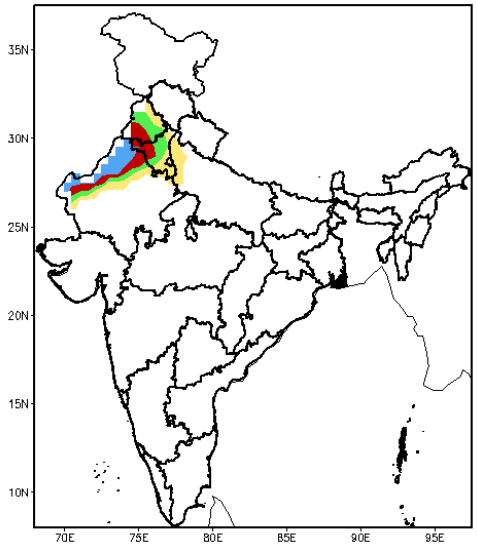


Day 3 FCST for 20200630

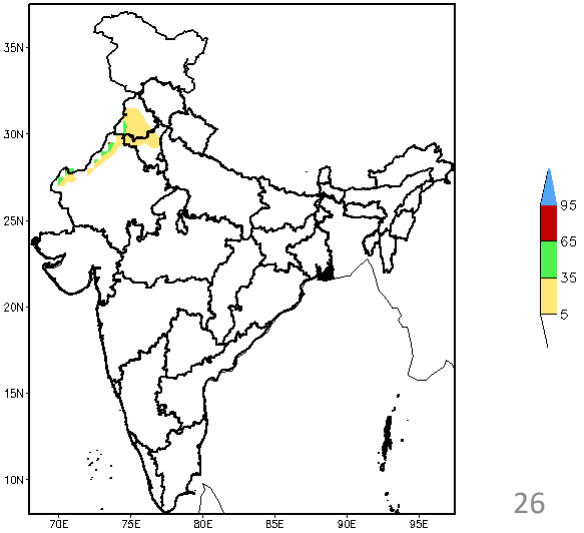
Day 3 Prob Tmax > 40 deg C



Day 3 Prob Tmax > 42 deg C



Day 3 Prob Tmax > 44 deg C



Thunderstorm and Lightning Events during 24-26 June 2020

More than 80 people were killed today due to lightning in various places in Bihar. Another 24 people were killed due to lightning in Uttar Pradesh.
The most number of deaths in Bihar were reported from the Gopalganj district (13) and in UP from Deoria District.

According to concerned departments, lightning strikes have left at least 32 and 12 injured in Bihar and Uttar Pradesh respectively. The strikes also caused damage to property and resulted in the deaths of over 40 animals in Bihar alone.

Source INDIA TODAY June 26,2020

Thunderstorm observed (from 0830 hours IST of 24 June to 0830 hours IST of 25): at isolated places over Jammu-Kashmir and Ladakh, Gilgit-
Baltistan, Muzaffarabad, Himachal
Pradesh, Punjab, Haryana, Chandigarh, Delhi, Uttar Pradesh, Rajasthan, Madhya
Pradesh, Saurashtra, Kutch, Bihar, Jharkhand, Sub-Himalayan West
Bengal, Sikkim, Assam, Meghalaya, Marathwada, Vidharbha, Telangana, south interior Karnataka, Rayalaseema.

Thunderstorm observed (from 1730 hours IST 25 June to 0830 hours IST of 26 June): at isolated places over Bihar (Bhagalpur, Purina, Gaya, Fursatganj), Uttar Pradesh
(Fursatganj, Bareilly, Bahraich, Varanasi, Lucknow), Jharkhand, Odisha, Gujarat Region, east Madhya
Pradesh, Chhattisgarh, Madhya
Maharashtra, Marathwada, Vidarbha, Chhattisgarh, Konkan, Goa, Karnataka, Rayalaseema, Tamil
Nadu, Puducherry, Karaikal, Assam, Meghalaya, west Bengal and Sikkim.

Source: All India Weather Summary (IMD)

GEFS 1534 based Probabilistic Prediction for Thunderstorm Indices

Computed various index such as, SCP, HEI, LayRH, wind gust and other conventional indices and obtained probabilistic forecast from GEFS (T1534)

Development of a perfect prognosis probabilistic model for prediction of lightning over south-east India

M Rajeevan[1,*], A Madhulatha[1], M Rajasekhar[2], Jyoti Bhate[1], Amit Kesarkar[1] and B V Appa Rao[2]

[1]*National Atmospheric Research Laboratory, Department of Space, Gadanki 517 112, India.*
[2]*Satish Dhawan Space Centre, SHAR, ISRO, Sriharikota, India.*
**Corresponding author. e-mail: rajeevan@narl.gov.in rajeevan61@yahoo.co.in*

JESS 2012

CFSv2 Monthly Forecasts of Tornado and Hail Activity

Chiara Lepore
Lamont-Doherty Earth Observatory, Columbia University, Palisades, New York

Michael K. Tippett
Department of Applied Physics and Applied Mathematics, Columbia University, New York, New York

John T. Allen
Department of Earth and Atmospheric Sciences, Central Michigan University, Mount Pleasant, Michigan

WAF, Oct 2018

$$\mathrm{HEI} = \exp[-15.53 + 0.72\log(\mathrm{cPrcp}) + 2.03\log(0\text{–}3\text{-km SRH}) + 0.51\log(\mathrm{MLCAPE})]D\Delta x\Delta y\cos\phi$$

VISUALIZING LONG-RANGE SEVERE THUNDERSTORM ENVIRONMENT GUIDANCE FROM CFSv2

BAMS, 2016

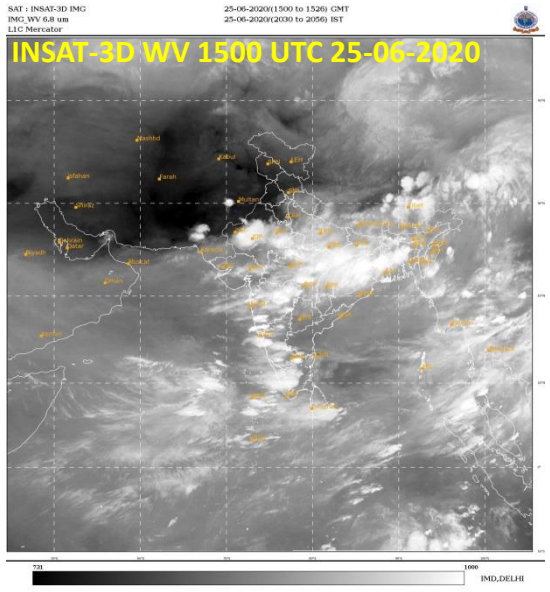
by Gregory W. Carbin, Michael K. Tippett, Samuel P. Lillo, and Harold E. Brooks

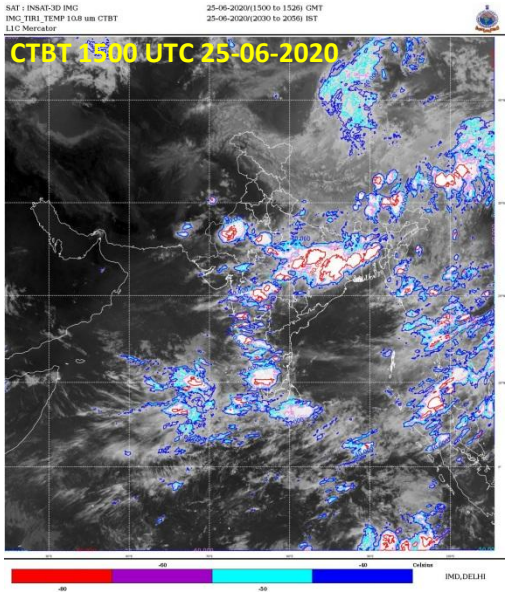
The CFSv2 Climate Forecast System is used to demonstrate new methods of visualizing large sets of model forecasts, with the application of extended-range forecasts for environments conducive to severe thunderstorms.

$$\mathrm{SCP} = (\mathrm{CAPE}/1000\ \mathrm{J\ kg^{-1}}) \times (\mathrm{SRH}/50\ \mathrm{m^{-2}\ s^{-2}}) \times (\mathrm{BWD}/20\ \mathrm{m\ s^{-1}}).$$

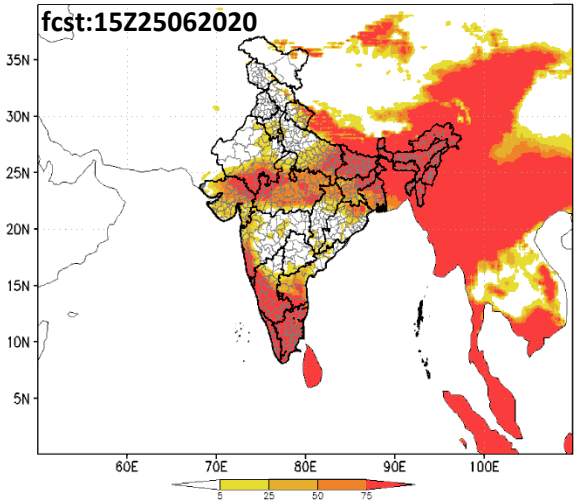
Supercell composite parameter (SCP), combines the fields of convective available potential energy (CAPE), storm-relative helicity (SRH) and bulk wind difference (BWD)

Probability of thunderstorm indices on 25th June, based on GEFS : IC 00Z 24 JUNE 2020

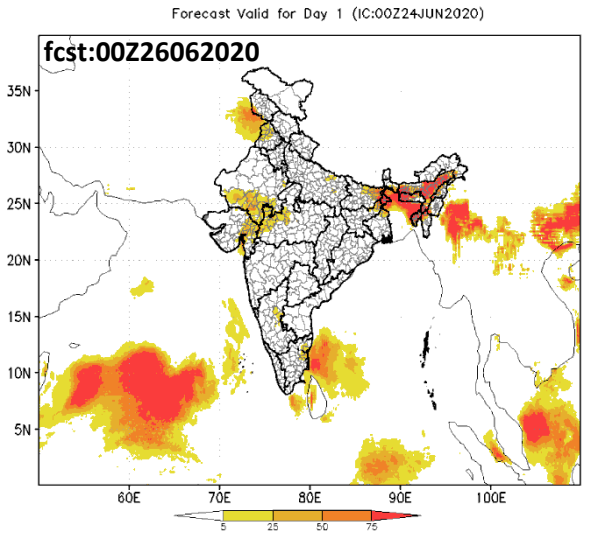




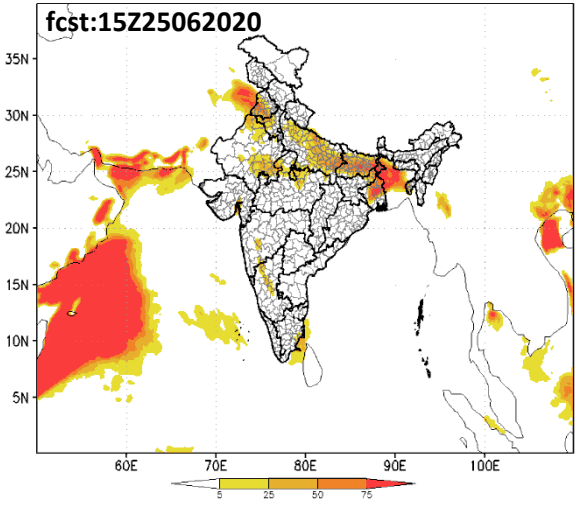
LAYRH Layer mean (1000-100 hPa) relative humidity



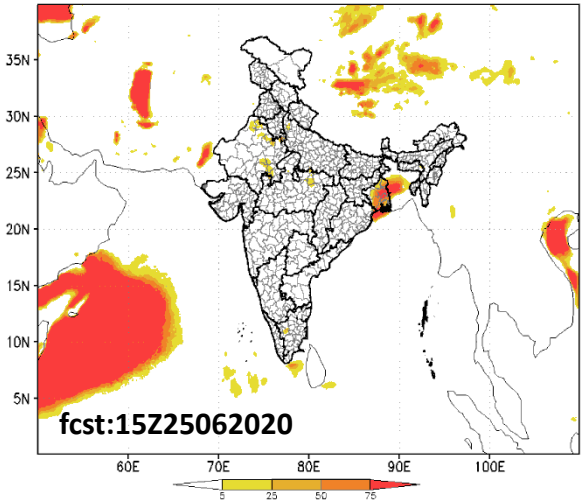
Hail Environment Index (HEI)



Supercell Composite Parameter (SCP)



Wind Gust >25kt



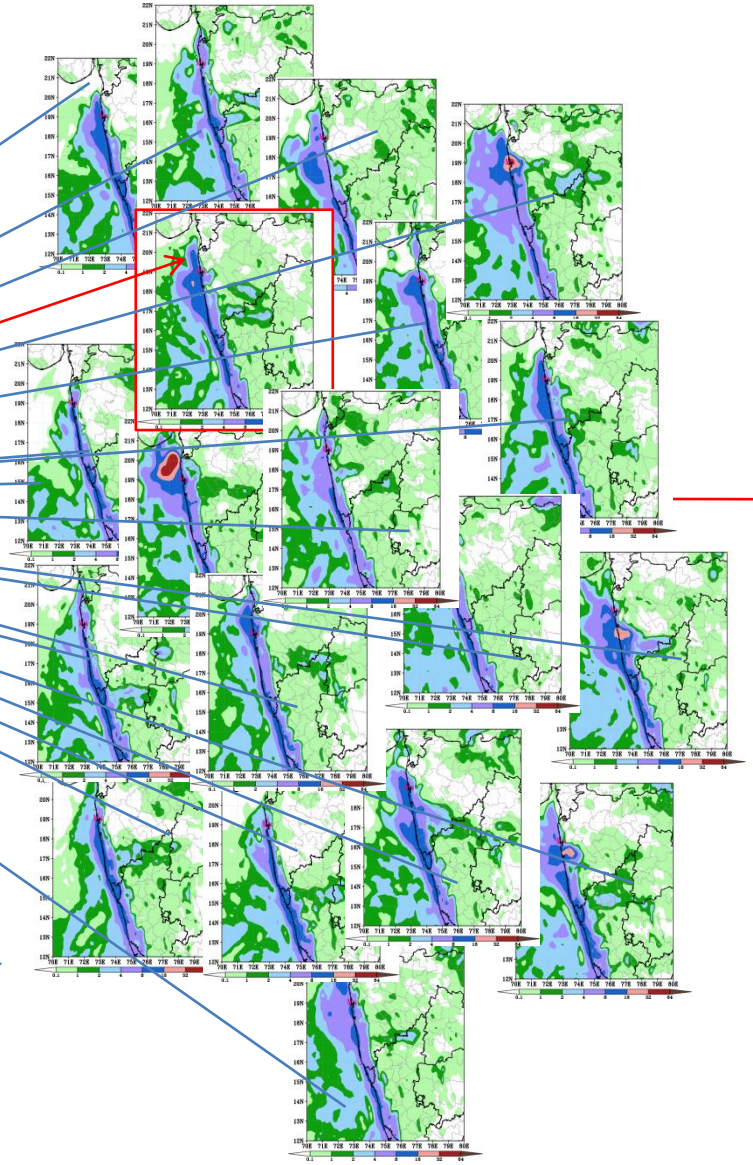
These products are available operationally at https://srf.tropmet.res.in/srf/hires_gefs/archive_thunderstorm.php

Sample ensemble forecast: IC 7 June 2018 00Z: forecast valid for 10 June 2018 00Z (+72h forecast)

Control run showed as →

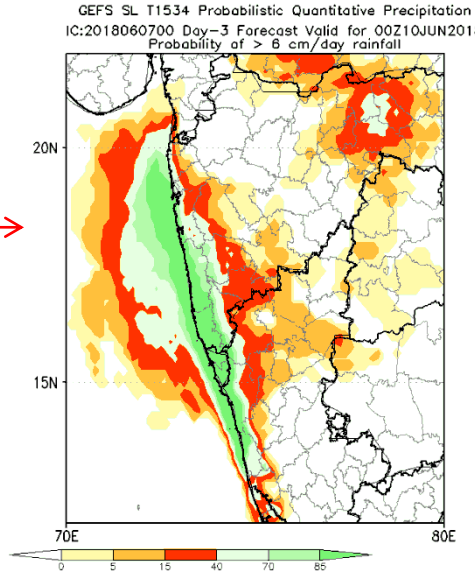
Initial Condition

Analysis

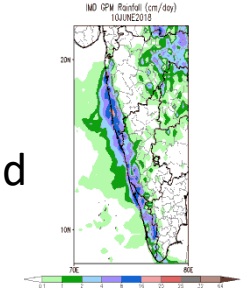


Forecast Uncertainty of 21 ensemble members

Probability of Rainfall > 6 cm/day



Observed Rainfall



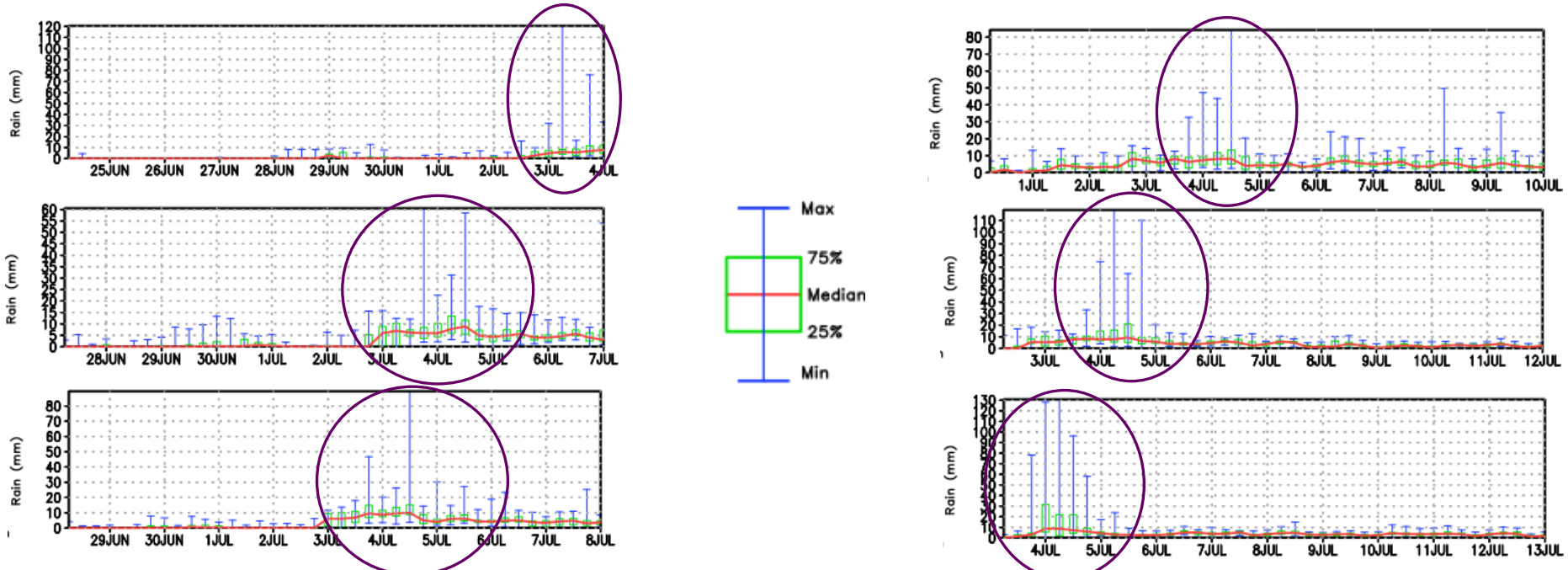
Severe waterlogging in several parts of Mumbai on 3rd to 5th July 2020

24 hr accumalated rain
5th July (SUNDAY)
Colaba: 129.6 mm
Santacruz: 200.8 mm
Thane: 280 mm

4th July (Saturday)
Malvan: 190 mm
Colaba: 170 mm
Tamhini Ghat: 90 mm
Koyana : 70 mm

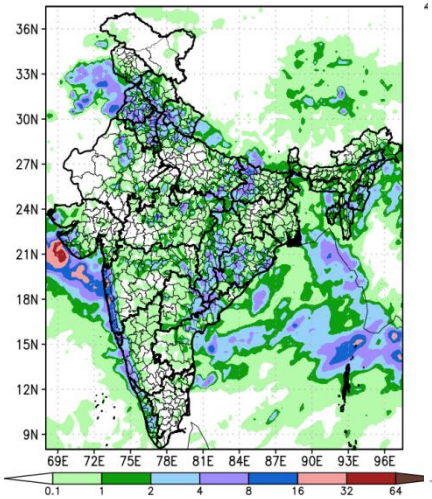
Mumbai and neighboring districts hit by heavy rains for three consecutive days 3,4 and 5th July.
Besides Mumbai neighboring Thane, Palghar, Raigadh districts also received heavy rains during these days.
These rainy spells were the result of trough from south Gujarat to Karnataka coast and a Mid Tropospheric Cyclonic circulation (MTC).

MUMBAI GEFS EPSgrams

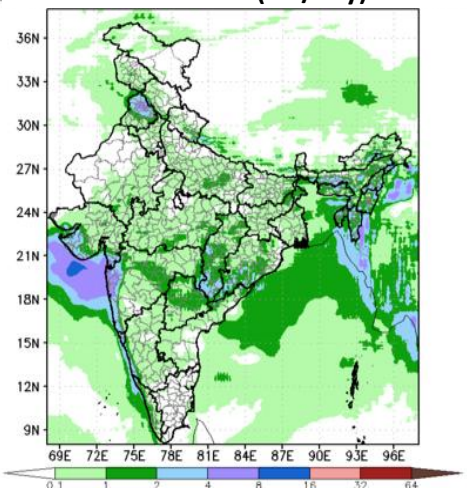


Day 1 GEFS T1534 prediction: 24 hr accumulated rain and its Probability valid for 03 Z 05 July 2020

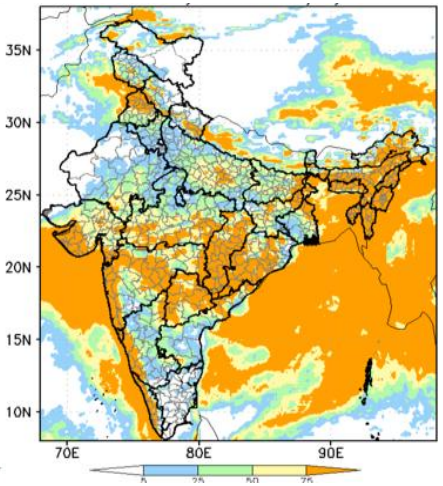
IMD Gridded Rainfall (cm/day)



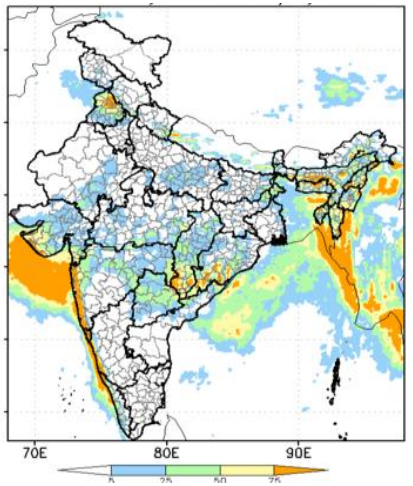
ENS mean Rainfall (cm/day)



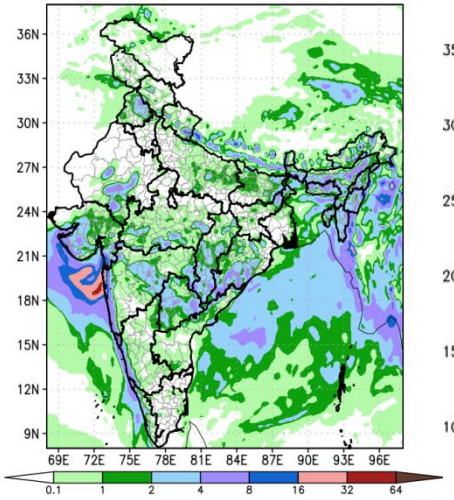
Rainfall > 2.5 mm/day probability



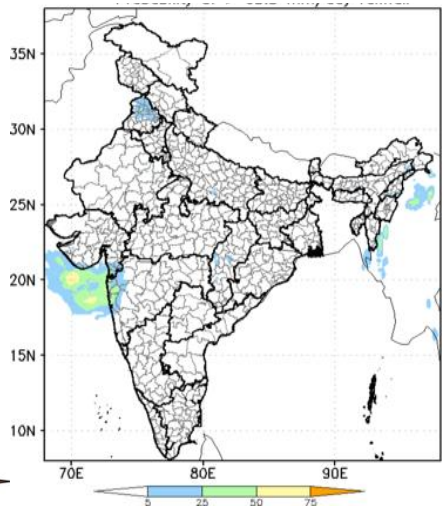
Rainfall > 15.6 mm/day probability



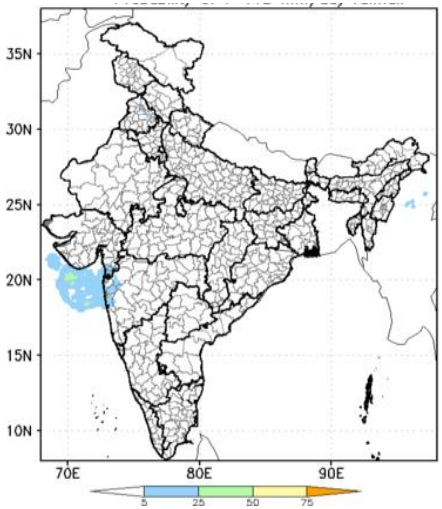
GFS Day 1 Rainfall (cm/day)



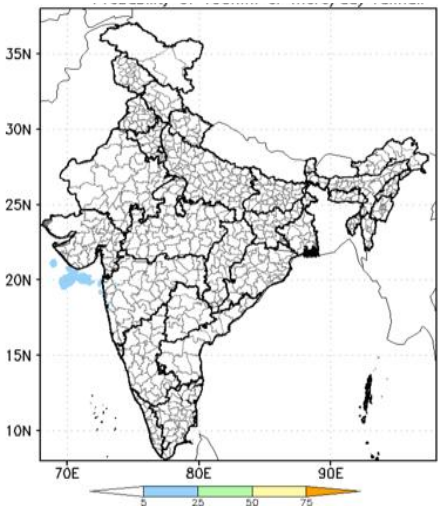
Rainfall > 65.5 mm/day probability



Rainfall > 115 mm/day probability

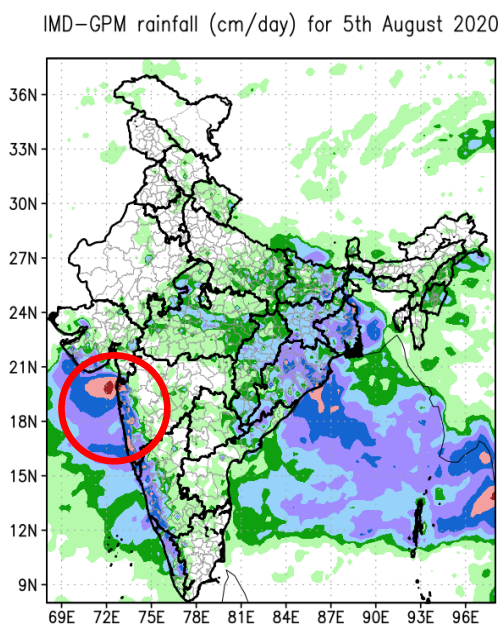


Rainfall > 195 mm/day probability

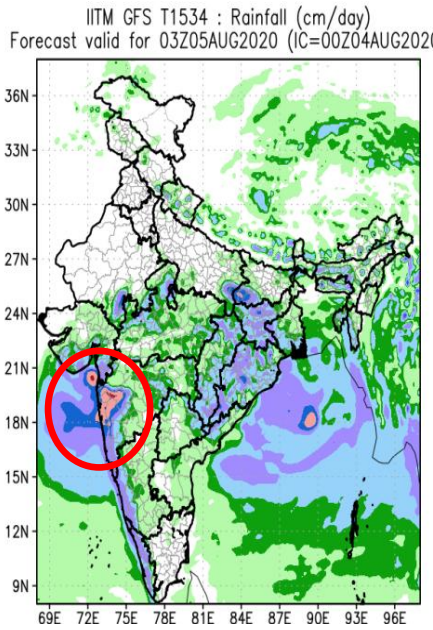


GFS T1534: valid for 5th Aug

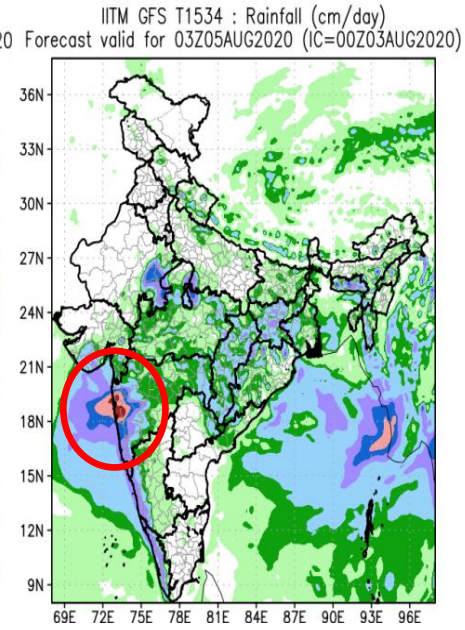
Observation (cmday^{-1}) 5th August



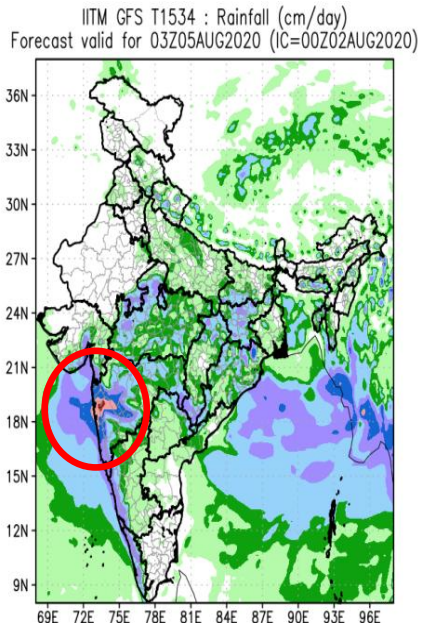
Day-1

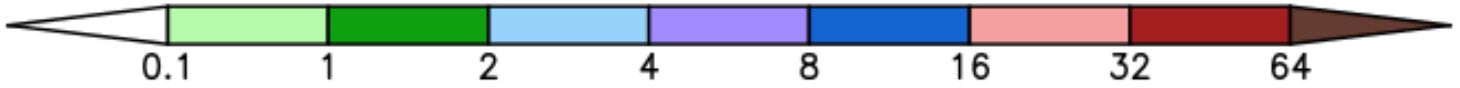


Day-2



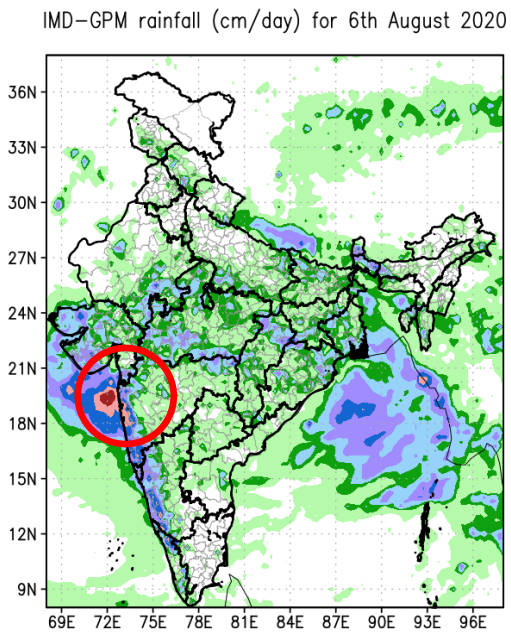
Day-3





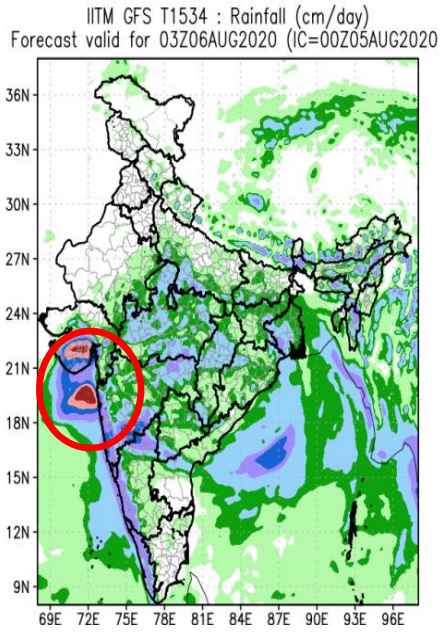
Observation (cmday^{-1})

6th August

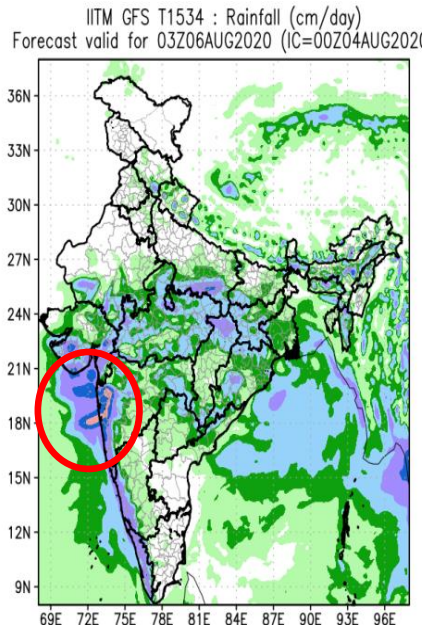


GFS T1534: valid for 6th Aug

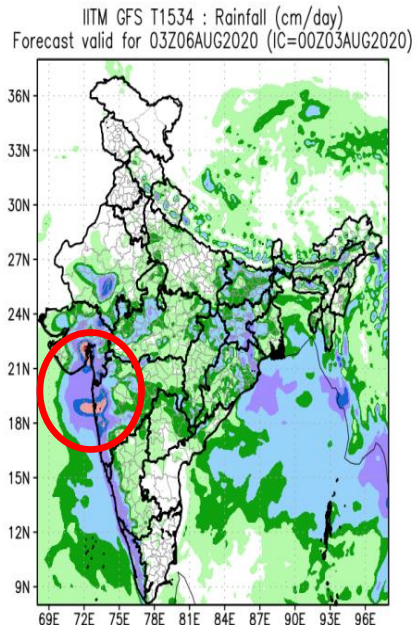
Day-1

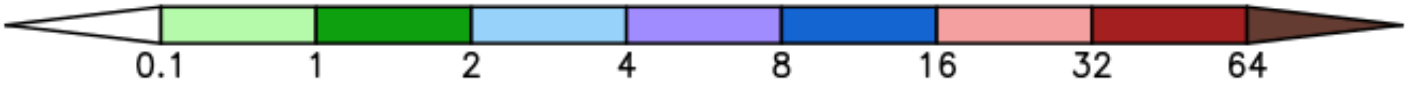


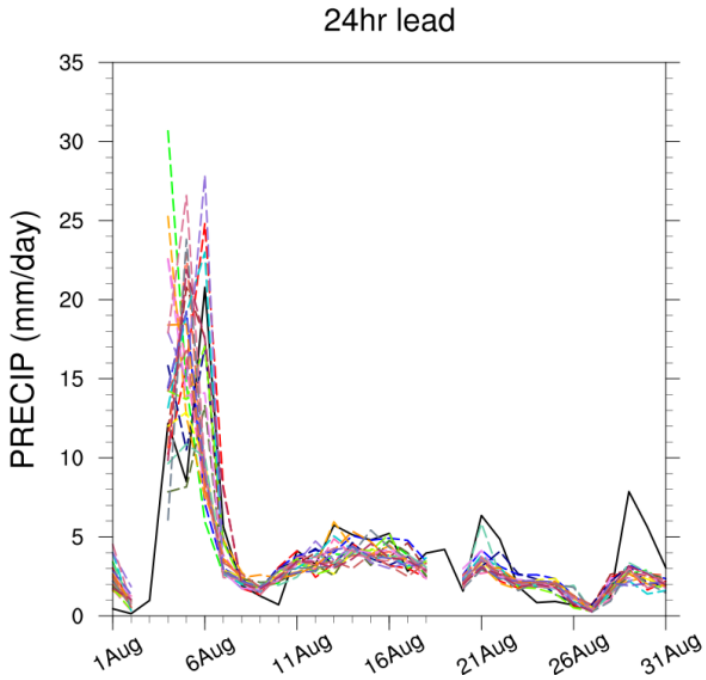
Day-2

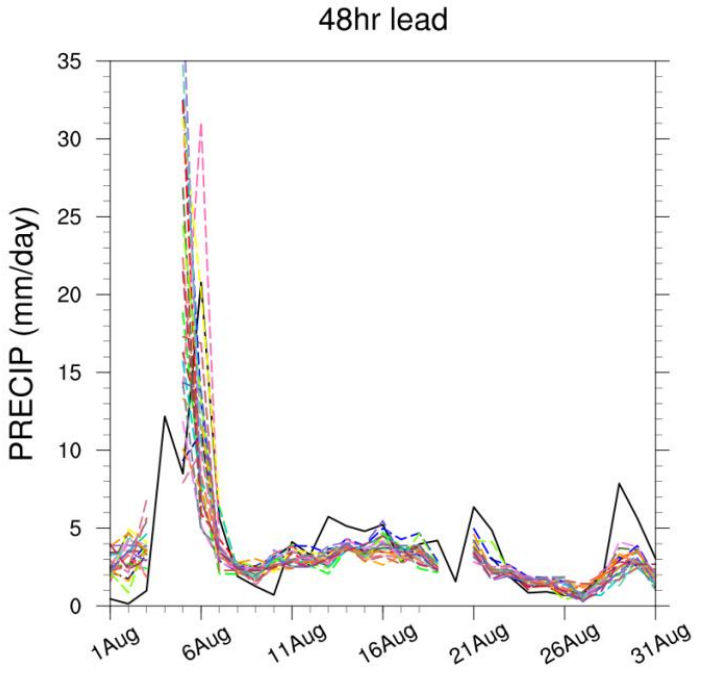


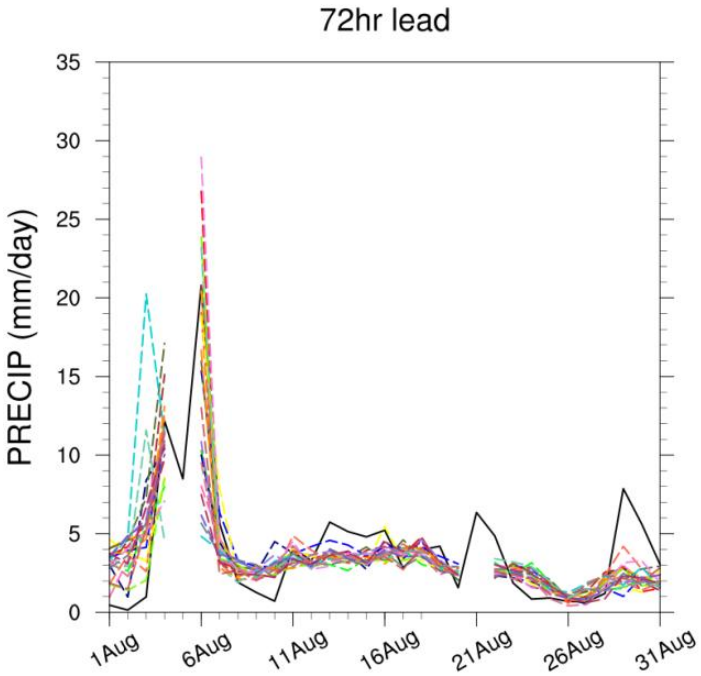
Day-3









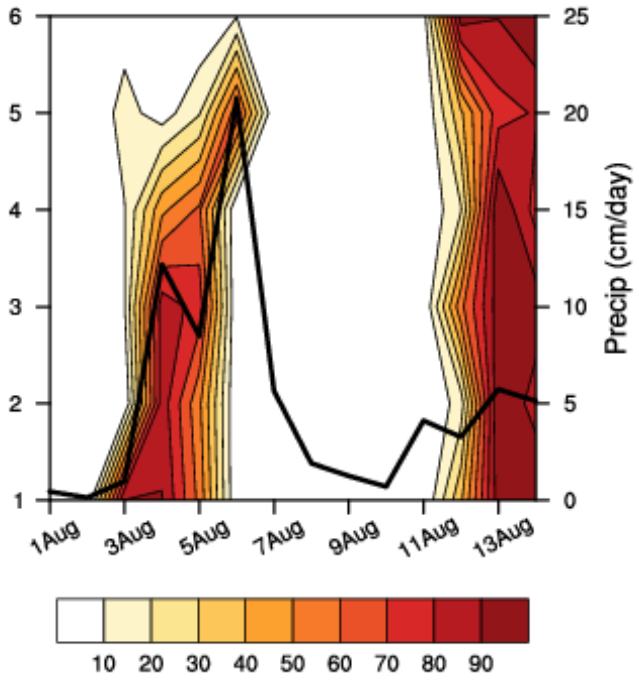


Time series of rainfall from all ensemble members for Mumbai

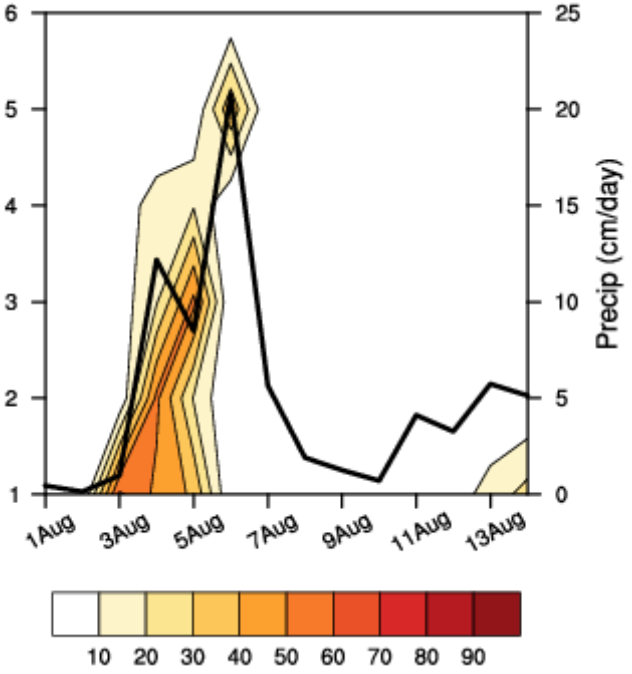
Heavy rainfall event (August) over Mumbai

GEFS rainfall Probability forecast Vs Lead time (days)
over Mumbai (18-19N, 71.75-73.25E)

(a) Threshold=clim+1SD



(b) Threshold = clim+2SD



IITM 21member ensemble GEFS IC/BC setup for WiFEX Fog forecast

Experimental forecast has initiated during 2020-2021 winter season

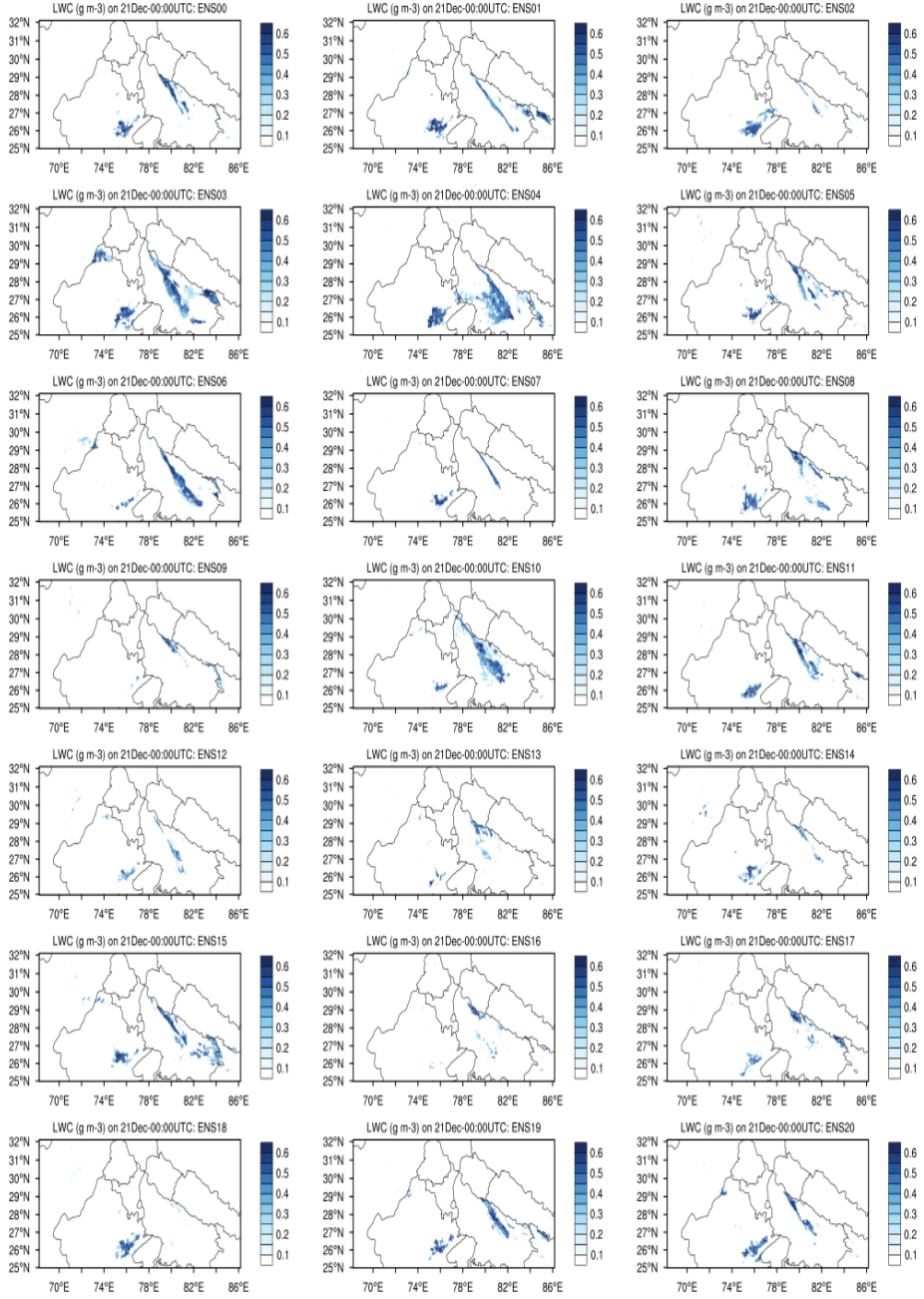
Validation of forecast will be done once fog season completes

Model products:

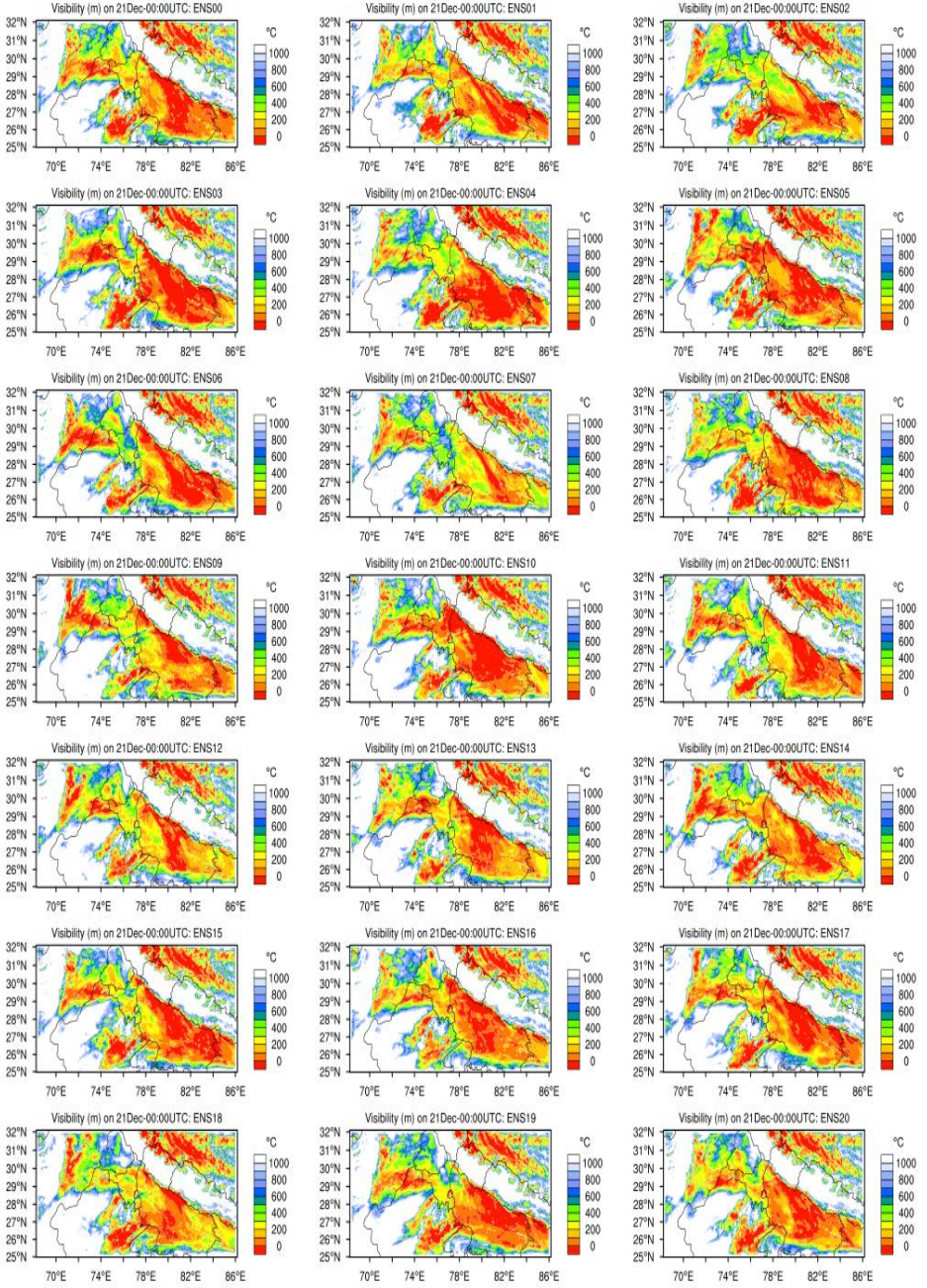
- 21member LWC (fog)
- 21member visibility(m)
- 21member probability forecast

Dr. Ghude et al.

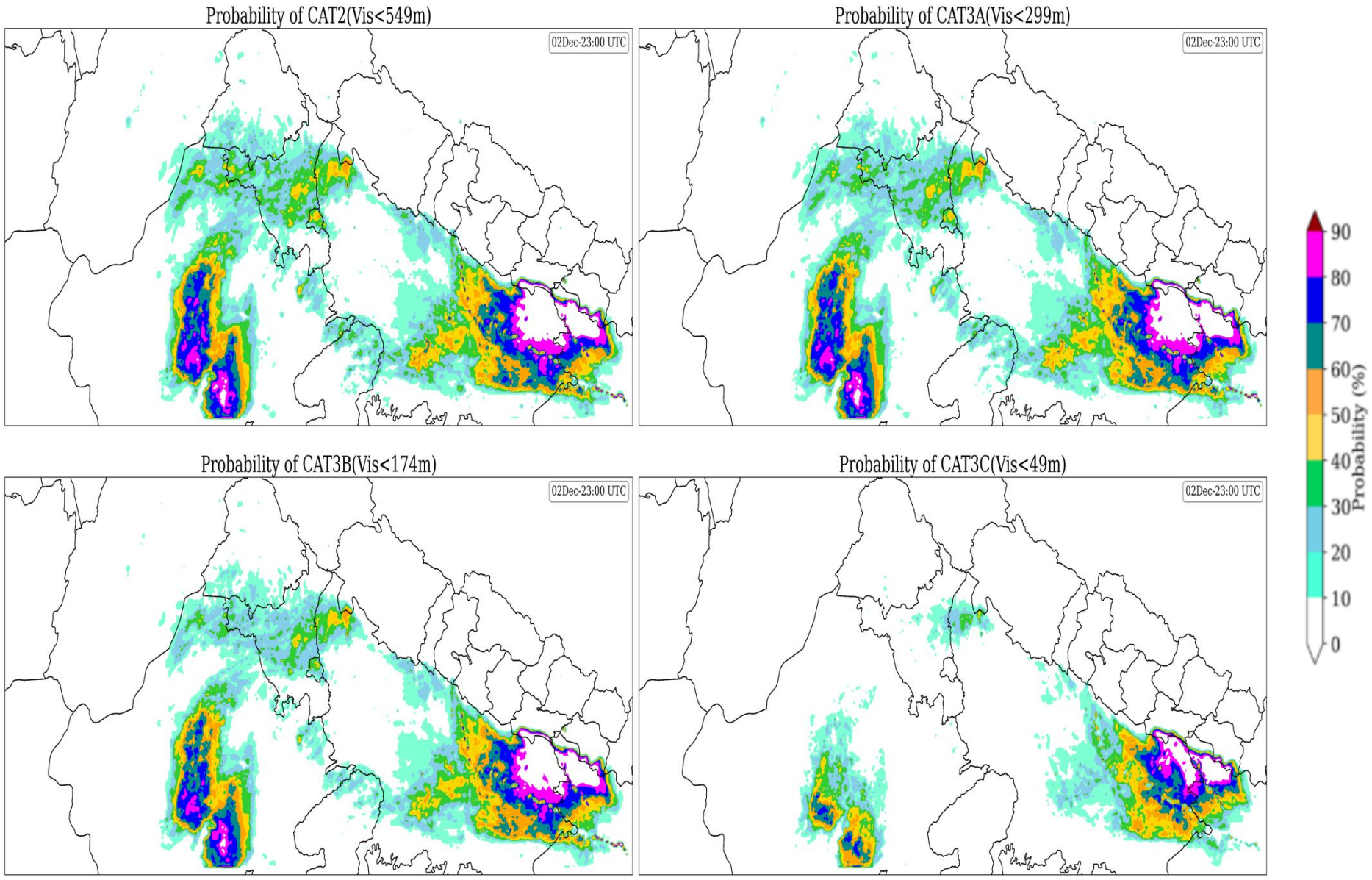
21 member ensemble LWC (fog) forecast



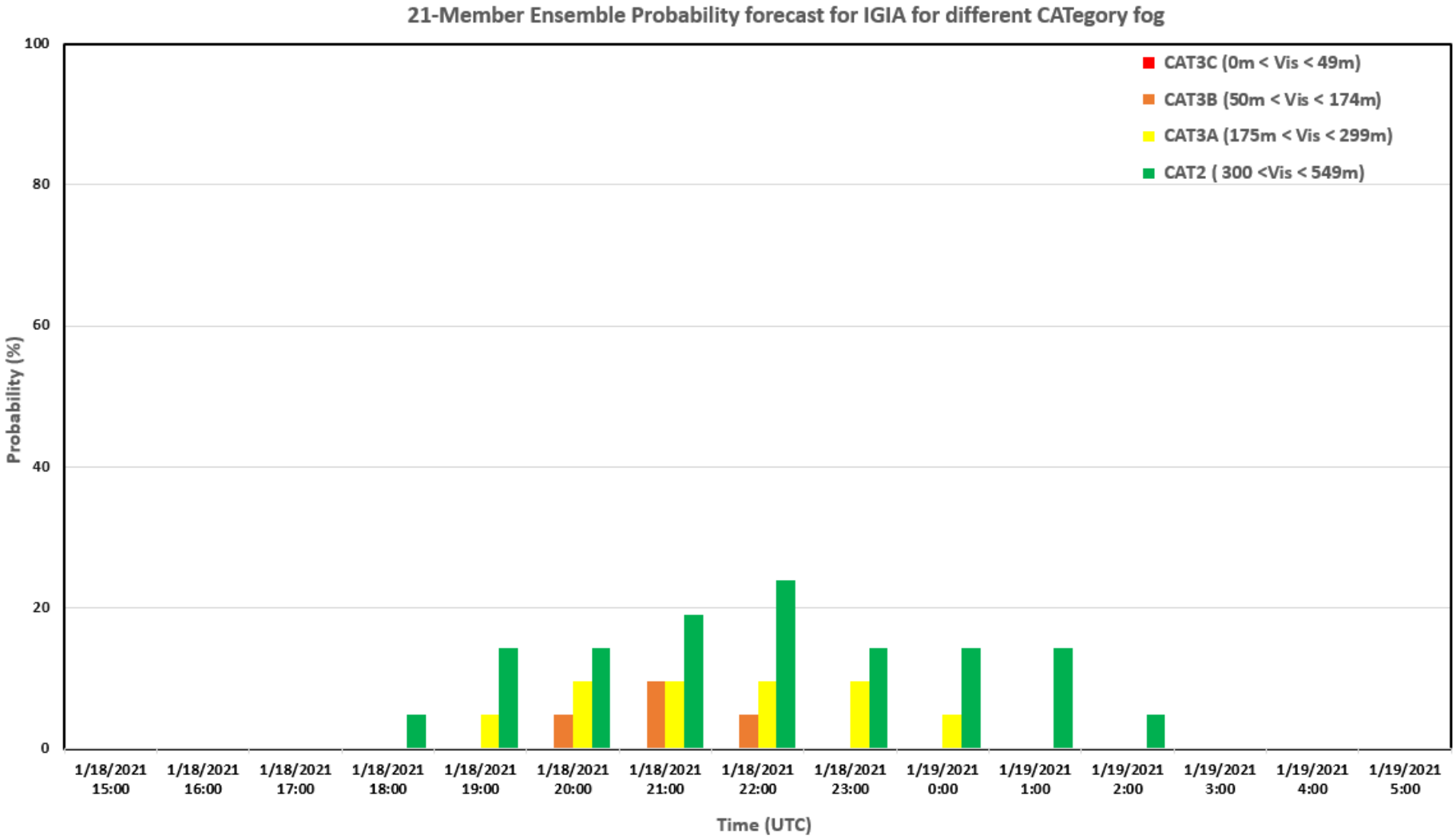
21 member ensemble Visibility (m) forecast



21 member GEFS ensemble WRF based probability forecast



Dr. Ghude et al.



Dr. Ghude et al.

Spatial Verification of Rain

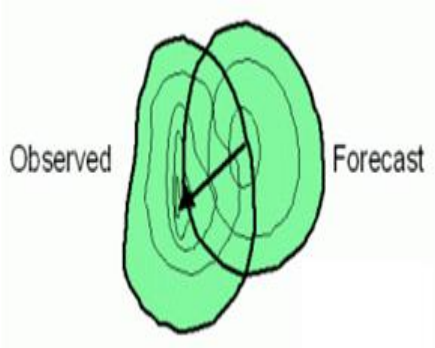
Contiguous Rain Area (CRA) method is a feature-based approach that isolates systems or features of interest and evaluates their properties, namely, location, size, intensity, and fine scale pattern.

- Error minimization is used to determine the best pattern match
- decompose the total error into components due to location error, volume (intensity) error, and pattern error.
- The total mean squared error (MSE) can be written as:

$$MSE_{total} = MSE_{displacement} + MSE_{volume} + MSE_{pattern}$$

The difference between the mean square error before and after translation is the contribution to total error due to displacement,

$$MSE_{displacement} = MSE_{total} - MSE_{shifted}$$



The error component due to volume represents the bias in mean intensity,

$$MSE_{volume} = (\boldsymbol{F} - \boldsymbol{X})^2$$

where $\boldsymbol{F}$ and $\boldsymbol{X}$ are the CRA mean forecast and observed values after the shift. The pattern error accounts for differences in the fine structure of the forecast and observed fields,

$$MSE_{pattern} = MSE_{shifted} - MSE_{volume}$$

Contiguous Rain Area (CRA)

Mean Square Error (MSE) and its decomposition is calculated by,

$$MSE_{total} = MSE_{displacement} + MSE_{pattern} + MSE_{volume}$$

$MSE_{displacement}$ is the error due to displacement of the location of the identified object.
$MSE_{pattern}$ is the error due to the fine structure of the features identified
MSE_{volume} is the error due to error in mean intensity.

	RMSE (mm/day)	$MSE_{displacement}$ (%)	MSE_{volume} (%)	$MSE_{pattern}$ (%)
4 Jun 2020 (Mumbai)	13.52	**48.5**	0.8	**50.7**
6 Aug 2020 (Mumbai)	39.4	**45.1**	0.1	**54.8**
22 Aug 2020 (Odisha)	23.04	**11.1**	4.4	**84.5**
28 Aug 2020 (Chhattisgarh)	46.5	**9.4**	3.9	**86.7**
20 Aug 2020 (MP)	35.02	**32.1**	3.0	**64.9**

SUMMARY

- **GEFS ensemble forecasts are found to provide reasonably good skill of various weather phenomena e. g. heavy rainfall, thunderstorms, fog and particularly tropical cyclones with longer lead over Indian region.**

- **GEFS forecast also found to be skilful for heat wave probability forecast.**

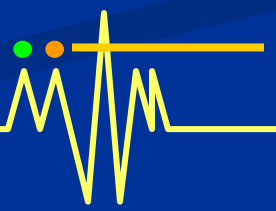
- **Probabilistic forecast captures the transition of monsonn variability and provides better skill heavy rainfall probability in longer lead.**

- **GEFS based rainfall probability for all the blocks, EPSGRAM, SKEW T log P diagram etc. have been developed and are available operationally for forecasters.**

- **There is a need to introduce SPPT (perturbation in physical tendencies) to improve the spread and RMSE and individual members fidelity also needs to be improved for achieveing better skill**

- . http://srf.tropmet.res.in/srf/hires_gefs/index.php

Thank You !



Spatial Verification of Rain

A good quantitative precipitation forecast (QPF) correctly predicts:
- rain area
- rain intensity
- location of rain system

Errors can occur in all of the above quantities. However, it is difficult to determine the source(s) of error using traditional verification statistics over the model domain.

Traditional verification methods focus on matches between the forecast and observations at individual stations or grid points, and do not consider the spatial relationship between the points. In addition, it may be difficult to interpret the verification results for a given spatial forecast when there is more than one feature of interest in the domain.

Contiguous Rain Area (CRA) method is a feature-based approach that isolates systems or features of interest and evaluates their properties, namely, location, size, intensity, and pattern.