Operational Challenges in Predicting Heavy Rainfall Events

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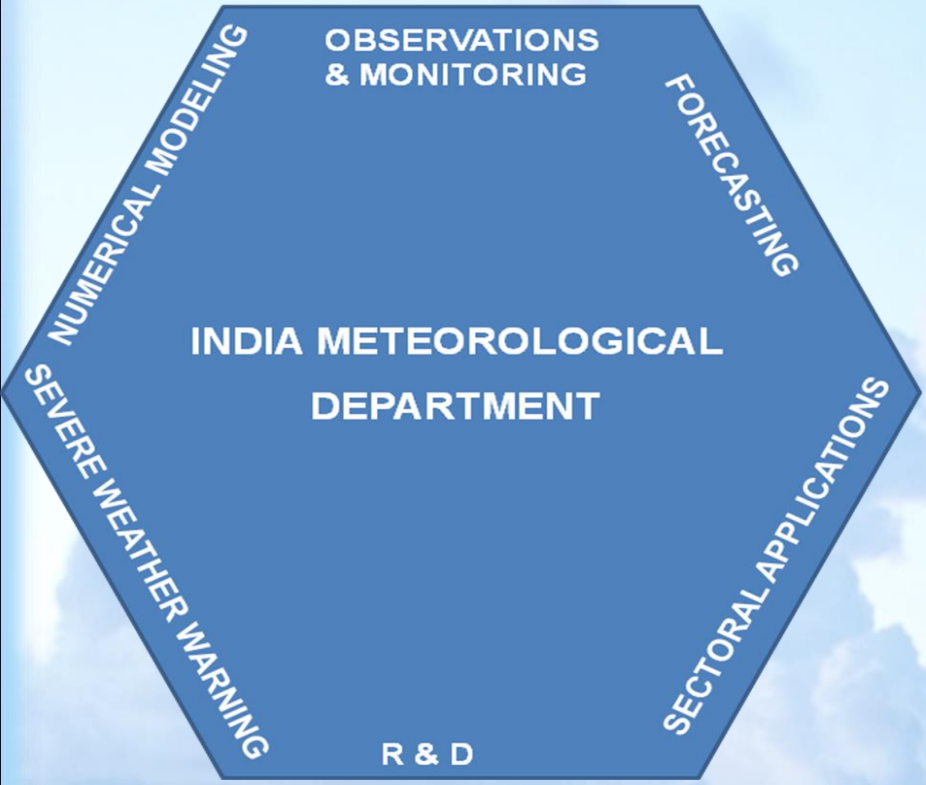
भारत मौसम विज्ञान विभाग
INDIA METEOROLOGICAL DEPARTMENT

Points to be covered:-

- **IMD's Operational Mandate**
- **Heavy Rainfall Events over India (Backgrounds)**
- **NWP modelling DSS for Heavy Rainfall Warning**
- **Forecast skill of Heavy Rainfall over India**
- **Some specific cases (Success and Failure) (Medium & Extended Range)**
- **Challenges and potential areas of improvement**

Weather and Climate Services for Self Reliant India

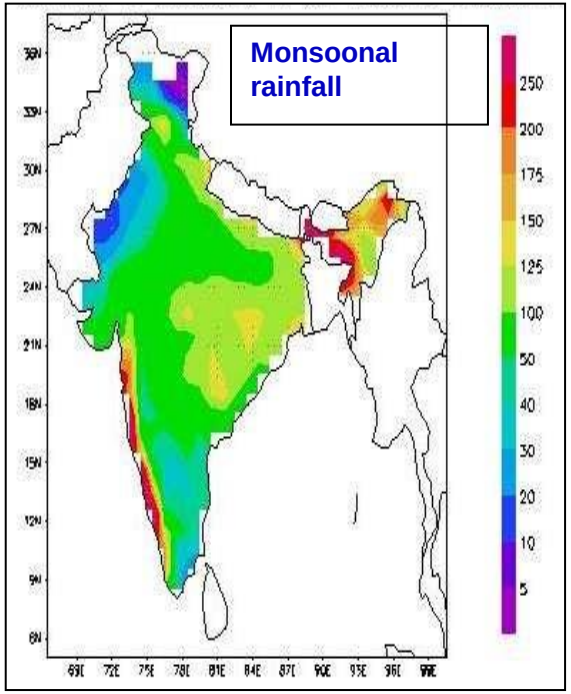


- Meteorological observations & forecast for optimum operation of weather sensitive activities
- Hence to enable enhancement in Economy
- No weather hazard to go undetected and unpredicted
- Accurate warnings against hazards with reasonable lead time, triggering response from disaster managers and public to save life and property.

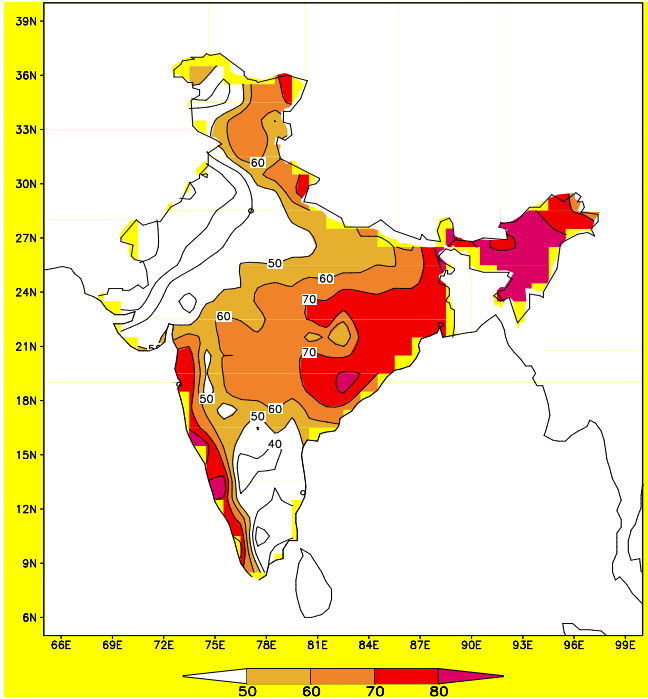
Monitoring and Forecasting Process by IMD

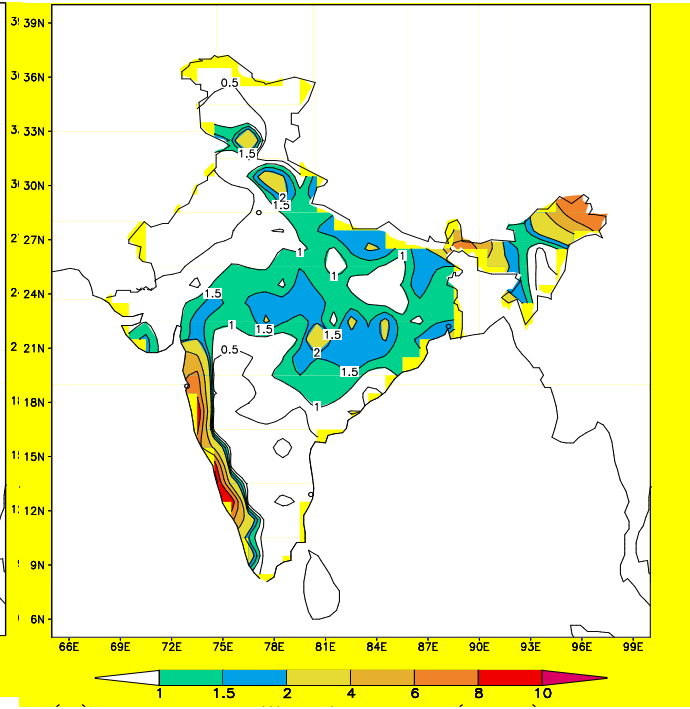
- IMD maintains round the clock watch with land, Ocean, atmosphere and space based observations
- IMD has a seamless forecasting strategy. IMD issues forecasts and warnings on different time scales and for different spatial scales:
  - **Nowcasting- up to six hours for all types of severe weather at all districts and stations**
  - **Short to medium range (up to 7 days) forecasts over cities, Blocks, districts and meteorological subdivisions**
  - **Extended range (up to 4 weeks) forecasts for 36 meteorological sub-divisions**
  - **Monthly and Seasonal Forecasts**

Monsoon Rainfall (JJAS)

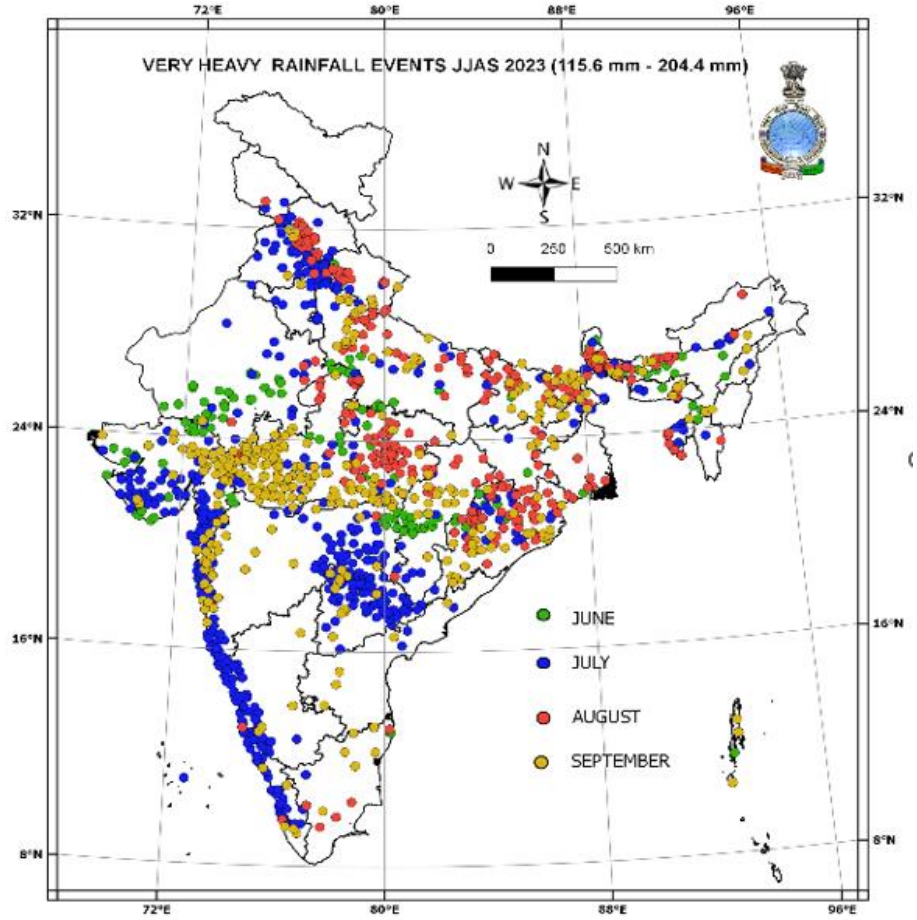


Mean % of Heavy rainfall days Mean % of Very heavy rainfall days

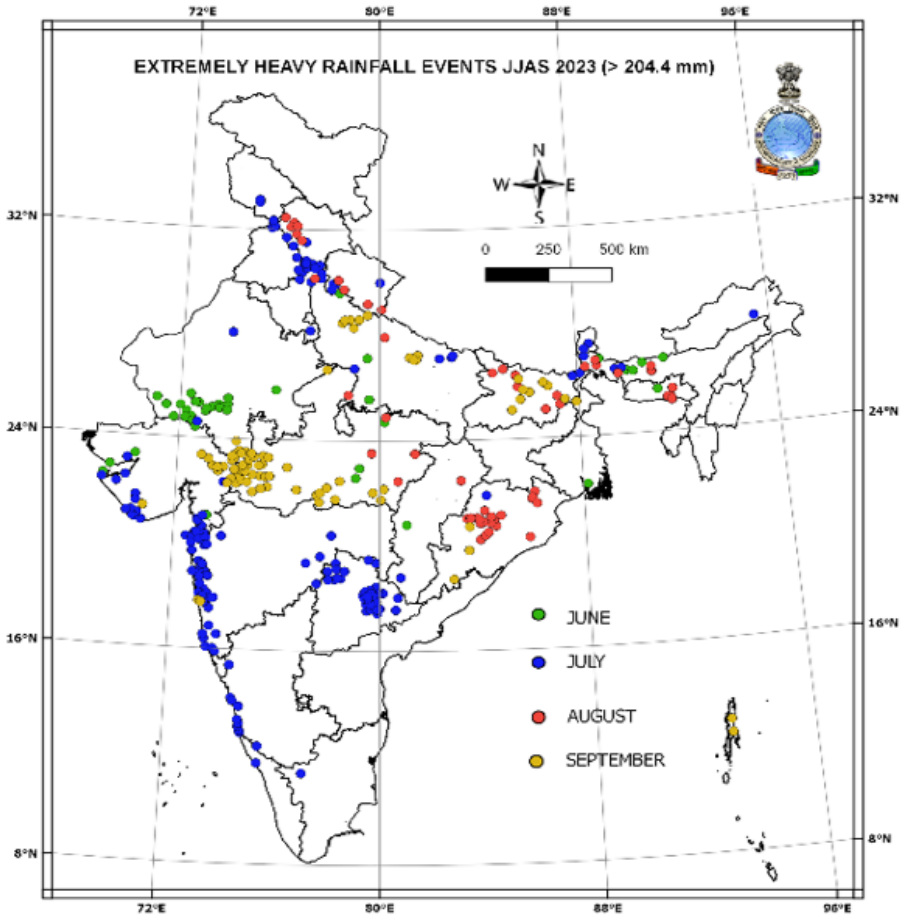




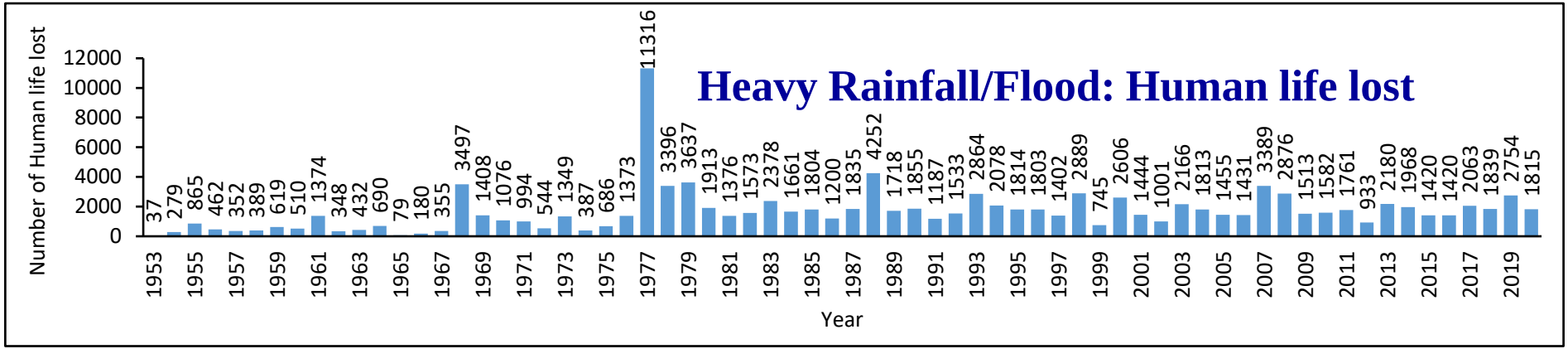
Location of Very Heavy rainfall over India during JJAS 2023

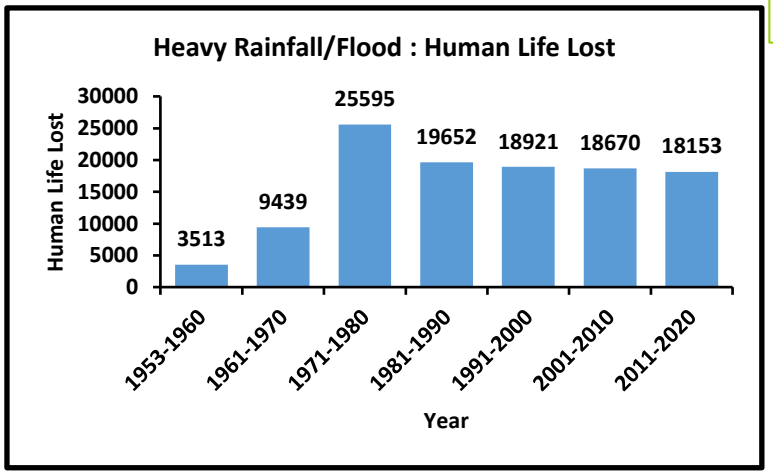


Location of Extremely Heavy rainfall over India during JJAS 2023



Flood Damage Statistics: India





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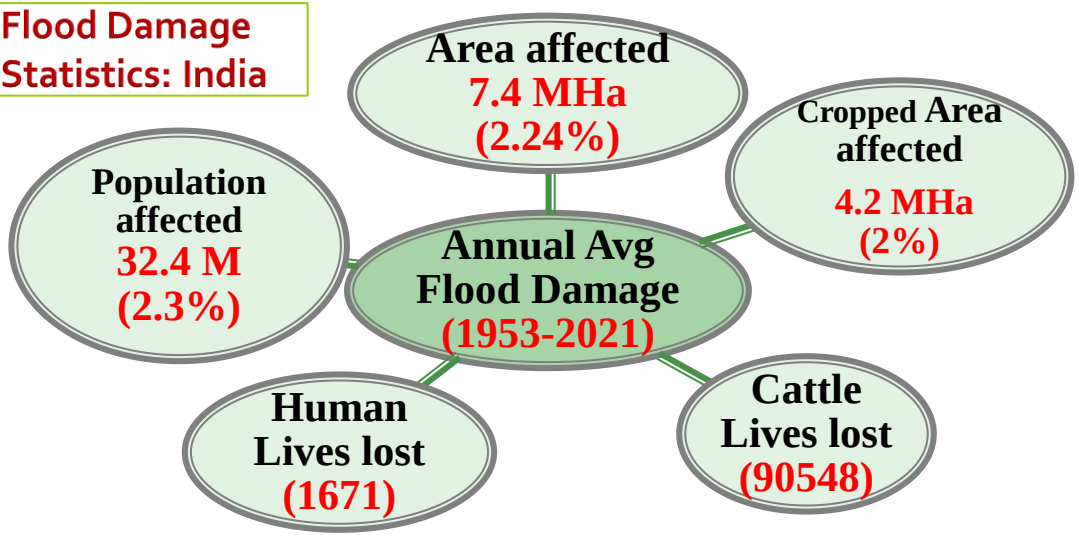


The Water Vapor Feedback

(Increase of heavy rainfall event in view of cc)

Temp dependence of saturation vapor pressure

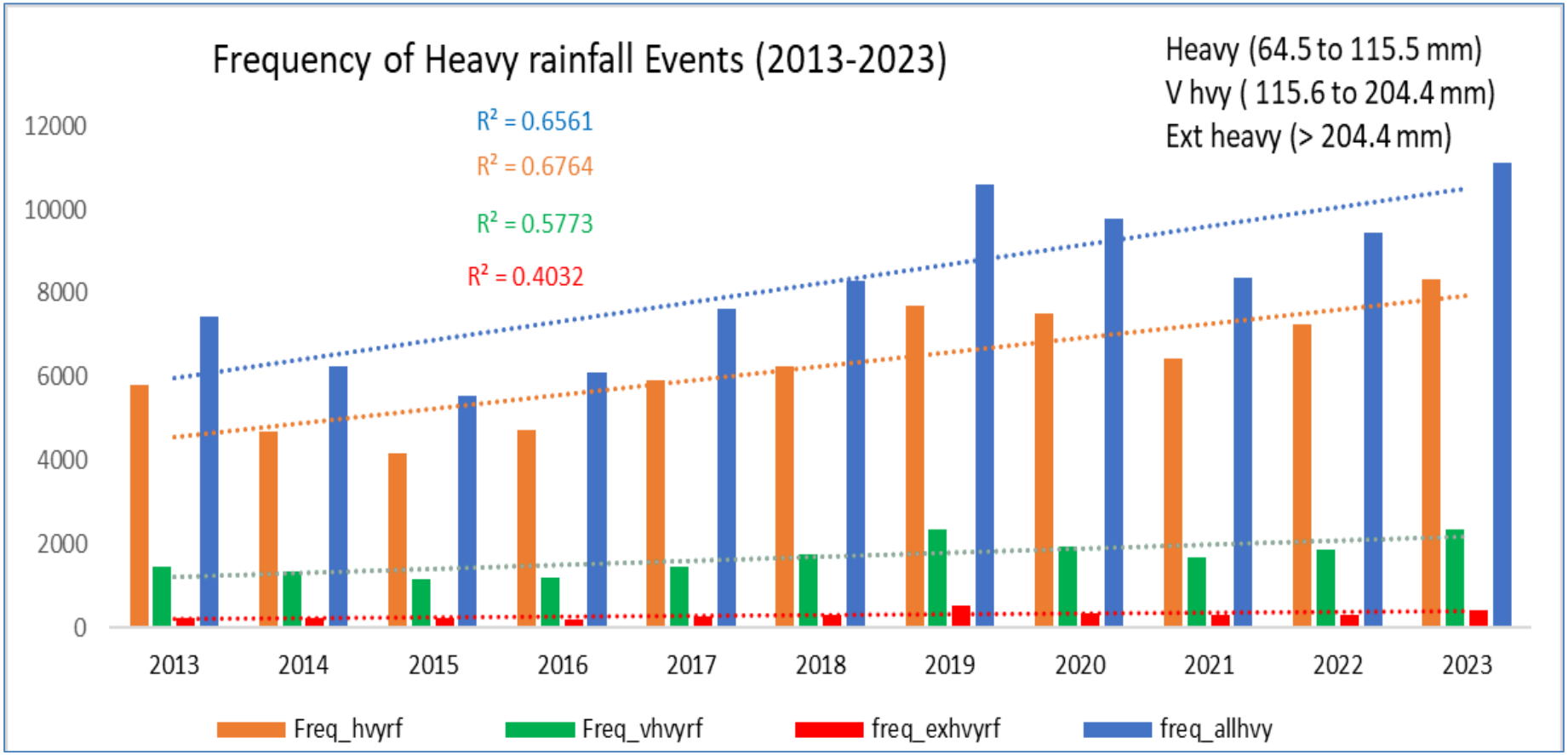
e_s: $e^{-5400/T}$

$$\frac{d \ln e_s}{dT} = \frac{5400}{T^2} \approx 0.06 \quad to \quad 0.1 \quad per \quad K$$

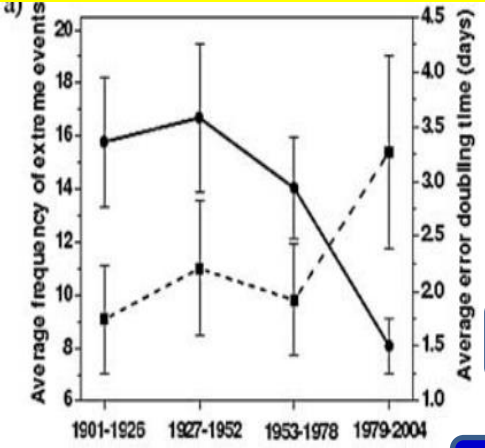
Direct consequence of global warming

Increase in the frequency of heavy precipitation events!

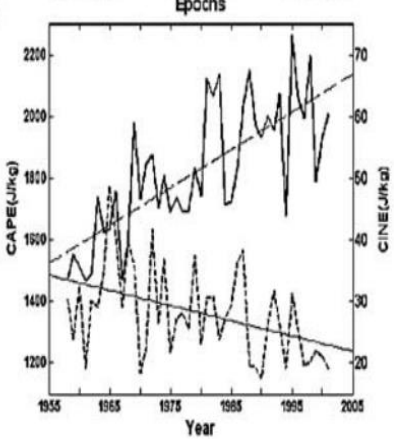
Frequency of Heavy, Very Heavy and Extremely Heavy rainfall over India during the period from 2013 to 2023



Global Warming on Rainfall Activity



Average error doubling time over central India and frequency of extreme events (rainfall >150 mm/day).



Daily CAPE and CINE during monsoon season

Global Warming

↓

Rise in Temperature

↓

Increase in Evaporation

↓

Increase in Moisture Content of Atmosphere

↓

Increase in Small Scale (Mesoscale) Convective System

↓

Formation of Low Pressure Area → **Increase in Rainstorms over Central & North India**

Major science themes/applications/services of IMD

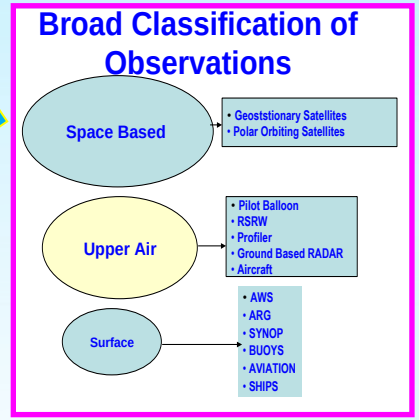
Forecast and Early Warning System

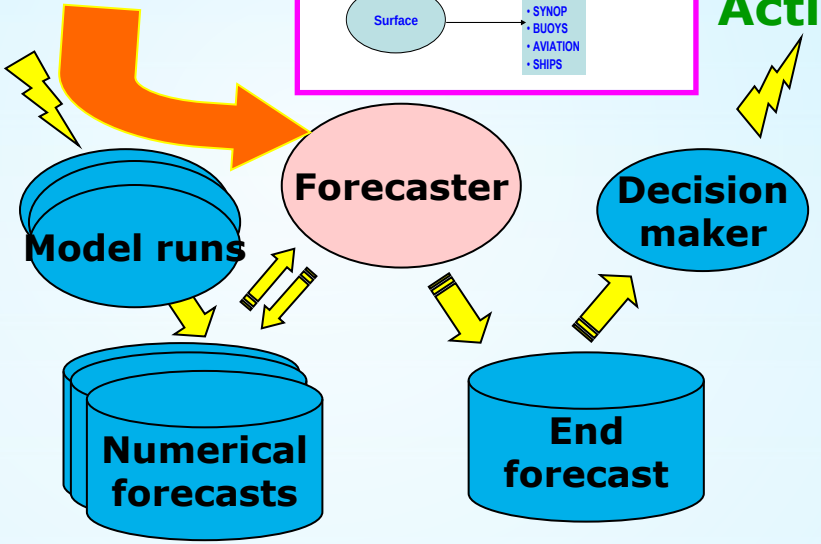
Initial conditions (Observations)

Runs of different Models,

Consecutive runs from the same model,

Ensemble runs ("choosing the best member")





Improved Forecast and Early warning system with respect to all the above components

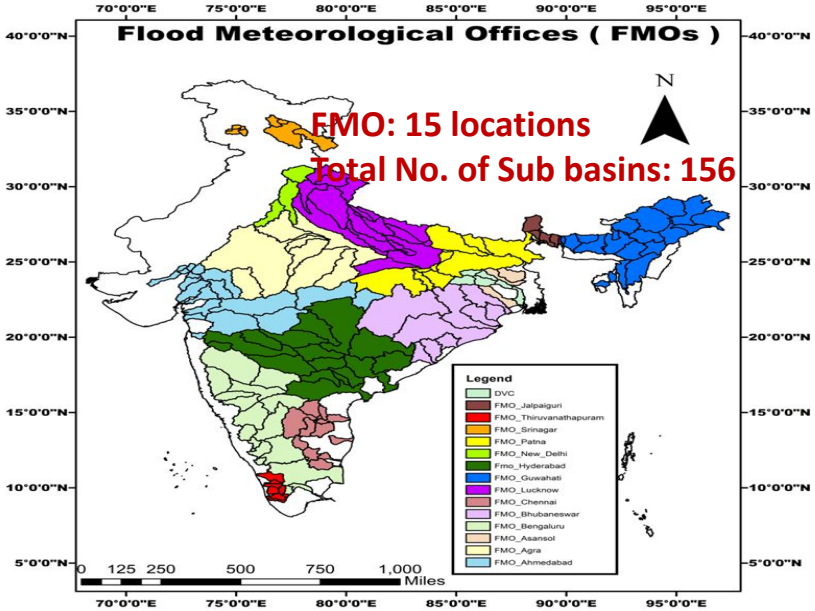
Riverine Flood Forecasting (Quantitative Precipitation Forecast)

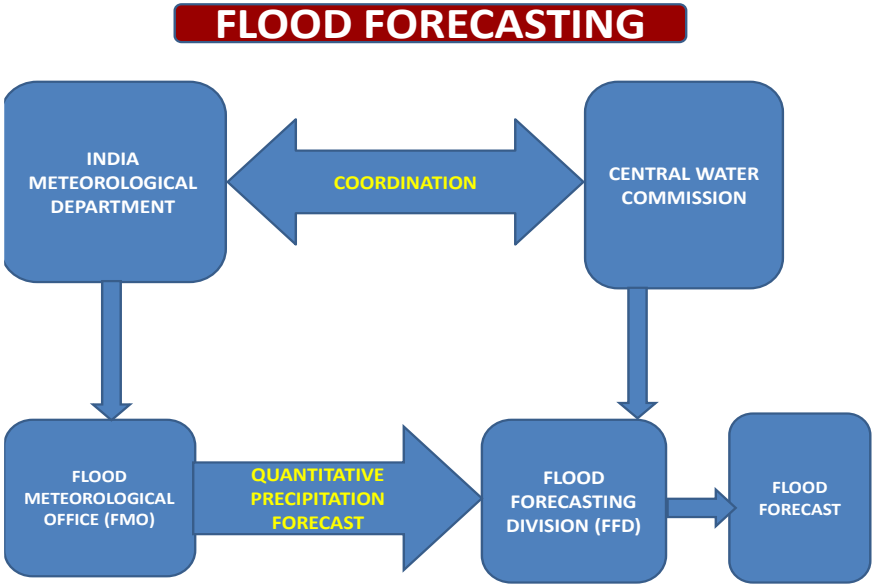
In India Flood Forecasting activity is the joint responsibility of

- **India Meteorological Department**
- **Central Water Commission.**

IMD provides Hydromet Input through their Flood Meteorological Offices(FMOs).

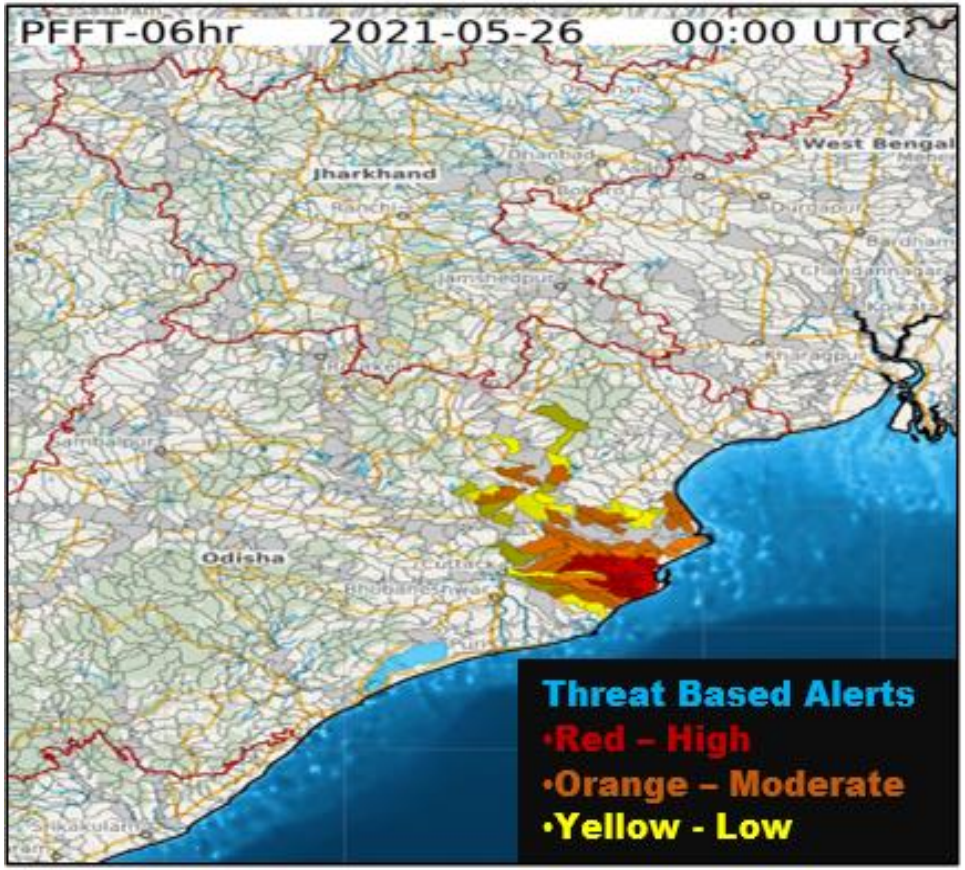
In hydromet input, Quantitative Precipitation Forecast (QPF) is the main input which is used in rainfall runoff models by CWC.





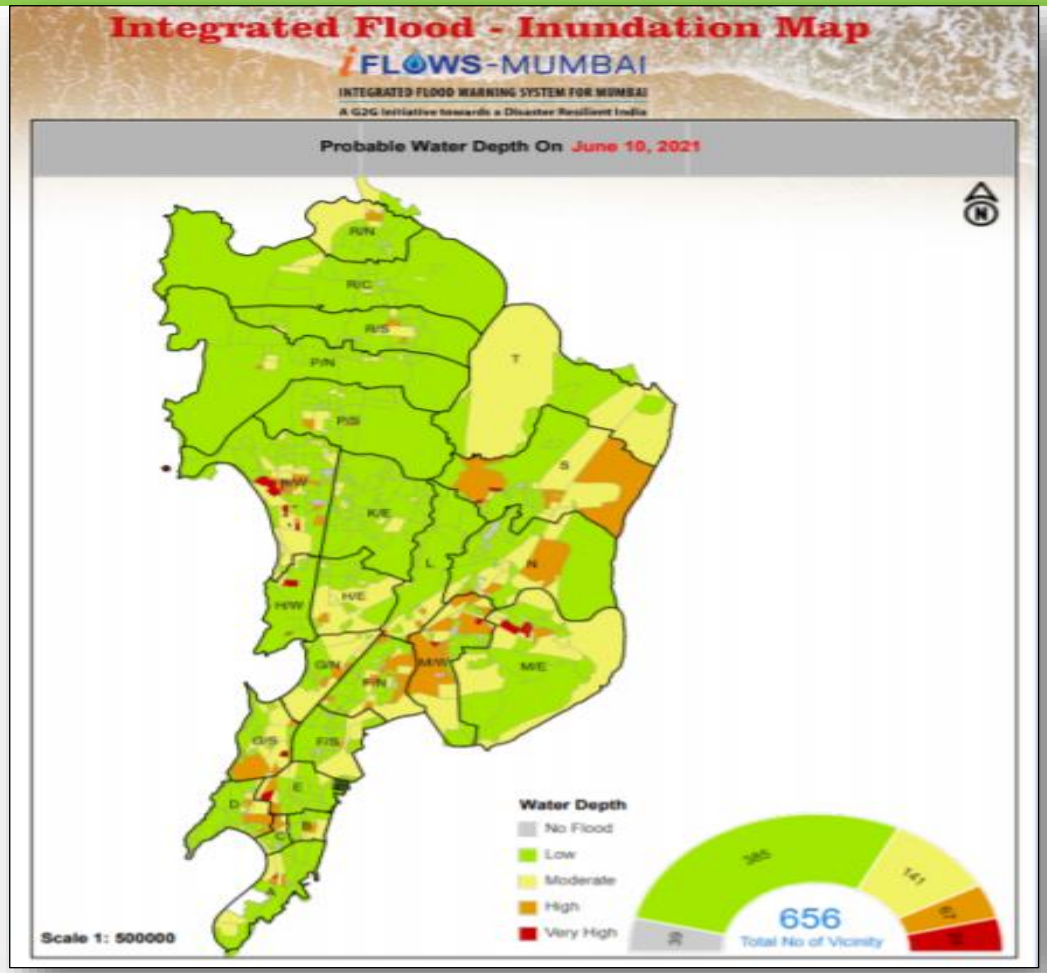
Flash Flood Forecasting

South Asia Flash Flood Guidance System (SAsiaFFGS)



- **Guidance for Bangladesh, Bhutan, India, Nepal, Sri Lanka.**
- **High resolution (4X4 km) and 30000 watersheds over Indian region.**
- **Capable of issuing flash flood Threat and risk for next 6 and 24 hours respectively.**

Urban Flood Forecasting



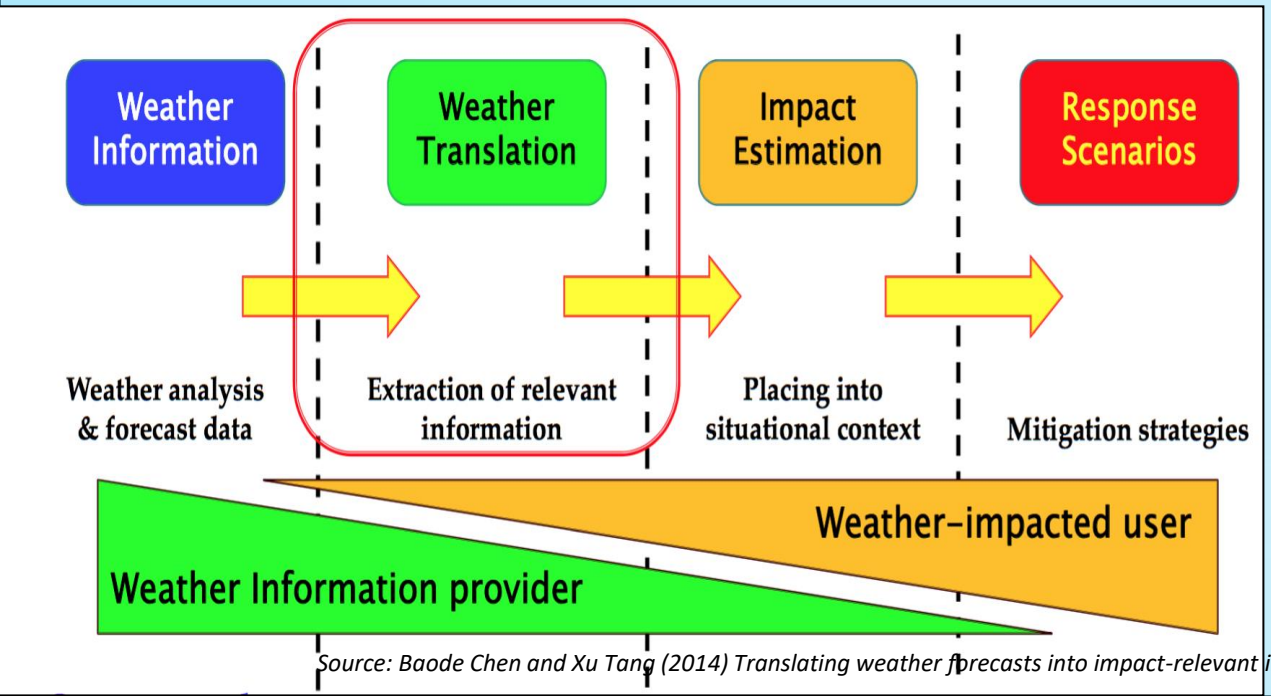
City Specific Flood Forecast (Integrated Flood Warning

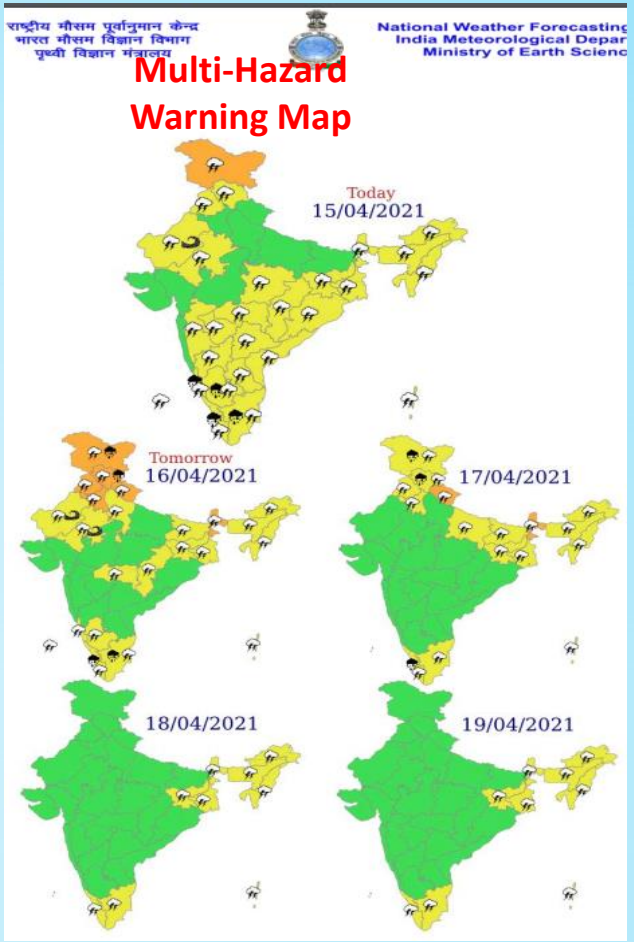
- Implemented at Mumbai and Chennai City.
- Ward-wise probable water depth/inundation.

Code	Water Depth (feet)
	No flood
	3-4
	4-5
	5-6
	>6

Impact-based Forecasting in IMD

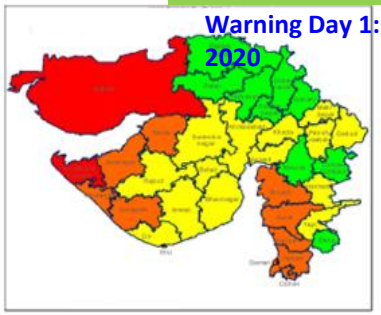
- Relevant information from weather forecast is extracted and placed into situation context to produce impact estimations;
- With potential impact information, response scenarios are set-up
- Targeted Hazards: Cyclone, Heavy rain/flood, Thunderstorm, Heat/cold wave

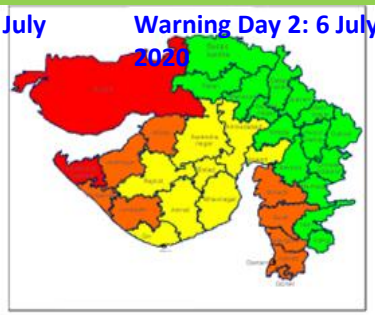


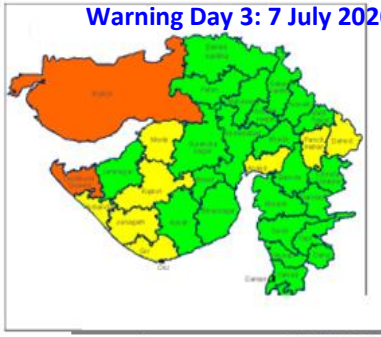


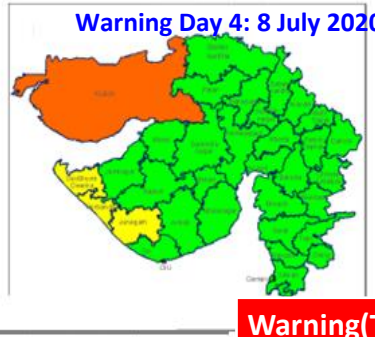
Source: Baode Chen and Xu Tang (2014) Translating weather forecasts into impact-relevant information

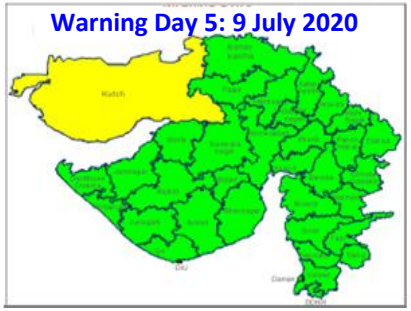
Impact Based Forecast(IBF) and Warnings for Heavy Rain











Warning(Take Action)
Alert(Be Prepared)
Watch (Be Updated)
No Warning (No Action)

IMPACT BASED FORECAST

Expected Impact with respect to red colour warning issued for the Districts namely Devbhoomi Dwarka, Porbandar, Jamnagar, Kutch:

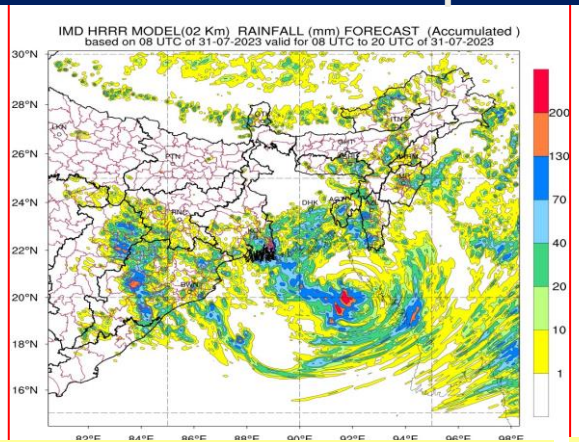
- ✓ Major damage to kuchcha roads due to inundation.
- ✓ Major disruption in traffic in city areas.
- ✓ Inundation of low lying areas leading to damage to kuchcha houses.
- ✓ Water logging in underpass in city areas.
- ✓ Sudden reduction in visibility during heavy downpour leading to road accidents.

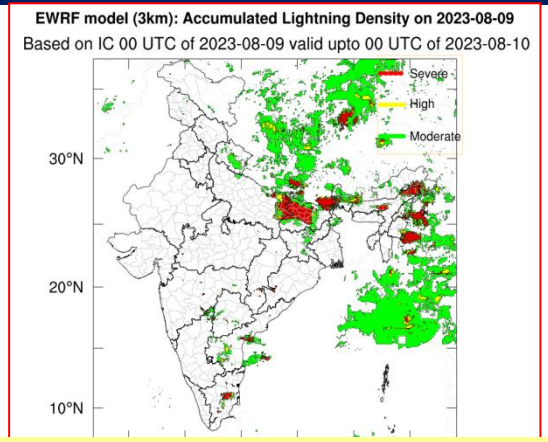
IBF & Warning Stages

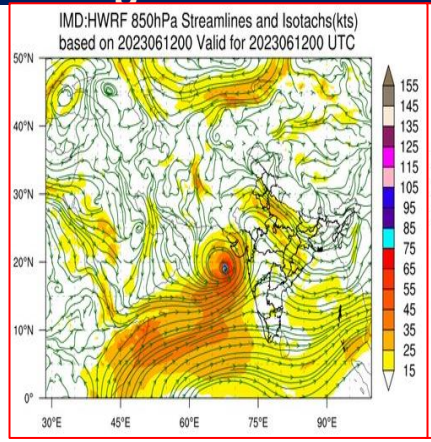
- **Stage -1: Heavy rainfall Watch-(3-4 days lead time daily update)**
- **Stage-2: Heavy rainfall Alert: (48 hours prior to the occurrence of event at 12 hourly updates)**
- **Stage-3: Heavy rainfall Warning (24 hours prior to the occurrence of event at 06/12-hourly updates)**
- **Stage-4: 12-Hours prior to occurrence event–at 3-hourly updates.**

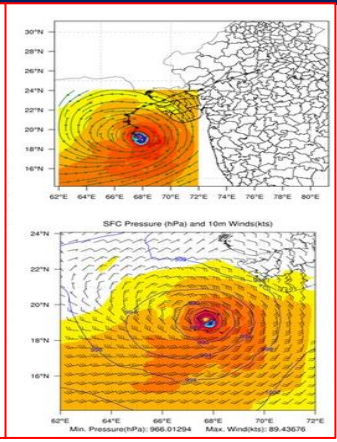
Temporal scales	Numerical NWP/Climate Models	Resolutions and Frequency of Update
Nowcasting to short range forecasting	• Weather Research Forecast (WRF) regional models • HRRR (with radar data assimilation) • E-WRF (with lightning data assimilation) • Coupled Hurricane WRF (HWRF)	• 03 km run for 3 days (Run 4 times a day) 00, 06, 12 & 18 UTC) • Run for 3 domains, 2 km resolution with forecast for 12 hours. (every 2 hrs) • Run 2 times a day (2 km Resl. 24 hr forecast • 18x6x2 km (During cyclone time) for 5 days
Medium range forecast	• Global Forecast System (GFS) Model • Global Ensemble Forecast System (GEFS)	• 12 km (Run four times a day ; 00, 12 UTC) for 10 days and 06 & 18 for 3 days) • 12 km (00 UTC) for 10 days; 20 Members
Extended range (ERF)	• Climate Forecast System (CFS) coupled models (16 members) with hidcast of 20 Years (2003-2020).	• 38 km (Run once in a week) for 32 days. Run based on every Wednesday and forecast is prepared for 4 weeks.
Multi-Model Ensemble (MME)	• MME forecast based on 6 Global models. (IMD-GFS, IMD-GEFS, NCEP-GFS, NCUM, JMA and ECMWF) • MME based track & intensity with 8 models – IMDGFS, ECMWF, NCEP, NCUM-G, NCUM-R, HWRF, UKMO, ECCC	• Regridded into 12km x12km and customized products are prepared based on all 6 models for 7 days. • Prepared during the cyclone time and used for operational forecast.

Examples of Some NWP Products Based on Regional Models





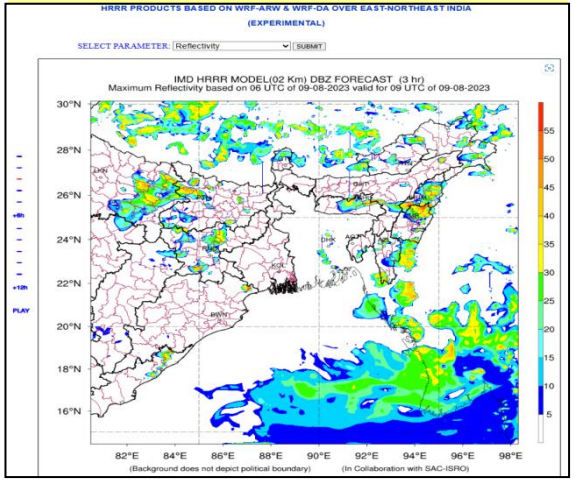


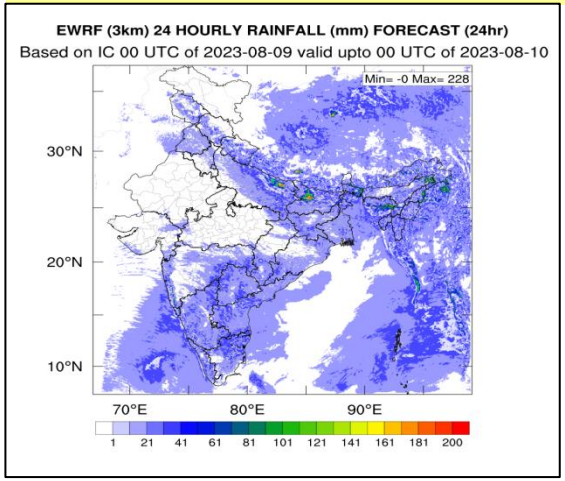


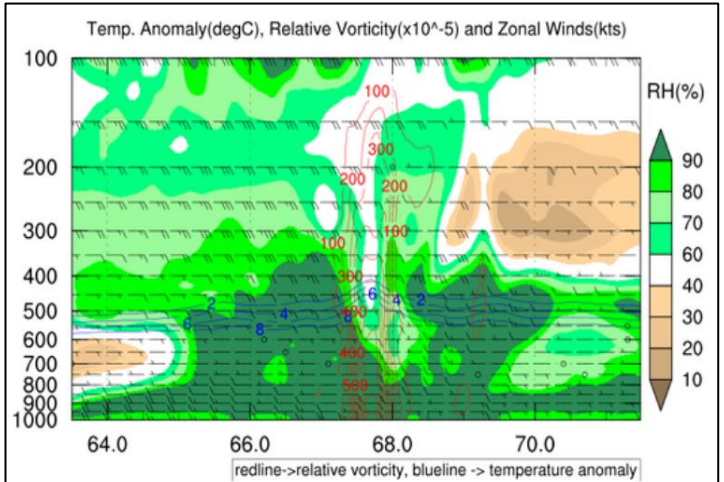
HRRR Rainfall Forecast & Reflectivity

EWRF Lightning density & Accumulated Rainfall

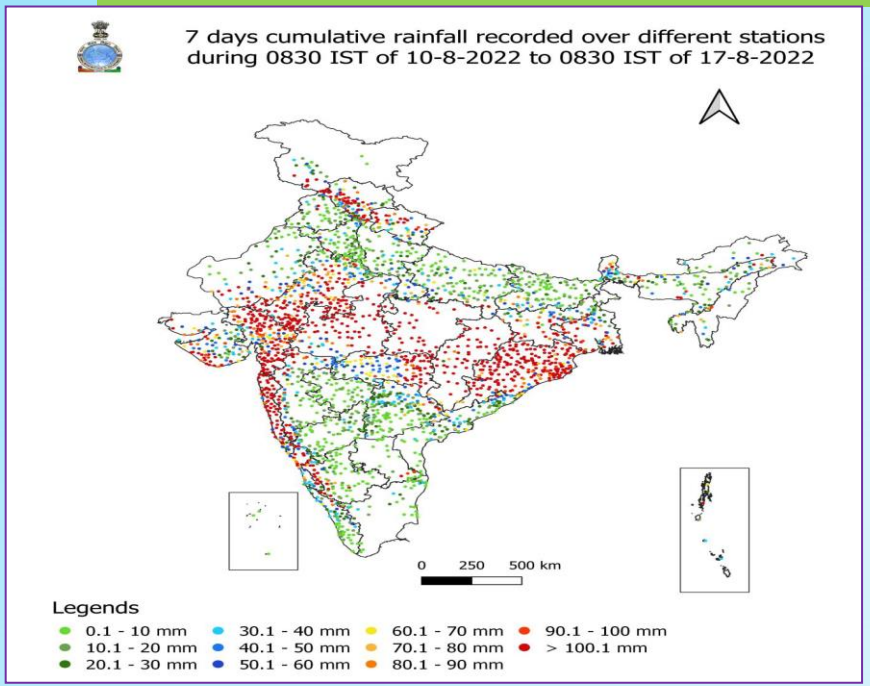
HWRF : TC Rainfall Forecast & Vorticity

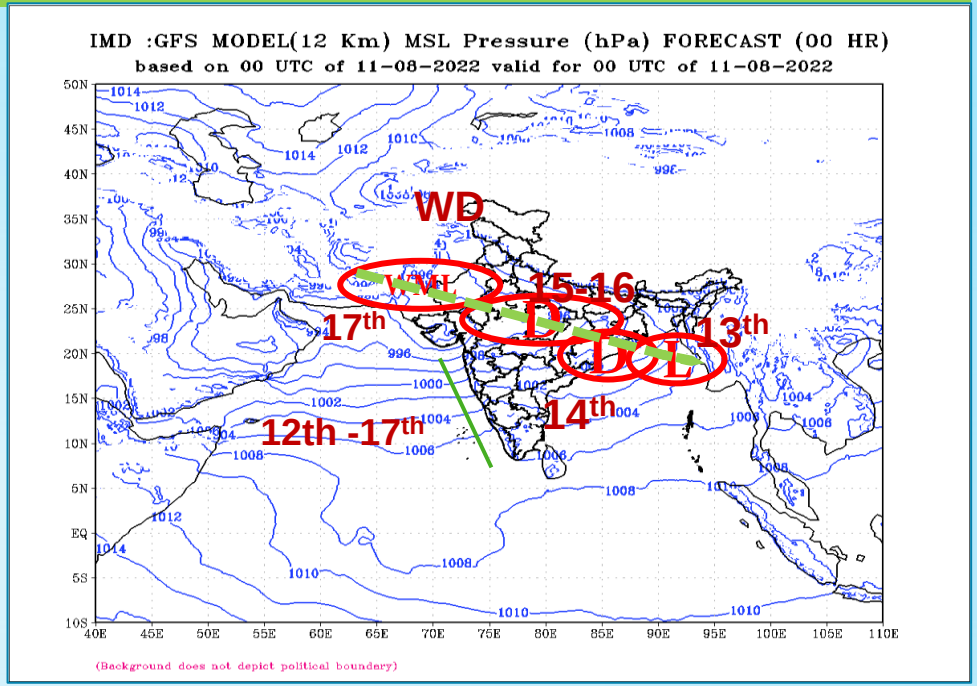






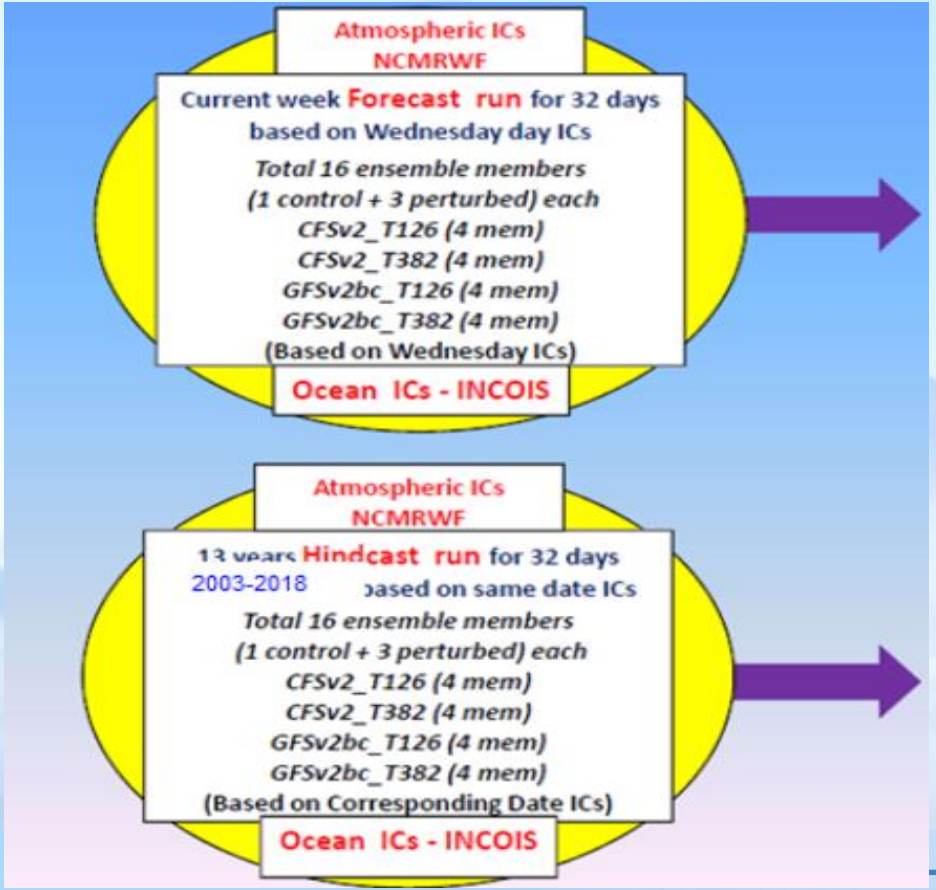
Major Synoptic Systems During the Last Week (11-17 August) 2022





- **Monsoon System-:** from 13th to 18th August
- **Monsoon trough**: Passes through the system (Mostly south of the normal position).
- **Western Disturbance**
- **Off-Shore Trough**: 12th to 17th August

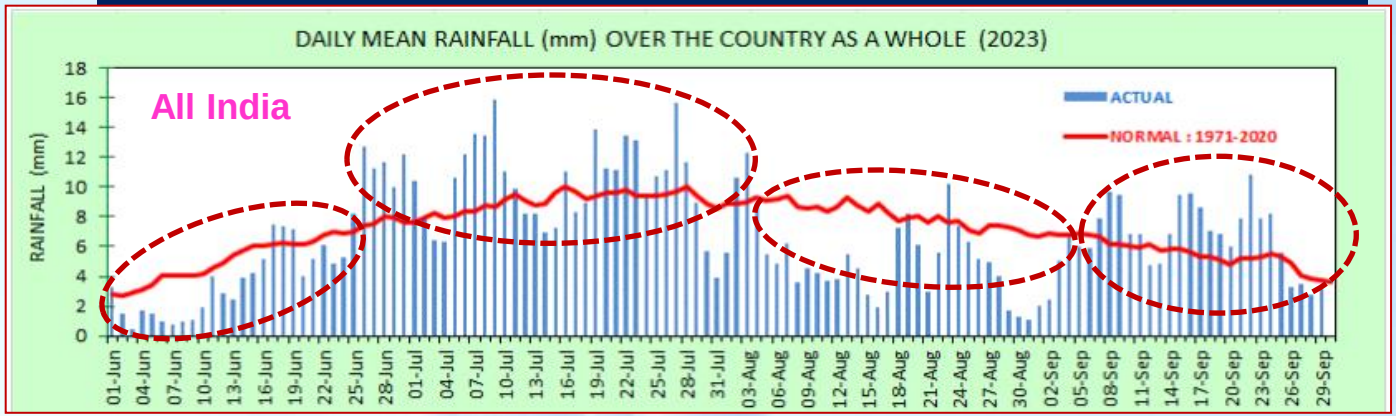
IMD's Operational Extended Range Forecast (ERF) System

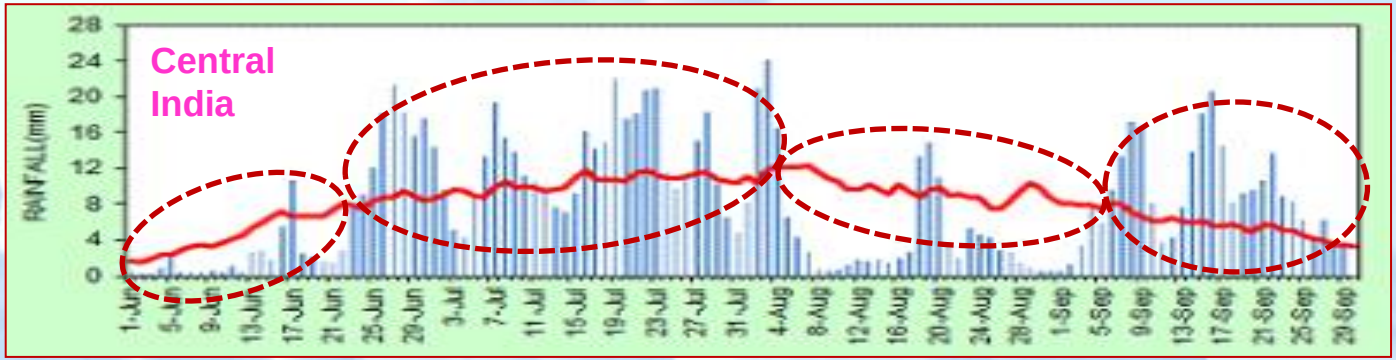


Bias Corrected
Forecasts for 4 Week
(Wind,Rainfall,Tmax,Tmin)
And its anomaly
Friday to Thursday

Week 1:(23 - 29 Feb 2024)
Week 2:(01- 07 Mar 2024)
Week 3:(08 – 14 Mar 2024)
Week 4:(15 – 21 Mar 2024)

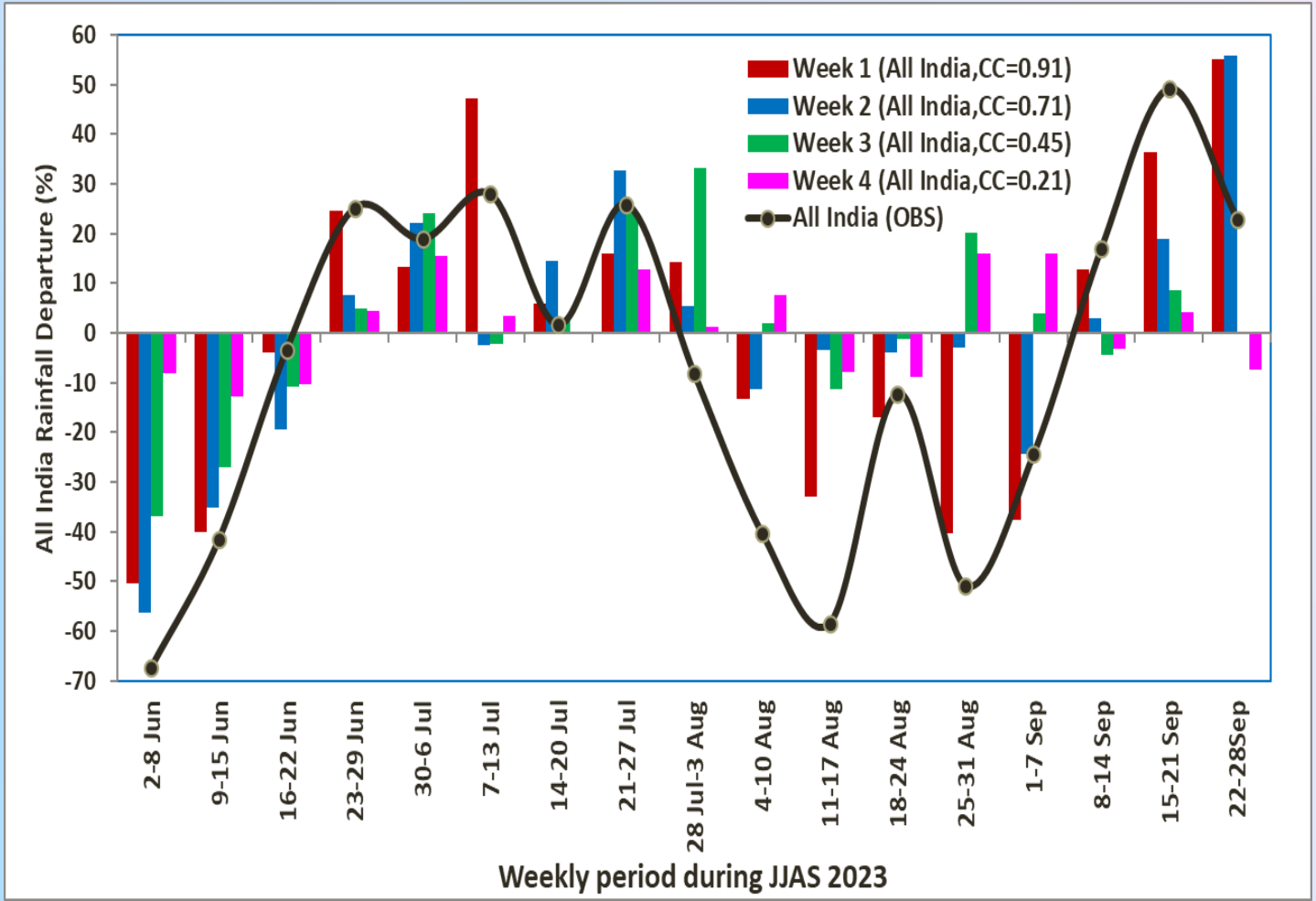
Daily All India and Central India Rainfall Time Series (Jun to Sep, 2023)





Intra-seasonal variability of monsoon is characterised by : Delayed and weak onset; Weak June, Active July, Weak August; Active September associated with delayed withdrawal of monsoon from many parts of northwest India

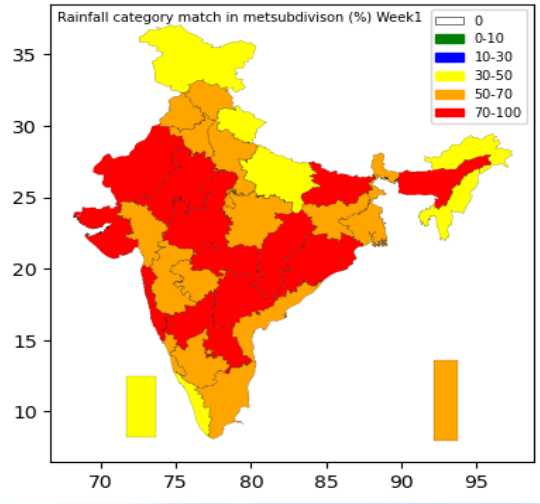
Quantitative Verification (All India)

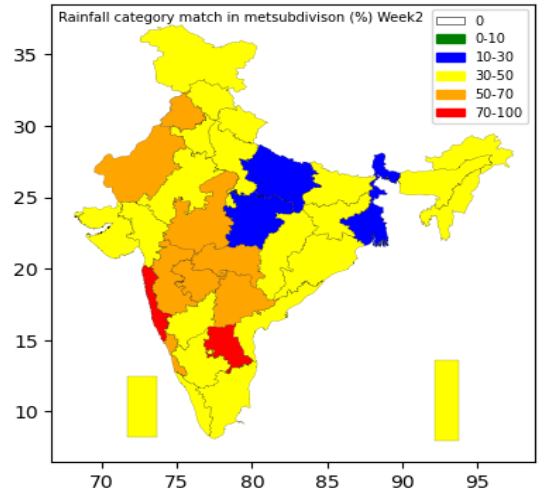


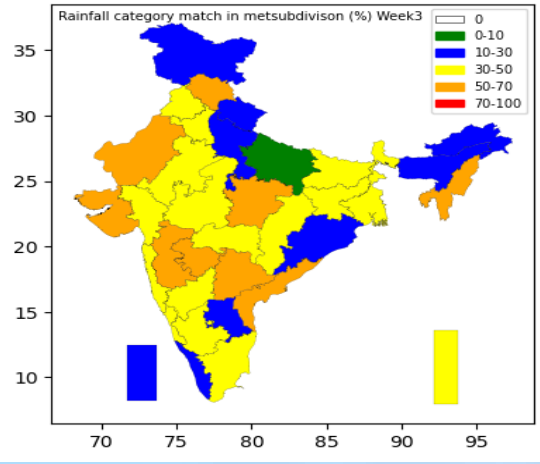
Category for verification of Met-Subdivision level forecast

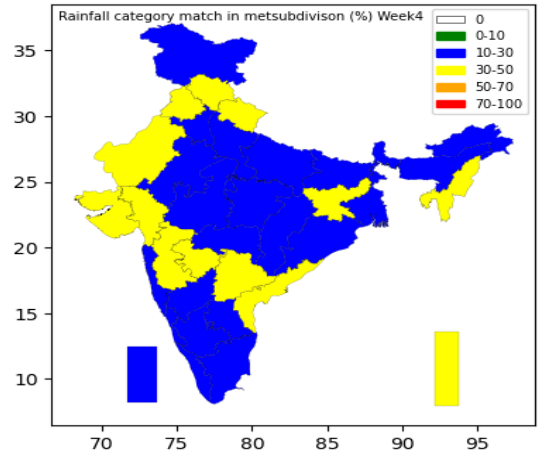
Categories	Hydrological	Agriculture
Large Excess (LE)	+60% or more	Above Normal (AN)
Excess (E)	+20% to +59%	
Normal (N)	+19% to -19%	Normal (N)
Deficient (D)	-20% to -59%	Below Normal (BN)
Large Deficient (LD)	-60% to -99%	
No Rain (NR)	-100%	

Percentage of correct category subdivisions

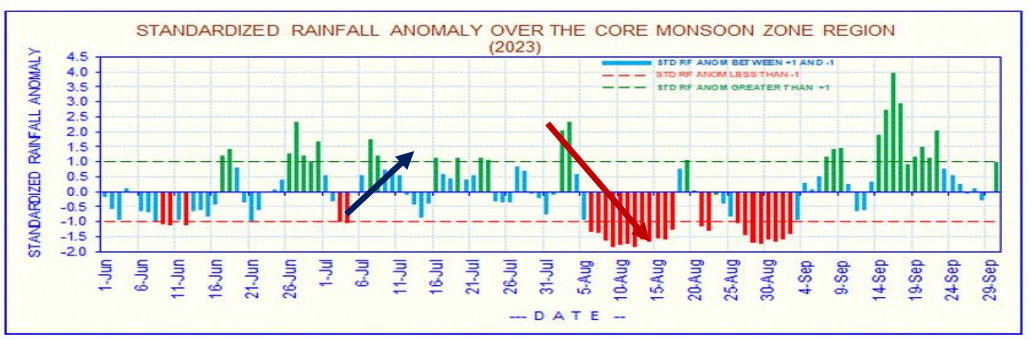


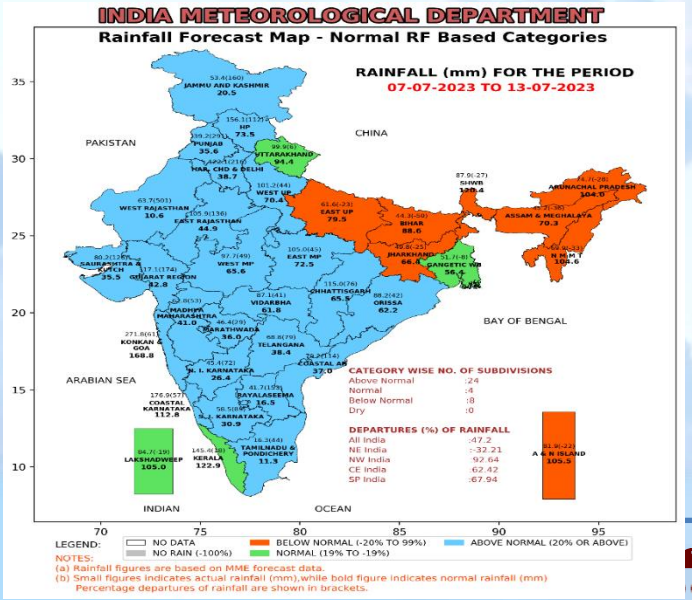


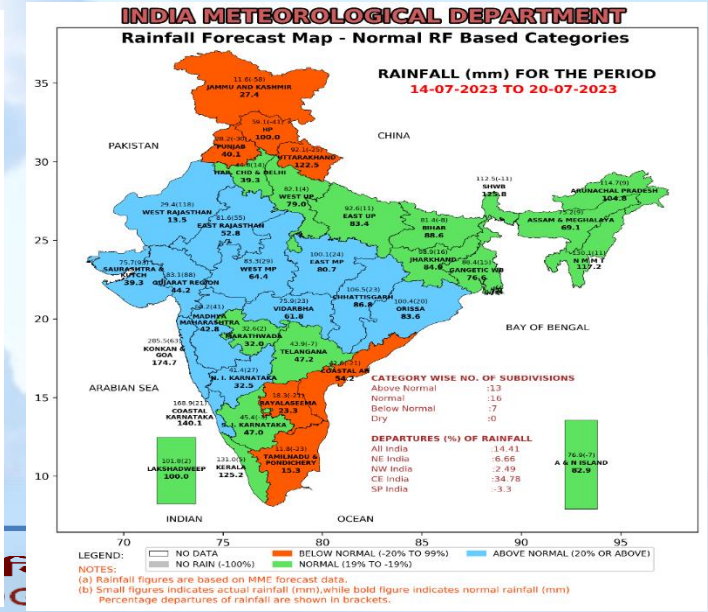




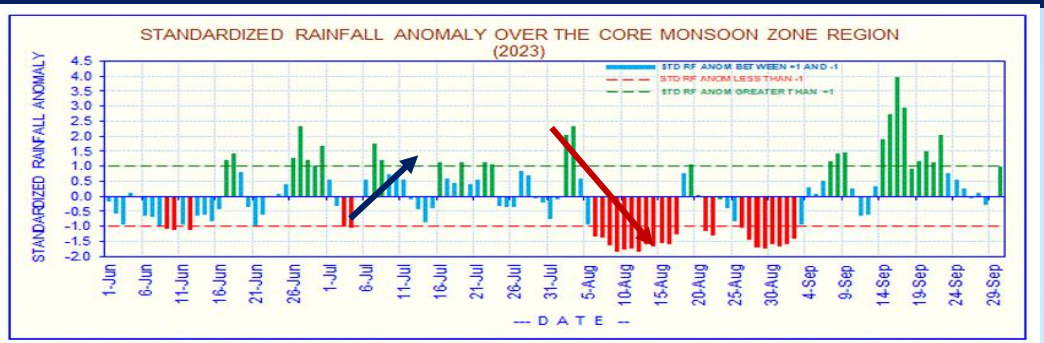
Forecast for Active July (Based on ERF IC of 05 July 2023)

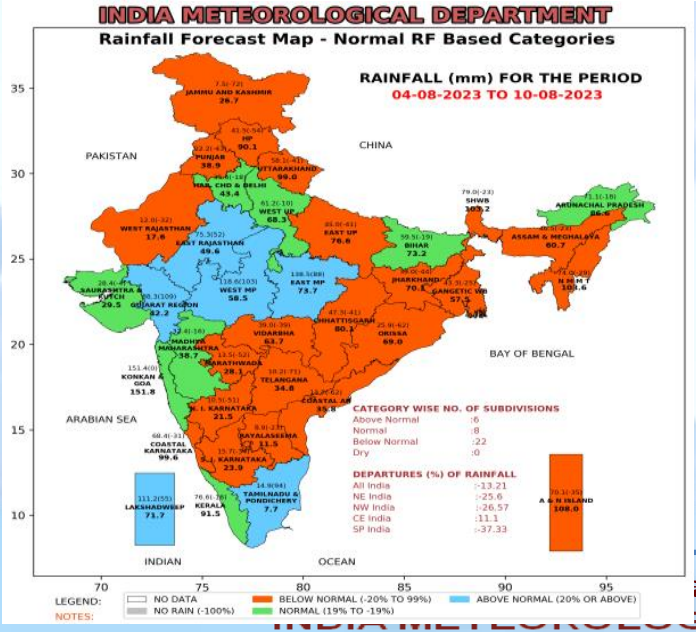


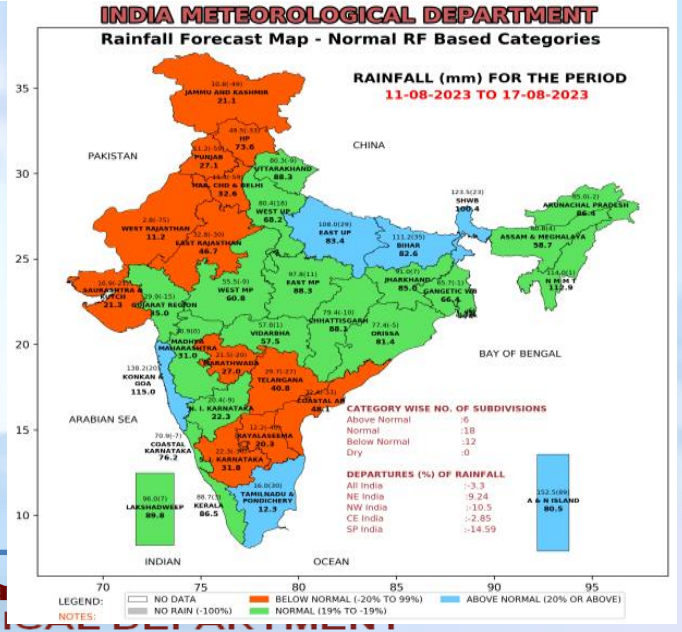




Forecast for Weak August (Based on IC of 02 August 2023)

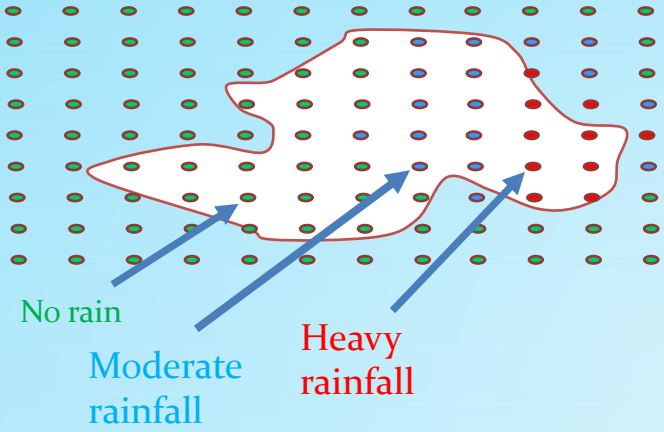






MME based heavy rainfall forecast-Methodology

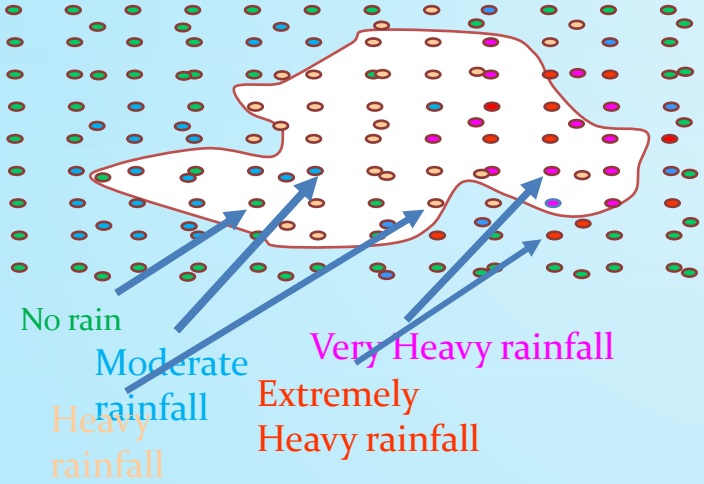
Model-1



Inside this polygon
Total grid points: 51
No of grid points showing moderate rainfall: 7
No of grid points showing heavy rainfall: 21
No of grid points showing very heavy rainfall: 12
No of grid points showing Ex. heavy rainfall: 4
Here,

- distribution of Heavy rainfall= = 41% (Scattered)
- distribution of Very Heavy rainfall= =23% (Isolated)
- distribution of Ex. Heavy rainfall= 8% (Isolated)

Multiple models



NWP Model data used

	Model	Agency	Resolution
1	IMD-GFS	IMD	12 km
2	GEFSmean	IMD	12 km
3	GFS	NCEP	25 km
4	UM	NCMRWF	12 km
5	GSM	JMA	25 km
6	NEPSmean	NCMRWF	12km
7	IFS	ECMWF	20 km

MME Based Met subdivision wise (36) Rainfall distribution and intensity forecast for 7 days

Distribution : DRY, ISOl, SCT, FWP, WS

Intensity :

AMOUNT	CATEGORY		AMOUNT	CATEGORY	
NIL	NO RAIN		64.5-115.5	HEAVY	
1-15	LIGHT		115.6-204.4	VERY-HEAVY	
15.1-64.4	MODERATE		>=204.5	EXTREMELY-HEAVY	

NUMERICAL WEATHER PREDICTION DIVISION

HOME | ARCHIVE | SWFP-SA | PUBLICATIONS | ALL MODELS >> | NOWCAST >> | SHORT RANGE FORECAST >> | MEDIUM RANGE FORECAST >> | EXTENDED RANGE FORECAST >>

DAY-01 | DAY-02 | DAY-03 | DAY-04 | DAY-05 | DAY-06 | DAY-07

Please check the Date of Rainfall Distribution Forecast as different Models has different updation time

DAY-01 SUB-DIVISION RAINFALL DISTRIBUTION FORECAST

S.NO.	SUB-DIVISION	BASED ON:00Z09082023 :VALID FOR:10082023	BASED ON:00Z09082023 :VALID FOR:10082023	BASED ON:00Z09082023 :VALID FOR:10082023	BASED ON:00Z09082023 :VALID FOR:10082023	BASED ON:00Z09082023 :VALID FOR:10082023	BASED ON:12Z08082023 :VALID FOR:10082023	BASED ON:00Z09082023 :VALID FOR:10082023	BASED ON:00Z09082023 :VALID FOR:10082023
		GFS	JMA	NCUM	NCEP_GFS	GEFS	NEPS	ECMWF	MME
01	A & N ISLAND	WS	FWS	WS	WS	WS	WS	FWS	WS
02	ARUNACHAL PRADESH	FWS	FWS	WS	WS	FWS	WS	WS	WS
03	ASSAM & MEGHALAYA	WS	FWS	WS	WS	WS	WS	WS	WS
04	N M M T	WS	FWS	WS	WS	WS	WS	WS	WS
05	SHWB & SIKKIM	WS	FWS	WS	FWS	WS	WS	WS	WS
06	GANGETIC WEST BENGAL	FWS	WS	WS	FWS	WS	WS	WS	WS
07	ORISSA	ISOL	ISOL	SCT	SCT	SCT	FWS	ISOL	SCT
08	JHARKHAND	FWS	WS	WS	FWS	WS	WS	SCT	FWS
09	BIHAR	WS	WS	WS	WS	WS	WS	WS	WS
10	EAST UTTAR PRADESH	WS	WS	SCT	FWS	WS	WS	FWS	WS
11	WEST UTTAR PRADESH	ISOL	SCT	ISOL	SCT	SCT	SCT	ISOL	SCT
12	UTTARAKHAND	FWS	WS	FWS	WS	FWS	WS	FWS	FWS
13	HAR. CHD & DELHI	DRY	DRY	SCT	ISOL	ISOL	ISOL	ISOL	ISOL
14	PUNJAB	SCT	ISOL	SCT	ISOL	SCT	SCT	SCT	SCT
15	HIMACHAL PRADESH	SCT	ISOL	SCT	SCT	ISOL	SCT	ISOL	SCT
16	JAMMU AND KASHMIR	ISOL	ISOL	ISOL	ISOL	ISOL	ISOL	ISOL	ISOL
17	WEST RAJASTHAN	DRY	DRY	DRY	DRY	ISOL	DRY	DRY	DRY
18	EAST RAJASTHAN	ISOL	ISOL	ISOL	DRY	DRY	ISOL	ISOL	ISOL
19	WEST MADHYA PRADESH	ISOL	ISOL	ISOL	ISOL	ISOL	ISOL	ISOL	ISOL
20	EAST MADHYA PRADESH	ISOL	ISOL	ISOL	DRY	ISOL	SCT	ISOL	ISOL

NUMERICAL WEATHER PREDICTION DIVISION

HOME | ARCHIVE | SWFP-SA | PUBLICATIONS | ALL MODELS >> | NOWCAST >> | SHORT RANGE FORECAST >> | MEDIUM RANGE FORECAST >> | EXTENDED RANGE FORECAST >>

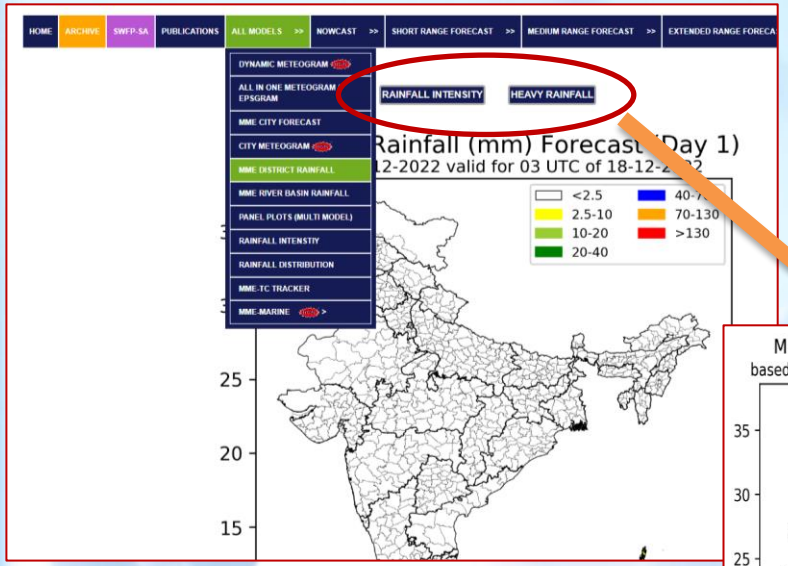
DAY-01 | DAY-02 | DAY-03 | DAY-04 | DAY-05 | DAY-06 | DAY-07

Please check the Date of Rainfall Intensity Forecast as different Models has different updation time

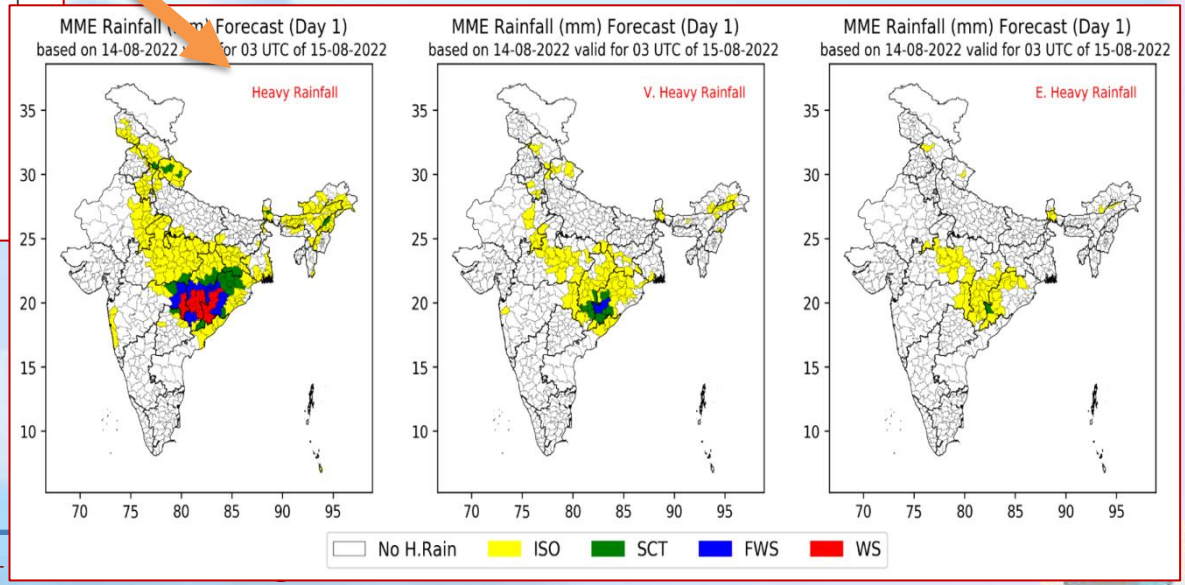
DAY-01 SUB-DIVISION HEAVY RAINFALL FORECAST

S.NO.	SUB-DIVISION	BASED ON:00Z09082023 :VALID FOR:10082023	BASED ON:00Z09082023 :VALID FOR:10082023	BASED ON:00Z09082023 :VALID FOR:10082023	BASED ON:00Z09082023 :VALID FOR:10082023	BASED ON:00Z09082023 :VALID FOR:10082023	BASED ON:12Z08082023 :VALID FOR:10082023	BASED ON:00Z09082023 :VALID FOR:10082023	BASED ON:00Z09082023 :VALID FOR:10082023
		GFS MEAN(MAX)	JMA MEAN(MAX)	NCUM MEAN(MAX)	NCEP_GFS MEAN(MAX)	GEFS MEAN(MAX)	NEPS MEAN(MAX)	ECMWF MEAN(MAX)	MME MEAN(MAX)
01	A & N ISLAND	7 (24)	4 (9)	8 (21)	7 (15)	7 (14)	9 (13)	6 (20)	6 (16)
02	ARUNACHAL PRADESH	17 (225)	10 (119)	18 (274)	15 (151)	11 (81)	17 (66)	22 (91)	17 (147)
03	ASSAM & MEGHALAYA	16 (89)	6 (38)	17 (147)	19 (93)	13 (65)	15 (73)	11 (58)	15 (85)
04	N M M T	19 (131)	12 (79)	11 (75)	14 (60)	17 (75)	11 (42)	11 (48)	13 (71)
05	SHWB & SIKKIM	15 (86)	15 (82)	14 (76)	7 (18)	9 (31)	12 (29)	18 (48)	15 (57)
06	GANGETIC WEST BENGAL	4 (15)	17 (48)	7 (32)	5 (16)	5 (12)	8 (23)	9 (33)	9 (31)
07	ORISSA	3 (43)	1 (10)	3 (15)	3 (19)	3 (27)	4 (21)	2 (14)	2 (21)
08	JHARKHAND	5 (22)	11 (78)	6 (36)	5 (28)	7 (18)	9 (41)	6 (45)	6 (41)
09	BIHAR	10 (41)	27 (78)	24 (328)	19 (92)	14 (32)	26 (64)	25 (114)	19 (101)
10	EAST UTTAR PRADESH	34 (281)	16 (46)	29 (403)	11 (88)	28 (74)	21 (88)	29 (504)	23 (174)
11	WEST UTTAR PRADESH	3 (48)	4 (28)	5 (191)	3 (19)	5 (28)	6 (101)	2 (20)	4 (61)
12	UTTARAKHAND	11 (91)	12 (74)	11 (99)	10 (29)	8 (42)	12 (67)	6 (32)	10 (66)
13	HAR. CHD & DELHI	1 (2)	1 (3)	2 (14)	2 (5)	1 (25)	2 (6)	1 (4)	1 (8)
14	PUNJAB	3 (29)	1 (4)	4 (22)	1 (6)	3 (20)	3 (14)	5 (18)	3 (18)
15	HIMACHAL PRADESH	3 (50)	1 (8)	3 (54)	2 (9)	3 (33)	3 (15)	2 (10)	2 (25)
16	JAMMU AND KASHMIR	1 (69)	1 (31)	1 (50)	1 (6)	1 (21)	1 (21)	1 (9)	1 (30)
17	WEST RAJASTHAN	1 (4)	1 (1)	1 (3)	1 (2)	1 (6)	1 (1)	1 (3)	0 (2)
18	EAST RAJASTHAN	1 (4)	1 (7)	1 (4)	1 (3)	1 (3)	1 (4)	1 (10)	0 (4)
19	WEST MADHYA PRADESH	1 (4)	1 (6)	2 (13)	1 (4)	1 (4)	2 (8)	2 (13)	1 (6)
20	EAST MADHYA PRADESH	1 (22)	1 (4)	2 (5)	1 (3)	2 (27)	3 (11)	2 (4)	1 (11)
21	GUJARAT REGION	2 (6)	4 (12)	2 (7)	2 (5)	2 (7)	2 (5)	3 (7)	2 (7)
22	SAURASHTRA & KUTCH	2 (4)	2 (7)	1 (2)	2 (3)	2 (4)	1 (3)	2 (6)	1 (4)

MME products at district scale for Heavy Rainfall

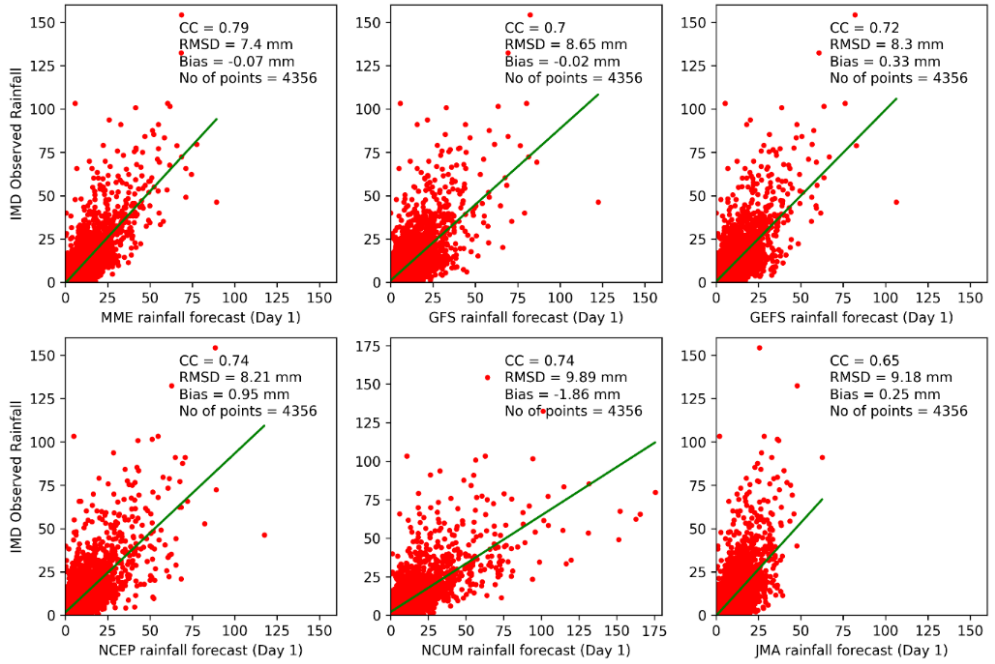


- Forecast up to day 5.
- Both mean rainfall at each districts.
- Updates two times in a day (10.15 am, and 12.30 pm)
- Heavy rainfall forecast also available in the website.
- Individual model based forecast including heavy rainfall forecast are also available at GIS platform.

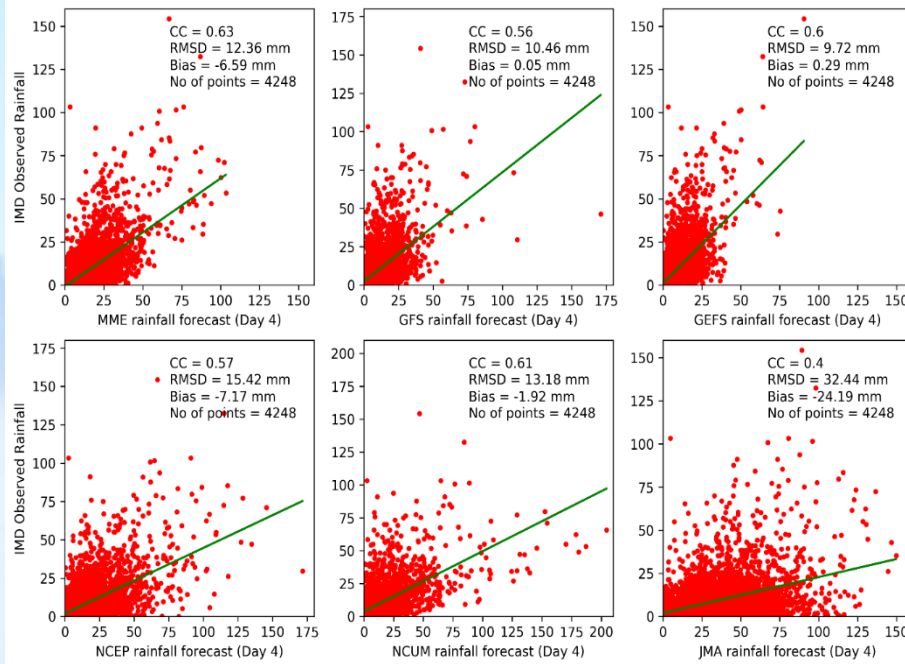


Verification of rainfall intensity over meteorological sub divisions (2023)

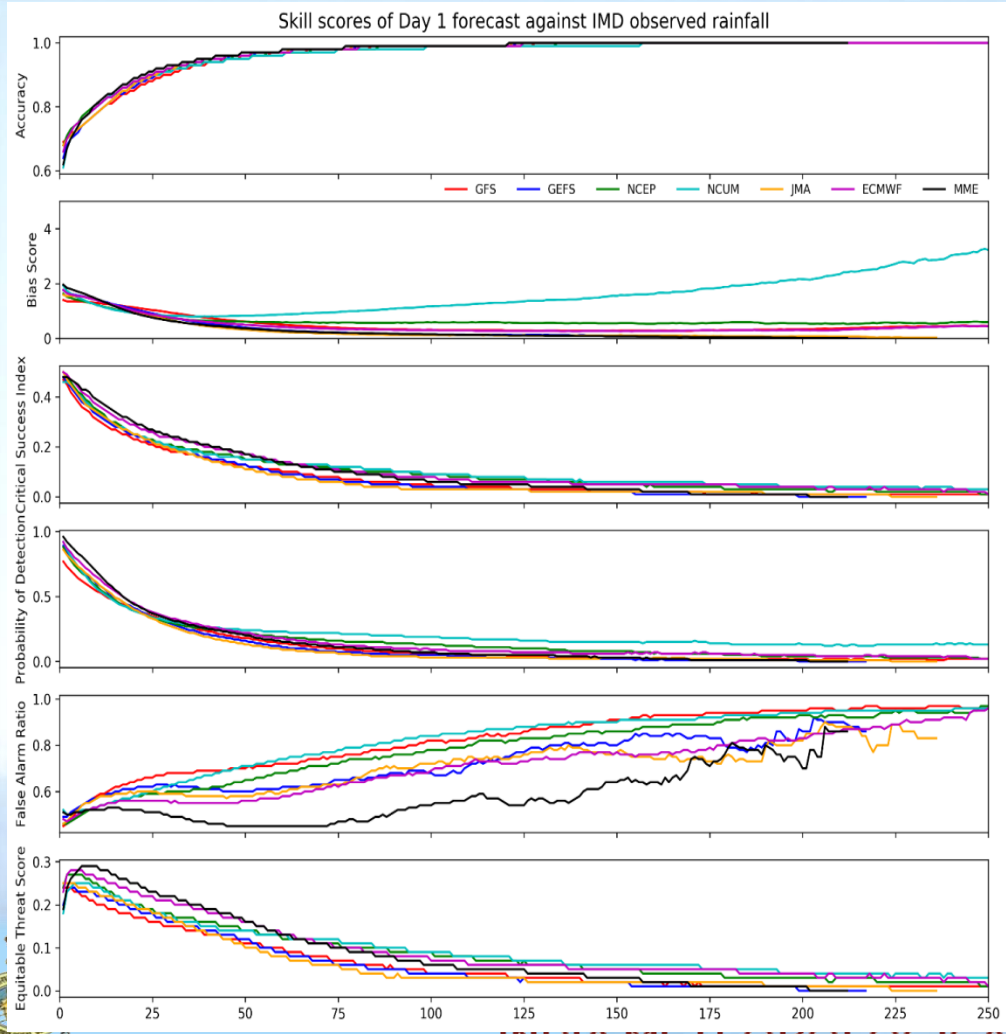
MME DAY1



MME DAY4



➢ MME performing well in terms of CC and RMSE



Skill scores of station rainfall predicted from various models at different rainfall thresholds

- As rainfall thresholds are increasing, different skill scores (POD, CSI, CTS) are reducing.

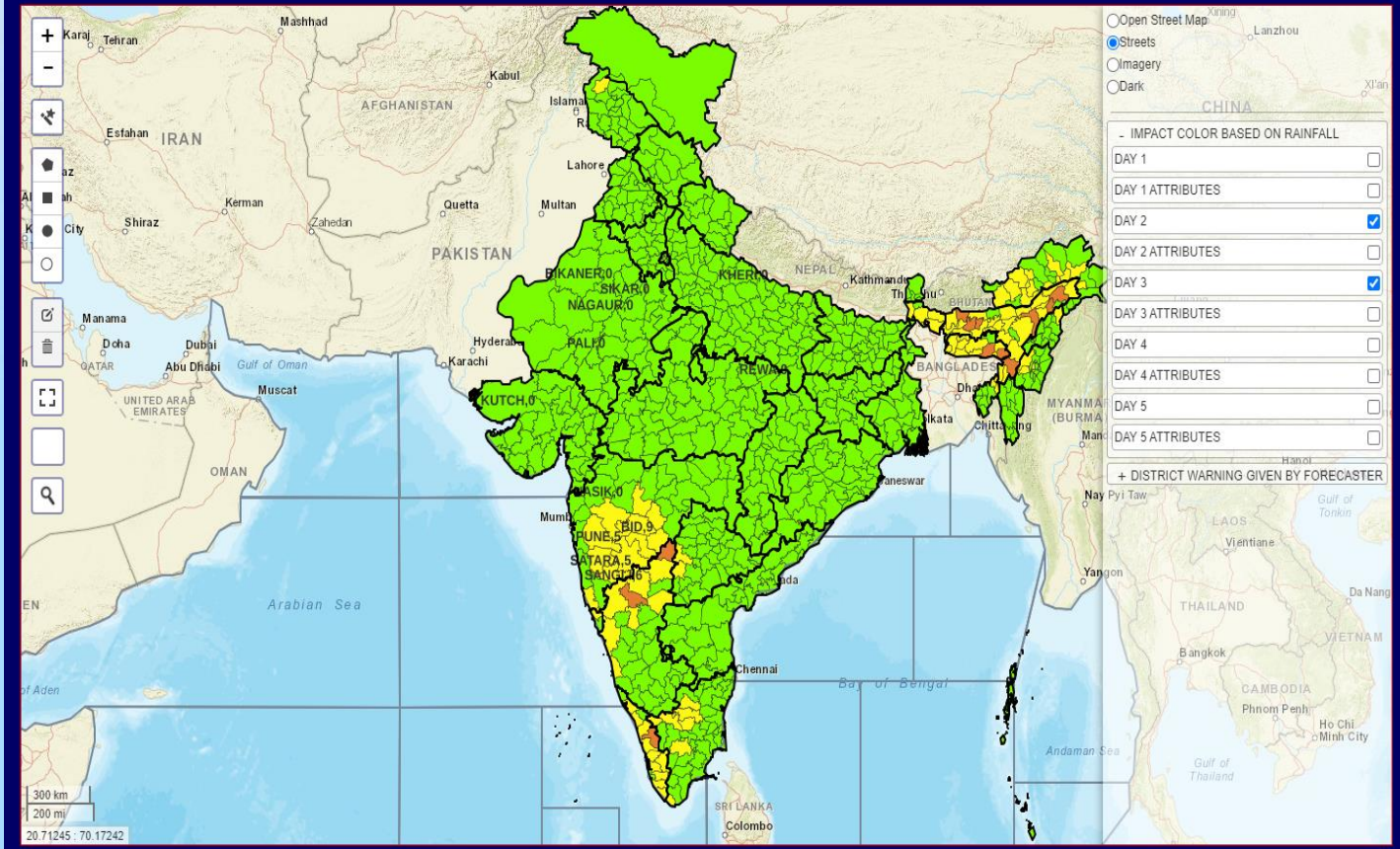
INTERACTIVE MAP FOR HEAVY RAINFALL

INDIA METEOROLOGICAL DEPARTMENT, NEW DELHI

MINISTRY OF EARTH SCIENCES

OBSERVATION | EXPOSURE | DISTRCT WISE | METSUBDIV WISE | MODEL ORIGINAL | FLASH FLOOD | IMPACT MATRIX | EXPOSURE_DETAIL | ABOUT

Export Features

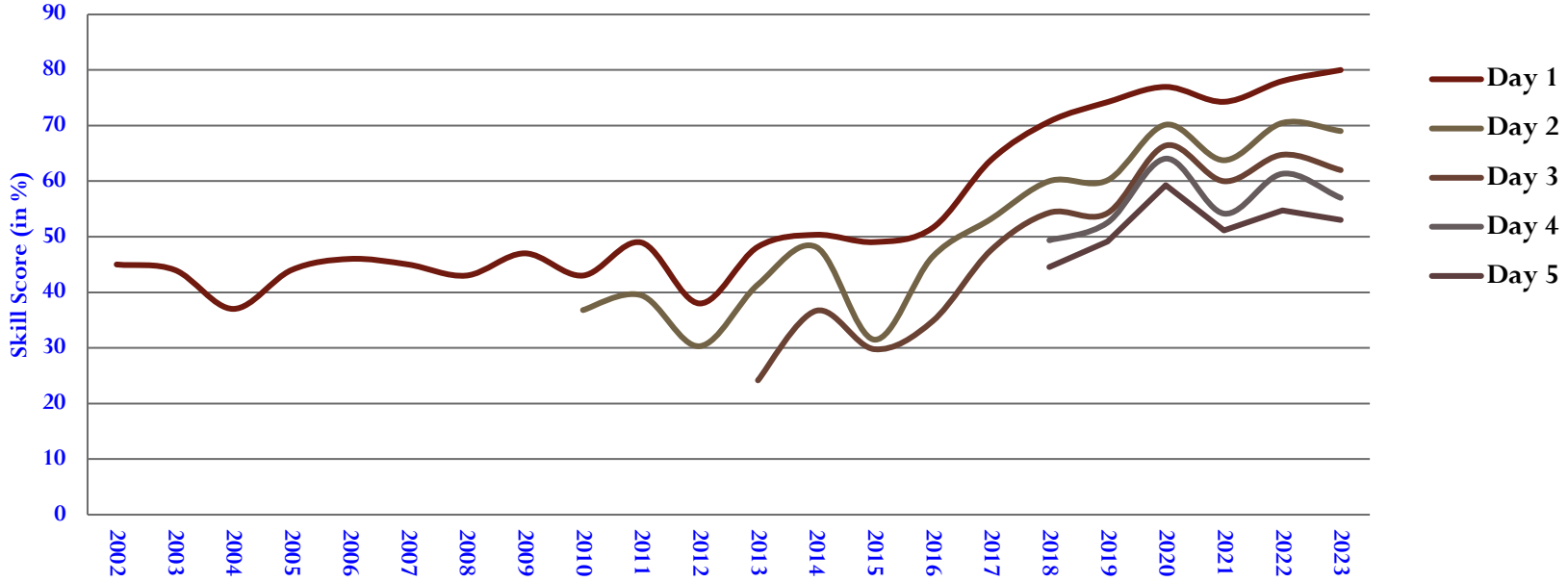


	NHR	HR	VH	EH
>90%	4	8	12	16
60-90%	3	7	11	15
30-60%	2	6	10	14
00-30%	1	5	9	13

NHR: NO HEAVY RAINFALL
HR: HEAVY RAINFALL
VH: VERY HEAVY RAINALL
EH: EXTREMELY HEAVY RAINFALL

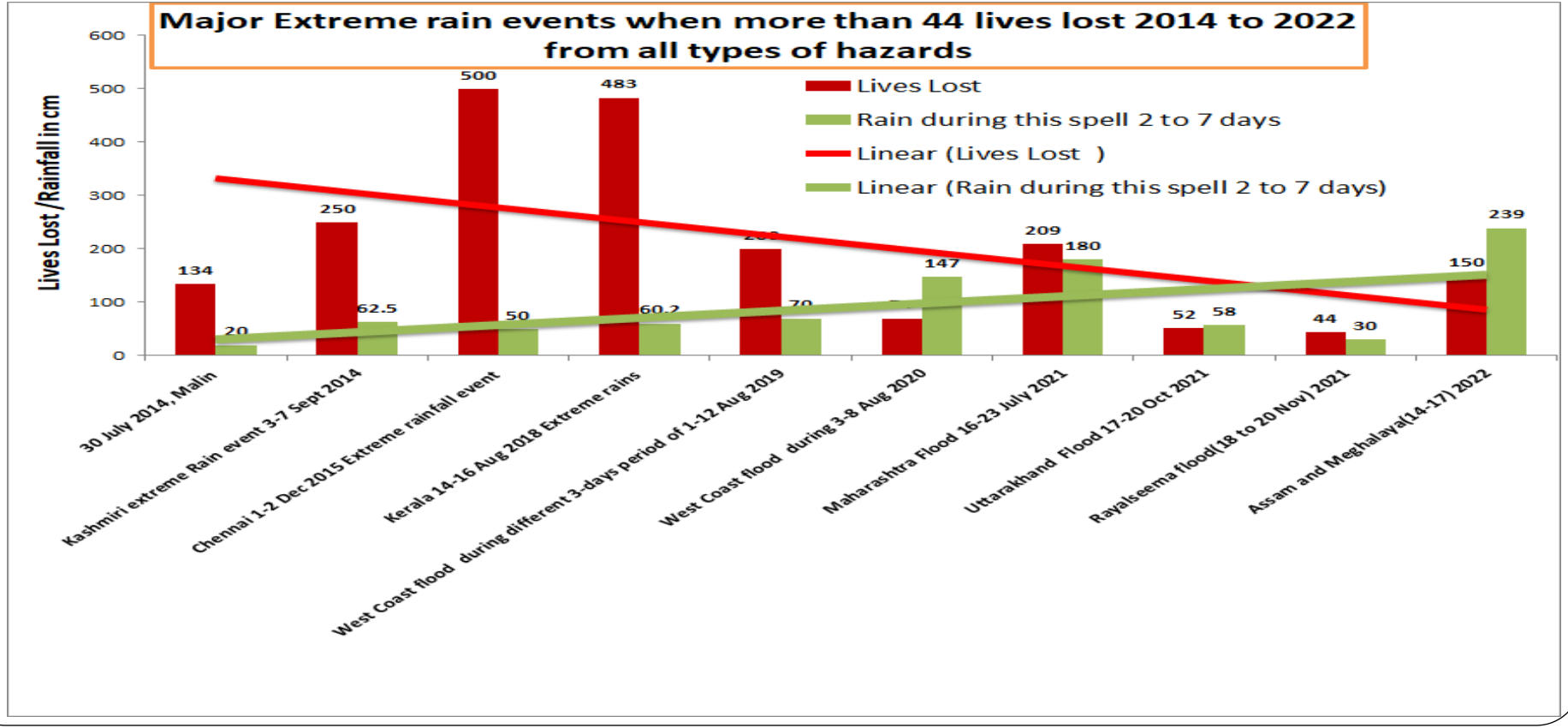
GFS Day1: 2024060500
WRF Day1: 2024060412
NCUM Day1: 2024060500
GEFS DAY1: 2024060412
NEPS DAY1: 2024060412

Day 5 skill in 2023 (53%) is better than Day 1 skill in 2016 (52%) and all proceeding years. Hence, there is improvement in lead period of forecast by 4 days



Probability of Detection (PoD) from 2002 to 2023 for Day 1 to Day 5

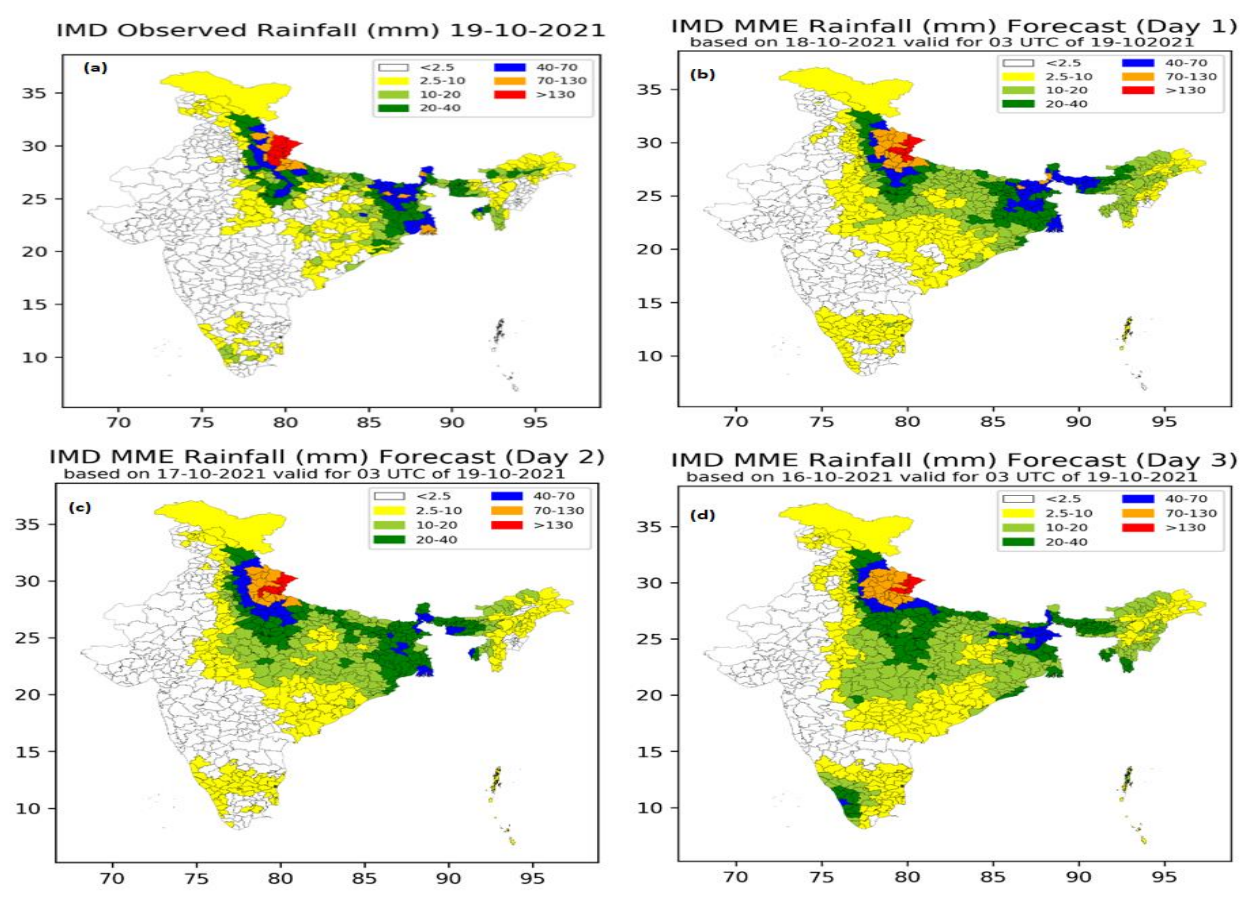
How impact of heavy related hazards have been reduced by improvement skill of Heavy rainfall warnings and Switching over to Impact based warning: Reduction of lives lost 2014-2022



Some Examples
(Success & Failure)

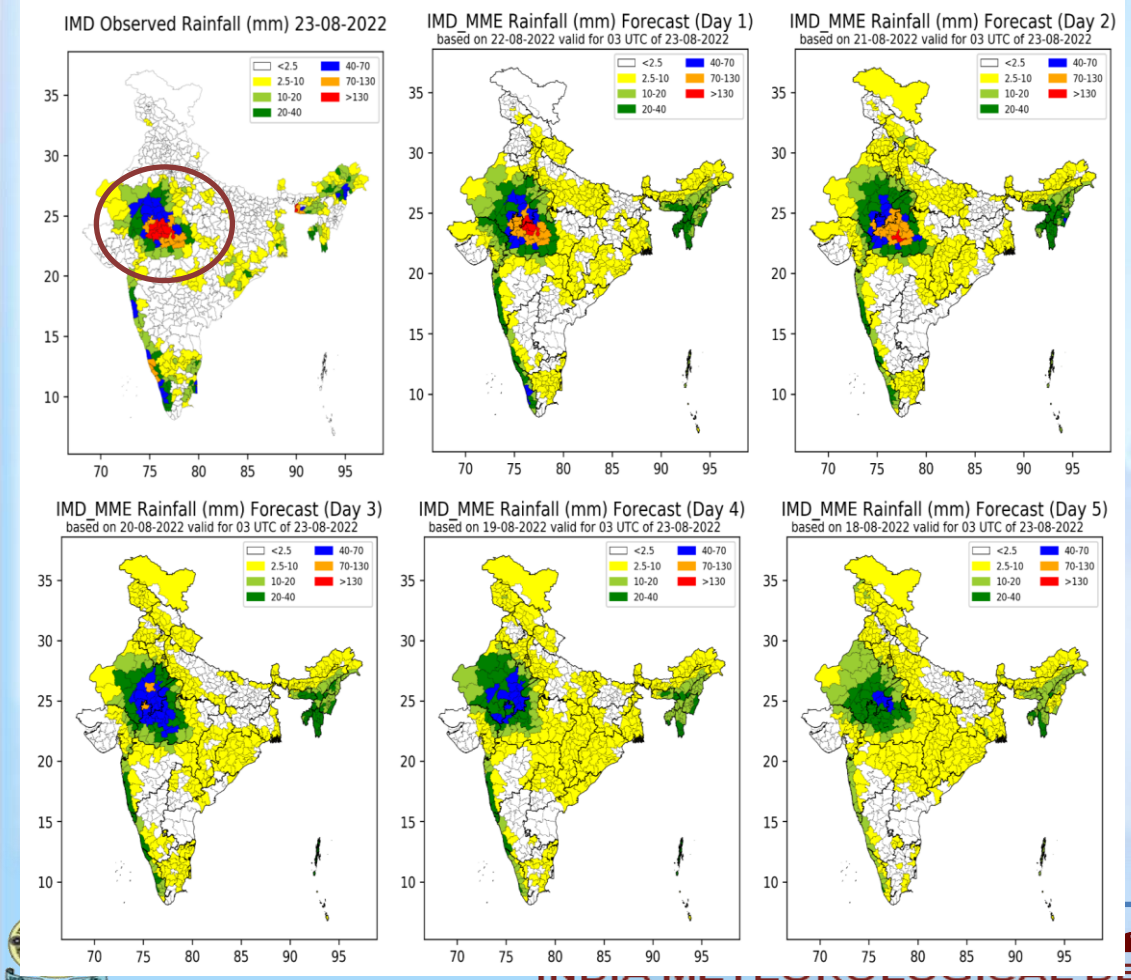
Extended and Medium Range

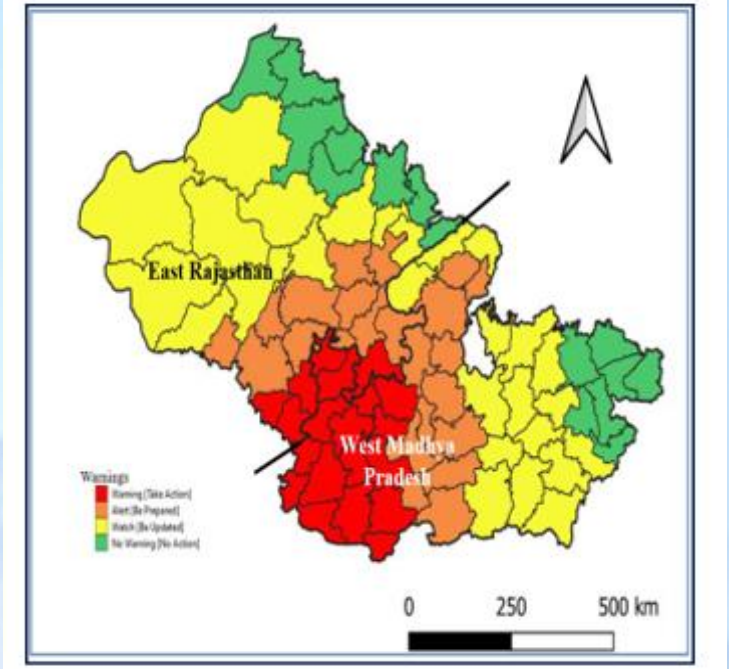
I- Case Study:- Qualitative comparison of extremely heavy rainfall reported at Uttarakhand state on 19th October 2021.



The extremely heavy rainfall observed at Uttarakhand is well predicted in MME day 1, day 2 and day 3 forecast.

ii- Case studies: Ex. Heavy rainfall events over central India (23 Aug 2022)





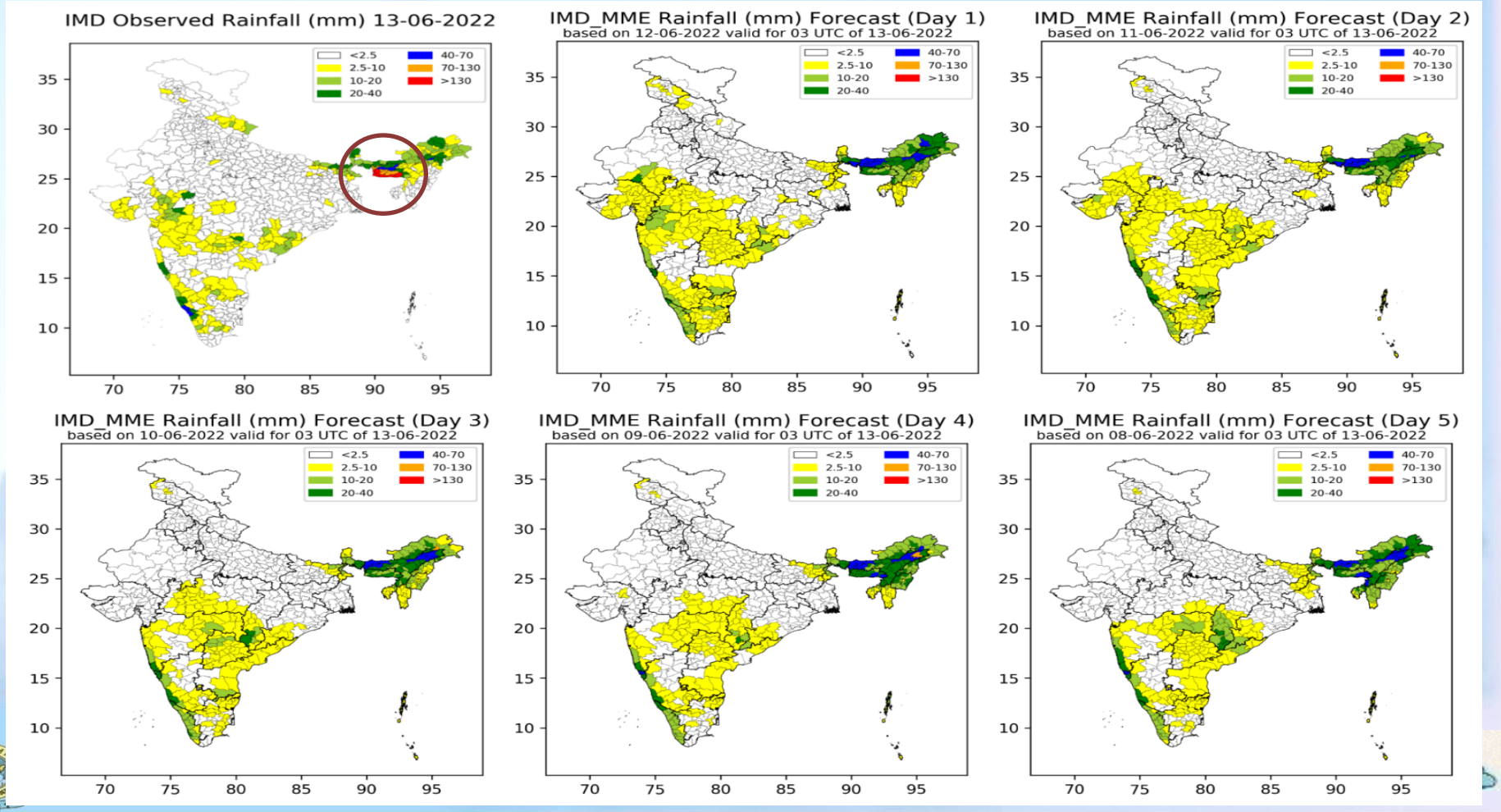
No Warning (No Action)

Watch(Be Updated)

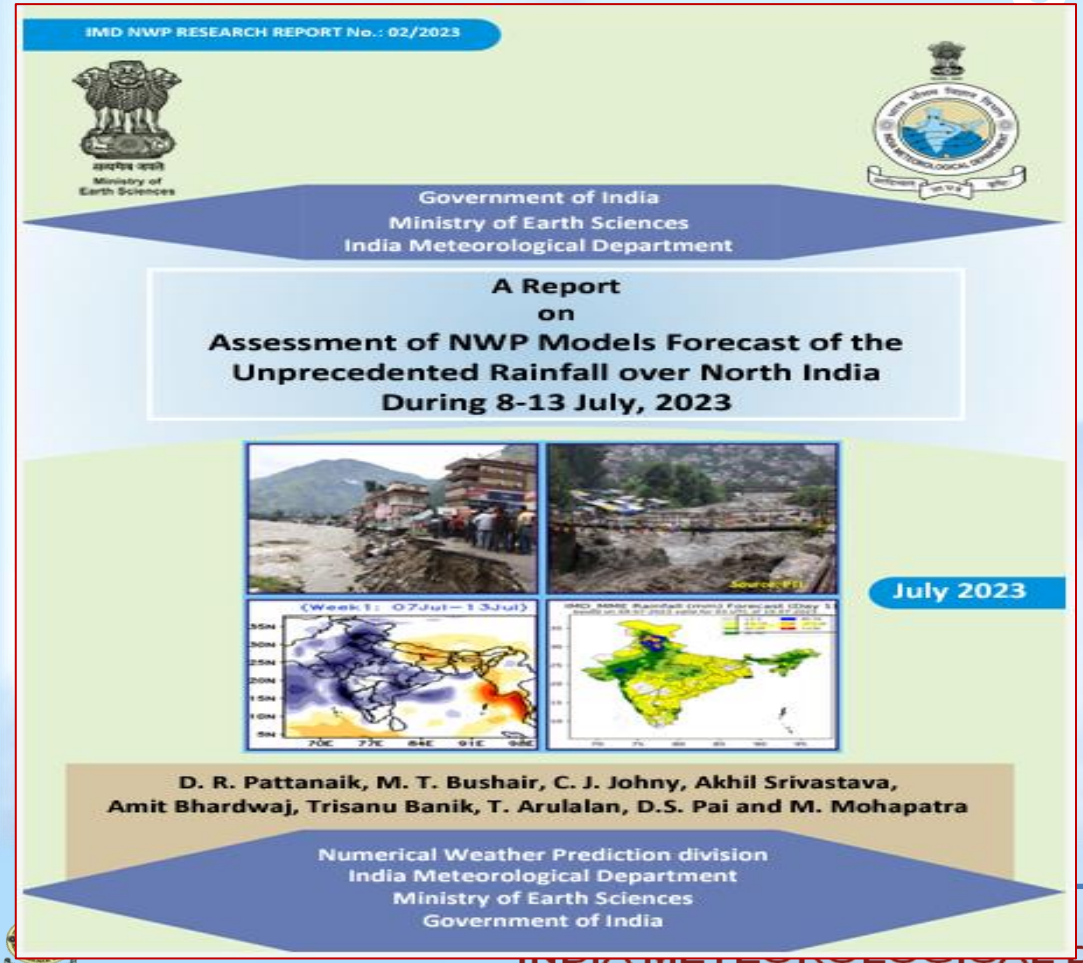
Alert(Be Prepared)

Warning(Take Action)

iii- Failed case:- Heavy rainfall over NE of India.



Some Challenging Issues



Though the ERF has got useful skill upto 2 to 3 weeks, there are occasions when the lead period is only one week.

The unprecedented rainfall over North India during 8-13 July associated with westerly-monsoon interaction could predict the active phase of monsoon with

iv -Leadtime of this event was small

ERF – 5th July, 2023

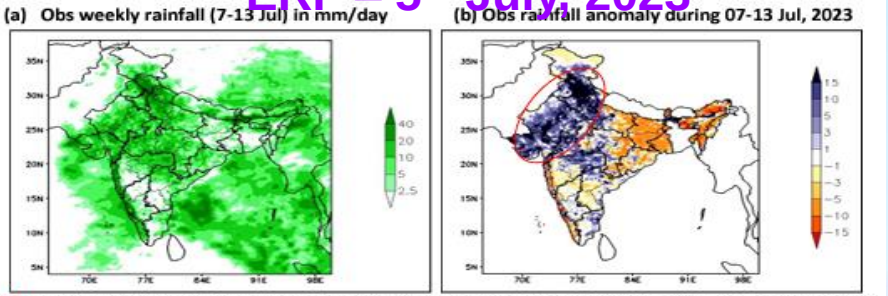
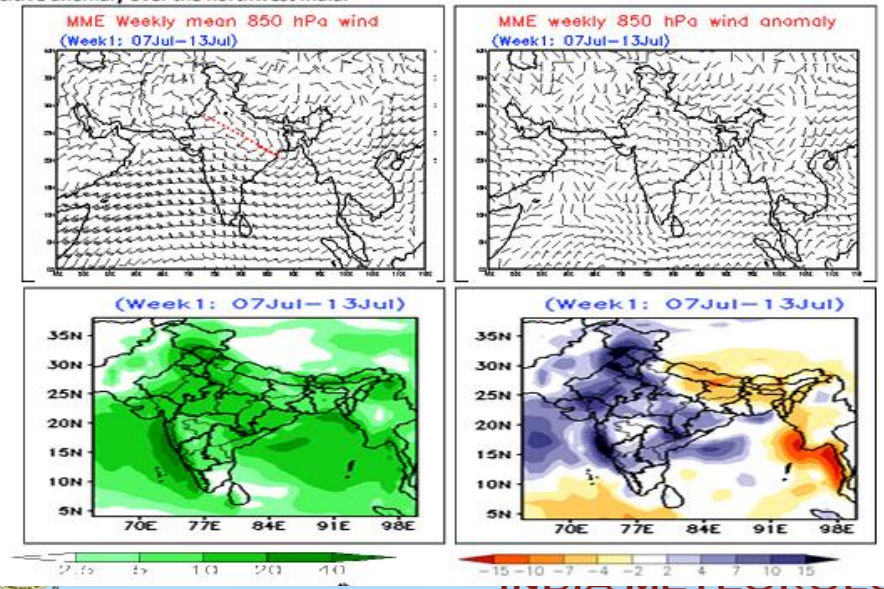
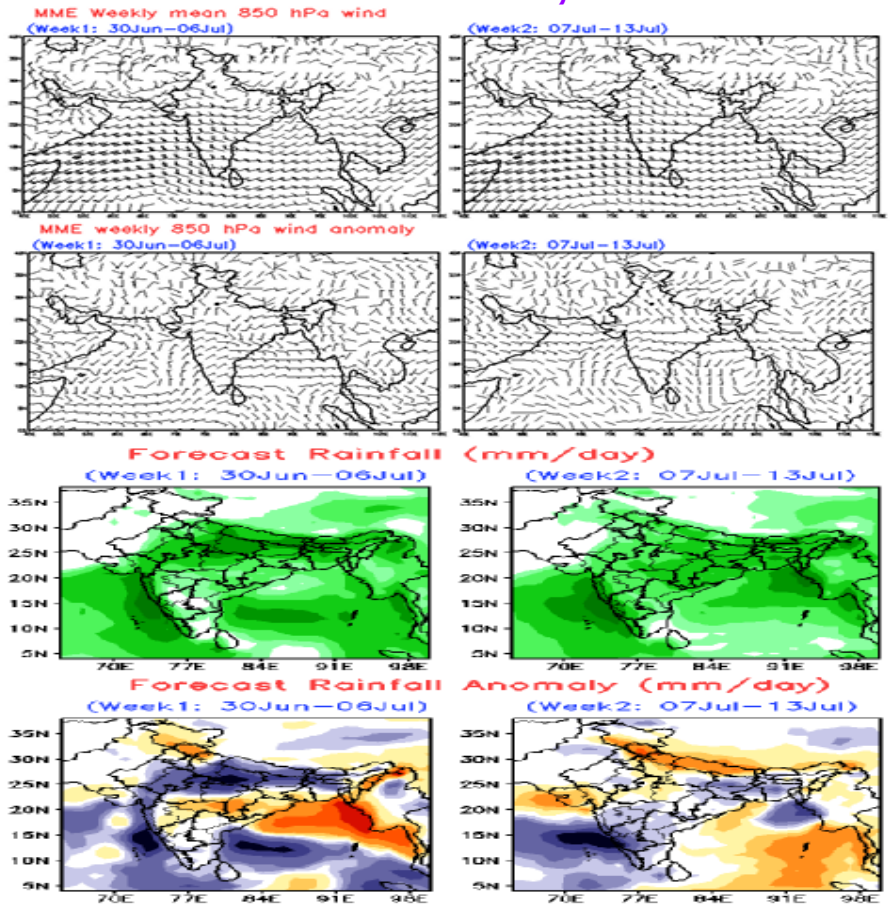


Fig. 17 : The weekly mean rainfall and its anomaly for the period from 07-13 July, 2023. **It indicates a large positive anomaly over the northwest India.**



ERF – 28 June, 2023



Met subdivision-wise forecast rainfall from the NWP model and MME valid for 10th July 0300 UTC

(a) Day 5 forecast based on 5th July IC (Valid for 10th July)

		GFS MEAN(MAX)	JMA MEAN(MAX)	NCUM MEAN(MAX)	NCEP_GFS MEAN(MAX)	GEFS MEAN(MAX)	NEPS MEAN(MAX)	ECMWF MEAN(MAX)	MME MEAN(MAX)
11	WEST UTTAR PRADESH	17 (56)	11 (35)	21 (253)	16 (61)	22 (5[illegible])	22 (45)	[illegible] (62)	16 (71)
12	UTTARAKHAND	16 (166)	6 (24)	18 (155)	15 (34)	11 (63)	17 (62)	8 (34)	12 (74)
13	HAR. CHD & DELHI	28 (82)	22 (44)	42 (202)	19 (45)	27 (44)	11 (33)	8 (29)	22 (68)
14	PUNJAB	41 (102)	53 (79)	27 (177)	52 (186)	26 (84)	7 (24)	43 (133)	33 (118)
15	HIMACHAL PRADESH	26 (202)	16 (61)	27 (254)	42 (142)	26 (142)	11 (38)	26 (119)	22 (130)
16	JAMMU AND KASHMIR	14 (309)	24 (189)	3 (49)	30 (318)	9 (85)	4 (19)	23 (327)	16 (165)

(b) Day 4 forecast based on 6th July IC (Valid for 10th July)

		GFS MEAN(MAX)	JMA MEAN(MAX)	NCUM MEAN(MAX)	NCEP_GFS MEAN(MAX)	GEFS MEAN(MAX)	NEPS MEAN(MAX)	ECMWF MEAN(MAX)	MME MEAN(MAX)
11	WEST UTTAR PRADESH	16 (81)	15 [illegible]	40 (289)	27 (137)	25 (6[illegible])	26 (93)	16 (69)	22 (106)
12	UTTARAKHAND	14 (148)	8 (36)	45 (444)	34 (136)	10 (58)	19 (75)	13 (63)	19 (131)
13	HAR. CHD & DELHI	5 (19)	29 (51)	40 (265)	7 (46)	18 (32)	19 (55)	24 (65)	19 (74)
14	PUNJAB	3 (16)	36 (65)	22 (153)	4 (42)	12 (31)	14 (53)	37 (115)	21 (102)
15	HIMACHAL PRADESH	19 (62)	25 (96)	20 (82)	16 (60)	13 (75)	15 (82)	37 (114)	20 (106)
16	JAMMU AND KASHMIR	5 (102)	18 (167)	5 (30)	4 (16)	5 (35)	4 (26)	18 (187)	10 (128)

(c) Day 3 forecast based on 7th July IC (Valid for 10th July)

		GFS MEAN(MAX)	JMA MEAN(MAX)	NCUM MEAN(MAX)	NCEP_GFS MEAN(MAX)	GEFS MEAN(MAX)	NEPS MEAN(MAX)	ECMWF MEAN(MAX)	MME MEAN(MAX)
11	WEST UTTAR PRADESH	16 (52)	14 (32)	44 (175)	15 (50)	25 (58)	17 (91)	11 (108)	16 (84)
12	UTTARAKHAND	13 (108)	6 (33)	14 (96)	17 (65)	11 (56)	23 (102)	17 (105)	14 (81)
13	HAR. CHD & DELHI	25 (93)	30 (48)	27 (172)	18 (40)	33 (52)	22 (89)	28 (95)	26 (84)
14	PUNJAB	21 (74)	37 (56)	101 (417)	26 (94)	17 (45)	26 (89)	77 (472)	43 (178)
15	HIMACHAL PRADESH	21 (174)	22 (82)	61 (364)	47 (87)	21 (110)	27 (138)	55 (354)	37 (191)
16	JAMMU AND KASHMIR	5 (157)	15 (143)	13 (169)	12 (67)	5 (45)	8 (83)	11 (553)	14 (173)

(d) Day 2 forecast based on 8th July IC (Valid for 10th July)

		GFS MEAN(MAX)	JMA MEAN(MAX)	NCUM MEAN(MAX)	NCEP_GFS MEAN(MAX)	GEFS MEAN(MAX)	NEPS MEAN(MAX)	ECMWF MEAN(MAX)	MME MEAN(MAX)
11	WEST UTTAR PRADESH	26 (85)	18 (54)	16 (275)	22 (82)	29 (80)	16 (125)	24 (86)	22 (117)
12	UTTARAKHAND	12 (99)	9 (42)	15 (155)	17 (49)	11 (81)	20 (143)	16 (56)	14 (93)
13	HAR. CHD & DELHI	38 (91)	34 (55)	26 (193)	24 (64)	43 (86)	39 (123)	30 (82)	35 (101)
14	PUNJAB	27 (90)	35 (73)	56 (286)	21 (121)	27 (96)	62 (268)	51 (515)	41 (224)
15	HIMACHAL PRADESH	50 (272)	23 (81)	49 (294)	56 (147)	45 (198)	53 (281)	62 (381)	52 (258)
16	JAMMU AND KASHMIR	9 (180)	15 (178)	16 (160)	10 (96)	9 (72)	18 (220)	20 (306)	15 (209)

(e) Day 1 forecast based on 9th July IC (Valid for 10th July)

		GFS MEAN(MAX)	JMA MEAN(MAX)	NCUM MEAN(MAX)	NCEP_GFS MEAN(MAX)	GEFS MEAN(MAX)	NEPS MEAN(MAX)	ECMWF MEAN(MAX)	MME MEAN(MAX)
11	WEST UTTAR PRADESH	22 (89)	19 (55)	23 (226)	23 (162)	23 (68)	18 (86)	26 (66)	22 (124)
12	UTTARAKHAND	16 (86)	10 (50)	15 (212)	13 (49)	9 (44)	15 (84)	13 (55)	14 (88)
13	HAR. CHD & DELHI	22 (74)	29 (47)	32 (211)	43 (133)	33 (68)	30 (96)	29 (112)	34 (124)
14	PUNJAB	9 (90)	42 (192)	43 (204)	23 (79)	13 (62)	51 (152)	30 (359)	33 (154)
15	HIMACHAL PRADESH	45 (169)	64 (211)	50 (248)	64 (108)	40 (144)	43 (188)	70 (328)	61 (204)
16	JAMMU AND KASHMIR	5 (80)	16 (205)	10 (128)	8 (55)	6 (52)	17 (213)	13 (245)	10 (137)

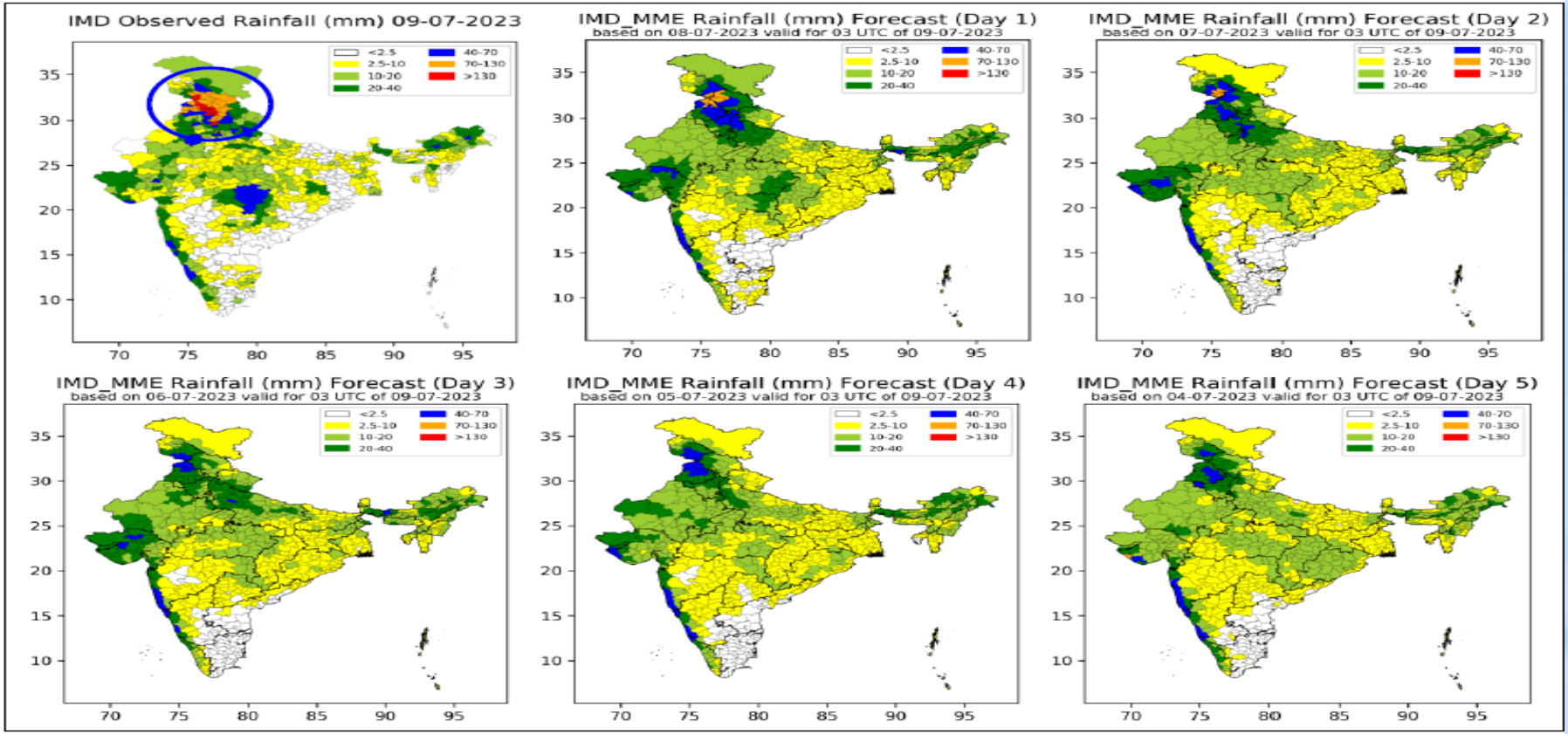
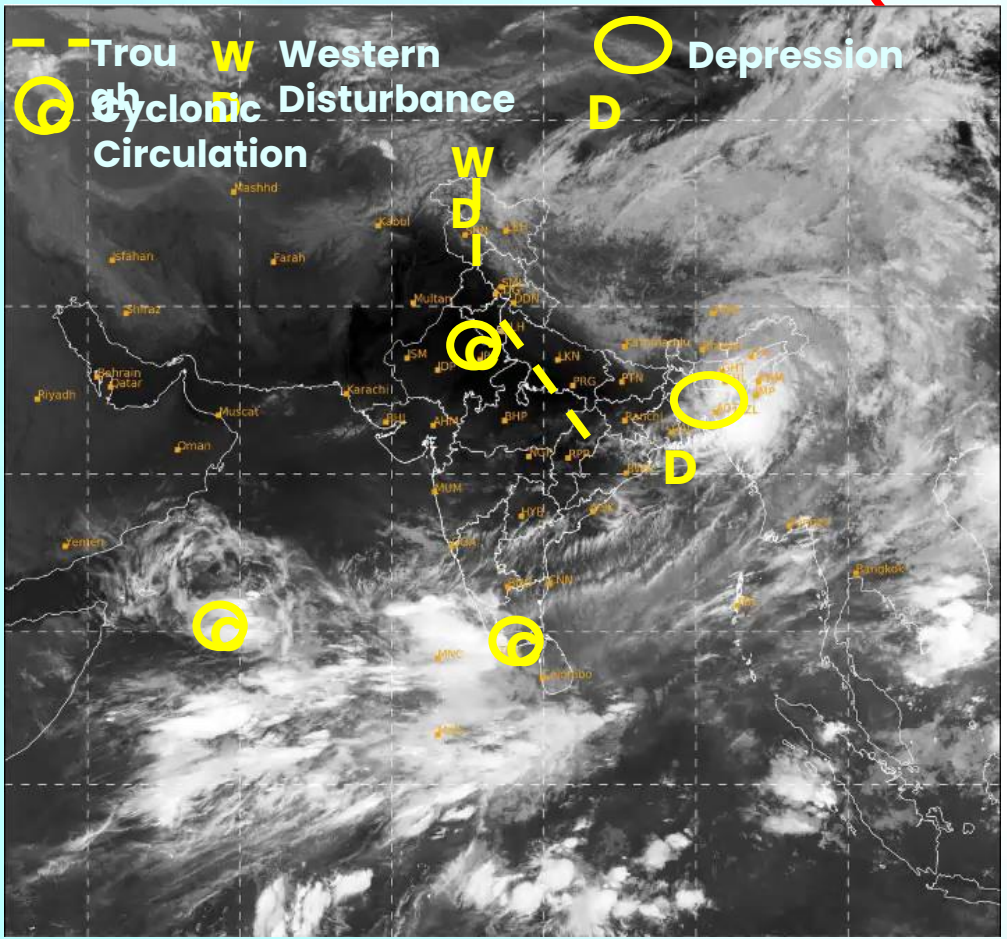


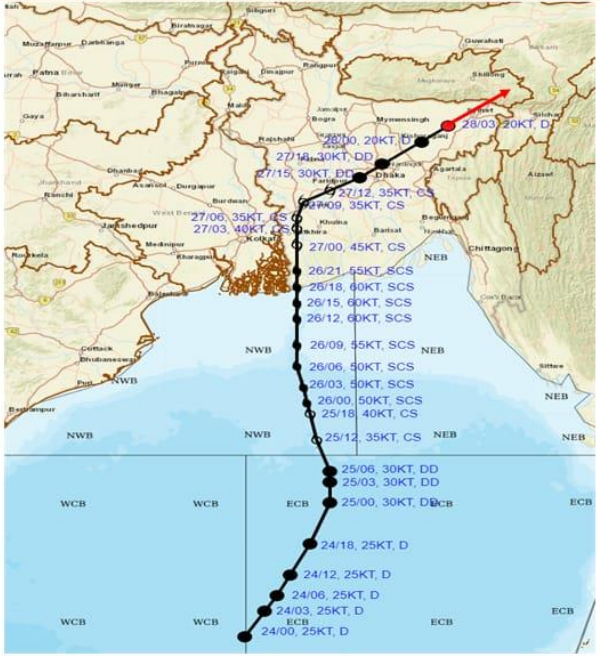
Fig. 25 : (MME-based forecast rainfall for 5 days (24 hr to 120 hr) **valid for 9th July 2023** along with the observed rainfall of the day.

The high rainfall belt over northern India is well predicted in the MME forecast on day 1 and day 2 forecasts. The day 3 to day 5 forecasts are predicted well with regard to the location, however, their intensity is slightly underestimated.

CASE – V : SYNOPTIC SYSTEM (28-29 MAY 2024)



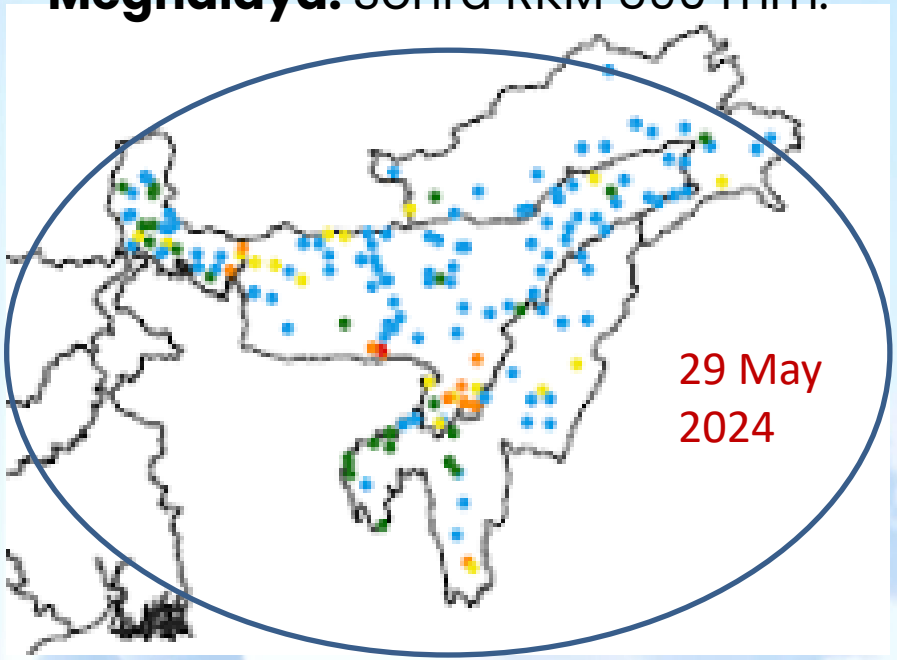
FORECAST TRACK ALONGWITH CONE OF UNCERTAINITY IN ASSOCIATION WITH DEPRESSION (REMANANT OF CYCLONIC STORM 'REMAL') OVER EAST BANGLADESH BASED ON 0300 UTC (0830 IST) OF 28TH MAY 2024.



DATE/TIME IN UTC
IST=UTC + 0530
L: LOW PRESSURE AREA
WML: WELL MARKED LOW PRESSURE AREA
D: DEPRESSION (17-27 KT)
DD: DEEP DEPRESSION (28-33 KT)
CS: CYCLONIC STORM (34-47 KT)
SCS: SEVERE CYCLONIC STORM (48-63KT)
VSCS: VERY SEVERE CYCLONIC STORM (64-89 KT)
ESCS: EXTREMELY SEVERE CYCLONIC STORM (90-119 KT)
SuCS: SUPER CYCLONIC STORM (≥ 120 KT)

LESS THAN 34 KT
34-47 KT
≥ 48 KT
OBSERVED TRACK
FORECAST TRACK
CONE OF UNCERTAINTY

Meghalaya: Sohra RKM 590 mm.



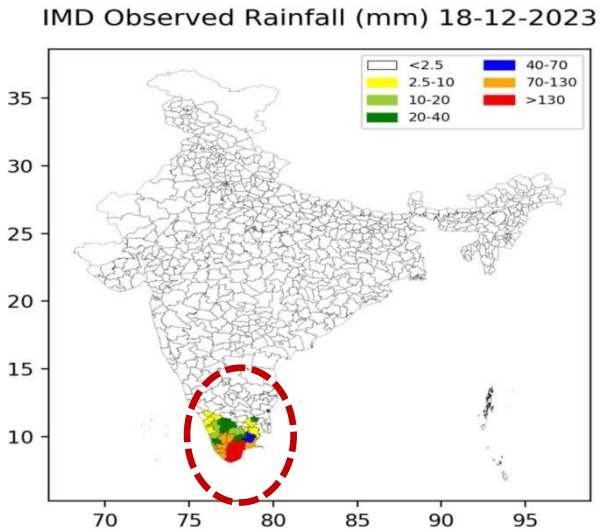
Heavy Rain Warning for Day 1 and Day 2

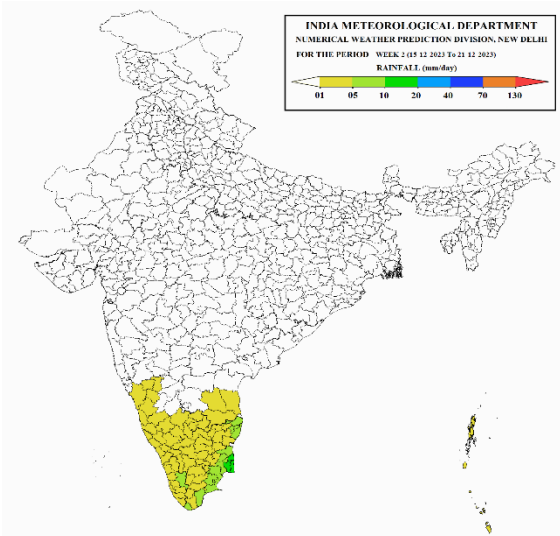
Legends

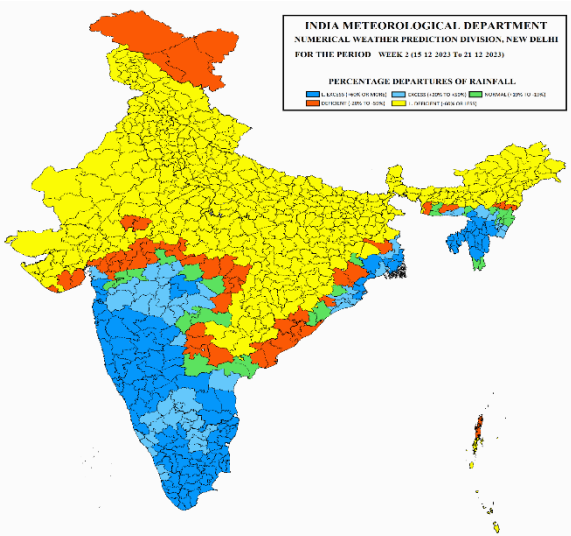
- Very Light to Light Rainfall (0.1 - 15.5 mm)
- Moderate Rainfall (15.6 - 64.4 mm)
- Heavy Rainfall (64.5 - 115.5 mm)
- Very Heavy Rainfall (115.6 - 204.4 mm)
- Extremely Heavy Rainfall (>=204.5 mm)

Case –vi :24 hr RF, 18 Dec, 2023 (946 mm

ERF week 2 (15 – 21 Dec 2023); IC -6th Dec

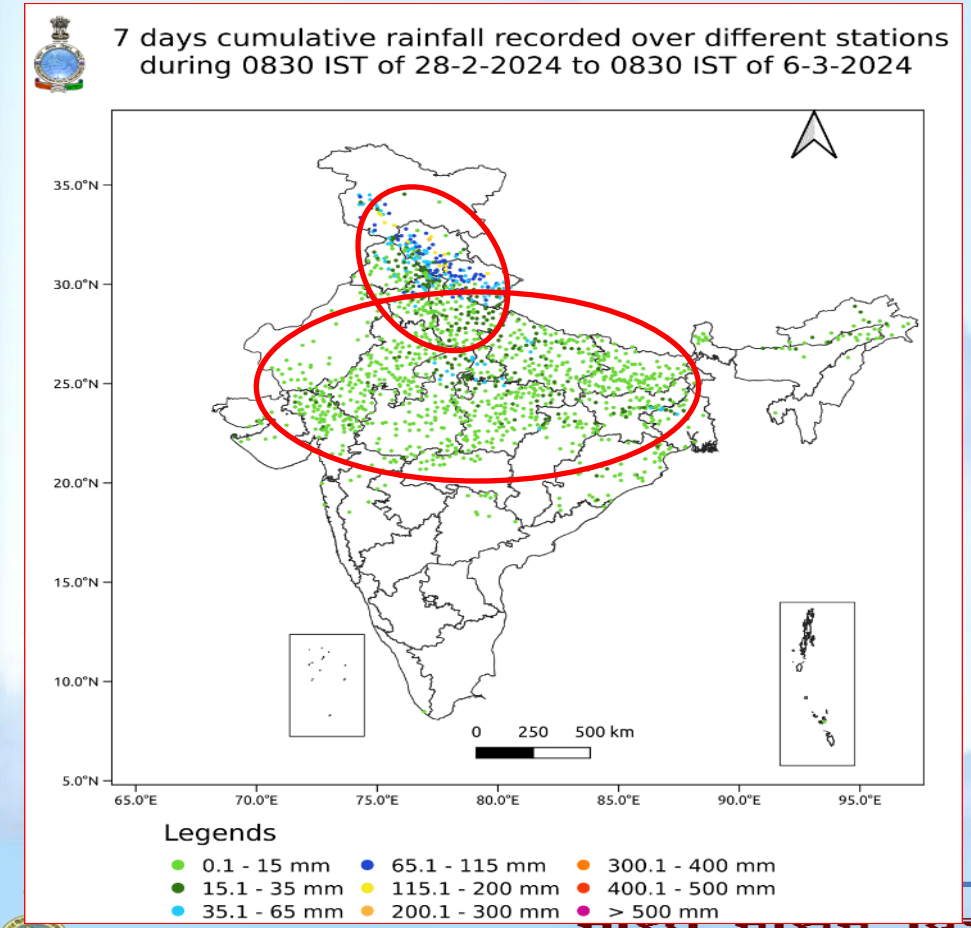


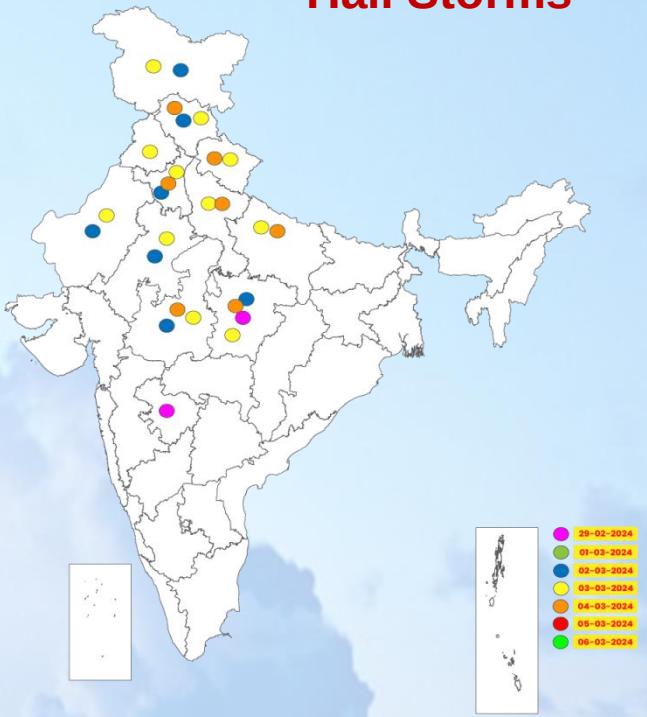




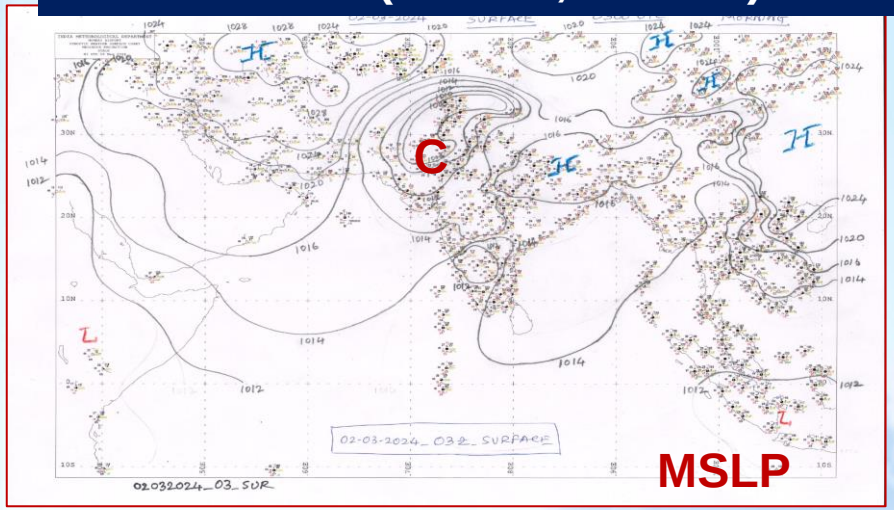
Forecast valid for 20231218	GFS	GEFS (mean)	NCEP	NCUM	JMA	ECMWF
Observation (946 mm)						
Day 1	126.6	46.4	200.0	856.3	64.0	373.1
Day 2	172.4	90.0	43.0	408.9	57.2	310.1
Day 3	351.6	189.0	12.4	160.6	38.4	162.2
Day 4	143.3	46.8	66.9	57.3	30.4	60.4
Day 5	103.9	40.0	126.3	97.2	24.9	134.9
Day 6	113.0	37.7	36.8	329.3	12.0	23.1
Day 7	98.5	27.5	217.2	59.4	14.0	73.4

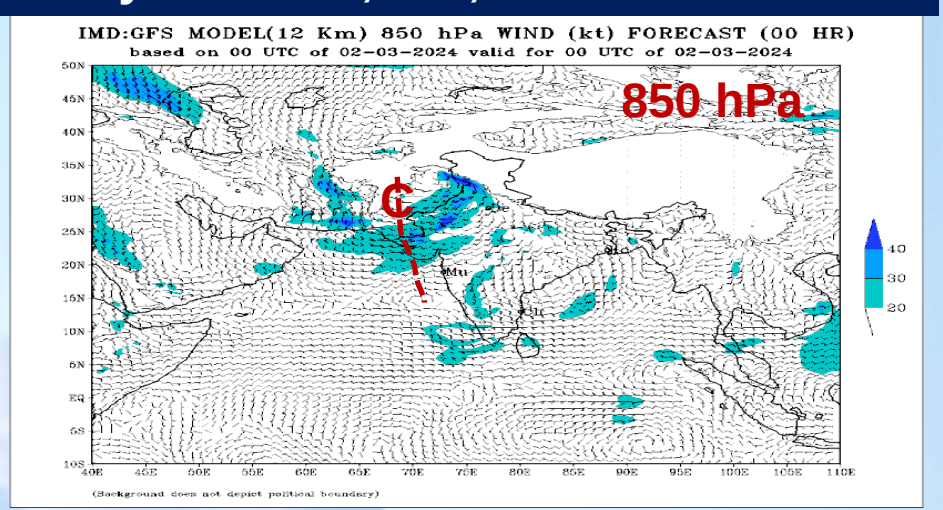
Case – v : ERF of Western Disturbances (1-7 Mar), 2024



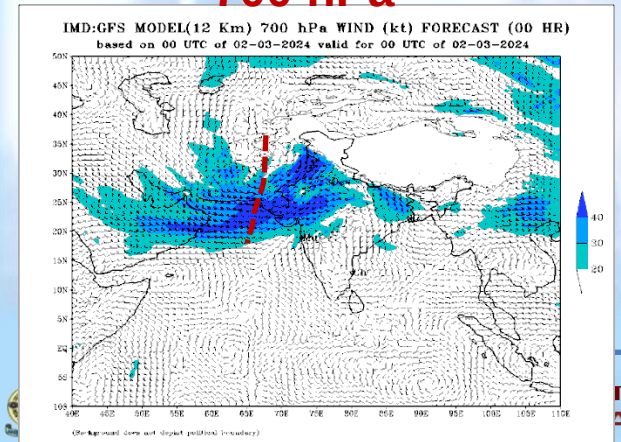


Surface chart (2nd Mar, 03 UTC) & GFS analysis at 850, 700, 500 & 200 hPa

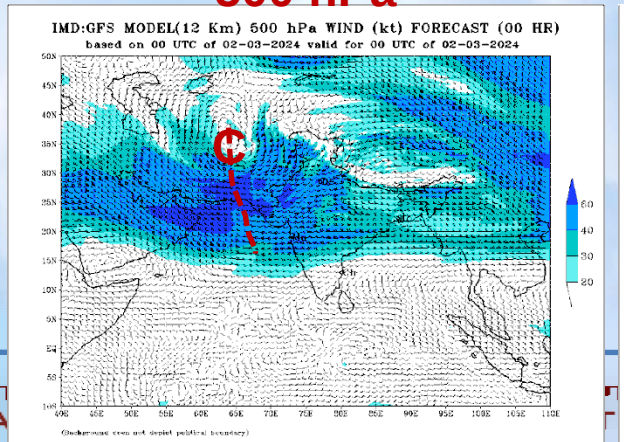




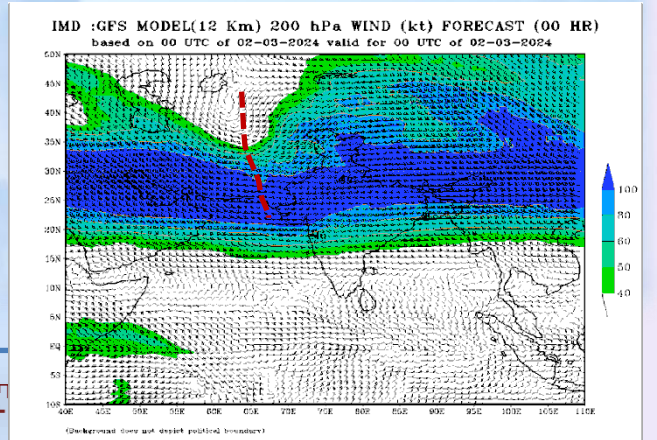
700 hPa



500 hPa

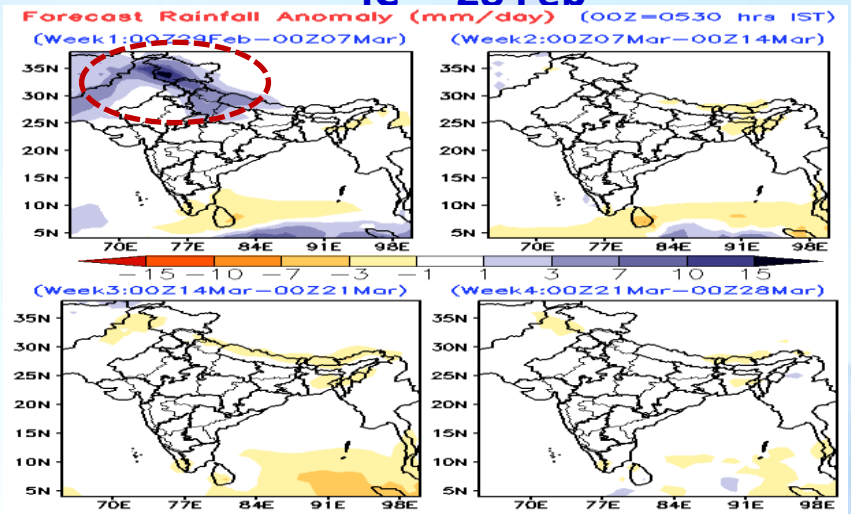


200 hPa

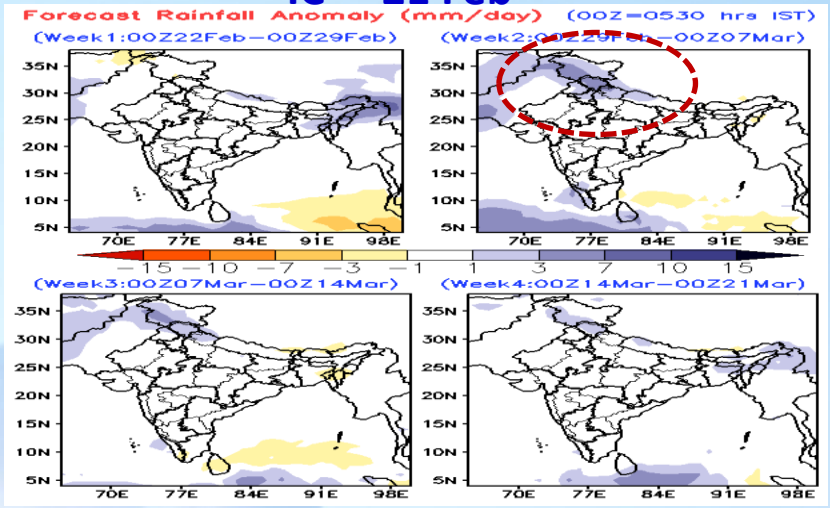


ERF Predicted weekly rainfall anomaly (1-7 Mar) : ICs : 28,21 and 14 Feb

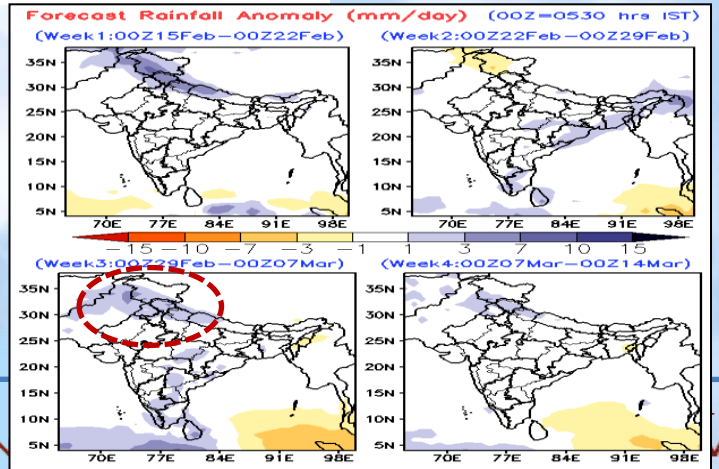
IC = 28 Feb



IC = 21 Feb



IC = 14 Feb



Challenges in Predictability of Mesoscale Events

- Predictability of meso-scale system is less
- Due to Global Warming the prediction of Extreme Rainfall Events likely to decrease
- Error doubling time of extreme rainfall event during last 30 years decreased from about 3 days to 1.5 days

Solutions to improve Predictability of Mesoscale Events

- Enhancement of observational network to detect mesoscale systems
- Improve data assimilation of models for these systems
- Use High Resolution Models
- To address uncertainty, provide probabilistic forecast
- Warning system & dissemination be made smarter to utilise reduced lead time to reach the last mile
- Capacity building of forecasters, disaster managers, media & general public

Future Plan

➢Significant improvement in MHEWS and DRR in recent years leading to a drastic reduction in loss of lives, especially due to cyclones and Heat Waves

➢Scope for weather hazard monitoring and forecasting to meet Early Warning for All Initiative of UN and WMO based on following:

❖Improved Value Chain (Observation→Modeling→ Forecasting → Severe weather warning→Sectoral Applications) including R&D.

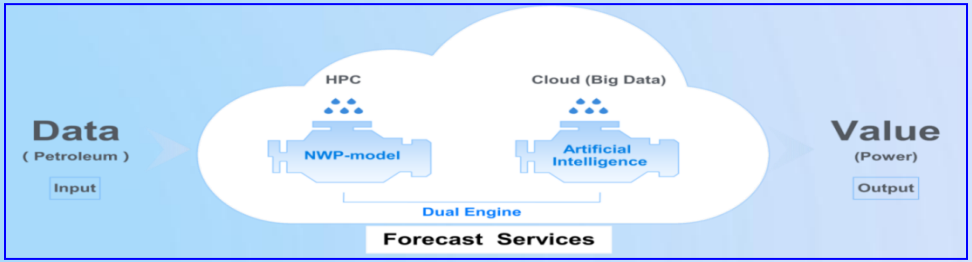
❖Dual engine concept : AI/ML application in conjunction with Numerical Weather Prediction (NWP) modeling to improve the point rainfall

❖Improvement in forecast accuracy by 10-15% by 2030

❖Forecasting of severe weather Hazards at Gram Panchayat level(5x5km) by 2030

❖Dynamic Impact based forecasting & risk based warning for all severe weather

❖Last mile connectivity to meet early warning for all (Har Pal Mausam and Har Ghar Mausam) by 2025



Thank you