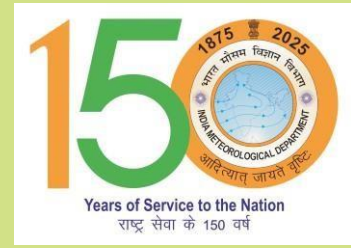




GOVERNMENT OF INDIA
MINISTRY OF EARTH SCIENCES
INDIA METEOROLOGICAL DEPARTMENT



IMD Met. Monograph: ESSO/MOES/IMD/SYNOPTICMET/01(2026)/33

Monsoon

A Report 2025

Edited by
M. Mohapatra, Naresh Kumar, and Satya Prakash

INDIA METEOROLOGICAL DEPARTMENT
MINISTRY OF EARTH SCIENCES
NEW DELHI – 110003 INDIA

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Government of India
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M. Mohapatra, Naresh Kumar, and Satya Prakash

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INDIA

2026

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PREFACE



The southwest monsoon rainfall in India is crucial as it supports the country's agricultural sector, which employs nearly half of the population and contributes significantly to the economy. Approximately 75% of India's annual rainfall occurs during the monsoon season, replenishing water resources like rivers, lakes, and groundwater, which are vital for irrigation and drinking water supplies. It also influences energy generation through hydropower and regulates regional ecosystems. Variations in monsoon patterns, such as excess or deficient rainfall, can lead to floods or droughts, affecting food security, livelihoods, and the overall economy.

Since 2005, the India Meteorological Department has published a detailed report on the monsoon every year to document various characteristics of the monsoon to serve as a quick reference to both operational and research communities. The present report on the southwest monsoon of 2025 has documented salient features of the southwest monsoon 2025. The report has been divided into 17 chapters, which highlight various features like the onset and withdrawal of monsoon, features of synoptic systems formed over the Indian region during the season, large-scale and regional circulation features and a description of meteorological analysis of significant weather events over different parts of the country, among others. It also covers forecast verification at various time scales, such as seasonal, extended range, short-to-medium range, and nowcast range.

The southwest monsoon season rainfall over the country as a whole during 2025 was normal (108% of the Long Period Average (LPA)). The monthly rainfall over the country as a whole was more than LPA during the month of June (109% of LPA), July (105% of LPA), August (105% of LPA) and September (115% of LPA). The homogeneous regions of Northwest India (127% of LPA), Central India (115% of LPA), and South Peninsula (110% of LPA) received above normal monsoon rainfall. However, East & Northeast India (80% of LPA) received below-normal rainfall. Out of the total 36 meteorological sub-divisions, 2 sub-divisions (West Rajasthan and East Rajasthan) covering 10% of the total area of the country received large excess seasonal monsoon rainfall, 12 sub-divisions constituting 35% of the total area received excess rainfall, 19 sub-divisions covering 46% of the total area of the country received normal rainfall, and 3 sub-divisions (Arunachal Pradesh, Assam & Meghalaya and Bihar) constituting 9% of the total area received deficient seasonal rainfall.

Southwest monsoon current advanced to the south Andaman Sea and Nicobar Islands on 13th May, 9 days ahead of its normal date. It set in over Kerala on 24th May, 8 days earlier

than its normal date. It covered the entire country by 29th June, 9 days earlier than its normal date of 8th July. Monsoon withdrawal commenced from west Rajasthan on 14th September, three days earlier than the normal date. The southwest monsoon withdrew from the entire country on 16th October 2024.

During the season, 19 Low Pressure Systems including 12 Low Pressure Areas, 5 Depressions and 2 Deep Depressions developed over the Indian region. During the season, the region witnessed formation of LPS on 68.8 days against the normal of about 57 days.

During the 2025 monsoon season, the El Niño-Southern Oscillation (ENSO) condition was neutral. However, repeated upwelling Kelvin waves and the associated Walker circulation pattern indicated a continuation of La Niña-like conditions in atmosphere, with enhanced ascent over the Indo-Pacific Warm Pool and subsidence over the central and eastern Pacific. Over the Indian Ocean, a negative Indian Ocean Dipole (IOD) developed from July onward, producing a strong east-west SST gradient that enhanced convection over the eastern Indian Ocean while suppressing it over the western basin. The Madden-Julian Oscillation (MJO) was weak in June, strengthened in July, remained active in August, and turned weak again in September, providing intermittent support to monsoon activity.

The operational forecast of IMD for the monsoon onset over Kerala for this year was correct as the forecast date of monsoon onset over Kerala was 27th May with a model error of ± 4 days and monsoon set in over Kerala on 24th May. IMD adopted the new strategy based on the existing statistical forecasting system and the newly developed Multi-Model Ensemble (MME) based forecasting system for the 2021 southwest monsoon season. The spatial tercile probability forecast for rainfall is also issued based on MME. In addition, monthly rainfall over the country as a whole for the months of June, July, August, September, and the second half of the season (August-September) was issued. IMD has also issued a separate forecast for the Monsoon Core Zone (MCZ) in addition to the four homogeneous regions. The seasonal forecast issued for homogeneous regions during the season was within the range of the forecast limit except the Northwest India. All the monthly outlooks were within the forecast limit, except the July. The forecast for the second half of the monsoon season (August –September) for the country as a whole also was in the forecast limit.

The present report spells out challenging aspects of monsoon monitoring, variability, and prediction. It provides valuable and authentic information about the 2025 southwest monsoon season for operational forecasters, researchers and other users.

Executive Summary

1	Document Title	Monsoon 2025: A Report
2	Document Type	Meteorological Monograph
3	Issue No	ESSO/MOES/IMD/SYNOPTICMET/01(2026)/33
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13	Originating Division	India Meteorological Department, New Delhi
14	Reviewing & Approving Authority	Director General of Meteorology, India Meteorological Department, New Delhi
15	End Users	Operational Forecasters, Modellers, Researchers and Government Officials, etc.
16	Abstract	<p>The report discusses the operational monitoring and forecasting aspects of the 2025 southwest monsoon. Various observed global and regional climate patterns associated with the 2025 monsoon have been highlighted. The report also presents monitoring of semi-permanent and transient weather systems, onset and progress of the monsoon during the season, rainfall distribution etc. using various tools such as automatic weather stations (AWSs) and satellite data, analysis of the extreme weather events occurred over various parts of the country such as heavy rainfall and associated floods, and meteorological explanation for the events, action taken by the local meteorological offices, etc. The southwest monsoon season rainfall over the country as a whole during 2025 was 108% of Long Period Average (LPA). During the season, 19 Low Pressure Systems including 12 Low Pressure Areas and 7 Depression/Deep Depressions developed over the Indian region. Potential regional and global climate anomaly patterns responsible for the observed rainfall features have been discussed. The performance of operational forecasts issued by IMD and NWP models at various time scales is also emphasized.</p>
17	Keywords	Southwest Monsoon, Forecast Verification, Rainfall, Satellite Imageries, Kharif crops, SST, OLR, NWP Models, ENSO, IOD, MJO.

1



OBSERVED RAINFALL FEATURES DURING THE SOUTHWEST MONSOON 2025

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This chapter contains the various spatial and temporal features of observed rainfall during the 2025 southwest monsoon season and its statistics.

1.1 Salient features of rainfall

The southwest monsoon season rainfall over the country as a whole during 2025 was 108% of Long Period Average (LPA). Rainfall distribution was generally well-distributed over major parts of the country with normal and above normal, except three meteorological sub-divisions namely Arunachal Pradesh, Assam & Meghalaya and Bihar. In the country as a whole, rainfall during the month of June (109 % of LPA), July (105 % of LPA), August (105 % of LPA) & September (115 % of LPA) were normal (within $\pm 19\%$ of LPA).

For the country as a whole, seasonal rainfall at the end of the southwest monsoon season (June to September) was 936.8 mm, which is 108% of 868.6 mm LPA (1971-2020) value.

The four homogeneous regions received seasonal rainfall as follows:

- i. East & Northeast India : 80% of LPA
- ii. Northwest India : 127% of LPA
- iii. Central India : 115% of LPA
- iv. South Peninsula : 110% of LPA

The country received monthly rainfall during the season as follows:

- i. June : 109% of its LPA
- ii. July : 105% of its LPA
- iii. August: 105% of its LPA
- iv. September: 115% of its LPA

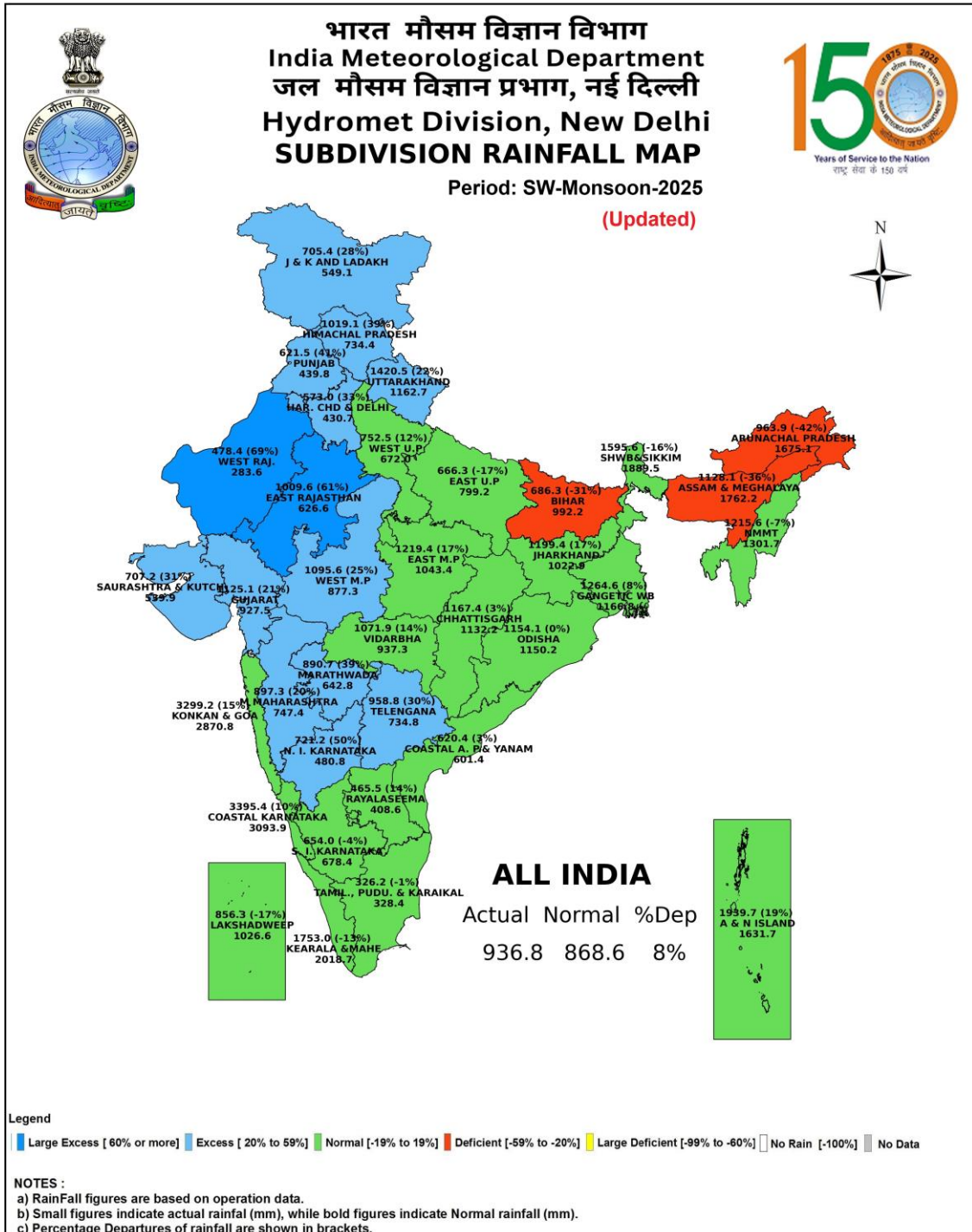


Fig. 1.1: Sub-division wise South-West monsoon rainfall distribution (% departure)

During the monsoon season, among the 36 meteorological sub-divisions in the country, 2 subdivisions (West Rajasthan and East Rajasthan) received Large Excess rainfall. Excess rainfall was recorded in 12 subdivisions, namely Uttarakhand; Haryana, Chandigarh & Delhi; Punjab; Himachal Pradesh; Jammu & Kashmir and Ladakh; West Madhya Pradesh; Gujarat Region; Saurashtra & Kutch; Madhya Maharashtra; Marathwada; Telangana; and North Interior Karnataka.

Normal rainfall was observed in 19 sub-divisions, including Andaman & Nicobar Islands, Nagaland, Manipur, Mizoram & Tripura, Sub-Himalayan West Bengal & Sikkim, Gangetic West Bengal; Odisha; Jharkhand; East and West Uttar Pradesh; East Madhya Pradesh, Konkan & Goa, Vidarbha, Chhattisgarh, Coastal Andhra Pradesh & Yanam, Rayalaseema, Tamil Nadu Puducherry & Karaikal, Coastal Karnataka, South Interior Karnataka, Kerala & Mahe and Lakshadweep. The remaining 3 subdivisions (Arunachal Pradesh, Assam & Meghalaya and Bihar) experienced Deficient rainfall (**Fig. 1.1**).

Fig. 1.2 illustrates the number of sub-divisions experiencing deficient (–20% to –59%) and large deficient (–60% to –99%) rainfall during the southwest monsoon season over the past eleven years.

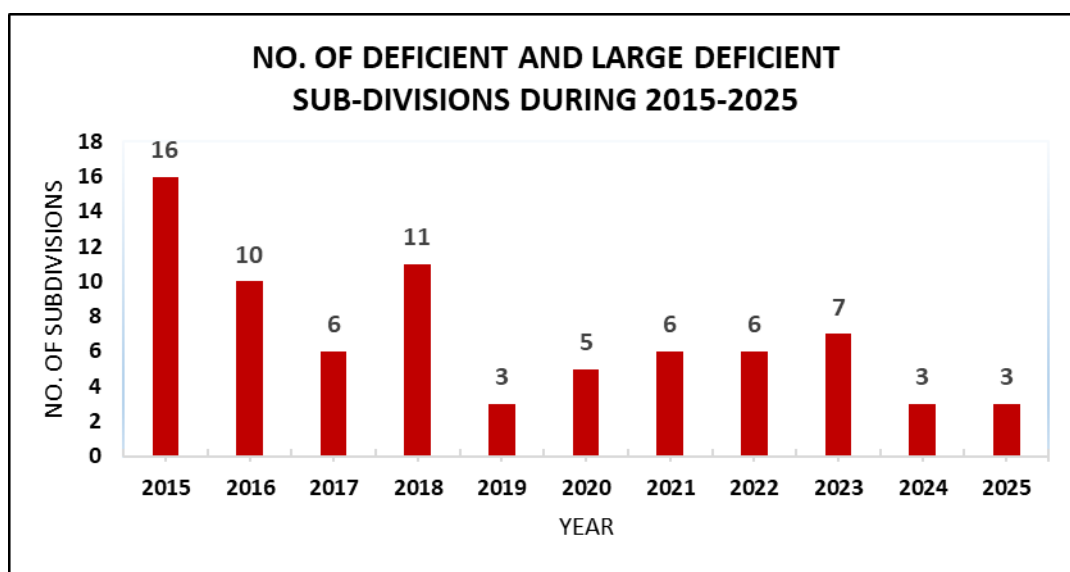


Fig. 1.2: Number of sub-divisions received deficient and large deficient rainfall during the last 11 years

Fig.1.3 shows the district wise rainfall distribution during the southwest monsoon season over the country. During the season, out of 738 districts for which data were available, 67 districts received large excess rainfall, 187 districts received excess rainfall, 327 districts received normal rainfall, 134 districts received deficient rainfall and 12 districts received large deficient rainfall. The percentage of districts with large excess/excess/normal and deficient/large deficient rainfall for the years 2013-2025

is given in the **Table 1.1**. It can be seen that during the 2025 southwest monsoon season, 80% of the districts received normal or excess rainfall, while only 20% of the districts experienced rainfall deficiency.

Table1.1: Percentage of districts with large excess/excess/normal and deficient/large deficient rainfall for the years 2013-2025

Year	Large Excess, Excess & Normal	Deficient & Large Deficient
2013	73	27
2014	54	46
2015	51	49
2016	68	32
2017	67	33
2018	61	39
2019	77	23
2020	75	25
2021	77	23
2022	72	28
2023	69	31
2024	78	22
2025	80	20

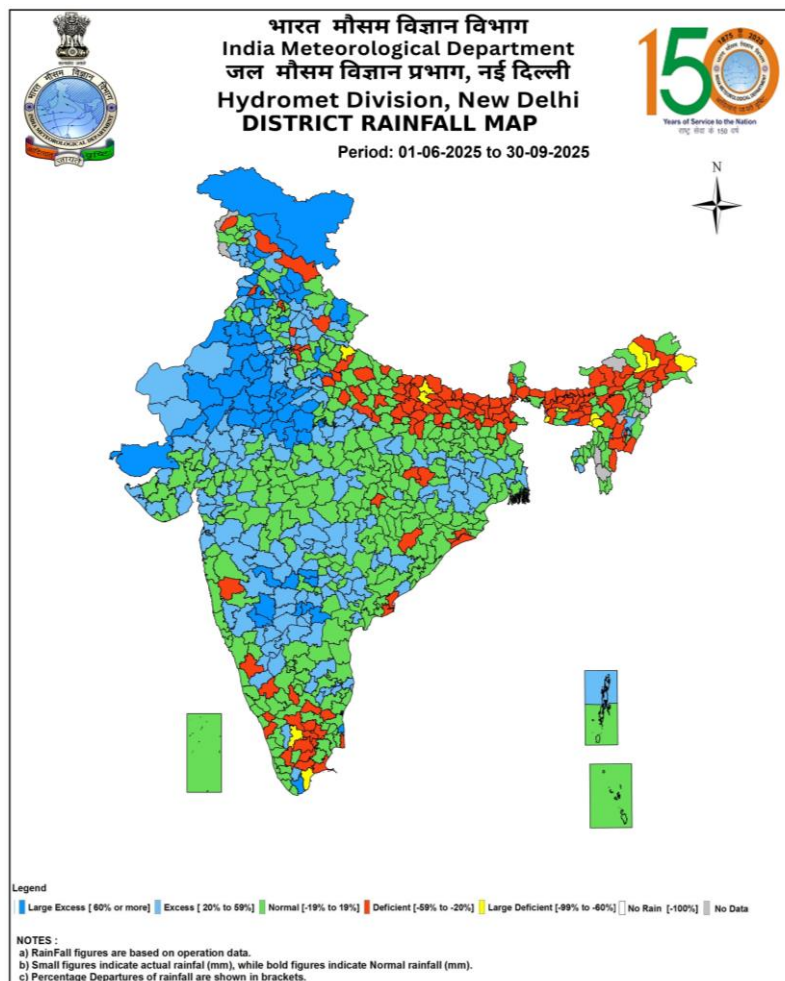


Fig. 1.3: District wise monsoon rainfall distribution (% departure)

1.2 Monthly Rainfall Distribution:

1.2.1 Meteorological Sub-division wise monthly distribution of rainfall:

June: For the month of June 2025, rainfall for the country as a whole was **109%** of its Long Period Average (LPA) value. Most of the sub divisions from East and North East India, South Peninsula and Marathwada and Chhattisgarh received deficient/large deficient rainfall. Remaining sub divisions received large excess/excess/normal rainfall. Rainfall over East Rajasthan (195 mm) was the second highest since 1901 after 1933 (210.0 mm). Rainfall over Assam & Meghalaya (297.7 mm) was the second lowest since 1901 after the lowest rainfall year 1981 (275 mm). Out of these 36 meteorological subdivisions, 7 received large excess rainfall, 8 received excess rainfall, 11 received normal rainfall, 10 subdivisions received deficient rainfall and none of the subdivisions received large deficient rainfall (**Fig.1.4a**).

July: For the month of July 2025, rainfall for the country as a whole was **105 %** of its Long Period Average (LPA) value. Twenty-eight (28) subdivisions received large excess/excess/normal rainfall except East UP, Bihar, SHWB, Assam & Meghalaya, Arunachal Pradesh, Andaman & Nicobar Islands, Tamil Nadu, Pudducherry & Karaikal and Rayalaseema. Rainfall over East Rajasthan (394 mm) was fifth highest since 1901. Rainfall over Assam & Meghalaya (262.7 mm) was the lowest since 1901 and rainfall over Arunachal Pradesh (273.8 mm) was the fourth lowest since 1901. Out of the 36 meteorological subdivisions, 3 received large excess rainfall, 7 received excess rainfall, 18 received normal rainfall and 08 subdivisions received deficient rainfall (**Fig. 1.4b**).

August: For the month of August 2025, rainfall for the country as a whole was again **105 %** of its Long Period Average (LPA) value. Thirty-two subdivisions received large excess/excess/normal rainfall except Odisha, West Madhya Pradesh, East Madhya Pradesh and Chhattisgarh. During August 2025, rainfall over North Interior Karnataka (239.9 mm) was 2nd highest since 1901. Rainfall over Telangana (366.9 mm) was 5th highest since 1901. Out of the 36 meteorological subdivisions, 7 received large excess, 7 received excess rainfall, 17 received normal rainfall and 5 subdivisions received deficient rainfall (**Fig. 1.4c**).

September: For the month of September 2025, rainfall for the country as a whole was **115%** of its Long Period Average (LPA) value, which is highest during the monsoon months of 2025. During this month, twenty-nine met-subdivisions received large excess/excess/normal rainfall whereas East UP, Bihar, Assam & Meghalaya, Arunachal Pradesh, SIK, Kerala & Mahe and Lakshadweep met-subdivisions received deficient rainfall. Rainfall over Marathwada (346.2 mm) was seventh highest since 1901 and rainfall over Arunachal Pradesh (144 mm) was second lowest since 1901. Out of the 36 meteorological subdivisions, 11 received large excess rainfall, 08 received excess rainfall, 10 received

normal rainfall, 07 subdivisions received deficient and none of the subdivision received large deficient rainfall (Fig.1.4d).

Monthly and seasonal sub-division wise rainfall statistics for the 2025 monsoon season are given in the Table 1.2.

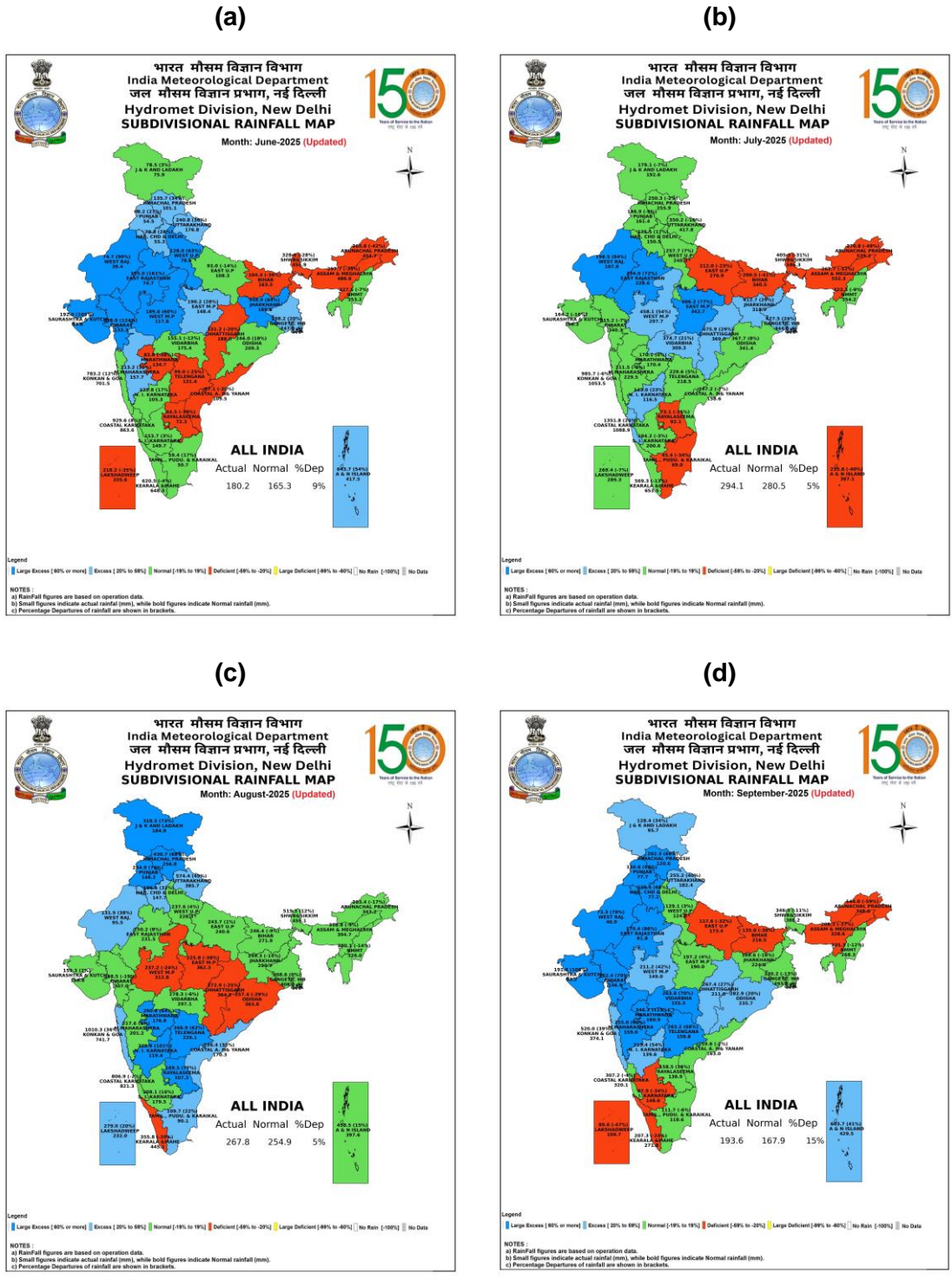


Fig. 1.4 (a-d): Monthly sub-division-wise rainfall departure for JJAS 2025

Table-1.2: Monthly and seasonal sub-division-wise rainfall statistics for the 2025 southwest monsoon season

(Red – Large Deficient & Dark Blue - Large Excess))

Sr. No.	METEOROLOGICAL SUBDIVISIONS	JUNE			JULY			AUGUST			SEPTEMBER			SW MONSOON		
		ACTUAL	NORMAL	% DEP.	ACTUAL	NORMAL	% DEP.	ACTUAL	NORMAL	% DEP.	ACTUAL	NORMAL	% DEP.	ACTUAL	NORMAL	% DEP.
1	A & N ISLAND	643.7	417.5	54%	233.8	387.1	-40%	458.5	397.6	15%	603.7	429.5	41%	1939.7	1631.7	19%
2	ARUNACHAL PRADESH	265.8	454.7	-42%	270.8	529.2	-49%	283.4	343.2	-17%	144.0	348.0	-59%	963.9	1675.1	-42%
3	ASSAM & MEGHALAYA	297.7	486.6	-39%	262.7	552.3	-52%	358.8	394.7	-9%	208.3	328.6	-37%	1128.1	1762.2	-36%
4	N M M T	327.5	353.2	-7%	323.3	354.2	-9%	280.1	326.0	-14%	235.3	268.3	-12%	1215.6	1301.7	-7%
5	SHWB & SIKKIM	328.6	455.9	-28%	405.3	586.3	-31%	515.3	459.1	12%	346.3	388.2	-11%	1595.6	1889.5	-16%
6	GANGETIC WEST BENGAL	298.2	247.9	20%	427.5	344.8	24%	308.6	308.3	0%	230.2	265.8	-13%	1264.6	1166.8	8%
7	ODISHA	246.0	209.3	18%	367.7	341.4	8%	257.4	363.8	-29%	282.9	235.7	20%	1154.1	1150.2	0%
8	JHARKHAND	348.9	189.5	84%	412.7	318.7	29%	249.3	290.7	-14%	188.6	224.0	-16%	1199.4	1022.9	17%
9	BIHAR	104.4	163.3	-36%	200.5	340.5	-41%	246.4	271.9	-9%	135.0	216.5	-38%	686.3	992.2	-31%
10	EAST U.P.	93.0	108.3	-14%	212.0	276.9	-23%	243.7	240.6	1%	117.6	173.4	-32%	666.3	799.2	-17%
11	WEST U.P.	128.0	78.6	63%	257.7	240.3	7%	237.6	228.3	4%	129.1	124.8	3%	752.5	672.0	12%
12	UTTARAKHAND	240.8	176.8	36%	350.2	417.8	-16%	574.4	385.7	49%	255.2	182.4	40%	1420.5	1162.7	22%
13	HAR. CHD & DELHI	70.8	55.3	28%	175.5	150.5	17%	196.6	147.7	33%	129.5	77.2	68%	573.0	430.7	33%
14	PUNJAB	69.2	54.5	27%	146.9	161.4	-9%	254.9	146.2	74%	150.6	77.7	94%	621.5	439.8	41%
15	HIMACHAL PRADESH	135.7	101.1	34%	250.3	255.9	-2%	430.7	256.8	68%	202.3	120.6	68%	1019.1	734.4	39%
16	JAMMU & KASHMIR & LADAKH	78.5	75.9	3%	179.1	192.6	-7%	319.5	184.9	73%	128.4	95.7	34%	705.4	549.1	28%
17	WEST RAJASTHAN	74.7	39.4	90%	198.5	107.8	84%	131.9	95.5	38%	73.3	40.9	79%	478.4	283.6	69%

Sr. No.	METEOROLOGICAL SUBDIVISIONS	JUNE			JULY			AUGUST			SEPTEMBER			SW MONSOON		
		ACTUAL	NORMAL	% DEP.	ACTUAL	NORMAL	% DEP.	ACTUAL	NORMAL	% DEP.	ACTUAL	NORMAL	% DEP.	ACTUAL	NORMAL	% DEP.
18	EAST RAJASTHAN	195.0	74.7	161%	394.0	228.6	72%	250.2	231.5	8%	170.4	91.8	86%	1009.6	626.6	61%
19	WEST MADHYA PRADESH	189.0	117.8	60%	458.1	297.7	54%	237.2	312.8	-24%	211.2	149.0	42%	1095.6	877.3	25%
20	EAST MADHYA PRADESH	190.2	148.4	28%	606.2	342.7	77%	225.8	362.3	-38%	197.2	190.0	4%	1219.4	1043.4	17%
21	GUJARAT REGION	298.9	133.3	124%	315.2	340.3	-7%	248.5	307.0	-19%	262.4	146.9	79%	1125.1	927.5	21%
22	SAURASHTRA & KUTCH	192.0	93.6	105%	164.2	196.3	-16%	159.3	156.8	2%	191.8	93.2	106%	707.2	539.9	31%
23	KONKAN & GOA	783.2	701.5	12%	985.7	1053.5	-6%	1010.3	741.7	36%	520.0	374.1	39%	3299.2	2870.8	15%
24	MADHYA MAHARASHTRA	213.2	157.7	35%	211.5	229.5	-8%	217.6	201.2	8%	255.0	159.0	60%	897.3	747.4	20%
25	MARATHWADA	83.6	134.7	-38%	170.1	170.4	0%	290.8	176.8	64%	346.2	160.9	115%	890.7	642.8	39%
26	VIDARBHA	155.1	175.4	-12%	374.7	309.3	21%	278.3	297.1	-6%	263.8	155.5	70%	1071.9	937.3	14%
27	CHHATTISGARH	151.2	188.0	-20%	475.9	369.0	29%	272.9	364.2	-25%	267.4	211.0	27%	1167.4	1132.2	3%
28	COASTAL A.P. & YANAM	87.1	109.5	-20%	147.2	158.6	-7%	226.4	170.3	33%	159.6	163.0	-2%	620.4	601.4	3%
29	TELANGANA	99.0	131.4	-25%	229.6	218.5	5%	366.9	226.1	62%	263.2	158.8	66%	958.8	734.8	30%
30	RAYALASEEMA	44.5	72.3	-38%	73.1	92.1	-21%	189.5	107.3	77%	158.5	136.9	16%	465.5	408.6	14%
31	TAMIL., PUDU. & KARAIKAL	59.4	50.7	17%	45.4	69.0	-34%	109.7	90.1	22%	111.7	118.6	-6%	326.2	328.4	-1%
32	COASTAL KARNATAKA	929.6	863.6	8%	1351.8	1088.9	24%	806.9	821.3	-2%	307.2	320.1	-4%	3395.4	3093.9	10%
33	N. I. KARNATAKA	122.8	105.3	17%	143.0	116.5	23%	239.9	119.4	101%	215.4	139.6	54%	721.2	480.8	50%
34	S. I. KARNATAKA	153.7	149.7	3%	194.2	200.6	-3%	208.1	179.5	16%	97.9	148.6	-34%	654.0	678.4	-4%
35	KERALA & MAHE	620.5	648.3	-4%	569.3	653.5	-13%	355.8	445.1	-20%	207.3	271.8	-24%	1753.0	2018.7	-13%
36	LAKSHADWEEP	218.2	335.6	-35%	269.4	289.3	-7%	279.0	232.0	20%	89.6	169.7	-47%	856.3	1026.6	-17%

The following **Table 1.3** gives the respective number of subdivisions receiving large excess, excess, normal, deficient and large deficient rainfall during the four months of monsoon season 2025.

Table 1.3: Month wise categorical distributions of no of sub divisions

Month Category	June	July	August	September
Large Excess	7	3	7	11
Excess	8	7	7	8
Normal	11	18	17	10
Deficient	10	8	5	7
Large Deficient	0	0	0	0
No Rain	0	0	0	0

1.2.2 District wise monthly distribution of rainfall

Monthly district wise rainfall distributions for June, July, August and September 2025 are shown in **Fig.1.5 (a-d)**. During the season, out of 738 districts, 67 districts received large excess rainfall, 187 received excess rainfall, 327 received normal rainfall, 134 received deficient rainfall and 12 received large deficient rainfall.

During the month of **June**, most of the districts of Arunachal Pradesh, Assam, Meghalaya, Nagaland, Tripura, Sikkim, Rajasthan, Madhya Pradesh, Goa, Maharashtra, Andhra Pradesh, Tamil Nadu, Puducherry (UT), Karnataka received large excess/excess/normal rainfall. Out of the total 738 districts for which data were available, 165 districts received large excess rainfall, 94 districts received excess rainfall, 204 received normal rainfall, 200 received deficient rainfall and 67 districts received large deficient rainfall during June 2025.

During the month of July, most districts of A & N Island (UT), Sikkim, West Bengal, Odisha, Uttarakhand, Rajasthan, Madhya Pradesh, Gujrat, Dadra & Nagar Haveli and Daman & Diu (UT), Goa, Maharashtra, Chhattisgarh, Andhra Pradesh, Telangana, Tamil Nadu, Puducherry (UT), Karnataka, Kerala and Lakshadweep (UT) received large excess/excess/normal rainfall. Out of the total 738 districts for which data were available, 94 districts received large excess rainfall, 125 districts received excess rainfall, 235 received normal rainfall, 200 received deficient rainfall and 76 districts received large deficient rainfall during in July 2025.

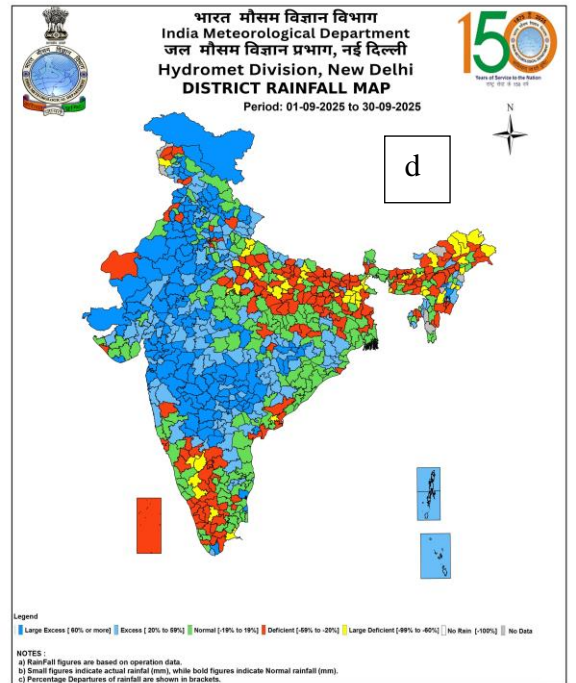
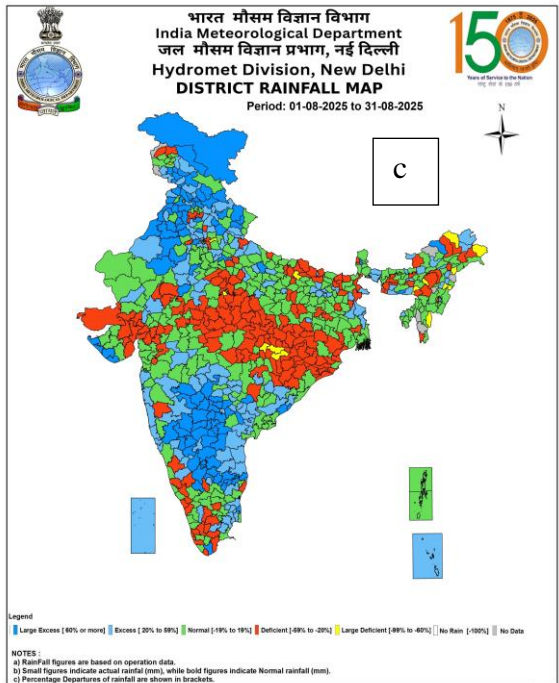
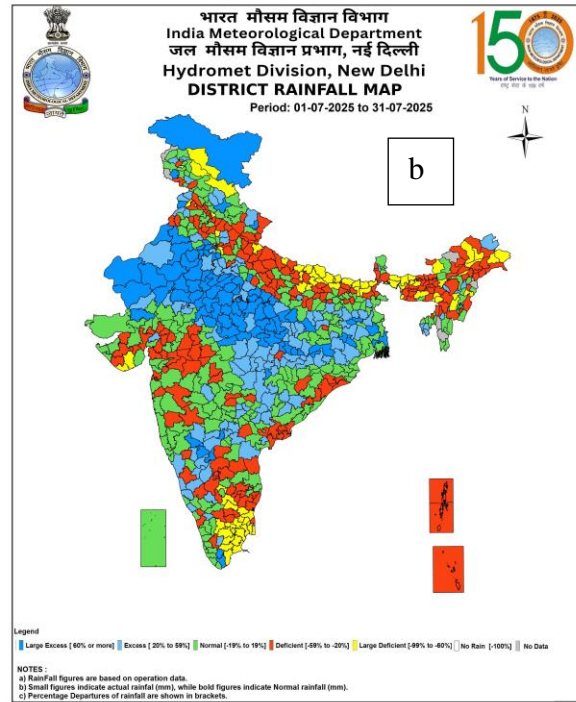
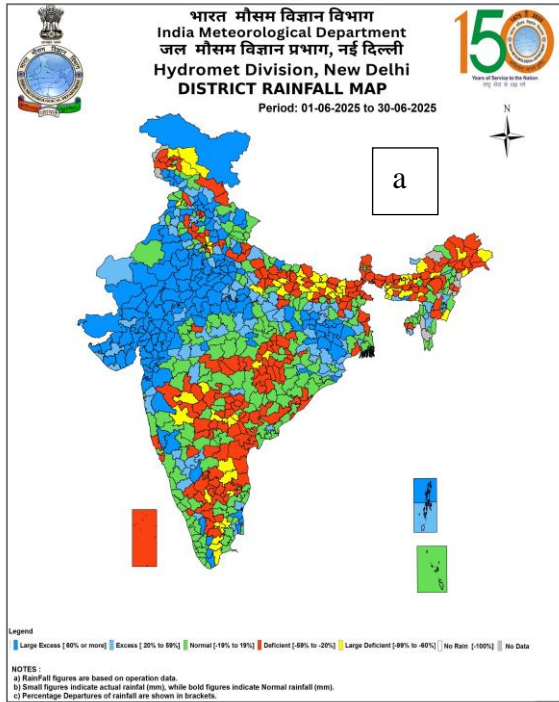


Fig. 1.5 (a-d): Monthly district wise rainfall departure for June, July, August and September, 2025

During the month of August, most districts of A & N Island (UT), Manipur, Mizoram, Tripura, Sikkim, West Bengal, Odisha, Jharkhand, Bihar, Uttar Pradesh, Uttarakhand, Haryana, Chandigarh (UT), Delhi, Punjab, Himachal Pradesh, Jammu & Kashmir (UT), Ladakh(UT), Rajasthan, Madhya Pradesh, Gujrat, Dadra & Nagar Haveli and Daman & Diu (UT), Goa, Maharashtra, Chhattisgarh, Andhra Pradesh, Telangana, Puducherry(UT), and Tamil Nadu received Large excess/excess/normal rainfall. Out of the total 738 districts for which data were available, 110 districts received large excess rainfall, 146 districts received excess rainfall, 272 received normal rainfall, 187 received deficient rainfall and 14 districts received large deficient rainfall during August 2025.

During the month of September, most districts of Sikkim, West Bengal, Odisha, Bihar, Jharkhand, Uttar Pradesh, Uttarakhand, Haryana, Chandigarh, Delhi, Himachal Pradesh, Rajasthan, Madhya Pradesh, Gujrat, Dadra & Nagar Haveli and Daman & Diu (UT), Goa, Maharashtra, Chhattisgarh, Andhra Pradesh, Telangana and Tamil Nadu received large excess/excess/normal rainfall. Out of the total 738 districts for which data were available, 167 districts received large excess rainfall, 150 districts received excess rainfall, 188 received normal rainfall, 177 received deficient rainfall and 48 districts received large deficient rainfall during September 2025.

The following **Table 1.4** gives number of districts receiving large excess (LE), excess(E), normal (N), deficient (D), large deficient (LD) or no rain (NR) during the months of June, July, August and September 2025 in each of the state.

Table 1.4: Month wise categorical distribution of no of districts in each state

STATES	JUNE							JULY							AUGUST							SEPTEMBER						
	LE	E	N	D	LD	NR	ND	LE	E	N	D	LD	NR	ND	LE	E	N	D	LD	NR	ND	LE	E	N	D	LD	NR	ND
A & N ISLAND (UT)	1	1	1	0	0	0	0	0	0	0	3	0	0	0	0	1	2	0	0	0	0	0	3	0	0	0	0	0
ARUNACHAL PRADESH	0	1	1	9	4	0	1	0	1	1	8	5	0	1	1	4	4	4	2	0	1	0	1	1	7	6	0	1
ASSAM	0	2	9	15	9	0	0	1	1	2	22	8	0	1	0	5	20	8	1	0	1	0	3	7	19	5	0	1
MEGHALAYA	1	1	0	4	5	0	0	0	0	1	6	4	0	0	1	3	1	5	1	0	0	0	0	3	4	4	0	0
NAGALAND	0	0	4	2	0	0	5	0	2	3	2	2	0	2	0	3	3	0	2	0	3	1	3	2	0	2	0	3
MANIPUR	0	3	3	2	1	0	0	0	1	4	3	1	0	0	0	1	7	1	0	0	0	1	2	0	5	1	0	0
MIZORAM	0	2	4	0	0	0	2	0	1	5	0	0	0	2	0	0	4	1	1	0	2	0	0	4	2	0	0	2
TRIPURA	0	1	5	2	0	0	0	0	3	4	1	0	0	0	0	1	7	0	0	0	0	0	3	3	2	0	0	0
SIKKIM	0	0	3	3	0	0	0	0	1	3	2	0	0	0	1	0	3	2	0	0	0	0	1	4	1	0	0	0
WEST BENGAL	2	3	8	10	0	0	0	4	3	11	3	2	0	0	0	6	12	5	0	0	0	0	1	13	8	1	0	0
ODISHA	3	9	15	3	0	0	0	2	7	15	6	0	0	0	0	1	5	24	0	0	0	3	10	16	1	0	0	0
JHARKHAND	13	5	4	2	0	0	0	4	11	8	1	0	0	0	0	2	13	9	0	0	0	0	3	11	7	3	0	0
BIHAR	0	4	5	17	12	0	0	0	1	12	13	12	0	0	0	7	20	11	0	0	0	0	1	6	27	4	0	0
UTTAR PRADESH	20	12	12	21	10	0	0	6	10	16	32	11	0	0	3	16	37	17	2	0	0	4	14	16	27	14	0	0
UTTARAKHAND	3	3	7	0	0	0	0	1	1	4	7	0	0	0	5	4	4	0	0	0	0	5	5	2	1	0	0	0
HARYANA	6	3	7	6	0	0	0	7	2	7	5	1	0	0	6	8	6	2	0	0	0	11	5	5	1	0	0	0
CHANDIGARH (UT)	0	1	0	0	0	0	0	0	0	0	1	0	0	0	0	0	1	0	0	0	0	1	0	0	0	0	0	0
DELHI	0	1	4	3	2	0	0	1	3	3	1	0	0	2	2	4	2	0	0	0	2	1	2	3	3	0	0	1
PUNJAB	7	5	6	3	1	0	0	1	4	7	9	1	0	0	14	3	4	1	0	0	0	12	4	3	3	0	0	0

HIMACHAL PRADESH	6	3	1	2	0	0	0	1	2	8	0	1	0	0	8	3	1	0	0	0	0	7	3	2	0	0	0	0
JAMMU & KASHMIR(UT)	5	1	3	8	3	0	0	1	3	11	3	2	0	0	5	5	7	2	1	0	0	7	3	4	5	1	0	0
LADAKH(UT)	1	0	0	0	1	0	0	1	0	0	0	1	0	0	2	0	0	0	0	0	0	2	0	0	0	0	0	0
RAJASTHAN	31	1	1	0	0	0	0	22	6	5	0	0	0	0	7	7	15	4	0	0	0	23	6	3	1	0	0	0
MADHYA PRADESH	19	13	19	1	0	0	0	29	8	8	7	0	0	0	0	3	16	32	1	0	0	13	15	17	7	0	0	0
GUJARAT	29	4	0	0	0	0	0	1	1	14	15	2	0	0	4	1	13	15	0	0	0	14	12	6	1	0	0	0
DADRA & NAGAR HAVELI AND DAMAN & DIU (UT)	2	0	1	0	0	0	0	0	0	0	2	1	0	0	1	0	2	0	0	0	0	2	1	0	0	0	0	0
GOA	0	0	1	1	0	0	0	0	0	2	0	0	0	0	0	2	0	0	0	0	0	0	0	0	2	0	0	0
MAHARASHTRA	5	3	13	12	3	0	0	0	7	19	10	0	0	0	5	13	13	5	0	0	0	22	10	3	1	0	0	0
CHHATISGARH	1	1	9	20	2	0	0	6	18	8	1	0	0	0	0	2	9	19	3	0	0	7	14	9	3	0	0	0
ANDHRA PRADESH	0	1	8	15	2	0	0	0	2	10	14	0	0	0	7	10	9	0	0	0	0	2	4	12	7	1	0	0
TELANGANA	0	1	10	17	5	0	0	1	11	17	4	0	0	0	15	12	6	0	0	0	0	19	12	2	0	0	0	0
TAMIL NADU	7	3	15	7	6	0	0	2	2	5	10	19	0	0	6	11	13	8	0	0	0	3	5	16	12	2	0	0
PUDUCHERRY (UT)	1	0	1	2	0	0	0	0	0	2	0	2	0	0	1	1	2	0	0	0	0	1	1	0	2	0	0	0
KARNATAKA	2	6	11	11	1	0	0	3	12	9	6	1	0	0	16	6	4	5	0	0	0	6	3	9	9	4	0	0
KERALA	0	0	13	1	0	0	0	0	1	10	3	0	0	0	0	0	7	7	0	0	0	0	0	6	8	0	0	0
LAKSHADWEEP (UT)	0	0	0	1	0	0	0	0	0	1	0	0	0	0	0	1	0	0	0	0	0	0	0	0	1	0	0	0
TOTAL	165	94	204	200	67	0	8	94	125	235	200	76	0	8	110	146	272	187	14	0	9	167	150	188	177	48	0	8

1.2.3 Daily rainfall distribution

Real-time daily rainfall (in mm) and its long-term (1971-2020) normal value for the country as a whole and for the four homogeneous regions during 1st June to 30th September are shown in **Fig. 1.6**. For the country as a whole, rainfall averaged was generally above or near normal on many days during Season. The average rainfall was above or near normal on 16 days during June, 17 days during July, 18 days during August and 17 days during September. On almost 17 occasions including the continuous periods of 17 - 20 June, 1 - 4 September and 27 - 28 September it was more than or equal to one and a half times its normal value. It was below normal at a stretch on 5 - 14 June, 11 - 23 July (except 14, 15 Jul), 31 July - 13 August, 10 - 13 September and 20 - 26 September (except 23 Sept).

Over the homogeneous region of Northwest India, daily rainfall was above normal on most of the occasions (54.1% days) (66 days out of 122 days) during the season. It was above normal at a stretch from 16 June - 4 July, 17 - 19 July, 29 July - 1 August, 22 August - 8 September (except 5 September), 16 - 19 September. However, rainfall was below for many days during first fortnight of June, 7 - 9 July, 22 - 28 July (except 26 July), 7 - 11 August, 16 - 21 August, 9 - 15 September and 20 - 29 September.

Over East & Northeast India, daily rainfall was below normal on most of the days (72.9% days) (89 days out of 122 days) during the season. It was below normal for most of the days during June (for 18 days), July (for 25 days), August (for 21 days) and September (for 25 days). At a stretch rainfall was below normal from 6 - 16 June, 26 June - 25 July (except 9 July), 30 July - 1 August, 14 - 21 August, 24 August - 13 September (except 2 September) and 18 - 30 September. However, it was above normal at a stretch from 1 - 5 June, 17 - 20 June, 2 - 5 August and 14 - 17 September.

Over Central India, daily rainfall was above normal for many days (52.4% days) (64 days out of 122 days) during the season. It was above normal value at a stretch from 15 June - 9 July (except 21 June), 24 - 27 July, 14 - 29 August (except 26 August), 1 - 8 September, 14 - 17 September and 22 - 29 September (except 26 September). However, it was below normal for many days during first fortnight of June, at a stretch from 13 - 22 July, 31 July - 13 August, 9 - 13 September and 18 - 21 September.

Over the South Peninsula, daily rainfall was below normal value on many days (51.6% days) (63 days out of 122 days) during the season. It was below normal from 1 - 8 June, 18 - 22 June, 28 June - 1 July, 4 - 16 July, 28 July - 4 August, 20 - 26 August and 4 - 10 September. However, it was above normal at a stretch from 11 - 17 June, 25 - 27 June, 17 - 27 July, 8 - 19 August, 27 August - 3 September (except 31 August), 16 - 23 September (except 20 September) and 26 - 28 September.

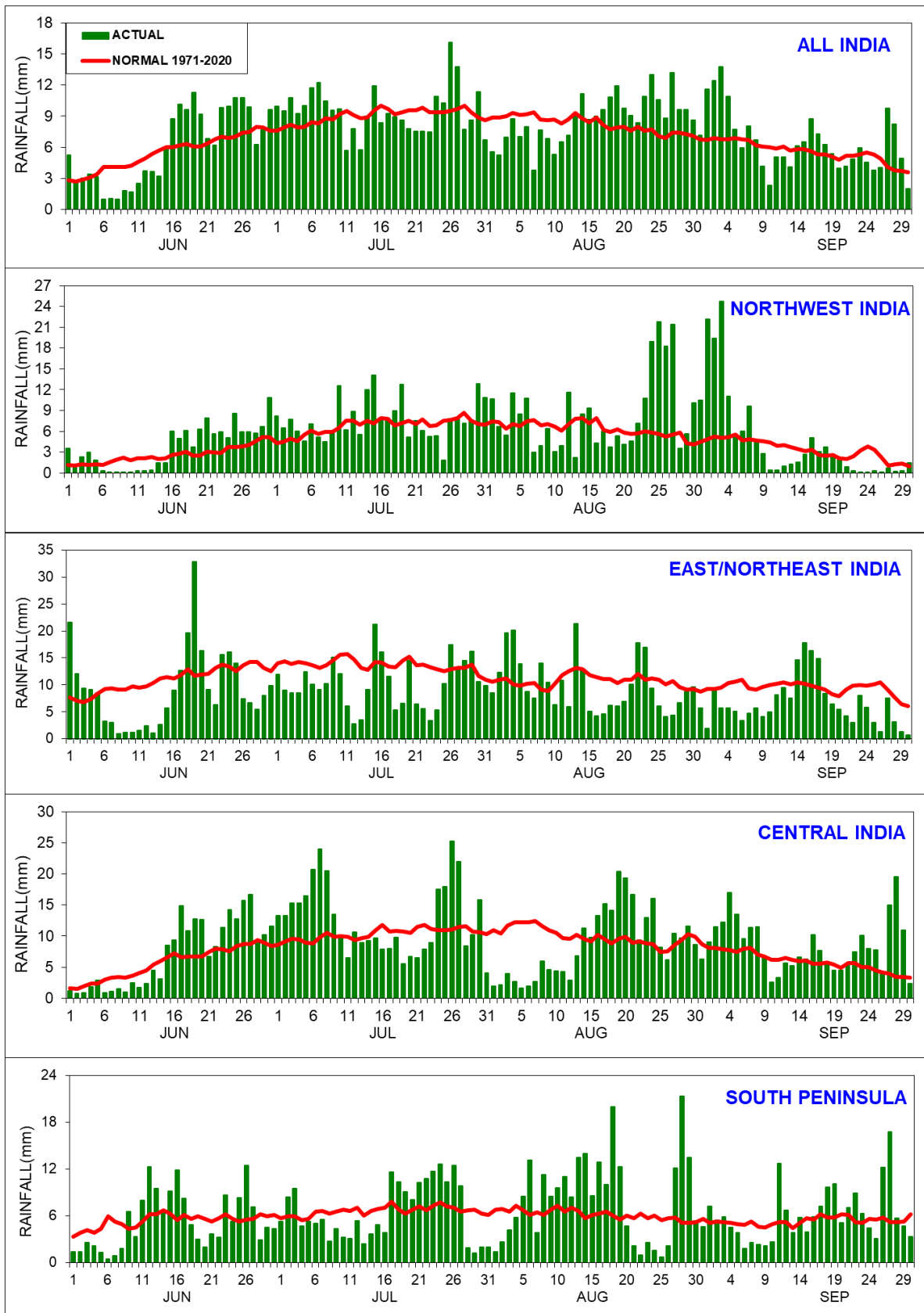


Fig. 1.6: Daily area weighted rainfall (mm) (vertical bars) and its long term (1971-2020) average (solid line) over the country as whole and the four homogeneous regions during the season

1.2.4 Weekly rainfall distribution

Fig. 1.7 shows the area-weighted cumulative weekly rainfall percentage departure for the country as a whole and for the four homogeneous regions, Northwest India, Northeast India, Central India, and the South Peninsula, during the 2025 monsoon season. Cumulative rainfall departure for the country as a whole was negative till the week ending 16 June except for the first week of the season, thereafter it was positive till the end of the season. ***The area weighted rainfall for the monsoon season this year was 108% of its LPA value.***

Cumulative weekly rainfall departure for northwest region was negative till week ending 16 June, except for the first week, thereafter it was positive till the end of the season. For East and Northeast region, the rainfall departure was negative for all the weeks of the season, except for the first week. For Central region, the cumulative weekly rainfall departure was positive for whole season except for the first three weeks. For South Peninsula region, the cumulative weekly rainfall departure was negative till the week ending 6th August, after that it was positive for all the weeks of the season.

Week by week and cumulative weekly rainfall percentage departure for each of the 36 meteorological subdivisions from 1 June to 30 September 2025 is shown in **Fig.1.8** and **Fig. 1.9**, respectively. Weekly rainfall was Large Excess, Excess or Normal during most of the weeks (more than 50% of the weeks) for some subdivisions viz. Andaman & Nicobar islands, Nagaland, Manipur, Mizoram & Tripura, Gangetic West Bengal, Odisha, Jharkhand, Uttarakhand, Haryana, Chandigarh & Delhi, Punjab, Himachal Pradesh, Jammu, Kashmir & Ladakh, West Rajasthan, East Rajasthan, West Madhya Pradesh, East Madhya Pradesh, Gujarat region, Konkan & Goa, Madhya Maharashtra, Marathwada, Chhattisgarh, Telangana, Tamil Nadu, Puducherry & Karaikal, Coastal Karnataka, North Interior Karnataka and South Interior Karnataka.

Similarly, cumulative weekly rainfall was also Large Excess, Excess or Normal during most of the weeks (more than 50% of the weeks) for most of the subdivisions viz. Andaman & Nicobar islands, Nagaland, Manipur, Mizoram & Tripura, Sub-Himalayan West Bengal & Sikkim, Gangetic West Bengal, Odisha, Jharkhand, East Uttar Pradesh, West Uttar Pradesh, Uttarakhand, Haryana, Chandigarh & Delhi, Punjab, Himachal Pradesh, Jammu, Kashmir & Ladakh, West Rajasthan, East Rajasthan, West Madhya Pradesh, East Madhya Pradesh, Gujarat region, Saurashtra & Kutch, Konkan & Goa, Madhya Maharashtra, Vidarbha, Chhattisgarh, Coastal Andhra Pradesh & Yanam, Telangana, Tamil Nadu, Puducherry & Karaikal, Coastal Karnataka, North Interior Karnataka, South Interior Karnataka and Kerala & Mahe.

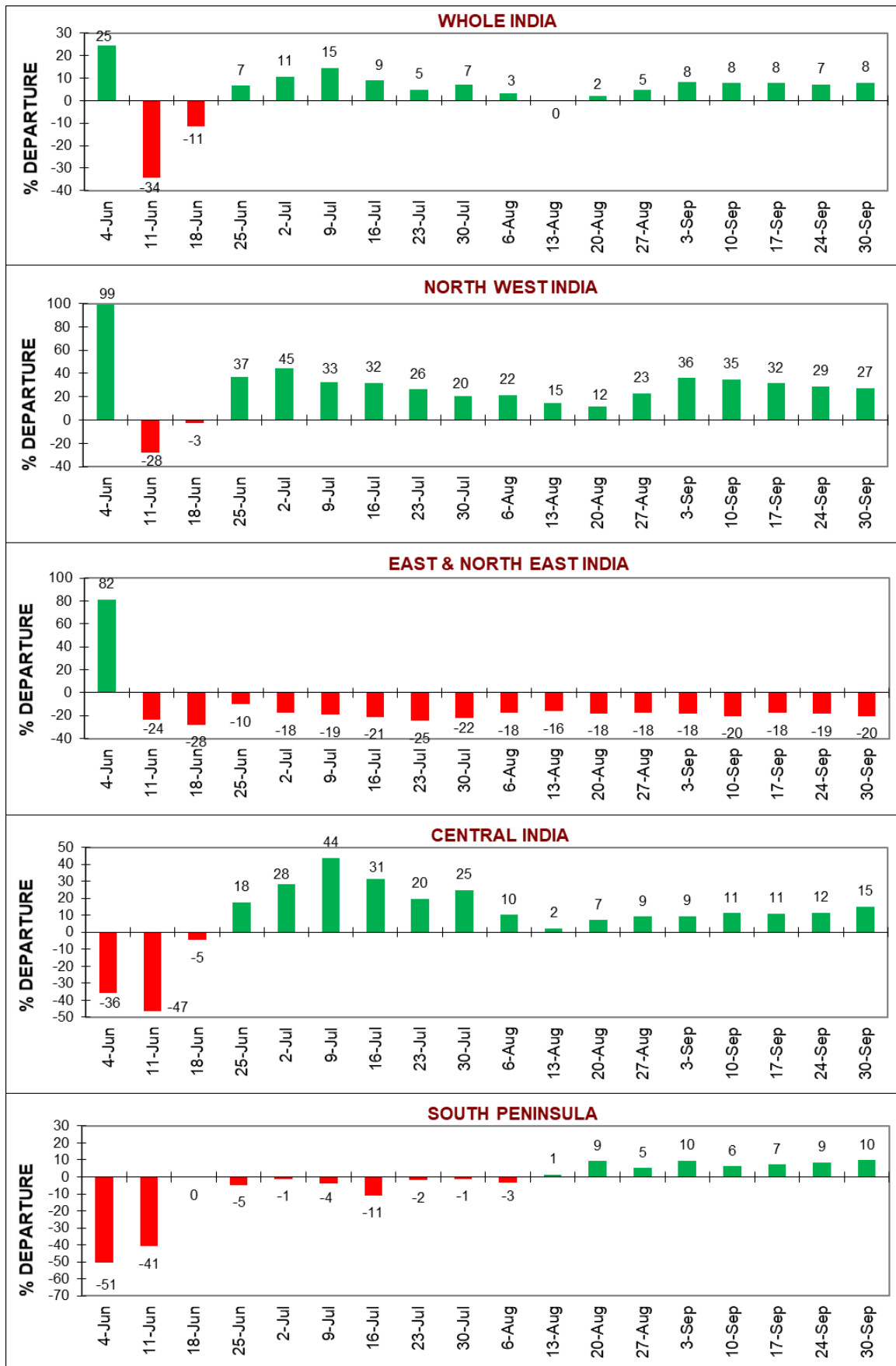


Fig. 1.7: Area weighted cumulative weekly rainfall percentage departure for the country as a whole and the four homogeneous regions

WEEKLY/PERIODICAL PROGRESS OF MONSOON 2025 (Rainfall % Dep.)

S.NO	MET.SUBDIVISION	WEEK ENDINGS																	
		1-4 Jun	11-Jun	18-Jun	25-Jun	2-Jul	9-Jul	16-Jul	23-Jul	30-Jul	6-Aug	13-Aug	20-Aug	27-Aug	3-Sep	10-Sep	17-Sep	24-Sep	25 - 30 SEPT
1	A & N ISLANDS	Blue	Red	Green	Blue	Blue	Blue	Blue	Blue	Blue	Blue	Blue	Blue	Blue	Blue	Blue	Blue	Blue	Blue
2	ARUNACHAL PRADESH	Blue	Blue	Blue	Blue	Blue	Blue	Blue	Blue	Blue	Blue	Blue	Blue	Blue	Blue	Blue	Blue	Blue	Blue
3	ASSAM & MEGHALAYA	Blue	Blue	Blue	Blue	Blue	Blue	Blue	Blue	Blue	Blue	Blue	Blue	Blue	Blue	Blue	Blue	Blue	Blue
4	NAG.,MANI.,MIZO.& TRIPURA	Blue	Blue	Blue	Blue	Blue	Blue	Blue	Blue	Blue	Blue	Blue	Blue	Blue	Blue	Blue	Blue	Blue	Blue
5	S.H.W.B. & SIKKIM	Blue	Blue	Blue	Blue	Blue	Blue	Blue	Blue	Blue	Blue	Blue	Blue	Blue	Blue	Blue	Blue	Blue	Blue
6	GANGATIC W.B.	Blue	Blue	Blue	Blue	Blue	Blue	Blue	Blue	Blue	Blue	Blue	Blue	Blue	Blue	Blue	Blue	Blue	Blue
7	ODISHA	Blue	Blue	Blue	Blue	Blue	Blue	Blue	Blue	Blue	Blue	Blue	Blue	Blue	Blue	Blue	Blue	Blue	Blue
8	JHARKHAND	Blue	Blue	Blue	Blue	Blue	Blue	Blue	Blue	Blue	Blue	Blue	Blue	Blue	Blue	Blue	Blue	Blue	Blue
9	BIHAR	Blue	Blue	Blue	Blue	Blue	Blue	Blue	Blue	Blue	Blue	Blue	Blue	Blue	Blue	Blue	Blue	Blue	Blue
10	EAST U.P.	Blue	Blue	Blue	Blue	Blue	Blue	Blue	Blue	Blue	Blue	Blue	Blue	Blue	Blue	Blue	Blue	Blue	Blue
11	WEST U.P.	Blue	Blue	Blue	Blue	Blue	Blue	Blue	Blue	Blue	Blue	Blue	Blue	Blue	Blue	Blue	Blue	Blue	Blue
12	UTTARAKHAND	Blue	Blue	Blue	Blue	Blue	Blue	Blue	Blue	Blue	Blue	Blue	Blue	Blue	Blue	Blue	Blue	Blue	Blue
13	HAR., CHANDI.& DELHI	Blue	Blue	Blue	Blue	Blue	Blue	Blue	Blue	Blue	Blue	Blue	Blue	Blue	Blue	Blue	Blue	Blue	Blue
14	PUNJAB	Blue	Blue	Blue	Blue	Blue	Blue	Blue	Blue	Blue	Blue	Blue	Blue	Blue	Blue	Blue	Blue	Blue	Blue
15	HIMACHAL PRADESH	Blue	Blue	Blue	Blue	Blue	Blue	Blue	Blue	Blue	Blue	Blue	Blue	Blue	Blue	Blue	Blue	Blue	Blue
16	JAMMU & KASHMIR	Blue	Blue	Blue	Blue	Blue	Blue	Blue	Blue	Blue	Blue	Blue	Blue	Blue	Blue	Blue	Blue	Blue	Blue
17	WEST RAJASTHAN	Blue	Blue	Blue	Blue	Blue	Blue	Blue	Blue	Blue	Blue	Blue	Blue	Blue	Blue	Blue	Blue	Blue	Blue
18	EAST RAJASTHAN	Blue	Blue	Blue	Blue	Blue	Blue	Blue	Blue	Blue	Blue	Blue	Blue	Blue	Blue	Blue	Blue	Blue	Blue
19	WEST M.P.	Blue	Blue	Blue	Blue	Blue	Blue	Blue	Blue	Blue	Blue	Blue	Blue	Blue	Blue	Blue	Blue	Blue	Blue
20	EAST M.P.	Blue	Blue	Blue	Blue	Blue	Blue	Blue	Blue	Blue	Blue	Blue	Blue	Blue	Blue	Blue	Blue	Blue	Blue
21	GUJARAT REGION	Blue	Blue	Blue	Blue	Blue	Blue	Blue	Blue	Blue	Blue	Blue	Blue	Blue	Blue	Blue	Blue	Blue	Blue
22	SAURASHTRA & KUTCH	Blue	Blue	Blue	Blue	Blue	Blue	Blue	Blue	Blue	Blue	Blue	Blue	Blue	Blue	Blue	Blue	Blue	Blue
23	KONKAN & GOA	Blue	Blue	Blue	Blue	Blue	Blue	Blue	Blue	Blue	Blue	Blue	Blue	Blue	Blue	Blue	Blue	Blue	Blue
24	MADHYA M'RASHTRA	Blue	Blue	Blue	Blue	Blue	Blue	Blue	Blue	Blue	Blue	Blue	Blue	Blue	Blue	Blue	Blue	Blue	Blue
25	MARATHAWADA	Blue	Blue	Blue	Blue	Blue	Blue	Blue	Blue	Blue	Blue	Blue	Blue	Blue	Blue	Blue	Blue	Blue	Blue
26	VIDARBHA	Blue	Blue	Blue	Blue	Blue	Blue	Blue	Blue	Blue	Blue	Blue	Blue	Blue	Blue	Blue	Blue	Blue	Blue
27	CHATTISGARH	Blue	Blue	Blue	Blue	Blue	Blue	Blue	Blue	Blue	Blue	Blue	Blue	Blue	Blue	Blue	Blue	Blue	Blue
28	COASTAL A.P.	Blue	Blue	Blue	Blue	Blue	Blue	Blue	Blue	Blue	Blue	Blue	Blue	Blue	Blue	Blue	Blue	Blue	Blue
29	TELANGANA	Blue	Blue	Blue	Blue	Blue	Blue	Blue	Blue	Blue	Blue	Blue	Blue	Blue	Blue	Blue	Blue	Blue	Blue
30	RAYALASEEMA	Blue	Blue	Blue	Blue	Blue	Blue	Blue	Blue	Blue	Blue	Blue	Blue	Blue	Blue	Blue	Blue	Blue	Blue
31	TAMIL NADU	Blue	Blue	Blue	Blue	Blue	Blue	Blue	Blue	Blue	Blue	Blue	Blue	Blue	Blue	Blue	Blue	Blue	Blue
32	COASTAL KARNATAKA	Blue	Blue	Blue	Blue	Blue	Blue	Blue	Blue	Blue	Blue	Blue	Blue	Blue	Blue	Blue	Blue	Blue	Blue
33	N.I.KARNATAKA	Blue	Blue	Blue	Blue	Blue	Blue	Blue	Blue	Blue	Blue	Blue	Blue	Blue	Blue	Blue	Blue	Blue	Blue
34	S.I.KARNATAKA	Blue	Blue	Blue	Blue	Blue	Blue	Blue	Blue	Blue	Blue	Blue	Blue	Blue	Blue	Blue	Blue	Blue	Blue
35	KERALA	Blue	Blue	Blue	Blue	Blue	Blue	Blue	Blue	Blue	Blue	Blue	Blue	Blue	Blue	Blue	Blue	Blue	Blue
36	LAKSHADWEEP	Blue	Blue	Blue	Blue	Blue	Blue	Blue	Blue	Blue	Blue	Blue	Blue	Blue	Blue	Blue	Blue	Blue	Blue

LEGEND:

 LARGE EXCESS +60% OR MORE	 EXCESS +20% TO +59%	 NORMAL +19% TO -19%
 DEFICIENT -20% TO -59%	 LARGE DEFICIENT -60% OR LESS	 NO RAIN

(वास्तविक समय के आंकड़ों पर आधारित)

Fig. 1.8: Sub-division wise weekly rainfall

CUMULATIVE PROGRESS OF MONSOON 2025 (Rainfall % Dep)

S.NO	MET.SUBDIVISION	CUMULATIVE WEEK ENDINGS																	
		1-4 Jun	11-Jun	18-Jun	25-Jun	2-Jul	9-Jul	16-Jul	23-Jul	30-Jul	6-Aug	13-Aug	20-Aug	27-Aug	3-Sep	10-Sep	17-Sep	24-Sep	30-Sep
1	A & N ISLANDS	Normal	Normal	Normal	Normal	Normal	Normal	Normal	Normal	Normal	Normal	Normal	Normal	Normal	Normal	Normal	Normal	Normal	Normal
2	ARUNACHAL PRADESH	Deficient	Deficient	Deficient	Deficient	Deficient	Deficient	Deficient	Deficient	Deficient	Deficient	Deficient	Deficient	Deficient	Deficient	Deficient	Deficient	Deficient	Deficient
3	ASSAM & MEGHALAYA	Deficient	Deficient	Deficient	Deficient	Deficient	Deficient	Deficient	Deficient	Deficient	Deficient	Deficient	Deficient	Deficient	Deficient	Deficient	Deficient	Deficient	Deficient
4	NAG.,MANI.,MIZO.& TRIPURA	Normal	Normal	Normal	Normal	Normal	Normal	Normal	Normal	Normal	Normal	Normal	Normal	Normal	Normal	Normal	Normal	Normal	Normal
5	S.H.W.B. & SIKKIM	Normal	Normal	Normal	Normal	Normal	Normal	Normal	Normal	Normal	Normal	Normal	Normal	Normal	Normal	Normal	Normal	Normal	Normal
6	GANGATIC W.B.	Normal	Normal	Normal	Normal	Normal	Normal	Normal	Normal	Normal	Normal	Normal	Normal	Normal	Normal	Normal	Normal	Normal	Normal
7	ODISHA	Normal	Normal	Normal	Normal	Normal	Normal	Normal	Normal	Normal	Normal	Normal	Normal	Normal	Normal	Normal	Normal	Normal	Normal
8	JHARKHAND	Normal	Normal	Normal	Normal	Normal	Normal	Normal	Normal	Normal	Normal	Normal	Normal	Normal	Normal	Normal	Normal	Normal	Normal
9	BIHAR	Deficient	Deficient	Deficient	Deficient	Deficient	Deficient	Deficient	Deficient	Deficient	Deficient	Deficient	Deficient	Deficient	Deficient	Deficient	Deficient	Deficient	Deficient
10	EAST U.P.	Normal	Normal	Normal	Normal	Normal	Normal	Normal	Normal	Normal	Normal	Normal	Normal	Normal	Normal	Normal	Normal	Normal	Normal
11	WEST U.P.	Normal	Normal	Normal	Normal	Normal	Normal	Normal	Normal	Normal	Normal	Normal	Normal	Normal	Normal	Normal	Normal	Normal	Normal
12	UTTARAKHAND	Normal	Normal	Normal	Normal	Normal	Normal	Normal	Normal	Normal	Normal	Normal	Normal	Normal	Normal	Normal	Normal	Normal	Normal
13	HAR., CHANDI.& DELHI	Normal	Normal	Normal	Normal	Normal	Normal	Normal	Normal	Normal	Normal	Normal	Normal	Normal	Normal	Normal	Normal	Normal	Normal
14	PUNJAB	Normal	Normal	Normal	Normal	Normal	Normal	Normal	Normal	Normal	Normal	Normal	Normal	Normal	Normal	Normal	Normal	Normal	Normal
15	HIMACHAL PRADESH	Normal	Normal	Normal	Normal	Normal	Normal	Normal	Normal	Normal	Normal	Normal	Normal	Normal	Normal	Normal	Normal	Normal	Normal
16	JAMMU & KASHMIR	Normal	Normal	Normal	Normal	Normal	Normal	Normal	Normal	Normal	Normal	Normal	Normal	Normal	Normal	Normal	Normal	Normal	Normal
17	WEST RAJASTHAN	Normal	Normal	Normal	Normal	Normal	Normal	Normal	Normal	Normal	Normal	Normal	Normal	Normal	Normal	Normal	Normal	Normal	Normal
18	EAST RAJASTHAN	Normal	Normal	Normal	Normal	Normal	Normal	Normal	Normal	Normal	Normal	Normal	Normal	Normal	Normal	Normal	Normal	Normal	Normal
19	WEST M.P.	Normal	Normal	Normal	Normal	Normal	Normal	Normal	Normal	Normal	Normal	Normal	Normal	Normal	Normal	Normal	Normal	Normal	Normal
20	EAST M.P.	Normal	Normal	Normal	Normal	Normal	Normal	Normal	Normal	Normal	Normal	Normal	Normal	Normal	Normal	Normal	Normal	Normal	Normal
21	GUJARAT REGION	Normal	Normal	Normal	Normal	Normal	Normal	Normal	Normal	Normal	Normal	Normal	Normal	Normal	Normal	Normal	Normal	Normal	Normal
22	SAURASHTRA & KUTCH	Normal	Normal	Normal	Normal	Normal	Normal	Normal	Normal	Normal	Normal	Normal	Normal	Normal	Normal	Normal	Normal	Normal	Normal
23	KONKAN & GOA	Normal	Normal	Normal	Normal	Normal	Normal	Normal	Normal	Normal	Normal	Normal	Normal	Normal	Normal	Normal	Normal	Normal	Normal
24	MADHYA M'RASHTRA	Normal	Normal	Normal	Normal	Normal	Normal	Normal	Normal	Normal	Normal	Normal	Normal	Normal	Normal	Normal	Normal	Normal	Normal
25	MARATHAWADA	Normal	Normal	Normal	Normal	Normal	Normal	Normal	Normal	Normal	Normal	Normal	Normal	Normal	Normal	Normal	Normal	Normal	Normal
26	VIDARBHA	Normal	Normal	Normal	Normal	Normal	Normal	Normal	Normal	Normal	Normal	Normal	Normal	Normal	Normal	Normal	Normal	Normal	Normal
27	CHATTISGARH	Normal	Normal	Normal	Normal	Normal	Normal	Normal	Normal	Normal	Normal	Normal	Normal	Normal	Normal	Normal	Normal	Normal	Normal
28	COASTAL A.P.	Normal	Normal	Normal	Normal	Normal	Normal	Normal	Normal	Normal	Normal	Normal	Normal	Normal	Normal	Normal	Normal	Normal	Normal
29	TELANGANA	Normal	Normal	Normal	Normal	Normal	Normal	Normal	Normal	Normal	Normal	Normal	Normal	Normal	Normal	Normal	Normal	Normal	Normal
30	RAYALASEEMA	Normal	Normal	Normal	Normal	Normal	Normal	Normal	Normal	Normal	Normal	Normal	Normal	Normal	Normal	Normal	Normal	Normal	Normal
31	TAMIL NADU	Normal	Normal	Normal	Normal	Normal	Normal	Normal	Normal	Normal	Normal	Normal	Normal	Normal	Normal	Normal	Normal	Normal	Normal
32	COASTAL KARNATAKA	Normal	Normal	Normal	Normal	Normal	Normal	Normal	Normal	Normal	Normal	Normal	Normal	Normal	Normal	Normal	Normal	Normal	Normal
33	N.I.KARNATAKA	Normal	Normal	Normal	Normal	Normal	Normal	Normal	Normal	Normal	Normal	Normal	Normal	Normal	Normal	Normal	Normal	Normal	Normal
34	S.I.KARNATAKA	Normal	Normal	Normal	Normal	Normal	Normal	Normal	Normal	Normal	Normal	Normal	Normal	Normal	Normal	Normal	Normal	Normal	Normal
35	KERALA	Normal	Normal	Normal	Normal	Normal	Normal	Normal	Normal	Normal	Normal	Normal	Normal	Normal	Normal	Normal	Normal	Normal	Normal
36	LAKSHADWEEP	Normal	Normal	Normal	Normal	Normal	Normal	Normal	Normal	Normal	Normal	Normal	Normal	Normal	Normal	Normal	Normal	Normal	Normal

LEGEND:

 LARGE EXCESS +60%OR MORE	 EXCESS +20% TO +59%	 NORMAL +19% TO -19%
 DEFICIENT -20%TO-59%	 LARGE DEFICIENT -60% OR LESS	 NO RAIN

(वास्तविक समय के आंकड़ों पर आधारित)

Fig. 1.9: Sub-division wise cumulative weekly rainfall

1.2.5 Heavy Rainfall Events

During the 2025 southwest monsoon season, very heavy rainfall (115.5 mm to 204.4 mm in 24 hours) / extremely heavy rainfall (≥ 204.5 mm in 24 hours) events were reported at many stations. The number of very heavy rainfall and extremely heavy rainfall events during the season is shown in **Fig. 1.10**. Some stations in Assam & Meghalaya, Coastal Karnataka, Gujarat region, Himachal Pradesh, Konkan & Goa, Madhya Maharashtra, South Interior Karnataka and Uttarakhand recorded more than seven very heavy rainfall events during the season (**Fig. 1.10a**). Many stations across the country experienced extremely heavy rainfall, as shown in **Fig. 1.10b**.

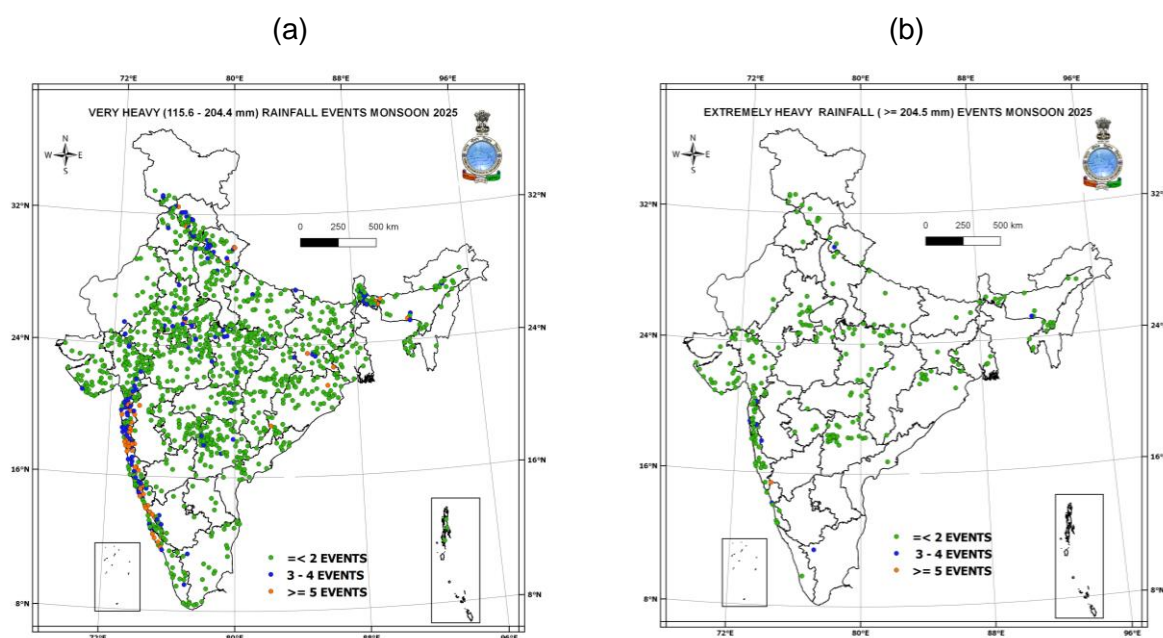


Fig. 1.10: The number of (a) very heavy rainfall (115.6 mm to 204.5 mm in 24 hours) events (b) extremely heavy rainfall (≥ 204.5 mm in 24 hours) events during June to September 2025

The month-wise and station-wise distribution of extremely heavy rainfall events is given in **Table 1.5**. Month-wise record rainfall (in 24 hrs.) reported during the monsoon season is given in **Table 1.6**.

Table 1.5: Monthwise list of stations, which reported extremely heavy rainfall (≥ 204.5 mm) in 24 hours during the monsoon season

DATE (JUNE 25)	STATION	NAME OF SUBDIVISION	RAINFALL (mm)
1	SILCHAR	ASSAM & MEGHALAYA	415.8
5	MAWKYRWAT	ASSAM & MEGHALAYA	210
12	KARWAR OBSY	COASTAL KARNATAKA	374.2
13	RAMESHWAR_AGRI	KONKAN & GOA	302.8
13	SHIRALI PTO	COASTAL KARNATAKA	244
14	RAJAPUR	KONKAN & GOA	250
15	MANDANGAD	KONKAN & GOA	250
15	PANAMBUR OBSY	COASTAL KARNATAKA	205.4
16	GAGANBAWADA	MADHYA MAHARASHTRA	215
16	AVALANCHE	TAMIL NADU & PUDUCHERRY	292
16	SHIRALI PTO	COASTAL KARNATAKA	278.4
17	GADHDA	SAURASHTRA & KUTCH	357
17	AVALANCHE	TAMIL NADU & PUDUCHERRY	207
19	MAWSYNRAM	ASSAM & MEGHALAYA	313.8
19	KHARIDWAR	GANGETIC WEST BENGAL	212.8
19	NIMDIH	JHARKHAND	289.6
19	KAPRADA	GUJARAT REGION	259
19	MATHERAN	KONKAN & GOA	262
20	PURULIA	GANGETIC WEST BENGAL	210
20	MANDAR	JHARKHAND	210.2
20	MAHABALESHWAR OBSY	MADHYA MAHARASHTRA	211.6
21	JAMBUGHODA	GUJARAT REGION	205
22	TIKAMGARH-AWS	EAST MADHYA PRADESH	215
22	VADALI	GUJARAT REGION	315
23	MUNGAOLI	WEST MADHYA PRADESH	264
24	KUMARGRAM	SHWB & SIKKIM	277
24	KAMREJ	GUJARAT REGION	275
24	JAWHAR	KONKAN & GOA	231
25	KATHIWADA	WEST MADHYA PRADESH	211
25	LUNAWADA	GUJARAT REGION	217
27	KHOWANG	ASSAM & MEGHALAYA	245
29	JAMSOLAGHAT	ORISSA	282.6
29	GHATSILA	JHARKHAND	298.4

DATE (JULY 25)	STATION	NAME OF SUBDIVISION	RAINFALL (mm)
1	PALLIAKALAN	EAST UTTAR PRADESH	212.7
1	MANDI	HIMACHAL PRADESH	216.8
1	MORENA-AWS	WEST MADHYA PRADESH	205
3	RAIPUR SR	WEST RAJASTHAN	252
3	VADGAM	GUJARAT REGION	269
3	KANKAVLI	KONKAN & GOA	220
3	CASTLE ROCK	COASTAL KARNATAKA	207.8
5	RITHI	EAST MADHYA PRADESH	230.4
6	BAMRA	ORISSA	285.4
6	CHOTHKABARWARA SR	EAST RAJASTHAN	214
7	BICHHIA	EAST MADHYA PRADESH	208
7	PALI	CHHATTISGARH	260
8	DEORI	WEST MADHYA PRADESH	209.4
8	WARASEONI	EAST MADHYA PRADESH	353.3
8	DEORI	VIDARBHA	226.5
9	BELONIA	N M M T	295
9	KATANGI	EAST MADHYA PRADESH	212.9
9	UMRER	VIDARBHA	284.4
12	KARWI	EAST UTTAR PRADESH	216
12	BEOHARI	EAST MADHYA PRADESH	251
12	MANKI	COASTAL KARNATAKA	224.6
13	BIJAWAR	EAST MADHYA PRADESH	303
14	MANDIRA DAM	ORISSA	224
16	HARIPUR	UTTARAKHAND	216.6
16	ROHA	KONKAN & GOA	210
17	CHUNAR	EAST UTTAR PRADESH	240
17	BHANPURA	WEST MADHYA PRADESH	215.4
17	NAIGARHI	EAST MADHYA PRADESH	252
17	MULKI	COASTAL KARNATAKA	298.2
18	CHAHTARPUR-aws	EAST MADHYA PRADESH	310
19	MERTA CITY	WEST RAJASTHAN	228
19	NAINWA	EAST RAJASTHAN	234
20	HAZUAH	ASSAM & MEGHALAYA	210.4
20	FALAKATA	SHWB & SIKKIM	228.8
22	LONAR	VIDARBHA	288
23	VENKATAPURAM	TELANGANA	258.2

24	MULCHERA	VIDARBHA	240.4
24	BEJJUR	TELANGANA	242.6
26	MAHABALESHWAR OBSY	MADHYA MAHARASHTRA	257.8
26	CASTLE ROCK	COASTAL KARNATAKA	234.6
27	CHAULDHOWAGHAT	ASSAM & MEGHALAYA	207.6
27	PUSHPRAJGARH	EAST MADHYA PRADESH	220
27	VADGAM	GUJARAT REGION	233
27	MAHABALESHWAR OBSY	MADHYA MAHARASHTRA	204.8
27	AVALANCHE	TAMIL NADU & PUDUCHERRY	260
27	CASTLE ROCK	COASTAL KARNATAKA	218.4
28	CHERRAPUNJI (RKM)	ASSAM & MEGHALAYA	204.6
28	RAMGANJMANDI SR	EAST RAJASTHAN	242
28	DASCROI	GUJARAT REGION	263
29	CHACHODA	WEST MADHYA PRADESH	205
30	KHANDAR SR	EAST RAJASTHAN	230
30	GUNA-AWS	WEST MADHYA PRADESH	323
30	DEORI	EAST MADHYA PRADESH	220.6

DATE (AUG 25)	STATION	NAME OF SUBDIVISION	RAINFALL (mm)
2	MAWSYNRAM	ASSAM & MEGHALAYA	215.2
2	UNA	HIMACHAL PRADESH	222.8
3	MAWSYNRAM	ASSAM & MEGHALAYA	350.4
4	PURNEA	BIHAR	270.6
5	BIJNOR	WEST UTTAR PRADESH	245
5	HARDWAR	UTTARAKHAND	304
5	PIRAVAM	KERALA	217.1
6	HARDWAR	UTTARAKHAND	222.2
7	LEMBUCHHERA	N M M T	214
8	COLONALGANJ	EAST UTTAR PRADESH	211
11	HARDWAR	UTTARAKHAND	242.4
13	KUMARGRAM	SHWB & SIKKIM	235.2
13	KHAGADIA	BIHAR	206
13	BHEEMINI	TELANGANA	238.4
14	RAMESHWAR_AGRI	KONKAN & GOA	214.2
14	TANUKU	COASTAL ANDHRA PRADESH	236.6
16	SANTACRUZ - IMD OBSY	KONKAN & GOA	244.7

16	GOVINDARAOPET	TELANGANA	217.6
17	PHANGOTA	PUNJAB	221.2
17	ERANDOL	MADHYA MAHARASHTRA	208
18	MHASLA	KONKAN & GOA	215
18	WARGAL	TELANGANA	228.4
18	CASTLE ROCK	COASTAL KARNATAKA	243.4
19	SUTRAPADA	SAURASHTRA & KUTCH	287
19	MATHERAN	KONKAN & GOA	254.6
19	GAGANBAWADA	MADHYA MAHARASHTRA	261
19	CASTLE ROCK	COASTAL KARNATAKA	221.6
20	KALYANPUR	SAURASHTRA & KUTCH	263
20	MATHERAN	KONKAN & GOA	438.4
20	LONAVALA_AGRI	MADHYA MAHARASHTRA	432
21	GANDEVI	GUJARAT REGION	237
21	MENDARDA	SAURASHTRA & KUTCH	284
22	SAWAIMADHOPUR TESIL SR	EAST RAJASTHAN	254
23	NAINWA	EAST RAJASTHAN	502
24	DAUSA	EAST RAJASTHAN	285
25	SANGRUR	PUNJAB	216.4
26	GURUDASPUR	PUNJAB	220
27	JAMMU	JAMMU & KASHMIR	380
27	BHUNGRA SR	EAST RAJASTHAN	224
27	SUKMA	CHHATTISGARH	210
27	YELLAREDDY	TELANGANA	253.6
28	KAMAREDDY	TELANGANA	412.6
29	LOHA	MARATHWADA	280.5
29	GANDHARI	TELANGANA	274.2
29	MANKI	COASTAL KARNATAKA	207.4

DATE (SEPT 25)	STATION	NAME OF SUBDIVISION	RAINFALL (mm)
1	BANBASA	UTTARAKHAND	256.4
1	NANGAL	PUNJAB	220
1	R L BBMB	HIMACHAL PRADESH	220
2	HATADIHI	ORISSA	225.1
2	SASANI	WEST UTTAR PRADESH	230
3	UDHAMPUR(IAF)	JAMMU & KASHMIR	295.8

4	LAIKERA	ORISSA	212.2
4	KUMBHRAJ	WEST MADHYA PRADESH	209
5	UMERPADA	GUJARAT REGION	214
7	SANCHORE	WEST RAJASTHAN	210
7	MADHBUN	GUJARAT REGION	244
8	MOUNNTABU TEHSIL SR	EAST RAJASTHAN	250
8	SUIGAM	GUJARAT REGION	397
8	RAPAR	SAURASHTRA & KUTCH	359
12	AMFU PUNDIBARI	SHWB & SIKKIM	217
12	HUZURABAD	TELANGANA	245.2
13	HARIPUR	UTTARAKHAND	253
14	FALAKATA	SHWB & SIKKIM	229.8
14	TAIBPUR	BIHAR	299.6
14	DHARMSALA	HIMACHAL PRADESH	232.4
15	MATHERAN	KONKAN & GOA	271.4
16	CHERRAPUNJI (RKM)	ASSAM & MEGHALAYA	210.8
17	KHAGADIA	BIHAR	219
19	WASHI	MARATHWADA	220
23	ALIPORE	GANGETIC WEST BENGAL	251.4
24	BURLA	ORISSA	226
29	KHANVEL	GUJARAT REGION	243.1
29	DIU	SAURASHTRA & KUTCH	264.2
29	TALASARI	KONKAN & GOA	242

Table 1.6: Record rainfall (in 24 hrs.) during the monsoon season

S. No.	STATION	RAINFALL DURING PAST 24 Hrs. (mm)	DATE	PREVIOUS RECORD (mm)	Date of record
			(June 25)		
1	BHILWARA	175	22-06-2025	81	28-06-2019
2	CHURU	85.1	30-06-2025	81.9	24-06-1988
3	MAHUVA	225.2	17-06-2025	179.6	30-06-1959
4	PURULIA	210	20-06-2025	147.6	23-06-1996
5	SOLAN (NAUNI)	85.6	29-06-2025	85.3	12-06-1983
6	TIKAMGARH	215	22-06-2025	136	30-06-2011
7	WASHIM	122.4	26-06-2025	121	15-06-2013
			(July 25)		

1	GUNA	323	30-07-2025	293.4	25-07-1958
2	JHARSUGUDA	205.2	06-07-2025	195.1	17-07-2002
3	KHAJURAH	160.4	13-07-2025	143.2	07-07-1981
4	NEW DELHI (RIDGE)	129.8	30-07-2025	124	11-07-2003
5	TADONG	124.6	29-07-2025	117	06-07-2005
6	TIKAMGARH	215	13-07-2025	180	03-07-1974
			(Aug 25)		
1	BAPATLA	135	13-08-2025	132.5	23-08-2000
2	BIJAPUR	151.2	06-08-2025	121.2	31-08-1954
3	GANNAVARAM	129.6	14-08-2025	122.7	31-08-2024
4	JAMMU	380	27-08-2025	282.2	16-08-2006
5	KARAIKAL	110.1	11-08-2025	92.2	31-08-2010
6	MANALI	102	26-08-2025	88.3	14-08-1970
7	NANDIGAMA	191.4	14-08-2025	136.5	09-08-2008
8	BAPATLA	135	13-08-2025	132.5	23-08-2000
			(Sep 25)		
1	BILASPUR	104.6	04-09-2025	83.8	19-09-2008
2	MEDAK	196	12-09-2025	192.2	21-09-2005
3	SOLAN (NAUNI)	187	01-09-2025	140.8	20-09-2008
4	TIRUPATTUR	167.2	19-09-2025	140.8	26-09-1978
5	BILASPUR	104.6	04-09-2025	83.8	19-09-2008

1.2.6. Drought and Aridity Monitoring

The IMD began monitoring the drought using drought monitoring indices, including the Standardized Precipitation Index (SPI), the Standardized Precipitation Evapotranspiration Index (SPEI), and the Aridity Anomaly Index (AAI), starting in 1967. The Standardized Precipitation Index (SPI) is an index used to measure drought, based solely on precipitation. This index is negative for drought and positive for wet conditions. As the dry or wet conditions become more severe, the index becomes more negative or positive, respectively. IMD also monitors drought using the climatic water balance technique. The aridity index is calculated as a fraction of water deficit/water need. The departure of the aridity index from normal percentage terms defines the severity of the drought. An anomaly of up to 25% is attributed to mild drought, 26-50% to moderate drought, and more than 50% to severe drought.

Fig. 1.11a shows the anomaly of the Aridity index from June to September 2025. Based on the AAI index, 23 districts experienced moderate arid conditions, and only 2 districts

experienced severe arid conditions. The details of the districts that experienced moderate to severe dry conditions are given in **Table 1.7**.

Cumulative SPI values for four months (June to September 2025) are given in **Fig. 1.11b** indicate extremely wet/severely wet conditions over parts of Haryana, Himachal Pradesh, Jammu & Kashmir, Karnataka, Madhya Pradesh, Maharashtra, Punjab, Rajasthan, Telangana, and Uttarakhand while, extremely dry/severe dry condition was observed over parts of Arunachal Pradesh, Assam, Bihar and Meghalaya. Based on the SPI index, 81 districts experienced severe to extreme wet conditions, and 44 districts experienced severe to extreme dry conditions. As indicated by these drought indices, the highest number of districts exhibiting dry/arid conditions is observed in the states of Arunachal Pradesh, Assam, and Bihar during the period of June to September 2025.

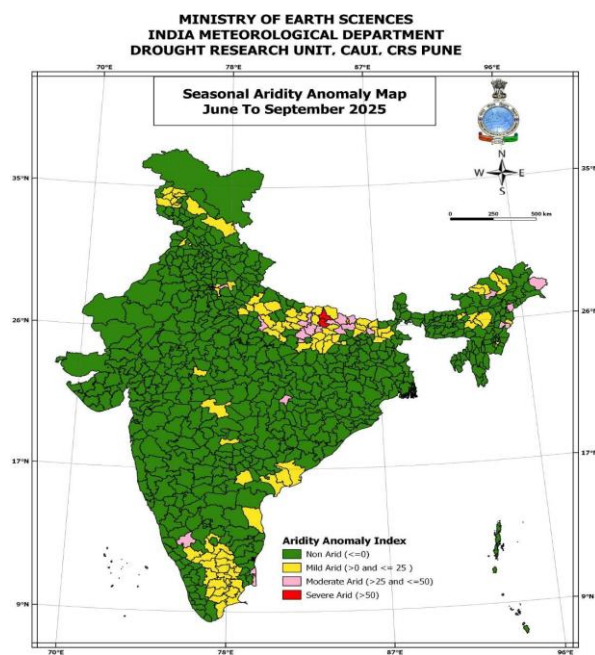


Fig. 1.11(a): Aridity Anomaly Index for the period June to September 2025

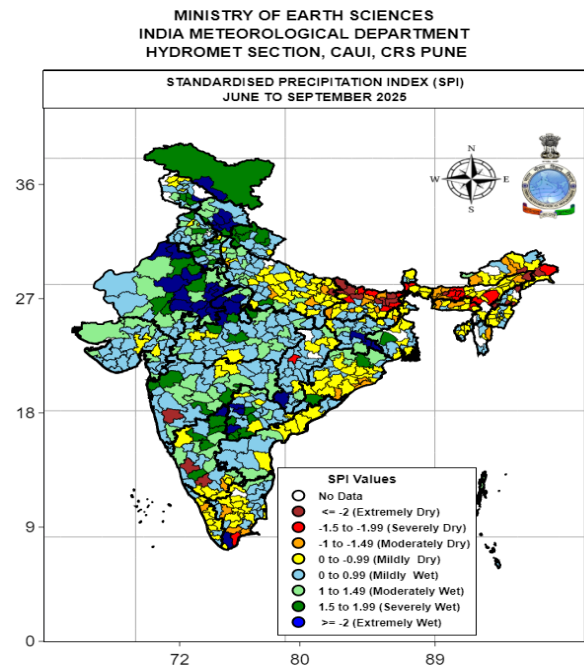


Fig. 1.11(b): Standardized Precipitation Index (SPI) for the period June to September 2025

Table 1.7: Districts in Moderately/Severely Arid conditions based on AAI for June to September 2025

State	Moderately Dry	Severely Dry
Arunachal Pradesh	Anjaw, Lower Subansiri	
Bihar	Purba Champaran, Gopalganj, Muzaffarpur, Saharsa, Saran, Sitamarhi	
Karnataka	Hassan	
Nagaland	Mon, Phek	
Tamil Nadu	Nagapattinam, Chennai	
Union Territory	Karaikal, Puduchery	
Uttar Pradesh	Ambedkarnagar, Azamgarh, Azamgarh, Jaunpur, Kanpur, Santkabirnagar, Panchshil Nagar	Deoria, Kushinagar
Chhattisgarh	Bemetara	

1.3 Conclusions

During the 2025 Southwest Monsoon season, the country as a whole received rainfall amounting to 108% of the Long Period Average (LPA), which falls within the normal range ($\pm 10\%$). Rainfall distribution was generally well-distributed over all the homogeneous region of the country, except Arunachal Pradesh, Assam & Meghalaya and Bihar meteorological sub-divisions in East North East region. In the country as a whole, rainfall during the month of June (109 % of LPA), July (105 % of LPA), August (105 % of LPA) & September (115 % of LPA) all are **normal** (<119%).

Regionally, during the monsoon season, homogeneous regions of Central India (115 % of LPA) and South Peninsula (110 % of LPA) received also **normal** rainfall, Northwest India (127 % of LPA) received **above normal** rainfall, while East & Northeast India (80 % of LPA) received below normal rainfall.

During the monsoon season, out of the 36 meteorological subdivisions in the country, 2 subdivisions (West Rajasthan and East Rajasthan) recorded Large Excess rainfall. Excess rainfall was observed in 12 subdivisions, namely Uttarakhand; Haryana, Chandigarh & Delhi; Punjab; Himachal Pradesh; Jammu & Kashmir and Ladakh; West Madhya Pradesh; Gujarat Region; Saurashtra & Kutch; Madhya Maharashtra; Marathwada; Telangana; and North Interior Karnataka. Normal rainfall was received in 19 subdivisions, including Andaman & Nicobar Islands; Nagaland, Manipur, Mizoram & Tripura (NMMT), Sub-Himalayan West Bengal & Sikkim, Gangetic West Bengal, Odisha, Jharkhand, East and West Uttar Pradesh, East Madhya Pradesh, Konkan & Goa, Vidarbha, Chhattisgarh, Coastal Andhra Pradesh & Yanam, Rayalaseema, Tamil Nadu, Puducherry & Karaikal, Coastal Karnataka, South

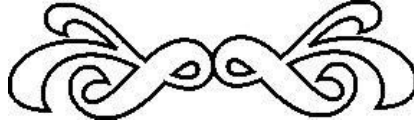
Interior Karnataka, Kerala & Mahe, and Lakshadweep. The remaining 3 subdivisions (Arunachal Pradesh, Assam & Meghalaya, and Bihar) experienced Deficient rainfall.

During the monsoon 2025, out of 738 districts, 67 districts received large excess rainfall, 187 districts received excess rainfall, 327 districts received normal rainfall, 134 districts received deficient rainfall and 12 districts received large deficient rainfall. During the season 80% of the districts recorded **normal to large excess** rainfall, the highest coverage since 2013, whereas only 20% of the districts were classified as deficient rainfall.

For the country as a whole, rainfall averaged was generally above or near normal on many days during Season. The average rainfall was above or near normal on 16 days during June, 17 days during July, 18 days during August and 17 days during September. On almost 17 occasions including the continuous periods of 17 - 20 June, 1 - 4 September and 27 - 28 September it was more than or equal to one and a half times of its normal value. It was below normal at a stretch on 5 - 14 June, 11 - 23 July (except 14, 15 Jul), 31 July - 13 August, 10 - 13 September and 20 - 26 September (except 23 Sept).

During the season, many districts in Arunachal Pradesh, Assam, Bihar, Karnataka and Uttar Pradesh experienced dry/arid conditions. Overall, the district-wise rainfall distribution shows mostly normal to wetter conditions.

2



REGIONAL CHARACTERISTICS OF THE SOUTHWEST MONSOON 2025

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This chapter discusses the observed features of southwest monsoon 2025 covering various synoptic conditions during the advance, mature and withdrawal phases.

2.1 Onset and advance of the southwest monsoon 2025

The Southwest Monsoon (SWM) commenced its advance on 13th May 2025, covering parts of the Nicobar Islands and the South Andaman Sea. This early progression was supported by a marked strengthening of westerly and southwesterly winds in the lower troposphere, reaching up to 20 knots. Enhanced cloudiness and significantly reduced outgoing longwave radiation ($OLR < 200 \text{ Wm}^{-2}$), together with widespread rainfall over the Nicobar Islands, provided clear dynamical and thermodynamical signals of monsoon establishment. The monsoon entered this region 9 days earlier than its climatological date and subsequently advanced rapidly into additional parts of the Bay of Bengal, as well as the entire Maldives and most of Sri Lanka.

By 24th May 2025, the monsoon made a swift and expansive progression over the remaining parts of the South Arabian Sea, Westcentral and Eastcentral Arabian Sea, the entire Lakshadweep region, Kerala, Mahe, parts of Karnataka, the Comorin area, many parts of Tamil Nadu, and large sections of the Southwest, Eastcentral, Westcentral, and North Bay of Bengal, extending also into parts of Mizoram. The official onset over Kerala occurred on 24th May, which is eight days earlier than the normal onset date of 1st June, making it the earliest onset since 2009.

Following its establishment over Kerala, the monsoon advanced rapidly across South India and the Northeastern region by 29th May. After this accelerated phase, the monsoon experienced a hiatus of approximately 17 days, with its further northward progress resuming on 16th June. By 26th June, most regions of the country were under monsoon influence, except for isolated pockets across Northwest Rajasthan, West Uttar Pradesh, South Punjab, South Haryana, and Delhi. The southwest monsoon ultimately covered the entire country by 29th June 2025, achieving full coverage nine days ahead of the climatological date of 8th July.

The isochrones of onset and subsequent advance of the Southwest Monsoon 2025 (Fig. 2.1) clearly depict the anomalously early initiation, rapid early-phase progression, stagnation, and the subsequent accelerated advance that led to the early entire country coverage. The spatiotemporal evolution reflects a combination of favourable large-scale atmospheric circulation patterns, sustained moisture transport from the Indian Ocean, and enhanced convective activity across the monsoon domain.

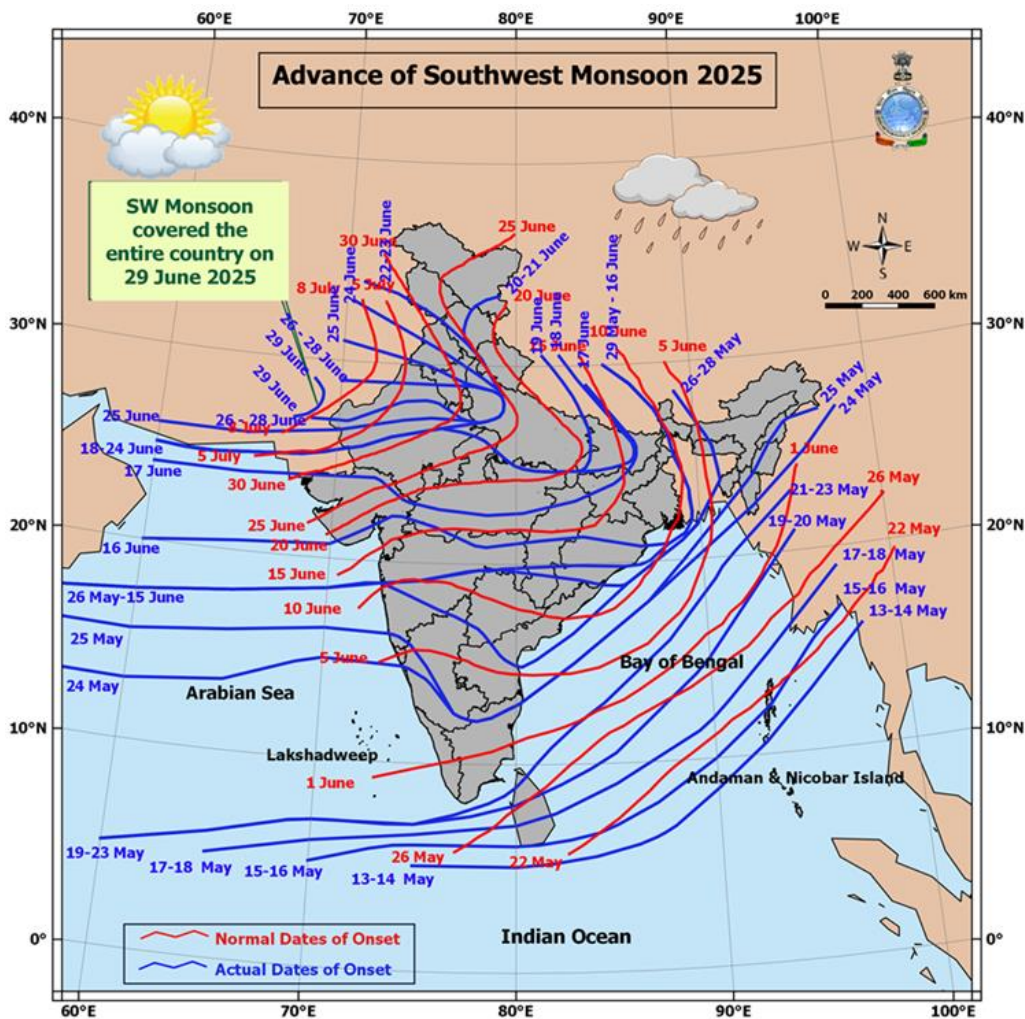


Fig. 2.1: Isochrones of the advance of southwest monsoon 2025

2.2 Semi-Permanent Systems

Monsoon semi-permanent systems are large-scale atmospheric systems that maintain relatively consistent positions throughout the monsoon season. The slight variations in their position and intensity play a seminal role in influencing the strength and duration of the SWM. Hence, monitoring of the semi-permanent features of the SWM is essential in operational weather forecasting.

2.2.1 Heat Low

Intense surface heating during summer generates a persistent thermal low-pressure system across much of southwestern Asia, with its core situated over northwestern India and Pakistan. This heat low (HL) typically develops in May and is closely associated with the onset of the low-level westerly monsoon flow. The HL is characterized by ascending motion below the 700-hPa level and descending motion above it, accompanied by convergent easterlies and the export of cyclonic vorticity into the middle and upper troposphere (Ramage 1965). The Arabian Sea branch of the summer monsoon is also strongly influenced by the evolution of HL (Hewitt and Jackson 2003; Bansod and Singh 1995). Ramage (1971) consistently emphasized the linkage between the intensity of the heat low and overall monsoon activity.

The establishment of the heat low over the Indian subcontinent—particularly over central Pakistan and adjoining northwestern India—plays a pivotal role in determining the strength of the SWM. Variations in the HL intensity frequently correlate with fluctuations in monsoon activity. Regions exhibiting the lowest surface pressures over the northwestern Indo-Pakistan sector effectively mark the centre of the HL. Its intensity typically increases through July and August before weakening gradually during September. Climatologically, the mean central pressure values of the heat low are approximately 998 hPa, 996 hPa, 998 hPa, and 1000 hPa for the respective peak summer months.

Fig. 2.2 depicts the day-to-day fluctuations in the intensity of the heat low during the 2025 southwest monsoon season. The analysis shows a strengthening of the heat low (i.e., decreasing pressure) up to the last week of June, followed by a subsequent weakening (increasing pressure). The minimum pressure within the heat low region occurred during the second and third weeks of June. Throughout July, substantial day-to-day variability is observed. A strengthening of the heat low is evident during the first half of August, after which the pressure briefly increased for a few days before intensifying again toward the latter part of the month. In September, the daily heat-low pressures exhibit a steady rise as the month advances.

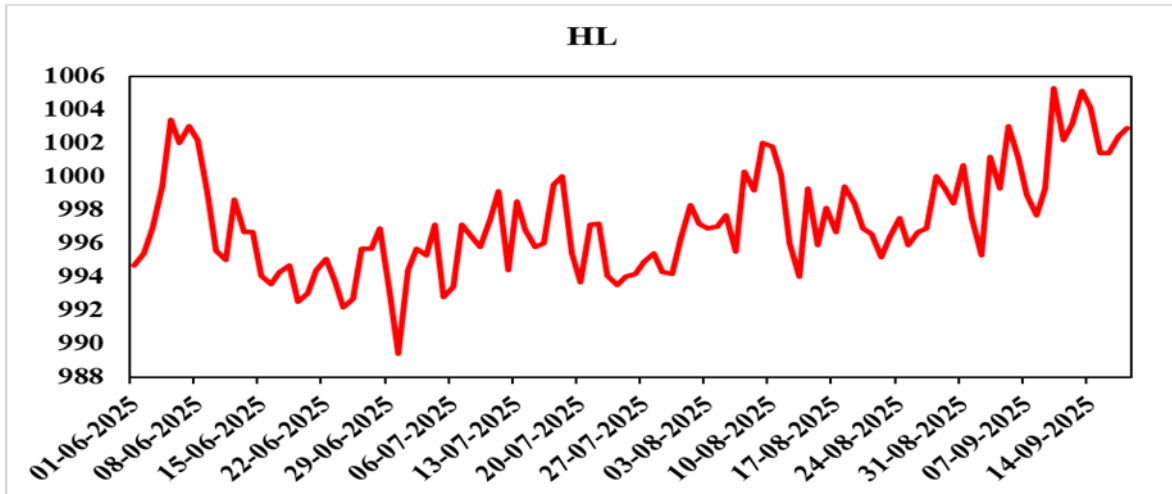


Fig. 2.2: The daily variation of the intensity of the Heat Low during the SW monsoon 2025

Month-wise variations and anomalies in heat-low intensity for the 2025 southwest monsoon are summarized in **Table 2.1**. The lowest monthly mean pressure was recorded in July at 995.8 hPa, corresponding to a departure of -0.2 hPa from the climatological mean. June recorded the next lowest value at 995.9 hPa, with a larger negative anomaly of -2.1 hPa. In August 2025, the mean sea-level pressure associated with the heat low was 995.94 hPa, which is 2.06 hPa below the climatological normal. In contrast, the September mean pressure was approximately 1 hPa higher than normal.

Table 2.1: Month-wise heat low pressure normal, actual pressure and pressure anomalies during SW monsoon 2025

Month	Normal Pressure (hPa)	2025 pressure (hPa)	Departure from normal (hPa)
June	998	995.9	-2.1
July	996	995.8	-0.2
August	998	995.94	-2.06
September	1000	1001.1	1.1

2.2.2 Mascarene High

The Mascarene High (MH) is an important component of the Indian summer monsoon system, and variations in its intensity are closely linked to monsoon rainfall variability. Located in the southwest Indian Ocean near 30°S and 50°E , the MH serves as a critical link in atmospheric interactions between the northern and southern hemispheres (Feng et al., 2003). Strengthening of the MH enhances the Somali Low-Level Jet, thereby intensifying the

summer monsoon circulation across tropical Asia and the western Pacific. Characteristically, a marked reduction in monsoon rainfall occurs about nine days after the MH attains its peak strength (Krishnamurti and Bhalme, 1976). Fluctuations in the MH are influenced by extratropical westerly waves originating in the southern hemisphere. When the MH intensifies, it strengthens the cross-equatorial flow, driving the Low-Level Jet and reinforcing monsoon circulation over the Arabian Sea (Sikka and Gray, 1981). The intensity of the MH is also associated with the timing of the monsoon onset over India and subsequent variations in monsoon activity (Okoola and Asnani, 1981).

Table 2.2: Month-wise averaged values of Mascarene High (MH) and their departures in 2025

Month	*Normal Pressure (hPa) (approx.)	Actual Pressure (hPa)	Departure from normal hPa (approx)
June	1023.0	1028.6	5.6
July	1025.5	1033.06	7.56
August	1026.0	1029.9	3.9
September	1023.5	1027.4	3.9

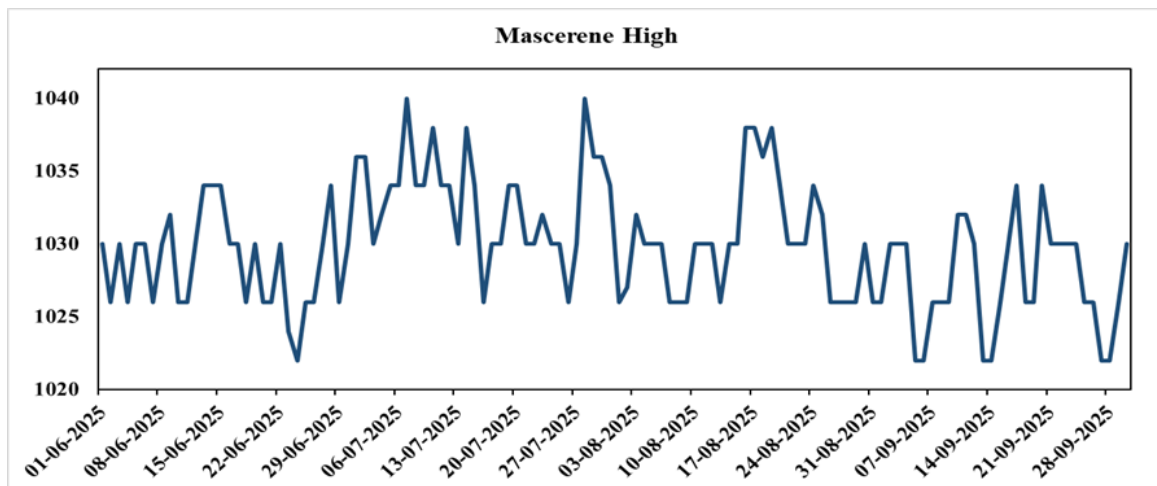


Fig. 2.3: Daily variations in the Mascarene High (hPa) during the southwest monsoon 2025

The daily variations of the MH from June to September 2025 reveal pronounced intra-seasonal fluctuations, with several distinct strengthening and weakening phases. During June, MH pressures generally fluctuated between 1027 and 1034 hPa, followed by a brief weakening toward the end of the month. A marked intensification occurred through early and mid-July, when pressures frequently exceeded 1038–1040 hPa, representing one of the strongest MH phases of the season. Late July and early August were characterized by alternating strengthening and weakening episodes. Another notable intensification appeared

in mid-August, with pressures again rising above 1034 hPa. From late August into early September, the MH weakened, fluctuating mostly between 1026 and 1032 hPa. September displayed strong day-to-day variability, with intermittent sharp rises and declines in pressure. Overall, the SWM 2025 season exhibited multiple strengthening events of the MH, likely influencing the cross-equatorial flow and modulating Indian summer monsoon circulation during this period.

2.2.3 Low Level Jet

The Low-Level Jet (LLJ), most pronounced at 850 hPa, typically attains core wind speeds of 20–30 m/s, occasionally strengthening to nearly 50 m/s near Madagascar and off the Somali coast. Originating from the Mascarene High, the LLJ features strong horizontal and vertical wind shear as it crosses the equator, flows along the East African highlands, enters the Arabian Sea, and extends eastward across India. While its axis remains relatively stable over the western Indian Ocean, it undergoes north–south oscillations over India and the eastern Indian Ocean in response to shifting convective heating. These shifts govern the active and break phases of the monsoon (Sikka and Gadgil, 1980). During active phases, the LLJ traverses peninsular India, enhancing rainfall. In break phases, it bifurcates over the eastern Arabian Sea, with one branch moving northeastward into the monsoon trough and another southeastward toward the equatorial convective zone (Joseph and Simon, 2005). Joseph and Sijikumar (2004) further noted that the LLJ core typically passes near 15°N during active phases, whereas during break phases it shifts southeastward, bypassing India and flowing near Sri Lanka between the equator and 10°N.



Fig. 2.4: The variations in the intensity of the LLJ during SW monsoon 2025

The analysis indicates that during the SWM 2025, the LLJ consistently exhibited wind speeds above 40 knots, frequently surpassing 50 knots from the onset of the season through

the end of July. This persistent strengthening is indicative of a robust monsoon circulation during this period. In August, the LLJ showed notable fluctuations, although its core winds generally remained above 40 knots. A marked weakening was observed during the first half of September, followed by a recovery in the latter half of the month. Overall, the month-wise variability suggests that the LLJ remained dynamically active throughout the season, maintaining wind strengths broadly comparable to its climatological mean.

2.2.4. Tibetan Anticyclone

The Tibetan Plateau, rising over 4,500 m and spanning roughly 2,000 km in length (600 km wide in the west and about 1,000 km in the east), plays a critical role in shaping the South Asian monsoon circulation. It acts both as a mechanical barrier to atmospheric flow and as an elevated heat source that warms the mid- to upper troposphere (Murakami, 1987). During the Indian summer monsoon, intense sensible and latent heating over the plateau generates a pronounced upper-tropospheric anticyclone. This warm-core Tibetan anticyclone is typically positioned near 26°N at 200 hPa and shifts poleward to around 30°N at 100 hPa. A well-developed, horizontally extensive anticyclone at 500 and 300 hPa—supported by strong circulation over Siberia, Mongolia, and northern China—is generally associated with widespread and well-distributed monsoon rainfall over India. Climatologically, the anticyclone lies near 25°N, 92°E in June and September, migrating northwestward to around 28°N, 88°E during July and August. Variations in its position and intensity exert a substantial influence on the spatial and temporal distribution of monsoon rainfall across India.

During the 2025 monsoon season, the Tibetan anticyclone—primarily centered over the southeastern Tibetan Plateau—exhibited marked variability in both its position and intensity, with clear implications for the distribution of monsoon rainfall over India. The anticyclone was not well established until 12 June, after which it developed rapidly and settled close to its climatological position by the final week of June. In July, its core oscillated between a southeastward or near-normal position during the first half and a near-normal to westward displacement during the second half. Throughout August, the anticyclone was predominantly located east of its climatological position in the first half, shifting to a near-normal or northwestward position in the latter half. In September, it remained largely west or northwest of its normal location, and its structure became indistinct during the second half of the month, indicating a weakening consistent with the season's withdrawal phase.

2.2.5. Monsoon trough

During the southwest monsoon season, the expansion of the heat low positioned over the Indo-Pakistan region gives rise to a trough that extends south eastward, reaching all the

way to Gangetic West Bengal. On surface weather charts, this trough line can be traced from Ganganagar to Kolkata, passing through Prayagraj. It carries with it westerly to south-westerly winds on its southern side, while the northern side experiences easterlies or south-easterly winds. The constantly shifting position of this monsoon trough (MT) line plays a pivotal role in determining the patterns of monsoon-related activities and the distribution of rainfall. When the MT line is situated near the foothills of the Himalayas, it marks a period referred to as the 'break-in monsoon.' During this phase, there is a decline in the amount of rainfall over most regions of the country. However, the Himalayan mountain range receives significant precipitation, often resulting in sporadic river flooding due to the rivers originating in that area.

After the establishment of the monsoonal circulation and the advancement of the monsoon over the Indian region, monitoring of the monsoon trough began on June, 30 2025. During July, the MT was observed near its normal or south of its normal position throughout, leading to enhanced rainfall activity over the monsoon core zone. In the first half of August, the trough remained close to its normal position. By the second week, while the western end of the monsoon trough was near its normal position, the eastern end was located south of its normal position. In the first half of September, the trough again lay south of its normal position, but in the second half, the western end shifted north of its normal position, while the eastern end remained south of its normal position due to the formation of synoptic systems in the Bay of Bengal.

2.2.6 Tropical Easterly Jet

The Tropical Easterly Jet (TEJ) plays a crucial role in the Southwest Monsoon circulation, particularly in the upper troposphere, at levels between 100 and 150 hPa. According to Krishnamurti and Bhalme (1976), this jet is predominantly located around the latitude of Chennai and extends from the eastern coast of Vietnam to the western coast of Africa. During the SWM season, the TEJ exhibits periodic northward and southward oscillations from its normal position. Typically, the TEJ undergoes an initial phase of acceleration from the South China Sea toward southern India, followed by a deceleration phase. This shift in speed generates an upper-level divergence pattern conducive to convective processes upstream of 70°E, while a subsidence tendency dominates downstream. Climatologically, the TEJ winds reach speeds of 55–60 knots in June, 70–75 knots in July, 60–65 knots in August, and 50–55 knots in September.

Daily variations of the TEJ during the SWM season of 2025 (**Fig. 2.5**) indicate a prolonged phase of strong easterly flow, with wind speeds consistently exceeding 60 knots from mid-June through July and again during mid-August. Pronounced short-term fluctuations were evident during the latter half of August. During the first half of September,

the TEJ exhibited a brief intensification, followed by increased variability toward the latter part of the month.

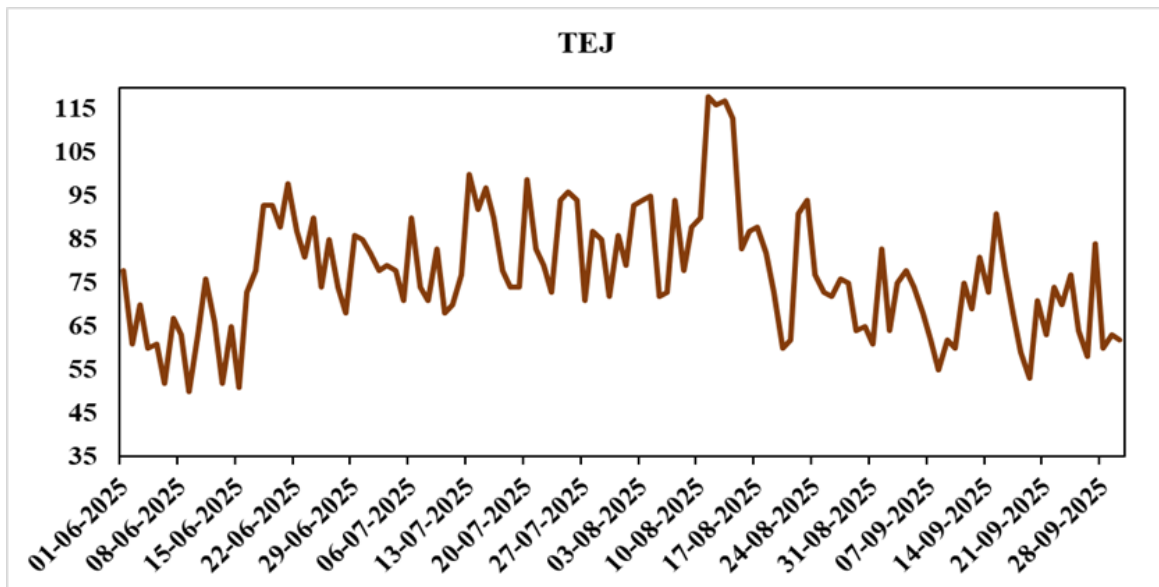


Fig. 2.5: The daily variations in the intensity of the TEJ during SW monsoon 2025

The monthly evolution of the TEJ also highlights notable meridional shifts in its core position. In June, the jet axis was primarily confined near 15°N. During July and August, it displayed significant north–south oscillations, extending as far north as 18°–20°N and remaining north of its climatological mean position on most days. By September, the TEJ gradually retreated southward and realigned close to 15°N, closely corresponding to its normal latitudinal position.

Table 2.3 summarizes the month-wise climatological mean wind speeds of the TEJ alongside the maximum monthly mean speeds observed during the 2025 SWM season. The comparison reveals that the TEJ remained anomalously stronger than its climatological average throughout the monsoon period, with the highest mean intensity recorded in August, followed sequentially by July, June, and September.

Table 2.3: Climatological speed of the TEJ and month wise averaged TEJ speed during monsoon 2025

Month	Climatological speed of TEJ (knots)	Monsoon 2025 TEJ speed (knots)
June	55-60	73
July	70-75	82
August	60-65	84
September	50-55	69

2.3 Other Features

2.3.1 Off-shore Trough

Offshore trough during SW monsoon 2025 with varying intensity and area has been depicted in **Table 2.4**.

Table 2.4: Appearance of the offshore trough and its duration during SWM 2025

Sr. No.	Period	Place of initial location	Place of final location	Remarks
1	19 June	North Konkan to north Kerala coasts	-	Less marked on 20 th June
2	3-7 July	Along Maharashtra-Karnataka coasts	Off south Gujarat-north Kerala coast	Less marked on 8 th July
3	24-27 July	Along Maharashtra-Kerala coasts	Along Gujarat-north Kerala coasts	Less marked on 28 th July
4	17-21 August	South Konkan to north Kerala coasts	Along Gujarat-Maharashtra coasts	Less marked on 22 nd August

2.3.2 Intensity of Australian High

The Australian high centred at 32.7 ° S / 135.5 ° E was strengthened by an average of about 10.8 and 10.3 hPa during the months of August and September 2025. It was above normal by 9.0, 4.5 hPa in the month of June and July 2025 respectively (see **Table 2.5**).

Table 2.5: Intensity of Australian High during June to September 2025 with its mean position at Lat. 32.7° S and Long 135.5° E

Month	*Normal Pressure (hPa) (Approx.)	Actual Pressure (hPa)	Departure from normal hPa (Approx)
June	1022.0	1031.2	+9.0
July	1022.0	1026.5	+4.5
August	1020.5	1031.3	+10.8
September	1018.0	1028.3	+10.3

2.4 Synoptic Disturbances during SWM 2025

The month wise synoptic systems formed over north Indian Ocean is shown in **Table 2.6**. Two deep depressions (one of them intensified into a Severe Cyclonic Storm in early

October), five depressions, three well-marked low-pressure areas, nine low pressure areas formed during the monsoon season 2025. The track of high intensity low-pressure systems is given in **Fig. 2.6**. More details are given in chapter 16.

Table 2.6: Number of systems formed during SWM-2025

Month	L	WML	D	DD	Total
June	4	1			5
July	1		4		5
August	2	2	1		5
September	2			2	4
Total	9	3	5	2	19

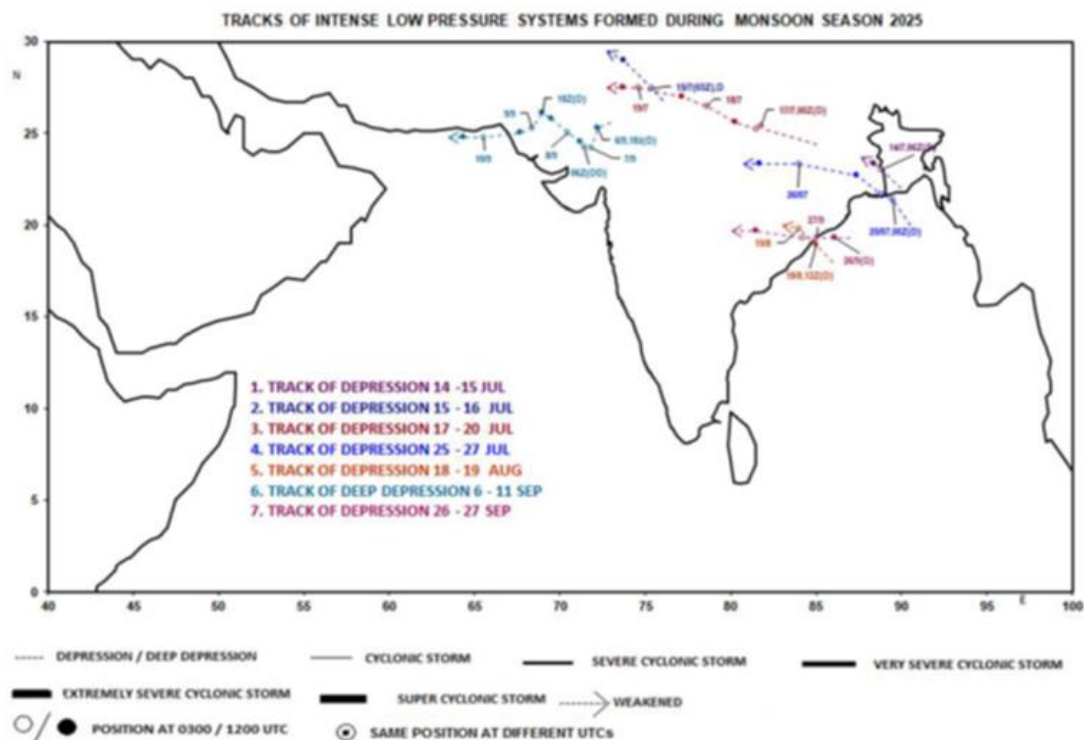


Fig. 2.6: Tracks of depressions during SWM 2025

2.4.2 Upper Air Cyclonic Circulations

There were 147 upper air cyclonic circulations (in lower, mid and upper tropospheric levels) which formed during the season. The month-wise distributions of these are: 46, 30, 32 and 39 during June, July, August and September respectively. Month wise distribution can be seen in **Table 2.7**.

Table 2.7: Month wise upper air cyclonic circulation and induced circulations for SWM-2025

Synoptic	June	July	August	September
Cyclonic circulations	46	30	32	39
Induced Cycir	-	-	-	-
Total	46	30	32	39

2.4.3 Eastward Moving Cyclonic Circulations, trough/Western Disturbances

During SWM-2025, 16 eastward-moving systems in upper level westerlies and 2 troughs in westerlies were observed. The month-wise distribution is depicted in **Table 2.8**.

Table 2.8: Month wise western disturbance and trough in westerlies during SWM-2025

Synoptic	June	July	August	September
Western Disturbances	4	5	4	3
Trough in westerlies	-	-	-	2
Total	4	5	4	5

2.5 Low-pressure Systems over Other Oceanic Areas during June to September 2025.

2.5.1 (i) Low-pressure Systems over West Pacific Ocean/ South China Sea

There were in all, 24 low pressure systems (reaching the intensity of Tropical depression and above) in the northwest Pacific Ocean / South China Sea during June – September 2025. The month wise break-up is given below:

Table 2.9: Month wise synoptic systems over the West Pacific Ocean/ South China Sea

Low pressure systems	June	July	August	September	Total
Tropical Depression (T.D.)	01	01	01	00	03
Tropical Storm (T.S.)	01	04	03	02	10
Typhoon (Ty)	01	04	02	03	10
Super Typhoon (S Ty)	00	00	00	01	01
Total	03	09	06	06	24

(ii) In South Indian Ocean

Three tropical cyclones formed in Southern Indian Ocean during June-Sept. 2025 viz.

- 1) 01 S (One) during 17 to 19 July 2025
- 2) 02 S (AWO) during 07 to 08 August 2025
- 3) 03 S (Blossom) during 09 to 12 September 2025

2.5.2 Troughs in the Mid Latitude Westerlies from Southern Hemispheres Affecting the Indian Monsoon

Upper Air Troughs in westerlies over South Indian Ocean, which penetrated to the north of latitude 30°S.

(Source: INOSHAC, CRS Pune)

The troughs in upper air westerlies which moved across the South Indian Ocean from west to east, penetrated to the north of Lat.30° S, in the Southern Hemisphere, during June to September 2025. The month wise break-up is as follows:

Table 2.10: Month wise number of troughs in mid and upper tropospheric Westerly in Southern hemisphere across South Indian Ocean during southwest monsoon

Atmospheric Level	June	July	August	September	Total
500 hPa	04	04	03	06	17
300 hPa	04	04	04	07	19

2.6 Withdrawal of the Southwest Monsoon

With a reduction in rainfall activity and the establishment of an anticyclonic circulation in the lower troposphere, the withdrawal of the SWM 2025 from northwest India commenced on 14th September, three days earlier than the normal date of 17 September. The initial withdrawal occurred over parts of West Rajasthan. Between 14 and 26 September, the monsoon withdrew from most parts of Rajasthan, the western Himalayan region, Punjab, Haryana, large parts of Gujarat, and some areas of Madhya Pradesh.

However, the subsequent withdrawal was delayed by nearly two weeks due to the development of a low-pressure system over the north and adjoining central Bay of Bengal. This system moved north-westwards and intensified into a Depression over central India. The remnant of the system later intensified into a cyclonic storm, *Shakti*, over the Arabian Sea. The formation and movement of this system inhibited further monsoon withdrawal over the remaining parts of the country.

Following the weakening of this system, conditions became favourable for further monsoon withdrawal. Consequently, the Southwest Monsoon retreated rapidly from most regions after 10th October. It withdrew from most parts of central and eastern India and some

parts of northeast India by 13th October and from the entire country by 16th October, one day later than the normal date (**Fig. 2.7**).

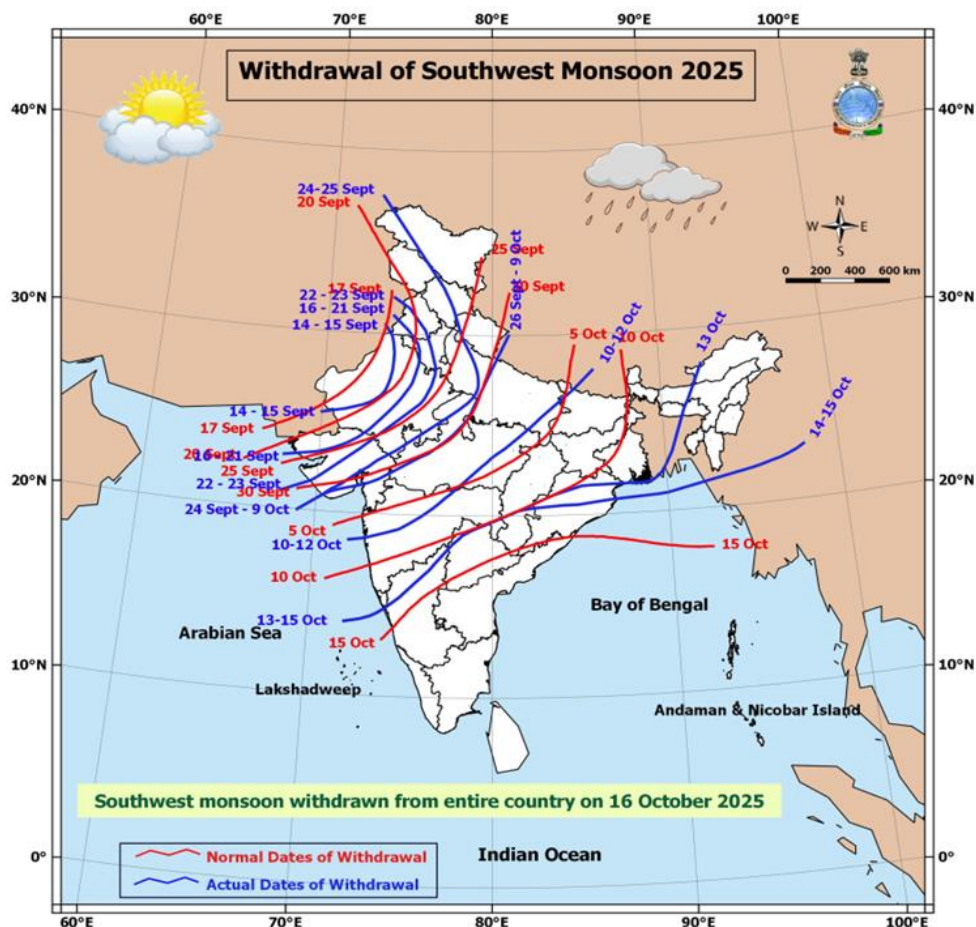


Fig. 2.7: Isochrones for withdrawal of South West Monsoon 2025

2.7 Concluding remarks

The SWM 2025 advanced over the South Andaman Sea and the Nicobar Islands on 13th May 2025, nearly nine days earlier than its normal onset. It reached Kerala on 24th May 2025, well ahead of the climatological date of 1st June, and subsequently covered the entire country by 29th June 2025, which was about nine days earlier than the normal date of 8th July.

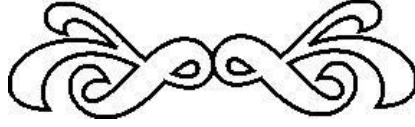
During the 2025 southwest monsoon season (June–September), the all-India rainfall was 108% of its Long Period Average (LPA), indicating an overall above-normal monsoon. On a monthly scale, rainfall over the country as a whole was 109% of LPA in June, 105% in July, 105% in August, and 115% in September. The observed rainfall distribution and departures during the season were largely consistent with the temporal and spatial variations of the semi-permanent synoptic features associated with the SWM circulation.

In terms of synoptic-scale systems, the monsoon season witnessed the formation of two deep depressions, five depressions, three well-marked low-pressure areas, and nine low pressure areas. With the establishment of an anticyclonic circulation over northwest India and the fulfilment of all dynamical and thermodynamical conditions necessary for monsoon withdrawal, the retreat of the SWM commenced from West Rajasthan on 14th September 2025, three days earlier than the normal date. The monsoon subsequently withdrew from the entire country on 16th October 2025.

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3



GLOBAL AND REGIONAL CIRCULATION ANOMALIES DURING MONSOON 2025

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This chapter presents the key global climate anomalies of the 2025 southwest monsoon season—including sea surface temperature, outgoing longwave radiation, and circulation patterns—and identifies the major factors responsible for the observed rainfall distribution over India.

3.1 Sea Surface Temperature (SST) Anomalies

3.1.1 Equatorial Pacific Ocean

The evolution of SST anomalies in the four Niño regions from December 2024 to November 2025 is shown in **Figure 3.1**. The Niño 3.4 SST anomaly indicated strong La Niña conditions in December 2024, with values well below the La Niña threshold. These negative anomalies gradually weakened during the early months of 2025, especially during the spring season. Following this weakening phase, ENSO-neutral conditions prevailed over the tropical Pacific from March to October 2025, as SST anomalies remained close to zero. By November 2025, the negative SST anomaly again crossed the La Niña threshold, signalling a return toward weak La Niña conditions.

The temporal evolution in the Niño 3, Niño 4, and Niño 1+2 regions generally followed a pattern similar to that of Niño 3.4, though some regional differences were evident in both magnitude and timing. In Niño 4 region, persistent negative SST anomalies were observed throughout most of the period, reflecting a predominantly cool central Pacific. Brief positive anomalies occurred only during June and July 2025, indicating a short-lived warming phase. In Niño 3 region, SST anomalies showed a weakening of La Niña conditions similar to Niño 3.4, with intermittent weak positive anomalies during late spring and early summer of 2025

before returning toward neutral. In contrast, Niño 1+2 region shows a positive SST anomaly from February to September 2025, indicating localized warming near the South American coast despite broader basin-wide neutral conditions.

Overall, the figure depicts a year characterized by the decay of La Niña, a prolonged neutral phase, and signs of re-emerging cooling toward the end of 2025. The regional differences highlight how ENSO evolution can vary spatially across the Pacific basin, with the easternmost region (Niño 1+2) showing the greatest deviation from the broader Pacific anomaly pattern.

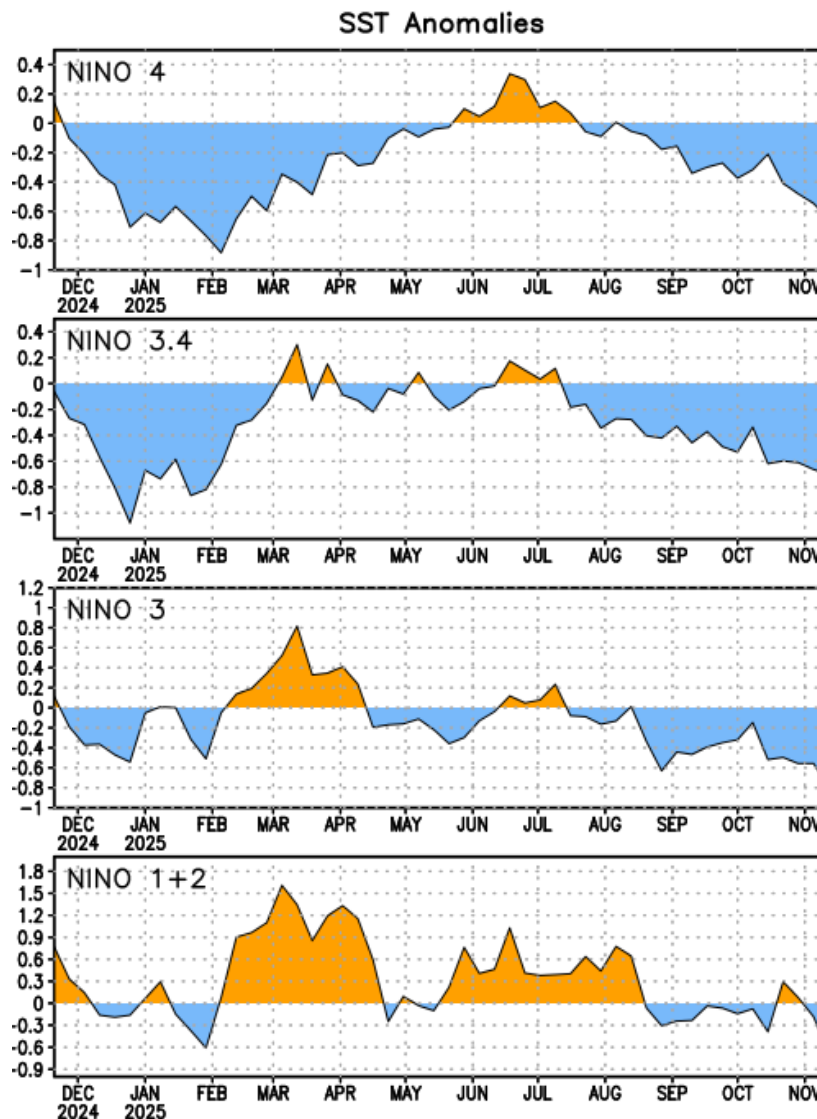


Fig. 3.1: Time series of sea surface temperature (SST) anomalies ($^{\circ}\text{C}$) averaged over the Niño regions—Niño 4 (150°W – 160°E , 5°N – 5°S), Niño 3.4 (5°N – 5°S , 170°W – 120°W), Niño 3 (5°N – 5°S , 150°W – 90°W), and Niño 1+2 (0° – 10°S , 90°W – 80°W). Data Source: NOAA ERSSTv5.

Figure 3.2 shows the monthly evolution of sea surface temperature (SST) anomalies from May to September 2025. Persistent negative SST anomalies were observed over the eastern equatorial Pacific throughout the period, gradually pronounced and extending westward into the central Pacific during July to September, indicating the development of La Niña-like conditions. In contrast, the northern Pacific exhibited widespread warm anomalies, which remained strong across all months. Over the Indian Ocean, a clear dipole-like pattern emerged from June onwards: warmer-than-normal SSTs appeared in the eastern tropical Indian Ocean near Indonesia and the eastern Bay of Bengal, while cooler-than-normal SSTs dominated the western tropical Indian Ocean and parts of the Arabian Sea. These coupled anomaly patterns across the Pacific and Indian Oceans collectively indicate significant ocean–atmosphere interactions influencing regional climate conditions during the 2025 monsoon season.

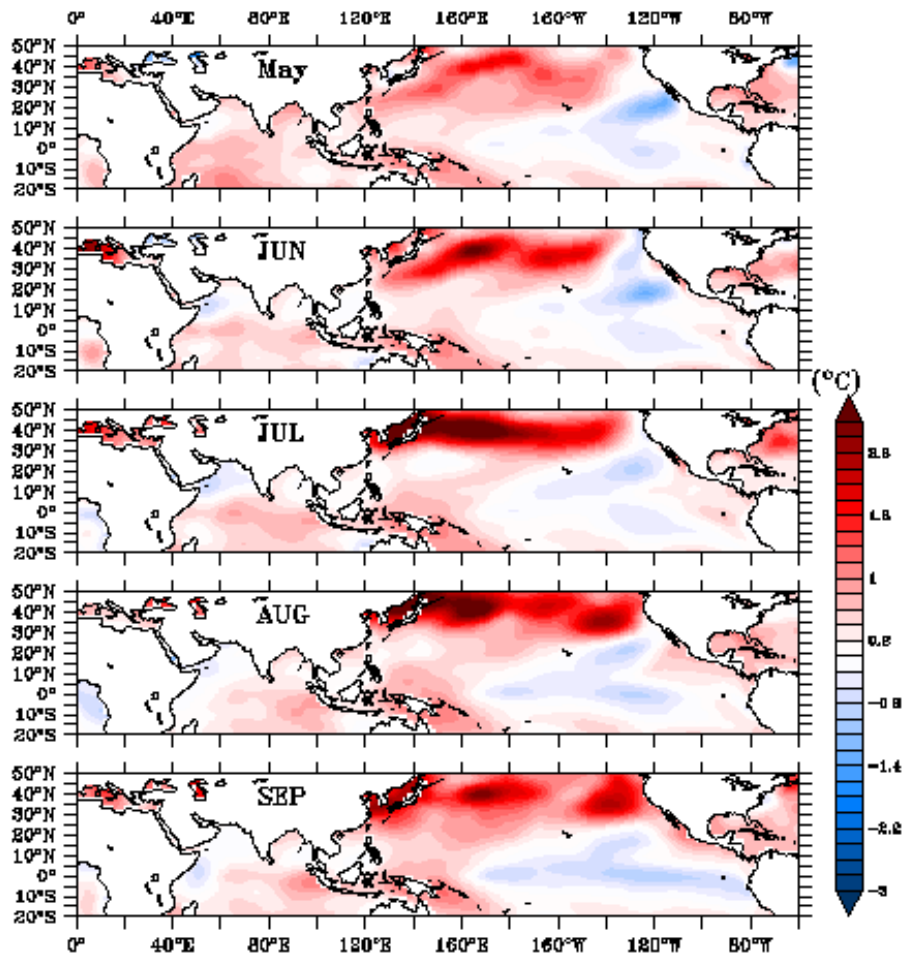


Fig. 3.2: Monthly sea surface temperature (SST) anomalies from May to September 2025 (Data Source: NOAA ERSSTv5)

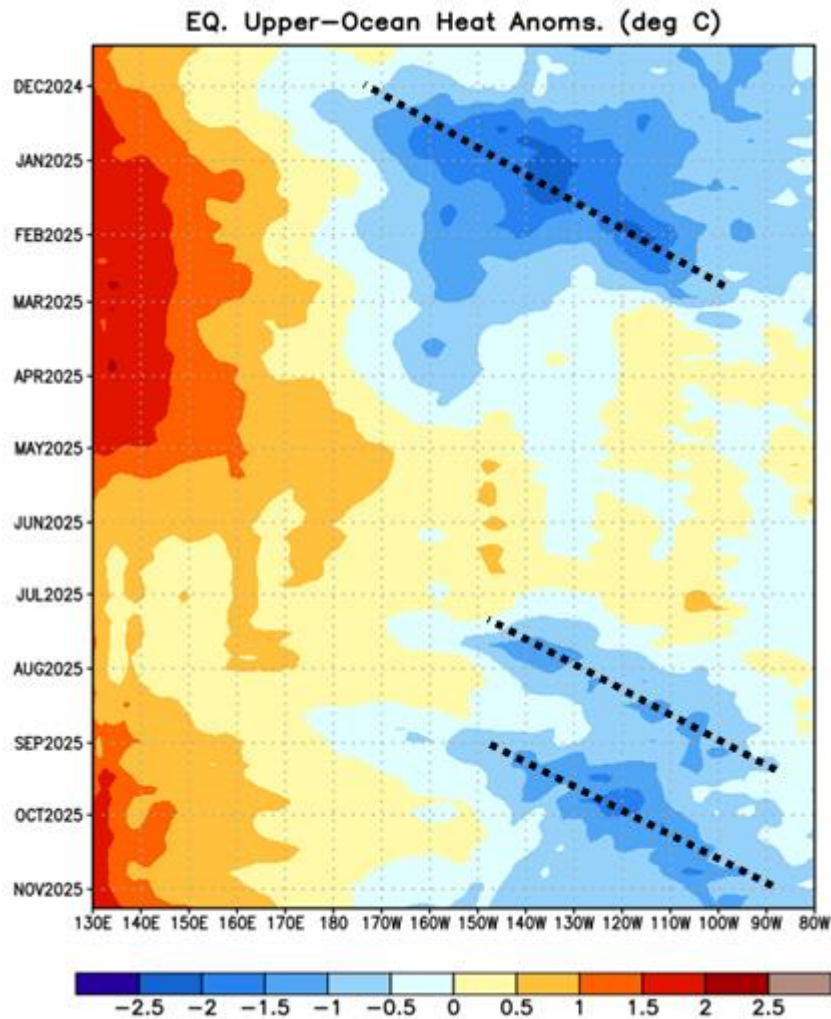


Fig. 3.3: Upper-ocean heat anomalies (in degrees Celsius) over the equatorial Pacific Ocean are shown. Thick dashed lines represent the warm (downwelling) phase, while the cool (upwelling) phase is represented by dotted lines. (Source: provided by NOAA)

The Hovmöller diagram (time versus longitude) of equatorial upper-ocean heat content anomalies from December 2024 to November 2025 is shown in **Figure 3.3**. The diagram indicates that the western equatorial Pacific remained predominantly warmer than normal from December 2024 through May 2025, while the central and eastern Pacific exhibited widespread negative heat content anomalies during this period. Embedded within this pattern, distinct phases of equatorial oceanic Kelvin wave activity are evident. A prominent upwelling Kelvin wave propagated eastward from January to April 2025, contributing to the early-year cooling in the central and eastern Pacific. A second upwelling event developed from July to September 2025, with its signature progressing eastward across the basin and reinforcing the negative subsurface anomalies in the eastern Pacific. A third upwelling event developed from September 2025 and continued through November 2025.

Overall, the sustained presence and repeated passage of upwelling equatorial Kelvin waves during 2025 played a key role in maintaining the below-average upper-ocean heat content across the central and eastern Pacific, consistent with the development and persistence of La Niña-like subsurface conditions throughout much of the year.

3.1.2 Indian Ocean

Figure 3.2 illustrates that sea surface temperature (SST) anomaly in the Indian Ocean shows a clear dipole-like pattern emerged from June onwards: warmer-than-normal SSTs appeared in the eastern tropical Indian Ocean near Indonesia and the eastern Bay of Bengal, while cooler-than-normal SSTs dominated the western tropical Indian Ocean and parts of the Arabian Sea. Meanwhile, **Figure 3.4** presents the Dipole Mode Index (DMI) time series from January 2024 to September 2025. The DMI represents the strength and phase of the Indian Ocean Dipole (IOD), defined by the anomalous sea surface temperature gradient between the western equatorial Indian Ocean (50°E–70°E, 10°S–10°N) and the southeastern equatorial Indian Ocean (90°E–110°E, 10°S–0°N; Saji et al., 1999).

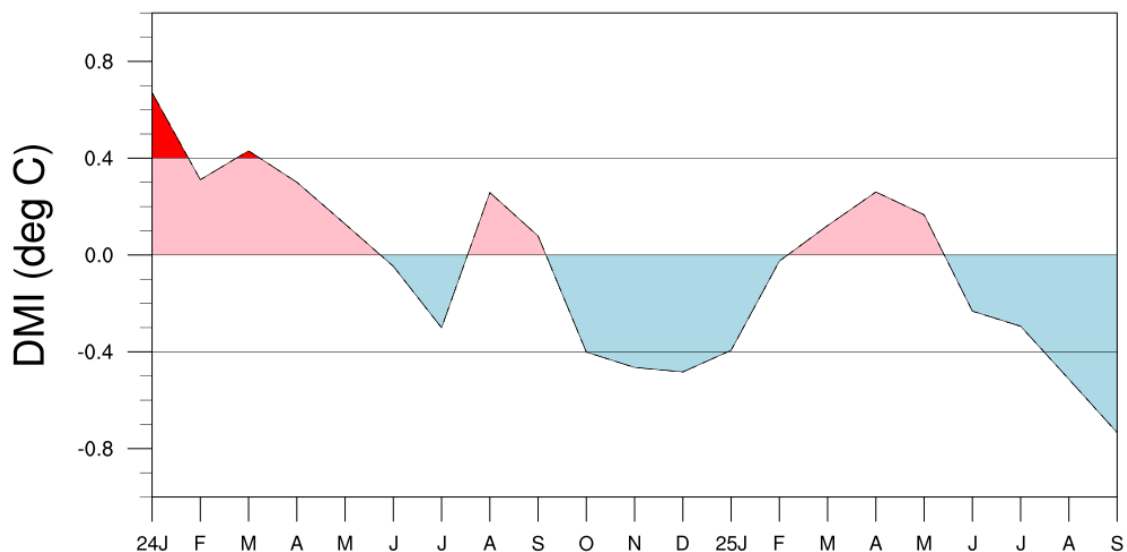


Fig. 3.4: Dipole Mode Index (DMI) Time series representing Indian Ocean Dipole Condition from January 2024 to September 2025. (Data Source: ERSSTv5)

During early 2024, the DMI remained slightly positive but within the neutral range, gradually weakening by mid-year. From May to November 2024, the index fluctuated around neutral to mildly negative values, indicating the absence of a strong IOD event during the 2024 monsoon season. A brief positive excursion occurred around August 2024, but it did not reach the threshold required to classify a positive IOD. The DMI turned distinctly

negative from October to December 2024, signalling the development of a weak negative IOD phase. Although this negative phase persisted into early 2025, its magnitude remained modest. From February to June 2025, the index returned to near-neutral or weakly positive values. However, by July–August 2025, the DMI again crossed the threshold for a negative IOD, with the negative anomaly strengthening through August and September 2025.

3.2 OLR and Low Level Wind Anomalies

Figure 3.5 (a–d) presents the monthly anomalies of Outgoing Longwave Radiation (OLR) and 850-hPa wind vectors for June, July, August, and September 2025. Negative OLR anomalies indicate enhanced convection and increased cloudiness, while positive anomalies correspond to suppressed convection and reduced cloud cover. The associated low-level wind anomalies provide insight into the dynamical circulation features influencing these convective patterns.

In June 2025, negative OLR anomalies dominated over most of India, extending into the Bay of Bengal, indicating enhanced convective activity during the onset phase of the monsoon. Negative anomalies below -20 W/m^2 were observed over northern and eastern India and adjacent oceanic regions, highlighting active convective zones. Conversely, positive OLR anomalies prevailed over the western equatorial Indian Ocean and parts of the Arabian Sea, signaling suppressed convection. Enhanced convection also appeared over the eastern equatorial Indian Ocean and much of the Maritime Continent. Westerly wind anomalies were observed over the equatorial Indian Ocean, supporting moisture transport toward the eastern basin. Additionally, an anomalous cyclonic circulation was present over north-central India, supporting enhanced convection in the region during June 2025.

In July 2025, strong negative OLR anomalies were observed across northwestern, central, and eastern India, with values locally below -30 W/m^2 , indicating vigorous convection associated with the monsoon peak. Negative anomalies also persisted over the northern Bay of Bengal, the eastern equatorial Indian Ocean, the Maritime Continent, and the western Pacific. Positive anomalies over the western Indian Ocean reflected sustained subsidence and convection suppression. An equatorial westerly wind anomaly was evident over the Indian Ocean, and enhanced low-level circulation anomalies were present over the Indian domain. Low-level cyclonic circulation anomalies over India and the Bay of Bengal further contributed to moisture convergence and enhanced rainfall activity.

August 2025 continued to show widespread negative OLR anomalies across most of India, particularly over northwest and central India where anomalies exceeded -25 W/m^2 . Convection remained strong over the eastern equatorial Indian Ocean and the central Maritime Continent. Positive OLR anomalies were noted over the western tropical Indian Ocean and parts of the southern Arabian Sea, highlighting an east–west asymmetry in the

convective pattern. Low-level winds exhibited strengthened westerly anomalies across the equatorial region, along with anomalous cyclonic circulation over northwest India, favouring enhanced monsoon moisture transport into the Indian subcontinent.

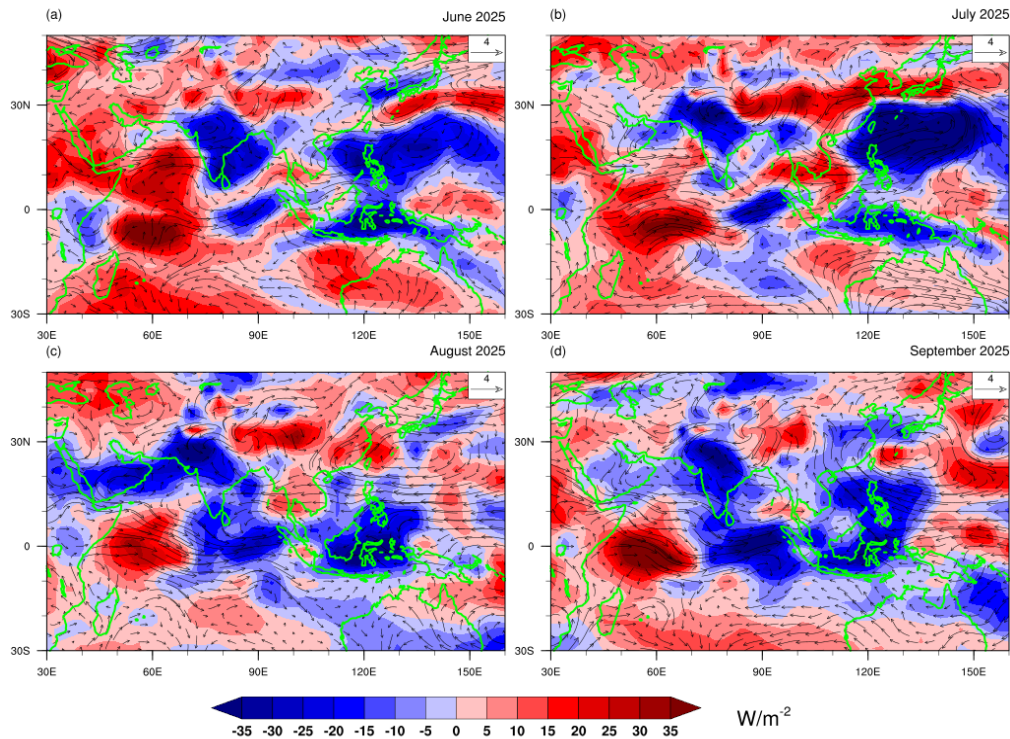


Fig. 3.5: The monthly anomalies of Outgoing Longwave Radiation (OLR) (shaded) and wind anomalies at 850 hPa (vectors) are shown for a) June, b) July, c) August, and d) September 2025

In September 2025, negative OLR anomalies were observed over most of the Indian landmass except northeastern India, as well as over the northern Bay of Bengal and the eastern parts of the Arabian Sea, indicating continued favourable convective conditions during the monsoon withdrawal phase. Persistent negative anomalies also extended across the eastern equatorial Indian Ocean, the Maritime Continent, and the western Pacific. Positive anomalies appeared over the western and central equatorial Indian Ocean. The wind anomaly pattern showed a continuation of anomalous cyclonic circulation over India and anomalous westerly wind anomalies over the equatorial Indian Ocean, supporting convective enhancement.

Overall, the monthly OLR and wind anomaly patterns from June to September 2025 highlight a season marked by stronger-than-normal convection over India and the eastern Indian Ocean, alongside persistent suppression over the western Indian Ocean.

(a)

JJAS 2025

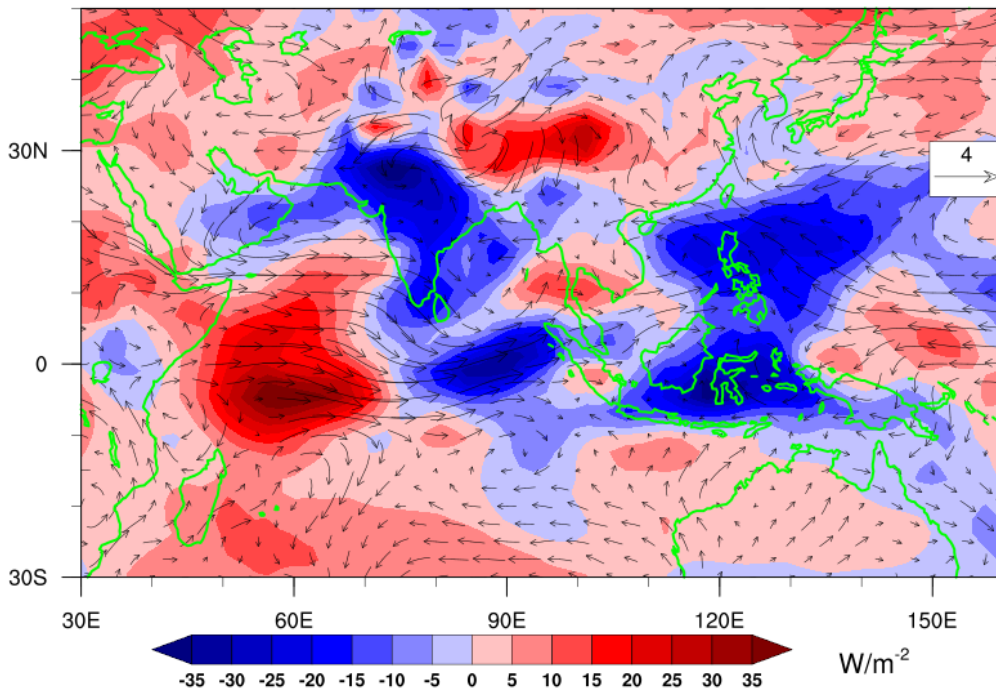


Fig. 3.6 OLR anomaly overlaid with 850hPa wind during June to September 2025

Figure 3.6 shows the seasonally averaged outgoing longwave radiation (OLR) anomalies overlaid with 850-hPa wind anomalies for the June–September (JJAS) 2025 monsoon season. The spatial pattern reveals prominent regions of enhanced and suppressed convection across the Indian Ocean and adjoining land areas. Large negative OLR anomalies—indicative of enhanced convection and increased cloudiness—were observed over central and northern India, extending southeastward into the Bay of Bengal and further into the Maritime Continent and western Pacific regions. Negative OLR anomaly less than -20 W/m^2 was observed over northwestern parts, suggesting active convective conditions during the season. Enhanced convection also extended across much of the eastern equatorial Indian Ocean, consistent with favourable large-scale upward motion.

In contrast, positive OLR anomalies, representing suppressed convection, were noted over the western and central equatorial Indian Ocean and parts of the western Arabian Sea. These regions experienced reduced cloudiness and subsidence, consistent with weakened convective activity.

The 850-hPa wind anomalies provide dynamical context to these convective patterns. Anomalous cyclonic circulation was evident over northwest India and the west-central Bay of Bengal, supporting moisture convergence and enhanced convection over these regions. Strong westerly wind anomalies were also observed over the equatorial Indian Ocean, further contributing to the convective asymmetry across the basin.

Overall, the JJAS 2025 OLR and low-level wind anomaly pattern reflects a season characterized by enhanced convective activity over India, the Bay of Bengal, and the eastern Indian Ocean, while convection was suppressed over the western Indian Ocean. This east–west dipole-like structure in convection is consistent with the negative IOD that developed during mid-2025.

3.3 Upper Tropospheric Circulation Anomalies

Figures 3.7 (a–d) depict the spatial distribution of monthly wind anomalies at the 200 hPa level from June to September 2025. The patterns highlight the evolution of upper-tropospheric circulation features associated with the Indian summer monsoon, including variations in the Tibetan anticyclone and the Tropical Easterly Jet (TEJ). In June 2025, the upper-level wind anomaly field shows a broad region of anomalous easterlies extending across much of central and southern India, indicating a strong Tropical Easterly Jet. An anomalous anticyclonic circulation is evident over the western part of the Tibetan Plateau, while weaker cyclonic anomalies appear over parts of East Asia. These features suggest that the Tibetan High was in its developing phase but not yet fully established during June 2025. The widespread easterly anomalies over the monsoon domain indicate an early-season enhancement of upper-level divergence that is supportive of monsoon activity.

In July 2025, an anomalous anticyclonic circulation strengthens over the Tibetan Plateau and adjoining regions, indicating a well-developed Tibetan High during the core monsoon month. Additionally, cyclonic wind anomalies appear over parts of East Asia. The associated easterly wind anomalies over southern India and the adjoining oceanic regions point to a strengthened TEJ. These features collectively indicate a robust upper-level monsoon circulation during July, which typically supports enhanced convective activity and vigorous monsoon conditions.

In August 2025, the Tibetan anticyclone remains strong, and a pronounced upper-level easterly wind anomaly is observed over India, with maximum wind speed over central India compared to south India. The cyclonic wind anomalies seen over East Asia during June and July are no longer evident.

In September 2025, a strong and well-organized Tibetan anticyclone persists, with its core positioned slightly eastward. The presence of strong easterly wind anomalies across southern India and the adjoining Arabian Sea denotes a strengthened Tropical Easterly Jet (TEJ). The combination of a strong Tibetan anticyclone and a robust TEJ during September 2025 is typically associated with enhanced upper-level divergence, which favors above-normal rainfall during the late monsoon season.

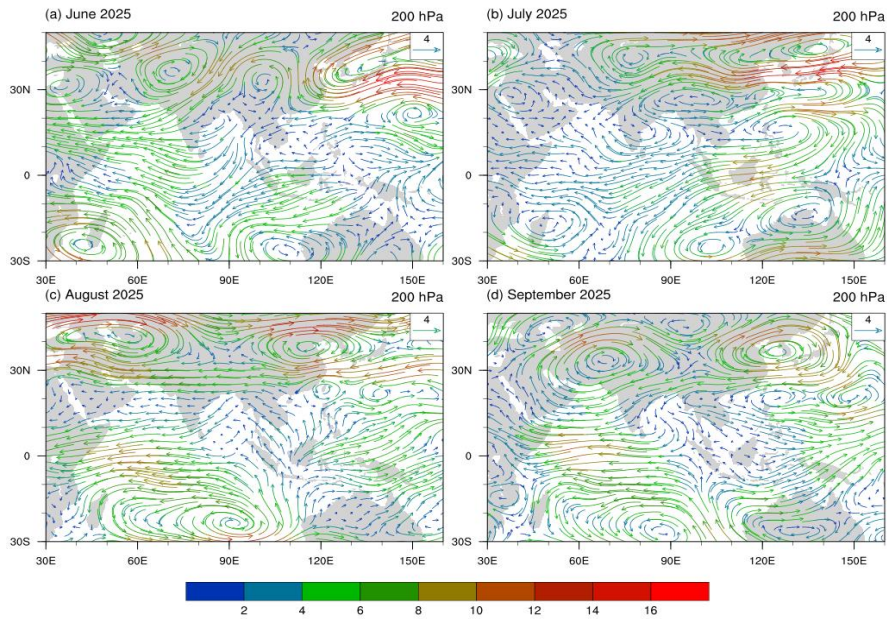


Fig. 3.7: Wind anomalies at 200 hPa during a) June b) July c) August d) September 2025

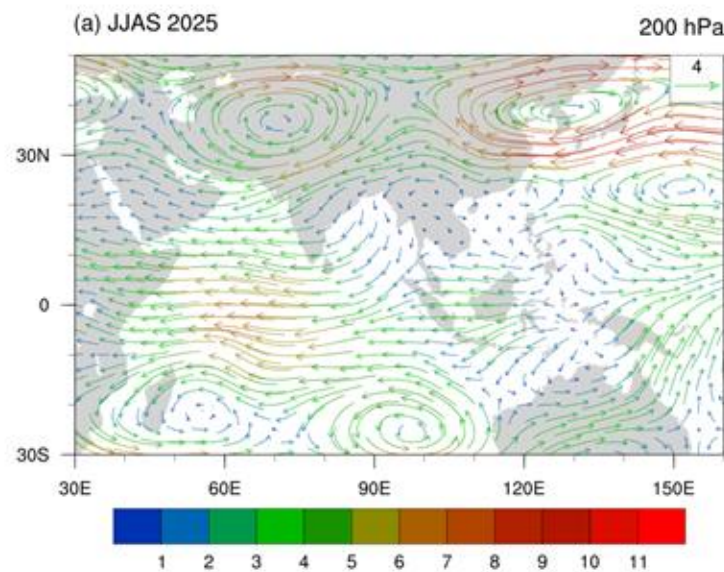


Fig. 3.8: Wind anomalies at 200 hPa during monsoon season (June to September) 2025

Figure 3.8 illustrates the wind anomalies averaged over the monsoon season (June–September) at the 200 hPa level for 2025. The seasonal mean pattern reveals a well-defined upper-tropospheric anticyclonic circulation over the Tibetan Plateau, indicating a climatologically strong Tibetan High during JJAS 2025. The anticyclone appears broad and well organized. Associated with this upper-level anticyclonic circulation, widespread easterly wind anomalies prevail across most parts of the country, including southern India, Sri Lanka,

and the adjoining Arabian Sea. This pattern suggests the presence of an enhanced Tropical Easterly Jet (TEJ) during the season. The strengthened TEJ typically supports increased upper-level divergence over the monsoon core region, thereby aiding deep convection and sustaining active monsoon conditions. Overall, the seasonal 200-hPa circulation anomalies for JJAS 2025 indicate a dynamically favorable upper-tropospheric environment, with a strong Tibetan anticyclone and a well-established TEJ that likely contributed to maintaining the vigor of the monsoon during the season.

3.4 Meridional Circulation Anomalies over Indian Region

Figure 3.9 (a–d) presents the monthly meridional circulation anomalies over the Indian monsoon region for June to September 2025, based on the latitude–height cross section of zonal–vertical wind anomalies and pressure vertical velocity ($\omega \times -1$). In June 2025, a broad and well-organized ascending motion is evident between the equator and 20°N. A corresponding band of descending motion appears north of 25°N.

In July 2025, the ascending branch weakens slightly compared to June but remains noticeable between the equator and 20°N. A subsidence anomaly is visible centered around 15N. The subsidence zone over 25–40°N persists. In August 2025, the ascending motion strengthens again, becoming more widespread and vertically deep from the equator to about 20°N. This enhanced ascent in August is consistent with increased convective activity observed during the month. The descending anomalies to the north of 25°N remain well defined. In September 2025, strong ascent continues over the equatorial region and around 15–20°N, producing two distinct ascending branches. The descent over 25–40°N also persists during this month, maintaining the typical meridional overturning structure associated with an active monsoon phase.

Overall, the meridional circulation anomalies for 2025 indicate consistent ascending motion over the monsoon latitudes (0–20°N) throughout the season, with the most pronounced ascent occurring in August and September. This vertical circulation pattern likely contributed to sustaining convective activity during key phases of the 2025 monsoon.

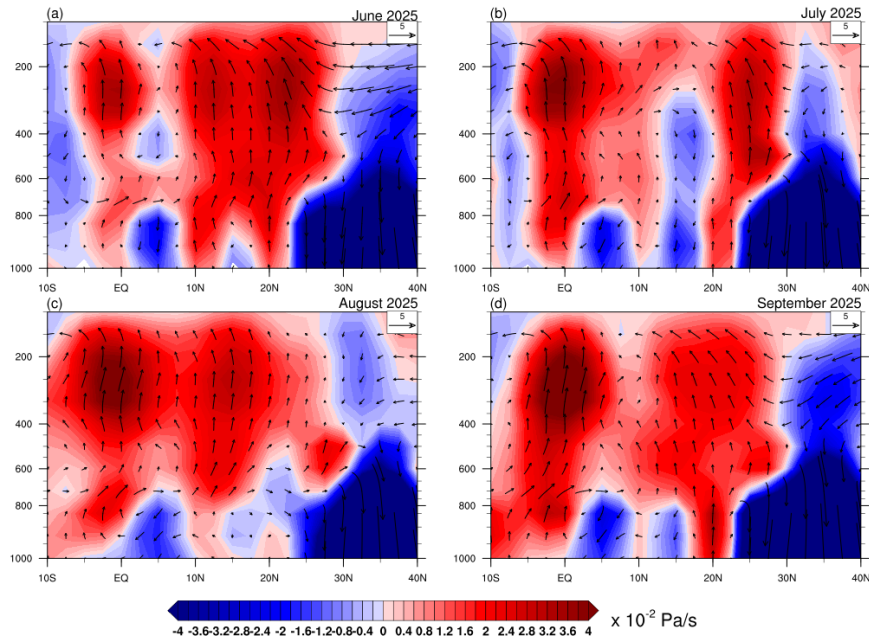


Fig. 3.9: Latitude-Height Circulation Cross-section and Omega during a) June, b) July, c) August, and d) September 2025. Pressure vertical velocity (Omega) is shaded. The anomalies are averaged over longitudes 70°E-90°E.

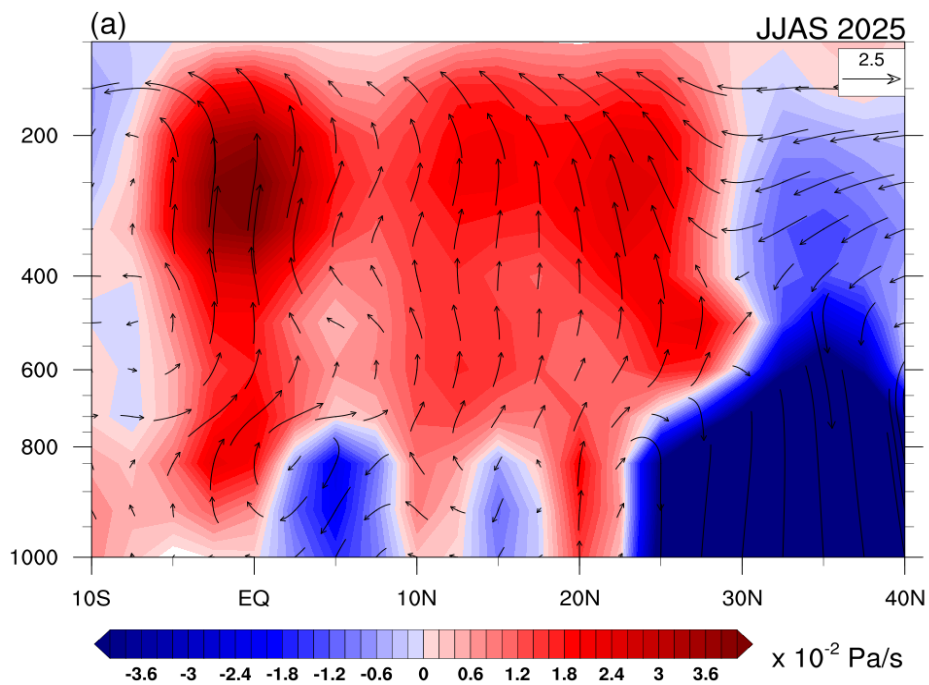


Fig. 3.10: Vertical cross-section of pressure vertical velocity overlaid with meridional vertical circulation for the monsoon season (June-September 2025). Pressure vertical velocity (omega) is shaded. The anomalies are averaged over longitudes 70°E to 90°E.

To examine the changes in meridional circulation over the Indian region during the monsoon season, a latitude–height cross-section of vertical velocity (ω) anomalies averaged over the longitudinal zone 70°E–90°E was analyzed for the JJAS season (**Figure 3.10**). The results show a broad and well-organized anomalous ascending motion extending from the equator to about 25°N. In contrast, anomalous descending motion is noted north of 25°N. These circulation features indicate the presence of strong rising motion over the Indian region during the 2025 monsoon season, which is consistent with enhanced convective activity and supports above-normal rainfall over the core monsoon zone.

3.4 Walker Circulation Anomalies

To analyze the Walker circulation anomaly during the monsoon season, longitudinal–height cross-sections of circulation and pressure vertical velocity (ω) anomalies averaged over 10°S–10°N are shown for each month of the monsoon season (**Figure 3.11a–d**). A broad region of enhanced ascending motion, extending from the eastern Indian Ocean to the Maritime Continent and into the western Pacific, is evident in June, August, and September. In contrast, this ascending branch weakens in July, with a narrow band of anomalous descending motion appearing over the eastern equatorial Indian Ocean.

Similarly, anomalous descending motion is observed over the central and eastern Pacific during June, August, and September 2025, although this descending branch is notably weaker in July 2025. Overall, these anomalous circulation features resemble a La Niña–like Walker circulation pattern, characterized by strengthened ascent over the Indo-Pacific Warm Pool and enhanced descent over the central and eastern Pacific.

Figure 3.12 presents the longitudinal-height cross section of circulation and pressure vertical velocity (ω) anomalies averaged over 10°S–10°N for the monsoon season (JJAS) 2025. The shading depicts ω anomalies, while vectors represent zonal and vertical wind anomalies. This figure highlights the anomalous Walker circulation during JJAS 2025. The pattern shows a broad region of enhanced ascending motion extending from the eastern Indian Ocean to the Maritime Continent and towards the western Pacific. In contrast, pronounced descending motion is observed over the central and eastern Pacific, consistent with suppressed convection in that region.

This east–west contrast in vertical motion reflects a La Niña–like Walker circulation during the 2025 monsoon season. The anomalous ascent over the Indo-Pacific Warm Pool and descent over the central/eastern Pacific indicate a strengthened zonal overturning circulation. These features align with other indicators during JJAS 2025 that pointed toward persistent La Niña–type conditions, contributing to enhanced convection over the monsoon domain and dynamically supporting the active phases of the Indian summer monsoon.

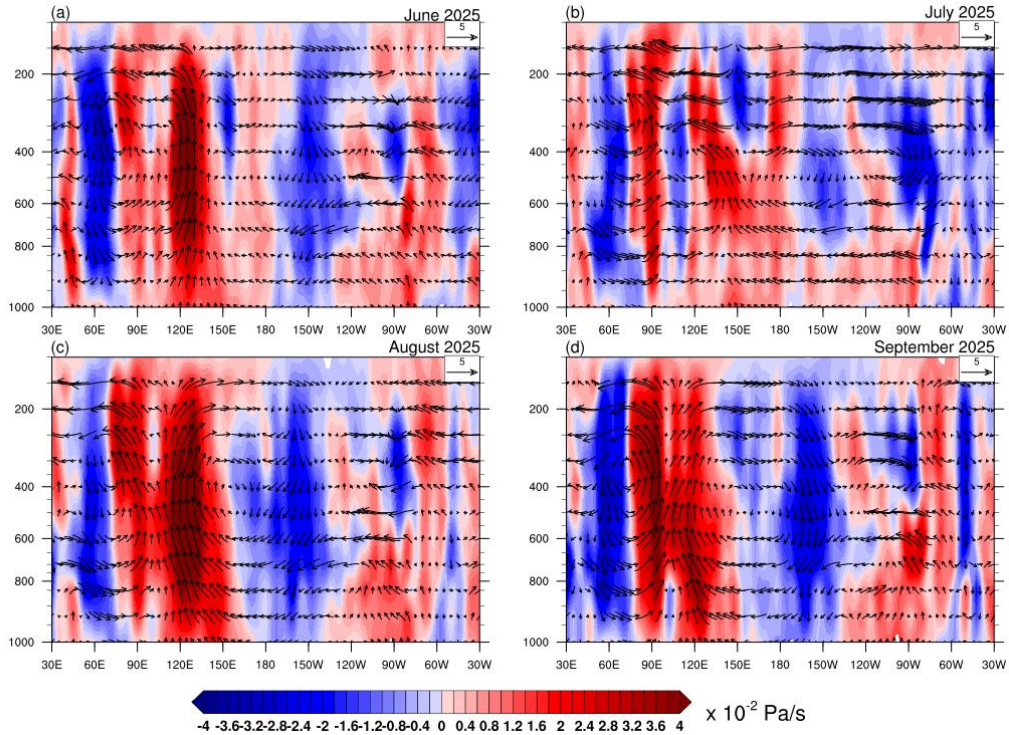


Fig. 3.11: Longitude-height circulation cross-section and vertical velocity (ω) anomalies for the Indian region during: a) June, b) July, c) August, and d) September 2025. Pressure vertical velocity (ω) is represented by shading. The anomalies are averaged over the latitudinal zone of 10°S to 10°N .

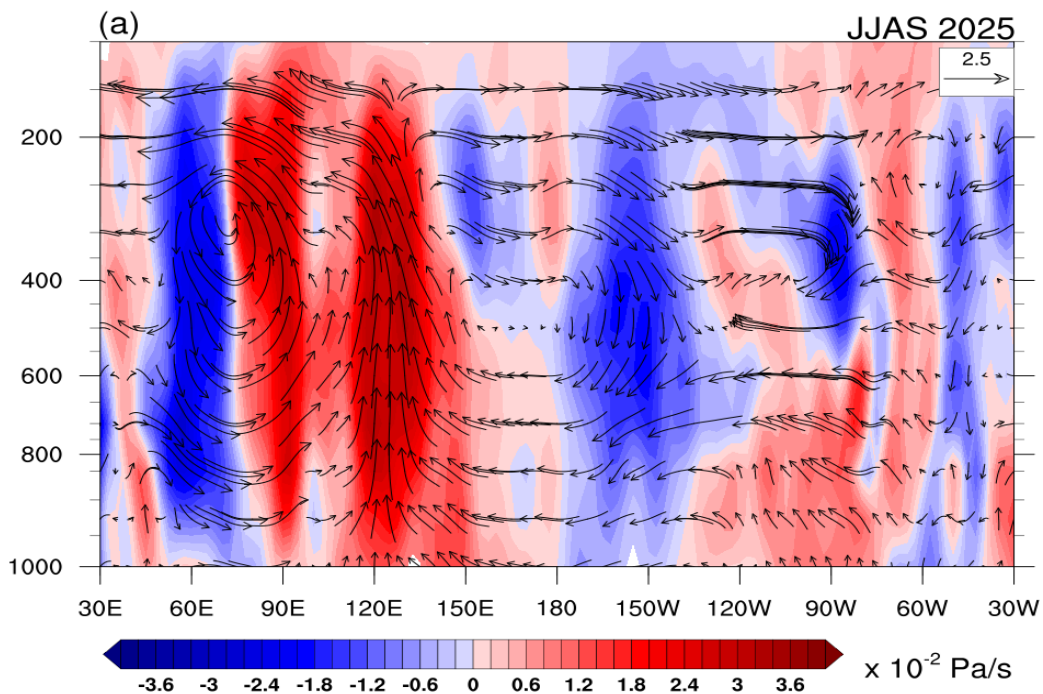


Fig. 3.12: Longitudinal height circulation cross-section and vertical velocity (ω , multiplied by -1) anomalies for the monsoon season (JJAS) 2025. Pressure vertical velocity (ω) is represented by shading. The anomalies are averaged over the latitudinal zone of 10°S to 10°N

3.5 Intra-seasonal rainfall variability during the Monsoon Season

The intra-seasonal variation of rainfall during the 2025 monsoon season is presented in **Figure 3.13**, showing the time series of daily standardized rainfall anomalies over the core monsoon zone (Rajeevan et al., 2010). During June 2025, rainfall anomalies remained close to normal in the first half of the month. However, two distinct active monsoon spells occurred during the second half of June, with several days showing anomalies above +1.0 standard deviation, indicating an early strengthening of monsoon conditions over the core region.

In early July, an active monsoon spell was observed, lasting until 8–9 July. This period featured multiple days with strong positive anomalies. Following this early-July active monsoon phase, rainfall largely remained within the normal range until the end of the month. A well-defined break monsoon spell developed in early August and persisted until mid-August, during which several days registered anomalies below -1.0 standard deviation, reflecting significantly weakened monsoon convection over central India.

After mid-August, rainfall conditions gradually improved, with intermittent normal and slightly positive anomalies. A short-lived active monsoon spell was observed during the third week of August. In September 2025, rainfall anomalies were positive on most days. Although the anomalies exceeded +1 standard deviation on several days, they did not meet the criterion for an active monsoon spell, which requires at least three consecutive days of rainfall anomalies greater than +1 standard deviation.

Overall, the 2025 monsoon season exhibited clear intra-seasonal variability. These fluctuations highlight the dynamic evolution of rainfall over the core monsoon zone during the season.

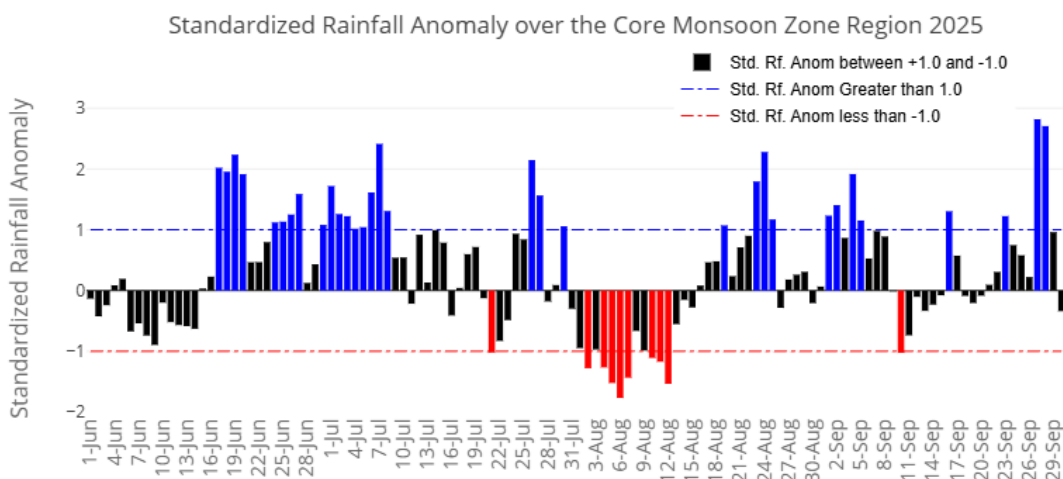


Fig. 3.13: Time series of standardized rainfall anomalies for the core monsoon zone during the 2025 monsoon season

3.6 Typhoon activity over West Pacific

The activity of West Pacific typhoons is an important factor responsible for subdued rainfall over the Northeast Indian region (Mooley and Shukla, 1989). Previous studies have discussed the relationship between Indian summer monsoon rainfall and typhoon activity over the West Pacific (Rajeevan, 1993; Vinay Kumar and Krishnan, 2005; and Pattanaik and Rajeevan, 2007). The tracks of the systems formed during the 2025 monsoon season (June to September) are depicted in **Figure 3.14**. Typically, typhoons form over the West Pacific, and their remnants moving westward contribute to the formation of low-pressure systems in the Bay of Bengal. During the 2025 monsoon season, many typhoons moved westward during August and September compared to June and July. This led to an increase in low-pressure systems in the Bay of Bengal during these months, attributed to the remnants of these West Pacific typhoons. This phenomenon positively impacted Indian summer monsoon rainfall, resulting in a positive rainfall anomaly in August and September 2025.

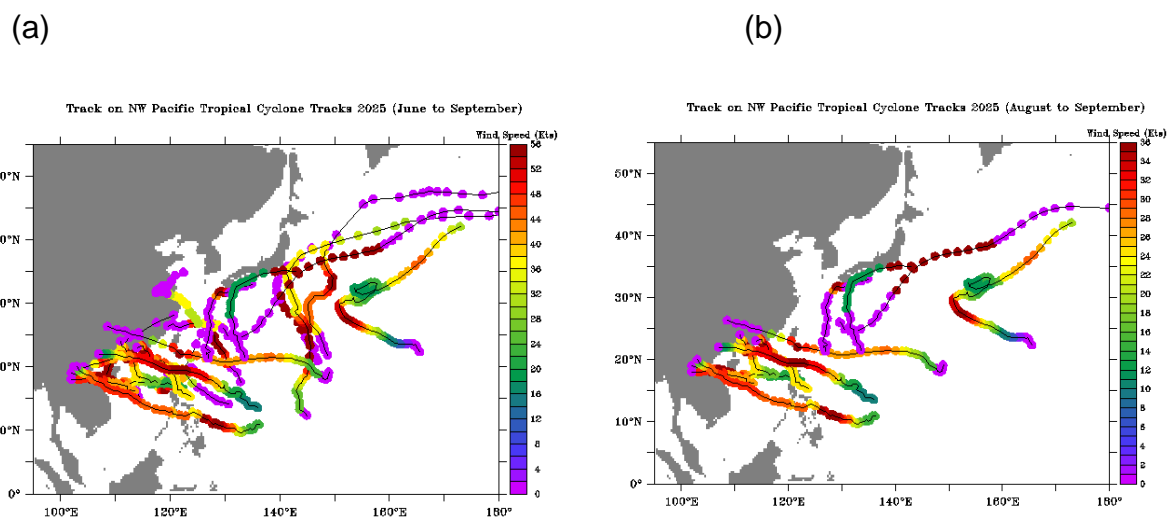


Fig. 3.14: Observed tracks of Typhoons formed over the Northwest Pacific Ocean from (a) June to September 2025 (b) August to September 2025 (Data source: Best track data JMA).

3.7 Rainfall distribution over the Indian Region

During the 2025 monsoon season, most meteorological sub-divisions of the country received large excess, excess, or normal rainfall, except Arunachal Pradesh, Assam & Meghalaya, and Bihar. Out of the 36 meteorological sub-divisions, 2 received large excess rainfall, 12 received excess rainfall, 19 received normal rainfall, and the remaining 3 sub-divisions experienced deficient rainfall (**Figure 3.15**). **Table 3.1** presents the sub-division-wise rainfall statistics (mm) for the Southwest Monsoon Season 2025.

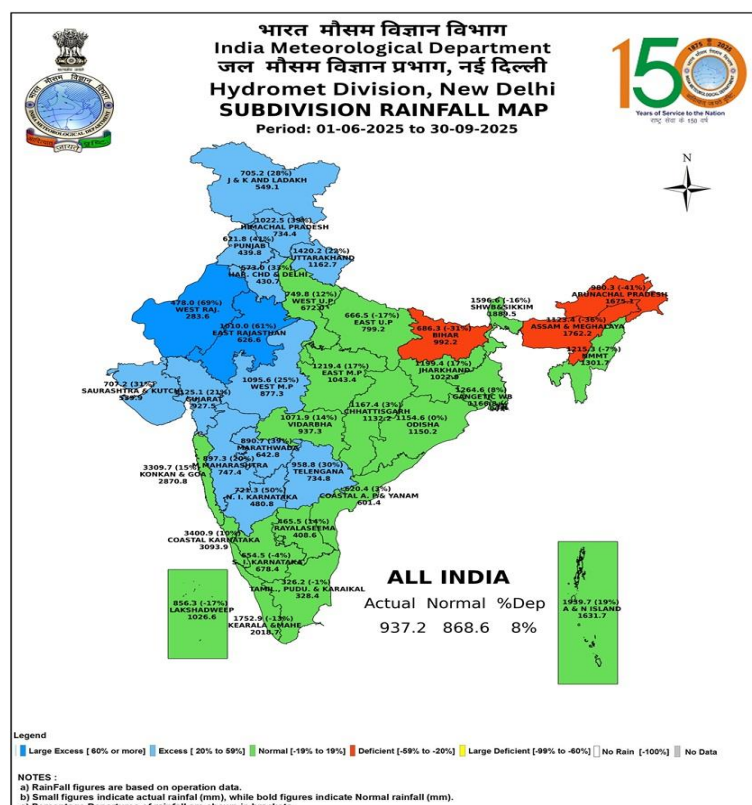


Fig. 3.15: Sub-division-wise rainfall distribution over India during southwest monsoon season (June to September) – 2025

Rainfall over East Rajasthan (1010.0 mm) was the second highest since 1901. Rainfall over West Rajasthan (478.0 mm) and North Interior Karnataka (721.3 mm) was the sixth highest since 1901. Rainfall over Assam & Meghalaya (1123.4 mm) was the lowest since 1901, while rainfall over Arunachal Pradesh (980.3 mm) was the third lowest since 1901.

Overall, the seasonal rainfall over India during the 2025 monsoon was above normal. Quantitatively, rainfall from June to September 2025 amounted to 108% of the long-period average (LPA). The month-to-month rainfall percentages for India as a whole were 109% of LPA in June, 105% in July, 105% in August, and 115% in September.

The realized rainfall for the season was 127% of its LPA over northwest India, 115% over central India, 110% over the south peninsula, and 80% over east and northeast India. Rainfall over the homogeneous region of northwest India (747.9 mm) was the highest since 2001 and the sixth highest since 1901, after the years 1917 (928.4 mm), 1988 (813.5 mm), 1975 (781.2 mm), 1916 (762.1 mm), and 1909 (753 mm). Rainfall over the homogeneous region of east and northeast India (1089.9 mm) was the second lowest since both 2001 and 1901; the previous lowest was in 2013 (1065.7 mm).

Table 3.1: Meteorological sub-division-wise rainfall statistics (mm) for the southwest monsoon season 2025

MONTH		JUNE	JULY	AUGUST	SEPTEMBER	SEASON
Number of subdivisions in different categories	Large Excess	7	3	7	11	2
	Excess	8	7	7	8	12
	Normal	11	18	17	10	19
	Deficient	10	8	5	7	3
	Large Deficient	0	0	0	0	0
	No Rain	0	0	0	0	0
Actual (mm)		180.0	294.1	268.1	193.6	937.2
LPA (mm)		165.3	280.5	254.9	167.9	868.6
Rainfall (% of LPA)		109	105	105	115	108

Figure 3.16 presents the sub-division-wise distribution of rainfall percentage departures for the four months of the 2025 monsoon season (June to September). The number of subdivisions that received excess, normal, deficient, or scanty rainfall during each month, along with the actual and Long Period Average (LPA) rainfall and the percentage of LPA for the country as a whole for each month and for the season are provided in Table 3.1.

Figure 3.16a shows the subdivision-wise monthly rainfall for June. In June 2025, 7 subdivisions received large excess rainfall, 8 received excess rainfall, 11 experienced normal rainfall, and 10 had deficient rainfall. The rainfall realized during June 2025 was 142% of its LPA over northwest India, 125% over central India, 97% over south peninsular India, and 83% over east and northeast India. Rainfall over the East & Northeast India region (272.9 mm) was the 17th lowest since 1901 and the 8th lowest since 2001.

Figure 3.16b shows the subdivision-wise monthly rainfall for July 2025. In this month, out of 36 meteorological subdivisions, 3 received large excess rainfall, 7 received excess rainfall, 18 received normal rainfall, and 8 received deficient rainfall. The realized rainfall for July 2025 was 122% of its LPA over central India, 113% over northwest India, 98% over the south peninsula, and 74% over east and northeast India. Rainfall over the East & Northeast India region (312.3 mm) was the 7th lowest since 1901 and the 4th lowest since 2001.

Figure 3.16c shows the subdivision-wise monthly rainfall for August 2025. In this month, out of 36 meteorological subdivisions, 7 received large excess rainfall, 7 received excess rainfall, 17 received normal rainfall, and 5 received deficient rainfall (Fig. 1a). Table 1 presents the subdivision-wise rainfall statistics (mm) for August 2025. The realized rainfall for August 2025 was 134% of its LPA over northwest India, 131% over the south peninsula, 91% over east and northeast India, and 86% over central India. August rainfall over the homogeneous region of northwest India (265.0 mm) was the 13th highest since 1901 and the

highest since 2001. Rainfall over the homogeneous region of the south peninsular region (250.6 mm) was the 8th highest since 1901 and the 3rd highest since 2001.

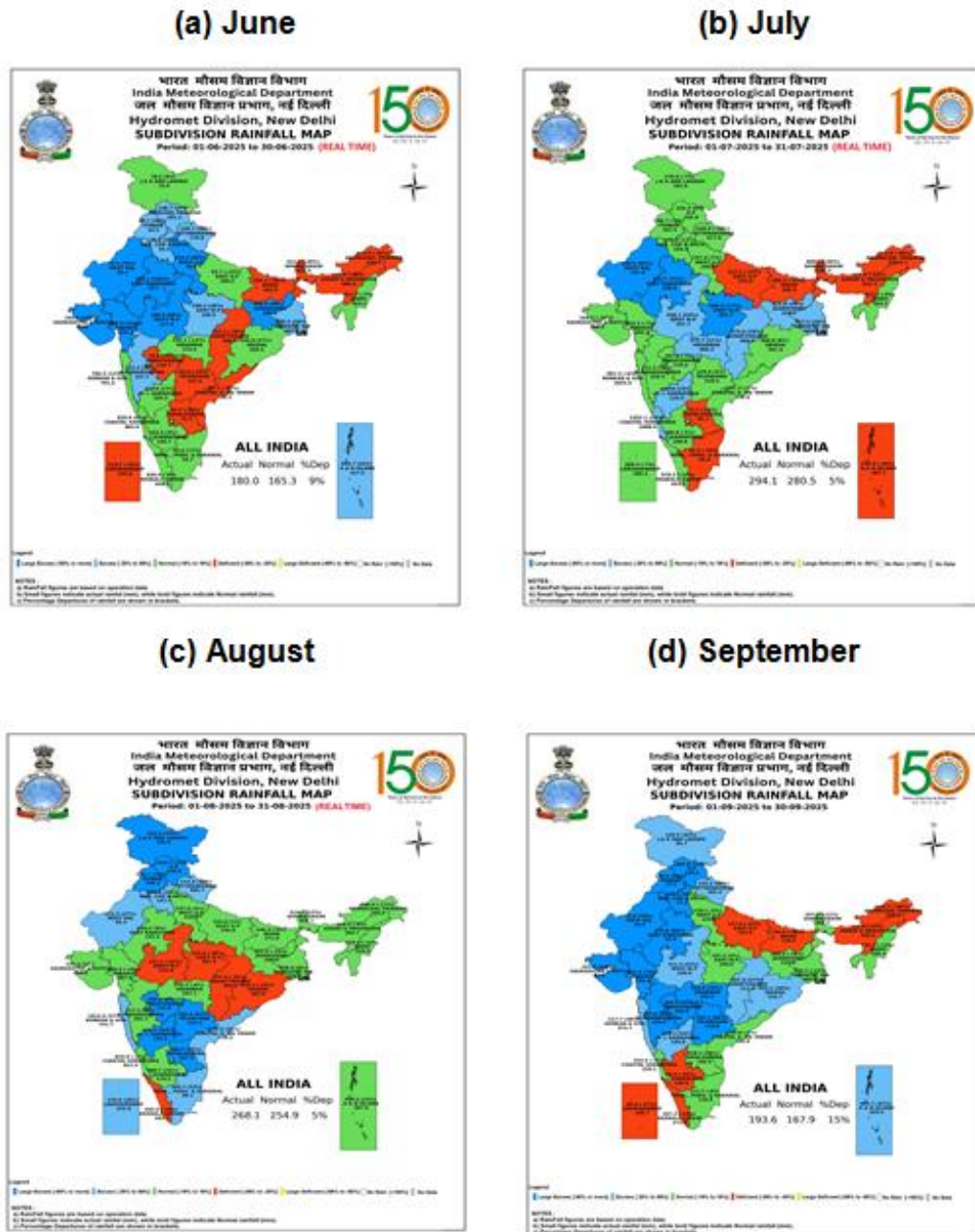


Fig. 3.16: Monthly sub-division-wise distribution of rainfall percentage departures during 2025

Figure 3.16d shows the subdivision-wise monthly rainfall for September 2025. In this month, out of 36 meteorological subdivisions, 11 received large excess rainfall, 8 received excess rainfall, 10 received normal rainfall, and 7 received deficient rainfall. The realized rainfall for September 2025 was 144% of its LPA over central India, 131% over northwest India, 112% over the south peninsula, and 69% over east and northeast India. Rainfall over northwest India in September 2025 was 134.2 mm, the 6th highest since 2001 and the 35th

highest since 1901. Over central India, the rainfall total was 255.3 mm, making it the 5th highest since 2001 and the 16th highest since 1901. In contrast, East & Northeast India received 195.9 mm of rainfall, which was the 2nd lowest since 2001 and the 6th lowest since 1901.

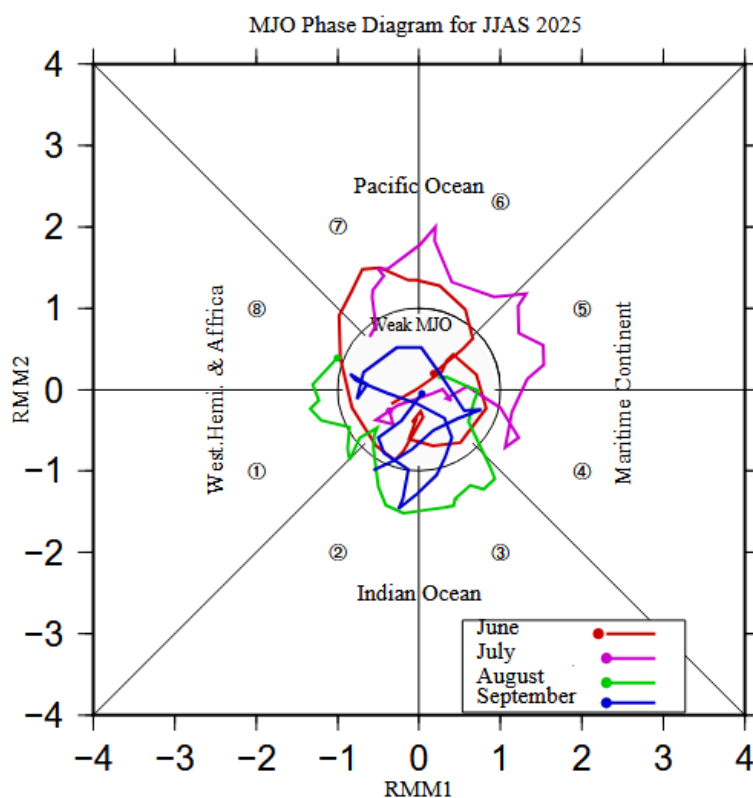


Fig. 3.17: The phase-space diagram depicts the MJO index during the monsoon season of 2025. The numbers inside the encircled sectors of the diagram represent 8 phases of the MJO

The Madden–Julian Oscillation (MJO), a key modulator of intra-seasonal monsoon variability (Wheeler and Hendon, 2004; Pai et al., 2009; Sabeerali et al., 2013), showed notable variations during June–September 2025 (**Figure 3.17**). In June, the MJO remained mostly weak, with a brief signal moving from the Western Pacific to the Western Hemisphere (Phases 6–1), followed later by a weak signal moving eastward from the Indian Ocean (phase 2 and 3) to Maritime Continent (Phase 4) before decaying at month’s end. In July, the MJO exhibited an organized progression, beginning over the Indian Ocean (Phases 2–3) with a weak amplitude in the first week, strengthening to an amplitude above one as it entered the Maritime Continent (Phase 4) during mid-July, and then moving into the Western Pacific (Phases 6–7) with a strong signal before weakening toward the end of the month. In August, the MJO remained active, originating in the Western Hemisphere (Phase 8) and propagating eastward through the Indian Ocean (Phases 1–3), before weakening as it approached the Maritime Continent (Phases 4–5). In September, the MJO activity was

generally weak, with amplitude below one in the first week, briefly strengthened above one while progressing into Phase 3 during the second week, and then weakened again, maintaining amplitudes below one for the remainder of the month.

3.8 Summary

The southwest monsoon season of 2025 produced above-normal rainfall over India, with June–September totals amounting to 108% of the Long Period Average (LPA). Monthly rainfall departures were consistently positive, with rainfall reaching 109 percent of LPA in June, 105% in both July and August, and 115% in September. Regionally, the seasonal rainfall was 127% of LPA over northwest India, 115% over central India, 110% over the south peninsula, and 80% over east and northeast India. Northwest India recorded its highest seasonal rainfall since 2001, while east and northeast India experienced the second lowest rainfall since 1901.

The season was marked by active synoptic disturbances, including several low-pressure areas and cyclonic circulations that significantly enhanced rainfall, particularly in July, August, and September. Many subdivisions recorded exceptionally high rainfall: Rainfall over East Rajasthan (1010.0 mm) was second highest since 1901. Rainfall over West Rajasthan and North Interior Karnataka (478.0 mm, 721.3 mm respectively) was 6th highest since 1901. Rainfall over Assam & Meghalaya (1123.4 mm) was lowest since 1901. Rainfall over Arunachal Pradesh (980.3 mm) was third lowest since 1901.

Large-scale climate drivers played an important role in shaping the 2025 monsoon. Over the Pacific, ENSO conditions remained neutral from March to October following the decay of the late-2024 La Niña. However, repeated upwelling Kelvin waves and the associated Walker circulation pattern indicated a continuation of La Niña–like conditions in atmosphere, with enhanced ascent over the Indo-Pacific Warm Pool and subsidence over the central and eastern Pacific. Over the Indian Ocean, a negative Indian Ocean Dipole developed from July onward, producing a strong east–west SST gradient that enhanced convection over the eastern Indian Ocean while suppressing it over the western basin. These ocean–atmosphere anomalies strengthened monsoon westerlies and supported enhanced convection over India.

Convection and circulation patterns throughout the season supported an active monsoon. Negative OLR anomalies prevailed across most of the Indian region, especially over northwest and central India. Low-level westerly anomalies and cyclonic circulations enhanced moisture transport, while the upper troposphere featured a strong Tibetan anticyclone and an intensified Tropical Easterly Jet, both conducive to vigorous monsoon activity. Meridional and zonal circulation analyses revealed persistent rising motion between the equator and 20°N, consistent with above-normal rainfall in the monsoon core zone.

Intra-seasonal variability included alternating active and break phases. June experienced two active spells, early July saw another active phase, and early August witnessed a clear break monsoon spell followed by recovery later in the month. September saw frequent positive rainfall anomalies. The Madden–Julian Oscillation remained weak in June, strengthened in July, remained active in August, and turned weak again in September, providing intermittent support to monsoon activity.

In summary, the 2025 monsoon was shaped by the combined influence of La Niña–like Pacific conditions, strengthened lower- and upper-level monsoon circulations, and favorable MJO phases during July and August. These factors contributed to above-normal rainfall over most of India, with particularly wet conditions over northwest and central regions and deficient rainfall over the eastern and northeastern parts of the country.

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4



HEAVY TO VERY HEAVY RAINFALL ACTIVITIES IN NORTHEAST INDIA (31 MAY – 5 JUNE) DURING THE SOUTHWEST MONSOON SEASON 2025

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This chapter analyses heavy to very heavy rainfall episode over Northeast India (NEI) during 31st May – 5th June 2025, driven by an active southwest monsoon phase and a Bay of Bengal low-pressure system. Heavy rainfall occurred across all sub-divisions, leading to significant hydro-meteorological impacts, including landslides, flash floods, and urban flooding. The analysis integrates synoptic conditions, rainfall distribution, and forecast verification to assess the event's characteristics and forecast performance.

4.1 Introduction

Northeast India (NEI) stands out as one of the rainiest regions of the Indian sub-continent, shaped by complex terrain and its unique interaction with the southwest monsoon (SWM). The region receives 60–70% of its annual rainfall during the SWM season (IMD, 2019). The region receives heavy rainfall during the SWM season, and these events are primarily caused by the monsoon trough, tropical disturbances, and the extratropical systems in westerlies (Srinivasan et. al., 1972; Mohapatra, 2008; Mohapatra et al., 2008, 2009; Das et al., 2009). Previous findings revealed that the orography of the region has a significant role in heavy rainfall activities in the region (Sinha Ray et. al., 1982, Goswami et. al., 2010; Mahanta et.al., 2013; Mohapatra, 2008). Goswami et al. (2010) examined the extreme rainfall over NEI and demonstrated that rather than being the result of lone thunderstorms, these extreme events occurred in association with monsoon synoptic events. Das et. al., (2009) concluded that the location of the monsoon trough and synoptic systems in and around NEI has an impact on the distribution of heavy rainfall over the region during

SWM. Additionally, break monsoon conditions, when the monsoon trough lies close to the foothills of the Himalayas, are extremely conducive for rainfall in NEI (Ramamurty, 1969; Rahecha and Pisharoty, 1996).

During the SWM season, rainfall in the region is often widespread, intense, and continuous, sometimes persisting for several days and leading to large-scale hydrometeorological impacts. Frequent episodes of heavy rainfall also give rise to flash floods and landslides. During 2025, the Southwest Monsoon set in over Northeast India on 24th May, and it has covered the entire NEI on 29th May. The overall monsoon rainfall (1 June–30 September 2025) showed a deficit over Arunachal Pradesh and Assam–Meghalaya, while Nagaland, Manipur, Mizoram, and Tripura (NMMT) received normal rainfall. Overall monsoon rainfall over Arunachal Pradesh (963.9 mm), Assam (993 mm) and Meghalaya (1548 mm) showed deficit (departure -42%, -32% and -43%, respectively) from normal during 2025, while normal monsoon rainfall over Nagaland (-12%), Manipur (-12%), Mizoram (-10%) and Tripura (4%). Despite this, the period 31st May – 5th June witnessed episodes of heavy to very heavy rainfall over several parts of the region.

This report presents an overview of heavy rainfall events observed during 31st May – 5th June 2025, discussing the prevailing synoptic conditions, rainfall distribution, and spatial variations across Northeast India.

4.2 Synoptic conditions during 31st May to 5th June 2025

The SWM has set in over Kerala on 24th May 2025, against the normal date of 1st June and simultaneously advanced into some parts of NEI also. Subsequently, on 29th May 2025, it has covered all the Northeastern states. On 27th May 2025, a low-pressure area was formed over the northwest Bay of Bengal off Odisha coast with its associated cyclonic circulation extending upto 7.6 km above mean sea level (amsl) and tilted southwards with height. This system became a well-marked low-pressure area on 28th May over the Northwest Bay of Bengal off Odisha coast with similar depth (7.6 km amsl) and tilt. It is then moved northwards and intensified into a Depression over the north Bay of Bengal and then further intensified into a Deep Depression on 29th May 2025 over the same region (near latitude 21.3° N and longitude 88.5° E). The system then moved north-northeastward and gradually weakened into a low-pressure area over North-East Assam & neighbourhood and became less marked on 31st May 2025. Although the system was less marked, its remnants, upper air cyclonic circulations (over northeast Assam on 1st June, 4th June, over Bangladesh on 5th June), triggered continuous heavy rainfall activity over the region. The 850 hPa wind fields (**Fig.4.1 (a-c)**) depict the strengthening southwesterlies over Northeast India during 30th May – 1st June 2025. A consistent inflow of moist southwesterly winds from the Bay of Bengal is seen advancing towards Assam and adjoining states, indicating the establishment

of lower-tropospheric monsoon flow. These winds provide favourable conditions for enhanced moisture transport and subsequent rainfall over the region.

The satellite borne visible imagery (**Fig. 4.1d**) on 31st May showed low to medium cloud embedded with deep convective cloud over NEI. This along with the strong southwesterly (**Fig. 4.1b**) led to a widespread spell of rainfall over the region and heavy to extremely heavy rainfall spells over Arunachal Pradesh, Meghalaya, Assam and Meghalaya on 31st May. Also, deep convection as observed from the low OLR distribution (**Fig. 4.1e**) and moisture incursion along the low-pressure system led to widespread heavy rainfall over the region. The unprecedented rainfall occurrence over South Assam on 1st June can be associated with deep convection over the southern part of NEI (**Fig. 4.1f**) and the Bay of Bengal, contributing to the moisture through southwesterly.

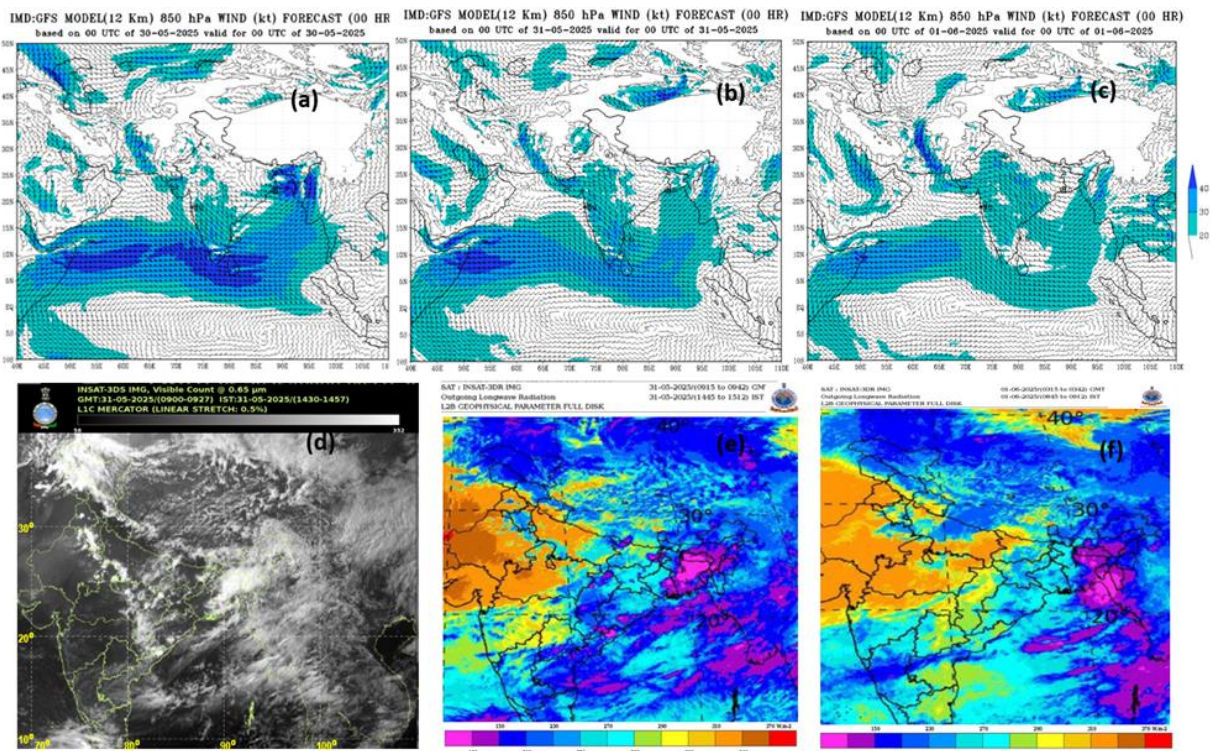


Fig. 4.1: Wind vectors at 850 hPa level taken from IMD-GFS analysis for (a) 30th May, (b) 31st May and (c) 1st June. INSAT-3D (d) Visible imagery and (e) OLR distribution on 31st May at 06 UTC INSAT-3D (f) OLR distribution on 01st June at 06 UTC.

4.3 Observed rainfall during 31st May to 5th June 2025

4.3.1 Spatial distribution and monsoon activity

Under the influence of above low-pressure system and southwest monsoon, NEI witnessed continuous fairly widespread (FWS) to widespread (WS) rainfall activity with isolated heavy rainfall occurrence (**Fig. 4.2**). Over the six days from 31st May to 5th June, light to moderate rainfall occurred widely across all 3 sub-divisions of Northeast India. Heavy

to very heavy rainfall was reported on multiple days across Arunachal Pradesh, Assam, Meghalaya, Nagaland, Manipur, Mizoram, and Tripura, with isolated extremely heavy falls observed especially over Meghalaya, Mizoram, and Tripura. During this period, the rainfall distribution over Arunachal Pradesh was widespread to fairly widespread, and monsoon activity varied from vigorous to normal, except on 5th June when monsoon activity was weak in the sub-division (**Table 4.1**).

Table 4.1: Spatial distribution of rainfall and monsoon activity over NEI during 31st May-05th June 2025

Date/Sub division	Arunachal Pradesh		Assam and Meghalaya		NMMT	
	Distribution	Monsoon activity	Distribution	Monsoon activity	Distribution	Monsoon activity
31-May-25	WS	VIGOROUS	WS	VIGOROUS	WS	VIGOROUS
01-June-25	WS	ACTIVE	WS	ACTIVE	WS	VIGOROUS
02-June-25	WS	ACTIVE	WS	NORMAL	WS	ACTIVE
03-June-25	FWS	NORMAL	WS	NORMAL	WS	ACTIVE
04-June-25	WS	NORMAL	FWS	NORMAL	WS	NORMAL
05-June-25	FWS	WEAK	WS	NORMAL	WS	NORMAL

In Assam & Meghalaya sub-division, the monsoon was vigorous and active initially two days of the week, while normal activity on subsequent four days, with widespread to fairly widespread rainfall during the same period. A similar monsoon conditions were also observed with widespread rainfall distribution over the NMMT sub-division for all six days of analysis. **Table 4.2** depicts the total amount of rainfall received from 31st May to 5th June 2025 in each state against its normal value. During this period, Meghalaya (260.2 mm) and Nagaland (97.4 mm) received the highest and lowest rainfall, respectively. Also, all the states in NEI received large excess rainfall compared to its normal. The highest departure of 253% over Mizoram and the lowest departure of 125% over Assam were observed.

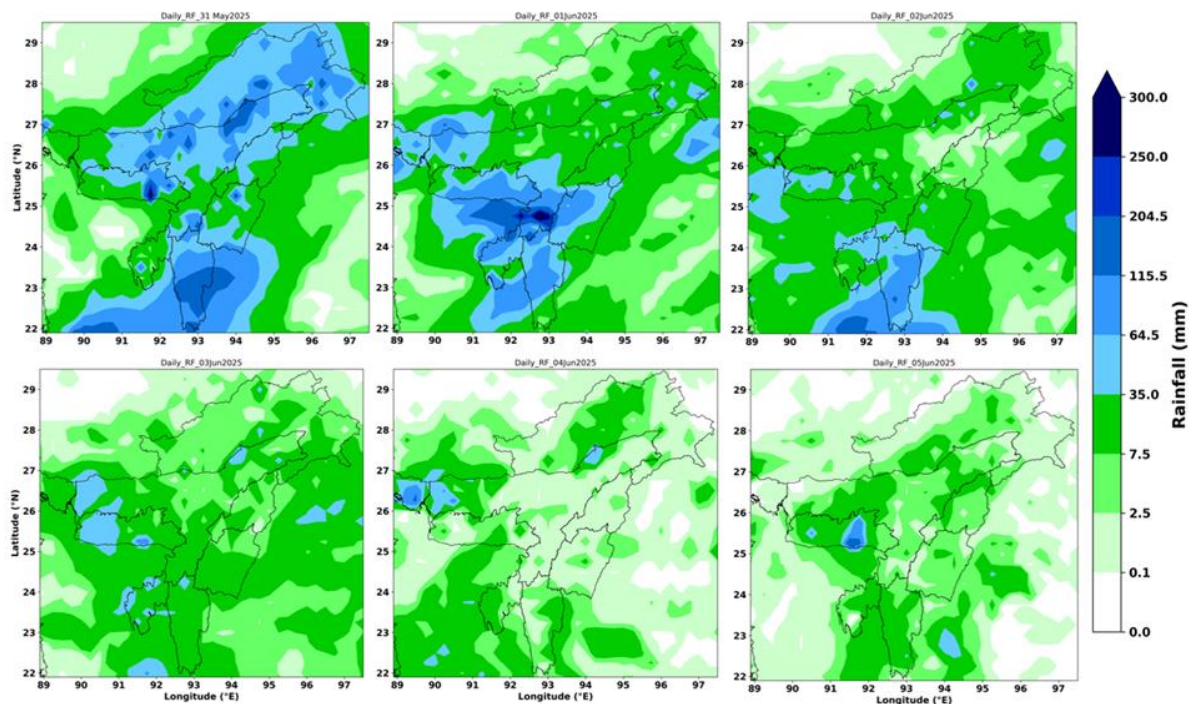


Fig. 4.2: Spatial distribution of observed rainfall from 31st May – 05th June 2025 from daily merged satellite gauge rainfall data at 0.25° x 0.25° grid resolution

Table 4.2: State-wise total rainfall (mm) with percentage departure from normal during 31st May - 05th June 2025

STATES	Actual	Normal	%Departure
ARUNACHAL PRADESH	163.4	63	159
ASSAM	151.8	67.5	125
MANIPUR	137.3	53.1	159
MEGHALAYA	260.2	97.4	167
MIZORAM	249.8	70.8	253
NAGALAND	97.4	38.7	151
TRIPURA	200.6	87.6	129

4.3.2 District-level rainfall analysis from station data

Between 31st May and 5th June, 13 districts (81%) reported excess to large-excess rainfall over Arunachal Pradesh, while 1 (1) district reported rainfall in the normal (large deficit) category out of a total of 16 districts. The highest and lowest rainfall was reported in the Papumpare and Dibang Valley districts respectively. Compared to the normal rainfall, the Changlang district reported the maximum large excess (419%), while the Dibang Valley reported the maximum large deficit (-98%) rainfall occurrence. During this period, 27 stations reported heavy (64.5 mm to 115.5 mm in 24 hours), 18 stations reported very heavy rainfall (115.6 to 204.4 mm in 24 hours), and 1 station reported extremely heavy rainfall (>204.5 mm in 24hours) in Arunachal Pradesh (**Table 4.3**), considering rainfall data from other observatories like AWS, CWC stations. The daily variation in the occurrence of three rainfall categories in each subdivision is presented in **Fig. 4.3**. The highest rainfall in Arunachal Pradesh was reported from the Anjaw district (26 cm) on 31st May, under the influence of the remnant of a deep depression as a cyclonic circulation over northeast Assam. Also, maximum number of heavy rainfalls received on 31st May 2025, which then slowly decreased till 5th June 2025.

Table 4.3: Heavy rainfall activity over the 3 sub-divisions and daily maximum reported from different sources including AWS, ARG and state observations

Sub-division	Ext Hvy	Very Hvy	Hvy	(Daily highest) (mm)
Arunachal Pradesh	1	18	27	262.0 (Hayuliang), 168.0 (Kibitoo), 88.4 (Pasighat), 106.5 (Longding), 68.5 (Itanagar).
Assam & Meghalaya	22	42	110	472.4 (Sohra), 415.8 (Silchar), 210.0 (Mawkyrwat), 107.5 (Mynkre), 86.8 (Dhubri_Cwc).
NMMT	2	22	41	219.0 (Saiha), 296.2 (Nutanbazar Cwc), 135.5 (Chawngte), 89.2 (Kadamtala Cwc)

Similarly, over Assam and Meghalaya, 40 districts (87%) reported excess to large-excess rainfall. In comparison, 4 districts (9%) reported rainfall in the normal category, and 2 (4%) districts reported the deficit category out of a total of 46 districts. The highest and lowest rainfall was reported in the South Khasi Hills district in the state of Meghalaya and Biswanath district in the state of Assam, respectively. Compared to the normal rainfall also,

the South Khasi Hills district and Biswanath district reported the maximum large excess (865%), and maximum deficit (-80%) rainfall occurrence. During this period, 110 heavy, 42 heavy to very heavy, and 22 extremely heavy rainfall occurrences were reported in the subdivision, where (Table 4.3) many places in Assam received unprecedented rainfall. Particularly, on the 31st May, 24-hour accumulated rainfall in Guwahati was 18 cm, which is the highest (extreme) observed rainfall for the month of May over Guwahati. Similarly, on 1st June, Silchar city received exceptionally heavy rainfall (415.8 mm), which is the extreme value for the month of June over Silchar. Over NMMT sub-division, 25 districts received excess to large excess, 3 districts received a deficit, while 1 district received normal rainfall. The highest and lowest rainfall was reported in the Saiha in the state of Mizoram and Gomati district in the state of Tripura, respectively. Compared to the normal rainfall (31st May to 5th June), Senapati districts in the state of Manipur and the Serchip districts in the state of Mizoram reported the maximum large excess (721%) and maximum deficit (-73%) rainfall occurrence, respectively. During this period, 41 heavy, 22 heavy to very heavy, and 2 extremely heavy rainfall occurrences were reported in the subdivision (Table 4.3).

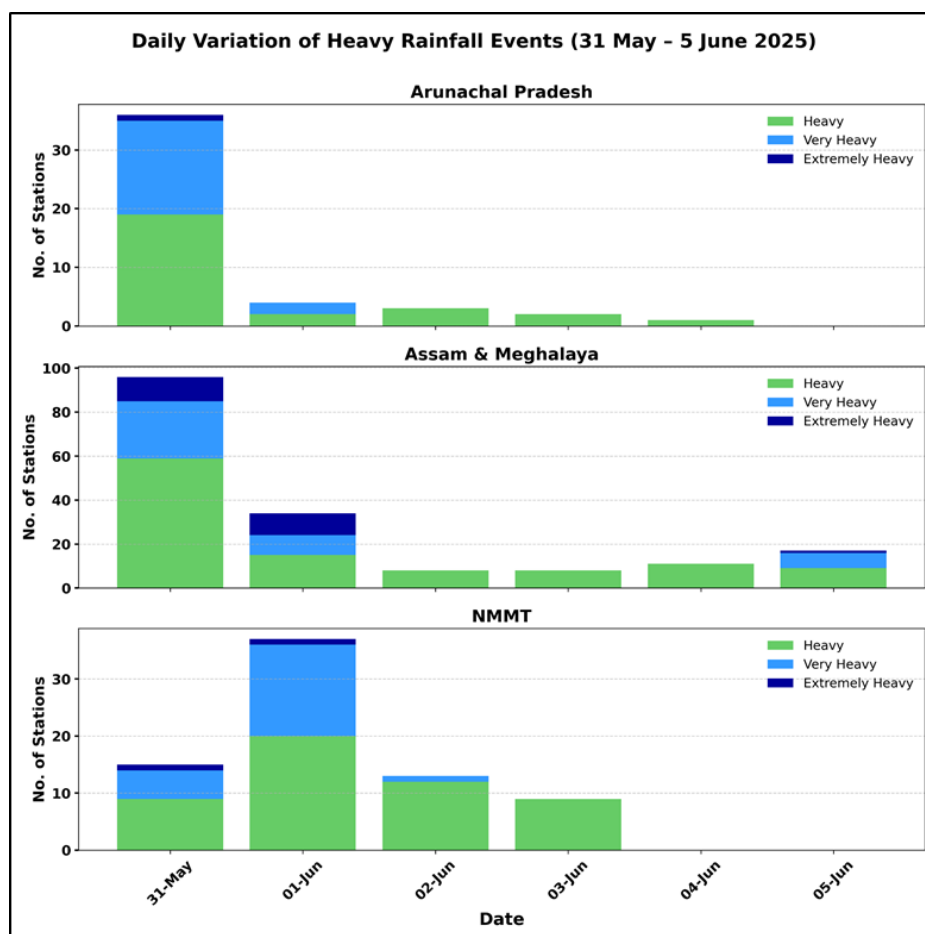


Fig. 4.3: Daily variation of heavy, very heavy and extremely heavy rainfall occurrence during 31st May to 05 June 2025 in the 3 subdivisions of NEI.

4.4 Weather Forecast and Warnings issued from 31st May to 05th June 2025

Daily weather forecast and possible warning issued for the region for reported period based on the synoptic weather condition analysis and model guidance with necessary value addition.

31/05/2025: Weather forecast of very likely (50-75%) occurrence of moderate rain at most places over Arunachal Pradesh, Assam, Meghalaya, Nagaland, Manipur & Mizoram and at many places over Tripura has been issued. Particularly, impact-based forecast was issued for water logging, flooding, landslide, uprooting of trees etc. with red alert were issued for Guwahati city where unprecedented rainfall occurred on 31/05/2025. Heavy to Very Heavy rainfall warnings were given at a few places with Extremely Heavy rainfall at isolated places over Meghalaya with very likely possibility (50% to 75%). Heavy to Very Heavy rainfall warnings were given at isolated places over Arunachal Pradesh, Assam, Nagaland, Manipur and Mizoram (very likely). Over Tripura heavy rainfall at isolated places was very likely.

01/06/2025: Forecast for moderate rainfall occurrence at most places of Arunachal Pradesh, Assam, Nagaland, Manipur, Mizoram and Tripura was issued. Impact based forecast with red alert were issued for Silchar city. Warnings issued for very likely occurrence of Heavy to Very Heavy rainfall at a few places with Extremely Heavy rainfall at isolated places over Assam and Tripura. While very likely warnings of Heavy to Very Heavy rainfall at isolated places over Arunachal Pradesh, Meghalaya, Nagaland, Manipur and Mizoram.

02/06//2025: Forecast issued for moderate rainfall occurrence at most places of Arunachal Pradesh, Assam, Nagaland, Manipur, Mizoram and Tripura. Warnings issued for very likely occurrence of Heavy to Very Heavy rainfall at isolated places over Arunachal Pradesh, Assam, Mizoram and Tripura, while Heavy rainfall at isolated places over Meghalaya, Nagaland and Manipur.

03/06/2025: Forecast issued for moderate rainfall occurrence at most places of Arunachal Pradesh, Assam, Nagaland, Manipur, Mizoram and Tripura. Warnings issued for Heavy to Very Heavy rainfall at isolated places over Assam and Mizoram, while, Heavy rainfall at isolated places over Arunachal Pradesh, Meghalaya, Manipur and Tripura.

04/06/2025: Forecast issued for moderate rainfall occurrence at most places of Arunachal Pradesh, Assam, Mizoram, Tripura and at many places over Nagaland, Manipur. Warning issued for very likely occurrence of Heavy to Very Heavy rainfall at a few places with Extremely Heavy rainfall at isolated places over Meghalaya, Heavy to Very Heavy rainfall at isolated places over Assam, and Heavy rainfall at isolated places over Arunachal Pradesh, Mizoram and Tripura.

05/06/2025: Forecast issued for moderate rainfall occurrence at most places of Assam, Meghalaya and Mizoram, at many places of Arunachal Pradesh and Tripura, and light to moderate rainfall at a few places over Nagaland and Manipur. Warnings issued for Heavy to Very Heavy rainfall at isolated places over Meghalaya, while Heavy rainfall at isolated places over Arunachal Pradesh, Assam, Mizoram and Tripura.

4.5 Forecast verification

The verification for heavy rainfall (≥ 7 cm) indicates good detection skill across all states (**Table 4.4**), with a POD of 1.0 throughout, confirming that all observed heavy rainfall events were successfully forecasted. However, the FAR remained very low in Assam (0.00) and moderately low in Meghalaya and Arunachal Pradesh (0.17), but increased notably in Nagaland (0.75), Manipur (0.60), Mizoram (0.50), and Tripura (0.50), indicating instances of over forecasting. The CSI ranged from 1.00 in Assam to lower values of 0.25–0.50 in Nagaland, Manipur, Mizoram, and Tripura. Overall, the forecasts were skillful in capturing the spatial occurrence as well as the intensity of rainfall. Forecast skill was better over Assam, Meghalaya, Arunachal Pradesh, and comparatively lower over the NMMT region due to higher false alarms for heavy rainfall. Although major events were predicted well, there is need for continued refinement in intensity prediction over the hilly terrains of the region.

Table 4.4: State-wise Verification for Heavy rainfall (≥ 7 cm) occurrences during the period 31st May-05 June 2025

States	POD	FAR	CSI
Arunachal Pradesh	1	0.17	0.83
Assam	1	0.00	1.00
Meghalaya	1	0.17	0.83
Nagaland	1	0.75	0.25
Manipur	1	0.60	0.40
Mizoram	1	0.50	0.50
Tripura	1	0.50	0.50

4.6 Summary

The period from 31st May to 5th June 2025 was marked by widespread monsoon activity across Northeast India, driven primarily by a low-pressure system over the Bay of Bengal and its subsequent remnants that persisted over the region. The deep convection, strong southwesterly moisture transport, and favorable synoptic conditions resulted in continuous

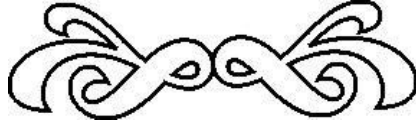
rainfall, with episodes of Heavy, Very Heavy, and Extremely Heavy falls across all three meteorological subdivisions. State-wise analysis showed that all states received large excess rainfall, with particularly high departures over Mizoram and Meghalaya. Continuous rain triggered consequent hydrometeorological events like landslides and flash floods, leading to large impact on life and property across all the states (<https://www.indiatoday.in/india/story/northeast-assam-manipur-arunachal-nagaland-sikkim-rain-flood-death-toll-lakhs-affected-2734810-2025-06-03>). Landslides were reported in Mizoram and Arunachal Pradesh, causing casualties and damaging infrastructure (<https://www.hindustantimes.com/india-news/19-dead-12-000-affected-as-rain-triggers-floods-landslides-across-northeast-101748675726207.html>). Urban areas like Guwahati and Silchar experienced urban flooding, disrupting transport and damaging infrastructure. Overall, this active monsoon spell underscores the sensitivity of the region to a moderate synoptic disturbance and highlights the need for continuous monitoring and timely forecast dissemination to mitigate hydro-meteorological risks.

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5



PROLONGED HEAVY RAINFALL ACTIVITIES OVER GUJARAT DURING 16-25 JUNE 2025

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This chapter discusses the observed features of prolonged rainfall activity over Gujarat state during 16-25 June 2025 along with forecast and warning issued and associated impacts.

5.1 Introduction

Gujarat state is situated in the extreme western parts of India and has mixed type of climate as it is surrounded by Thar Desert in the northeast, Arabian Sea in the west & southwest, central plains to east and Western Ghats to its southeast. The climate ranges from arid climate in north Gujarat, sub-humid climate in south Gujarat and semi-arid climate in rest of the state. Hydrologically, the Gujarat State falls in central India and meteorologically it is divided into two sub-divisions namely Gujarat Region and Saurashtra-Kutch. In a recent study (Ray et al., 2009; Mohanty et al., 2014) it has been found that the average seasonal rainfall has increased appreciably in the decade 2004-2013 for both sub-divisions of Gujarat state. The frequency of heavy rains (>65 mm) has increased significantly in all observatories of Gujarat state as well as the rainfall extremes for south Gujarat region and Saurashtra have increased in the past decades. In another study (Guhathakurta and Revadekar, 2017) on rainfall variability and long-term trend of rainfall considering four homogeneous regions of India it was found that rainfall during the month of July shows a decreasing trend over most parts of the central India, while during June and August it shows increasing trend over the central and south-western parts of the country. Eleven stations out of sixteen stations of Gujarat have shown increasing trends (>5%/decade) in monsoon rainfall and significant increasing trends are observed for the frequency of heavy and very

heavy rainfall events over the state (Dave et al., 2017; Dave and James 2017). As per a report by Gujarat Institute of Disaster Management (GIDM) on rainfall variability over Gujarat State, the rainfall over the state is turning erratic with time and heavy rainfall days are increasing resulting in flood-like situations over the state (GIDM, 2022).

The state of Gujarat receives most of its annual rainfall in the southwest (SW) monsoon season, from June 1st to September 30th. Normally SWM season enters the state of Gujarat by 15th June and covers the entire state by 30th June and withdraws from the state by 15th October. The length of rainy season during SW Monsoon at different stations of Gujarat prevails from 66 days (at Bhachau) to 96 days (at Ubharat) with mean period of 81 days (Lunagaria, et al., 2022).

5.2 Southwest Monsoon Season-2025 over Gujarat

This year, the southwest monsoon (SWM) entered in southern Gujarat on 16th June with a delay by 1 day against the normal date of advance (15th June). It stagnated over south Gujarat till 29th June and then advanced over interior parts of state on 30th June and covered entire state by 5th July. The state experienced good rainfall activity throughout the monsoon season, with frequent spells of heavy to very heavy rain with occasional isolated extremely heavy falls. The withdrawal of the SWM started from Kutch and northern parts of Gujarat from 26th September and it withdrew completely from Gujarat by 10th October against 5th October, the normal date of withdrawal from Gujarat i.e. delayed by 5 days. **Fig. 5.1(a) & (b)** depicts the advancement and withdrawal of SW monsoon-2025 along with normal dates over the country.

A number of weather systems including Depressions/Lows/troughs/Cycirns/Off-Shore trough etc. remained active during the season. In addition, the Low Level Jet was also strong on many days during the season. All these resulted in frequent spells of significant rainfall over the state throughout the season with a number of isolated heavy to very heavy rainfall events. Occasionally, isolated extremely heavy falls were also observed over the state.

This monsoon season Gujarat State as a whole as well as both sub-divisions i.e. Gujarat Region and Saurashtra and Kutch received excess rainfall as compared to respective Long Period Average (LPA). Gujarat state received 891.2 mm rainfall in Monsoon 2025, which is 25% more than its Long Period Average (LPA) of 711.9 mm. However, as compared to last monsoon season, it is observed an overall decrease of 16% in seasonal rainfall.

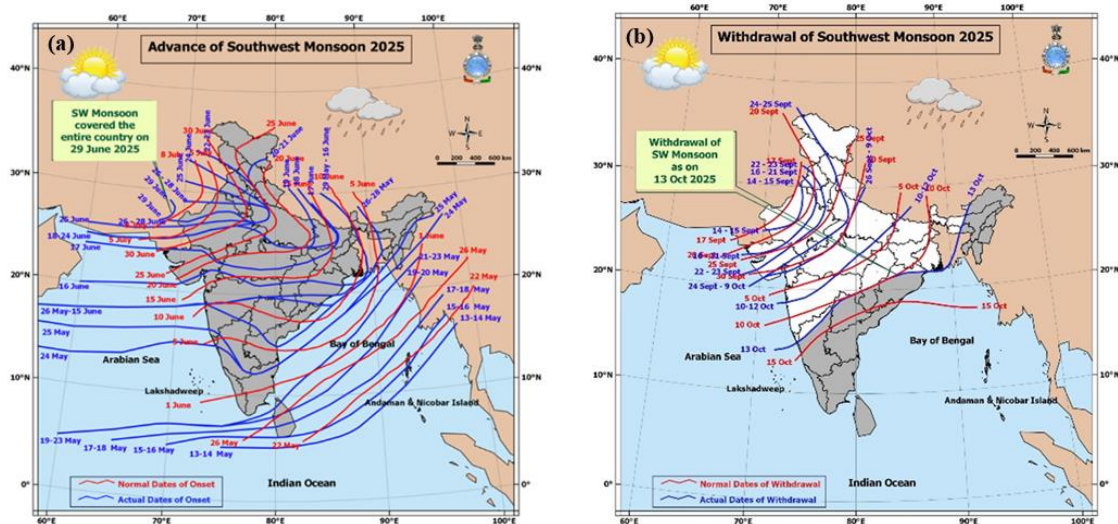


Fig. 5.1: (a) Advance and (b) withdrawal dates of SW Monsoon-2025 against respective normal dates

Meteorological sub-division wise, Gujarat region received 21% more rainfall while Saurashtra & Kutch received 31% more rainfall than the long period average (LPA). Month wise analysis of monsoon rainfall shows that rainfall activity was in large excess category during June (+115% departure from LPA) and September (+90% departure from LPA) and in normal category during July and August (-11% departure from LPA each). This is depicted in **Fig. 5.2**, which gives the district-wise percentage rainfall departure for the season as a whole (June 2025 – September 2025). Only Kutch district received large excess (61%) rainfall whereas Banaskantha, Sabarkantha, Mahisagar, Bharuch, Valsad, Narmada, Surat, Tapi, Kheda & Chota Udepur in Gujarat Region and Devbhoomi Dwarka, Porbandar Morbi, Bhavnagar and Junagarh in Saurashtra received excess rainfall. All remaining districts received normal category rainfall.

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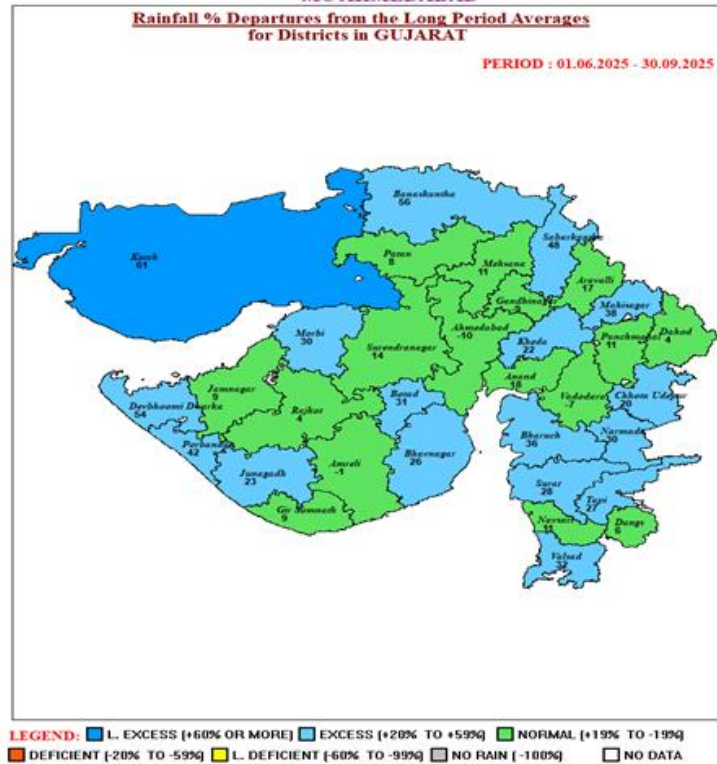


Fig. 5.2: District-wise SW monsoon-2025 seasonal rainfall percentage departures over Gujarat

5.3 Prolonged heavy rainfall spell during 16-25 June, 2025

5.3.1 Synoptic Situations

A prolonged heavy rainfall spell was noticed over the state during 16 to 25 June, 2025. Isolated heavy to very heavy rainfall with isolated extremely heavy falls were observed (past 24hours) over Gujarat Region on 19, 22, 24 & 25 June and over Saurashtra-Kutch on 17th June whereas isolated heavy to very heavy rainfall was observed over Gujarat region on 20, 21, 23 & 26 June and over Saurashtra-Kutch on 18 & 23 June. The SW monsoon was vigorous over Gujarat region on 19 & 22 June and over Saurashtra-Kutch on 17, 18 & 23 June. It was active over Gujarat Region on 15, 17, 20, 23, 24 and 25 June.

The main synoptic systems responsible for this prolonged spell of heavy rainfall included:

1. A trough from North Rajasthan & neighbourhood to West Madhya Pradesh at 1.5 km above mean sea level on 15-06-2025, which became less marked on 16-06-2025.
2. A trough ran form cyclonic circulation associated with low-pressure area over Gujarat region & neighbourhood to Jharkhand across Madhya Pradesh & north Chhattisgarh at 0.9 km above mean sea level on 17th June and became less marked on 18th June.
3. An upper air cyclonic circulation over Gujarat & Neighbourhood extending upto 7.6 km above mean sea level on 16.06.2025. Under its influence, a **low pressure area**

formed over Gujarat & neighbourhood on 17.06.2025 with the associated upper air cyclonic circulation extended up to 5.8 km above mean sea level tilting southwards with height. It moved in northwards and lay over central parts of Rajasthan on 18th June 2025 and became less marked on 19th June. However, the associated upper air cyclonic circulation lay over Southwest Rajasthan extending up to 1.5 km above mean sea level on 19th. It also became less marked on 20th.

4. A trough ran from Punjab to north Gujarat Region across the above cyclonic circulation over central parts of Rajasthan between 3.1 & 5.8 km above mean sea level on 18th June. It was noticed from northwest Uttar Pradesh to north Gujarat Region across another cyclonic circulation over northeast Rajasthan & neighbourhood between 3.1 & 5.8 km above mean sea level on 19th & 20th June and from northeast Bangladesh to south Gujarat region across cyclonic circulation associated with another low pressure area over southwest Bihar and central parts of Madhya Pradesh at 3.1 km above mean sea level on 21st June. On 22nd June, it developed characteristics of shear line oriented in east-west direction from south Pakistan to a cyclonic circulation over Bangladesh and adjoining Gangetic West Bengal across central parts of Rajasthan, northwest Madhya Pradesh, cyclonic circulation associated with low pressure area over central parts of south Uttar Pradesh & neighbourhood and Jharkhand between 1.5 & 4.5 km above mean sea level tilting southwards with height. It became less marked on 23rd.
5. An off-shore trough at sea level chart noticed from north Konkan coast to north Kerala coast on 19th which became less marked on 20th June.
6. An upper air cyclonic circulation lay over northeast Rajasthan & neighbourhood extending up to 1.5 km above mean sea level on 21st which became less marked on 22nd June.
7. An upper air cyclonic circulation lay over Saurashtra & Kutch at 3.1 km above mean sea level on 23rd June which became less marked on 24th June.
8. A trough ran from northeast Arabia Sea to the cyclonic circulation over south Jharkhand & neighbourhood at 3.1 km above mean sea level on 24th June. On 25th June, it ran from northeast Arabian Sea to the cyclonic circulation over northeast Madhya Pradesh across south Gujarat, north Madhya Maharashtra and extends between 3.1 & 5.8 km above mean sea level. On 26th it ran from northeast Arabian Sea to low pressure area over northwest Bay of Bengal and adjoining coastal areas of Odisha and West Bengal across south Gujarat, Madhya Pradesh, Chhattisgarh & extending between 1.5 & 7.6 km above mean sea level.

5.3.2 Rainfall Realised

The combination of different weather systems as discussed above and their mutual interaction resulted in prolonged heavy rainfall spell lasting for about 10 days. The maximum intensity rain was reported over Saurashtra-Kutch on 17th June and over Gujarat Region on 22nd June. Isolated extremely heavy rainfall was reported over Saurashtra-Kutch on 17th June (max 357 mm in Botad district) and over Gujarat region on 19 June (max. 259 mm in Valsad district), 21 June (max. rainfall 205 mm in Panchmahal district), 22 June (max. 315 mm in Sabarkantha district), 24 June (max. 275 mm in Surat district) & 25 June (max. 217 mm in Mahisagar district).

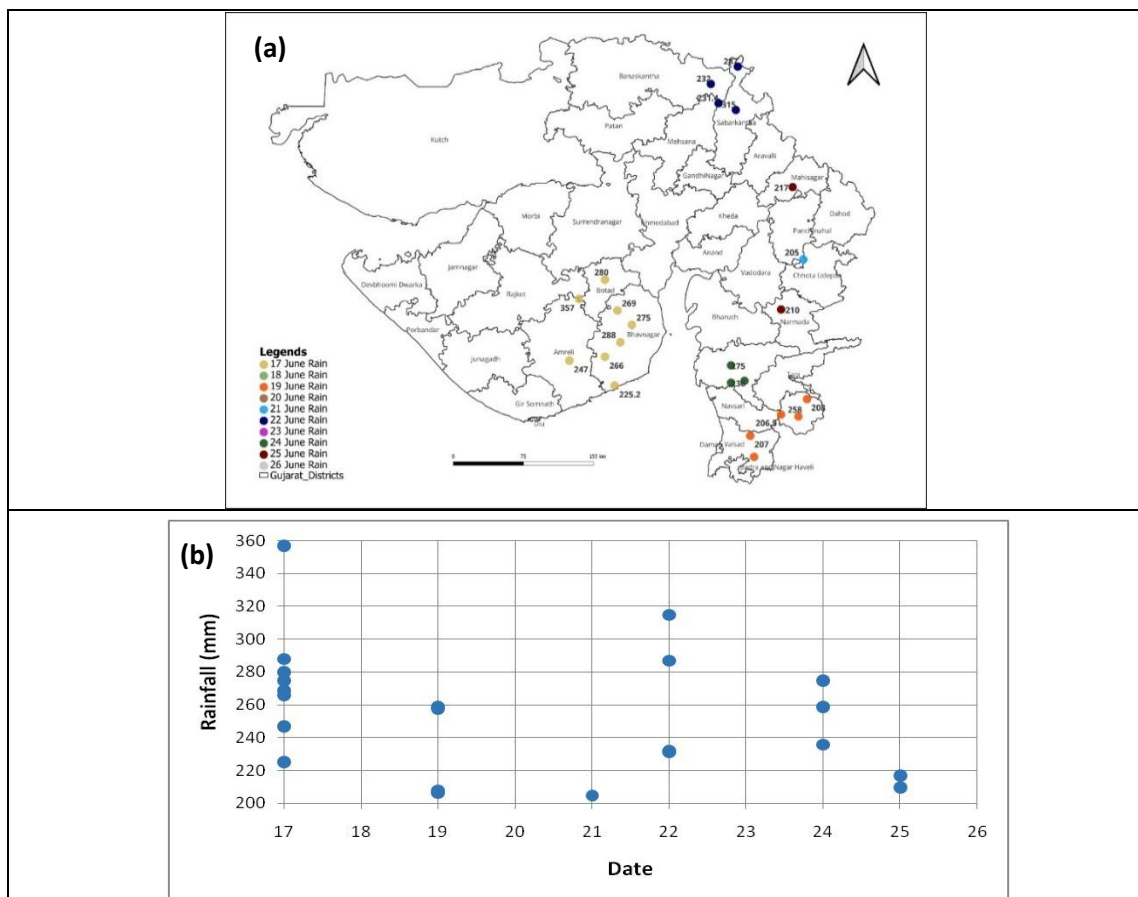


Fig. 5.3: Date wise (a) Location and (b) density of stations along with 24 hour realised rainfall (mm) for extremely very heavy rainfall events during 17 to 26 June

The realised extremely rainfall over Gujarat region and Saurashtra-Kutch from 16 to 25 June 2025 are presented in GIS map (Fig. 5.3a). The first spell of extremely heavy rain recorded on 17th June was concentrated over south-eastern parts of Saurashtra comprising of Bhavnagar, Amreli and Botad districts with a number of stations of Bhavnagar district getting extremely heavy falls. There was no extremely heavy rain reported over Saurashtra

during the remaining days of the study period. The second and subsequent spells of extremely heavy rain were observed over Gujarat Region. The first one reported on 19th June and was concentrated over south Gujarat region (Valsad and Dang districts). The second on 21st to 22nd June over eastern (Panchmahal) & North (Sabarkantha and Banaskantha districts) Gujarat Region and the third one on 24th to 25th June over southern (Surat) and eastern (Narmada & Mahisagar districts) parts of Gujarat region. **Fig 5.3(b)** shows the date wise density of stations reporting extremely heavy rainfall during the period 17-26 June 2025. On 17th June, highest 7 stations reported extremely heavy rain with maximum rainfall of 359 mm over Dadhda in Botad district. On 19, 21, 22, 24 & 25 June only 2-3 stations reported extremely heavy rain, the maximum 315mm over Vadali in Sabarkantha district.

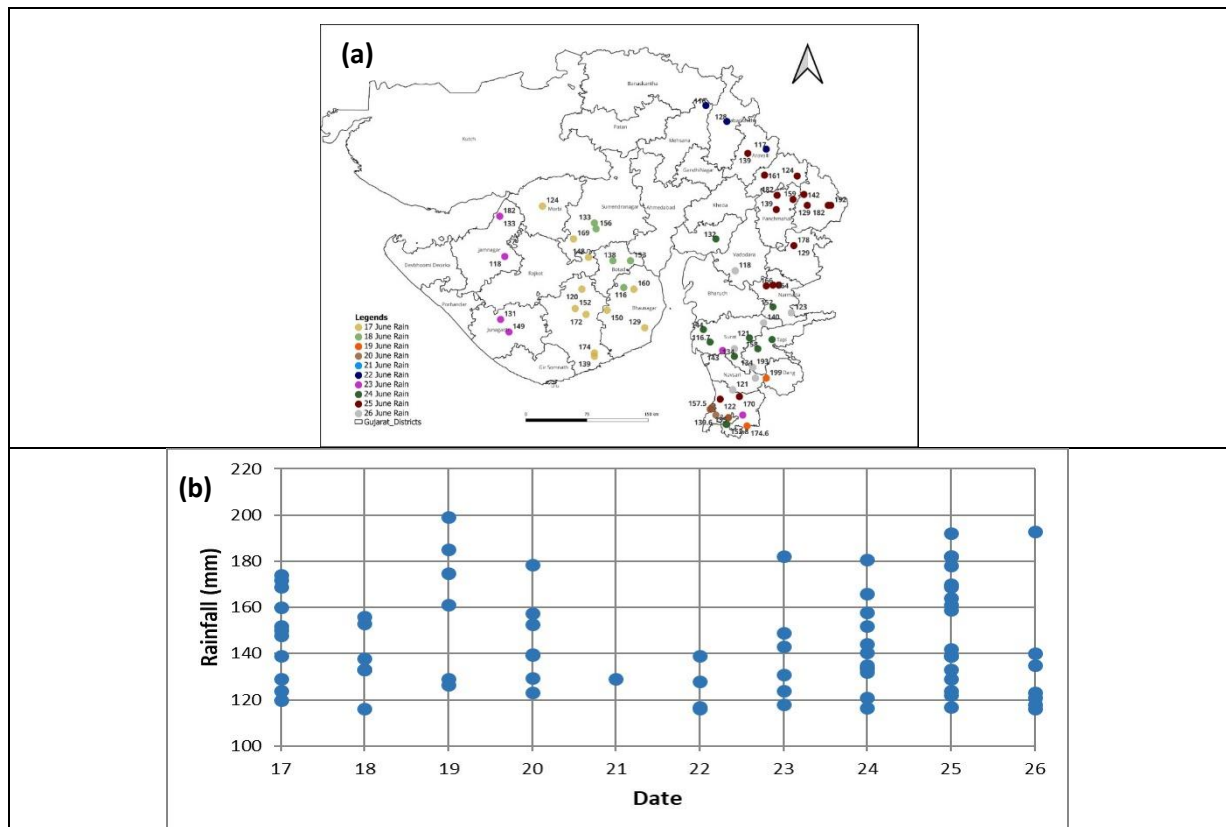


Fig. 5.4: Date wise (a) Location and (b) density of stations along with 24 hour realised rainfall (mm) for very heavy rainfall events during 17 to 26 June

As far as the very heavy rainfall spells are concerned (**Fig. 5.4a**), there were two spells over Saurashtra. First during 16th to 17th June over central & eastern parts (Bhavnagar, Amreli, Botad, Surendranagar, Morbi & Rajkot) and second on 22nd June covering western districts (Junagarh and Jamnagar) of the Saurashtra. The very heavy rainfall spells over Gujarat Region started from 18th June onwards and during 18-25 June it covered mainly

southern (Navsari, Valsad, Surat, Tapi, Dang, Narmada, Vadodara districts and UT Daman, Dadra & Nagar Haveli) and eastern parts of Gujarat Region along the Madhya Pradesh and Rajasthan Borders (Chota Udepur, Dahod, Mahisagar, Aravalli, Sabarkantha, Mehsana, Kheda and Anand districts). During the study period, almost every day a number of stations received very heavy rainfall (**Fig. 5.4b**) and on 25th highest 17 stations reported very heavy rain. The maximum rainfall in this category was 199 mm over Vaghai in Dang district on 19th June.

5.3.3 Satellite guidance

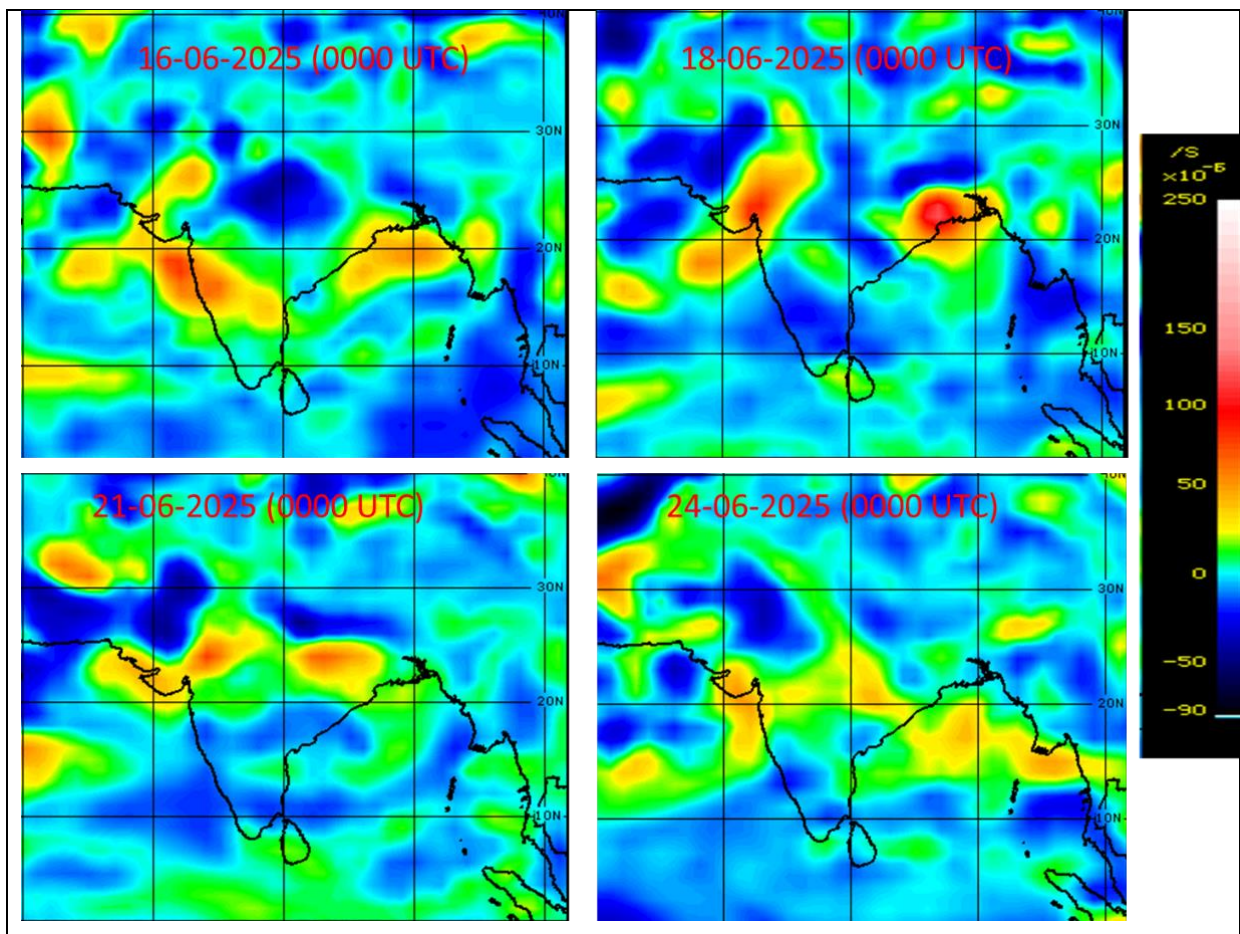


Fig. 5.5: Snapshot of CIMSS Meteosat-7 Products of 700 hPa relative vorticity (10^{-6} s^{-1} ;) during 16th, 18th, 21st and 24th June 2025.

The 700hpa relative vorticity ranged from $+50$ to $+100 \times 10^{-6} \text{ s}^{-1}$ at 0000 UTC on 16th and 18th June, 2025 (**Fig. 5.5**). Similarly, 700hPa relative vorticity of more than $70 \times 10^{-6} \text{ s}^{-1}$ at 0000 UTC on 21st and 24th June, 2025, was observed. Vorticity with a positive value (50–100) promotes the formation of storm cells. Hence, the presence of a significantly elevated positive vorticity value further confirms the likelihood of heavy to very heavy with extremely

heavy precipitation in Gujarat region as well as Saurashtra-Kutch region during 16th, 18th, 21st and 24th June 2025.

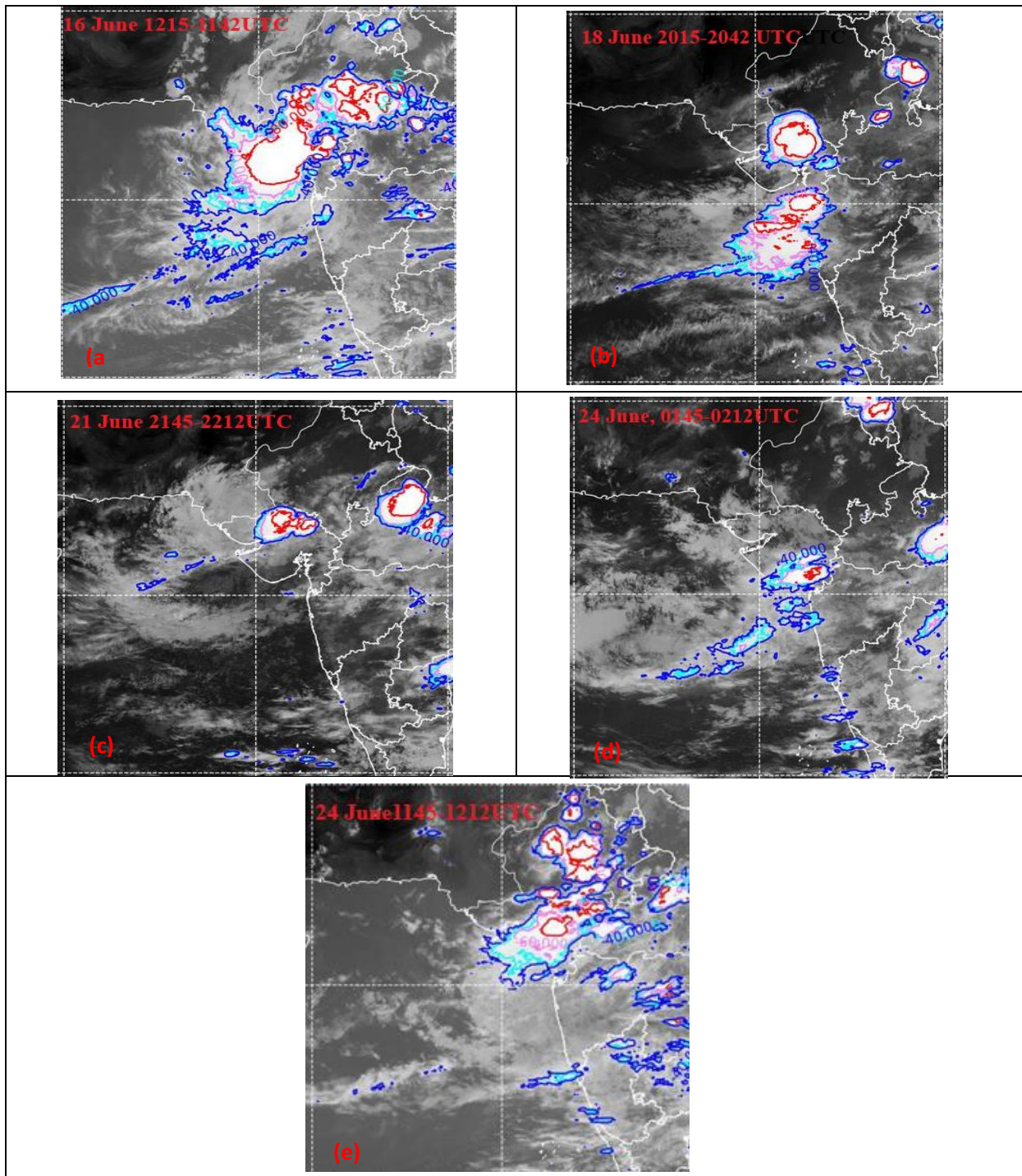


Fig. 5.6 a to e: INSAT-3DR satellite CTBT imageries of (a) 16th June, (b) 18th June (c) 21st June (d) 24th June morning & (e) 24th June evening

The INSAT 3-DR satellite CTBT imagery (**Fig. 5.6a**) of 16th (1115-1242UTC) shows a large cloud mass with CTBT of around -80°C covering entire Saurashtra and adjoining

Gujarat region indicating strong convection associated with the cyclonic circulation over Gujarat & Neighbourhood which intensified into low pressure area on 17th. This resulted scattered heavy to very heavy rain with isolated extremely heavy falls over Saurashtra on 16th. As the system moved northwards, the rainfall belt shifted to north Gujarat, however the intensity and spatial extent reduced significantly causing only isolated heavy to very heavy rainfall over Saurashtra & north Gujarat during 17-19 June (**Fig. 5.6b**). As is clear from satellite imageries (**Fig. 5.6c to e**) of other dates also, the cloud mass was not organised much and there were small patches of intense convection covering isolated pockets of the state resulting in spells of heavy to very heavy rain with occasional isolated heavy falls over different parts of the state.

5.3.3 NWP Model guidance

Fig. 5.7 shows GFS MSLP and 925hPa & 500hPa wind analysis and 24-hour rainfall forecast plots for 00UTC of 16th, 18th, 21st, 23rd and 24th June-2025. The MSLP analysis of 16th June shows a low pressure area over NE Arabian sea and adjoining Gujarat coasts. The 925, 850 and 500hPa wind analysis also show the associated cyclonic circulation over the same area leading to significant moisture incursion and its convergence over the region. The 24-hour rainfall forecast of GFS also captured well the extremely heavy rainfall over coastal Saurashtra. The GFS MSLP analysis field of 18th, 21st, 23rd and 24th June for other dates does not show any significant weather system except narrow spaced isobars indicating strong pressure gradient leading to strengthening of low level westerlies/southwesterlies (up to 30-40Kts) along Gujarat coast and adjoining coastal areas causing significant moisture incursion from Arabian Sea as confirmed from lower level winds. The 925hPa wind analysis of 18th June also shows a trough extending from central parts of Rajasthan to south Gujarat coast, while the 500hPa wind analysis of 24th shows an east-west shear zone around 20°N. The 24-hour rainfall forecast of GFS shows very heavy rainfall over south Gujarat region on 18th June. No other guidance of extremely/very heavy rainfall was given by in GFS in 24-hour rainfall plots of 21st, 23rd and 24th June.

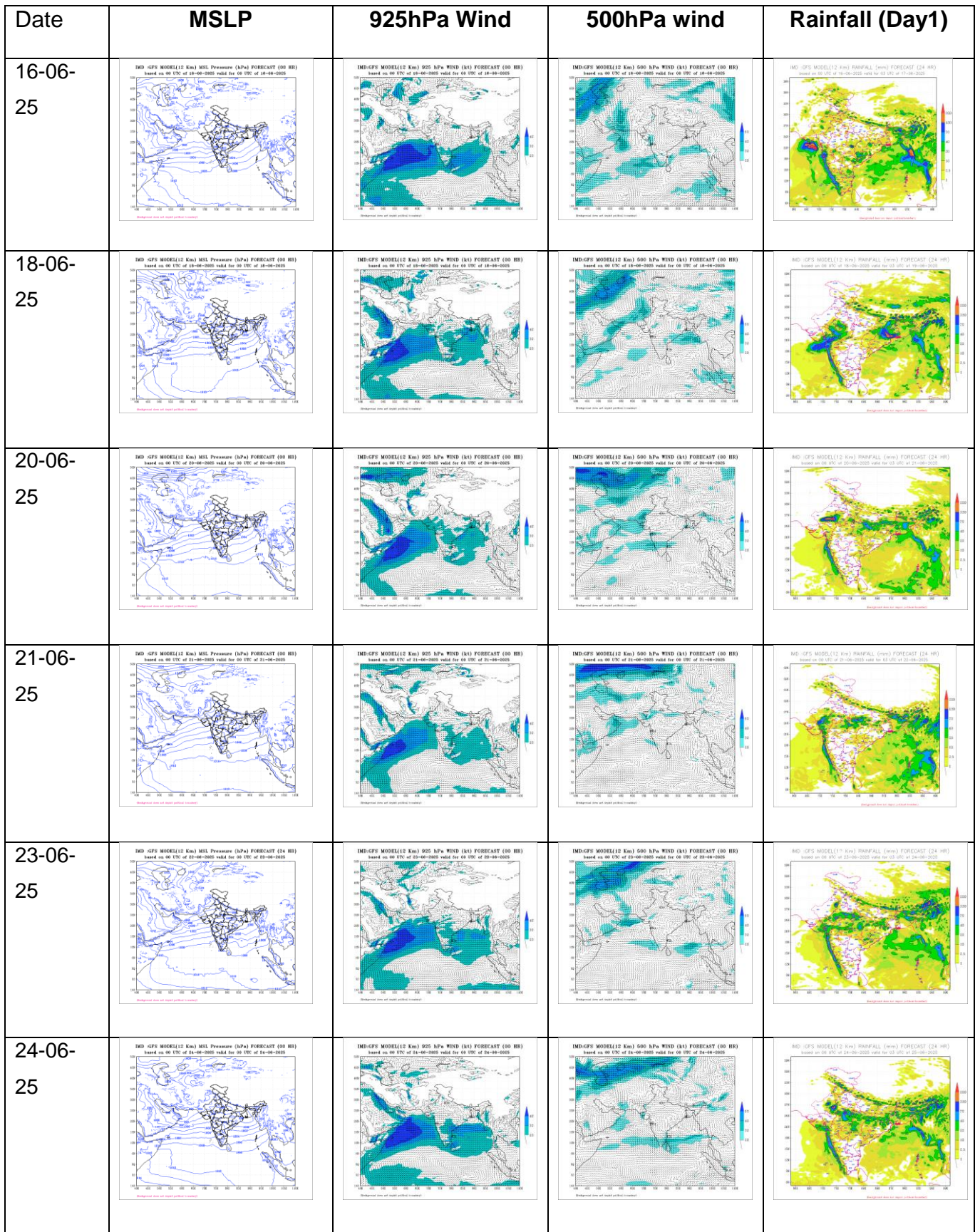


Fig. 5.7: GFS 00UTC analysis MSLP, 925 & 500 hPa winds for 16, 18, 21, 23 & 24 June, 2025

5.3.4 Operational Forecast & Warnings

Due to the prevailing synoptic situations as well as NWP model guidance, the forecasts and warnings for the extreme rainfall activity were issued well in advance. For the isolated extremely heavy rainfall event over Saurashtra on 16th June, warning for isolated heavy to very heavy rainfall (orange alert) over Saurashtra was issued 4 days in advance i.e. on 13th June, which was upgraded to isolated extremely heavy (red alert) on 16th June (**Fig. 5.8a**).

For the isolated heavy to very heavy rainfall event over Saurashtra on 17th June, warning for isolated heavy rainfall (yellow alert) over Saurashtra was issued 5 days in advance i.e. on 13th June, which was upgraded to isolated very heavy (orange alert) on 15th June i.e. three days in advance and to isolated extremely heavy rainfall (red alert) on 16th June (**Fig. 5.8a**).

For the isolated extremely heavy rainfall event over Gujarat Region on 18th June, warning for isolated heavy rainfall (yellow watch) over Gujarat Region was issued 6 days in advance i.e. on 13th June, which was upgraded to isolated heavy to very heavy (orange alert) on 16th June (**Fig. 5.8a**).

For isolated very heavy rainfall event over Gujarat Region on 19th June, warning for isolated heavy rain (yellow alert) over south Gujarat region was issued 7 days in advance i.e. on 13th June which was upgraded to isolated very heavy (orange alert) 3 days in advance i.e. on 17th June (**Fig. 5.8a**).

For isolated extremely heavy rainfall over north Gujarat Region on 21st June, heavy rainfall at isolated places over north Gujarat Region was issued 5 days in advance i.e. on 17th June which was upgraded to isolated extremely heavy (red alert) on the day i.e. on 21st June (**Fig. 5.8b**).

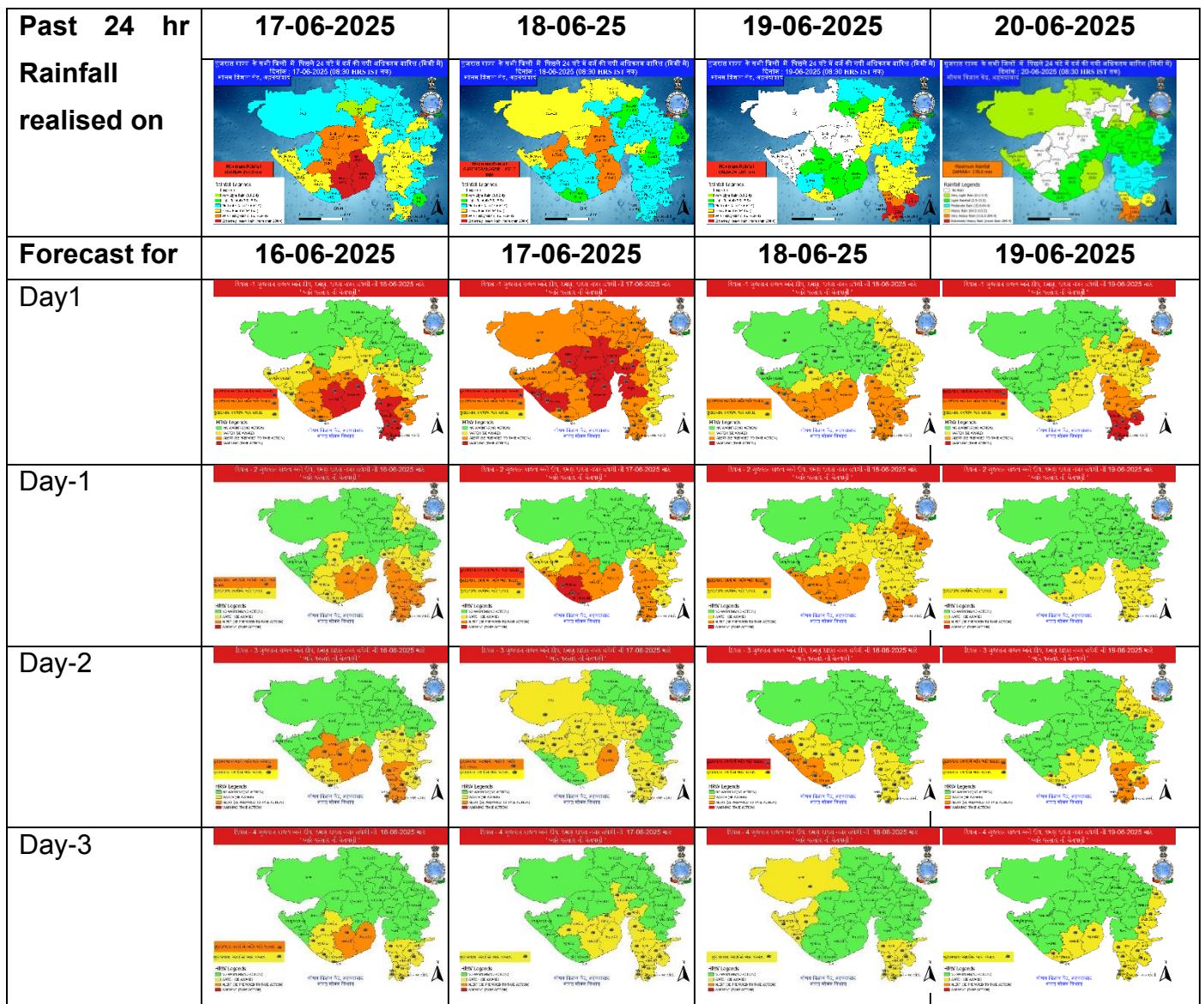
For isolated very heavy rainfall over Gujarat Region and Saurashtra-Kutch on 22nd June, warning for isolated heavy rainfall for Gujarat Region was issued 7 days in advance (on 15th June) and for Saurashtra-Kutch 6 days in advance (on 16th June), which were upgraded to isolated heavy to very heavy by 6 (on 16th June) & 2 days (on 21st June) in advance for Gujarat Region and Saurashtra-Kutch respectively. Warning was further upgraded to isolated extremely heavy (red alert) rain for both sub-divisions on 22nd June (**Fig. 5.8b**).

For isolated extremely heavy rainfall over Gujarat Region on 23rd June, warning for isolated heavy to very heavy rainfall (orange alert) for Gujarat Region was issued 7 days in advance i.e. 17th June. Similarly, the extremely heavy rainfall event on 24th over Gujarat region was predicted well with warning for very heavy rainfall (orange alert) on 20th June upgraded to extremely heavy rainfall (red) on 24th June (**Fig. 5.8c**).

For the very heavy rainfall event of 25th June over Gujarat Region isolated heavy rainfall warning (yellow alert) was issued 7 days in advance i.e. on 19th June which was first upgraded to isolated heavy to very heavy on 20th June (**Fig. 5.8c**).

On 20th June, synoptically only a trough was noticed from northwest Uttar Pradesh to north Gujarat Region across a cyclonic circulation over northeast Rajasthan & neighbourhood between 3.1 & 5.8 km above mean sea level. Also, the GFS 24hour rainfall forecast (00 & 12 UTC run) indicated only light to moderate (upto 40mm) rainfall over Gujarat (Fig. 5.7). Based on the above guidance, warning for isolated heavy rain (yellow watch) was given for Gujarat Region (Fig. 5.8b). However, extremely heavy rain of 205mm was reported by state government rain gauge station Jambughoda in Panchmahal district. The second highest was 129 mm over state government raingauge Jetpur Pavi in Chotaudepur district. The event was covered by district level nowcast.

The seven-days district wise heavy rainfall warnings maps from 16th to 25th June are shown in Fig. 5.8 a to c below:



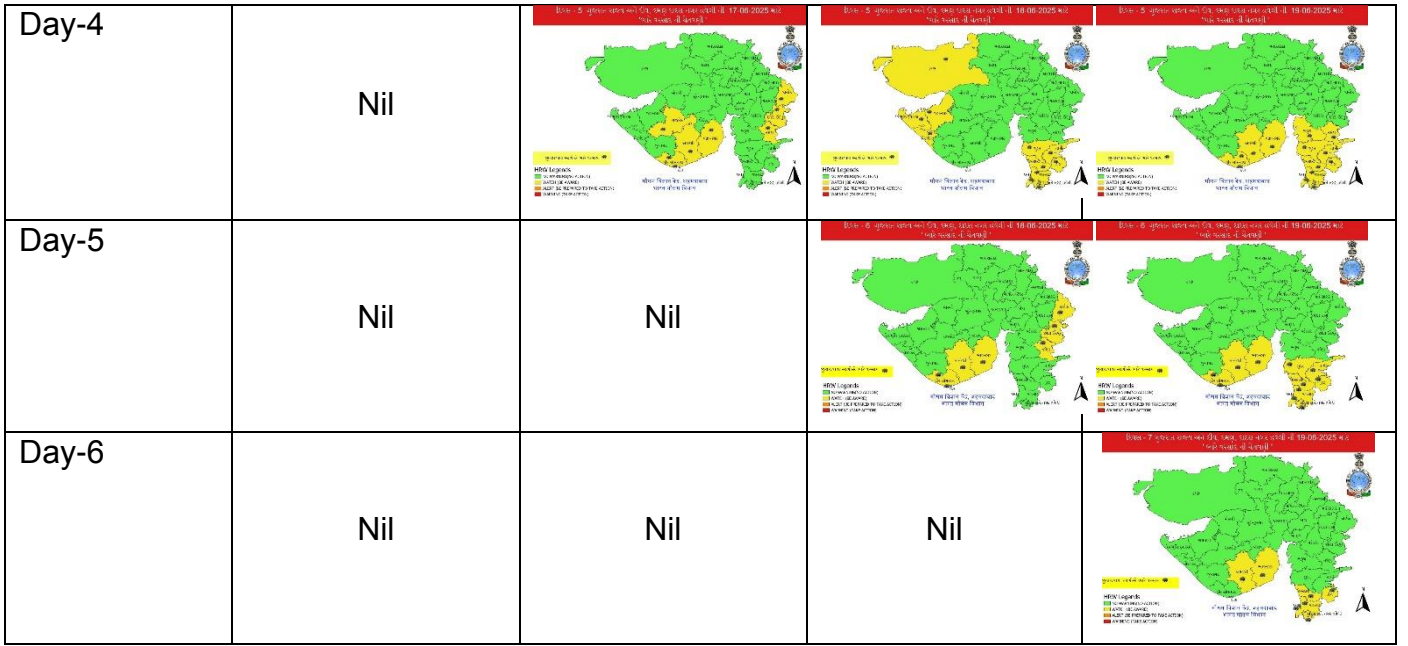
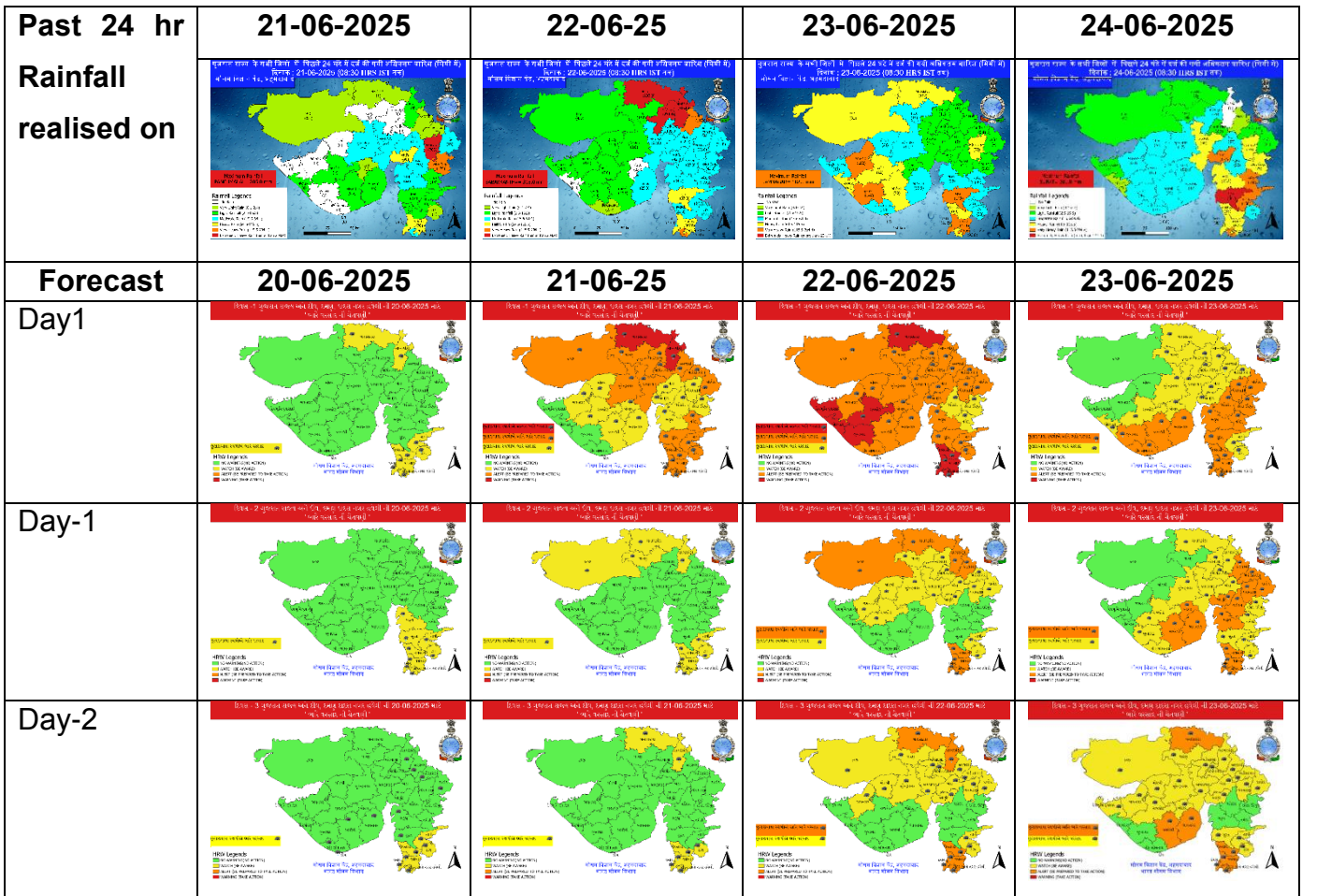


Fig. 5.8a: District-wise rainfall warning maps (Day to Day-6) along with realised rainfall maps during the period 16-19 June 2025



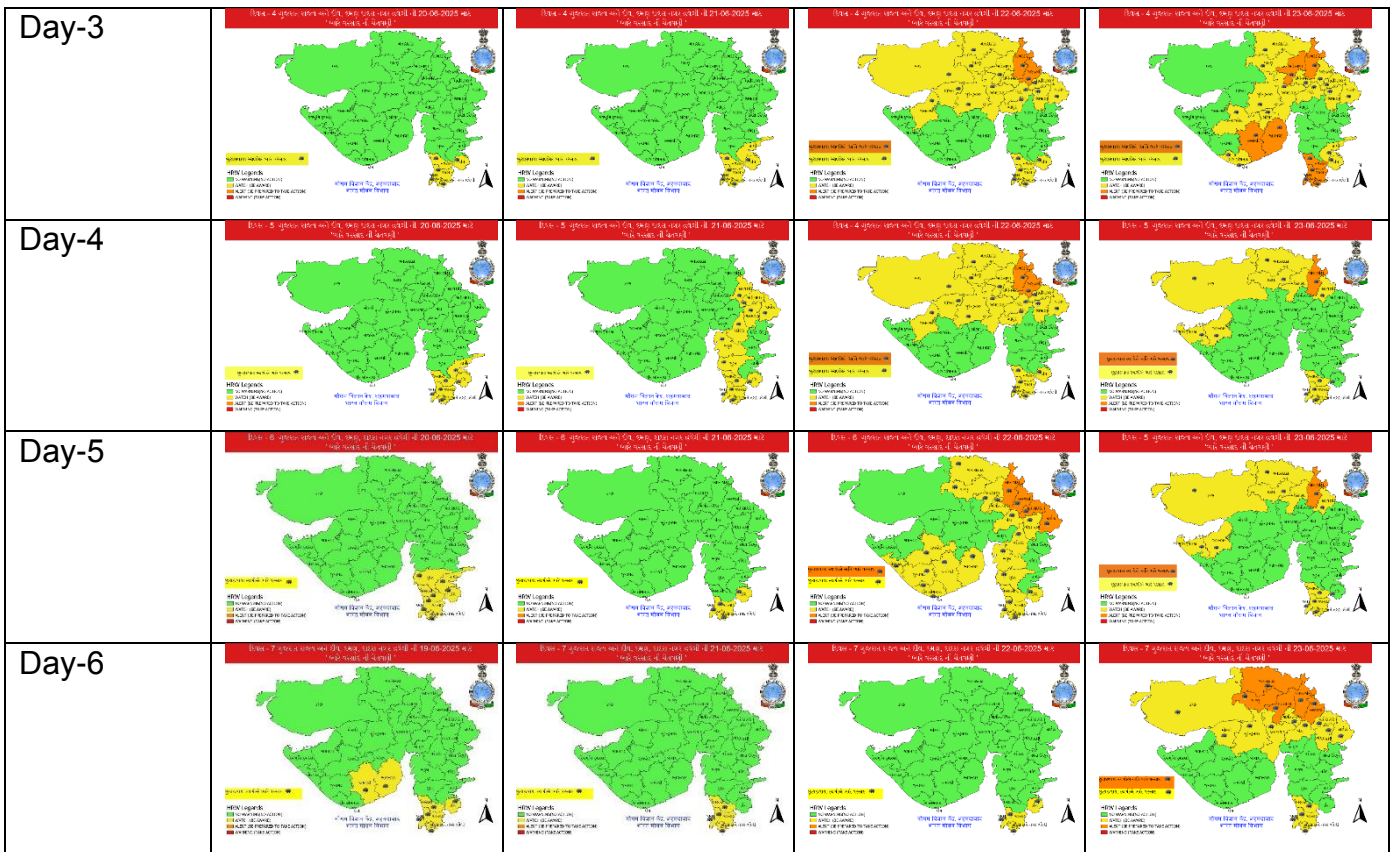


Fig. 5.8b: District-wise rainfall warning maps (Day to Day-6) along with realised rainfall maps during the period 20-23 June 2025

Past 24 hr Rainfall realised on	25-06-25	26-06-2025	-	-
				-
Forecast for	24-06-25	25-06-2025	-	-
Day1			-	-
Day-1			-	-

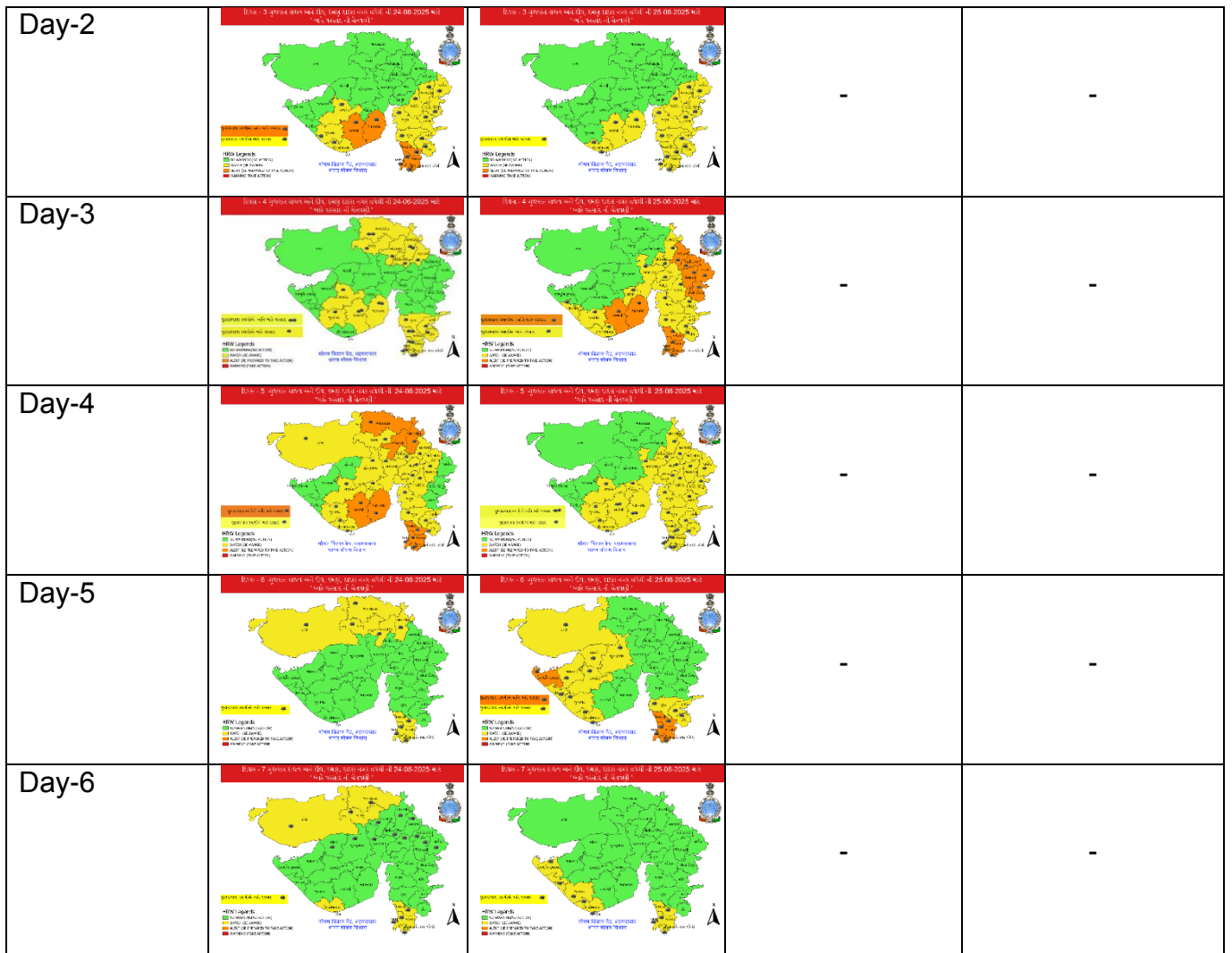


Fig. 5.8 c: District-wise rainfall warning maps (Day to Day-6) along with realised rainfall maps during the period 24-25 June 2025

5.3.5 Dissemination of Warning/Bulletin issued

Appropriate and timely warnings/bulletins were issued and disseminated to state authorities, district authorities and various stake holders using all means of communication like email, WhatsApp etc. and warnings maps as well as daily weather video were also uploaded on social media like Facebook, X, Instagram, Facebook during the period. Press release and special bulletins were started from 14th June onwards and a total of 25 each of press releases and special bulletins (14-06-2025 to 09-07-2025) were issued during the prolonged spell of heavy rainfall activity. Flash flood guidance bulletin were also issued as and when required, the first one for Saurashtra was issued on 14th June. Snippets of the special weather bulletin no. 3 (**Fig. 5.9**) and flash flood bulletin issued on 16-06-2025 presented below (**Fig. 5.10**).

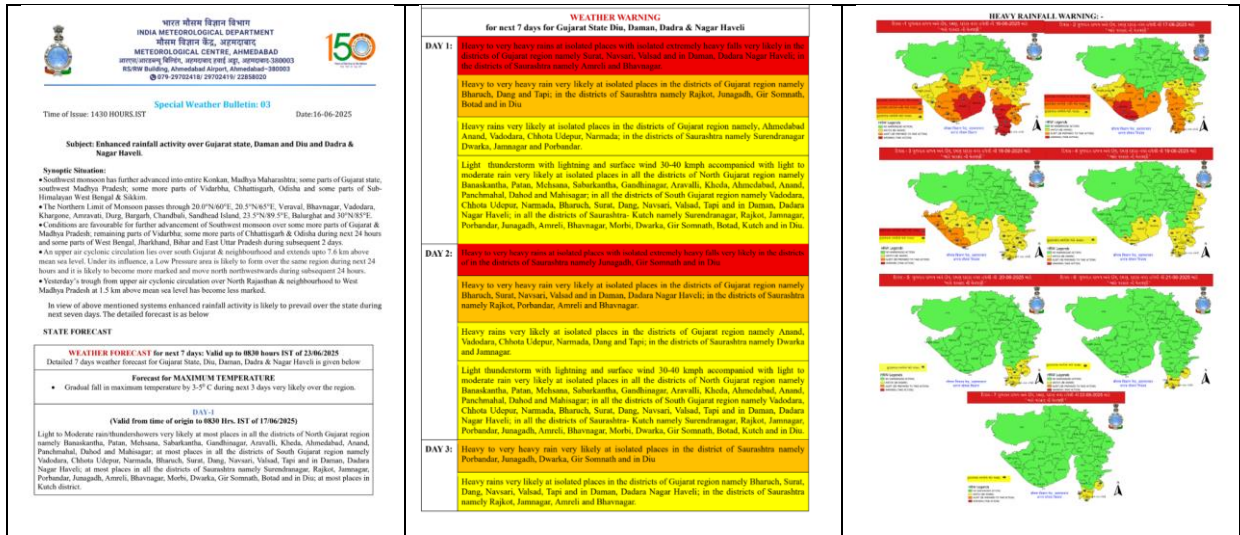


Fig. 5.9: Snippets of the special weather bulletin no. 3 issued on 16th June, 2025

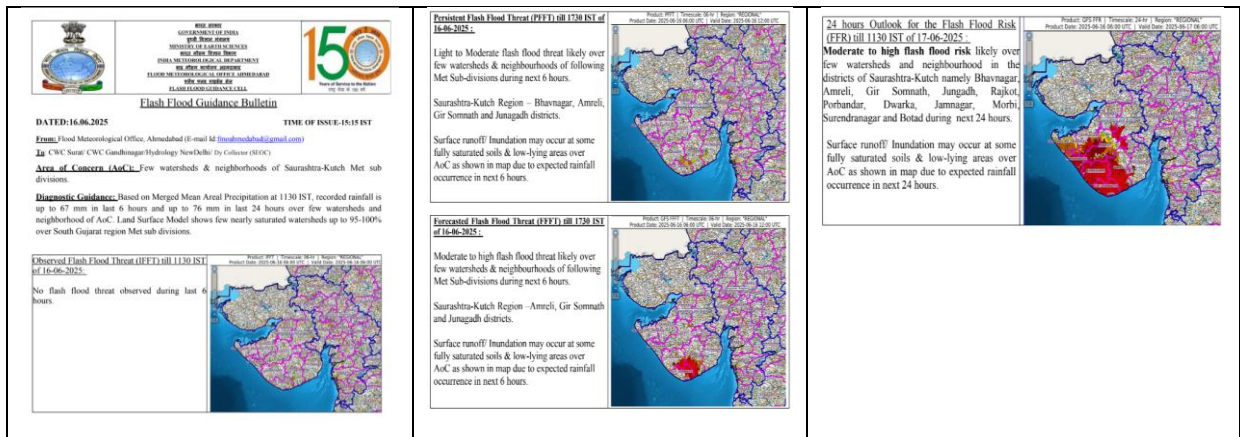


Fig. 5.10: Snippets of the flash flood guidance bulletin issued on 16th June, 2025

5.3.6 Damage Report

The prolonged spell of heavy rainfall with isolated very heavy to extremely heavy falls resulted in significant loss to life and property. As per media report (<https://www.ndtv.com/india-news/heavy-rainfall-in-gujrat-claims-7-lives-and-over-100-rescued-8707685>), 7 people died in very first spell of isolated extremely heavy rainfall in Botad district. Inundation of low lying areas, Landslides (<https://indianexpress.com/article/cities/ahmedabad/monsoon-fury-in-gujarat-landslide-blocks-road-in-banaskantha-147-talukas-receive-rain-orange-alert-issued-till-june-26-10082135/>) and uprooting of trees, resulted in different parts of the state (Fig. 5.11 to 5.13).

7 Dead, Over 100 Rescued Amid Heavy Rainfall In Gujarat

Tragedy struck in the Botad district, where the bodies of seven individuals were recovered after their eco-car was swept away by flash floods near Lathidad village

Indo-Asian News Service | [India News](#) | Jun 19, 2025 16:41 pm IST

Read Time: 3 mins

Share



Fig. 5.11: Rescue operations in Botad district after extremely heavy rainfall event of 16th June (Photo-NDTV)

Monsoon fury in Gujarat: Landslide blocks road in Banaskantha; 147 talukas receive rain, orange alert issued till June 26

As on Sunday 6 am, Gujarat has recorded an average of 16 per cent rainfall, the State Emergency Operation Centre (SEOC) said

By: **Express News Service**
Ahmedabad | June 22, 2025 11:47 PM IST
3 min read

As Trusted Source on

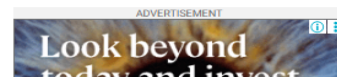


Fig. 5.12: Media Reports (Indian Express) of Landslide in Banaskantha district



Fig. 5.13: Snapshots of rescue operations in Daman district as shared by state government authorities on WhatsApp

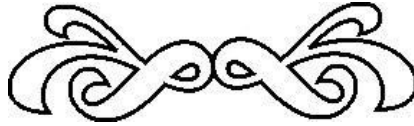
5.4 Conclusion

The presence of low-pressure system, cyclones, trough/shear zone and off-shore trough over the region and occasionally their mutual interaction created an environment conducive to widespread and prolonged rainfall, with some areas receiving more than 300 mm of rain in a day. This unprecedented rainfall led to inundation of low-lying areas, landslides, uprooting of trees etc. resulting in significant loss to life and property. The event was forecasted well in advance with timely dissemination of impact-based warnings to the state disaster authorities and other stakeholders using all means of communication including social media; which enabled the concerned authorities to take timely action for mitigation measures thereby minimizing the loss to life and property.

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6



HEAVY RAINFALL ACTIVITIES AND ASSOCIATED IMPACTS OVER RAJASTHAN DURING THE SOUTHWEST MONSOON 2025

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This chapter discusses the observed features of heavy rainfall activities and associated impacts over the state of Rajasthan during the southwest monsoon 2025.

6.1 Introduction

The north-western Indian state of Rajasthan is well known for its semi-arid climate, with a normal seasonal rainfall of 435.6 mm based on the 1971–2020 base period. The Southwest Monsoon 2025 witnessed record large excess rainfall over Rajasthan, the highest in the past 108 years. The rainfall occurred during monsoon season (June-September, 2025) over the Rajasthan state as a whole was 715.2 mm against its normal of 435.6 mm which is 164% of its long period average (LPA) based on data of 1971-2020. The rainfall received over the state was large Excess (Departure +64% of long period average). The previous record of highest ever rainfall were 839.1 mm in 1917 and 683.2 mm in 1908 during the period of 1901-2025 in Rajasthan. Meteorological subdivision wise 161% of its LPA over East Rajasthan and 170% of its LPA over West Rajasthan observed during the monsoon season. The chief features of monsoon rainfall over Rajasthan are as follows:

- In 2025, the Southwest Monsoon advanced over Kerala on 24 May and reached Rajasthan on 18 June, which was the normal date of onset. Thereafter, the monsoon covered the entire state by 29 June, about nine days earlier than the

normal of 8 July.

- Monthly rainfall received over the state was 133% of LPA in June, 78% of LPA in July, 118% of LPA in August and 182% of LPA in September.
- Cumulatively, 128 mm rainfall recorded in the month of June 2025. The observed rainfall was the 2nd highest in the history of June during the period of 1901-2025. Earlier, the highest rainfall 156.9 mm recorded in 2023 in June.
- Cumulatively, 287.1 mm rainfall recorded in the month of July 2025. The observed rainfall was the 3rd highest in the history of July during the period of 1901-2025. Earlier, the highest rainfall 308.7 mm was recorded in 1956 in July and the 2nd highest rainfall 288 mm was recorded in 1908 in July.
- Cumulatively, 715.2 mm rainfall recorded in the month of June to September 2025 (Monsoon season total). The observed rainfall was the second highest in the history of Monsoon season total during the period of 1901-2025. Earlier, the highest rainfall 844.2 mm recorded in 1917 in August.
- Out of total 33 districts, 20 districts received large excess rainfall (Departure +60% or more), 12 districts received excess rainfall (Departure +20% to +59%) and 01 districts received normal rainfall (Departure -19% to +19%) during the season.
- District wise highest rainfall 1593.5 mm (92% large excess than normal) observed in Baran followed by 1333.1 mm (102% large excess than normal) in Sawai Madhopur district.
- Southwest monsoon withdrew from parts of West Rajasthan on September 14, 2025 (about 3 days before normal date). Thereafter, monsoon withdrew from the entire state by 26th September against normal date of 30th September (about 4 days before normal date).

6.2 Observed Rainfall Distribution

6.2.1 Seasonal cumulative rainfall

The district-wise, subdivision-wise, and seasonal rainfall over the state during the Southwest Monsoon 2025 are presented in **Table 6.1**, along with the respective long-period average (LPA) values and percentage departure from normal. The seasonal rainfall over Rajasthan was 164% of its LPA during the Southwest Monsoon 2025. East Rajasthan received 161% of its LPA, while West Rajasthan received 170% of its LPA. Out of 33 districts, 20 districts recorded large excess rainfall and 13 districts recorded excess rainfall. None of the districts experienced normal, deficient, or scanty rainfall during the season. The district wise rainfall % Departures from the Long Period Average for June-Sept depicted in **Fig. 6.1** and cumulative rainfall is depicted in **Fig. 6.2**.

Table 6.1: CUMULATIVE RAINFALL STATISTICS (01/06/2025 to 30/09/2025)

SR NO.	NAME	ACTUAL RAINFALL (MM)	NORMAL RAINFALL (MM)	DEPARTURE FROM NORMAL	CATEGORY
1	RAJASTHAN AS WHOLE	715.9	435.6	64	LARGE EXCESS
2	EAST RAJASTHAN	1010.5	626.6	61	LARGE EXCESS
3	WEST RAJASTHAN	481.2	283.6	70	LARGE EXCESS

EAST RAJASTHAN

1	AJMER	878	458.3	92	LARGE EXCESS
2	ALWAR	730.9	545.9	34	EXCESS
3	BANSWARA	1117.5	886	26	EXCESS
4	BARAN	1593.5	832	92	LARGE EXCESS
5	BHARATPUR	790.5	543.3	45	EXCESS
6	BHILWARA	1013.2	604.5	68	LARGE EXCESS
7	BUNDI	1251.6	644.4	94	LARGE EXCESS
8	CHITTOGARH	929.4	727.2	28	EXCESS
9	DAUSA	1240.8	594.5	109	LARGE EXCESS
10	DHOLPUR	1133.5	584.1	94	LARGE EXCESS
11	DUNGARPUR	878.4	706.5	24	EXCESS
12	JAIPUR	918.5	524.3	75	LARGE EXCESS
13	JHALAWAR	1121.5	884.3	27	EXCESS
14	JHUNJHUNU	694	408.8	70	LARGE EXCESS
15	KARALI	1083.5	595.8	82	LARGE EXCESS
16	KOTA	1242.2	732.2	70	LARGE EXCESS
17	PRATAPGARH	1220.6	914.2	34	EXCESS
18	RAJSAMAND	836.9	538.1	56	EXCESS
19	SAWAI MADHOPUR	1333.1	661.5	102	LARGE EXCESS
20	SIKAR	804.6	407.1	98	LARGE EXCESS
21	SIROHI	1075	873	23	EXCESS
22	TONK	1149.8	566.8	103	LARGE EXCESS
23	UDAIPUR	890	617.7	44	EXCESS

WEST RAJASTHAN

24	BARMER	389.5	272.7	43	EXCESS
25	BIKANER	383.9	247	55	EXCESS
26	CHURU	636.1	334	90	LARGE EXCESS
27	HANUMANGARH	574.7	253.6	127	LARGE EXCESS
28	JAISALMER	223.5	176.9	26	EXCESS
29	JALORE	766.8	417.8	84	LARGE EXCESS
30	JODHPUR	501.3	292.6	71	LARGE EXCESS

31	NAGOUR	746.7	369.5	102	LARGE EXCESS
32	PALI	836.9	491.6	70	LARGE EXCESS
33	SRI GANGANAGAR	454.2	204.7	122	LARGE EXCESS

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MC JAIPUR

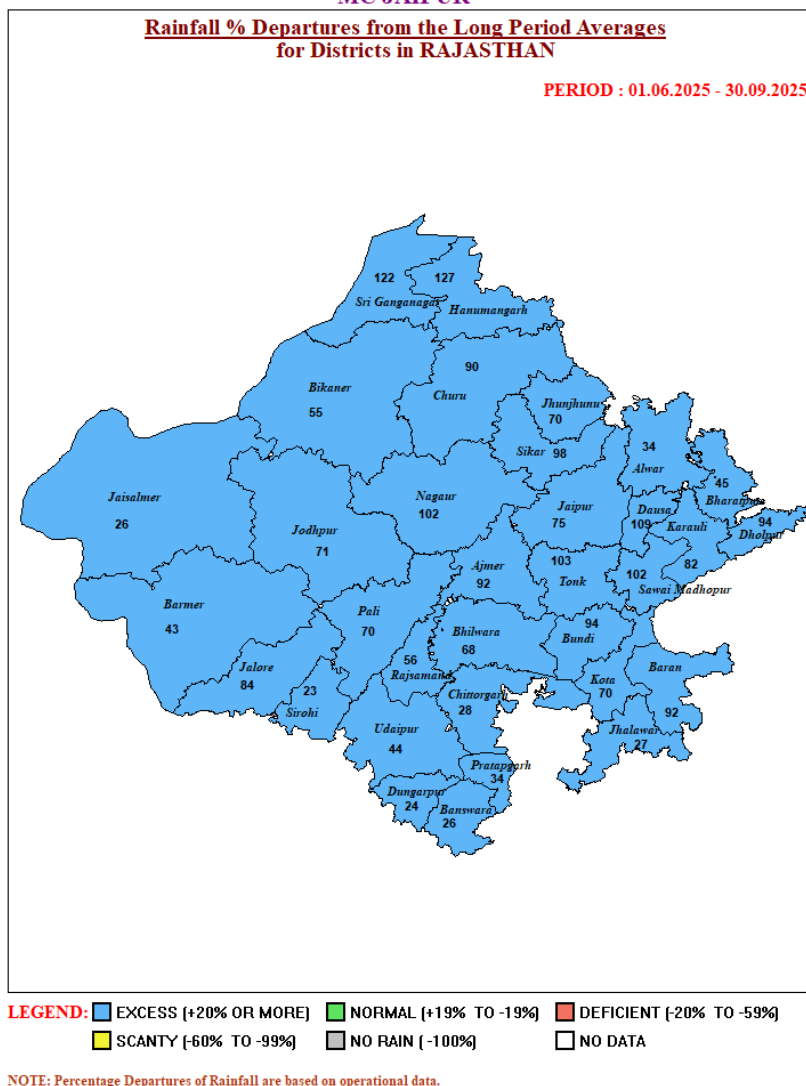


Fig. 6.1: District wise June-September 2025 Rainfall % Departures from the Long Period Average

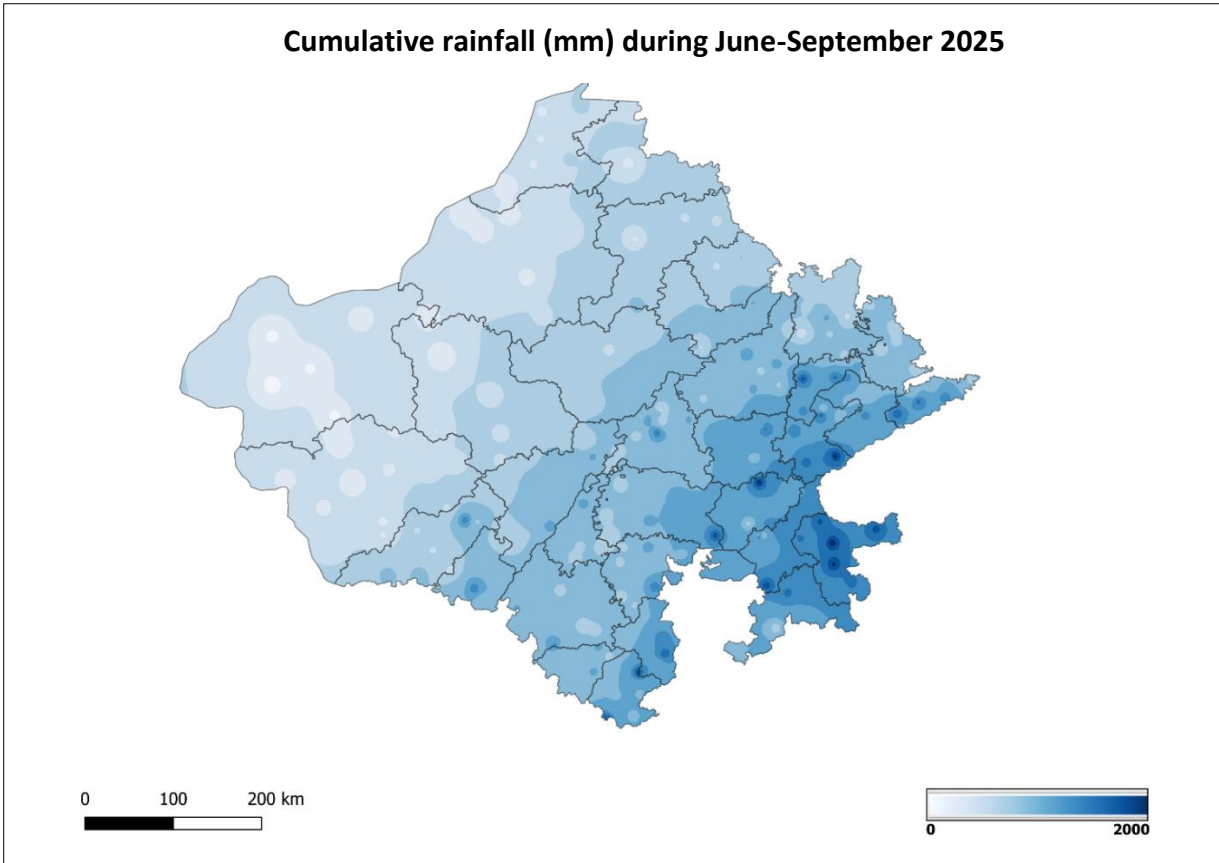


Fig 6.2: Spatial distribution of cumulative seasonal Rainfall (mm)

Table 6.2: Top Ten monsoon (1901-2025) for Rajasthan

Sr. No.	Year	Actual rainfall (mm)	Normal Rainfall (mm) based upon 1971-2020 data	Departure from LPA
1	1917	839.1	435.6	93 %
2	2025	715.9	435.6	64 %
3	1908	683.2	435.6	57 %
4	2024	678.5	435.6	56 %
5	1975	667.1	435.6	53 %
6	1973	658.1	435.6	51 %
7	1944	636.2	435.6	46 %
8	2022	596.1	435.6	37 %
9	2019	579.3	435.6	33 %
10	1994	573.4	435.6	32 %

The south-eastern and central parts of the state received comparatively higher rainfall. In terms of percentage departure from normal, Sirohi district received the least rainfall (123% of LPA), while Hanumangarh district received the highest rainfall (227% of LPA). The rainfall

recorded over Rajasthan as a whole during the monsoon season (June–September) 2025 was 715.9 mm against its normal of 435.6 mm, which is 164% of its long-period average (LPA) based on data for 1971–2020. The top ten highest monsoon rainfall during the period 1901–2025 are shown in **Table 6.2**.

6.2.2 Monthly Rainfall

The monthly rainfall during monsoon season (June to September) for the state as a whole and its two meteorological sub divisions with respective LPA values and % departure from normal is given in **Table 6.3**.

Table 6.3: Month wise rainfall (mm)

Month	Rajasthan as whole			East Rajasthan			West Rajasthan		
	Actual rainfall (mm)	LPA (mm)	Departure (%)	Actual rainfall (mm)	LPA (mm)	Departure (%)	Actual rainfall (mm)	LPA (mm)	Departure (%)
June	128	55	133	195	74.7	161	74.7	39.4	90
July	287.1	161.4	78	394.9	228.6	73	201.3	107.8	87
August	184.4	155.8	18	250.2	231.5	8	132	95.5	38
September	116.3	63.5	83	170.4	91.8	85	73.3	40.9	79

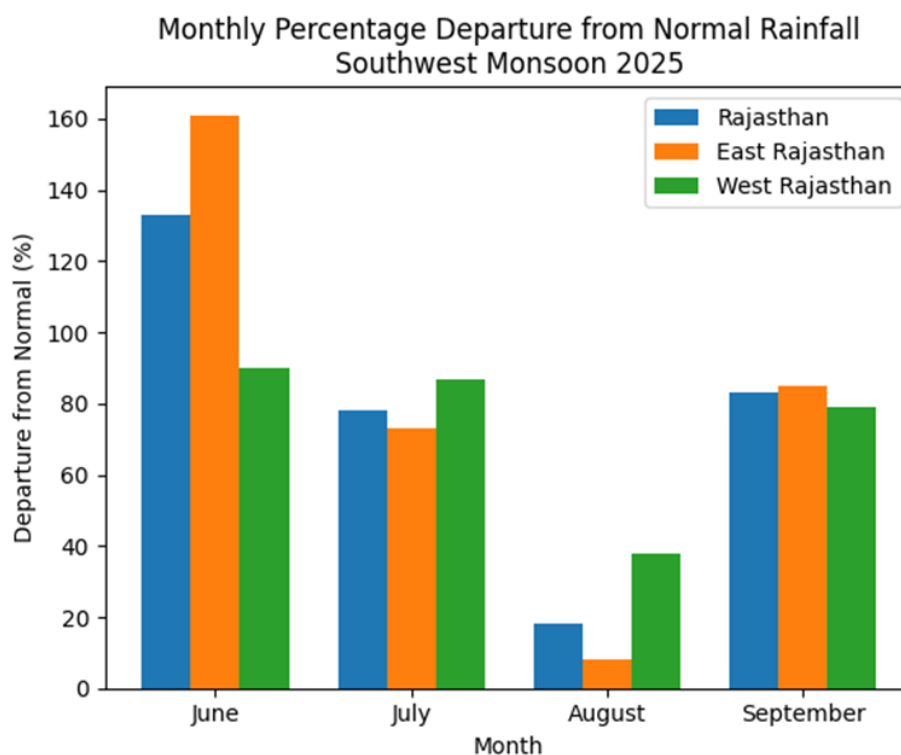


Fig. 6.3: Month wise % departure from normal

Both East Rajasthan and West Rajasthan received their highest rainfall during month of June which was 261 % of LPA (large excess) and 190 % of LPA (large excess) respectively. Meteorological sub-division wise rainfall % departure from normal for June-September is depicted in **Fig. 6.3**.

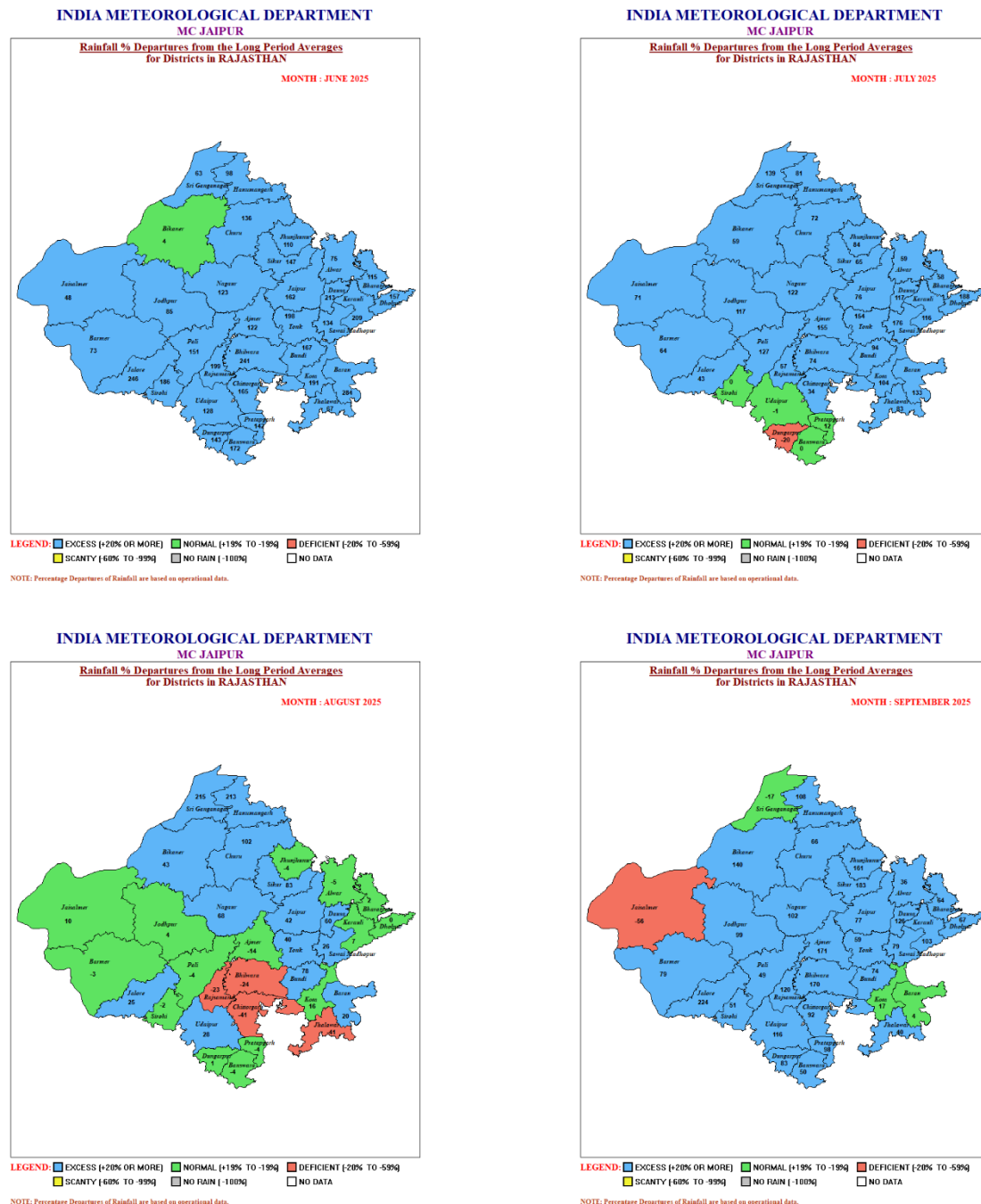


Fig. 6.4: Districtwise Monthly Distribution of rainfall % departure over Rajasthan

Excess rainfall occurred over many districts of the state during the monsoon season. The percentage departure from normal on a district-wise basis is shown in **Fig. 6.4**.

Deficient rainfall was observed over few districts of South Rajasthan during July and August, while the remaining districts received normal to excess rainfall during this period. Similarly, excess rainfall was observed over most districts in September, except Jaisalmer district, which recorded deficient rainfall.

6.2.3 Weekly rainfall

The weekly rainfall % departure from normal is depicted in **Fig. 6.5**. Out of the 11 weeks that showed a positive rainfall anomaly, 3 weeks were in June, 5 weeks in July, 2 weeks in August, and 1 week in September. The largest negative weekly rainfall anomaly occurred in the week ending 11 September (– 99 % of LPA). The highest positive rainfall anomalies were during the week ending 26 June (262 % of LPA), followed by the week ending 21 August (244 % of LPA). The increase in weekly rainfall during the season was mainly due to low-pressure systems traversing along the monsoon trough.

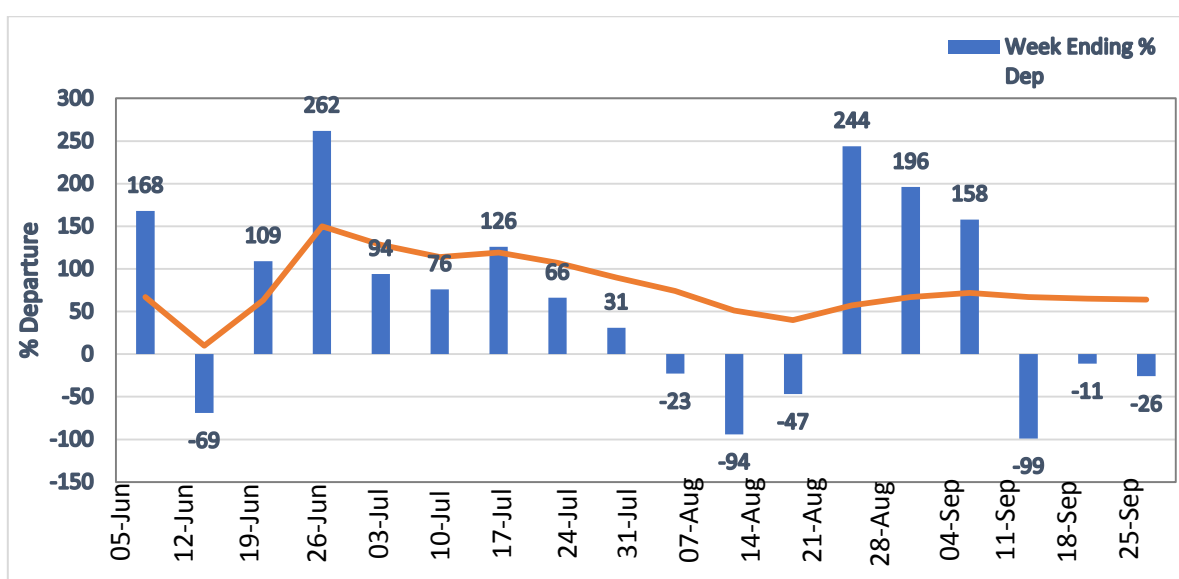


Fig. 6.5: Week by week progress and cumulative rainfall (% departure from normal) over Rajasthan as whole

6.2.4 Heavy Rainfall event

Heavy to extremely heavy rainfall occurred over isolated to many places in many districts of the state on a few days. The districts of Banswara, Baran, Bhilwara, Ajmer, Kota, Dholpur, Jaipur, Pratapgarh, Udaipur, and Jhalawar recorded heavy rainfall on a comparatively large number of days during the season. The district-wise daily distribution of heavy to extremely heavy rainfall for Monsoon 2025 is shown in **Fig. 6.6**. The occurrence of extremely heavy rainfall during the season is summarized in **Table 6.4**.

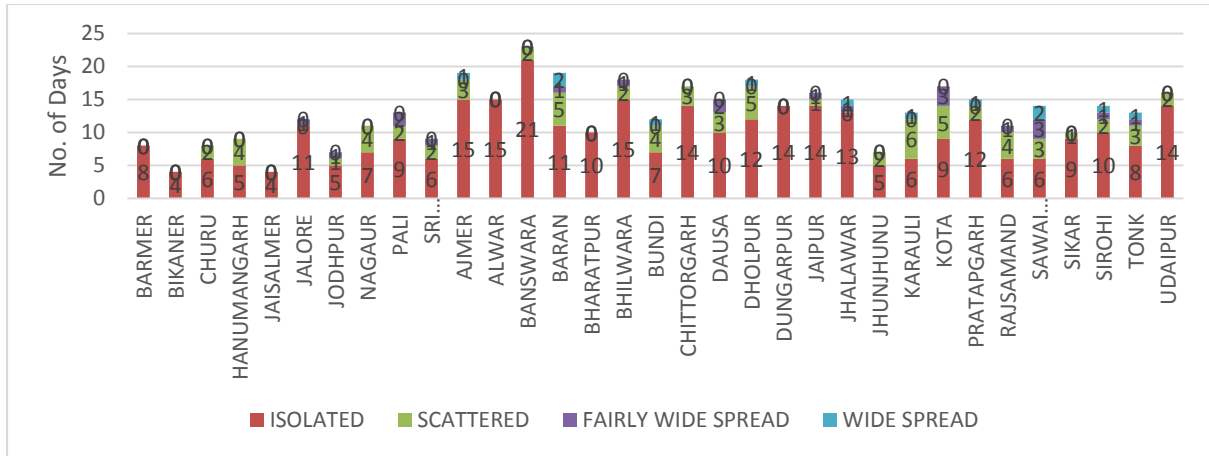


Fig. 6.6: Districtwise Daily Heavy to Extremely Heavy Rainfall Distribution

Table 6.4: Extremely Heavy Rainfall observed in 24 hours during Southwest Monsoon 2025

S. No.	Station	Date	Amount (in mm)	District
1	Nainwa	23 August	502.0	Bundi
2	Keshorai Patan	23 August	310.0	Bundi
3	Dausa	24 August	285.0	Dausa
4	Digod	23 August	272.0	Kota
5	Sawai Madhopur	22 August	254.0	Sawai Madhopur
6	Raipur	03 July	252.0	Pali
7	Mount Abu	08 September	250.0	Sirohi
8	Ramganj Mandi	28 July	242.0	Kota
9	Anta	23 August	240.0	Baran
10	Baran	23 August	237.0	Baran
11	Chhipabarod	23 August	235.0	Baran
12	Nainwa	19 July	234.0	Bundi
13	Khandar	30 July	230.0	Sawai Madhopur
14	Merta	19 July	228.0	Nagaur
15	Bhungra	27 August	224.0	Banswara
16	Malarna Dungar	30 July	218.0	Sawai Madhopur
17	Chauth ka Barwara	06 July	214.0	Sawai Madhopur
18	Sawai Madhopur	30 July	213.0	Sawai Madhopur
19	Keshorai Patan	22 August	212.0	Bundi
20	Sanchole	07 September	210.0	Jalore
21	Niwai	23 August	206.0	Tonk

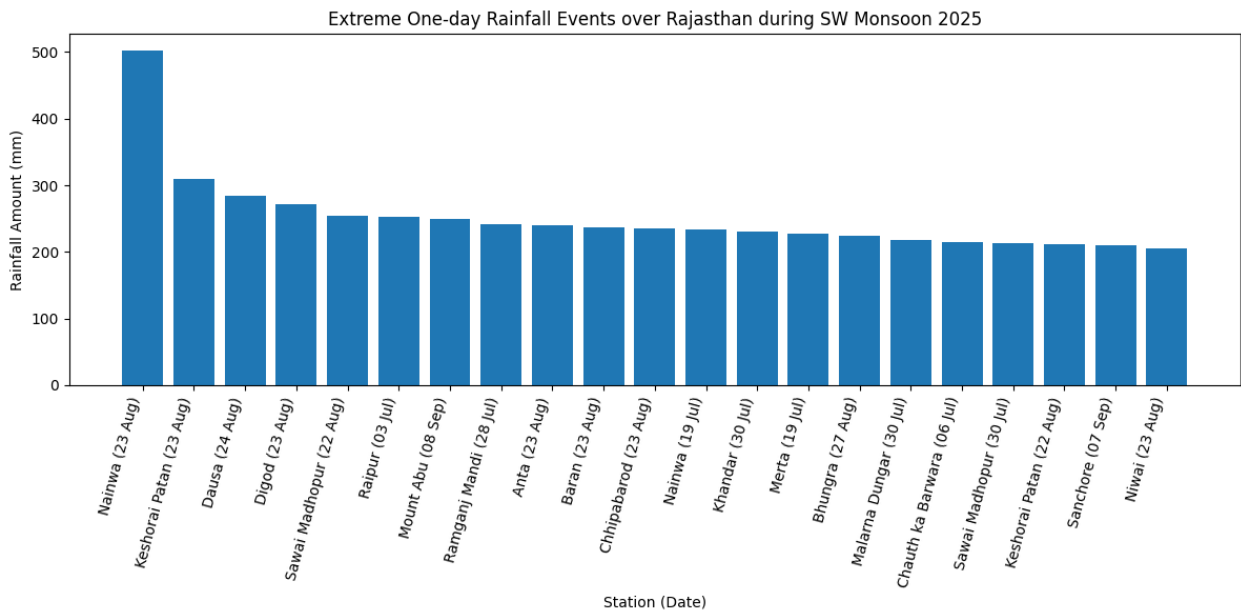


Fig. 6.7: Extremely Rainfall observed during monsoon 2025

The extreme rainfall in 24 hours observed over different stations of Rajasthan shown in **Fig. 6.7**. Month-wise very heavy and extremely heavy rainfall events are shown in **Fig. 6.8**. Most of the very heavy to extremely heavy rainfall events occurred in July and August. The highest one day rainfall — 502 mm — was recorded at Nainwa on 23 August.

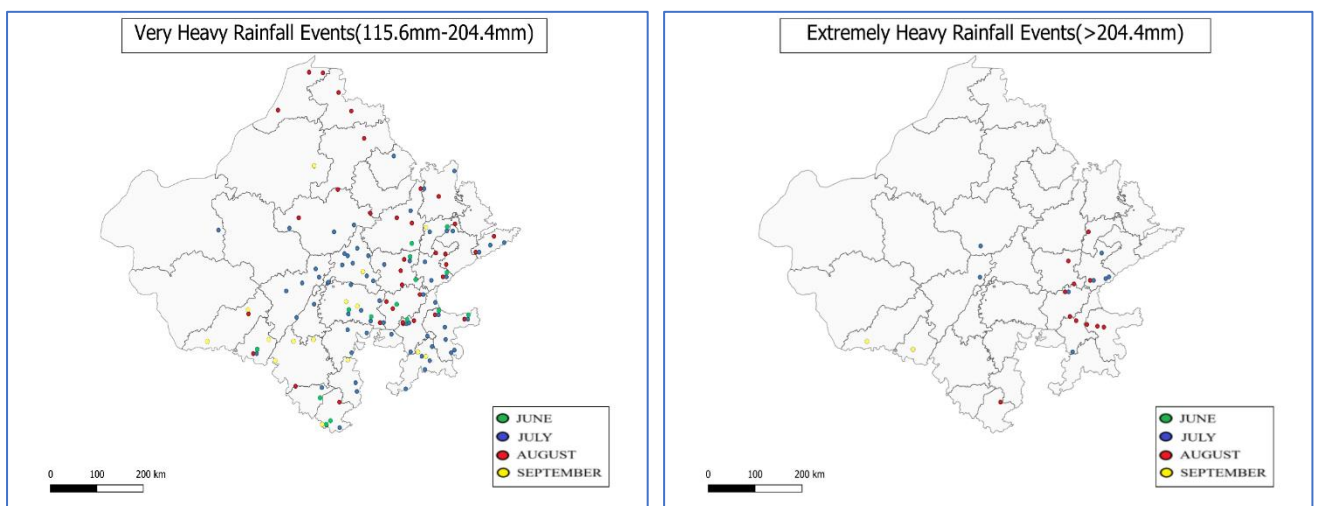


Fig. 6.8: The distribution of Very Heavy Rainfall and Extremely Heavy Rainfall

6.2.5 Daily monsoon rainfall

The daily actual observed rainfall and the normal rainfall over the entire state are depicted in **Fig. 6.9(a)**. Active monsoon conditions were observed from 16 June onwards and persisted until 2 August. The next spell of active monsoon was observed from 22 August

to 10 September during the monsoon season. Sub-division wise daily rainfall is also depicted in **Fig. 6.9(b-c)**.

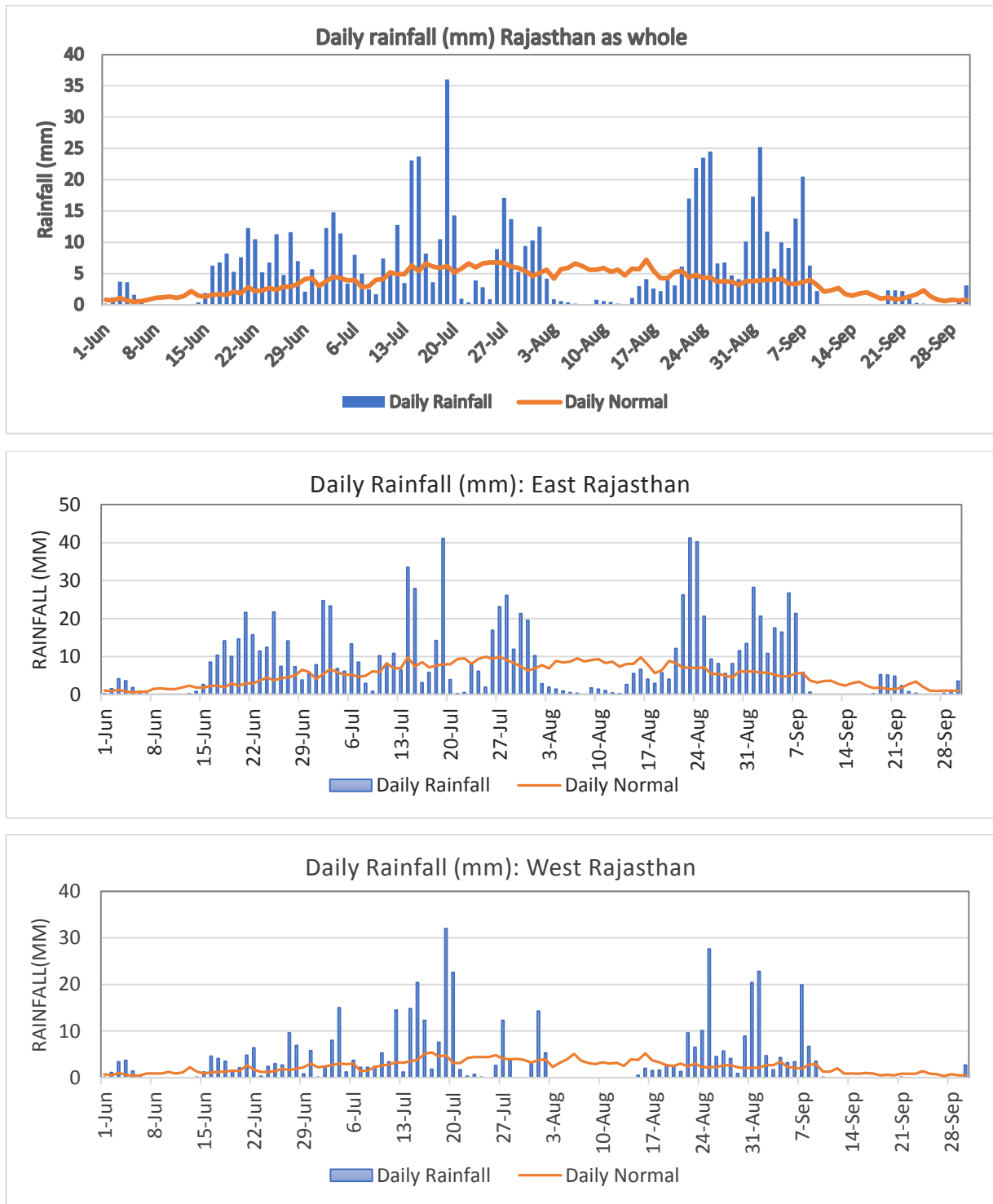


Fig. 6.9: Daily Rainfall – West Rajasthan

6.3 Heavy rainfall Impact observed over Rajasthan

The SW monsoon 2025 in Rajasthan was notably active and intense, with rainfall large excess and widespread impacts across the state. Record rains and persistent waterlogging disrupted life in several districts. Early warning weather alerts (red/orange/yellow) were issued repeatedly by the IMD Jaipur for heavy rainfall, flash floods, lightning, and flooding risk etc. The causality and damage report as per SDAMA and Media coverage is given in **Table 6.5**.

Table 6.5: District wise impact observed due to heavy rainfall events in Rajasthan (Sources SDRF and media report)

Period	Deaths (Districts)	Injured (Districts)	Livestock Loss	Damage / Impacts	Media Reporting
Mid-June (15–20 Jun 2025)	9 (Bharatpur, Jaisalmer, Banswara, Sikar, Jodhpur)	1 (Dholpur)	3	Few houses/walls damaged or collapsed	Lightning fatalities and rain-related damage in eastern Rajasthan reported by local and national media
Late June (22–30 Jun 2025)	15 (Churu, Baran, Bundi, Jhalawar, Bharatpur, Dungarpur, Kotputli-Behror)	11 (Churu, Chittaurgarh, Bundi, Jhalawar)	7	Some houses damaged	fatalities, wall collapses, and heavy rain-related disruptions reported
Early July (01–07 Jul 2025)	14 (Dholpur, Beawar, Ajmer, Jaipur, Kota, Tonk, Sriganganagar, Hanumangarh)	9 (Dholpur, Jaipur)	11	Houses damaged	Drowning incidents (notably Tonk) and early-July monsoon disruptions reported
Mid-July (10–20 Jul 2025)	22 (Bharatpur, Beawar, Alwar, Bundi, Kota, Tonk, Pali, Ajmer)	—	—	Flooding, traffic blockages, houses damaged	casualties and structural collapses reported by state and national media
Late July (23 Jul – 05 Aug 2025)	11 (Jhalawar, Karauli, Dholpur, Tonk)	21 (mainly Jhalawar)	1	Houses damaged; multi-district flooding	School collapse and 7 deaths in Jhalawar, house collapses in Karauli, lightning fatalities reported

Mid-August (12– 17 Aug 2025)	3 (Pali-2 drowning due to nala flooding; Banswara-1 lightning)	—	—	Localised flooding	Lightning casualties and isolated flooding
Late-August (21–31 Aug 2025)	7 (Balotra, Pali, Dausa, Hanumangarh, Banswara)	9 (Balotra, Hanumangarh)	15	Houses damaged	Lightning deaths in Balotra and flooding/house-collapse
Early September (01– 08 Sep 2025)	4 (Deeg, Pali, Sriganganagar)	3 (Deeg)	9	Houses damaged	house collapse and lightning incidents reported

7



INTENSE RAINFALL ACTIVITIES AND ASSOCIATED IMPACTS OVER JAMMU & KASHMIR DURING SOUTHWEST MONSOON 2025

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This chapter discusses the observed features of intense rainfall activities and associated impacts over meteorological sub-division of Jammu & Kashmir during the southwest monsoon 2025.

7.1 Introduction

The chief features of monsoon rainfall over Jammu & Kashmir are as follows:

- The southwest monsoon seasonal rainfall during June to September for J&K meteorological sub-division as a whole remained 128.6% of Long Period Average (LPA).
- Quantitatively, SW monsoon seasonal rainfall during 22nd June (onset) to 24th September 2025 received 696.6 mm against the Long Period Average of 541.5 mm based on data of 1990-2020 (128.6% of its LPA).
- Monsoon advanced in J&K on 22nd June, seven days prior to its normal onset date and covered entire met sub-division on 23rd June 2025.
- In June 2025, the sub-division received 78.5 mm of rainfall against 75.9 mm of long period average which is in normal category (3% departure)
- In July 2025, the sub-division received 179.1 mm of rainfall against 192.6 mm of long period average which is also in normal category (-7% departure).
- In August 2025, J&K met sub-division received 310.7 mm of rainfall against 184.9 mm of long period average which is in large excess category (68% departure).

- In September 2025, J&K met sub-division received 128.4 mm of rainfall against 95.7 mm of long period average which is in excess category (34% departure).
- Out of 22 districts wherein rainfall was reported during monsoon 2025, 8 received large excess rainfall, 4 districts received excess rainfall, 7 districts received normal rainfall, 2 districts received deficit rainfall and large deficit in 1 district.
- Daily rainfall data was above normal during the entire period except during the initial phase of the monsoon period. Cumulative rainfall remained above normal during 2nd week of August till withdrawal of the monsoon.
- Establishment of an anti-cyclone in the lower tropospheric levels, substantial reduction in moisture content and prevalence of north-westerly dry winds indicated the withdrawal of southwest monsoon from many parts of J&K during last week of September.

7.2 Onset and advance of Monsoon 2025 in J&K

Monsoon advanced in J&K on 22nd/23rd June, seven days prior to its normal onset date and covered entire Met subdivision on 23rd June 2025. After advancing over Kerala on 24th May, 6 days prior to its normal schedule, the monsoon has advanced steadily into the rest of the southern states, and covers the entire country in time. After onset, good spell of rainfall received in many districts of J&K MET sub division in the month of June, July & August & September with more or less uniform spatial distribution in both Jammu Division and Southern parts of Kashmir Division throughout the subdivision in the entire season (**Fig. 7.1**).

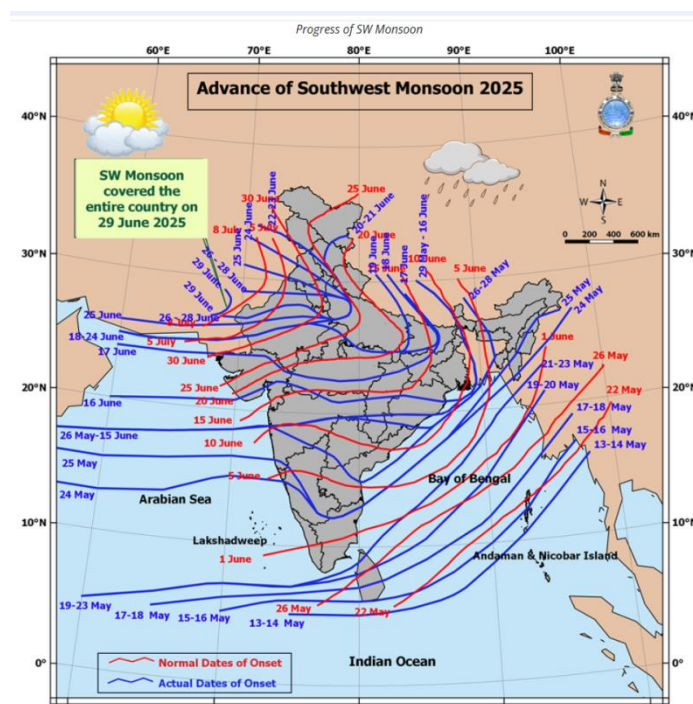


Fig. 7.1: Advancement of southwest monsoon 2025

7.3 Rainfall distribution over J&K

The Jammu & Kashmir subdivision received 696.6 mm of rainfall against its average of 541.5 mm with overall 3% departure during monsoon 2025. Daily time-series of rainfall and daily cumulative rainfall during monsoon period for the sub-division is shown in **Figs. 7.2** and **7.3**, respectively. As evident from these plots, daily rainfall data was above normal during most of the time except the initial phase. Cumulative rainfall remained above normal during 2nd week of August till first week of September.

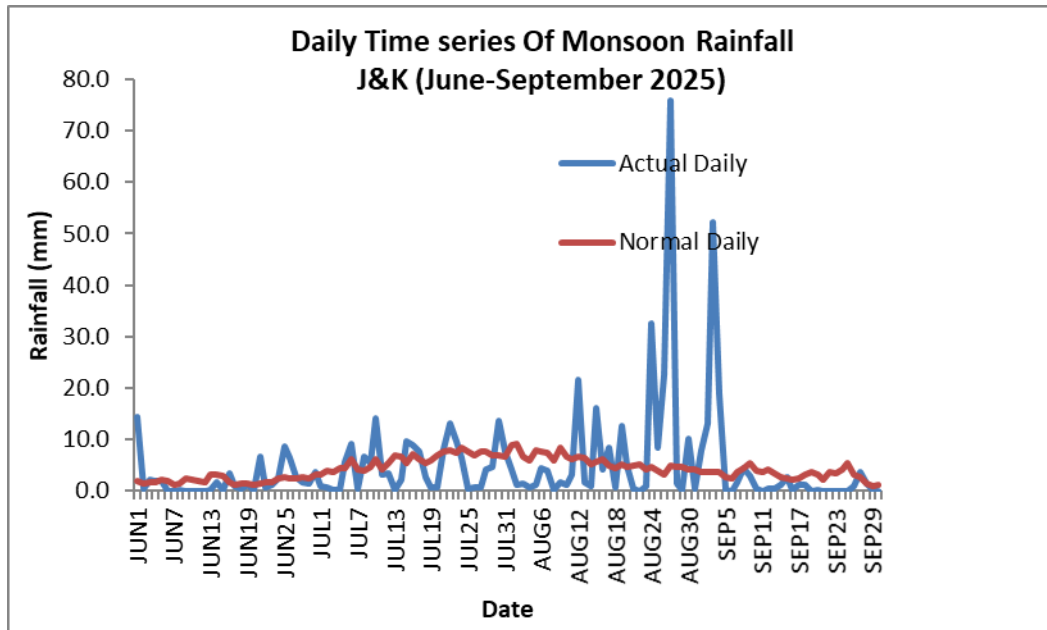


Fig. 7.2: Daily time-series of monsoon rainfall over J&K during 2025

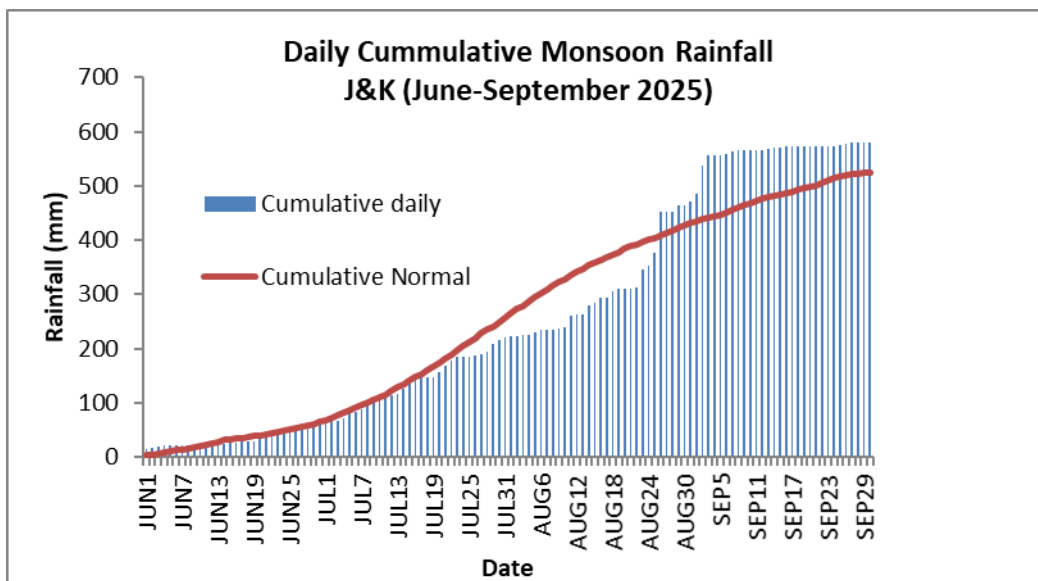


Fig. 7.3: Daily cumulative monsoon rainfall over J&K during 2025

7.3.1 District wise rainfall over J&K

Out of 22 districts wherein rainfall was reported during monsoon 2025, 8 received normal rainfall, 11 received deficit rainfall and large deficient in 3 districts. Percentage departure of district wise rainfall from normal is shown in **Table 7.1**.

Table 7.1: Percentage departure of district wise rainfall from normal over J&K during the southwest monsoon 2025

JK AND LADAKH (UT)	Actual Rainfall (mm)	Normal Rainfall (mm)	% Dep	Category
ANANTNAG	383.7	316.8	21	E
BADGAM	193.7	215.9	-10	N
BANDIPORE	171.3	207.4	-17	N
BARAMULA	193.6	213.2	-9	N
DODA	887.4	423.6	109	LE
GANDERBAL	261.9	271.1	-3	N
JAMMU	1120	929.3	21	E
KARGIL	44.8	10.1	344	LE
KATHUA	1280.8	1246	3	N
KISTWAR	260.8	423.6	-38	D
KULGAM	317.2	330.5	-4	N
KUPWARA	185.1	246.8	-25	D
LADAKH (LEH)	115.3	25.7	349	LE
POONCH	607.5	679.9	-11	N
PULWAMA	230.6	191.1	21	E
RAJOURI	1108.8	713.7	55	LE
RAMBAN	702.3	416.4	69	LE
REASI	2432.3	1545.4	57	LE
SAMBA	1269	804	58	LE
SHOPIAN	119.4	279.3	-57	LD
SRINAGAR	287.8	235.3	22	E
UDHAMPUR	1831.5	999.3	83	LE
SUBDIVISION RAINFALL	696.6	541.5	29	E

7.3.2 Monthly rainfall distribution over J&K

Monthly rainfall distribution for the month of June, July, August and September and for first & second half of monsoon 2025 for J&K subdivision is given in **Table 7.2**.

Table 7.2: Monthly rainfall distribution over J&K during the southwest monsoon 2025

Months	Actual (mm)	Normal (mm)	% of LPA
June	78.5	75.9	100
July	179.1	192.6	93
August	310.7	184.9	168
September	128.4	95.7	134
June – July (1st Half)	257.6	268.5	96
August – September (2nd Half)	439.1	280.6	156

June: In June 2025, the met sub-division received 78.5 mm of rainfall against 75.9 mm of long period average which is 3% departure and comes under normal category. Highest rainfall received in Reasi district (actual rainfall 306.3 mm against normal rainfall of 139.9 mm) followed by Rajouri (actual rainfall 185.9 mm against normal rainfall of 88.1 mm) and Udhampur (actual rainfall 154.6 mm against normal rainfall of 85.3 mm) respectively. The rainfall during June 2025 was normal for entire sub-division with couple of heavy spells at few places. District wise rainfall for the month of June is given in **Table 7.3**.

Table 7.3: District wise rainfall over J&K during June 2025

JK AND LADAKH (UT)	Actual Rainfall (mm)	Normal Rainfall (mm)	% Dep	Category
ANANTNAG	46.3	65.8	-30	D
BADGAM	22.6	38.7	-42	D
BANDIPORE	13.2	40.7	-68	LD
BARAMULA	32.5	55.9	-42	LD
DODA	67.2	78.6	-15	N
GANDERBAL	32.7	74.8	-56	LD
JAMMU	119.8	74.9	60	LE
KARGIL	1.2	4	-70	LD
KATHUA	132.3	105.9	25	E
KISTWAR	29.5	78.6	-62	LD
KULGAM	22.4	72	-69	LD
KUPWARA	31	55.9	-44	D
LADAKH (LEH)	14.5	2.6	458	LE
POONCH	87.5	112.5	-22	D
PULWAMA	31.7	35.3	-10	N
RAJOURI	185.9	88.1	111	LE
RAMBAN	79.5	80.8	-2	N
REASI	306.3	139.9	119	LE
SAMBA	155	82.6	88	LE
SHOPIAN	20.2	39.6	-49	LD
SRINAGAR	30.9	45.4	-32	D
UDHAMPUR	154.6	85.3	81	LE
SUBDIVISION RAINFALL	78.5	75.9	3	N

July: In July 2025, sub-division received 179.1 mm of rainfall against 192.6 mm of long period average which is -7% departure which comes under normal category. Highest rainfall received in Reasi dist (actual rainfall 606.5 mm against normal rainfall 584.3 mm) followed by Udhampur district (actual rainfall 481.9 mm against normal rainfall 402.9 mm) and Rajouri (actual rainfall 379.9 mm against normal rainfall 232.9 mm) respectively. The overall rainfall received during month of July remained in normal category (-7% departure). Thus, in first half of the monsoon (June and July), the sub-

division received 257.6 mm of rainfall against 268.5 mm of long period average which is only 96 % of LPA. July month also received heavy spells of rainfall during all the four weeks. District wise rainfall for the month of July is given in **Table 7.4**.

Table 7.4: District wise rainfall over J&K during July 2025

JK AND LADAKH (UT)	Actual Rainfall (mm)	Normal Rainfall (mm)	% Dep	Category
ANANTNAG	95.9	93.7	2	N
BADGAM	49.9	62	-20	D
BANDIPORE	78.1	68.4	14	N
BARAMULA	72	57.3	26	E
DODA	167.1	140.1	19	N
GANDERBAL	96.2	65.9	46	E
JAMMU	280.2	391.4	-28	D
KARGIL	0.4	1.9	-79	LD
KATHUA	355.6	514.4	-31	D
KISTWAR	39	140.1	-72	LD
KULGAM	78.9	96.8	-19	N
KUPWARA	67.5	82.8	-18	N
LADAKH (LEH)	26.7	11.2	138	LE
POONCH	261.5	244.3	7	N
PULWAMA	50.5	50.9	-1	N
RAJOURI	379.9	232.9	63	LE
RAMBAN	127	127.9	-1	N
REASI	606.5	584.3	4	N
SAMBA	293	258.2	13	N
SHOPIAN	30	99.2	-70	LD
SRINAGAR	86.4	75.1	15	N
UDHAMPUR	481.9	402.9	20	E
SUBDIVISION RAINFALL	179.1	192.6	-7	N

August: In August 2025, J&K met sub-division received 310.7 mm of rainfall against 184.9 mm of long period average which is in large excess category (68% departure). Highest rainfall received in Reasi district (actual rainfall 1024.7 mm against normal rainfall 626.3 mm) followed by Udhampur (actual rainfall 900.3 mm and normal rainfall 347.1 mm) and Samba (actual rainfall 720.5 mm and normal rainfall 319.5 mm) respectively. Heavy spells of rainfall intermittently received during 2nd, 3rd and 4th week of August. District wise rainfall for the month of August is given in **Table 7.5**.

Table 7.5: District wise rainfall over J&K during August 2025

JK AND LADAKH (UT)	Actual Rainfall (mm)	Normal Rainfall (mm)	% Dep	Category
ANANTNAG	136.4	101.1	35	E
BADGAM	70	71	-1	N
BANDIPORE	59.3	74.2	-20	D
BARAMULA	62.9	64.4	-2	N
DODA	488.2	125.1	290	LE
GANDERBAL	65.7	79.1	-17	N
JAMMU	545.2	355.8	53	LE
KARGIL	32.6	2	1530	LE
KATHUA	664.5	457.3	45	LE
KISTWAR	102.5	125.1	-18	N
KULGAM	105.5	93.2	13	N
KUPWARA	58.9	76.5	-23	D
LADAKH (LEH)	54.7	5.6	877	LE
POONCH	236.3	201.3	17	N
PULWAMA	85.9	72.7	18	N
RAJOURI	356.4	250.5	42	E
RAMBAN	286.2	122.7	133	LE
REASI	1024.7	626.3	64	LE
SAMBA	720.5	319.5	126	LE
SHOPIAN	33.5	106.5	-69	LD
SRINAGAR	88.4	76.8	15	N
UDHAMPUR	900.3	347.1	159	LE
SUBDIVISION RAINFALL	310.7	184.9	68	LE

September: In September 2025, J&K met sub-division received 128.4 mm of rainfall against 95.6 mm of long period average which is in excess category (34% departure). Highest rainfall received in Reasi (actual rainfall 494.8 mm against normal rainfall 205.9 mm) followed by Udhampur (actual rainfall 294.7 mm against normal rainfall 175.7 mm) respectively. Thus in 2nd half of the monsoon (August and September), the sub-division received 439.6 mm of rainfall against 280.6 mm of long period average which is only 156% of LPA. District wise rainfall for the month of September is given in **Table 7.6**.

Table 7.6: District wise rainfall over J&K during September 2025

JK AND LADAKH (UT)	Actual Rainfall (mm)	Normal Rainfall (mm)	% Dep	Category
ANANTNAG	105.2	60.4	74	LE
BADGAM	51.3	46	11	N
BANDIPORE	20.8	28.7	-28	D
BARAMULA	26.2	38.5	-32	D
DODA	164.9	88.3	87	LE
GANDERBAL	67.4	65.2	3	N

JAMMU	174.7	114	53	LE
KARGIL	10.6	2.5	324	LE
KATHUA	128.5	198.2	-35	D
KISTWAR	89.8	88.3	2	N
KULGAM	110.5	71.3	55	LE
KUPWARA	27.9	36.3	-23	D
LADAKH (LEH)	19.4	6.6	194	LE
POONCH	22.8	128	-82	LD
PULWAMA	62.6	33.2	89	LE
RAJOURI	186.6	145	29	E
RAMBAN	209.7	89	136	LE
REASI	494.8	205.9	140	LE
SAMBA	100.5	147.6	-32	D
SHOPIAN	35.7	37.6	-5	N
SRINAGAR	82	41.4	98	LE
UDHAMPUR	294.7	175.7	68	LE
SUBDIVISION RAINFALL	128.4	95.7	34	E

7.4 Extreme weather events over J&K during monsoon 2025

The major extreme weather events over the met sub-division during the months of June, July, August and September 2025 along with associated impacts are given in **Table 7.7**.

Table 7.7: Extreme weather events and associated impact over J&K during monsoon 2025

Month June	DIST	NATURAL EVENTS	INTENSITY/ VISIBILITY	HUMAN		LIVESTOCK PERISHED	OTHER DAMAGES	ADDITIONAL REMARKS
				DEATHS	INJURIES			
2 nd June	Shopian	hailstorm	Great	-	-	-	Orchards	A residential house suffered damage in Krusan Lolab area of north Kashmir's Kupwara district after it was hit by a lightning.
4 th June	Kulgam	Cloud burst	Great	1	-	-	-	A woman died after a cloudburst hit the Damhal Hanjipora area in south Kashmir's Kulgam district.
26 th June	Rajouri	Cloud burst/Flashfloods	Great	3	-	-	-	Three persons, including two children, died as flash floods triggered by coudbursts and heavy rains

Month	DIST	NATURAL EVENTS	INTENSITY/ VISIBILITY	HUMAN		LIVESTOCK PERISHED	OTHER DAMAGES	ADDITIONAL REMARKS
				DEATHS	INJURIES			
July								
7 th	Poonch	Cloud burst	Great	1	-	-	-	A cloudburst occurred in Khori Wala Bela Bala of Loran tehsil in Poonch, Source: - PTI
10 th	Poonch	Landslides	Great	1	-	-	-	A girl was killed after a landslide triggered by rains in Poonch district . Source:- Greater Kashmir
21 st 184 mm	Reasi	Landslides	Great	1	10	-	-	A landslide struck the old track to the Vaishno Devi shrine in Reasi leaving one dead & at least four pilgrims injured. Source:- Greater Kashmir
21 st	Poonch	Landslides	Great	1	many	-	-	A tragic incident occurred in Kalsa Bhainch area of Poonch district after a landslide Source:- Greater Kashmir
23 rd 102 mm	Reasi	Landslides	Great	2	5	-	-	Reports from Reasi. Source:- Daily Excelsior

30 th 42 mm	Ramban	Flash floods	Great	2	-	-	-	A tragic incident unfolded in the Sanasar area of Ramban district, where two government teachers were swept away by flash floods while riding a motorcycle Source:- Greater Kashmir
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DATE & Rainfall	DIST	NATURAL EVENTS	INTENSITY	HUMAN		LIVESTOCK PERISHED	OTHER DAMAGES	ADDITIONAL REMARKS
				DEATHS	INJURIES			
August 1 st 3.7mm	Reasi	Landslides	Great	2	4	-	-	landslide hit the road stretch at Sulkh Pattian and debris fell over the vehicle. Source:- Greater Kashmir
5 th	Kulgam	Gusty Winds	Great	2	2	-	-	Two members of a nomadic family from Reasi district lost their lives and two others sustained injuries after strong winds uprooted trees that fell on their tent. Source:- Greater Kashmir
14 th	Kishtwar	Cloudburst/ Flashfloods	Great	63	38		Shops, Structures, vehicles, Roads, electric poles etc.	A massive cloudburst struck Chashoti, Source:- Daily Excelsior
14 th 138.2 mm	Rajouri	Heavy rain/ Landslides	Great	2	4	-	Structures etc.	Heavy rainfall caused widespread destruction across Rajouri district. Source:- Daily Excelsior

17 th 95 mm	Kathua	Cloudburst	Great	4	many	-	Structures,Railway track, Highway	Four persons were killed and several others injured after a cloudburst hit Ghati area of Kathua district. Source:- Kashmir News Corner
23 rd 90 mm	Kathua	Flash floods	Great	1	-	-	Vehicle (car)	At least one person was killed after a flash flood near Dreamland Park in Kathua district swept away a car, the vehicle has been pulled out of the rubble. Source:- Greater Kashmir
26 th 284 mm	Reasi	Landslides	Great	32	many	-	-	At least 32 people died & many injured in the Vaishno Devi landslide in Reasi district, triggered by heavy, relentless rains. Source:- Greater Kashmir
26 th 380 mm	Jammu	Heavy Rainfall	Local media	6				Heavy rainfall resulted 6 deaths in Jammu district due to drowning, flooding & collapse of Kachha house incidents.
30 th 16.8 mm	Ramban	Cloudburst	Great	3	-	-	-	A cloudburst accompanied by heavy rainfall struck the Rajgarh area of Ramban, resulting in the three persons losing life and causing several people to go missing. Source:- Kashmir News Corner
30 th 72 mm	Reasi	Landslides	Great	7	-	-	-	A family of seven died after a landslide, triggered by heavy rainfall, struck a residential house in Bhadder village of Mahore tehsil in Reasi district.. Source:- Kashmir News Observer

Month September	DIST	NATURAL EVENTS	INTENSITY/ VISIBILITY	HUMAN		LIVESTOCK PERISHED	OTHER DAMAGES	ADDITIONALREMARKS
				DEATHS	INJURIES			
2 nd	Anantnag	Lightning	Great	1	-	-	-	A teenage boy died after being struck by lightning in south Kashmir's Anantnag district. The 16-year-old boy was hit by lightning at Nawkhan near Margan Top, leading to his on-spot death.
2 nd	Jammu	Heavy rains	Great	1	-	-	Houses etc.	A man along with his vehicle was swept away by the strong currents of overflowing Nullah in Bantalab in Jammu after heavy downpour. Several houses were damaged in Akhnoor as the surging Chenab inundated villages along its embankments, including Kotli, Hamir, among others. The most affected village was Fattu Kotli in Garkhal.
3 rd	Rajouri	Gusty winds	Great	2	-	-	-.	A mother-daughter duo got buried under the debris of their Kachcha house, which collapsed in Kangri village of Sunderbani in Rajouri district amid heavy rains .

7.5 Withdrawal of southwest monsoon from J&K during 2025

Dry weather prevailed over Northwestern parts since 12th September. Monsoon in 2025 withdrew from western parts of northwest India on 13th – 14th September 2025 against the normal date of 17th September, 3-4 days prior to its normal withdrawal (Fig. 7.4). Establishment of an anti-cyclone in the lower tropospheric levels, substantial reduction in moisture content and prevalence of North-westerly dry winds indicated the withdrawal of southwest monsoon from many parts of J&K during last week of September.

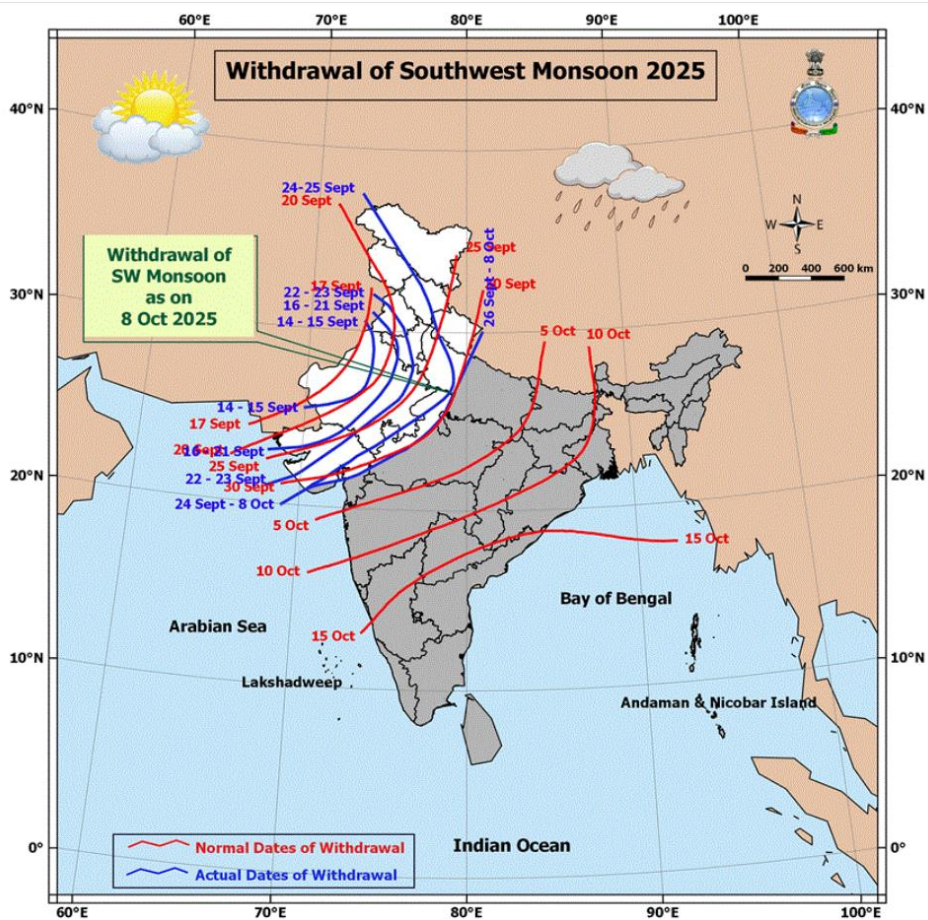
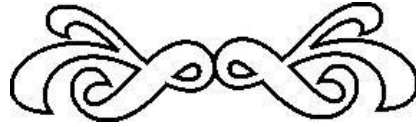


Fig. 7.4: Withdrawal of southwest monsoon 2025

8



INTENSE RAINFALL ACTIVITIES AND ASSOCIATED IMPACTS OVER HIMACHAL PRADESH DURING SOUTHWEST MONSOON 2025

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This chapter discusses the observed features of intense rainfall activities and associated impacts over meteorological sub-division of Himachal Pradesh during the southwest monsoon 2025.

8.1 Introduction

During the year 2025, the southwest monsoon advanced into Himachal Pradesh on 20 June 2025 and covered the entire state by 24 June 2025, which is one day earlier than the normal date (25 June). Over the past 29 years, the earliest onset was recorded on 09 June 2000, while the most delayed onset occurred on 05 July 2010.

The seasonal (June–September) rainfall over the state was excess, with 1022.5 mm recorded against the normal of 734.4 mm, representing a departure of +39% (**Fig. 8.1**). This ranks as the 15th highest seasonal rainfall in the last 125 years (1901–2025) and the highest in the past 29 years. The all-time highest seasonal rainfall remains 1314.6 mm recorded in 1922.

The withdrawal of the southwest monsoon commenced from parts of Himachal Pradesh on 24 September 2025 and was completed by 26 September 2025, which is one day later than the normal withdrawal date (25 September).

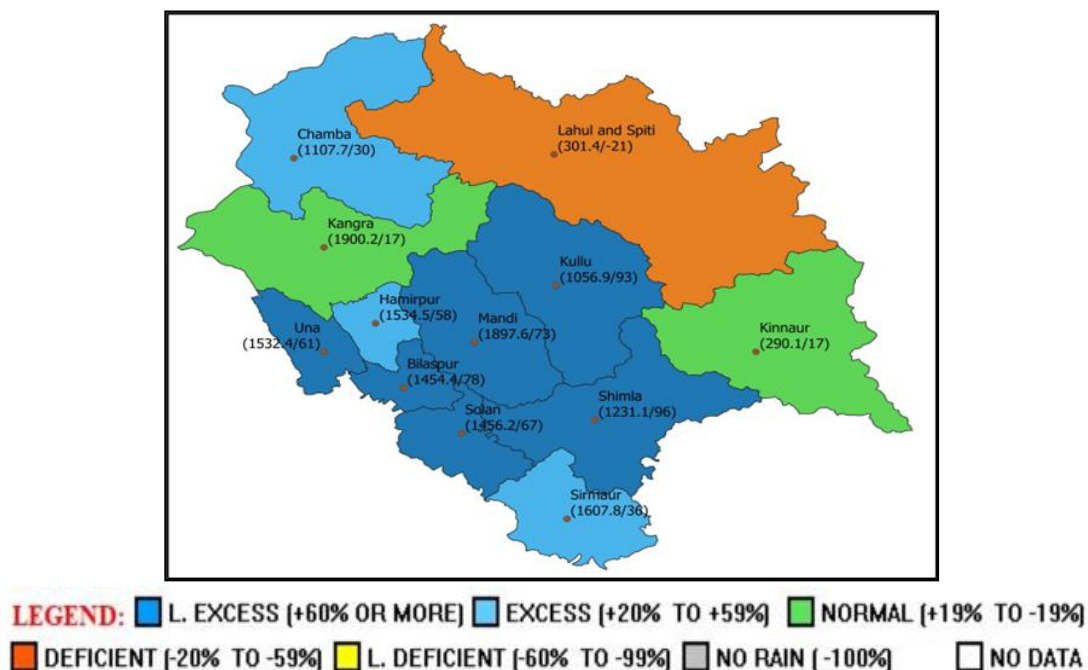


Fig. 8.1: Rainfall (mm) and percentage departure from Long Period Average over Himachal Pradesh.

8.2 Progress of Southwest Monsoon

8.2.1 June 2025

Himachal Pradesh experienced scattered to widespread precipitation on several days during June, with weak to normal monsoon activity prevailing on most days. Active monsoon conditions were observed on 8 days (04th, 05th, 17th, 18th, 21st, 25th, 26th, and 30th June), while vigorous activity occurred on 29th June 2025.

The state recorded 135.0 mm rainfall, which is 34% above normal (101.1 mm) and ranks as the 21st highest June rainfall since 1901. The highest June rainfall on record remains 252.7 mm (1971).

- Highest rainfall: Mandi (306.2 mm)
- Lowest rainfall: Lahaul-Spiti (22.5 mm)
- Highest positive departure: Hamirpur (+86%)
- Highest negative departure: Lahaul-Spiti (-53%)

District-wise distribution (**Fig. 8.2**):

- Large excess: Hamirpur, Mandi, Shimla, Solan, Sirmaur
- Excess: Bilaspur, Kangra, Kullu, Una
- Normal: Chamba
- Deficient: Remaining districts

Isolated hailstorm activity was reported over Chamba (03 June) and Shimla (03 and 05 June 2025). Episodes of heavy to very heavy rainfall were observed over several districts.

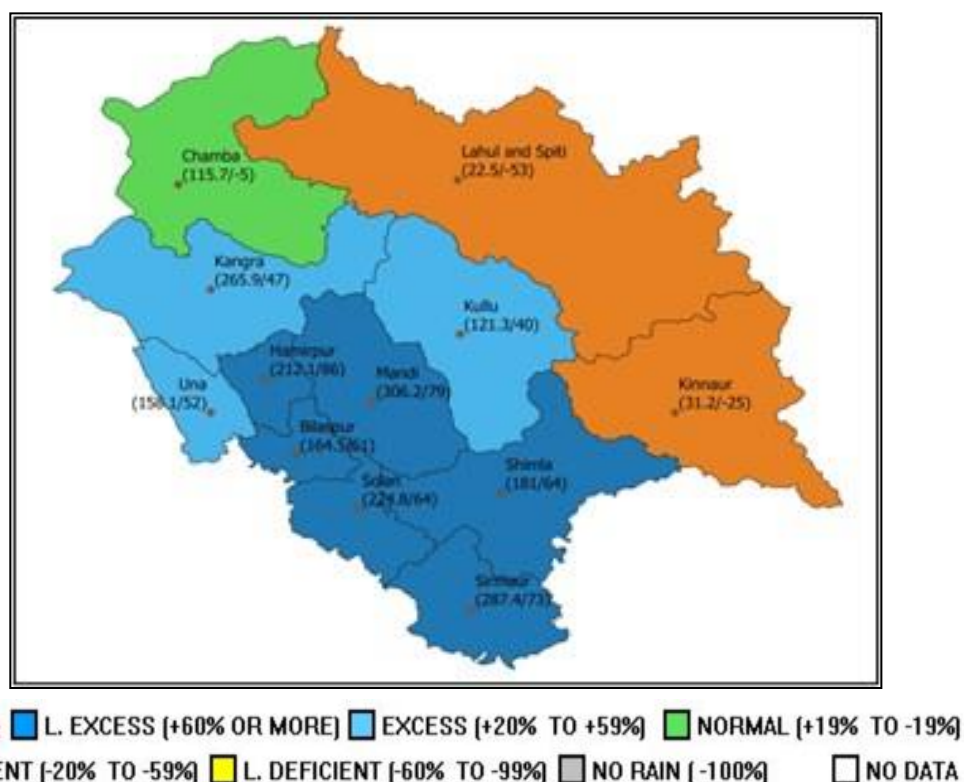


Fig. 8.2: Rainfall (mm) and percentage departure during June 2025

8.2.2 July 2025

During July, the state received scattered to fairly widespread precipitation, with active monsoon conditions on 5 days and vigorous activity on 01 July 2025.

The total rainfall was 250.3 mm, which is near normal (-2%) compared to 255.9 mm.

- Highest rainfall: Mandi (574.7 mm)
- Lowest rainfall: Lahaul-Spiti (32.2 mm)
- Highest positive departure: Shimla (+70%)
- Highest negative departure: Lahaul-Spiti (-75%)

District-wise classification (**Fig. 8.3**):

- Large excess: Shimla
- Excess: Kullu and Mandi
- Normal: Majority of districts
- Large deficient: Lahaul-Spiti

Extremely heavy rainfall events were recorded over Mandi district on 01 and 29 July 2025, along with multiple instances of heavy to very heavy rainfall across the state.

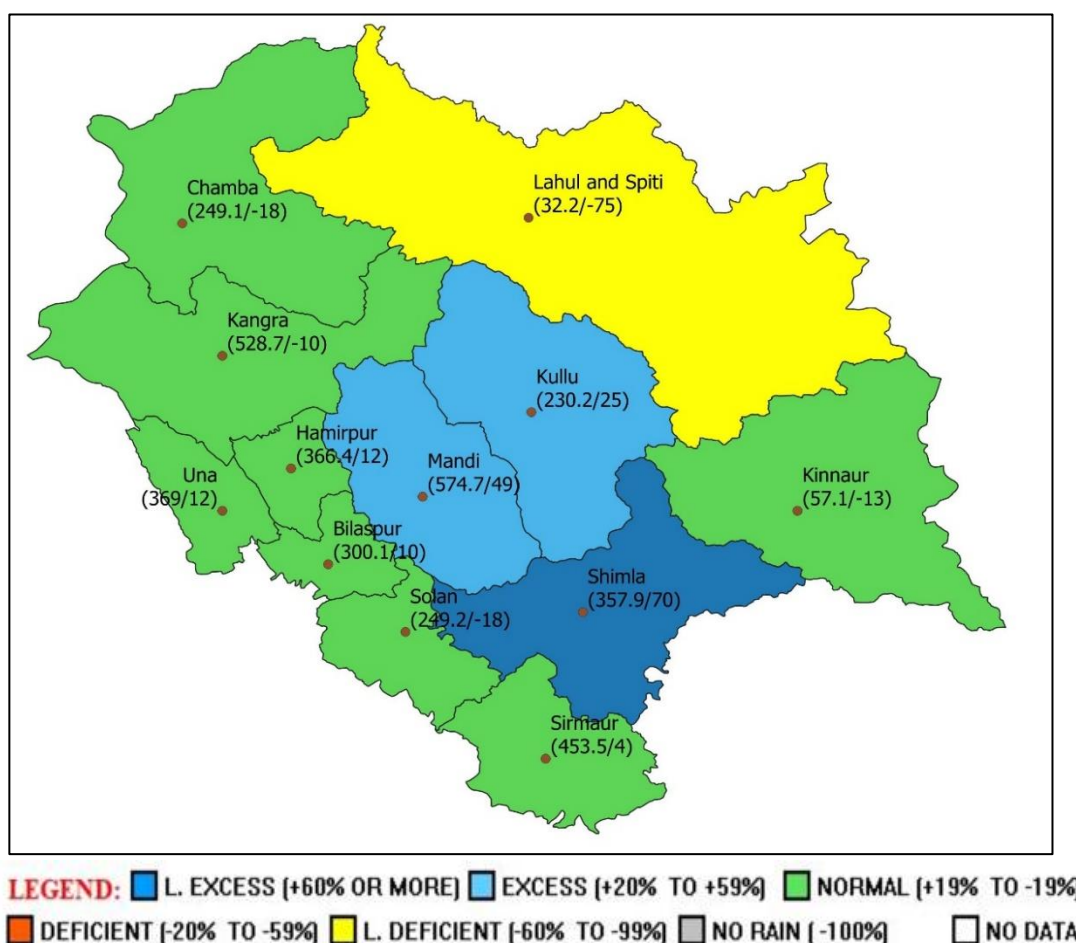


Fig. 8.3: Rainfall (mm) and percentage departure during July 2025

8.2.3 August 2025

August witnessed widespread precipitation with normal to active monsoon conditions on several days and vigorous activity on 25th and 26th August 2025.

The state recorded 431.3 mm rainfall, which is 68% above normal (256.8 mm). This is the 9th highest August rainfall since 1901 and the highest since 1949. The all-time highest August rainfall remains 542.4 mm (1927).

- Highest rainfall: Kangra (816.2 mm)
- Lowest rainfall: Lahaul-Spiti (129.7 mm)
- Highest positive departure: Kullu (+165%)

District-wise distribution (**Fig. 8.4**):

- Large excess: Bilaspur, Chamba, Kinnaur, Kullu, Mandi, Shimla, Solan, Una
- Excess: Hamirpur, Kangra, Sirmaur
- Normal: Lahaul-Spiti

An extremely heavy rainfall event was recorded over Una district on 02 August 2025, along with several heavy and very heavy rainfall episodes across the state.

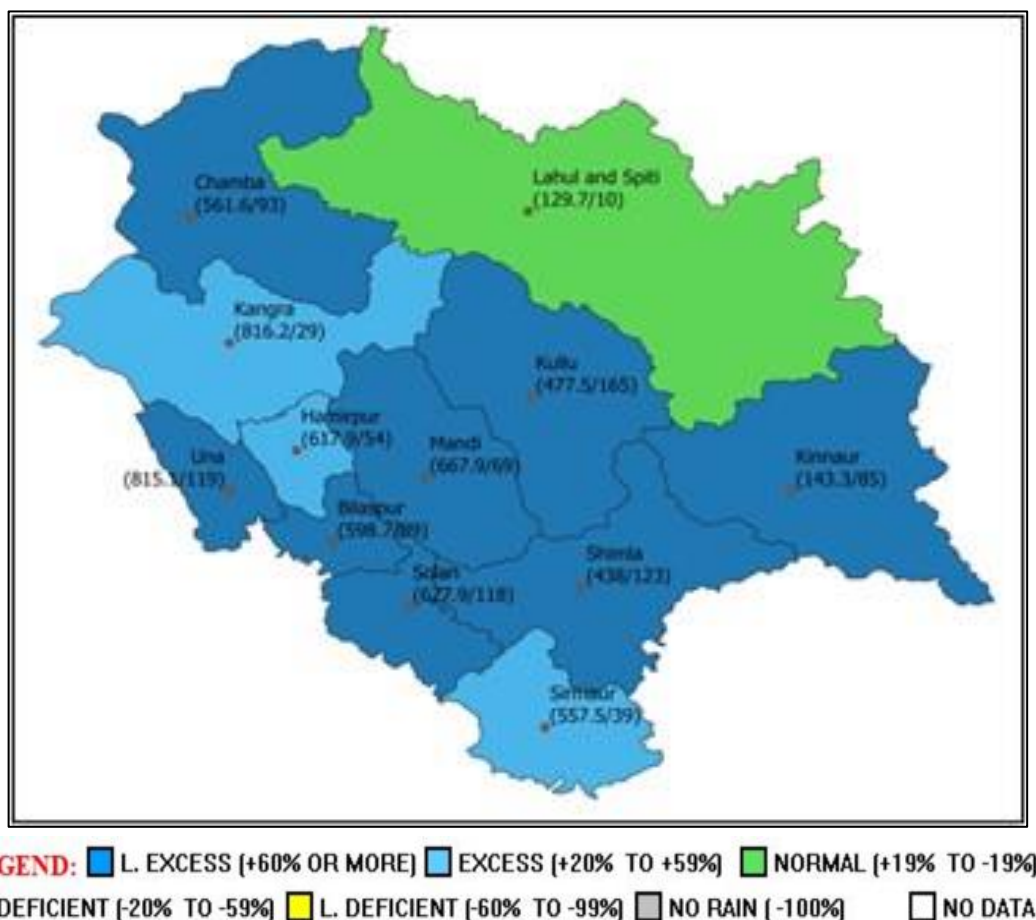


Fig. 8.4: Rainfall (mm) and percentage departure during August 2025

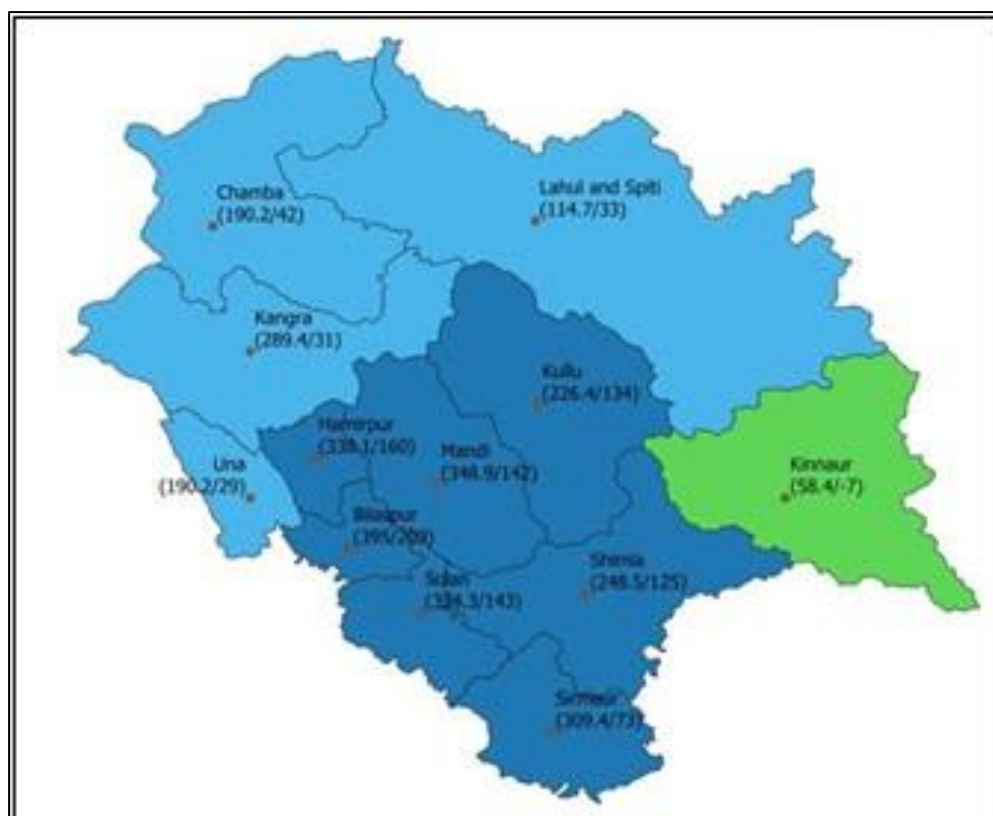
8.2.4 September 2025

In September, Himachal Pradesh recorded 205.7 mm rainfall, which is 71% above the normal value (120.6 mm).

District-wise distribution (**Fig. 8.5**):

- Large excess: Bilaspur, Hamirpur, Kullu, Mandi, Shimla, Sirmaur, Solan
- Excess: Chamba, Kangra, Lahaul-Spiti, Una
- Normal: Kinnaur

Extremely heavy rainfall events were recorded over Bilaspur (01 September) and Kangra (14 September 2025).



LEGEND: ■ L. EXCESS (+60% OR MORE) ■ EXCESS (+20% TO +59%) ■ NORMAL (+19% TO -19%)
 ■ DEFICIENT (-20% TO -59%) ■ L. DEFICIENT (-60% TO -99%) ■ NO RAIN (-100%) ■ NO DATA

Fig. 8.5: Rainfall (mm) and percentage departure during September 2025

8.3 Withdrawal of Southwest Monsoon

The southwest monsoon began withdrawing from parts of Himachal Pradesh on 24 September 2025 and completely withdrew from the state by 26 September 2025, which is slightly later than the climatological normal date.

8.4 Impacts Associated with Intense Rainfall

During the southwest monsoon season of 2025, Himachal Pradesh experienced a significant number of extreme rainfall events, including approximately:

- 9 extremely heavy rainfall events
- 96 very heavy rainfall events
- ~330 heavy rainfall events

These events triggered multiple landslides and flash floods across various parts of the state. The combined impact of intense rainfall, landslides, and flash floods resulted in:

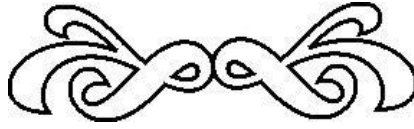
- Loss of human lives and injuries
- Damage to residential structures (both pakka and kutcha houses)
- Severe damage to physical infrastructure, including roads, bridges, and public utilities
- Substantial economic losses across affected regions

The 2025 monsoon season highlights the increasing vulnerability of Himachal Pradesh to extreme weather events, emphasizing the need for enhanced preparedness, resilient infrastructure, and improved early warning systems.

8.5 Conclusion

The southwest monsoon of 2025 over Himachal Pradesh was marked by excess seasonal rainfall, frequent intense precipitation events, and widespread impacts. The season ranks among the most significant in recent decades, both in terms of rainfall magnitude and associated damages. Strengthening disaster risk reduction strategies and improving forecasting capabilities remain critical for minimizing future impacts in this ecologically sensitive Himalayan region.

9



INTENSE RAINFALL ACTIVITIES AND ASSOCIATED IMPACTS OVER UTTARAKHAND DURING SOUTHWEST MONSOON 2025

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This chapter discusses the observed features of intense rainfall activities and associated impacts over Uttarakhand during the southwest monsoon 2025.

9.1 Introduction

Southwest monsoon (June to September) is the principal rainy season for Uttarakhand. The state receives 1162.7 mm average rainfall during the monsoon season, which is around 80% of total annual rainfall. The annual average rainfall of Uttarakhand is 1478 mm. Rudraprayag district experiences highest average monsoon rainfall of about 1549 mm. District-wise average monsoon rainfall of Uttarakhand is depicted in **Fig. 9.1** and the month-wise average rainfall of Uttarakhand State is shown in **Fig. 9.2**.

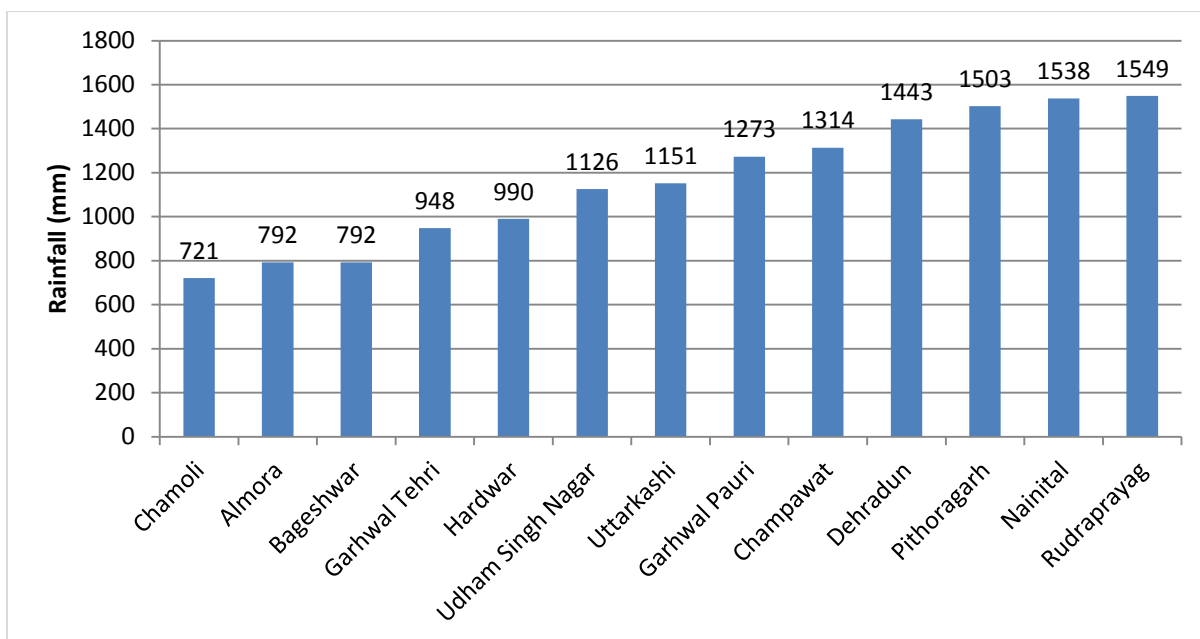


Fig. 9.1: District-wise average monsoon rainfall of Uttarakhand (1971-2020)

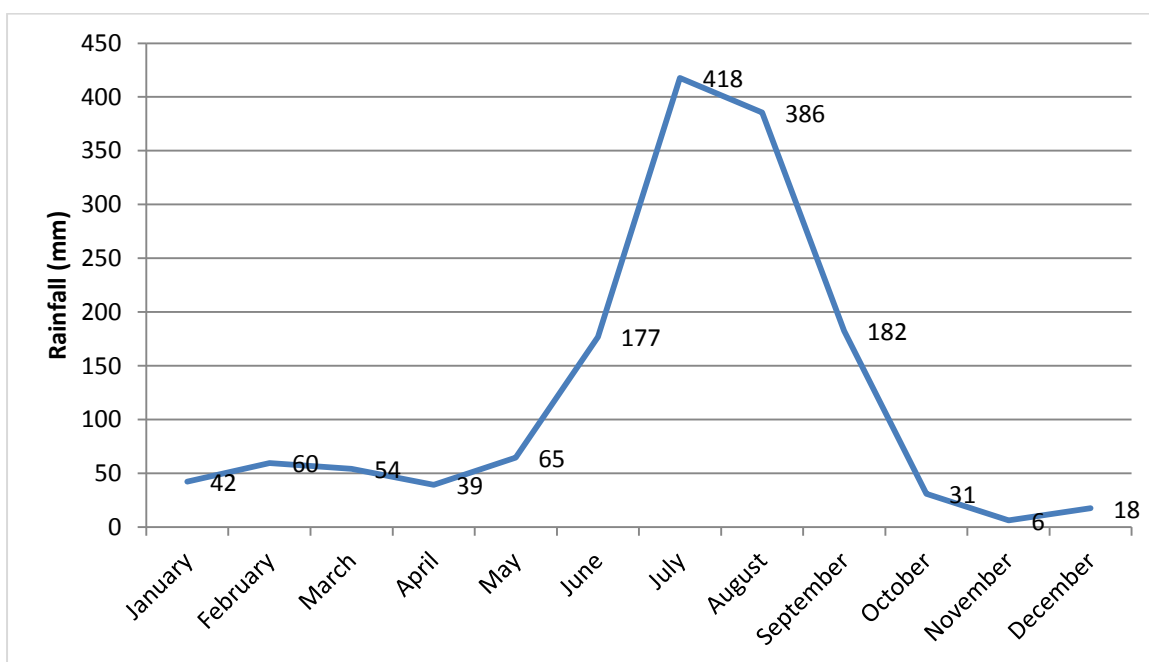


Fig. 9.2: Month-wise average rainfall of Uttarakhand State

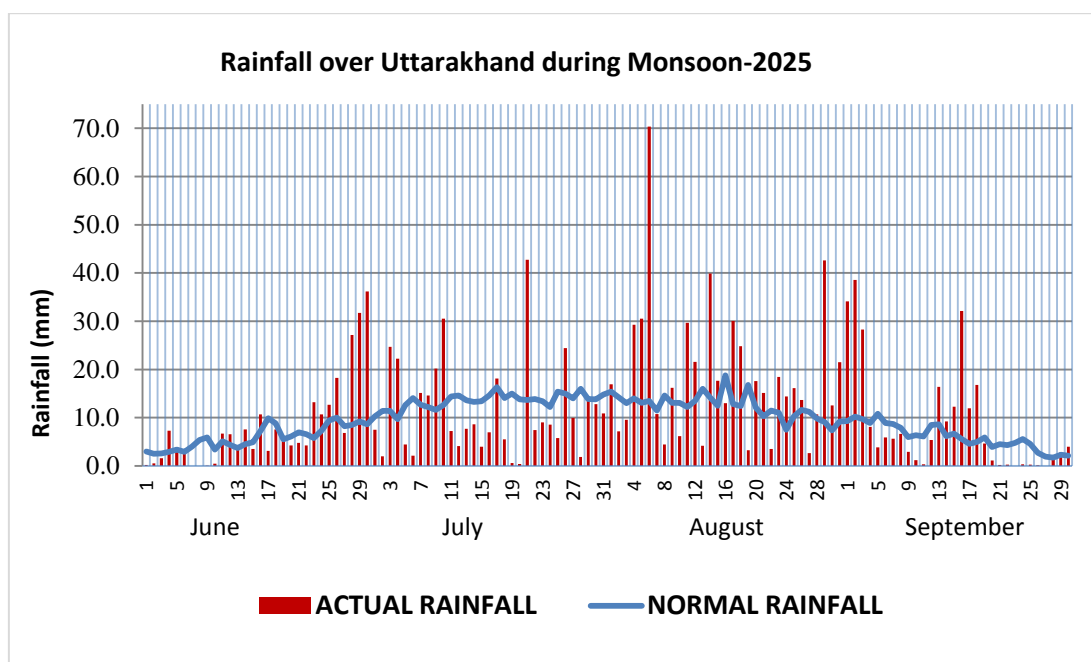
9.2 Rainfall activity during Monsoon 2025

The southwest monsoon 2025 advanced into many parts of Uttarakhand on 20th June, 2025 and covered the entire Uttarakhand State on 24th June 2025. The rainfall observed (1420.5 mm) from June to September for the state as a whole was excess (122%) as compared to the long period average (LPA) of 1162.7mm. The seasonal rainfall intensity distribution over the State was in the categories of large excess, excess, normal and deficient.

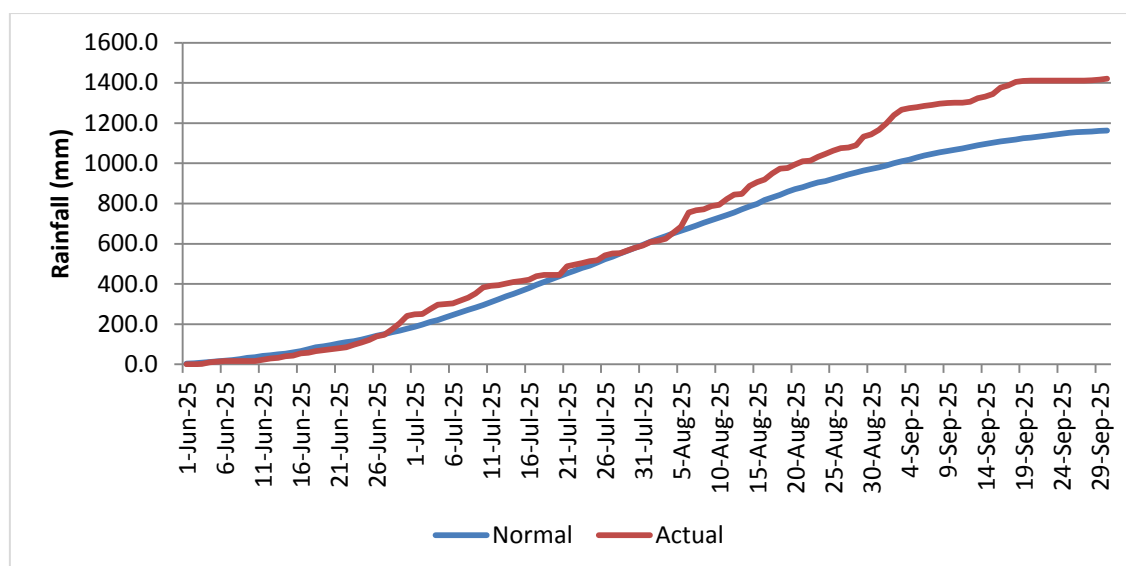
Out of 13 districts of Uttarakhand, 02 districts (Bageshwar & Chamoli) received large excess, 05 districts (Almora, Dehradun, Tehri Garhwal, Haridwar & Udham Singh Nagar) received excess, 05 districts (Champawat, Nainital, Pithoragarh, Rudraprayag & Uttarkashi) received normal and 01 district (Pauri Garhwal) received deficient seasonal rainfall. In terms of area, 53% area received excess to large excess rainfall, 39% area received normal rainfall and 8% area received deficient rainfall. Monthly rainfall over Uttarakhand as a whole was 136% of LPA in June, 84% of LPA in July, 149% of LPA in August and 140% of LPA in September. The amount of rainfall (in terms of % of LPA) was maximum in August month and minimum in July month.

The day-to-day comparison of the actual and normal rainfall of Uttarakhand state as a whole is shown in **Fig. 9.3(i)**. The State received 30 mm or more average daily rainfall on 12 occasions during the season. The State received highest average daily rainfall of 70.3 mm on 06th August 2025. The daily cumulative actual and normal rainfall of Uttarakhand is shown in **Fig. 9.3(ii)**. The cumulative rainfall was less than the LPA till last week of June, thereafter the rainfall increased and the cumulative rainfall become more than normal and remained so till third week of July and the cumulative rainfall become near normal till 05.08.2025. Thereafter, the rainfall increased steeply reaching 22% above LPA by end of September 2025.

District-wise analysis shows that the maximum number of rainfall days was over Bageshwar district (114 days) and minimum number of rainfall days was over Haridwar district (80 days). Widespread to fairly widespread rainfall occurred on 96 days (maximum) over Bageshwar district and 51 days (minimum) over Haridwar district.



(i)



(ii)

Fig. 9.3: (i) Daily actual and normal rainfall and (ii) daily cumulative actual and normal rainfall of Uttarakhand state as a whole

9.2.1 Heavy or more rainfall during Monsoon 2025

During June to September 2025 a total of 776 number of heavy or more rainfall observations were reported by Manual & AWS/ARG stations of IMD, State Government and Central Water Commission (CWC) in Uttarakhand. Out of this maximum number of 362 heavy or more rainfall observations were recorded in the month of August. The number of stations reporting each category of heavy or more rainfall i.e. heavy, very heavy and extremely heavy rainfall is given in **Table 9.1**. The date-wise list of stations reporting heavy or more rainfall is shown in **Table 9.2**.

Table 9.1: Number of stations reported heavy or more rainfall during June to September 2025

Month	Number of stations reported heavy or more rainfall	Number of stations reported heavy rainfall	Number of stations reported very heavy rainfall	Number of stations reported Extremely heavy rainfall
June-2025	121	102	19	-
July-2025	156	134	21	1
August-2025	362	261	93	8
September-2025	137	101	31	5

Source of data: Manual & AWS/ARG stations of IMD, State Government and CWC

Table 9.2: Date-wise list of stations reporting Heavy, Very Heavy and Extremely heavy rainfall during (i) June, (ii) July, (iii) August and (iv) September 2025

Date	Stations with Heavy to Extremely Heavy Rainfall (mm)	Number of stations reporting			
		Heavy or more rainfall	Heavy rainfall	Very heavy rainfall	Extremely heavy rainfall
11-Jun-25	Sama-90.0, Rameshwar-76, Ukhimath-71.0, Pithoragarh_Kvk-76.0, Shama_AWS-87.0	5	5	-	-
12-Jun-25	Chamoli-88.2, Sama -69.0, Shama_AWS-67.0, Loharkhet-67.0, Song-72.0, Agastyamuni-64.0	6	6	-	-
14-Jun-25	Kaladhungi-91.0	1	1	-	-
16-Jun-25	Mohkampur-65.2, Asharori-94.5, Sahastradhara_lti-70.0	3	3	-	-
18-Jun-25	Kalagarh -106.4	1	1	-	-
19-Jun-25	Chorgalia_UKG-66.0	1	1	-	-
21-Jun-25	Narendranagar-81.5, Kalsi -71.5	2	2	-	-
22-Jun-25	Gaurikund-69.2, Roorkee-67.0, Niranjanpur-67.0	3	3	-	-
23-Jun-25	Loharkhet-107.0, Kapkot-106.2, Sama-103.0, Chamoli-93.6, Song-96.0, Shama_AWS-97.5	6	6	-	-
24-Jun-25	Sama-118.0, Sama_AWS-111.0, Haripur-100.0, Rudraprayag-78.8, Nainital (Snow view)-75.0, Rudra_Pr prayag-100.5, Bhikiyasain-69.0	7	6	1	-
25-Jun-25	Haldwani-129.2, Loharkhet-66.0, Chorgalia-88.0, Haldwani_AWS-74.0	4	3	1	-
26-Jun-25	Banbasa-81.0, Loharkhet-78.0, Bangapani-78.0, Kapkot-75.0, Purola-68.0, Mori_AWS -84.5, Kosani-76.5, Song-71.0	8	8	-	-
27-Jun-25	Loharkhet-83.0, Song-75.0	2	2	-	-
28-Jun-25	Chamoli-185.4, Jollygrant-169.2, Sama-145.0, Loharkhet-138.0, Kapkot-118.0, Dehradun-97.8, Narendra Nagar-75.5, Rudraprayag-74.5, Jollygrant-148.5, Shama-142.0, Song-117.0, Mohakampur-94.5, Sankri-87.0, Lansdown-86.0, Maldevta-81.0, Satpuli-76.0, Budha	21	13	8	-

	Kedar-74.5, Hatibharkala-72.5, Asharori-71.0, Dehradun-70.5, Narendra Nagar -70.0				
29-Jun-25	Ganganagar-193.2 ,Narendra Nagar -167.5, Jollygrant-150.4,Rishikesh- 113.3,Dehradun(CWC)-113.3, Kotdwar-98, banbasa-90.0, Dhanolti-85.0, Mussoorie- 76.1,Jhakoli-76.0,Devprayag-74.2,Dehradun- 71.0, Lansdown-70, Nandkaseri-67.2, Karanprayag-65, Sahastradhara_Iiti-157.0, Narendra Nagar-142.0,Jollygrant- 131.0,Maldevta-123.5,Agastyamuni-107.0, Rikhnikhal-102.0, Hatibharkala-101.5, Kanda- 85.0, Tharali-79.0, Sult-78.5, Lansdown-77.5, Utt. Tech. Uni.-70.5, Niranjanpur-69.0, Jakholi- 66.5, Mohakampur-66.0	30	23	7	-
30-Jun-25	Devprayag-173.2, Barkot-111.0, Purola-105.0, Dhanaulti-100.0, Lansdown-78.0, Bhatwari- 73.0, Uttarkashi-72.0, Tehri_CWC-69.3, Dehradun-68.5, Jollygrant-65.6, Hatibharkala- 127.5, Barkot-115.0, Sahastradhara_Iiti-111.0, Dhanolti-102.0, Lansdown-101.0, NarendraNagar -95.5, Maldevta-95.0, Kanatal- 84.5, Dehradun-75.0, Utt. Tech. Uni.-68.5, Mohakampur-65.0	21	19	2	-
Total Number of Heavy or more events in month of June		121	102	19	-
2025					

(i)

Date	Stations with Heavy to Extremely Heavy Rainfall (mm)	Number of stations reporting			
		Heavy or more rainfall	Heavy rainfall	Very heavy rainfall	Extremely heavy rainfall
3-Jul-25	Loharkhet-132.0, Shama-120.0, Kapkote-68.0, Didihat-65.0, Koti-187.0, Song-118.0, Shama- 106.0, Dewal-105.0, Soneprayag-97.0, Karnaprayag-89.0,Berinag-77.5, Chakrata-69.0, Didihat-67.0	13	9	4	-

4-Jul-25	Jakholi-80.0, Maneri-67.0, Sama-65.0, Dangoli-111.0, Kosani-88.5, Jakholi-77.0	6	6	-	-
7-Jul-25	Loharkhet-173.0, Sama-125.0, Tejam-120.0, Bangapani-82.0, Tehri-81.4, Shama-111.0, New Tehri-94.0, Rani Mazra-74.5	8	5	3	
8-Jul-25	Narendra Nagar-110.0, Rishikesh-95.4, Dharchula-93.2, Loharkhet-93.0, Bangapani-72.0, Jollygrant-66.8, Sama-65.0,	7	7	-	-
9-Jul-25	Sama-107.0, Loharkhet-93.0, Haldwani-88.0, Uttarkashi-77.0, Uttarkashi (Cwc)-75.6, Song-116.0, Shama-100.0, Nainital-78.0	8	7	1	-
10-Jul-25	Mussoorie-130.2, Shukratal-129.8, Kapkot-124.0, Kathgodam-114.2, Dharasu-105.0, Mukteshwar-96.6, Ranikhet-96.0, Dunda-88.0, Bangapani-88.0, Dhanolti-80.0, Khatima-78.0, Nainital-76.5, Sama-75.0, Narendranagar-74.0, Banbasa-72.0, Mohkampur-71.2, Rudraprayag-70.8, Marora-68.6, Ganganagar-66.2, Chinyalisaur-65.0, Hatibharkala-118.5, Maldevta-116.0, Dehradun-106.0, Kanatal-94.0, Kapkote-93.0, Dhanolti-87.5, Rikhnikhal-86.0, Sahastradhara_Iti-85.0, Kashipur-84.0, Jaspur-83.5, Gadarpur-82.0, Satpuli-81.5, Kashipur_Aws400-79.5, Mukteshwar-76.5, Ucost-71.5, Khatima-70.0, Sultanpur Patti-68.5, Shama-68.5, Mohakampur-67.0, Lansdown-65.5	40	35	5	-
14-Jul-25	Lansdown-76.0, Sahastradhara_Iti-71.0, Hatibharkala-69.5	3	3	-	-
16-Jul-25	Haripur-216.6, Mussoorie-79.4, Kalsi -203.0, Koti-101.0, Maldevta-68.5	5	3	1	1
17-Jul-25	Haridwar-166.3, Pantnagar-97.8, Mussoorie-80.2, Kalsi -90.5, Pantnagar_Amfu-86.5, Hatibharkala-66.5	6	5	1	-
21-Jul-25	Banbasa-161.0, Bhagwanpur-95.0, Haridwar-93.2, Haldwani-90.0, Lansdown-88.0, Didihat-86.8, Dakpatthar- 85.2, Chaukhutiya-82.0, Nandkeshri-78.2, Devprayag-75.6, Mussoorie-74.4, Dehradun-73.5, Rishikesh-72.2, Koteshwar-71.4, Kotdwar-70.0, Karnprayag-67.6, Sama-67.0, Lansdown-120.0, Bastia-120.0, Tanakpur-108.0,	38	35	3	-

	Utt. Tech. Uni.-101.0, UCOST-97.5, Chaukhutiya-96.5, Liti-85.0, Sahastradhara_Iti-81.5, Chorgalia-80.0, Kosani-79.5, Dangoli-79.5, Hatibharkala-78.5, Rikhnikhal-74.5, Didihat-74.5, Mohakampur-71.5, Sult-70.0, Haldwani-69.5, Kalsi-67.0, Kanda-67.0, Vikas Nagar-66.5, Dhanolti-64.5				
22-Jul-25	Bhagwanpur-65.0	1	1	-	-
23-Jul-25	Didihat-118.0, Dharchula-92.2, Thal-90.5, Jauljibi-88.0, Thal-80.0, Ganai Gangoli-66.5	6	5	1	
26-Jul-25	Ganganagar-126.8, Mori-89.0, Loharkhet-87.0, Kapkot-74.0, Mori -113.0, Agastyamuni-76.0, Song-67.5, Hatibharkala-65.0	8	7	1	-
27-Jul-25	Shama-122.0, Loharkhet-93.0, Kapkote-78.0, Dharchula-66.0	4	3	1	-
29-Jul-25	Jollygrant-68.4, Narendra Nagar -78.5, Jollygrant-76.0	3	3	-	-
Total Number of Heavy or more events in month of July 2025		156	134	21	1

(ii)

Date	Stations with Heavy to Extremely Heavy Rainfall (mm)	Number of stations reporting			
		Heavy or more rainfall	Heavy rainfall	Very heavy rainfall	Extremely heavy rainfall
2-Aug-25	Kashipur_Aws400-95.0	1	1	-	-
3-Aug-25	Tejam-120.0, Bangapani-116.0, Kaladhungi-90.0, Sama-82.0, Haldwani-146.5, Ramnagar-96.5, Liti-88.0, Shama-71.0	8	5	3	-
4-Aug-25	Kotdwar-170.0, Tejam-160.0, Loharkhet-138.0, Sama-137.0, Bangapani-136.0, Haldwani-129.2, Narendra Nagar-115.0, Kalagarh-111.0, Haridwar-103.0, Rishikesh-89.4, Chamoli-86.6, Lansdown-80.0, Dehradun-78.5, Bhagwanpur-70.0, Munsiyari-69.6, Didihat-68.4, Khatima-65.0, Hatibharkala-174.5, Liti-153.0, Lansdown-150.0, Narendra Nagar -132.0, Shama-120.0, Kalsi -112.0, Song-87.5, Narayan Ashram-81.0, Sahastradhara_Iti-77.5, Mohakampur-74.5	27	16	11	

5-Aug-25	Haridwar-304.0, NarendraNagar-172.5, Rishikesh -145.2, Jollygrant -135.2, Kotdwar -122.0, Roshnabad - 95.0, Laksar -85.0, Roorkee -84.7, Dehradun -77.6, Haripur -70.8, Kashipur -70.0, Ucost-132.0, Narendra Nagar -131.5, Jollygrant-123.5, Utt. Tech. Uni.-112.0, Yamkeshwar-97.5, Mohakampur-75.0	17	10	6	1
6-Aug-25	Haridwar-222.2, Narendra nagar-205.0, Rishikesh-193.6. Kichha-185.0. Kashipur-177.0. Jollygrant-175.2 Bageshwar-165.0. Roshnabad-165.0, Pantnagar-155.2. Raysi-152.0. Jaspur-150.0. Haldwani-141.2, Jan Ki_Chattj 138.0. Someshw.ar-116.0 Laksar-135.0, Nainital-131.7, argani-130.0. Satyanarayan-119.6; Pauri-112.0. Kaladhungi-112.0, Kotdwar-111.0, Mukteshwar-107.4. Loharkhet-107.0. Dianaulti-105.0. Betalghat-105.0, Rameshwar-103.0, Maneri-103.0, Sama-102.0, Dharasu-101.0, Marora-101.0, Kapkot-100.0, Rudrapur-99.0, Chorgaliya-98.0, Kainchi Dham-97.3, Gairsain-96.0, Koteswar-94.0, Roorkee-92.8, Devprayag-90.5, Khansyu-90.0, Srinagar-89.2, Rudraprayag-87.8, Khatima-86.0, Dehradun-83.4, Lansdown-80.0, Gadarpur-80.0, Berinag-78.2, Kuthnaur-78.0, Birahi-77.6, Bajptw-75.0, Chaulthutiya-75.0, Keertinagar-75.0, Lohaghat-71.6, Banbasa-70.0, Bhagwanpur-70.0, Champawat-68.0, Maldevta-265.0, Narendra Nagar -230.0, Bajpur-213.0, Kichha-183.0, Kashipur_Aws400-181.5, Sultanpur Patti-176.0, Sahastradhara_Iti-173.0, Ganai Gangoli-164.0, Kanda-164.0, Kashipur-160.0, Yamkeshwar-156.0, Jaspur-155.0, Jollygrant-155.0, Gadarpur-150.0, Gular Bhoj-150.0, Jasur-150.0, Takula-144.0, Parpunda_Khal-139.0, Dangoli-131.0, Pantnagar_Amfu-131.0, Sult-124.0, Rikhnikhal-118.0, Hatibharkala-113.5, Satpuli-113.5, Kosani-110.0, Rudrapur-109.0, Berinag-108.0, Bhimtal-108.0, Liti-	107	67	35	5

107.0, Nainital-107.0, Chorgalia-106.0, Pauri-99.5, Th_Kosiyakutoli-99.0, Betalghat-96.5, Shama-96.0, Lansdown-94.0, Tanakpur-90.0, Mukteshwar-88.5, Bastia-85.0, Haldwani-83.5, Ramnagar-83.5, Jageshwar-82.5, Kirtinagar-82.5, Jainti-81.0, Mohakampur-79.5, Song-79.0, Chaukhutiya-78.5, Gangolihat-77.0, Lohaghat-75.5, Syunsi -74.5, Champawat-73.5, Bhainsiya Chhana -69.0

8-Aug-25	Kalsi -103.0, Haripur-71.0 , Sahastradhara_Iiti-65.5	3	3	-	-
9-Aug-25	Rudrprayag-104.6, Maldevta-104.0, Sahastradhara_Iiti-70.5	3	3	-	-
10-Aug-25	Liti-75.0	1	1	-	-
	Haridwar-242.4, Roshnabad-140.0, Bhagwanpur-120.0, Sama-106.0, Loharkhet-94.0, Didihat-83.0, Jollygrant-78.2, Roorkee-76.4, Nainital-69.5, Dehradun-67.8,	22	18	3	1
11-Aug-25	Karnprayag-67.6, Kaladhungi-126.0, Maldevta-100.5, Yamkeshwar-100.0, Narendra Nagar -95.5, Ramnagar-94.0, Hatibharkala-73.0, Song-72.0, Bajpur-71.5, Gochar-70.5, Didihat-70.5, Mohakampur-68.0				
12-Aug-25	Sahastradhara_Iiti-185.0, Maldevta-182.0, Hatibharkala-163.5, Dhanaulti-100.0, Mori-96.0, Narendra Nagar-87.5, Dehradun-65.1, Tehri (Cwc)-64.8, Sahastradhara_Iiti-185.0, Maldevta-182.0, Hatibharkala-163.5	11	5	6	-
13-Aug-25	Haripur-75.4	1	1	-	-
14-Aug-25	Haridwar-201.4, Pantnagar-178.2, Haldwani-163.0, Nainital-127.7, Kotdwar-123.0, Mukteshwar-92.0, Chaukhutiya-91.0, Bageshwar-82.0, Rameshwar-78.0, Rishikesh-77.6, Lohaghat-77.4, Roshnabad-70.0, Kashipur-70.0, Champawat-65.0, Chorgalia-309.0, Pantnagar_Amfu-193.0, Haldwani-169.5, Gular Bhoj-153.0, Gadarpur-113.0, Bhimtal-110.0, Rudrapur(Ukg)-105.0, Chaukhutiya-98.0, Champawat-96.5, Kichha-91.0, Mukteshwar-88.0, Champawat-86.5,	37	28	8	1

	Takula -80.5, Jainti-80.5, Bageshwar-76.5, Kanda-74.0, Dangoli-73.0, Pancheshwar-72.5, Kashipur_Aws400-70.0, Th_Kosiyakutoli-68.0, Berinag-67.5, Utt. Tech. Uni.-66.0, Ucost-66.0				
16-Aug-25	Rishikesh -106.6, Loharkhet -86.0, Sama -75.0, Narendra Nagar-70.0, Didihat -64.8, Tapovan-79.5, Didihat-78.0, Narendra Nagar -77.0, Shama-66.5	9	9	-	-
17-Aug-25	Dangoli-117.0, Jakholi-92.0, Liti-92.0, Hatibharkala-88.0, Barkot-86.5, Tharali-82.5, Shama-82.5, Maldevta-80.5, Thal-73.0, Bageshwar-72.0, Kanda-70.5, Sahastradhara_Iti-69.5, Didihat-67.0, Sama-92.0, Jakholi-84.0, Mori-82.0, Dhanaulti-80.0, Loharkhet-78.0, Didihat-77.4, Uttarkashi-76.0, Bageshwar-75.0, Nandkesri-74.2, Barkot-74.0, Mussoorie-71.3, Uttarkashi_CWC-70.2, Laksar-70.0	26	25	1	
18-Aug-25	Narendra Nagar-106.0, Devprayag-94.2, Roorkee-89.6, Srinagar-81.8, Tehri-80.4, Tehri (Cwc)-68.5, Haridwar-67.2, Dhanaulti-67.0, Chakrata-94.0, Narendra Nagar -86.5, Yamkeshwar-80.5, New Tehri-76.5	12	12	-	-
20-Aug-25	Uttarkashi-131.0, Uttarkashi_CWC-130.6, Loharkhet-92.0, Dharchula-82.4, Ranikhet-77.0, Maneri-67.0, Kanda-96.0, Shama-91.0, Song-82.5	9	7	2	
21-Aug-25	Tanakpur-147.0, Liti-134.0, Bastia-111.0, Maldevta-71.5, Banbasa-117.0, Sama-100.0	6	3	3	
23-Aug-25	Sama-192.0, Loharkhet-183.0, Bhagwanpur-110.0, Jollygrant-105.4, Roorkee-85.0, Kapkot-76.0, Shama-153.0, Tharali-147.0, Song-146.5, Thal-97.0, Jollygrant-94.0	11	6	5	-
24-Aug-25	Loharkhet-94.0, Uttarkashi_CWC-85.4, Uttarkashi-65.0, Jan_Ki_Chatti-65.0	4	4		
26-Aug-25	Jan Ki Chatti-80.0, Nainital-75.5	2	2	-	-
27-Aug-25	Kalsi-65.5	1	1	-	-
28-Aug-25	Pantnagar-113.2, Sultanpur Patti-94.5, Thal-92.5, Bajpur-77.0	4	4	-	-

29-Aug-25	Haripur-177.0, Kapkot-140.0, Karnprayag-135.8, Jakholi-128.0, Ukhimath-125.0, Sama-119.0, Dharchula-112.4, Khatima-112.0, Chamoli-104.6, Roshnabad-100.0, Loharkhet-99.0, Didihat-84.6, Nanadprayag-80.0, Chakrata-78.0, Nandkeshri-76.4, Banbasa-73.6, Ganganagar-73.2, Kalsi -143.5, Jakholi-142.0, Karnaprayag-112.5, Tanakpur-110.0, Shama-107.0, Koti-100.5, Liti-99.0, Chakrata-93.0, Song-88.5, Khatima-81.0, Bastia-76.0, Agastyamuni-71.5, Didihat-71.5,	30	22	8	-
31-Aug-25	Banbasa-160.4, Rishikesh-118.3, Pantnagar-108.8, Khatima-84.5, Uttarkashi_CWC-77.4, Kapkot-65.0, Pantnagar_Amfu-94.0, Didihat-80.0, Rudrapur_UKG-67.5, Shama-65.0	10	8	2	-
Total Number of Heavy or more events in month of August 2025		361	260	93	8

(iii)

Date	Stations with Heavy to Extremely Heavy Rainfall (mm)	Number of stations reporting			
		Heavy or more rainfall	Heavy rainfall	Very heavy rainfall	Extremely heavy rainfall
1-Sep-25	Banbasa-256.4, Khatima-181.0, Chakrata-127.0, Purola-120.0, Tanakpur-174.0, Bastia-170.0, Koti-152.0, Chakrata-146.0, Devidhura-129.0, Khatima-120.5, Keertinagar-95.0, Jan_Ki_Chatti-95.0, Tiuni-92.4, Haripur-93.2, Mussoorie-78.4, Champawat-78.0, Mukteshwar-75.6, Jollygrant-72.4, Rameshwar-72.0, Kuthnaur-70.0, Barkot-67.0, Jainti-111.5, Kalsi -90.5, Kichha-82.5, Nainbagh-82.0, Pati-81.0, Champawat-80.5, Jageshwar-80.0, Bhainsiya_Chhana-70.0, Mukteshwar-69.0, Naugaon-69.0, Maldevta-66.0	32	22	9	1
2-Sep-25	Haldawani-116.6, Chorgalia-118.0, Mukteshwar-98.4, Khatima-92.5,	29	27	2	0

	Betalghat-85.0, Munsiyari-82.4, Rameshwar-77.0, Bhagwanpur-75.0, Pithoragarh-74.1, Kashipur-69.5, Almora- 68.2, Lohaghat-65.2, Nainital-114.0, Th_Kosiyakutoli-98.0, Bhimtal-91.0, Dangoli-87.0, Pati -86.5, Chaubatia_Ranikhet-86.0, Mukteshwar- 79.5, Khatima-79.5, Jainti-78.5, Sitlakheth- 78.0, Jageshwar-75.5, Ganai Gangoli- 72.5, Nainidanda-71.5, Devidhura-70.0, Kashipur_Aws400-69.5, Bajpur-69.5, Champawat-65.0,				
3-Sep-25	Khatima-142.0, Banbasa-122.0, Nainital- 107.5, Haldwani-84.2, Mussoorie-64.7, Jan_Ki_Chatti-95.0, Nainidanda-65.0, Khatima-96.5, Chorgalia-96.5, Haldwani- 68.5, Nainital-65.0, Koti-72.5,	12	10	2	0
4-Sep-25	Jan Ki Chatti-65.0	1	1	0	0
10-Sep-25	Haripur-80.6	1	1	0	0
12-Sep-25	Shama-128.0, Champawat-73.0, Lohaghat-68.0,	3	2	1	0
13-Sep-25	Haripur-253.0, Narender Nagar- 230.0, Kalsi_UKG-305, Mussorie-188.2, Jollygrant-111.4, Shama-111.0, Haridwar-80.2, Maldevta-110.0, Nainbagh-102.0, Jollygrant-101.5, Sahastradhara_Iti-71.5, Ucost-65.5	12	8	1	3
14-Sep-25	Haripur-74.2	1	1	0	0
15-Sep-25	Devprayag-192.6, Thal-190.0, Thal- 154.0, Didihat-100.0, Didihat-109.0, Lansdown-66.5	6	3	3	0
16-Sep-25	Sahastradhara_ITI-264.0, Maldevta- 149.0, Didihat-124.0, Kalsi -119.5 Narendra Nagar-200.0, Haripur-170.6, Thal-130.0, Tejam-128.0, Haldwani- 124.6, Nainital-123.0, Jollygrant-106.8, Loharkhet-97.0, Didihat-96.0, Bangapani- 92.0, Mussoorie-95.0, Sama-80.0,	27	17	6	4

	Ganganagar-68.2, Rishikesh-66.4, Uttarkashi_CWC-66.2, Nainital-105.0, Jollygrant-93.0, Hatibharkala-89.5, Thal- 85.0, Song-80.0, Bhimtal-75.5, Rani_Chawri-71.5, Pokhari-69.5				
17-Sep-25	Roshnabad-148.0, Haridwar-133.8, Berinag-82.5	3	1	2	0
18-Sep-25	Narendra Nagar-175.0, Mussoorie-117.0, Sama-92.0, Dehradun-83.0, Bhagwanpur-75.0, Haripur-69.8, Mohakampur-73.5	7	5	2	0
29-Sep-25	Sama-68.0, Song-77.0, Didihat-66.5	3	3	0	0
Total Number of Heavy or more events in month of September 2025		137	101	31	5

(iv)

The district-wise distribution of heavy rainfall based on DRMS data is shown in **Fig. 9.4**. The maximum number of heavy rainfall days was observed over Bageshwar district (34 days) and minimum over Almora district (6 days).

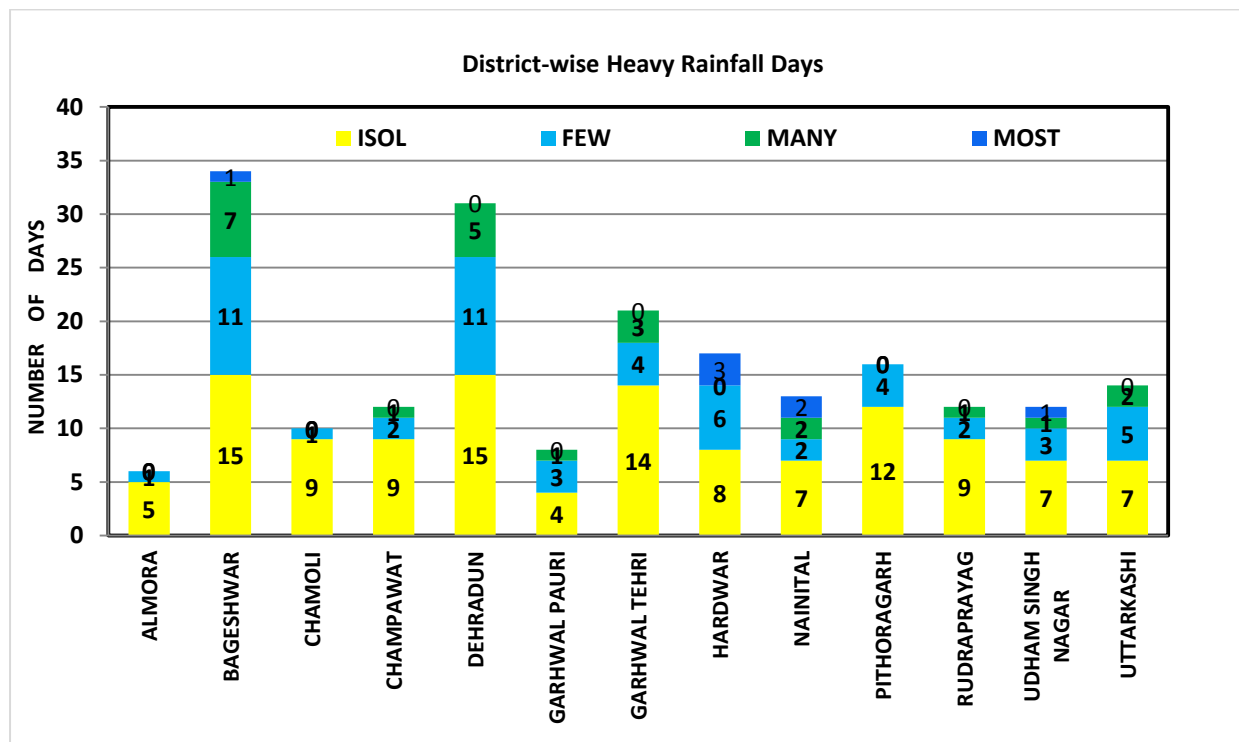


Fig. 9.4: District-wise heavy rainfall days during monsoon 2025 over Uttarakhand

9.2.2 Intense spells of Rainfall (based on AWS data) in Monsoon 2025

The intensity of rainfall spells are calculated using AWS data. **Table 9.3** shows the number of very intense (31-50 mm/hour) and extremely intense (51-100 mm/hour) spells observed over Uttarakhand from June to September 2025. A total of 133 very intense and 33 extremely intense spells were observed over Uttarakhand with highest spells in Dehradun district (57) followed by Bageshwar (19) and Tehri (15) districts. The frequency of intense spell was highest in the month of August (76) followed by July (65) June (15) and September (10).

Table 9.3: Month-wise count of the Intense spells of Rainfall (based of AWS data) over districts of Uttarakhand during Monsoon 2025. VIS and EIS indicate Very Intense Spell and Extremely Intense Spell, respectively.

Month	Jun-25		Jul-25		Aug-25		Sep-25		Monsoon 2025
	VIS	EIS	VIS	EIS	VIS	EIS	VIS	EIS	
District/ category									Total (District-wise)
Uttarkashi	-	-	1	-	-	-	1	-	2
Rudraprayag	-	-	-	1	2	-	-	-	3
Tehri	1	1	5	3	4	1	-	-	15
Pauri	3	-	2	-	1	-	-	-	6
Chamoli	-	-	1	-	3	-	1	-	5
Dehradun	5	2	15	5	20	7	3	-	57
Haridwar	-	1	2	-	-	-	-	-	3
US Nagar	1	-	1	1	7	4	2	-	16
Bageshwar	-	-	9	1	7	2	-	-	19
Nainital	1	-	4	1	4	-	3	-	13
Almora	0	-	4	-	3	-	-	-	7
Pithoragarh	-	-	7	1	6	1	-	-	15
Champawat	-	-	1	-	3	1	-	-	5
Total (category-wise)	11	4	52	13	60	16	10	0	
Total (month-wise)	15		65		76		10		
Total (state)	166								

9.3 High impact weather events over Uttarakhand during Southwest Monsoon 2025

9.3.1 Case I: Dharali, District- Uttarkashi on 05th August 2025

A devastating debris flow on afternoon of August 5, 2025, in the Khirgad stream in Uttarkashi district destroyed homes, buildings, bridges, and roads, resulting in significant loss of life (02 human causality and 67 reported missing) and property in Dharali and Harsil villages. This resulted in a fan-shaped deposit of sediment & debris at Dharali village (~20ha area, ~750m X ~450m), at the confluence of the Kheer Gad & Bhagirathi River (NRSC). The satellite image of the affected area is shown in **Fig. 9.5**.



Fig. 9.5: Pre and Post event Satellite images of Dharali, Uttarkashi district, Uttarakhand, India (Source: NRSC)

9.3.1.1 Synoptic situation on 05th August 2025

The monsoon trough at mean sea level passed through Amritsar, Patiala, Muzaffarnagar, Kheri, Valmik Nagar and thence east-northeastwards to the Arunachal Pradesh close to foot hills of Himalayas on 05th August 2025. The western end of monsoon trough shifted a little southwards on 06th August and passed through Ferozepur, Karnal, Moradabad, Kheri, Jalpaiguri and thence northeastwards to the Arunachal Pradesh close to foothills of Himalayas.

A trough ran from northwest Uttar Pradesh to northeast Arabian Sea across south Haryana, East Rajasthan & Gujarat at 3.1 km above mean sea level on 05th August. On 06th August the trough ran from central parts of north Uttar Pradesh to northern parts of Kutch across East Rajasthan & north Gujarat between 3.1 & 4.5 km above mean sea level. A Western Disturbance as a trough in middle tropospheric level with its axis at 5.8 km above mean sea level ran roughly along Long. 72°E to north of 30°N on 05th August. The Western Disturbance as a cyclonic circulation over Punjab & neighborhood at 5.8 km with a trough aloft in middle tropospheric level with its axis at 7.6 km above mean sea level ran roughly along Long 73°E to north of 32°N on 06th August. An upper air cyclonic circulation laid over Himachal Pradesh & adjoining Uttarakhand at 1.5 km above mean sea level on 06th August.

9.3.1.2 Weather activity over Uttarkashi district from 03rd to 06th August 2025

Under the influence of above synoptic systems light to moderate rainfall was recorded at most places with heavy to very heavy rainfall at a few places and extremely heavy at isolated places in Uttarakhand on 06th August. The Monsoon activity remained vigorous over the state on 06th August. There are 7 District-wise Rainfall Measuring Stations (DRMS) of IMD in Uttarkashi district. The rainfall data are also collected from 6 Automatic Weather Stations (AWS) and 5 non-DRMS stations available in the district. Very light to light rainfall was reported in Uttarkashi district on 3rd August 2025 and very light to moderate rainfall on 04th & 05th August 2025. Moderate rainfall was observed at many places with heavy to very heavy rainfall at isolated places in Uttarkashi district on 6th August, 2025 i.e. between 08:30 IST of 5th August and 08:30 IST of 6th August. The 24-hour accumulated rainfall reported at different stations in Uttarkashi district from 03rd to 06th August, 2025 is given in **Table 9.4**. There are an AWS and a manual rainfall measuring station in Harsil, which are the closest stations to Dharali. Harshil AWS reported 18.5 mm and Harsil manual station reported 20.6 mm rainfall on 06th August 2025. **Fig. 9.6** shows the spatial distribution of rainfall over Uttarakhand recorded on 06th August 2025 and star (black) shows the location of Dharali.

Table 9.4: Rainfall at different rain gauge stations of Uttarkashi district during 3-6, August 2025

	Station	03 rd Aug	04 th Aug	05 th Aug	06 th Aug
DRMS	Barkot	0.0	5.0	18.0	40.0
	Bhatwari	0.0	30.0	10.0	46.0
	Dunda	0.0	13.0	0.0	0.0
	Uttarkashi_cwc	0.8	8.2	27.0	41.4
	Uttarkashi	1.0	8.0	27.0	48.0
	Purola	2.0	15.0	12.0	50.0

	Mori	0	2.0	18.0	0.0
NON-DRMS	Chinalisayur	0	8.0	1.0	46.0
	Maneri	0.0	2.0	31.0	103.0
	Beef/Jan ki chatti	0.0	27.0	9.6	138.0
	Kuthnaur	10.0	12.0	10.0	78.0
	Harsil (CWC)	0.0	0.0	6.2	20.6
AWS	Sankri	8.0	34.0	16.0	52.0
	Gangotri	1.0	-	-	3.0
	Jan ki chatti	0.5	14.5	28.5	42.0
	Barkot	0.5	4.0	12.5	46.5
	Naugaon	0.0	14.0	16.5	50.0
	Harsil	0.0	3.5	9.0	18.5

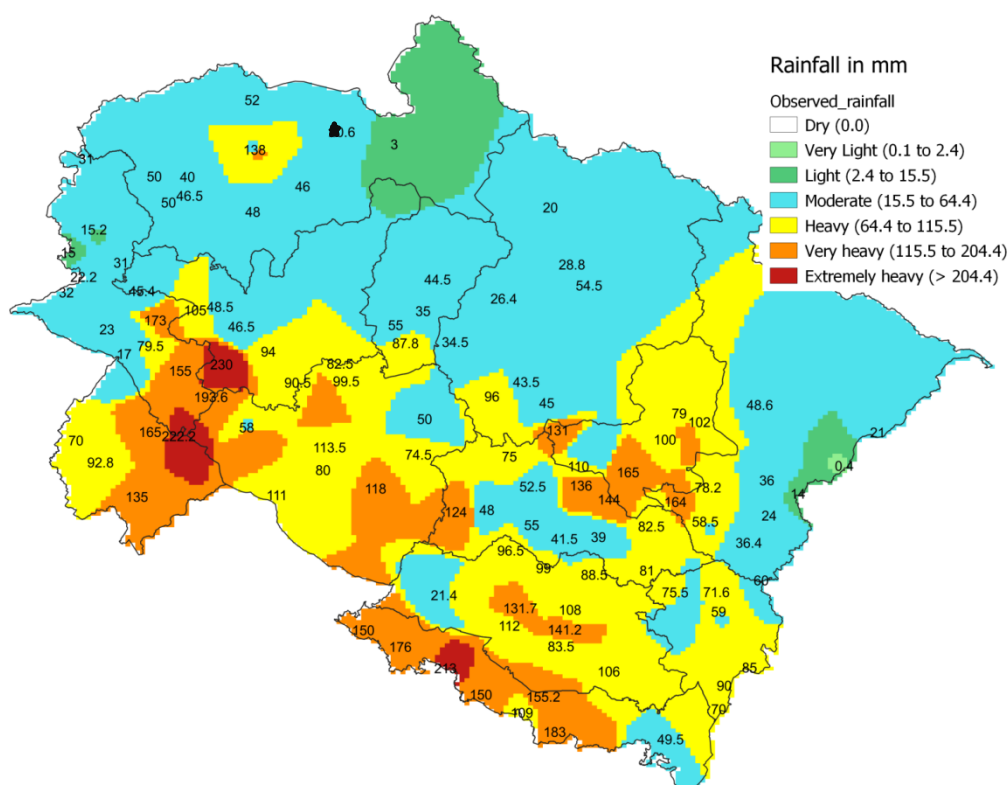
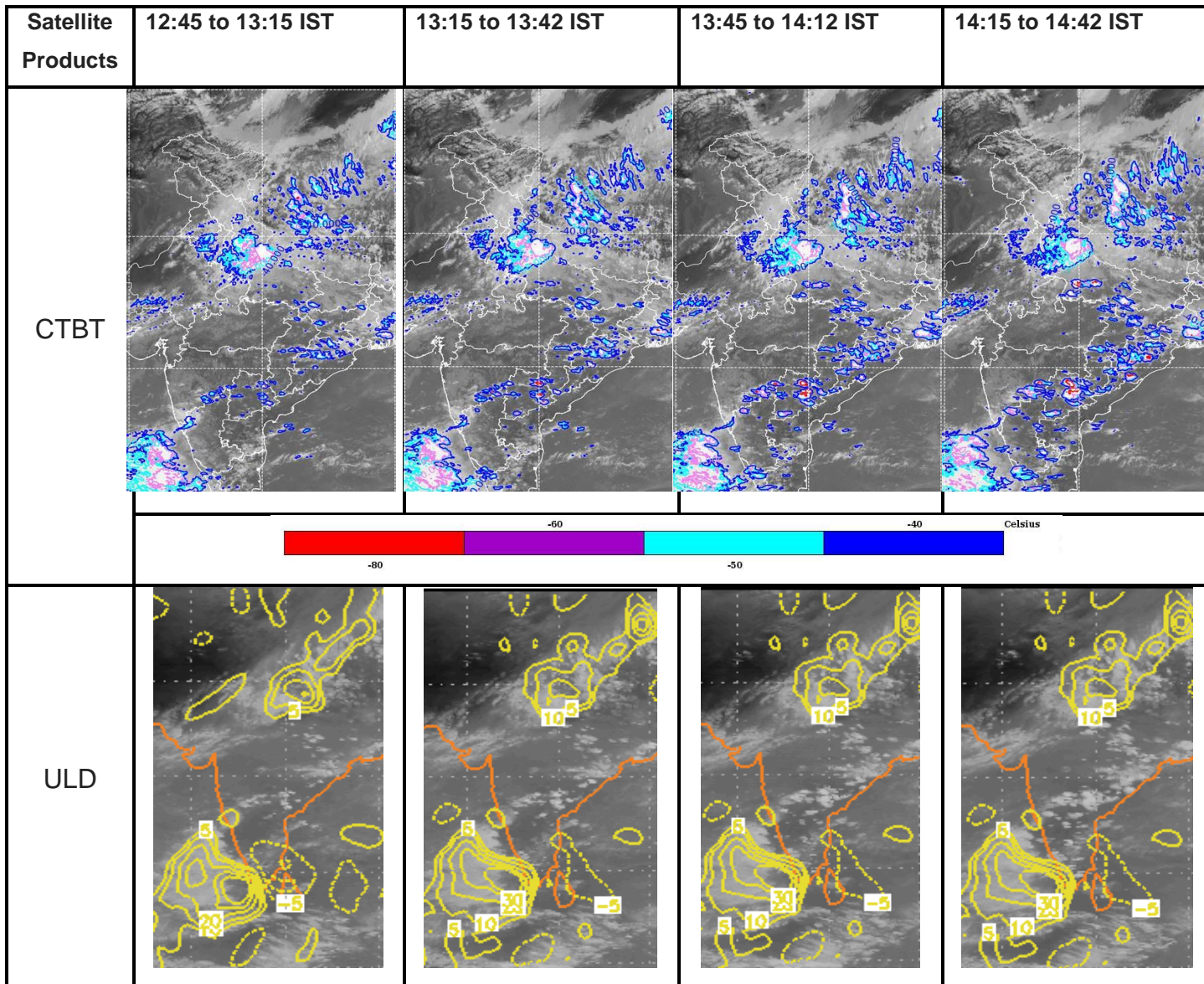


Fig. 9.6: 24-hour accumulated rainfall recorded on 06th August 2025

9.3.1.3 Satellite analysis

The July and August are wettest months for Uttarakhand and more than 800 mm rainfall, which is more than 50% of total annual rainfall of Uttarakhand, is observed during these two months. Consequently, the cloudiness is higher during these two months over Uttarakhand.

The analysis of satellite images shows that most part of Uttarakhand was cover with clouds from 04th August till the morning of 06th August. However, the thick cloud mass and lowest Cloud Top Brightness Temperature (CTBT) of around -60°C was over southern parts of Uttarakhand for most the time during the period. The region with CTBT around -40 to -50°C was extended upto the Uttarkashi district. The region of maximum low-level convergence (LLC) and upper-level divergence (ULD) was over Uttarakhand due to the presence of favourable synoptic systems from surface to middle-tropospheric levels. The region of maximum ULD shifted little north westwards during 13:15 to 13:42 IST scan with region of 5 to $10 \times 10^{-5} \text{ s}^{-1}$ divergence over Uttarkashi district. However, the area of higher LLC reduced during 13:15 to 13:42 IST scan with $5 \times 10^{-5} \text{ s}^{-1}$ convergence values over southern parts of Uttarakhand. **Fig. 9.7** shows the CTBT, satellite-derived ULD, LLC and WWV from 12:45 to 14:42 IST of 05th August. The thick cloud mass and area of highest CTBT remained over south Uttarakhand region till afternoon and shifted over northern parts of Uttarakhand during evening and nighttime of 05th August. The satellite-derived Water Vapour Winds (WWV) shows the position of trough in westerlies between 500-250 hPa levels roughly along Long. 72°E to the north of Lat.30°N. The trough in westerlies was almost stationary over the same region with very little fluctuation in the position on 05th August.



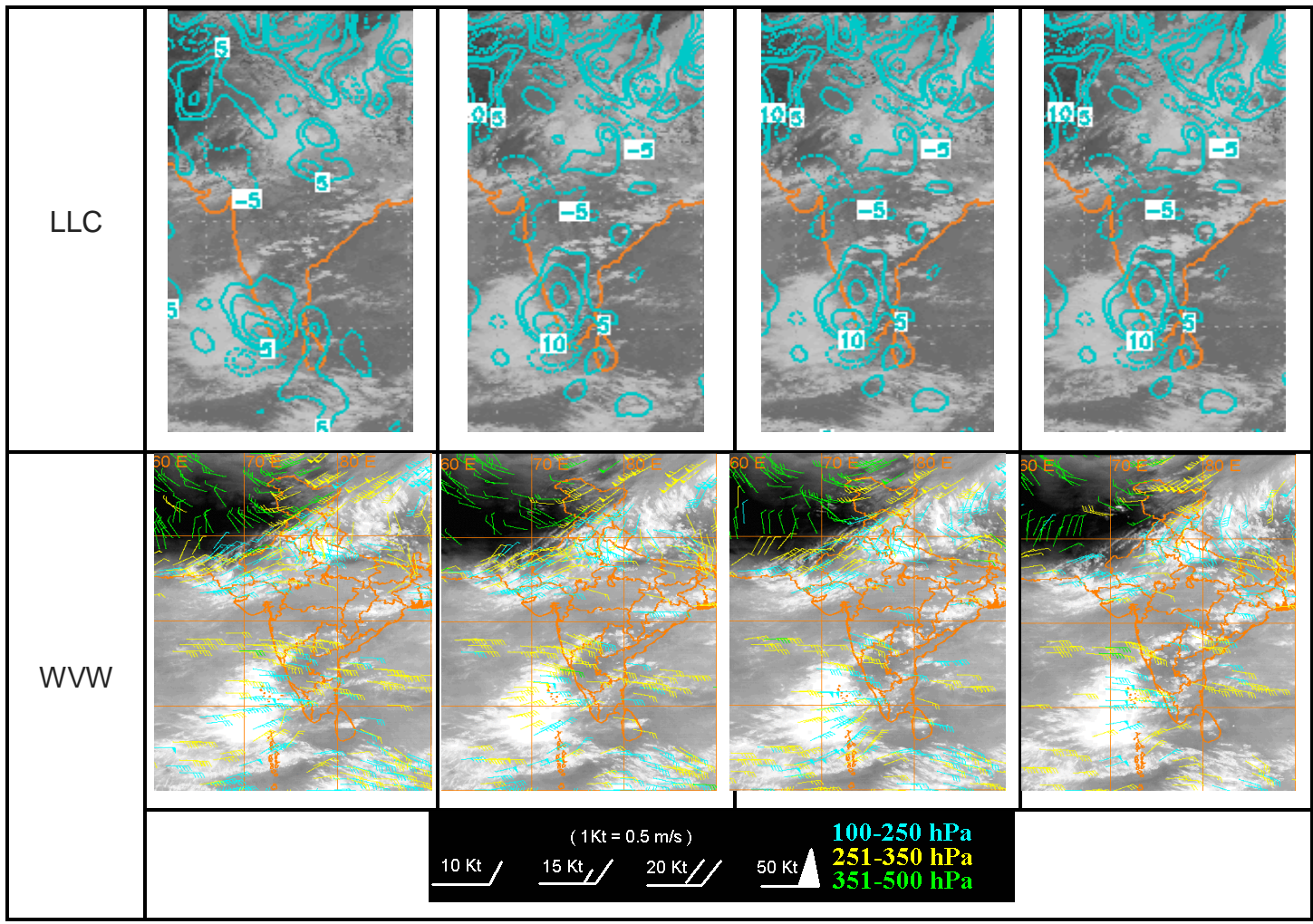


Fig 9.7: CTBT, ULD, LLC and WWV based on INSAT 3D from 12:45 to 14:42 IST of 05th August

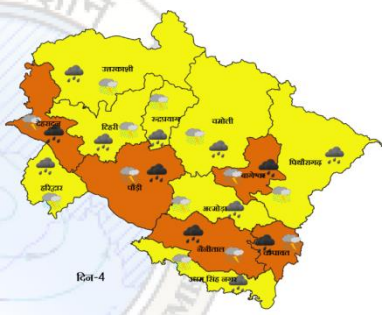
9.3.1.4 Weather forecast and warnings

Weather forecast and warnings for 05th August 2025 issued since 02nd August 2025 for Uttarkashi District is given in **Table 9.5**. Heavy rain (64.5-115.5 mm) warning for Uttarkashi district for 05th August was first issued on 02nd August 2025. Heavy to very heavy rainfall (up to 204.4 mm) warning was issued for Dehradun, Pauri, Tehri, Nainital, Bageshwar and Champawat districts. Very heavy to extremely heavy rainfall (more than 204.5 mm) was issued for Haridwar, Udham Singh Nagar and Nainital Districts. The heavy rainfall warning for Uttarkashi was continued till 05th August 2025 and upgraded to “heavy to very heavy” rainfall (up to 204.4 mm) at 18:00 IST of 05th August.

Flash Flood Guidance was issued on 05.08.2025 with validity from 06:00 UTC of 05.08.2025 till 06:00 UTC of 06.08.2025. On 04th & 05th August 2025, 24-hours CAP alerts/warnings were issued for Uttarkashi district. In addition to that nowcast CAP alerts/warnings were also issued for Uttarkashi district on 4th night/5th morning.

These forecasts and warning were disseminated through Common Alerting Protocol (CAP), National IMD website (<https://mausam.imd.gov.in>), MC, Dehradun’s website (<https://mausam.imd.gov.in/dehradun>), emails, Social Media (Facebook & Twitter handles) and WhatsApp Groups. Forecasts and warning were also disseminated Electronic and Print media as well as the Multi-media messages were generated for dissemination to general public for awareness and mitigation measures. For search and rescue operations, special forecast and Nowcast for Dharali area and Uttarkashi district was issued from 05th August, 2025.

Table 9.5: Medium-range weather forecast and warnings for Uttarkashi district

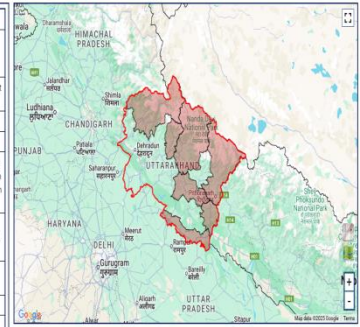
Date of issue	Weather Warning for Uttarkashi district 5 th August	Warning map
02.08.2025	<ul style="list-style-type: none"> •Heavy rain (64.5-115.5 mm) likely to occur at isolated places in Uttarkashi district of Uttarakhand. •Thunderstorm accompanied with lightening /intense to very intense spell of rain likely to occur at isolated places in Uttarkashi district of Uttarakhand. 	

03.08.2025	<ul style="list-style-type: none"> •Heavy rain (64.5-115.5 mm) likely to occur at isolated places in Uttarkashi district of Uttarakhand. •Thunderstorm accompanied with lightening /intense to very intense spell of rain likely to occur at isolated places in Uttarkashi district of Uttarakhand. 	
04.08.2025	<ul style="list-style-type: none"> •Heavy rain (64.5-115.5 mm) likely to occur at isolated places in Uttarkashi district of Uttarakhand. •Thunderstorm accompanied with lightening /intense to very intense spell of rain likely to occur at isolated places in Uttarkashi district of Uttarakhand. 	
05.08.2025	<ul style="list-style-type: none"> •Heavy rain (64.5-115.5 mm) likely to occur at isolated places in Uttarkashi district of Uttarakhand. •Thunderstorm accompanied with lightening /intense to very intense spell of rain likely to occur at isolated places in Uttarkashi district of Uttarakhand. 	
05.08.2025 (18:00 IST)	<ul style="list-style-type: none"> •Heavy rain to very Heavy (up to 204.4 mm) likely to occur at isolated places in Uttarkashi district of Uttarakhand. •Thunderstorm accompanied with lightening /intense to very intense spell of rain likely to occur at isolated places in Uttarkashi district of Uttarakhand. 	
<p>Flash Flood Guidance issued on 05.08.2025: Valid from 06:00 UTC of 05.08.2025 till 06:00 UTC of 06.08.2025.</p>	<div> <p>24 hours Outlook for the Flash Flood Risk (FFR) till 1130 IST of 06-08-2025 :</p> </div> <div> <p>Low to Moderate flash flood risk likely over few watersheds & neighbourhoods of following Met Sub-divisions during next 24 hours.</p> </div> <div> <p>Uttarakhand - Almora, Bageshwar, Chamoli, Champawat, Dehradun, Haridwar, Nanital, Pauri Garhwal, Pithoragarh, Rudraprayag, Tehri Garwal, Udham Singh Nagar and Uttarkashi districts. West Uttar Pradesh - Bijnor and Jyotibaphule Nahgar districts.</p> </div> <div> <p>Surface runoff/ Inundation may occur at some fully saturated soils & low-lying areas over Area of Concern (AoC) as shown in map due to expected rainfall occurrence in next 24 hours.</p> </div> <div> </div>	

24-hours CAP Warnings issued for Uttarkashi district on 04th and 05th August 2025

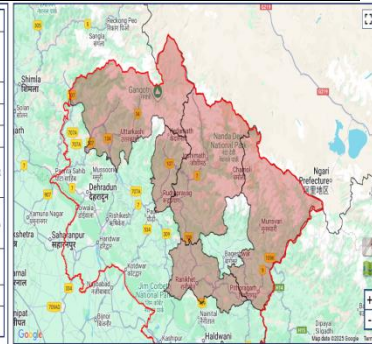
24 hour CAP Warnings issued on 04th August 2025 at 10:07 AM for Uttarkashi district:

Sender Name:	IMD Dehradun	Entry Date & Time:	04 Aug 2025, 10:13 AM
Time of Issue/Effective Date & Time:	04 Aug 2025, 10:07 AM	Valid Upto:	05 Aug 2025, 10:07 AM
Area Description:	Almora, Chamoli, Champawat, Pithoragarh, Rudra Prayag, Udhm Singh Nagar, Uttar Kashi districts of Uttarakhand		
Event Description:	Heavy Rain	Urgency:	Expected
Severity:	WATCH	Certainty:	Very Likely
Message Body:	(Date: 04.08.2025, Time: 10:00) Watch: Heavy Rain accompanied with thunderstorm/lightning is very likely to occur at isolated places over Almora, Chamoli, Champawat, Pithoragarh, Rudra Prayag, Udhm Singh Nagar and Uttar Kashi districts of Uttarakhand in next 24 hours.		
Forwarding Status:	Notified to Uttarakhand SDMA	Dissemination Status:	Pushed to Dissemination Media by concerned SDMA
Warning Generated By:	IMD Dehradun	User Contact No.:	7078675082
Instruction:	Please follow SDMA guidelines.		
Warning Status:	VIEW		



24 hour CAP Warnings issued on 05th August 2025 at 01:27 PM for Uttarkashi district:

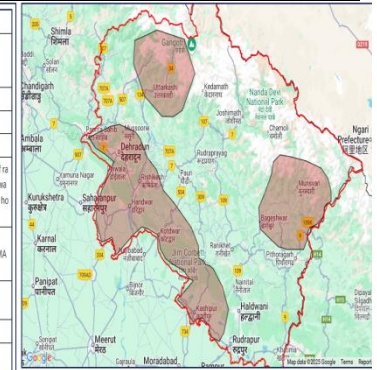
Sender Name:	IMD Dehradun	Entry Date & Time:	05 Aug 2025, 1:40 PM
Time of Issue/Effective Date & Time:	05 Aug 2025, 12:27 PM	Valid Upto:	06 Aug 2025, 12:27 PM
Area Description:	Almora, Chamoli, Pithoragarh, Rudra Prayag, Uttar Kashi districts of Uttarakhand		
Event Description:	Heavy Rain	Urgency:	Expected
Severity:	WATCH	Certainty:	Very Likely
Message Body:	(Date: 05.08.2025, Time: 13:00) Watch: Heavy Rain accompanied with thunderstorm/lightning is very likely to occur at isolated places over Almora, Chamoli, Pithoragarh, Rudra Prayag, Uttar Kashi districts of Uttarakhand in next 24 hours.		
Forwarding Status:	Notified to Uttarakhand SDMA	Dissemination Status:	Pushed to Dissemination Media by concerned SDMA
Warning Generated By:	IMD Dehradun	User Contact No.:	7078675082
Instruction:	Please follow SDMA guidelines.		
Warning Status:	VIEW		



Nowcast CAP Warnings issued for Uttarkashi district on 05th August 2025

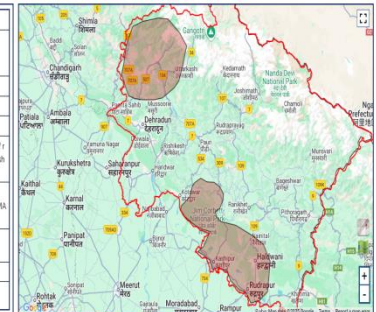
Time of issue: 00:17 AM on 05/08/2025

Sender Name:	IMD Dehradun	Entry Date & Time:	05 Aug 2025, 02:21 AM
Time of Issue/Effective Date & Time:	05 Aug 2025, 01:17 AM	Valid Upto:	05 Aug 2025, 3:12 AM
Area Description:	Isolated places in Haridwar, Dehradun, Pauri, Tehri, Uttarkashi, US Nagar, Nainital, Bageshwar, Pithoragarh		
Event Description:	Thunder shower	Urgency:	Expected
Severity:	WATCH	Certainty:	Likely
Message Body:	(05.08.2025/ 00:17 IST) Thunderstorm accompanied with lightning / Intense spell of rain is very likely to occur at isolated places over Dehradun, Haridwar, Nainital, Pauri Garhwal, Tehri Garhwal, Udhm Singh Nagar, Uttar Kashi, Bageshwar, Pithoragarh in next 3 hours.		
Forwarding Status:	Notified to Uttarakhand SDMA	Dissemination Status:	Pushed to Dissemination Media by concerned SDMA
Warning Generated By:	IMD Dehradun	User Contact No.:	7078675082
Instruction:	Please follow SDMA guidelines.		
Warning Status:	VIEW		

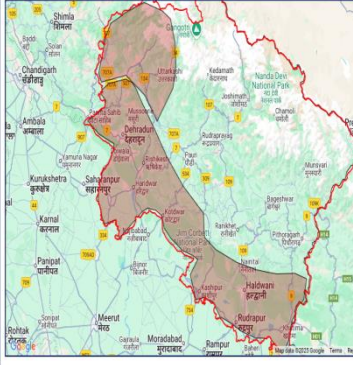


Time of issue: 03:33 AM on 05/08/2025

Sender Name:	IMD Dehradun	Entry Date & Time:	05 Aug 2025, 3:44 AM
Time of Issue/Effective Date & Time:	05 Aug 2025, 3:33 AM	Valid Upto:	05 Aug 2025, 6:58 AM
Area Description:	Pauri, US Nagar, Nainital and Uttarkashi		
Event Description:	Thunder shower	Urgency:	Expected
Severity:	WATCH	Certainty:	Very Likely
Message Body:	(05.08.2025/03:30 IST) Thunderstorm accompanied with lightning / Intense spell of rain is very likely to occur at isolated places over Dehradun, Tehri Garhwal, Uttarkashi, Nainital, Pauri Garhwal, Udhm Singh Nagar in next 3 hours.		
Forwarding Status:	Notified to Uttarakhand SDMA	Dissemination Status:	Pushed to Dissemination Media by concerned SDMA
Warning Generated By:	IMD Dehradun	User Contact No.:	7078675082
Instruction:	Please follow SDMA guidelines.		
Warning Status:	VIEW		



Time of issue: 06:25 AM on 05/08/2025		<table border="1"> <tr> <td>Sender Name:</td> <td>IMD Dehradun</td> <td>Entry Date & Time:</td> <td>05 Aug 2025, 6:28 AM</td> </tr> <tr> <td>Time of Issue/Effective Date & Time:</td> <td>05 Aug 2025, 6:25 AM</td> <td>Valid Upto:</td> <td>05 Aug 2025, 9:05 AM</td> </tr> <tr> <td>Area Description:</td> <td colspan="3">Haridwar, Uttarakashi, Tehri, Pauri, Dehradun, US Nagar, Nainital, Champawat</td> </tr> <tr> <td>Event Description:</td> <td>Thunder shower</td> <td>Urgency:</td> <td>Expected</td> </tr> <tr> <td>Severity:</td> <td>WATCH</td> <td>Certainty:</td> <td>Likely</td> </tr> <tr> <td>Message Body:</td> <td colspan="3"> Message in English: (05.08.2025/06:27 IST) Thunderstorm accompanied intense spell of rain is likely to occur at isolated places over Champawat, Dehradun, Haridwar, Nainital, Pauri Garhwal, Tehri Garhwal, Udham Singh Nagar, Uttar Kashi in next 2-3 hours. </td> </tr> <tr> <td>Forwarding Status:</td> <td>Notified to Uttarakhand SDMA</td> <td>Dissemination Status:</td> <td>Pushed to Dissemination Media by concerned SDMA</td> </tr> <tr> <td>Warning Generated By:</td> <td>IMD Dehradun</td> <td>User Contact No:</td> <td>7078675082</td> </tr> <tr> <td>Warning Status:</td> <td colspan="3"> <input type="button" value="VIEW"/> </td> </tr> <tr> <td colspan="4" style="text-align: center;"> <input type="button" value="REGENERATE WARNING"/> </td> </tr> </table>		Sender Name:	IMD Dehradun	Entry Date & Time:	05 Aug 2025, 6:28 AM	Time of Issue/Effective Date & Time:	05 Aug 2025, 6:25 AM	Valid Upto:	05 Aug 2025, 9:05 AM	Area Description:	Haridwar, Uttarakashi, Tehri, Pauri, Dehradun, US Nagar, Nainital, Champawat			Event Description:	Thunder shower	Urgency:	Expected	Severity:	WATCH	Certainty:	Likely	Message Body:	Message in English: (05.08.2025/06:27 IST) Thunderstorm accompanied intense spell of rain is likely to occur at isolated places over Champawat, Dehradun, Haridwar, Nainital, Pauri Garhwal, Tehri Garhwal, Udham Singh Nagar, Uttar Kashi in next 2-3 hours.			Forwarding Status:	Notified to Uttarakhand SDMA	Dissemination Status:	Pushed to Dissemination Media by concerned SDMA	Warning Generated By:	IMD Dehradun	User Contact No:	7078675082	Warning Status:	<input type="button" value="VIEW"/>			<input type="button" value="REGENERATE WARNING"/>			
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Time of Issue/Effective Date & Time:	05 Aug 2025, 6:25 AM	Valid Upto:	05 Aug 2025, 9:05 AM																																								
Area Description:	Haridwar, Uttarakashi, Tehri, Pauri, Dehradun, US Nagar, Nainital, Champawat																																										
Event Description:	Thunder shower	Urgency:	Expected																																								
Severity:	WATCH	Certainty:	Likely																																								
Message Body:	Message in English: (05.08.2025/06:27 IST) Thunderstorm accompanied intense spell of rain is likely to occur at isolated places over Champawat, Dehradun, Haridwar, Nainital, Pauri Garhwal, Tehri Garhwal, Udham Singh Nagar, Uttar Kashi in next 2-3 hours.																																										
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9.3.2 Case II: Tharali, District- Chamoli on 23rd August 2025

Flash flood and mudslide severely affected the Tharali town located on the banks of the Pindar river in district-Chamoli, Uttarakhand, in the early hours of August 23, 2025. The debris and mud flow engulfed homes, vehicles, and roads, causing 01 human causality, 01 reported missing, 09 injured and complete damage to 11 houses, partial damage to 30 houses and damage to 11 vehicles.

9.3.2.1 Synoptic situation on 22nd and 23rd August 2025.

The monsoon trough at mean sea level passed through Suratgarh, Rohtak, Fatehgarh, Gaya, Digha and thence east southeastwards to northeast Bay of Bengal on 22nd August and through Ganganagar, Gwalior, Banda, Dehri, centre of low-pressure area over Gangetic West Bengal & neighbourhood and thence east southeastwards to northeast Bay of Bengal on the morning of 23rd August 2025.

An upper air cyclonic circulation laid over southwest Uttar Pradesh & neighborhood extending up to 7.6 km above mean sea level tilting southwestwards with height on 22nd August. The upper air cyclonic circulation moved little south eastwards on 23rd August and laid over central parts of north Madhya Pradesh & adjoining areas of south Uttar Pradesh extending upto 5.8 km above mean sea level tilting southwestwards with height.

9.3.2.2 Weather activity over Chamoli district on from 21st to 23rd August 2025

There are 5 DRMS stations and 8 automatic stations in Chamoli district. Light to moderate rainfall was observed in Chamoli district on 21st August and very light to light on 22nd August. Light to moderate rainfall was recorder at most places in Chamoli district on 23rd August with very heavy rainfall over Tharali AWS (**Table 9.6**). The intense rainfall at Tharali started in evening with two spells of very intense rainfall of 38 mm/h and 36 mm/h during 1315 to 1415 UTC and 1745 to 1845 UTC respectively. The other stations that received very intense rainfall were Song and Shama in Bageshwar district with 41 mm/hour during 1345 to 1445 UTC and 32 mm/hour during 1615 to 1715 UTC. The rainfall data of Tharali station was available till

2215 UTC and thereafter the station didn't record the data. **Fig. 9.8** shows the spatial distribution of daily rainfall over Uttarakhand.

Table 9.6: (i) 24-hour accumulated rainfall over manual and automatic stations in Chamoli district of Uttarakhand from 21st to 23rd August 2025. (ii) List of stations recorder >30mm/hour rainfall on 23rd August in Uttarakhand.

(i)

	Station	21 st Aug	22 nd Aug	23 rd Aug
DRMS	Chamoli	15.4	1.4	7.6
	Gairsain	9.0	0.0	44.0
	Joshimath	0.8	1.4	9.0
	Karnaprayag	24.2	0.8	9.4
	Tharali	12.2	1.1	18.5
AWS	Auli	12	7.5	19
	Badrinath	1	0	14
	Dewal	13	0	62
	Gochar	22.5	0	0.5
	Karnaprayag	16.5	0.5	4
	pandukeshwar	1	1	23.5
	Pokhari	40	0	5.5
	Tharali	17	1.5	147(upto 2215 UTC)

(ii)

Station (District)	Intense spell (>=30 mm/hour)	Total Rain (mm)
Tharali (Chamoli)	1315 to 1415 UTC 38.0 mm 1745 to 1845 UTC 36.0 mm	147.0 (upto 2215 UTC)
Song (Bageshwar)	1345 to 1445 UTC 41.0mm	146.0
Shama (Bageshwar)	1615 to 1715 UTC 32.0 mm	153.0

RAINFALL RECORDED AT 08:30 HRS IST ON DATE 23.08.2025

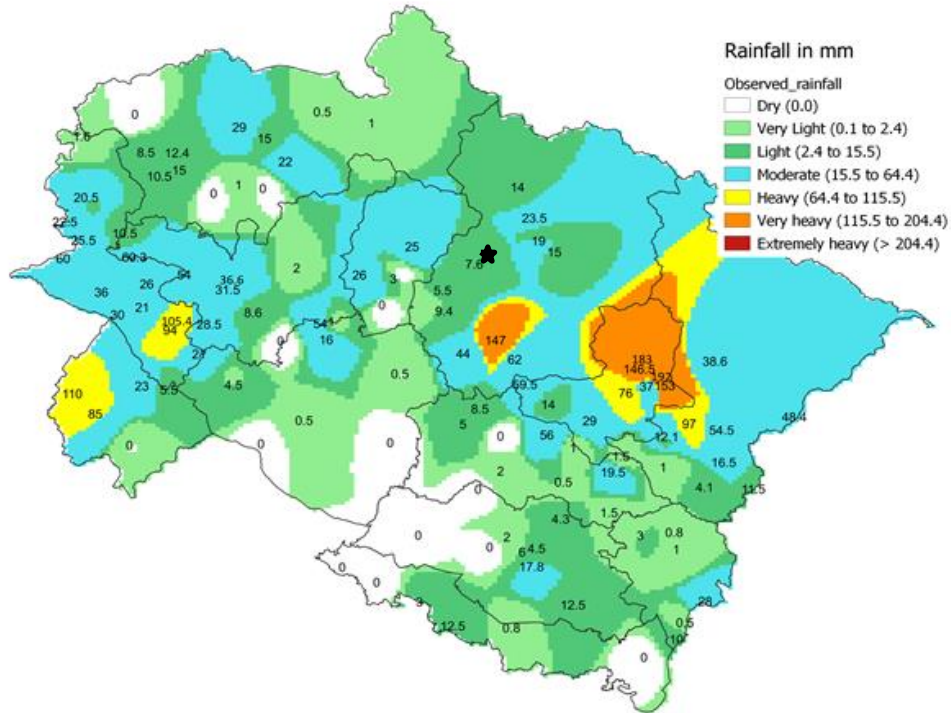



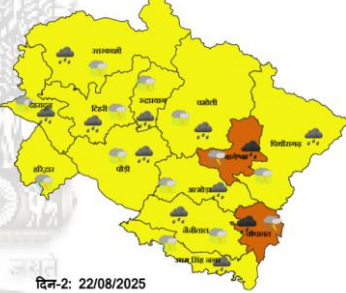



Fig. 9.8: 24-hour accumulated rainfall recorded on 23rd August 2025. Black star shows the location of Tharali.

9.3.2.3 Weather forecast and warnings

Weather forecast and warnings for 22nd August 2025 (08:30 IST of 22nd to 08:30 IST of 23rd August) issued since 18th August 2025 for Chamoli District is given in **Table 9.7**. Heavy rain (64.5-115.5 mm) warning for Chamoli district for 22nd August was first issued on 18th August 2025. Heavy to very heavy rainfall (up to 204.4 mm) warning was issued for Bageshwar and Champawat districts on 21st August. The region of Heavy to very heavy rainfall warning was extended to include the Pithoragarh district on 22nd August. The orange CAP alert in nowcast was issued for Chamoli, Bageshwar and Pithoragarh districts at 10:10 PM of 22nd August which was valid upto 1:10 AM of 23rd August.

Table 9.7: Medium-range weather forecast and warnings for Chamoli district

Date of issue	Weather Warning for Chamoli district for 22 nd August (08:30 IST of 22 nd to 08:30 IST of 23 rd August)	Warning map
18.08.2025	<ul style="list-style-type: none"> •Heavy rain (64.5-115.5 mm) likely to occur at isolated places in Chamoli district of Uttarakhand. •Thunderstorm accompanied with lightening /intense to very intense spell of rain likely to occur at isolated places in Chamoli district of Uttarakhand. 	 <p>दिन-5</p>
19.08.2025	<ul style="list-style-type: none"> •Heavy rain (64.5-115.5 mm) likely to occur at isolated places in Chamoli district of Uttarakhand. •Thunderstorm accompanied with lightening /intense to very intense spell of rain likely to occur at isolated places in Chamoli district of Uttarakhand. 	 <p>दिन-4: 22/08/2025</p>
20.08.2025	<ul style="list-style-type: none"> •Heavy rain (64.5-115.5 mm) likely to occur at isolated places in Chamoli district of Uttarakhand. •Thunderstorm accompanied with lightening /intense to very intense spell of rain likely to occur at isolated places in Chamoli district of Uttarakhand. 	 <p>दिन-3: 22/08/2025</p>
21.08.2025	<ul style="list-style-type: none"> •Heavy rain (64.5-115.5 mm) likely to occur at isolated places in Chamoli district of Uttarakhand. •Thunderstorm accompanied with lightening /intense to very intense spell of rain likely to occur at isolated places in Chamoli district of Uttarakhand. 	 <p>दिन-2: 22/08/2025</p>
22.08.2025	<ul style="list-style-type: none"> •Heavy rain (64.5-115.5 mm) likely to occur at isolated places in Chamoli district of Uttarakhand. •Thunderstorm accompanied with lightening /intense to very intense spell of rain likely to occur at isolated places in Chamoli district of Uttarakhand. 	 <p>दिन-1: 22/08/2025</p>

24-hours CAP Warnings issued for Chamoli district on 22nd August 2025:

Message for SDMA:(Effective Date & Time: 22 Aug 2025, 2:05 PM Expiry Date & Time: 23 Aug 2025, 2:05 PM) Heavy rain accompanied with Thunderstorms/lightning and very intense spell of rain likely to occur at isolated places in Dehradun, Tehri, Pauri, Uttarkashi, Chamoli, Rudraprayag, Nainital, Almora and Udham Singh Nagar districts of Uttarakhand in next 24 hours.



Nowcast CAP Warnings issued for Chamoli district on 22nd August 2025

Message for SDMA :(Effective Date & Time: 22 Aug 2025, 10:10 PM Expiry Date & Time: 23 Aug 2025, 1:10 AM) Thunderstorm accompanied with lightning/Heavy Rain/intense to very intense spell of rain is very likely to occur at a few places over Bageshwar, Chamoli, Pithoragarh, Rudra Prayag, Pauri Garhwal, in next 3 hours.



9.3.3 Case III: Rudraprayag, Chamoli, Tehri and Bageshwar districts on 29th August 2025

In the early morning hours of 29th August 2025, debris and mudslides at different places in Rudraprayag, Chamoli, Tehri and Bageshwar districts caused multiple instances of loss of life and property. As per State Emergency Operation Center (SEOC) 2 people died, 1 injured and 3 reported missing while 5-6 houses were damaged in village Pausari, Kapkot (Bageshwar). 1 died and 8 reported missing while 30-40 families were stranded in Basukedar and Jakholi (Rudraprayag). 2 people died, 2 injured, 25 cattle reported missing after a house was damaged in village Mopata, Tharali (Chamoli). 2 cattle died after a cowshed was damaged in village Genwali, Balganaga (Tehri Garhwal). 2 cattle died after a cowshed was damaged in village Sumarth, Ghansali (Tehri Garhwal).

9.3.3.1 Synoptic situation on 28th & 29th August 2025.

The monsoon trough passed through Sri Ganganagar, Shivpuri, Damoh, centre of low-pressure area over central parts of Chhattisgarh & neighbourhood, Kalingapatnam and thence to east-southeastwards to central Bay of Bengal on 28th August. The western end of monsoon

trough moved little southwards and eastern end a little northwards on 29th August. The monsoon trough passed through Bikaner, Kota, Guna, Damoh, Pendra Road, Sambalpur, Puri and thence to east-southeastwards to central Bay of Bengal on 29th August. A Western Disturbance as a cyclonic circulation laid over north Pakistan & adjoining Punjab and extended upto 5.8 km above mean sea level on 28th & 29th August 2025.

9.3.3.2 Weather activity over Rudraprayag, Chamoli, Tehri and Bageshwar districts from 26th to 29th August 2025


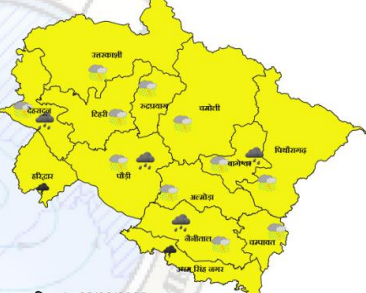
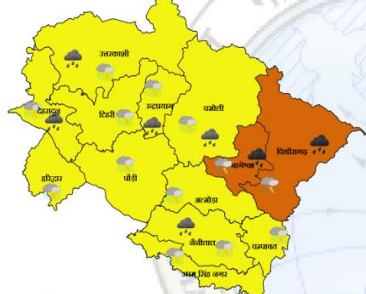
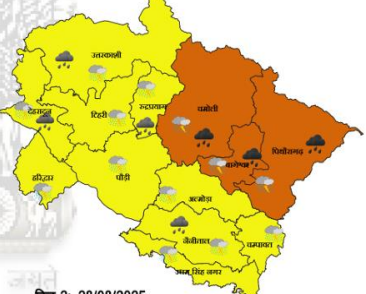
Based on the manual and automatic rainfall observations, light to moderate rainfall were observed over Bageshwar, Chamoli, Rudraprayag and Tehri districts from 26th to 28th August 2025. Under the influence of above synoptic systems heavy to very heavy rainfall were observed at isolated places in Bageshwar, Chamoli, Rudraprayag and Tehri districts on 29th August. The Yellow colour highlights the stations closest to the places where damages were reported (**Table 9.8**). **Fig. 9.9** shows the spatial distribution of daily rainfall over Uttarakhand.

Table 9.8: 24-hour accumulated rainfall over manual and automatic station in Bageshwar, Chamoli, Rudraprayag and Tehri districts of Uttarakhand from 26th to 29th August 2025

District	Station	26-08-2025	27-08-2025	28-08-2025	29-08-2025
Bageshwar	Bageshwar	8	0	9	38
Bageshwar	Bageshwar	6	-	6.5	21.5
Bageshwar	Dangoli	-	-	3	61.5
Bageshwar	Garud	4	0	3	27
Bageshwar	Kanda	24	-	21.5	30.5
Bageshwar	Kapkot	11	0	48	140
Bageshwar	Kapkote	-	1.5	-	-
Bageshwar	Liti	-	-	46	99
Bageshwar	Loharkhet	21	2	33	99
Bageshwar	Sama	22	0	48	119
Bageshwar	Shama	19	-	44.5	107
Bageshwar	Song	13.5	1	25.5	88.5
Tehri garhwal	Devprayag	20.8	1.2	0	14.2
Tehri garhwal	Dhanaulti	26	11	0	11
Tehri garhwal	Ghansali	13	5	0	22
Tehri garhwal	Keertinagar	45	1	0	43
Tehri garhwal	Narendra nagar	28	5	0	29
Tehri garhwal	Tehri (cwc)	32.8	5.2	0	17.1

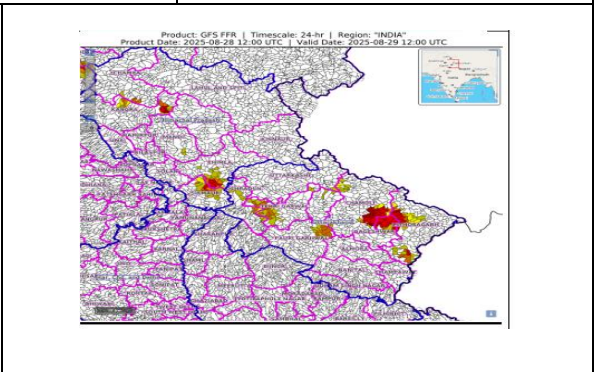
Tehri garhwal	Tehri	18.4	1.6	0	7
Tehri garhwal	Dhanolti	-	5.5		9
Tehri_garhwal	Chamba	21.5	3	4	-
Tehri_garhwal	Kanatal	38	0.5	1	4
Tehri_garhwal	Kirtinagar	10	1	-	15.5
Tehri_garhwal	Nainbagh	11.5	6.5	-	31.5
Tehri_garhwal	Narendra nagar	17	3	-	18.5
Tehri_garhwal	New tehri	18.5	-	-	-
Tehri_garhwal	Rani_chawri	28	3.5	0.5	16.5
Rudraprayag	Agastyamuni	5	20.5	3	71.5
Rudraprayag	Ganganagar	22.8	0	3.4	73.2
Rudraprayag	Jakholi	11	3	2	128
Rudraprayag	Jakholi	12.5	0.5	-	142
Rudraprayag	Rudraprayag	6.4	0.6	1.6	53.2
Rudraprayag	Ukhimath	10	2.2	7.1	125
Chamoli	Auli	5	0.5	31	50.5
Chamoli	Badrinath	7	2		-
Chamoli	Chamoli	4.2	0.2	1.2	104.6
Chamoli	Dewal	5	-	30	45.5
Chamoli	Gairsain	8	0	5	62
Chamoli	Gochar	3	-	1.5	-
Chamoli	Joshimath	5.6	0.8	26.6	30.6
Chamoli	Karnaprayag	3	-	11.5	112.5
Chamoli	Karnprayag	4.4	0	14.2	135.8
Chamoli	Pandukeshwar	3	-	-	18
Chamoli	Pokhari	3	-	2	60.5
Chamoli	Tapovan	3	0.5	-	-
Chamoli	Tharali	5.2	0	22.5	28.5
Chamoli	Nandkeshri	17.8	0	32.6	76.4
Chamoli	Nandprayag	0	0	0	80

Table 9.9: Medium-range weather forecast and warnings for Rudraprayag, Chamoli, Tehri and Bageshwar districts

Date of issue	Weather Warning for Rudraprayag, Chamoli, Tehri and Bageshwar districts for 28 th August (08:30 IST of 28.08.2025 to 08:30 IST of 29.08.2025)	Warning map
24.08.2025	<ul style="list-style-type: none"> •Heavy rain (64.5-115.5 mm) likely to occur at isolated places in Bageshwar district of Uttarakhand. •Thunderstorm accompanied with lightening /intense to very intense spell of rain likely to occur at isolated places in Rudraprayag, Chamoli, Tehri and Bageshwar districts of Uttarakhand. 	 <p>दिन-5: 28/08/2025</p>
25.08.2025	<ul style="list-style-type: none"> •Heavy rain (64.5-115.5 mm) likely to occur at isolated places in Bageshwar district of Uttarakhand. •Thunderstorm accompanied with lightening /intense to very intense spell of rain likely to occur at isolated places in Rudraprayag, Chamoli, Tehri and Bageshwar districts of Uttarakhand. 	 <p>दिन-4: 28/08/2025</p>
26.08.2025	<ul style="list-style-type: none"> •Heavy to very heavy rain (115.6-204.4 mm) likely to occur at isolated places in Bageshwar district of Uttarakhand. •Heavy rain (64.5-115.5 mm) likely to occur at isolated places in Rudraprayag and Chamoli districts of Uttarakhand. •Thunderstorm accompanied with lightening /intense to very intense spell of rain likely to occur at isolated places in Rudraprayag, Chamoli, Tehri and Bageshwar districts of Uttarakhand. 	 <p>दिन-3: 28/08/2025</p>
27.08.2025	<ul style="list-style-type: none"> •Heavy to very heavy rain (115.6-204.4 mm) likely to occur at isolated places in Chamoli and Bageshwar districts of Uttarakhand. •Heavy rain (64.5-115.5 mm) likely to occur at isolated places in Rudraprayag district of Uttarakhand. •Thunderstorm accompanied with lightening /intense to very intense spell of rain likely to occur at isolated places in 	 <p>दिन-2: 28/08/2025</p>

	Rudraprayag, Chamoli, Tehri and Bageshwar districts of Uttarakhand.	
28.08.2025	<ul style="list-style-type: none"> •Heavy to very heavy rain (115.6-204.4 mm) likely to occur at isolated places in Chamoli and Bageshwar districts of Uttarakhand. •Heavy rain (64.5-115.5 mm) likely to occur at isolated places in Rudraprayag district of Uttarakhand. •Thunderstorm accompanied with lightening /intense to very intense spell of rain likely to occur at isolated places in Rudraprayag, Chamoli, Tehri and Bageshwar districts of Uttarakhand. 	<p>दिन-1: 28/08/2025</p>

Flash Flood Guidance issued on 28.08.2025 at 17:30 IST
24 hours Outlook for the Flash Flood Risk (FFR) till 1730 IST of 29-08-2025 : Low to Moderate flash flood risk likely over few watersheds & neighbourhoods of following Met Sub-divisions during next 24 hours.
 Uttarakhand – Chamoli, Pauri Garhwal, Tehri Garhwal, Dehradun and Pithoragarh districts.

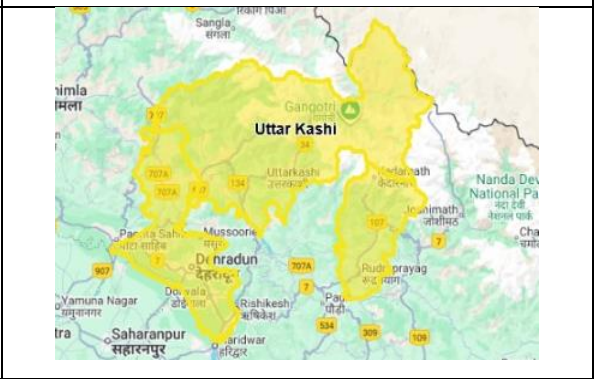


24-hours CAP Warnings:

24 hour CAP (Date:28.08.2025,Time:0930 IST)
 Heavy to Very Heavy Rain accompanied with Thunderstorms/lightning and very intense to extremely intense spell of rain is very likely to occur at isolated places over Bageshwar, Chamoli, Champawat, Pithoragarh and Udham Singh Nagar districts of Uttarakhand in next 24 hours.



24 hour CAP (Date:28.08.2025,Time:0930 IST)
 Heavy Rain accompanied with thunderstorms/lightning and intense to very intense spell of rain is very likely to occur at isolated places over Dehradun, Nainital, Rudra Prayag and Uttar Kashi districts of Uttarakhand in next 24 hours.



24 hour CAP (Date:28.08.2025,Time:0930 IST)

Thunderstorms accompanied with lightning and intense to very intense spell of rain is likely to occur at isolated places over Almora, Haridwar, Pauri Garhwal and Tehri Garhwal districts of uttarakhand in next 24 hours.



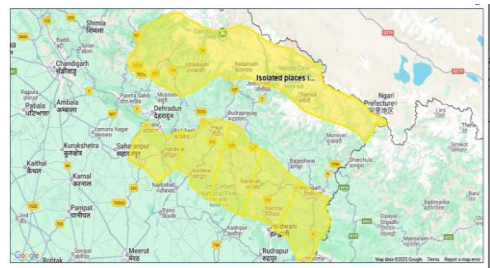
Nowcast CAP Warnings:

Time of issue: 00:00 AM on 29/08/2025

•Moderate to Heavy Rain / Thunderstorm accompanied with lightning / intense to very intense spell of rain is very likely to occur at a few places over Bageshwar, Chamoli, Pithoragarh, Rudraprayag, Dehradun, Tehri Garhwal in next 3 hours.

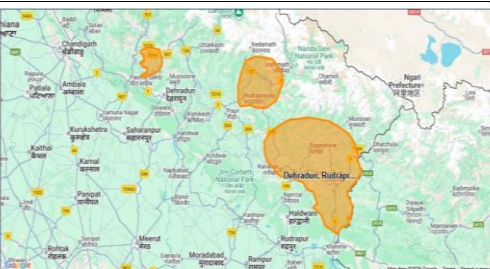


•Moderate Rain / Thunderstorm accompanied with lightning / intense spell of rain is likely to occur at isolated places over Almora, Bageshwar, Chamoli, Champawat, Dehradun, Haridwar, Nainital, Pauri, Pithoragarh, Rudraprayag, Tehri, US Nagar, Uttarkashi in next 3 hours.

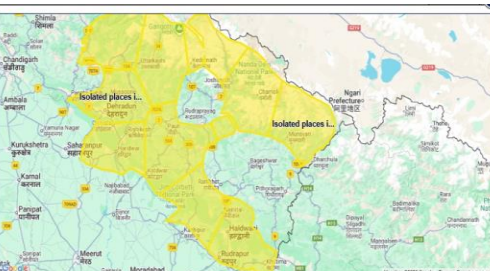


Time of issue: 03:01 AM on 29/08/2025

•Moderate to Heavy Rain / Thunderstorm accompanied with lightning / intense to very intense spell of rain is very likely to occur at isolated places over Dehradun, Tehri Garhwal, Chamoli, Rudra Prayag, Almora, Bageshwar, Champawat, Nainital, Pithoragarh in next 3 hours.



•Moderate Rain / Thunderstorm accompanied with lightning / intense spell of rain is likely to occur at isolated places over Almora, Bageshwar, Chamoli, Champawat, Dehradun, Haridwar, Nainital, Pauri, Pithoragarh, Rudraprayag, Tehri, US Nagar, Uttarkashi in next 3 hours.



9.3.4 Case IV: Dehradun and Tehri Districts on 15th September 2025

The heavy to extremely heavy rainfall on 15th September over Dehradun & Tehri districts caused flooding, landslide and mudslide resulting in loss of life and washout of bridge and roads at multiple locations in Dehradun district and adjoining areas of Tehri District. As per the SEOC, 2 to 3 people were reported missing in Sahastradhara, Dehradun with significant

damage to buildings, property, and roads. One person died after being swept by water currents/heavy flow of water in DIT College, Rajpur Road, Dehradun. One person died due to house collapse by debris in Jharipani, Dehradun. There were multiple incidents, all from Dehradun city, of people being swept away due to strong water flow in Bhagat Singh Colony, Tapkeshwar and Shikhar Falls.

The withdrawal of southwest monsoon from Northwest India commenced on 14th September, 2025 against the normal date of 17th September. The line of withdrawal of southwest monsoon passed through 30.5°N /73.5°E, Sri Ganganagar, Nagaur, Jodhpur, Barmer and 25.5°N /70°E on 15th August. The episodes of heavy to extremely rainfall are not uncommon during withdrawal phase of southwest-monsoon.

9.3.4.1 Weather activity over Dehradun & Tehri districts on 16th September 2025

During the 24-hour period from 08:30 IST of 15th September to 08:30 IST of 16th September 2025, widespread rainfall activity was observed over Dehradun and Tehri districts, with fairly widespread heavy to very heavy rainfall and isolated extremely heavy rainfall over Dehradun district. Isolated heavy to very heavy rainfall was observed over Tehri district in areas adjoining Dehradun district. **Table 9.10** shows 24-hour accumulated rainfall over Dehradun and Tehri districts of Uttarakhand on 16th September 2025. **Fig. 9.10** shows the spatial distribution of daily rainfall over Uttarakhand.

Table 9.10: 24-hour accumulated rainfall over manual and automatic station in Dehradun and Tehri districts of Uttarakhand on 16th September 2025

District	Instrument type	Station	24-hours accumulated rainfall (08:30 IST of 15 th to 08:30 IST of 16 th September)
Dehradun	Manual	Haripur	170.6
		Jollygrant	106.8
		Mussoorie	95
		Rishikesh	66.4
		Dehradun	28.4
		Chakrata	0
		Tyuni	0
	Automatic	Sahastradhara	264
		Maldevta	149

		Kalsi	119.5
		Jollygrant	93
		Hatibharkala	89.5
		Utt. Tech. Uni.	28.5
		Mohakampur	27
		Ucost	21
		Vikas Nagar	11.5
		Chakrata	0.5
Tehri	Manual	Narendra Nagar	200
		Tehri (Cwc)	45.8
		Devprayag	44.8
		Dhanaulti	40
		Keertinagar	18
		Tehri	2.2
	Automatic	Rani_Chawri	71.5
		Nainbagh	32
		Kanatal	13
		Kirtinagar	10.5
Ghansali		0	

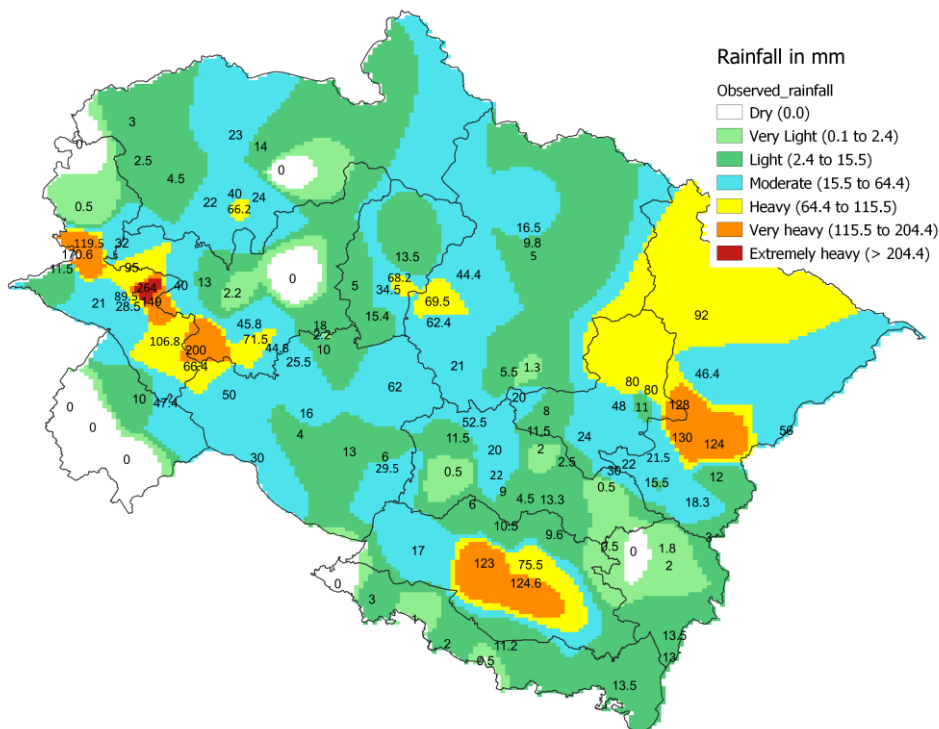


Fig. 9.10: 24-hours accumulated rainfall recorded on 16th September 2025

9.3.4.2 Weather forecast and warnings




Weather forecast and warnings for 15th September 2025 (valid from 08:30 IST of 15.09.2025 to 08:30 IST of 16.09.2025) issued since 11th September 2025 for Dehradun and Tehri districts are presented in **Table 9.11**. Heavy rain (64.5–115.5 mm) warning for Dehradun district was first issued on 11th September 2025, along with a warning of thunderstorm accompanied with lightning and intense to very intense spells of rainfall at isolated places over Dehradun and Tehri districts. The same warning level was continued on 12th and 13th September 2025, indicating persistence of favorable synoptic conditions for heavy rainfall activity.

On 14th September 2025, the rainfall warning for Dehradun district was upgraded to Heavy to Very Heavy rain (115.6–204.4 mm) at isolated places, while the warning for thunderstorm with lightning and intense to very intense rainfall spells continued for both Dehradun and Tehri districts. In view of the anticipated rainfall activity, Flash Flood Guidance (FFG) was issued on 15th September 2025 at 17:30 IST, indicating Low to Moderate flash flood risk over a few watersheds in Uttarakhand, including Dehradun and Tehri districts, valid till 17:30 IST of 16th September 2025.

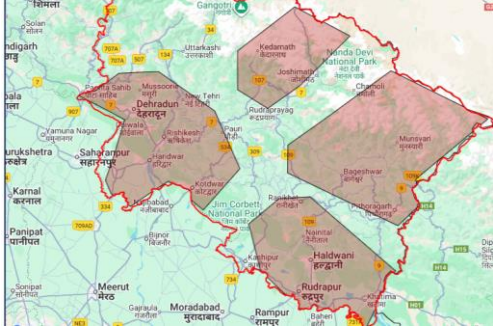


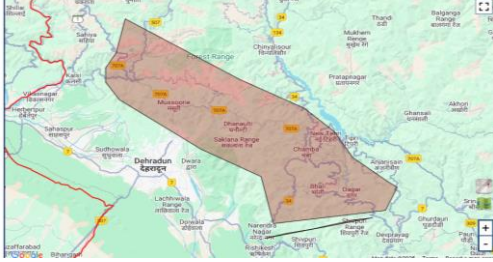
Further, a 24-hour CAP warning was issued at 12:53 IST on 15th September 2025, indicating Heavy to Very Heavy rain accompanied with thunderstorms, lightning and very intense to extremely intense rainfall spells at isolated places over Dehradun district and

adjoining districts during the next 24 hours. Subsequently, multiple Nowcast CAP orange and red warnings were issued from night of 15th till morning of 16th September 2025, indicating the imminent occurrence of severe weather.

Table 9.11: Medium-range weather forecast and warnings for Dehradun & Tehri districts

Date of issue	Weather Warning for Dehradun & Tehri districts for 15 th September 2025 (08:30 IST of 15.09.2025 to 08:30 IST of 16.09.2025)	Warning map
11.09.2025	<ul style="list-style-type: none"> •Heavy rain (64.5-115.5 mm) likely to occur at isolated places in Dehradun district of Uttarakhand. •Thunderstorm accompanied with lightening /intense to very intense spell of rain likely to occur at isolated places in Dehradun and Tehri districts of Uttarakhand. 	 <p>दिन-5: 15/09/2025</p>
12.09.2025	<ul style="list-style-type: none"> •Heavy rain (64.5-115.5 mm) likely to occur at isolated places in Dehradun district of Uttarakhand. •Thunderstorm accompanied with lightening /intense to very intense spell of rain likely to occur at isolated places in Dehradun and Tehri districts of Uttarakhand. 	 <p>दिन-4: 15/09/2025</p>
13.09.2025	<ul style="list-style-type: none"> •Heavy rain (64.5-115.5 mm) likely to occur at isolated places in Dehradun district of Uttarakhand. •Thunderstorm accompanied with lightening /intense to very intense spell of rain likely to occur at isolated places in Dehradun and Tehri districts of Uttarakhand. 	 <p>दिन-3: 15/09/2025</p>

14.09.2025	<ul style="list-style-type: none"> ●Heavy to very heavy rain (115.6-204.4 mm) likely to occur at isolated places in Dehradun district of Uttarakhand. ●Thunderstorm accompanied with lightening /intense to very intense spell of rain likely to occur at isolated places in Dehradun and Tehri districts of Uttarakhand. 	<p>चित्र-2: 15/09/2025</p>
15.09.2025	<ul style="list-style-type: none"> ●Heavy to very heavy rain (115.6-204.4 mm) likely to occur at isolated places in Dehradun district of Uttarakhand. ●Thunderstorm accompanied with lightening /intense to very intense spell of rain likely to occur at isolated places in Dehradun and Tehri districts of Uttarakhand. 	<p>चित्र-1: 15/09/2025</p>
<p>Flash Flood Guidance issued on 15.09.2025 at 17:30 IST</p> <p>24 hours Outlook for the Flash Flood Risk (FFR) till 1730 IST of 16-09-2025 : Low to Moderate flash flood risk likely over few watersheds & neighbourhoods of following Met Sub-divisions during next 24 hours.</p> <p>Uttarakhand - Almora, Bageshwar, Chamoli, Champawat, Dehradun, Nainital, Pauri Garhwal, Pithoragarh, Rudraprayag, Tehri Garwal and Uttarkashi districts.</p>		<p>Product: WRF FFR Timescale: 24-hr Region: "INDIA" Product Date: 2025-09-15 12:00 UTC Valid Date: 2025-09-16 12:00 UTC</p>
24-hours CAP Warnings:		
<p>24 hour CAP (Date:15.09.2025,Time:1253 IST)</p> <p>Heavy to Very Heavy Rain accompanied with Thunderstorms/lightning and very intense to extremely intense spell of rain is very likely to occur at isolated places over Bageshwar, Champawat, Dehradun, Pithoragarh, Nainital and Udham Singh Nagar districts of Uttarakhand in next 24 hours.</p>		
Nowcast CAP Warnings:		
<p>Time of issue: 08:43 PM on 15/09/2025</p> <p>●Moderate Rain / Thunderstorm with intense to very intense spell of rain is very likely to occur at isolated places over Dehradun, Tehri, Haridwar, Pauri, Chamoli,</p>		

<p>Pithoragarh, Rudraprayag, Bageshwar, Nainital and US Nagar districts in next 3 hours.</p>	
<p>Time of issue: 10:41 PM on 15/09/2025</p> <ul style="list-style-type: none"> Severe Thunderstorm with Moderate rain and intense to very intense spell of rain is very likely to occur at isolated places over Dehradun, Tehri and adjoining areas in next 2 hours. 	
<p>Time of issue: 11:41 PM on 15/09/2025</p> <ul style="list-style-type: none"> Severe Thunderstorm with Moderate to heavy rain and very intense to extremely intense spell of rain is very likely to occur at isolated places over Dehradun, Nainital and adjoining areas of Tehri and Pauri districts in next 3 hours. 	
<p>Time of issue: 03:21 AM on 16/09/2025</p> <ul style="list-style-type: none"> Severe Thunderstorm with lightning/Moderate rain/intense to very intense spell of rain is very likely to occur at isolated places over Tehri and Dehradun districts in next 3 hours. 	

9.4 Trend of occurrence of heavy rainfall events over Uttarakhand

An analysis of frequency of all categories of heavy rainfall events during Monsoon season over Uttarakhand has been carried out to find the trend in the frequency of extreme events. There has been steady increase in number of heavy and more rainfall events in Uttarakhand since 2019 as shown in **Table 9.12** and **Fig. 9.11**. The Mann–Kendall non-parametric statistical trend test shows non-significant (at 95% significance) increasing trend in total number of events (heavy or more) in Uttarakhand.

Table 9.12: Number of heavy or more rainfall events based on 10 years data of 50 DRMS stations of Uttarakhand

Years	Heavy	Very heavy	Extremely heavy	Total
2016	116	24	2	142
2017	125	33	1	159
2018	106	24	2	132
2019	71	18	1	90
2020	83	14	2	99
2021	108	23	3	134
2022	107	28	1	136
2023	131	29	4	164
2024	139	38	2	179
2025	163	41	4	208

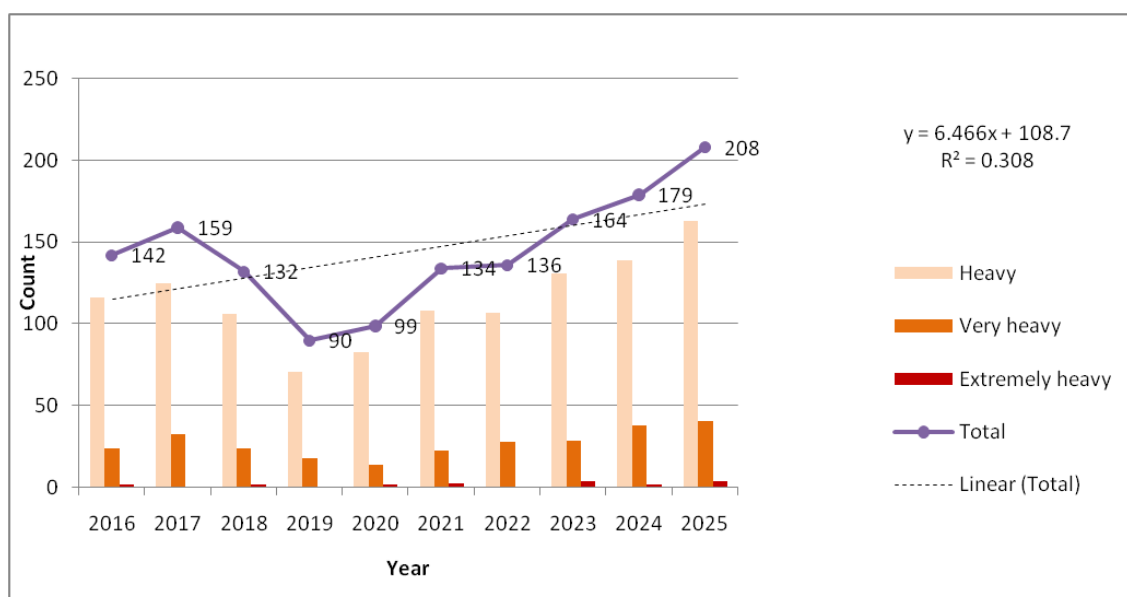


Fig. 9.11: Yearly number of heavy, very heavy and extremely heavy events observed over Uttarakhand during monsoon season

9.5 Conclusion

The southwest monsoon season of 2025 over Uttarakhand was characterized by above-normal rainfall, frequent heavy to extremely heavy rainfall events, and multiple high-impact hydro-meteorological disasters. The State as a whole received 122% of its Long Period Average (LPA) rainfall, with more than half of the geographical area (53%) experiencing

excess to large excess rainfall, underscoring the anomalous nature of the monsoon season. The month of August 2025 contributed to the highest number of heavy, very heavy, and extremely heavy rainfall events, as well as the maximum frequency of very intense and extremely intense hourly rainfall spells.

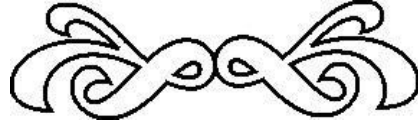
The case studies of four high impact events due to flash floods, debris flows, landslides and mudslides, resulting in significant loss of life, property, livestock, and infrastructure viz. Dharali (05 August), Tharali (23 August), Rudraprayag, Chamoli, Tehri and Bageshwar on 29 August, and Dehradun–Tehri (15 September) were discussed in detail. The weather forecast and warnings for high impact events are provided at medium-range and nowcast scale. However, the rapid development, high spatial variability, and very short temporal scale of intense rainfall over mountainous regions continue to pose challenges for precise impact-based forecasting and disaster preparedness.

The trend analysis of the last decade shows a consistent increase in the number of heavy and above rainfall events since 2019, with 2025 recording the highest number of such events, although the Mann–Kendall test indicates a statistically non-significant increasing trend at the 95% confidence level. This nevertheless points towards a growing risk of extreme rainfall occurrences in the State, necessitating enhanced monitoring and preparedness. Given Uttarakhand's high vulnerability due to steep topography, fragile geology and increasing exposure, heavy rainfall-induced disasters are likely to remain a recurring challenge, making continuous improvement in early warning systems and community preparedness imperative.

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10



SATELLITE-BASED FEATURES OF THE SOUTHWEST MONSOON – 2025

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This chapter discusses observed features of the southwest monsoon – 2025 such as monsoon onset over Kerala, withdrawal from the northwest India, active and break spells of monsoon, and monthly & seasonal rainfall using meteorological satellite datasets.

10.1 Introduction

Reliable weather and climate services are crucial for socio-economic benefits of the nation. The operational geostationary meteorological satellites became an integral part of the observation systems for real-time monitoring of tropical and sub-tropical weather systems, and their nowcasting. A geostationary satellite provides repetitive measurements over about 40% area of the globe. India began its own geostationary meteorological satellite program – Indian National Satellite system (INSAT) in 1982. Along with India, currently United States of America, Europe, Japan, China, Russia, and South Korea have their own geostationary meteorological satellites in orbit. Due to consistent advancement in the meteorological instruments onboard INSAT geostationary satellites and their resolutions, it became possible to monitor the Indian monsoons and high-impact severe weather system in real-time at finer spatial and temporal scales for disaster management and risk mitigation (Srinivasan and Joshi, 2007; Giri et al., 2025). These satellites also enabled near real-time weather nowcasting and adequate determination of centre, structure and intensity of any tropical cyclone over the North Indian Ocean (Goyal et al., 2017; Kishtawal, 2019; Prasad et al., 2021). These satellites enabled the development of several geophysical products for a wide range of applications, and also serve as a reliable source of observations for the monitoring of dynamic atmospheric and oceanic features at diurnal to seasonal timescales. Apart from

meteorological payloads, INSAT geostationary satellites have onboard data collection systems for environmental monitoring, search and rescue systems for the humanitarian rescue operations, and communication payload for telecommunication support.

Currently two third-generation INSAT meteorological satellites viz., INSAT-3DR and INSAT-3DS are operational. INSAT-3DR was launched on 8th September, 2016 and INSAT-3DS was launched on 17th February, 2024, and are placed at 74°E and 82°E, respectively (**Fig. 10.1**). Both satellites have four instruments namely, six-channel Very High Resolution Radiometer (VHRR) or imager, 19-channel atmospheric sounder, Data Relay Transponder (DRT), and Satellite-Aided Search & Rescue (SAS&R). The imagers onboard INSAT-3DR and INSAT-3DS satellites are kept in staggered mode to obtain new set of data at 15-minute interval, even though the temporal resolution of each imager is 30-minute. Atmospheric sounder onboard both satellites provide data at hourly temporal resolution. Both imagers have additional capability of rapid-scan, which is usually activated during the development of tropical cyclones over the North Indian Ocean (Mohapatra et al., 2021). During the rapid-scan, temporal resolution enhances to 4.5-minute for a selected sector of the full disk. The general specifications of the INSAT-3DR/3DS imager are given in **Table 10.1**. The spatial resolutions of visible and SWIR channels are 1 km, spatial resolutions of MIR, TIR1 and TIR2 are 4 km, and that of WV channel is 8 km.

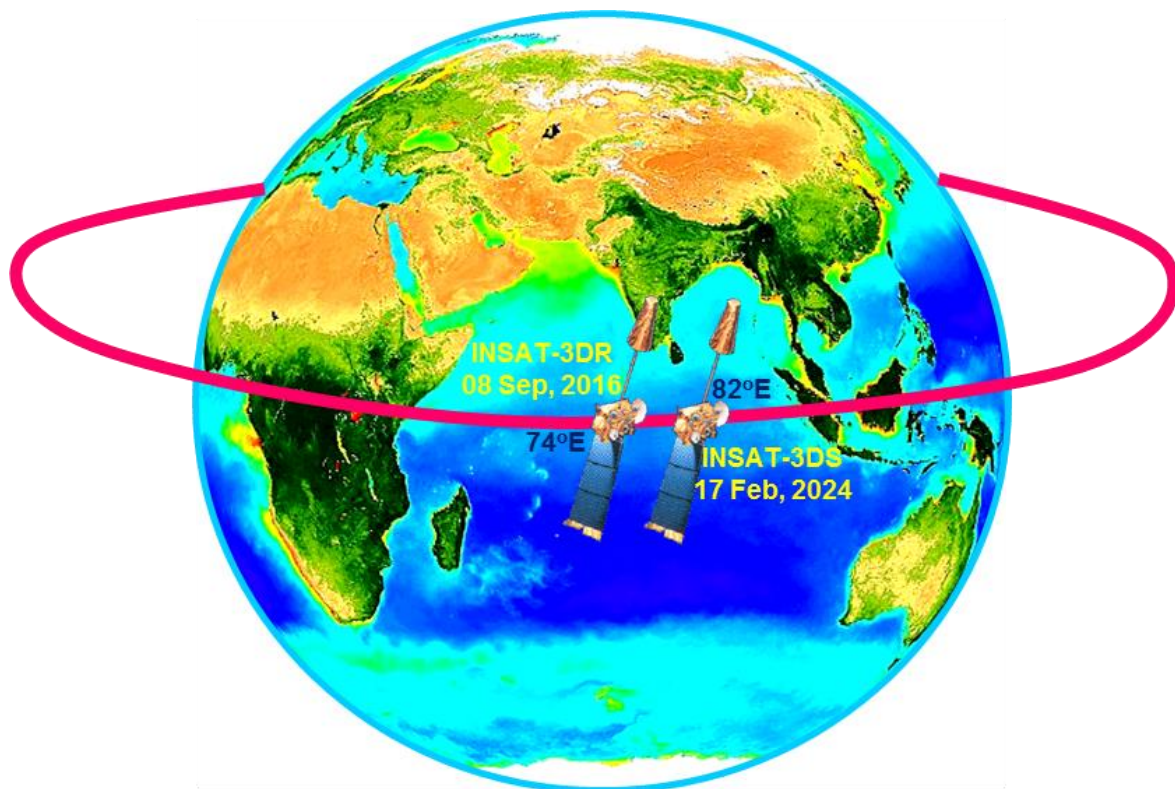


Fig. 10.1: Position of INSAT-3DR and INSAT-3DS satellites over the equatorial Indian Ocean

Table 10.1: Specifications of INSAT-3DR/3DS imager instruments

Channel Number	Spectral Band	Spectral Interval	Spatial Resolution
1.	Visible (Vis)	0.55-0.75 μm	1 km
2.	Shortwave Infrared (SWIR)	1.55-1.70 μm	1 km
3.	Midwave Infrared (MIR)	3.80-4.00 μm	4 km
4.	Water Vapour (WV)	6.50-7.10 μm	8 km
5.	Thermal Infrared 1 (TIR1)	10.3-11.3 μm	4 km
6.	Thermal Infrared 2 (TIR2)	11.5-12.5 μm	4 km

TIR channel was splitted into two channels - TIR1 and TIR2 for more accurate sea surface temperature estimation. TIR2 is also known as dirty window channel and about twice more sensitive to low level moisture than TIR1. The difference between TIR1 and TIR2 measurements quantifies the differential WV absorption in the atmosphere and used to correct the atmospheric absorption of the upwelling radiation to obtain more accurate SST estimate. MIR channel was introduced for reliable detection of night-time fog and low cloud. In addition, MIR along with SWIR channel enables better land-cloud discrimination and detection of surface features. About 50 geophysical products are derived in real-time from VHRR data and more than a dozen of distinct products are derived from the sounder instrument through the Multi-mission Meteorological Data Receiving and Processing System (MMDRPS) at IMD, New Delhi (Giri et al., 2023). These products along with raw data are shown to be very useful in various meteorological applications. These meteorological products along with customized raw datasets have proven to be very useful in various applications such as operational weather forecasting, monitoring and nowcasting of convective weather events, tropical cyclone monitoring, numerical model data assimilation, agriculture, power, aviation, tourism, and renewable energy sectors.

India receives about three-fourths of its annual rainfall from the southwest or summer monsoon season usually spanning from June to September. The Indian summer monsoon rainfall is vital for agricultural production and Indian economy. But, the Indian summer monsoon rainfall exhibits large spatial and temporal variability. The all-India seasonal monsoon rainfall for June – September was about 94 cm in 2025, which is 108% of long period average of 87 cm. This chapter discusses the various aspects of the southwest monsoon – 2025 using satellite data and products.

10.2 Monitoring of the monsoon onset and withdrawal using satellite data

The monsoon onset over Kerala (MOK) is considered as beginning of the southwest monsoon rainy season for the country. MOK is operationally declared by IMD based on rainfall, wind field and outgoing longwave radiation (OLR) criteria since 2006 and are given by: (a) If at least 8 out of 14 rain gauge stations in Kerala state (namely Minicoy, Amini, Thiruvananthapuram, Punalur, Kollam, Allapuzha, Kottayam, Kochin, Trissur, Kozhikode, Talassery, Cannur, Kasargode and Mangalore) report daily rainfall of 2.5 mm or more for two consecutive days after 10th May, MOK may be declared on the second day if following two criteria are also satisfied in concurrence. (b) Depth of westerlies in IMD wind analysis or satellite-derived winds should be maintained upto 600 hPa over the area bounded by 0^o-10^oN and 55^o-80^oE. In addition, zonal wind speed over the area bounded by 5^o-10^oN and 70^o-80^oE should be of the order of 15-20 knots at 925 hPa. (c) The INSAT derived OLR value should be lower than 200 Wm⁻² in the area bounded by 5^o-10^oN and 70^o-75^oE.

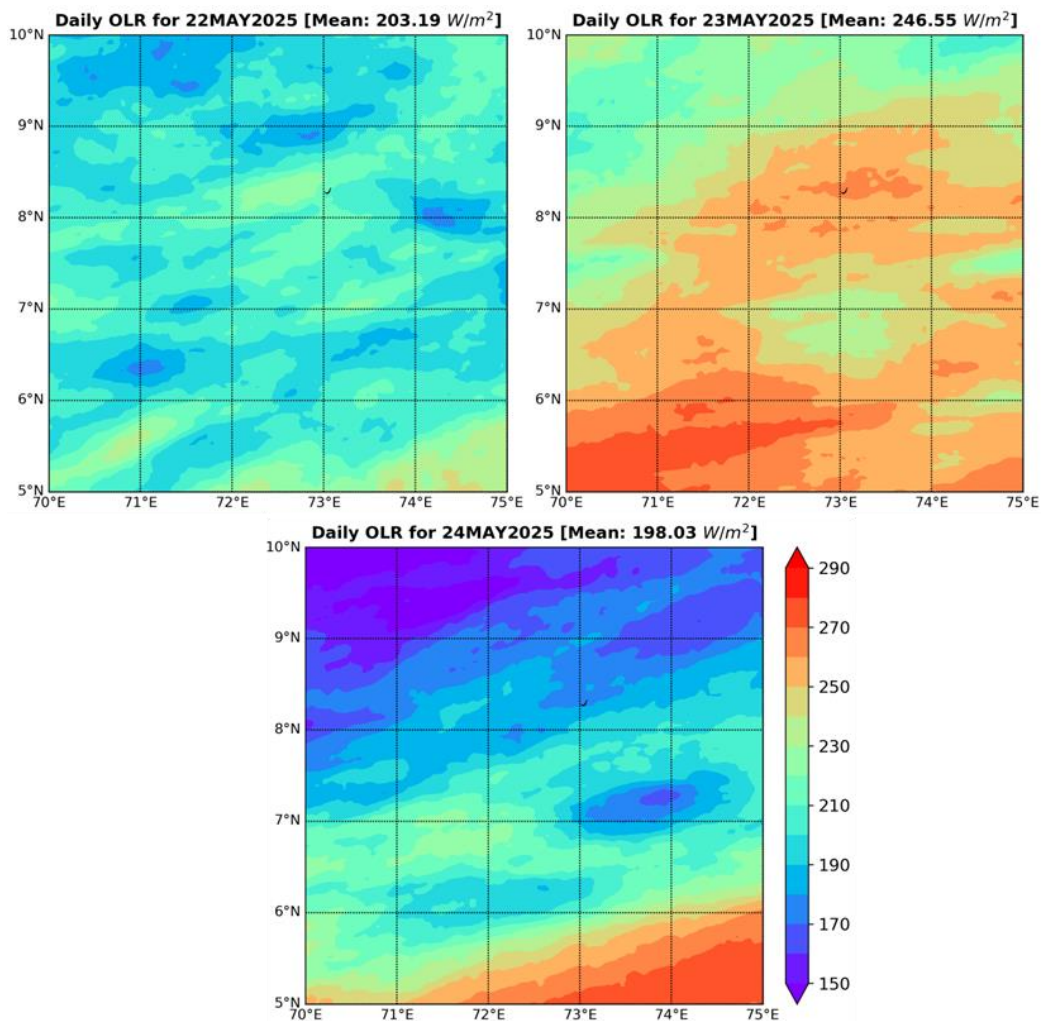


Fig. 10.2: Mean daily OLR from INSAT-3DR for region bounded by 5^o-10^oN and 70^o-75^oE during 22nd – 24th May, 2025. Daily OLR values averaged for the region are also given.

The monsoon onset over Kerala was declared on 24th May, eight days earlier than the normal date of 1st June. The spatial distributions of INSAT-derived daily mean OLR for the area bounded by 5°-10°N and 70°-75°E for the period of 22nd – 24th May, 2025 are shown in **Fig. 10.2**. The average OLR for the 5° × 5° box is about 203 Wm⁻² on 22nd May, which increased to about 247 Wm⁻² on 23rd May and became about 198 Wm⁻² on 24th May. Hence, the criterion of OLR was completely satisfied on 24th May for declaration of MOK.

Fig. 10.3 shows the spatial distributions of INSAT-3DR TIR1 imagery at 0815 hrs IST of 24th May, 2025. It shows cloud coverage over entire west coast of India and adjoining Arabian Sea region. The brighter clouds usually correspond to deep convection and good rainfall activity. The daily accumulated rainfall ending at 0830 hrs IST of 24th May, 2025 using INSAT-3DR satellite is shown in **Fig. 10.3**. Four distinct rainfall products based on different algorithms are operationally generated from the VHRR measurements. One of them is the Hydro-Estimator Method (HEM) available at 4 km spatial resolution and shown to be reasonable in the southwest monsoon rainfall estimation (Prakash and Bhan, 2023). The spatial distribution of HEM rainfall shows widespread rainfall activity over the state of Kerala with isolated heavy to very heavy rainfall activity over north coastal region. Isolated heavy to very heavy rainfall activity is also observed over Karnataka and Maharashtra, and heavy rainfall activity over Tamil Nadu. It led to simultaneous monsoon advance over some parts of Karnataka, Tamil Nadu and northeast India on the same day of MOK.

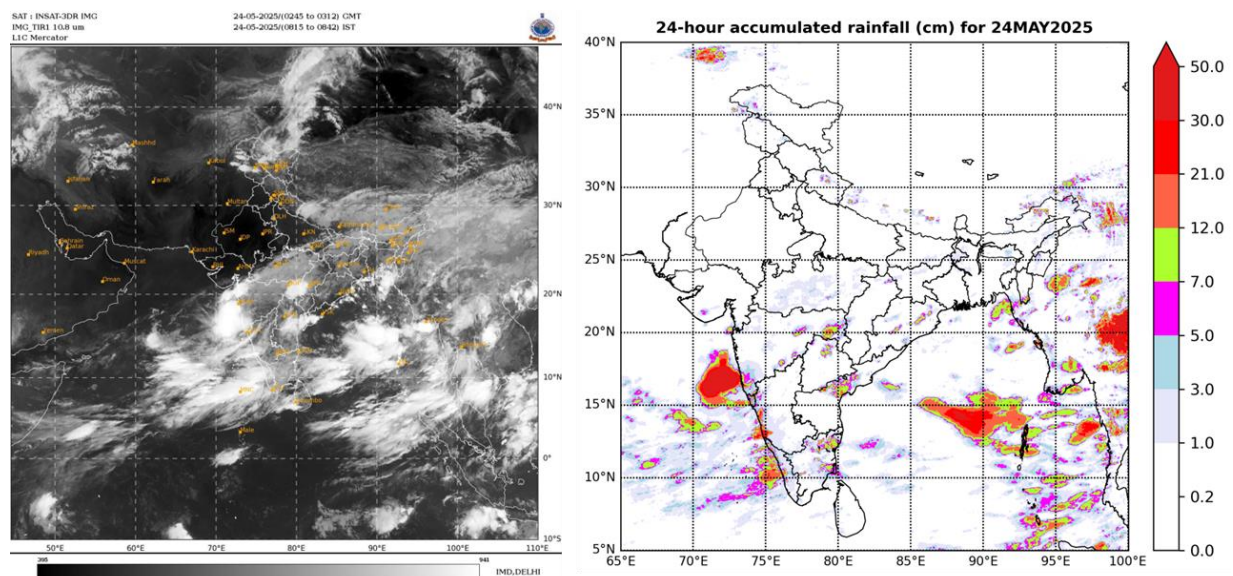


Fig. 10.3: INSAT-3DR TIR1 cloud imagery and daily accumulated HEM rainfall for 24th May, 2025

The withdrawal of the southwest monsoon from the extreme northwest India is operationally declared by IMD based on the following major synoptic features: (a) Cessation of rainfall activity over the area for continuous 5 days after 1st September, (b) Establishment

of an anticyclone in the lower troposphere of 850 hPa and below (c) Considerable reduction in moisture content is seen in satellite water vapour imageries and T-Phi grams. The southwest monsoon was withdrawn from some parts of West Rajasthan on 14th September, 2025 against the normal date of 17th September. The daily accumulated HEM rainfall over the country for 9th – 14th September, 2025 is shown in **Fig. 10.4**. It clearly depicts that there was no rainfall activity over the West Rajasthan and adjoining areas during the period. Most of the rainfall activities during this period were over eastern and northeastern parts of the country. Heavy to extremely rainfall spell over Bihar, Sub-Himalayan West Bengal & Sikkim and Assam & Meghalaya during the period was observed due to a cyclonic circulation over Bihar and another cyclonic circulation over North Bangladesh and southerly/southeasterly wind convergence over the region from North Bay of Bengal. In addition, formation of a Low Pressure Area and its movement from south Odisha-Andhra Pradesh coasts to central India during 12th – 14th September caused heavy to extremely heavy rainfall spell across the region. The satellite water vapour imagery overlaid with corresponding wind vectors for 14th September, 2025 at 0215 UTC indicates less moisture in middle and upper tropospheric levels over north and northwest India, and daily mean OLR map showed no convection over the West Rajasthan (**Fig. 10.5**).

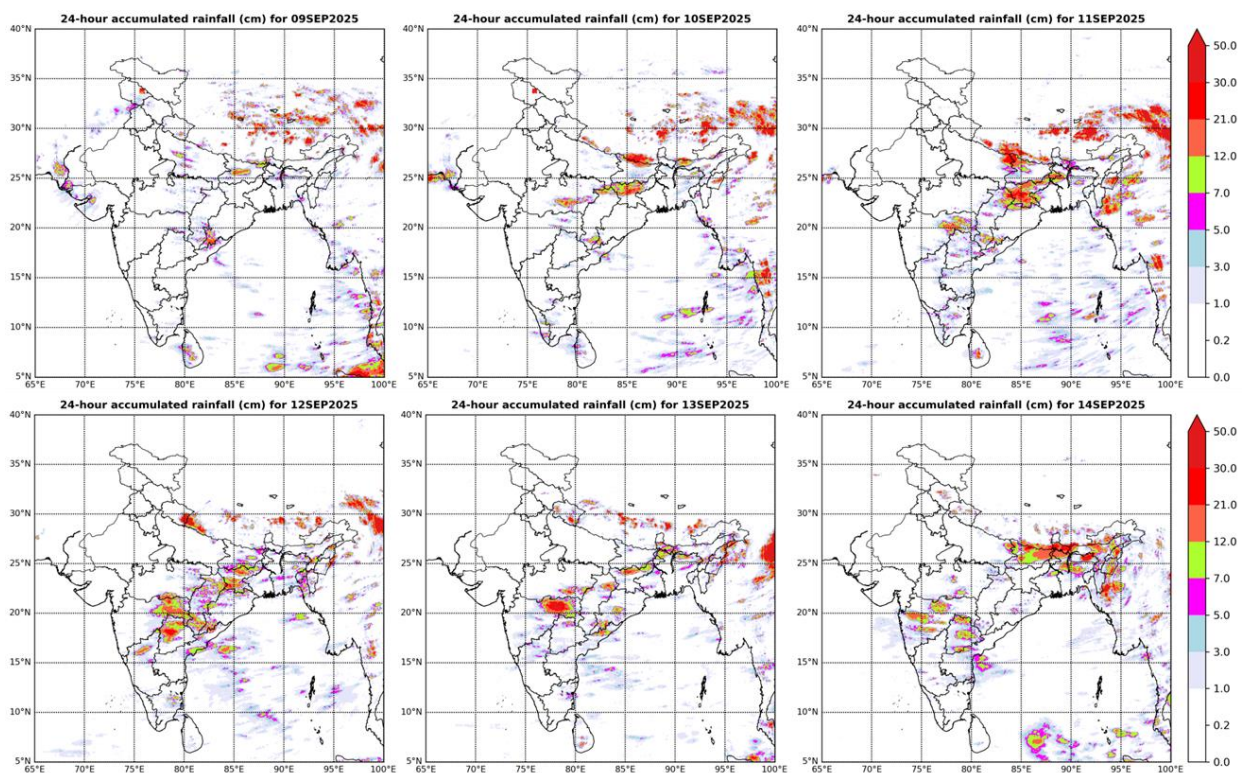


Fig. 10.4: Spatial distributions of INSAT-3DR HEM daily accumulated rainfall during 9th – 14th September, 2025

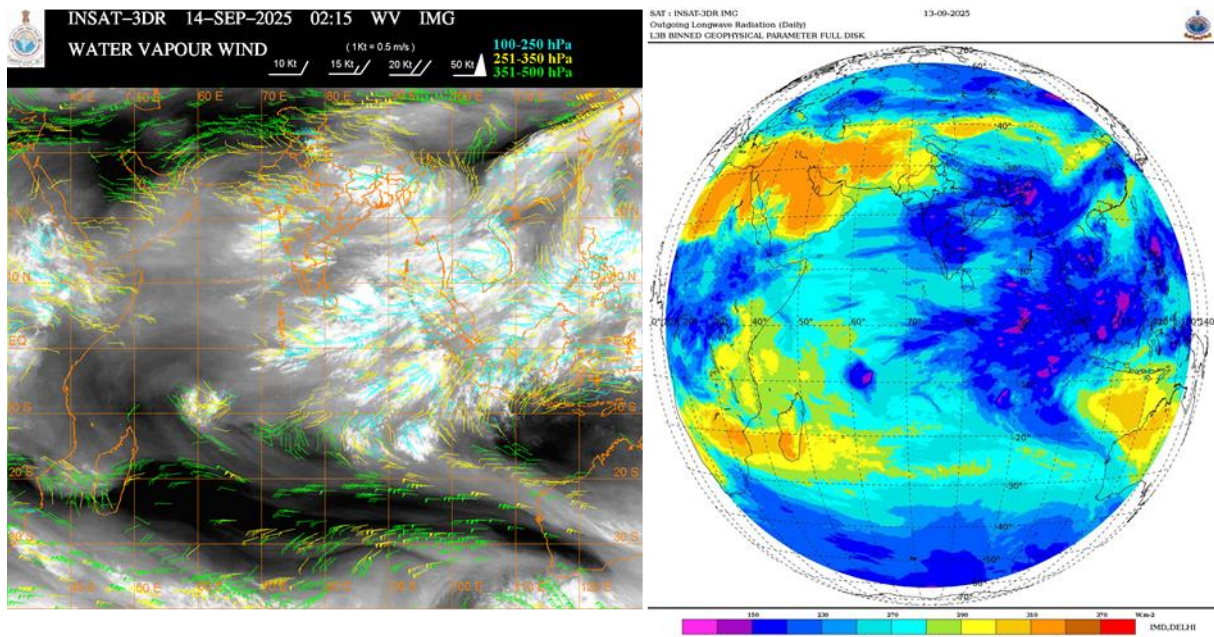


Fig. 10.5: INSAT-3DR water vapour wind vector and daily mean OLR on 14th September, 2025

10.3 Monitoring of active and break spell of monsoon using satellite data

The southwest monsoon precipitation exhibits notable intra-seasonal variations leading to active and break spells of rainfall over the core monsoon zone. These intra-seasonal variations of monsoon rainfall are crucial for agricultural production over the country. Active and break spells of monsoon rainfall are defined based on IMD rain gauge-based gridded precipitation dataset over the critical high monsoon precipitation region of the central India known as core monsoon zone (roughly from 18.0°N – 28.0°N and 65.0°E – 88.0°E) for the peak monsoon months of July and August (Rajeevan et al., 2010). The break spell is defined as the period with standardized rainfall anomaly over the core monsoon zone less than -1.0 consecutively for three days or more, whereas the active periods with standardized rainfall anomaly more than $+1.0$ consecutively for three days or more. Climatologically, there are 7 days of active and break events during the period of July and August, and the all-India seasonal monsoon rainfall is negatively correlated with number of break days (Rajeevan et al., 2010).

There are two break spells (4th – 7th August and 10th – 12th August), and two active spells (1st – 8th July and 23rd – 25th August) during the peak monsoon months of 2025. Hence, the peak monsoon months of 2025 consisted of 11 days of active spell and 7 days of break spells. The spatial distributions of INSAT-based daily mean OLR and daily accumulated HEM rainfall over the Indian region for one active spell and one break spell of the monsoon 2025 is discussed. **Fig. 10.6** shows daily OLR and rainfall for 23rd – 25th August while the monsoon was in active spell, and **Fig. 10.7** shows the same for a break spell during 10th – 12th August, 2025.

Lower mean daily OLR indicates normal position of the monsoon trough during the active spell of 23rd – 25th August. In addition, a low pressure area was over Gangetic West Bengal and neighbourhood on 23rd August, which moved to northeast Madhya Pradesh and neighbourhood on 24th August and became less marked on 25th August. It caused heavy to very heavy rainfall at isolated places over Odisha, Jharkhand, Chhattisgarh and east Madhya Pradesh. Two upper air cyclonic circulations and a western disturbance were also over the northwest India during this period. These systems cause heavy to very heavy rainfall activities over east Rajasthan and adjoining Madhya Pradesh during this period. The HEM rainfall also indicates very heavy to extremely heavy rainfall over east Rajasthan during the period (Fig. 10.6).

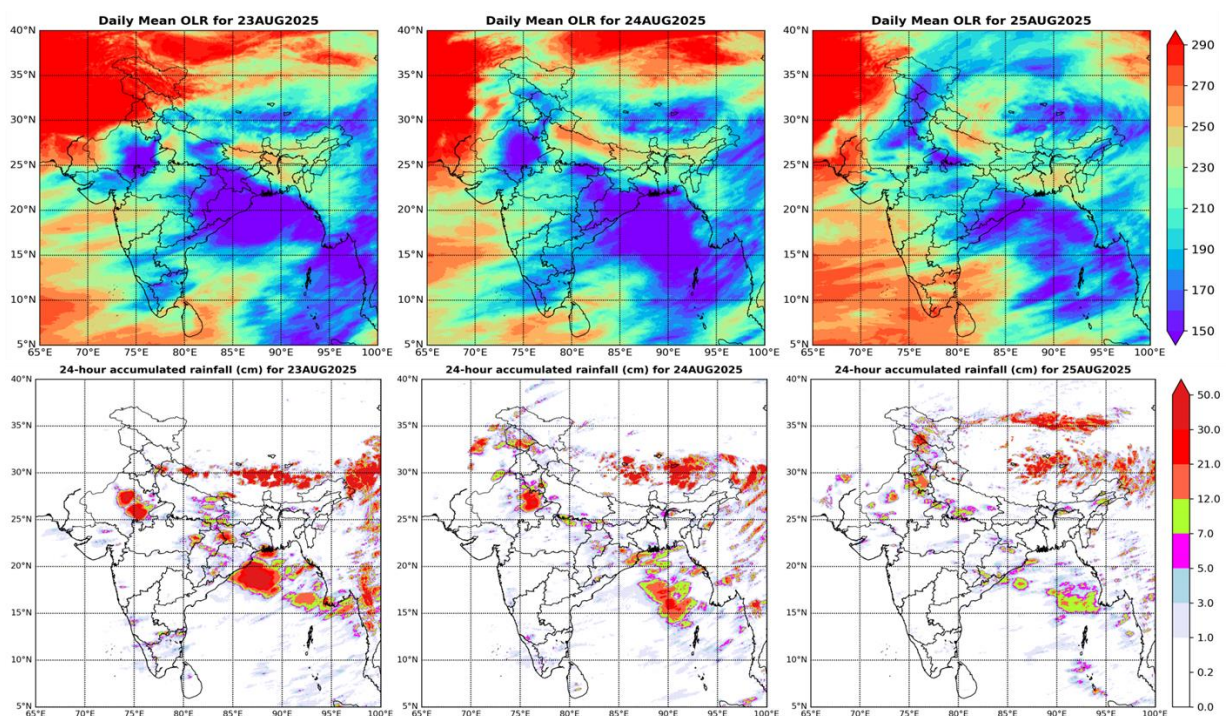


Fig. 10.6: Spatial distribution of INSAT-3DR daily mean OLR and daily accumulated HEM rainfall during an active spell of the southwest monsoon for 23rd – 25th August, 2025

During 10th – 12th August, the western end of the monsoon trough was north of its normal position and eastern end near the foothills of the Himalayas led to break spell of monsoon over the country. The mean daily OLR during this period (Fig. 10.7) clearly indicates lower magnitudes corresponding to more convection over the region. The daily HEM rainfall shows enhanced rainfall over north India, along the Himalayan foothills and south peninsular India, while weak rainfall activity over the core monsoon zone.

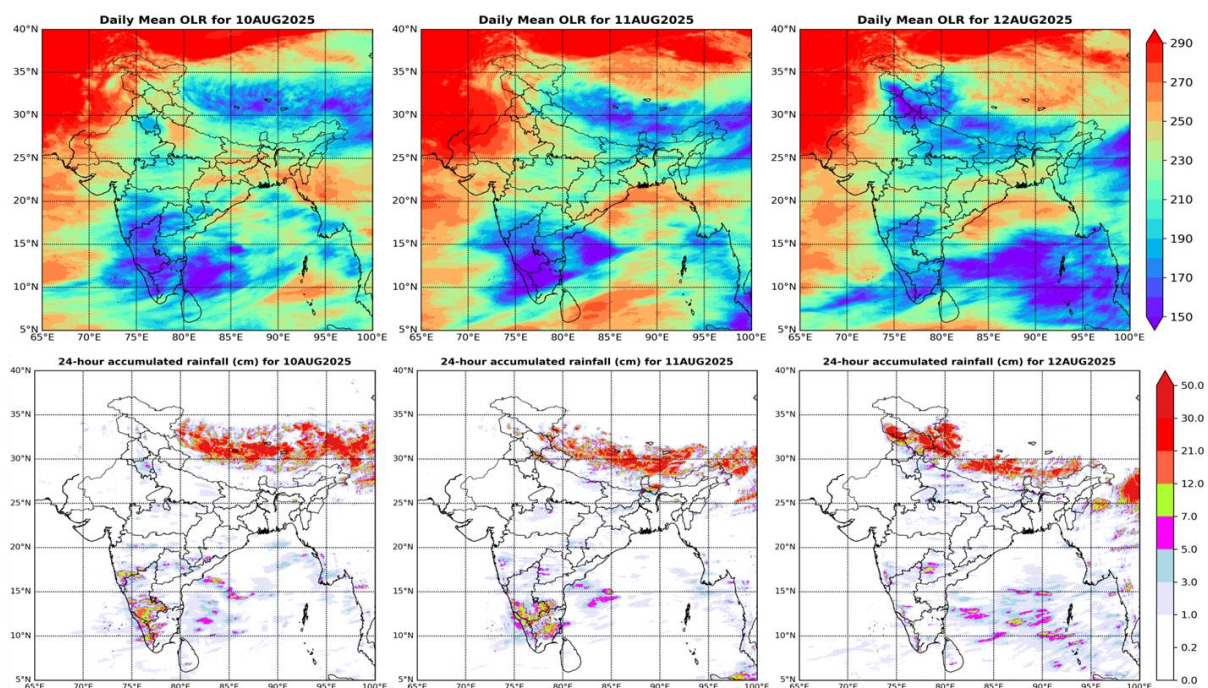


Fig. 10.7: Spatial distribution of INSAT-3DR daily mean OLR and daily accumulated HEM rainfall during a break spell of the southwest monsoon for 10th – 12th August, 2025

10.4 A case of interaction between monsoon circulation and western disturbance

During 22nd – 27th August, very heavy to isolated heavy rainfall spell over northwest India including east Rajasthan, Punjab, Haryana and Jammu & Kashmir was observed. It caused landslides over the hilly region and severe flooding over Jammu, Punjab and parts of Rajasthan along with flash floods in some areas of this region. The monsoon trough was near its normal position during the period. An active western disturbance was seen as a trough in middle to upper tropospheric levels and its axis was running roughly along 28°N to the north of 32°N on 24th and 25th August. The water vapour channel imagery (**Fig. 10.8**) clearly indicates the trough at morning hours of 25th August. In addition, there were two cyclonic circulations over the northwest India during this period. One of them was over northwest Madhya Pradesh and neighbourhood extending upto 5.8 km above mean sea level and another over Punjab and neighbourhood extending upto 1.5 km above mean sea level. The slow moving western disturbance interacted with these two cyclonic circulations, which caused heavy to very heavy rainfall over Jammu & Kashmir, Punjab, Haryana and adjoining areas of Rajasthan. The TIR1 brightness temperature indicates intense to very intense convection over these areas corresponding to intense rainfall activity as shown by the daily accumulated HEM rainfall.

The RGB products include information from three spectral channels of INSAT-3R/S imager and provide detailed information of cloud type. The advantage of RGB products is the ability to look at a single image to identify a feature instead of analysing multiple spectral

channels individually. The SWIR, visible and TIR1 channels are used to generate daytime RGB or Day Microphysics (DMP) product, while brightness temperature differences between TIR1 & TIR2, and MIR channels are used to generate night-time RGB or Night Microphysics (NMP) product. These RGB products have significantly minimized the misclassification between low clouds, snow and fog, and play an important role in day-to-day weather monitoring and nowcasting. The RGB products are proven to be useful in detection and monitoring of convective activities, thunderstorms and fog over the Indian region. **Fig. 10.8** illustrates the capability of satellite imagery and products to monitor severe weather activities associated with interaction between monsoon circulations and western disturbances effectively during the southwest monsoon period.

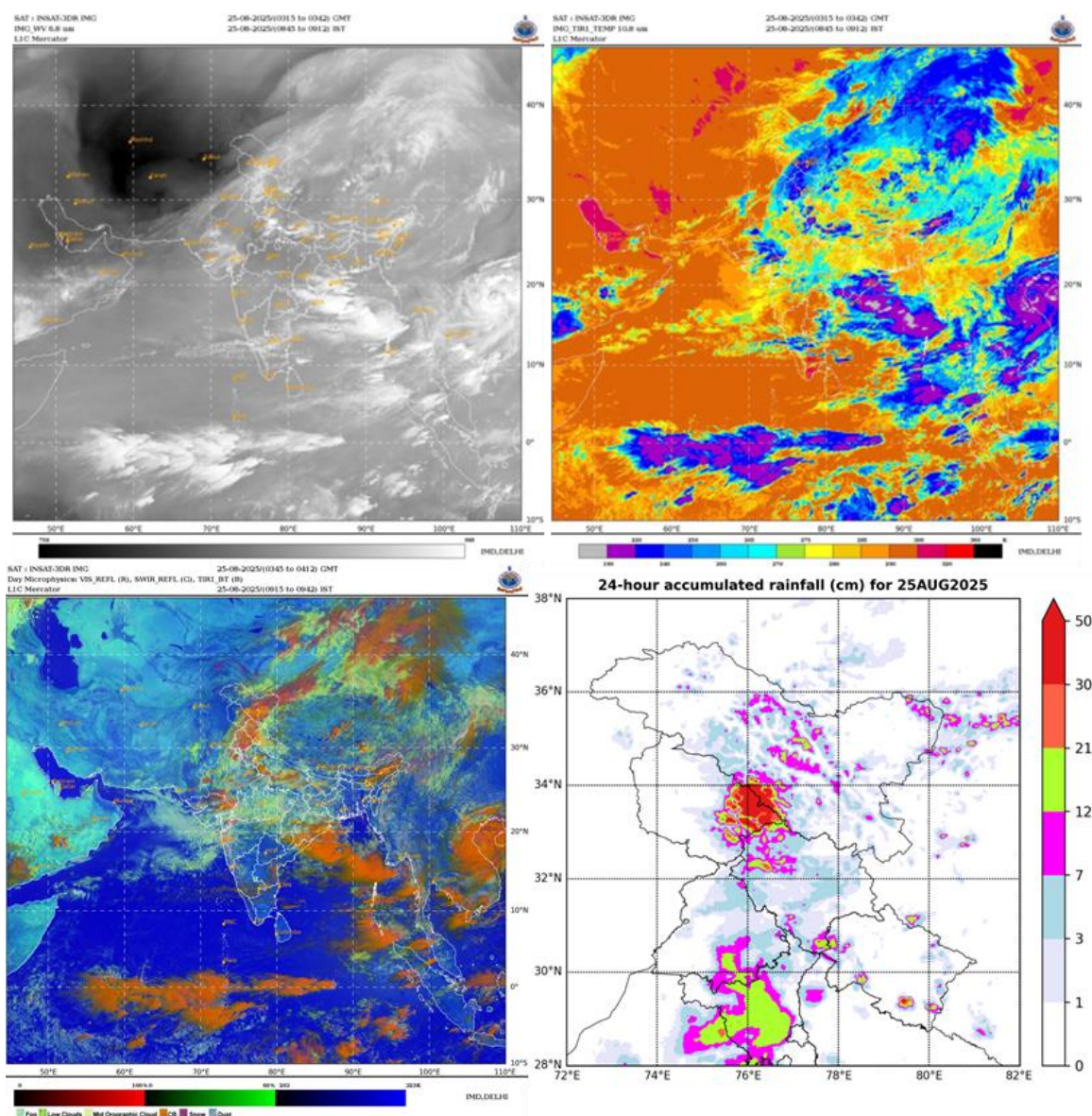


Fig. 10.8: INSAT-3DR water vapour imagery, TIR1 brightness temperature, day microphysics products for a specific time of 25th August, 2025 and corresponding daily HEM rainfall.

10.5 Monthly and seasonal monsoon rainfall from merged satellite-gauge data

The rainfall products derived from satellites have certain bias and errors, while rain gauge observations available over the land only. In addition, the spatial distributions of rain gauges are not uniform across the country due to several factors. Hence, synergistic use of satellite rainfall product with rain gauge observations provides an optimal solution to monitor monsoon rainfall over the Indian region consisting both land and oceanic area. India Meteorological Department (IMD) and National Centre for Medium Range Weather Forecasting (NCMRWF) have collaboratively developed a merged satellite-gauge daily rainfall dataset at a spatial resolution of $0.25^\circ \times 0.25^\circ$ for the region bounded by 30°S - 40°N latitude and 50° - 110°E longitude. This dataset has been developed by combining daily IMD rain gauge observations with near real-time Global Precipitation Measurement (GPM)-based multi-satellite precipitation product (Mitra et al., 2025). This daily gridded rainfall product is available in near real-time since October 2015 and is shown to be one of the best available gridded rainfall products over the region for monsoon studies, cyclone rainfall characterization and numerical model output verification.

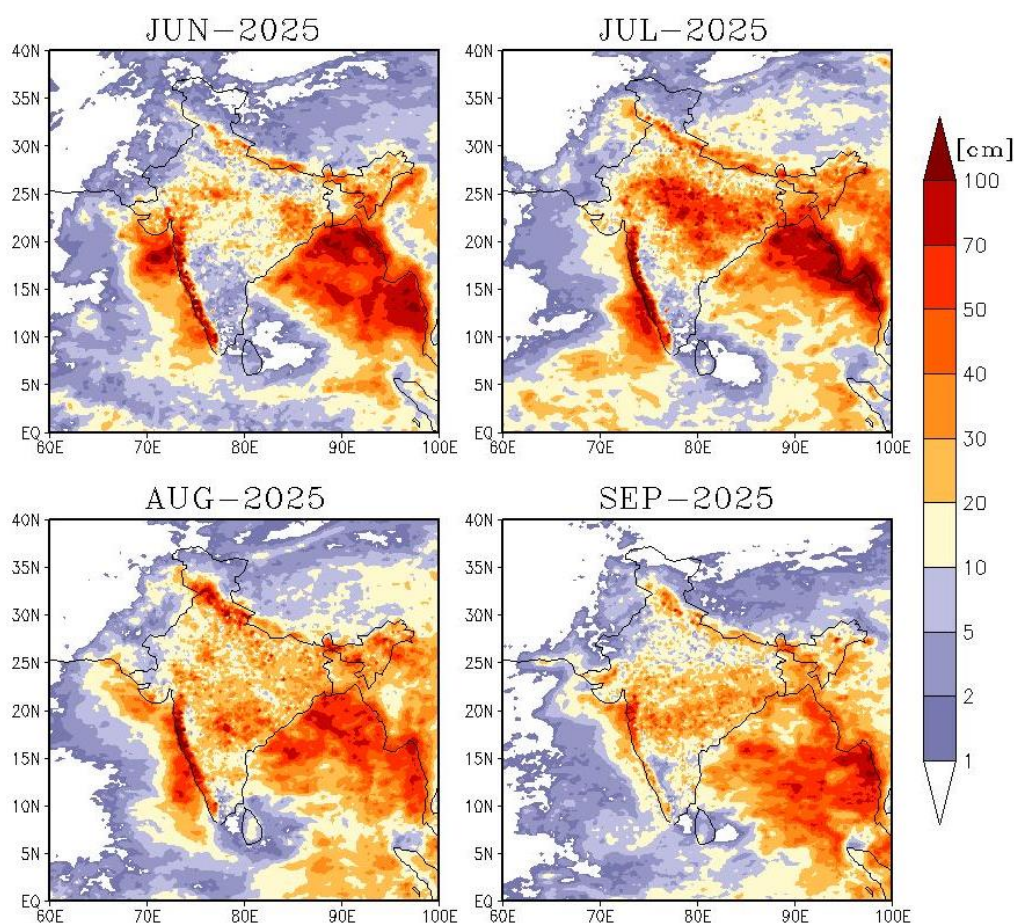


Fig. 10.9: Spatial distributions of monthly monsoon rainfall during 2025 over the Indian region using merged satellite-gauge rainfall dataset

Fig. 10.9 shows spatial distributions of monthly monsoon rainfall for 2025 over the Indian region using the merged satellite-gauge rainfall product. The oceanic region of North Bay of Bengal, east central Bay of Bengal, Andaman Sea and eastern Arabian Sea receive substantial rainfall during the season along with the Indian landmass. The largest mean monthly rainfall during the month of July followed by August, September and June over India is captured reasonably well by this rainfall dataset. The northward propagation of daily monsoon rainfall is illustrated in **Fig. 10.10** using the merged satellite-gauge rainfall dataset. The northward propagation of rainfall from the equatorial Indian Ocean to the foothills of the Himalayas is a prominent feature of intra-seasonal oscillation of the southwest monsoon, which causes active and break cycles of rainfall over the country (Gadgil, 2003).

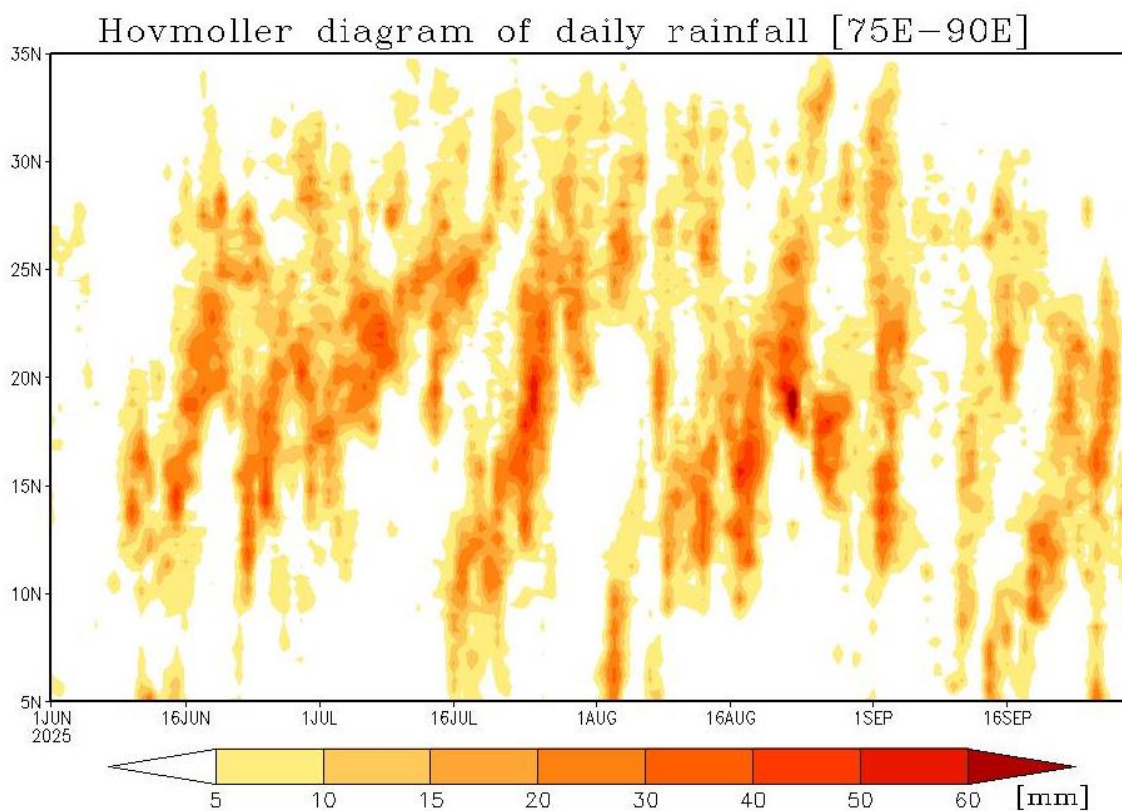


Fig. 10.10: Northward propagation of daily monsoon rainfall during 2025 over the Indian region using merged satellite-gauge rainfall dataset

Fig. 10.11 shows spatial distributions of seasonal monsoon rainfall for 2025 over the Indian region using the merged satellite-gauge rainfall product. The mean monsoon rainfall features such as high mean rainfall along west coast, central India and northeast India are well captured. The western part of the country received above normal monsoon rainfall during 2025. Rain gauge based observations also showed that west and east Rajasthan received more than 60% above normal seasonal monsoon rainfall during 2025.

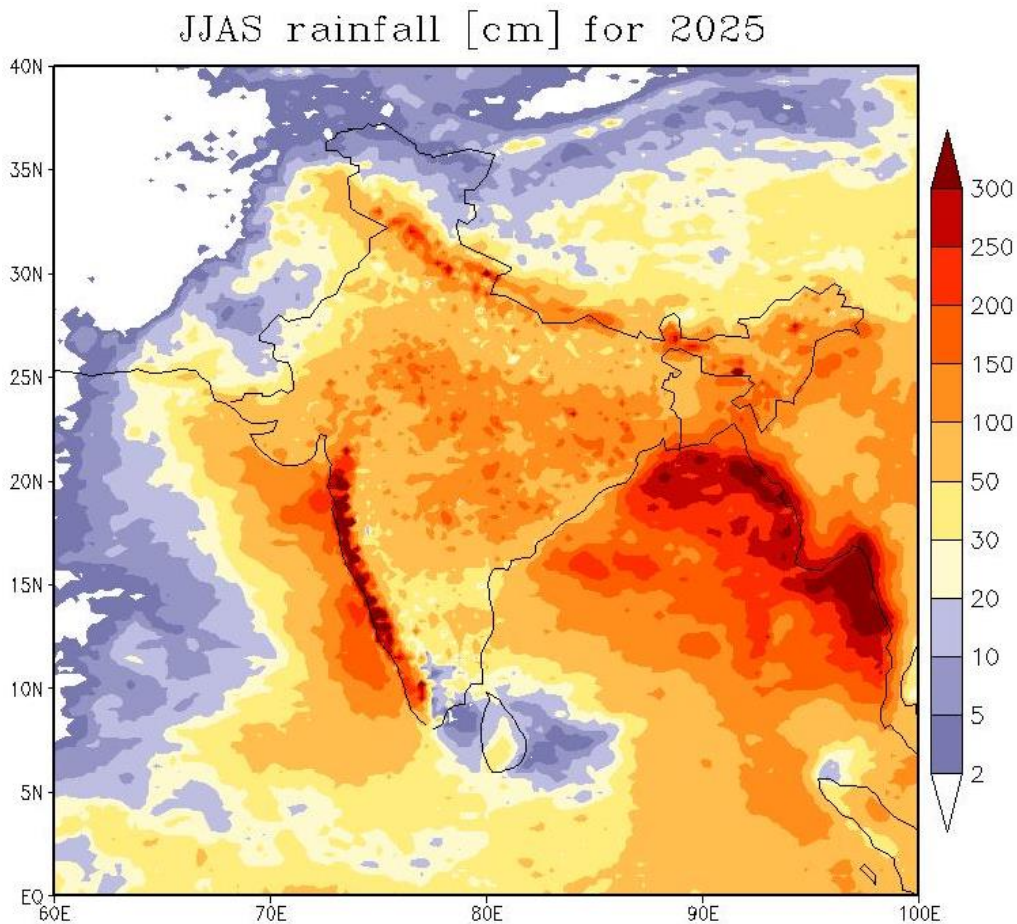


Fig. 10.11: Spatial distributions of seasonal monsoon rainfall (June – September) during 2025 over the Indian region using merged satellite-gauge rainfall dataset

10.6 Conclusions

Geostationary meteorological satellites play critical role in operational weather monitoring and forecasting. India has currently two third-generation geostationary meteorological satellites – INSAT-3DR and 3DS in operation. The meteorological products derive from these satellites along with customized raw datasets have proven to be very useful in various applications such as operational weather forecasting, monitoring and nowcasting of convective weather events, tropical cyclone monitoring, numerical model data assimilation, agriculture, power, aviation, tourism, and renewable energy sectors. This chapter demonstrates the capability of INSAT-3DR/S satellite imagery and products in monitoring of different aspects such as onset, withdrawal, active and break spell, and interaction of monsoon circulation with western disturbance during the southwest monsoon during 2025. The merged satellite-gauge daily rainfall product provides a complete rainfall analysis during the season over the Indian region including oceanic and neighbouring land masses. The monthly and seasonal monsoon rainfall using the merged satellite-gauge rainfall dataset has been analysed for the monsoon season of 2025.

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11



VERIFICATION OF SHORT-TO-MEDIUM RANGE OPERATIONAL FORECAST OF HEAVY RAINFALL DURING MONSOON 2025

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This chapter highlights the skill of short-to-medium range operational forecast of heavy rainfall at all-India and meteorological sub-divisional scales for the southwest monsoon period of 2025.

11.1 Introduction

Rainfall is a vital source of freshwater and plays a crucial role in the global energy and water cycle (Kinter and Shukla 1990). It is one of the primary variables of the hydrological cycle, significantly influencing weather patterns and the overall climate system. The social and economic implications of rainfall are profound, impacting human livelihoods more than any other atmospheric variable (Gadgil 2003; Gadgil and Srinivasan 2010; Revadekar and Preethi 2012). Given the importance of agriculture to India's economy, the country is highly dependent on the distribution and variability of rainfall. Approximately 75% of India's annual rainfall is derived from the southwest (SW) monsoon, making it a critical factor in determining the country's agricultural productivity and economic stability (Gadgil and Gadgil 2006). India's rainfall patterns are both complex and diverse, shaped by a variety of geographical, climatic, and seasonal factors. During the southwest monsoon, India experiences high variability in rainfall distribution. Regions such as the Western Ghats and northeastern India receive significant amounts of rainfall, while the northwest and central areas, including Rajasthan, receive comparably less precipitation. This disparity is influenced by a combination of geographical features and climatic factors, leading to heterogeneous rainfall

patterns across the country (Gadgil and Gadgil 2006; Kumar et al. 2006). The variability not only affects local ecosystems but also has profound implications for agriculture and water resources management (Singh et al. 2014).

Heavy rainfall events can have significant socio-economic and environmental repercussions in India. Intense precipitation often leads to severe flooding, particularly in low-lying urban areas that lack sufficient drainage systems. The catastrophic Chennai floods of 2015 exemplify the devastating impact of such events, where unprecedented rainfall caused widespread destruction, loss of life, and considerable damage to infrastructure (Radhakrishnan et al. 2024). Additionally, heavy rainfall negatively impacts agriculture by causing crop damage and promoting soil erosion, leading to economic losses for farmers and raising concerns over food security (Kumari et al. 2020). The consequences extend to public health as well; increased waterlogging can elevate the risks of waterborne diseases like cholera and malaria, further straining public health systems.

Forecasting heavy rainfall is critical for effective disaster management and mitigation strategies. Timely and accurate weather predictions allow communities to prepare and respond proactively to potential flooding and other hazards. The Indian Meteorological Department (IMD) has implemented advanced meteorological tools and models to improve forecasting accuracy and enhance early warning systems (Mohapatra et al. 2023; Mohapatra and Sharma 2021). Moreover, farmers depend on precise rainfall forecasts to optimize their agricultural practices, thereby reducing the risk of crop failures. Urban planners also leverage rainfall data to design resilient infrastructure, integrating measures for drainage and flood control to mitigate the impacts of heavy rainfall events.

The Indian Meteorological Department (IMD) issues heavy rainfall warnings at various scales: at the meteorological sub-divisional scale from the National Weather Forecasting Centre (NWFC), and at the district scale and station level from Meteorological Centres (MC) and Regional Meteorological Centres (RMC) located in state headquarters. These warnings are critical for effective disaster management and preparedness. These warnings are based on advanced weather models and real-time data, helping authorities take preventive measures against potential flooding and associated hazards (IMD 2023). The effectiveness of these warnings relies on their accuracy, which is regularly evaluated against observed rainfall data to improve forecasting skills.

The forecast verification is a fundamental practice in meteorology that enhances the accuracy and reliability of weather predictions. By continuously assessing forecast performance, meteorologists can improve models, build public trust, and support economic resilience. As the climate continues to change, the importance of robust forecast verification processes will only grow, ensuring that communities are better prepared for the impacts of severe weather. The Indian Meteorological Department (IMD) plays a crucial role in this

process, regularly evaluating the forecasts and warnings issued at various spatial and temporal scales to enhance their accuracy. This article specifically focuses on assessing the heavy rainfall warnings issued at the meteorological sub-divisional scale against observed rainfall data across the country, highlighting the need for ongoing improvements in predictive capabilities.

11.2 Data and Methods

To validate the heavy rainfall warnings issued by the National Weather Forecasting Centre (NWFC) at the meteorological sub-divisional scale (here after OprFcst), daily observed rainfall data from District-wise Rainfall Monitoring Stations (DRMS) are utilized. The extensive DRMS network comprises both automated and manual rain gauges strategically positioned across the country, allowing for accurate and timely collection of rainfall data. During the 2025 southwest monsoon, the DRMS network included approximately 6,000 rain gauge stations across the country, ensuring a well-distributed coverage.

According to IMD nomenclature, rainfall of 64.5-124.4 mm/day at any location is categorized as 'heavy rain,' 124.5-244.4 mm/day as 'very heavy,' and rainfall exceeding 244.5 mm/day as 'extremely heavy.' In this study, warnings for heavy, very heavy, and extremely heavy rainfall issued by the NWFC are grouped into a single category (heavy rainfall and above) and verified against observed rainfall of 64.5 mm and above for matches. The skill of OprFcst is evaluated for southwest monsoon 2025 using different verification scores. The four count (a, b, c, d) events in the 2×2 contingency table, which contains the number of hits (a), false alarms (b), misses (c), and correct rejections (d) are used to assess the performance of the OprFcst. The contingency table is a useful way to see what types of errors are being made (Table 11.1). A perfect forecast system would produce only hits and correct negatives. Variety of categorical statistics is computed from the elements in the contingency table to describe particular aspects of forecast performance. The Percentage Correct (PC), Probability of Detection (POD), False Alarm Rate (FAR), Critical Success Index (CSI) and Equitable Theat Score are calculated based on the contingency table. This analysis has been conducted across 36 meteorological sub-divisions to assess regional performance, with an overall skill score evaluated at the all-India level. The equations to estimate different skill score based on 2×2 contingency table (**Table 11.1**) is provided below.

Table 11.1: 2 × 2 contingency table to estimate different skill score

Event Forecasted	Event Observed	
	Yes	No
Yes	a	b
No	c	d

$$PC = (a+d)/(a+b+c+d)$$

$$POD = a/(a+c)$$

$$CSI = a/(a+b+c)$$

$$FAR = b/(b+d)$$

$$MR = 1 - POD = c/(a+c)$$

$$ETS = (a - E)/(a+b+c - E)$$

$$\text{Where } E = (a+b)(a+c)/(a+b+c+d)$$

A brief description of these statistical scores is given by (Levine and Wilks 2000; Gairola, Bushair, and Kumar 2020).

11.3 Key Features of Southwest Monsoon 2025

The 2025 Southwest Monsoon season in India presented unique characteristics in its onset, progression, withdrawal, and rainfall distribution. It set in over Kerala early on May 24, 2025, seven days earlier than the normal onset date of June 1. The monsoon advanced swiftly across the country, covering all regions by June 29—ten days ahead of its typical full-coverage date of July 8. The withdrawal of the monsoon also exhibited distinctive patterns. It began retreating from parts of West Rajasthan and Kachchh on September 14, somewhat later than the standard withdrawal date of September 17. However, by October 16, the Southwest Monsoon had completely withdrawn from the entire country. This date also marked the commencement of Northeast Monsoon rainfall over the southern peninsular regions, facilitating the seasonal transition.

From June 1 to September 30, 2024, the total rainfall for the country as a whole was recorded at 937.2 mm, which is 8% above the normal rainfall of 868.6 mm. **Fig. 11.1** provides an all-India rainfall map at meteorological sub-division scale for the season. Of the 36 meteorological sub-divisions, 33 received normal, excess, or large excess rainfall, with only three (Bihar, Assam & Meghalaya and Arunachal Pradesh) recording below-normal rainfall. The 2025 monsoon season was also marked by the formation of several low-pressure systems (LPSs), which significantly impacted rainfall distribution. The season saw a total of 18 LPS events, covering 69 days. These included one deep depression, six

depressions, two well-marked low-pressure area, and nine low-pressure systems. The presence of these systems sustained rainfall activity across various parts of India, influencing both localized heavy rainfall events and widespread precipitation over extended periods.

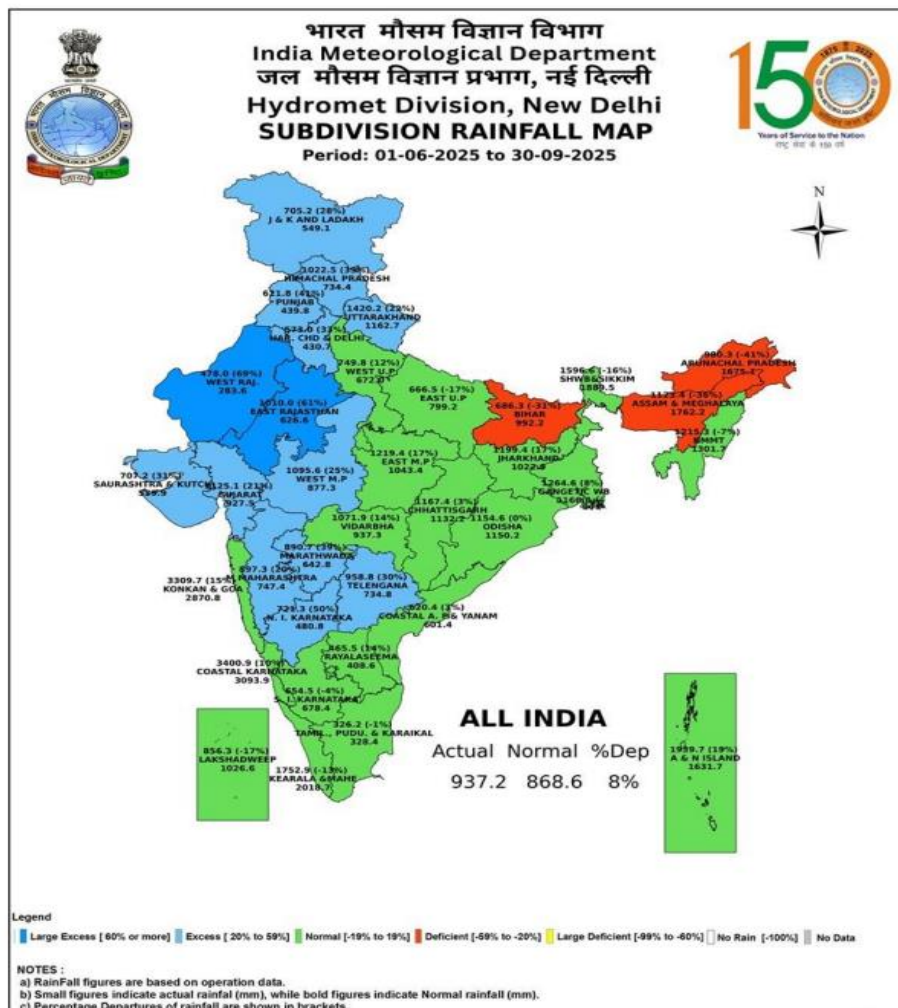


Fig. 11.1: Meteorological sub-divisional scale season accumulated rainfall (mm) and its departure from the normal (given in parentheses)

The southwest monsoon season of 2025 experienced numerous heavy rainfall events nationwide, highlighting the monsoon's strength and variability. Approximately 11,321 heavy rainfall events, 2656 very heavy rainfall events, and 354 extremely heavy rainfall events were recorded. The highest frequency of heavy rainfall was reported in the Konkan & Goa region (682), followed by Telangana (665) and Odisha (625). For very heavy rainfall events, the maximum occurrences were in Konkan & Goa (255), SHWB & Sikkim (211), and Gujarat Region (160). Extremely heavy rainfall events were most frequent in Konkan & Goa (45), followed by the Gujarat region (33) and Telangana (31). Lakshadweep, Andaman &

Nicobar Islands, Rayalaseema and Arunachal Pradesh not reported extremely heavy rainfall during the season. **Fig. 11.2** shows the number of heavy, very heavy, and extremely heavy rainfall incidents across meteorological subdivisions throughout the season. In this study, heavy, very heavy, and extremely heavy rainfall is grouped into a single category for verification purposes.

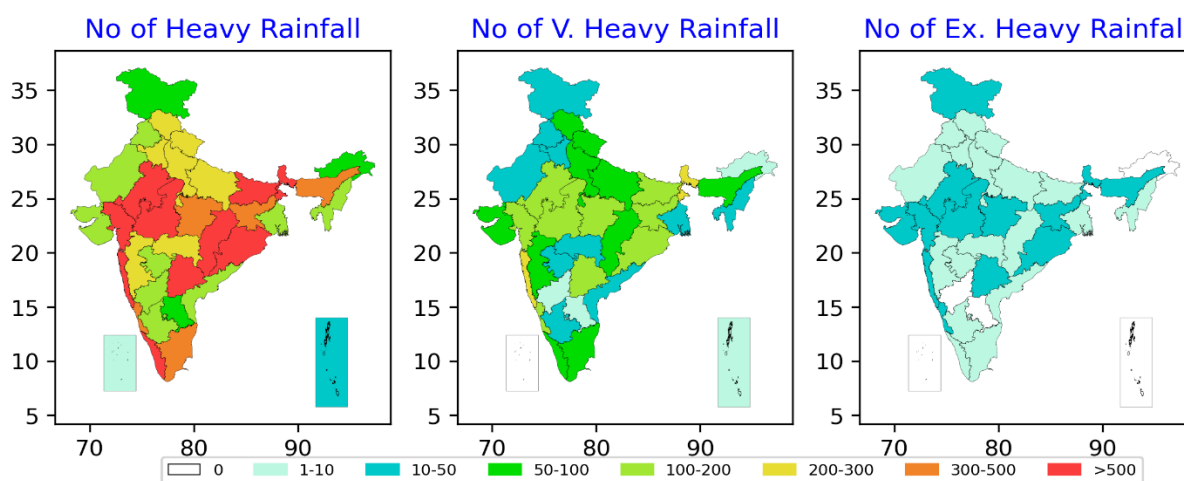


Fig. 11.2: The number of heavy, very heavy, and extremely heavy rainfall incidents across meteorological subdivisions throughout the SW monsoon season 2025

11.4 Performance of operational forecast during southwest monsoon 2025

11.4.1 Skill scores at all India scale

The analysis of all India (country as a whole) skill scores from the OprFcst verification for the 2025 Southwest Monsoon season (June 1 to September 30) provides insights into the accuracy of heavy rainfall (>64.5 mm) forecasts over a five-day period (**Fig. 11.3**). The Percentage Correct (PC), which reflects overall forecast accuracy (including correct occurrences and correct non-occurrences), gradually decreases over the forecast period, with values of 0.75, 0.73, 0.72, 0.71, and 0.68 for Days 1 through 5, respectively. This downward trend indicates a steady reduction in accuracy with increasing lead time, which is a common pattern in weather forecasting.

The Probability of Detection (POD), which measures the forecast ability to correctly identify actual heavy rainfall events, is relatively high at 0.85 on Day 1, showing a strong initial detection capability. However, POD decreases steadily across the forecast days, reaching 0.64 by Day 5. The False Alarm Ratio (FAR), which indicates the proportion of incorrect heavy rainfall predictions, has remained relatively stable over time, fluctuating between 0.34 and 0.31 from Day 1 to Day 5. A reduction in FAR is crucial for improving the reliability of weather forecasts, as high false alarm rates can lead to public distrust and

undermine the effectiveness of early warning systems. Lowering the FAR will not only enhance the accuracy of predictions but also ensure that communities can better prepare for and respond to actual heavy rainfall events, ultimately reducing the risk of damage and loss. Therefore, it is essential to refine forecasting methods and improve data accuracy to achieve this goal in the future.

The Critical Success Index (CSI), which combines both POD and FAR, follows a similar trend to POD, starting at 0.60 on Day 1 and declining to 0.48 by Day 5. This index is an indicator of the overall forecast skill for heavy rainfall events and reflects a gradual reduction in forecast skill with increasing lead time.

The Missing Rate (MR), which represents the fraction of actual heavy rainfall events missed by the forecast (1-POD), increases from 0.15 on Day 1 to 0.36 on Day 5. This increase indicates that more heavy rainfall events go undetected as the forecast period extends, emphasizing the need for issuing heavy rainfall warnings at higher lead times. The increasing Missing Rate (MR) from Day 1 to Day 5, along with the improvement in the False Alarm Ratio (FAR) during the same period, suggests that while the forecast becomes more conservative, the lack of heavy rainfall warnings at higher lead times may lead to undetected rainfall events, highlighting a critical gap in forecasting accuracy.

Overall, these results illustrate the potential capability of Oprfcst for issuing heavy rainfall warnings with a lead time of up to 5 days. This capability is significant, as it allows for proactive measures to be taken in anticipation of severe weather events, enhancing public safety and preparedness. However, a typical forecast degradation pattern is also observed, where forecast skill is highest at shorter lead times and gradually diminishes over the five days.

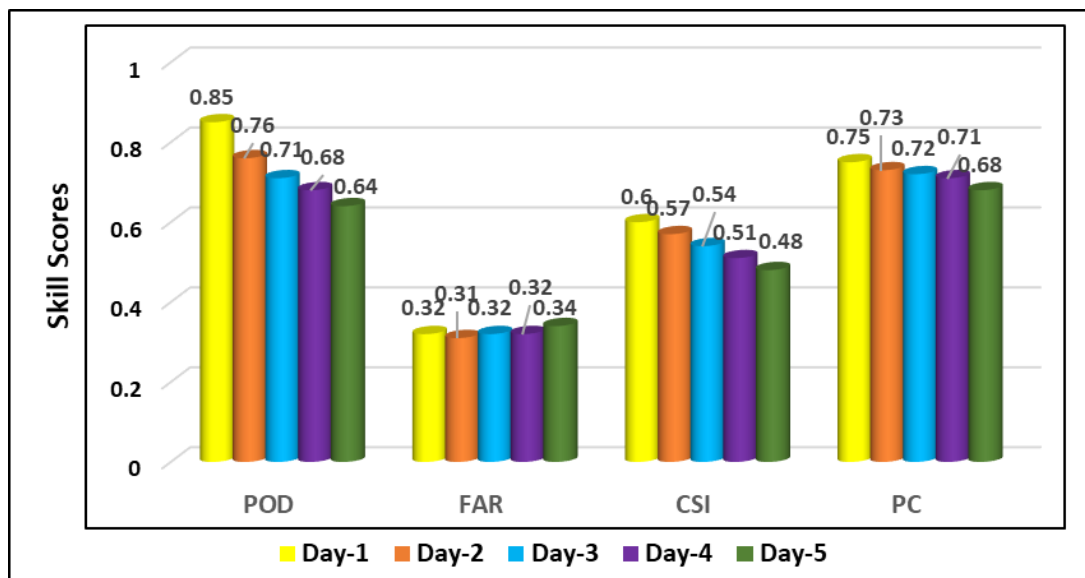


Fig. 11.3: The skill scores of operational forecasts of heavy rainfall at all India scale during southwest monsoon 2025

11.4.2 Skill scores at meteorological sub-divisional scale

The skill scores of OprFcst during SW monsoon 2025 at meteorological sub divisions are also estimated and shown in **Fig. 11.4** to **Fig. 11.8**. The OprFcst of heavy rainfall for the season exhibits varying skill scores across different meteorological sub-divisions and lead times (Day 1 to Day 5). The Probability of Detection (POD) skill score, which indicates the ability to accurately forecast occurrences of heavy rainfall, reveals significant regional variations across the 36 meteorological subdivisions over a 5-day forecast period. POD values close to 1 suggest high detection accuracy, while lower values indicate weaker forecast performance.

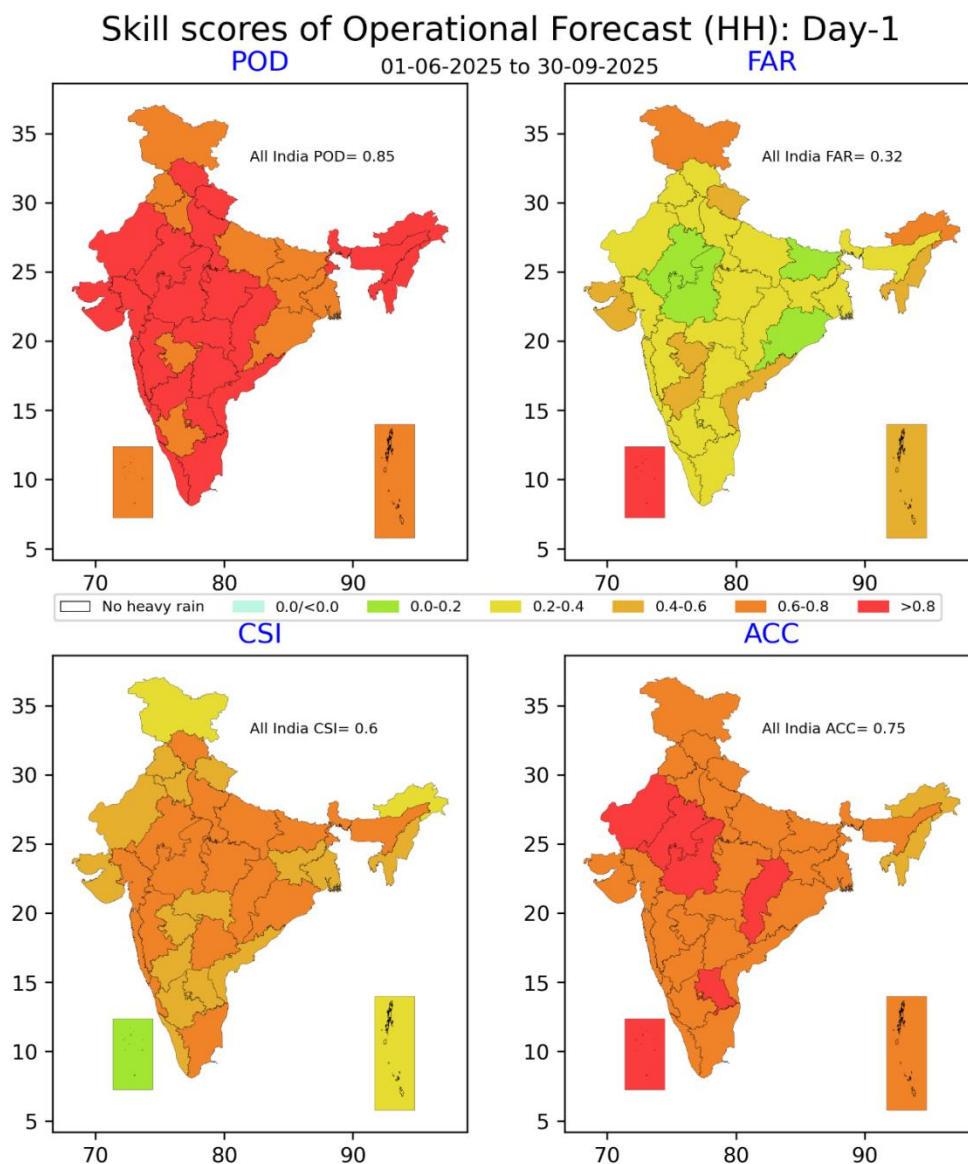


Fig. 11.4: The skill scores of operational forecasts of heavy rainfall over different meteorological sub-divisions during southwest monsoon 2025

For the Day-1 forecast, Konkan & Goa records the highest POD value of 0.97, followed by Madhya Maharashtra (0.96), Chhattisgarh (0.93), Uttarakhand (0.93) and NMMT (0.92), indicating excellent detection of heavy rainfall events in these regions during short-range forecasts. Several subdivisions maintain relatively high POD values during the early forecast days, though a gradual reduction is observed with increasing lead time.

Sub-divisions such as Andaman & Nicobar Islands (0.62), Jharkhand (0.66), and Lakshadweep (0.67) show comparatively lower POD values even on Day-1, indicating weaker detection capability. The degradation of POD with forecast lead time is particularly evident over Lakshadweep, where the POD drops sharply to 0.00 by Day-5, and over Andaman & Nicobar Islands, where POD decreases from 0.62 on Day-1 to 0.15 on Day-5. Similar declining trends are observed over Marathwada, Rayalaseema, and Telangana, highlighting reduced forecast skill at longer lead times.

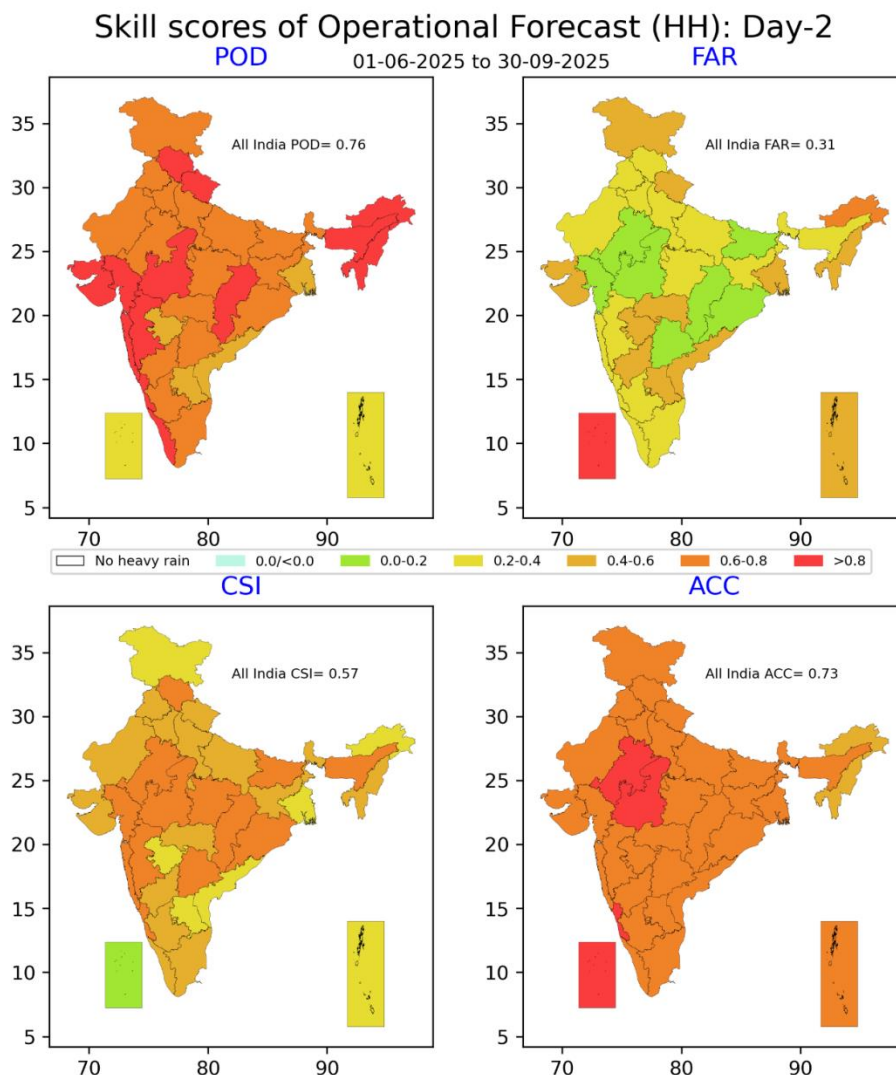


Fig. 11.5: Similar to Fig. 11.4, but for Day 2 forecast

The False Alarm Ratio (FAR), which represents the proportion of forecasted heavy rainfall events that did not occur, also exhibits substantial spatial variability. Lower FAR values indicate higher forecast reliability. On Day-1, East Rajasthan shows the lowest FAR value of 0.10, followed by Odisha (0.11), West Madhya Pradesh (0.15), Bihar (0.18), and Chhattisgarh (0.21), reflecting high reliability of heavy rainfall forecasts over these regions. These subdivisions continue to maintain relatively low FAR values through subsequent forecast days. In contrast, Lakshadweep exhibits very high FAR values, reaching 0.87 on Day-1, indicating frequent false alarms. Other subdivisions with high FAR values on Day-1 include Arunachal Pradesh (0.63), Jammu & Kashmir (0.62), and Andaman & Nicobar Islands (0.56). Persistently high FAR values over these regions suggest a tendency towards overprediction of heavy rainfall events.

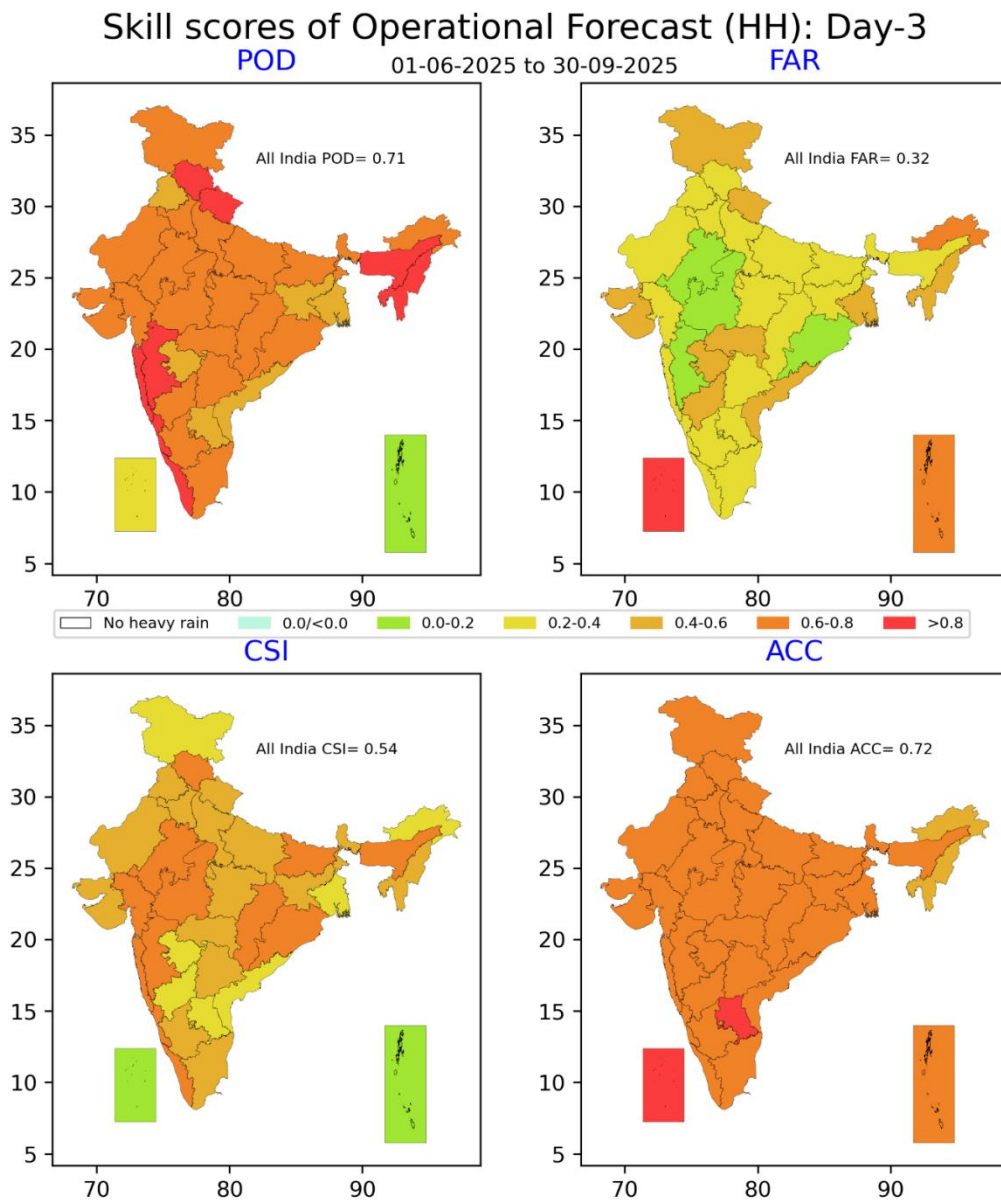


Fig. 11.6: Similar to Fig. 11.4, but for Day 3 forecast

The Threat Score (TS), also referred to as the Critical Success Index (CSI), provides a balanced assessment by combining both POD and FAR. Higher TS values indicate better overall forecast performance.

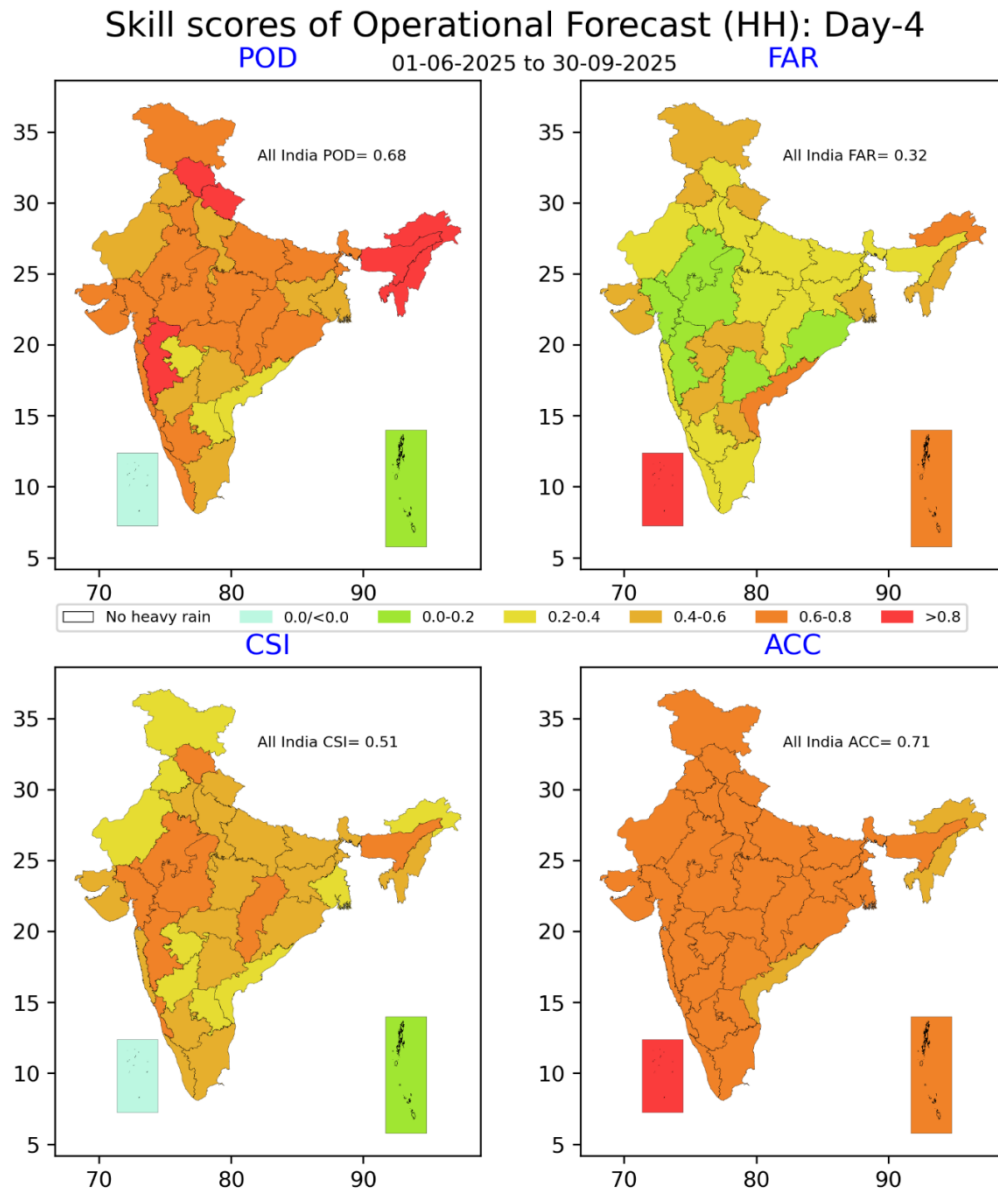


Fig. 11.7: Similar to Fig. 11.4, but for Day 4 forecast

On Day-1, the highest TS values are observed over West Madhya Pradesh (0.79) and East Rajasthan (0.79), followed by Chhattisgarh (0.75), Konkan & Goa (0.74), and Madhya Maharashtra (0.72), demonstrating strong overall forecast skill in these regions. These subdivisions generally retain relatively higher TS values compared to others, even as lead time increases. Conversely, Lakshadweep records the lowest TS value of 0.12 on Day-1, indicating poor forecast performance. Other subdivisions with low TS values include Jammu

& Kashmir (0.33), Andaman & Nicobar Islands (0.35), Arunachal Pradesh (0.36), and Marathwada (0.42). The TS values over many of these regions further decline with forecast lead time, underscoring the challenges in accurately forecasting heavy rainfall events in the medium range.

The Equitable Threat Score (ETS), which accounts for correct forecasts occurring purely by chance, provides a more robust measure of forecast skill compared to TS/CSI, particularly for relatively rare events such as heavy rainfall. ETS values range from negative values to 1, with higher positive values indicating better forecast performance beyond random chance, while values near zero suggest little skill. The spatial distribution of ETS for the Operational Forecast during SW Monsoon 2025 reveals considerable variability across meteorological subdivisions and forecast lead times. Subdivisions such as Konkan & Goa, West Madhya Pradesh, East Rajasthan, Chhattisgarh, Madhya Maharashtra, Assam & Meghalaya, and Uttarakhand exhibit relatively higher ETS values, especially during Day-1 and Day-2 forecasts, indicating strong and equitable forecast skill for heavy rainfall events. In contrast, subdivisions including Lakshadweep, Andaman & Nicobar Islands, Jammu & Kashmir, Rayalaseema, and Marathwada show low ETS values across most forecast days, reflecting limited skill after accounting for chance agreement. A systematic decline in ETS with increasing lead time is evident across almost all subdivisions, highlighting reduced forecast effectiveness in the extended range. Overall, the ETS analysis corroborates the results obtained from POD, FAR, and TS, emphasizing that regions with balanced detection capability and lower false alarms demonstrate superior equitable forecast skill during the monsoon season.

The Bias Score (BS) provides a measure of the frequency bias in forecasting heavy rainfall events by indicating whether the forecast system tends to overpredict or underpredict occurrences relative to observations. A BS value of unity represents an unbiased forecast, values greater than one indicate over-forecasting (wet bias), and values less than one indicate under-forecasting (dry bias). The spatial distribution of BS for the Operational Forecast (not shown in this report) during the Southwest Monsoon 2025 shows considerable variation across meteorological subdivisions and forecast lead times. Several subdivisions exhibit BS values close to unity during the short-range forecasts, indicating a reasonably balanced representation of heavy rainfall events. However, a tendency towards overforecasting is observed over certain subdivisions, particularly during the early forecast days, while underforecasting becomes more evident in a few regions at longer lead times. Subdivisions such as Lakshadweep, Andaman & Nicobar Islands, and parts of northwest India show pronounced bias characteristics, consistent with their higher FAR and lower POD values. In contrast, regions exhibiting relatively higher POD and CSI values generally maintain BS values closer to unity, reflecting a better balance between event detection and

false alarms. Overall, the Bias Score analysis highlights the presence of both wet and dry biases in the operational heavy rainfall forecasts, emphasizing the importance of bias correction and region-specific calibration to improve forecast reliability across different lead times.

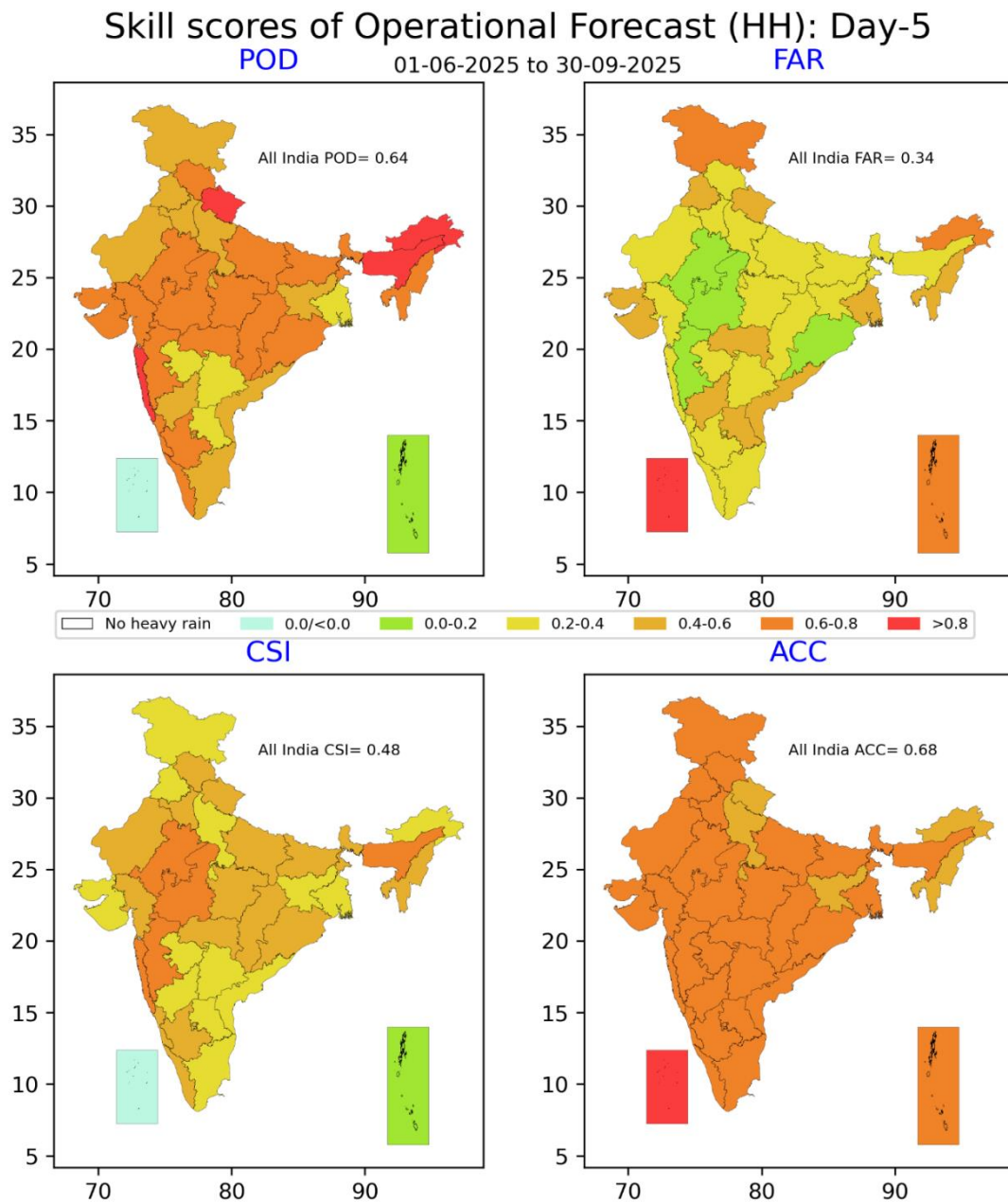


Fig. 11.8: Similar to Fig. 11.4, but for Day 5 forecast

Overall, meteorological subdivisions that experience frequent and well-organised heavy rainfall events, such as Konkan & Goa, West Madhya Pradesh, East Rajasthan, Chhattisgarh, Madhya Maharashtra, Assam & Meghalaya, Uttarakhand, and Sub-Himalayan West Bengal & Sikkim, demonstrate comparatively strong and sustained forecast

performance up to Day-5. These regions consistently maintain higher POD and CSI values, along with positive and relatively higher ETS, from short- to medium-range forecasts, indicating robust event detection capability and reliable forecast skill beyond chance even at longer lead times. In contrast, subdivisions such as Lakshadweep, Andaman & Nicobar Islands, Jammu & Kashmir, Punjab, Marathwada, and Rayalaseema exhibit persistently low CSI and ETS values across all forecast days up to Day-5, reflecting substantial uncertainty and limited skill in predicting heavy rainfall events. The degradation of skill with lead time is particularly pronounced over these regions, highlighting the challenges posed by the sporadic occurrence of heavy rainfall, complex regional dynamics, and lower predictability. This clear contrast in forecast performance up to Day-5 underscores the strong dependence of heavy rainfall forecast skill on regional rainfall characteristics and emphasizes the need for targeted improvements and region-specific calibration to enhance medium-range forecasting capability over climatologically challenging areas.

This assessment underscores the necessity for region-specific forecast strategies to enhance accuracy in longer lead times, particularly in regions with high rainfall variability. As lead times increased, forecast accuracy generally declined, with POD, CSI, and PC values reducing across all regions, while FAR increased. This pattern suggests that while short-term forecasts are generally more reliable, there is a need for improved accuracy in longer lead times, especially in regions with high rainfall variability.

11.5 Conclusion

This study presents a comprehensive evaluation of heavy rainfall forecasts issued by the Indian Meteorological Department (IMD) during the Southwest Monsoon (SWM) season 2025, utilizing observed rainfall data from the District-wise Rainfall Monitoring Stations (DRMS) and verified at the meteorological sub-divisional scale. The assessment highlights the importance of reliable heavy rainfall forecasts for disaster risk reduction, hydrological management, agriculture, and infrastructure planning, underscoring their significant socio-economic relevance.

At the meteorological sub-divisional scale, the Operational Forecast demonstrates a strong capability to detect heavy rainfall events during short- and medium-range forecasts over several rainfall-prone regions. Subdivisions such as Konkan & Goa, West Madhya Pradesh, East Rajasthan, Chhattisgarh, Madhya Maharashtra, Assam & Meghalaya, Uttarakhand, and Sub-Himalayan West Bengal & Sikkim consistently exhibit higher POD and CSI values, along with positive and relatively higher ETS, sustaining skill up to Day-5. These results indicate robust detection capability and reliable forecast skill beyond chance over regions with frequent and well-organised heavy rainfall activity.

In contrast, subdivisions including Lakshadweep, Andaman & Nicobar Islands, Jammu & Kashmir, Punjab, Marathwada, and Rayalaseema show persistently lower CSI and ETS values across most forecast lead times, reflecting considerable uncertainty in forecasting heavy rainfall events. The reduced skill over these regions is attributed to the sporadic nature of heavy rainfall, complex regional processes, and limited predictability, which pose significant challenges to medium-range forecasting.

The verification results indicate a systematic degradation of forecast skill with increasing lead time up to Day-5, evident across most meteorological subdivisions. This decline is characterized by a gradual reduction in the Probability of Detection (POD) and Critical Success Index (CSI), accompanied by an increase in the False Alarm Ratio (FAR), reflecting reduced forecast confidence in the medium range. The Equitable Threat Score (ETS) further corroborates this behaviour, showing diminishing skill beyond short-range forecasts, particularly for regions with sporadic heavy rainfall occurrences.

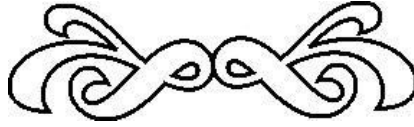
Overall, the analysis underscores a strong dependence of heavy rainfall forecast skill on regional rainfall characteristics. While the Operational Forecast performs reasonably well over climatologically active monsoon regions up to Day-5, the results highlight the need for region-specific calibration, improved representation of local processes, and targeted bias correction to enhance forecast accuracy over climatologically challenging and less predictable areas.

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12



VERIFICATION OF OPERATIONAL EXTENDED RANGE FORECAST DURING SOUTHWEST MONSOON 2025

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This chapter highlights the skill of operational extended range forecast in prediction of monsoon onset as well as active and break spells for the southwest monsoon period of 2025.

12.1 Introduction

Extended range forecast (ERF) covering the time scale from one week to about a month in the tropics is one of the most challenging tasks in atmospheric sciences. It fills the gap between medium-range weather forecasting and seasonal forecasting. The ERF time scale is certainly a difficult time range for weather forecasting, as the timescale is sufficiently long so that much of the memory of the atmospheric initial conditions is lost and on the other hand, the monthly mean time average is not large enough for the atmospheric signal associated with the ocean anomalies to emerge over the atmospheric noise. Though the seasonal forecast of monsoon has its relevance for the policy maker the forecast of monsoon in intermediate time scale is critical for the optimization of planting and harvesting. Thus, the forecasting of monsoon breaks in the extended range time scale, 2 to 4 weeks in advance is of great importance for agricultural planning (sowing, harvesting, etc.), which can enable tactical adjustments to the strategic decisions that are made based on the longer-lead seasonal forecasts and also will help in timely review of the prevailing monsoon conditions for providing outlooks to farmers. Several analyses have shown that sub-seasonal variability of monsoon has two preferred locations on a broader spatial scale, a strong

continental convergence zone associated with convection over the land (continental) region (between 10°-25°N) and the other over the eastern equatorial Indian Ocean. The intra-seasonal variability can be defined as the see-saw pattern of the two convergence systems oscillating out of phase with one another. The oscillation is accompanied by a northward phase propagation of rainfall and other circulation feature anomalies. Hence, monsoon intra-seasonal oscillation (MISO) is associated with an explicit northward propagation of positive or negative precipitation (or convection) anomalies. Such oscillations bring a sequence of active monsoon and break monsoon situation, which is spells of dry and wet conditions, that often lasts for one to two week or more. Sub-seasonal variability of monsoon rainfall has dominant variance associated with 30-60 day periodicity, and has a common mode of variability with the seasonal mean, which is hypothesized to be strengthening (weakening) the seasonal mean in its active (break) phases and the large scale structure of active/break phases, 30-60 day mode and seasonal mean are often similar.

Forecasting of intra-seasonal oscillations and synoptic variability is a great challenge and it is an integral part of the India Meteorological Department's operational forecasting strategy. The forecast of Intra-seasonal oscillation provides forewarning and outlook in different time scales and hence it is important for several stakeholder applications. It is not only the agriculture sector that benefited from the proper outlook of extended range forecast, but a skilful extended range forecast can also be very useful for reservoir operation in managing floods during the monsoon season (Pattanaik and Das, 2015; Praveen et al., 2022). Pattanaik and Das (2015) have demonstrated the usefulness of extended range forecast in a pilot study over the Mahanadi River basin in Odisha in the case of 2011 flood. In the present article the performance of operational ERF over India evaluated during the southwest monsoon season from June to September, 2024 is documented in this article.

12.2 Operational ERF system of IMD

At present, the ERF system at IMD is running operationally once a week every (Wednesday) and the forecast is generated for 4 weeks starting from subsequent Friday to Thursday and so on. The current operational ERF modelling system is a suite of models at different resolutions based on the CFSv2 coupled model adopted from NCEP (**Fig. 12.1**). As demonstrated in **Fig. 12.1**, the Multi-model ensemble (MME) out of the above 4 suite of models are run operationally for 32 days based on every Wednesday initial condition with 4 ensemble members (one control and 3 perturbed) each for CFSv2T382, CFSv2T126, GFSbcT382 and GFSbcT126. The oceanic component is the GFDL Modular Ocean Model V.4 (MOM4). The operational suite of models consists of (i) CFSv2 at T382 (≈ 38 km) (ii) CFSv2 at T126 (≈ 100 km) (iii) GFSbc (bias-corrected SST from CFSv2) at T382 and (iv)

GFSbc at T126 with 4 members each (Total 16 members). This is based on the Ensemble Prediction System (EPS) of IITM developed by Abhilash *et al.* (2014b) and Abhilash *et al.* (2015). For 2024 operational forecast the hindcast run is performed for 16 years (2003 to 2018) as shown in **Fig. 12.1**. The average ensemble forecast anomaly of all the 4 sets of models runs of 4 members each (total 16 members) based on every Wednesday is calculated by subtracting corresponding 16- year model hindcast climatology on every Wednesday, which is valid for 4 weeks for days 2-8 (week1; Friday to Thursday), days 09-15 (week2; Friday to Thursday), days 16-22 (week3; Friday to Thursday) and days 23-29 (week4; Friday to Thursday). This ERF system is very suitable to predict the active-break cycle of monsoons, which can be used for various applications.

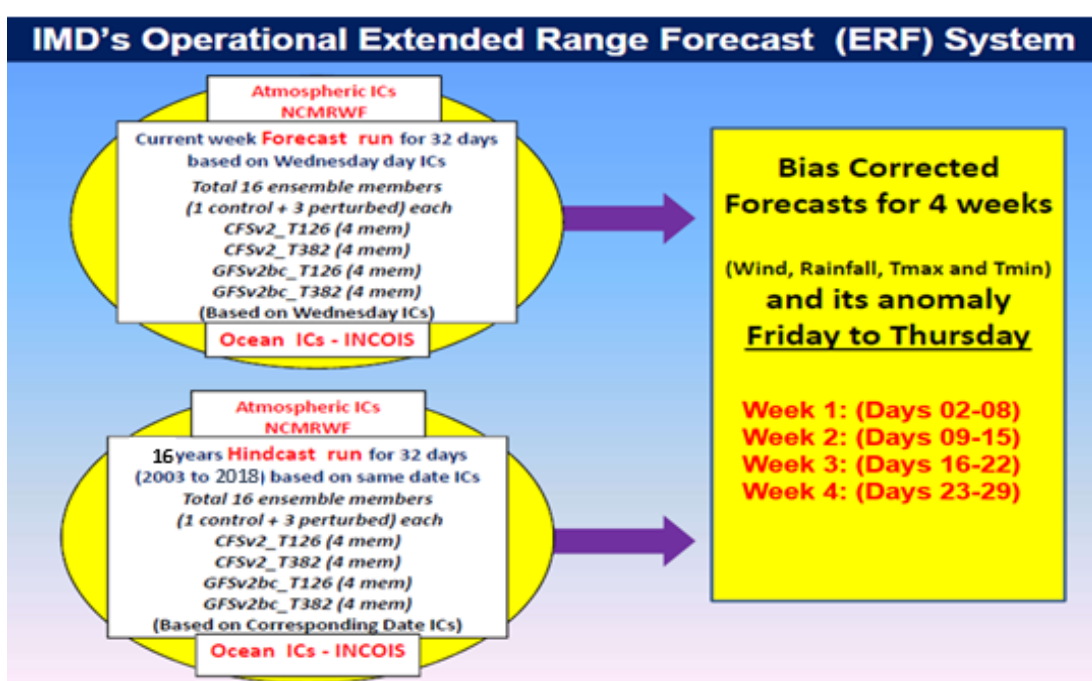


Fig. 12.1: IMD's Operational Extended Range Forecast (ERF) System for 2024 monsoon

The model was initially developed at IITM (Sahai *et al.*, 2013; Sahai *et al.*, 2015), and was run using the atmospheric and oceanic initial conditions available from NCEP once every 5 days with a forecast for 4 pentads. However, three major changes were carried out before it was implemented in IMD during 2016 such as the hindcast and forecast runs being carried out with atmospheric and oceanic initial conditions available from NCMRWF and INCOIS respectively and not from NCEP. Secondly, the forecast day was fixed on Wednesday of every week and not at the interval of 5 days. Finally, the outputs are prepared for 4 weeks and not the pentads. The evolution of the operational ERF system used in IMD since 2008 is discussed in the review paper by Pattanaik *et al.*, (2019).

12.3 Verification of Extended Range Forecast during Monsoon 2025

With a seasonal rainfall of 108% of its Long Period Average (LPA), the monsoon season 2025 from June to September witnessed above-normal rainfall with a monthly departure of 109% in June, 105% in July, 105% in August, and 115% in September. The onset of the southwest monsoon over Kerala had taken place over Kerala on 24th May against normal date of onset on June 1, and covered the entire country by 29th June, 9 days ahead of the normal date. Monsoon withdrawal commenced from west Rajasthan on 23rd September (with a delay of 6 days).

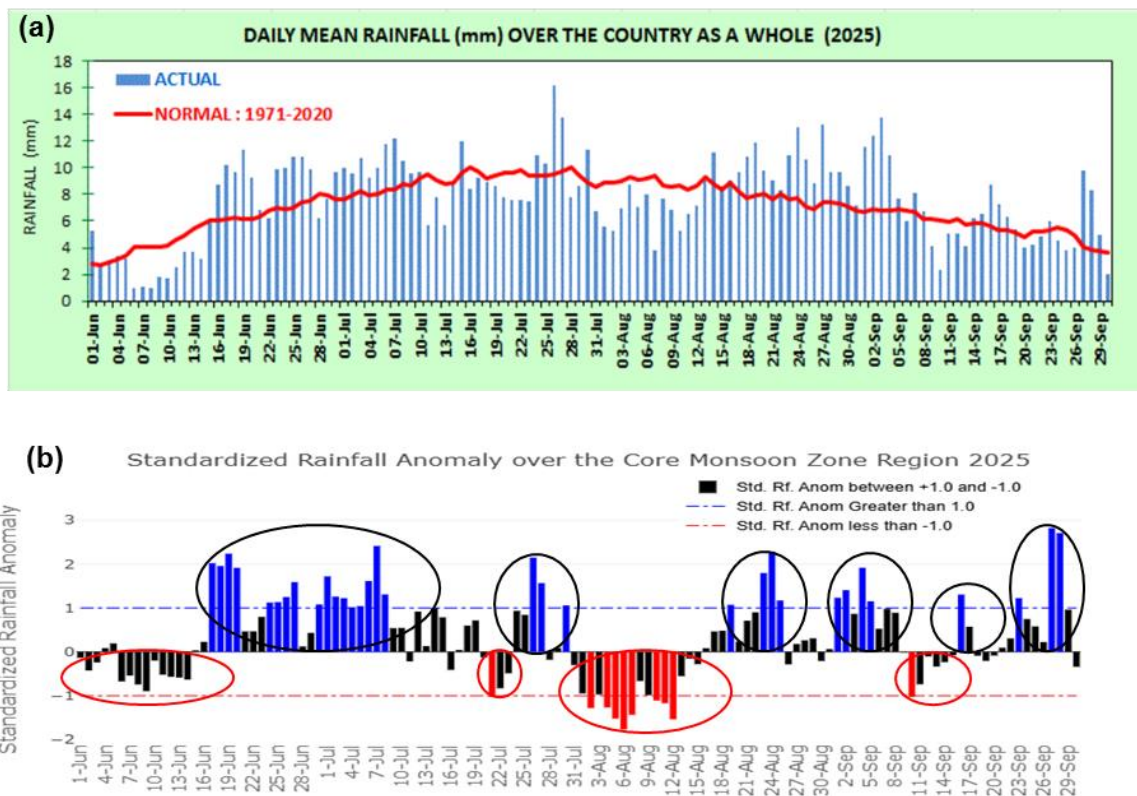


Fig. 12.2: (a) Daily actual and normal rainfall over India from June to September, 2025 (b) The corresponding time series of daily standardized rainfall anomaly over the core monsoon region

The daily monsoon rainfall time series averaged over the country along with the normal rainfall during the period from June to September is shown in **Fig. 12.2a**. The corresponding daily rainfall departure over the core monsoon region is also shown in **Fig. 12.2b**. After the early onset over Kerala, the wet and dry spells of rainfall activity during 2025 monsoon as shown in **Fig. 12.2a-b** witnessed different phases of monsoon as indicated below.

- (i) Early onset with the weak phase of monsoon in first half of June
- (ii) Active monsoon phase from middle of June to early July

- (iii) Weak phase of monsoon in the middle of July
- (iv) Active phase of monsoon in the end of July
- (v) Weak phase of monsoon in early August
- (vi) Active phase of monsoon in second half of August
- (vii) Short period weak phase in the second week of September
- (viii) Active phase in the end of September

12.3.1 Onset with the weak phase of monsoon in June

The Southwest monsoon reached Kerala on 24th May, 8 days before the normal onset date of 1st June. From there, it progressed rapidly and covered South India and North-East India by 29th May. Further progress started 16th June and covered entire country on 29th June 2025 9 days ahead against normal date 8th July. Thus, there was an early onset with slightly reduced monsoon activity during early phase of June as seen from the daily time-series graph (Fig. 12.2a-b). The extended-range forecast of 850 hPa wind and rainfall based on the IC of 14th May indicated the onset of monsoon in the week 2 forecast coinciding with actual onset (Fig. 12.3).

ERF, IC : 14 May 2025 (850 hPa wind & Rainfall)

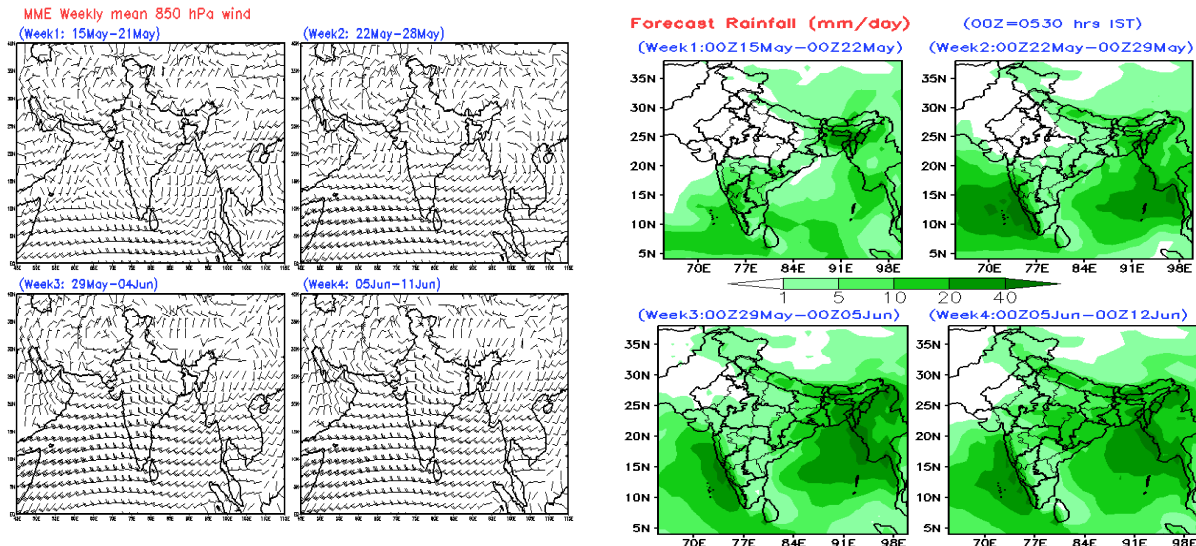
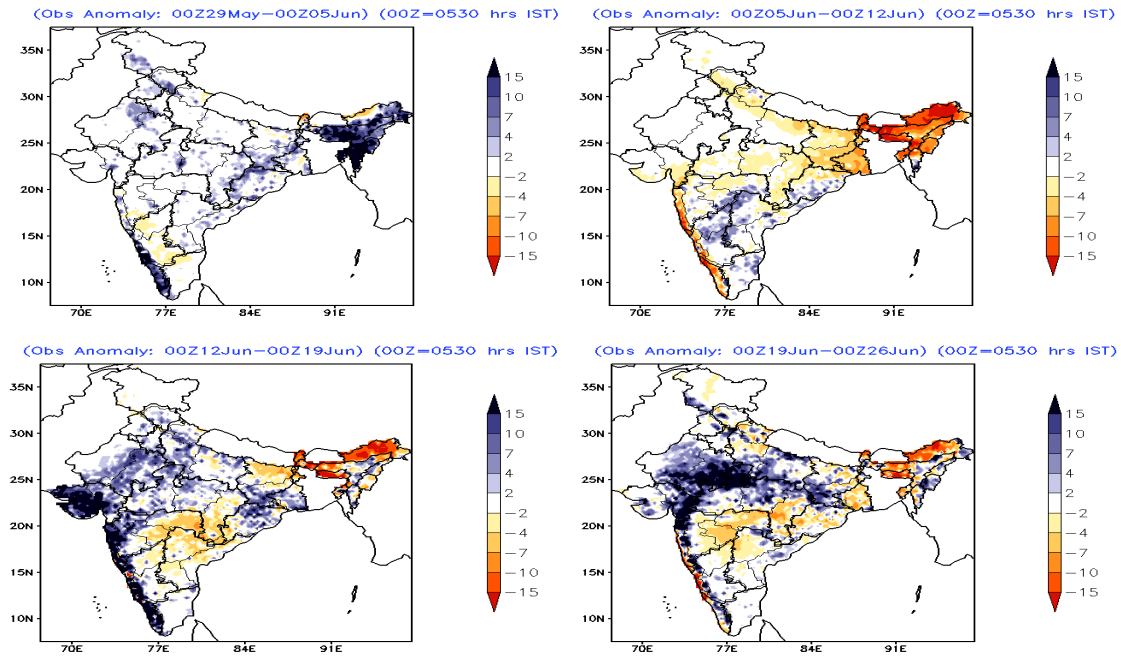


Fig. 12.3: ERF 850 hPa mean wind and rainfall forecasts for four weeks valid for the period from 15 May to 12 June, 2025 based on 14th May IC

The pattern of observed rainfall anomaly pattern (Fig. 12.4a) during the first half of June over most parts of India is reasonably well captured in the ERF based on 28th May (Fig. 12.4b-c). Rainfall anomaly pattern in NW India in third week of June is not captured in forecasts based on both ICs. Forecasts based on both ICs are not able to capture Rainfall

anomaly pattern in NE India in fourth week of June. Model is able to forecast rainfall anomalies in June with a reasonably good accuracy in most parts.

(a) Observed weekly rainfall anomaly for 4 weeks (29 May-26 June), 2025



(b) ERF, IC : 28th May, 2025

(c) ERF, IC : 04 June, 2025

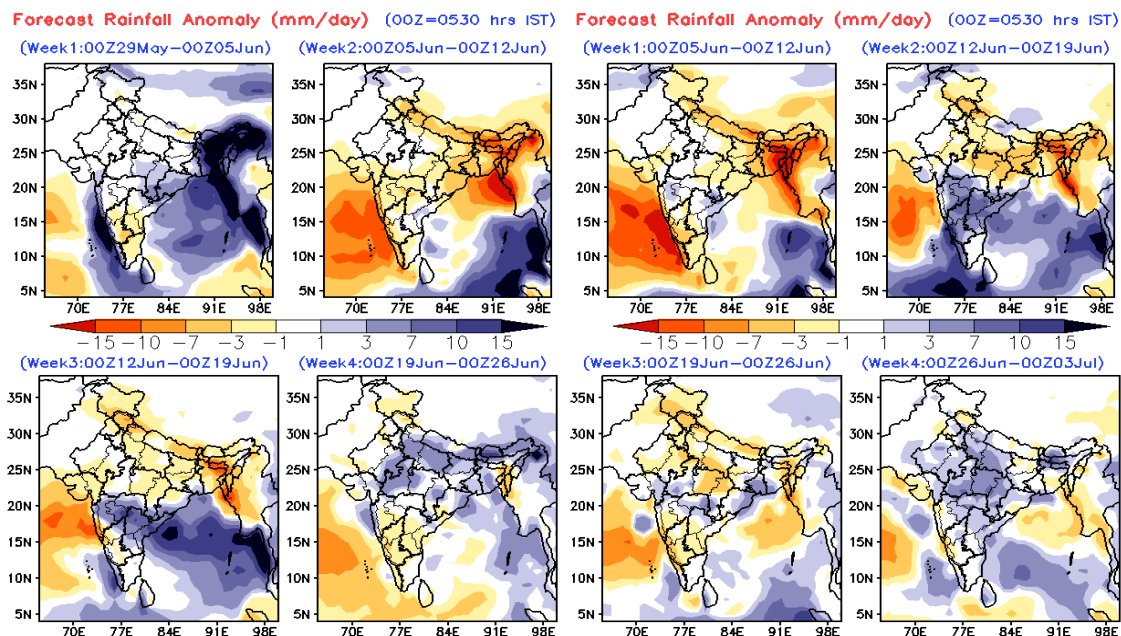


Fig. 12.4: (a) Weekly observed rainfall anomaly for four weeks from 29 May -26 June, 2025. (b) The ERF rainfall anomaly for 4 weeks is based on 28th May IC and valid for 29 May to 26 June, 2025. (c) The ERF rainfall anomaly for 4 weeks is based on 4th June 2025 and valid for 05 June to 03 July, 2025.

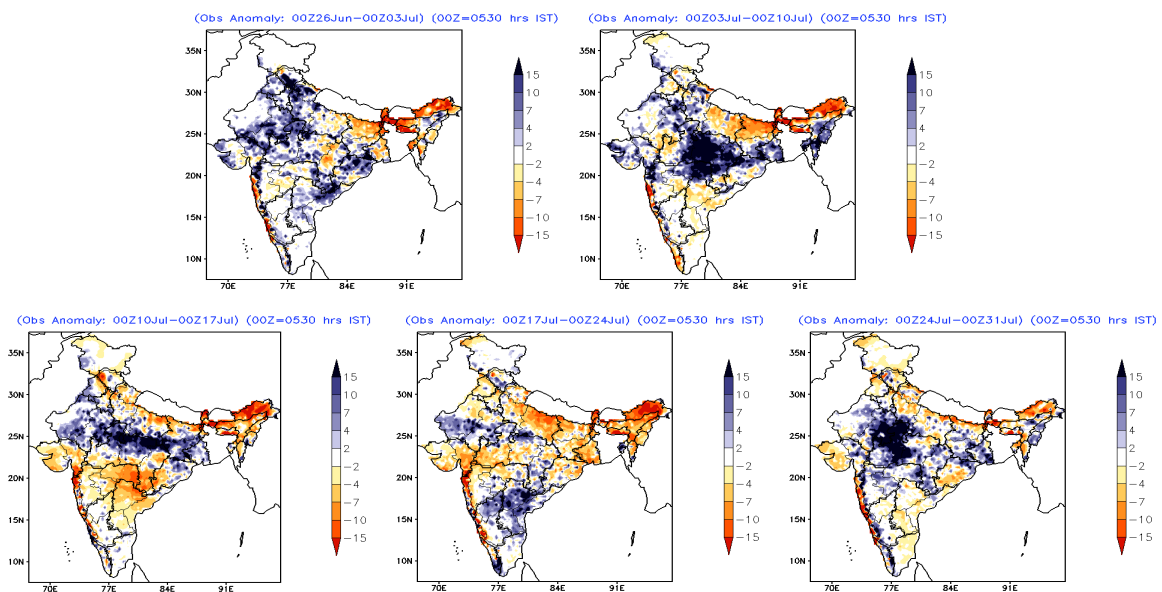
12.3.2 Monsoon during July

The observed rainfall anomaly for 4 weeks valid from 29 June to 31 July 2025 is shown in (Fig. 12.5a). It shows positive anomaly in many parts of NW India in the first week of July, negative anomaly in west coast in entire July, positive rainfall anomaly in central India in Week 2 & week 3 and last week of July. The corresponding ERF rainfall anomalies for 4 weeks based on 25 June, 2025 and 02 July 2025 are given in (Fig. 12.5b). ERF based on 25th June IC could capture rainfall anomaly patterns in most parts of the country in week 1 - week 3 forecasts while the model is not able to capture anomaly patterns in some parts over south India in last two weeks of July in the forecasts based on IC 25 June and 02 July. Although model forecasted rainfall anomaly pattern in last 2 weeks of July in forecasts based on subsequent week IC (not shown). The rainfall anomaly pattern is predicted in July with reasonable accuracy with two weeks forecast lead time.

12.3.3 Monsoon during August

In August, there is a positive anomaly in rainfall pattern in Indo-Gangetic plain and Tamil Nadu in Week 1, Andhra Pradesh and Tamil Nadu in week 2, west India and coastal regions of Kerala-Karnataka in week 3 and Northwest India in week 4 as can be seen from Fig. 12.6a. The week 1 ERF based on 30th July could capture positive anomaly over regions in week 1 – week 4 forecasts while in week 4 overestimation can be seen in central India. (Fig. 12.6b-c). The ERF based on 6th August IC is able to predict positive anomalies over the regions in week 1 - week 3 forecasts while over estimation of rainfall can be seen in central India in week 3 forecasts.

(a) Observed weekly rainfall anomaly for 4 weeks (29 June-31 July), 2025



(b) ERF, IC : 25 June, 2025

(c) ERF IC: 02 July, 2025

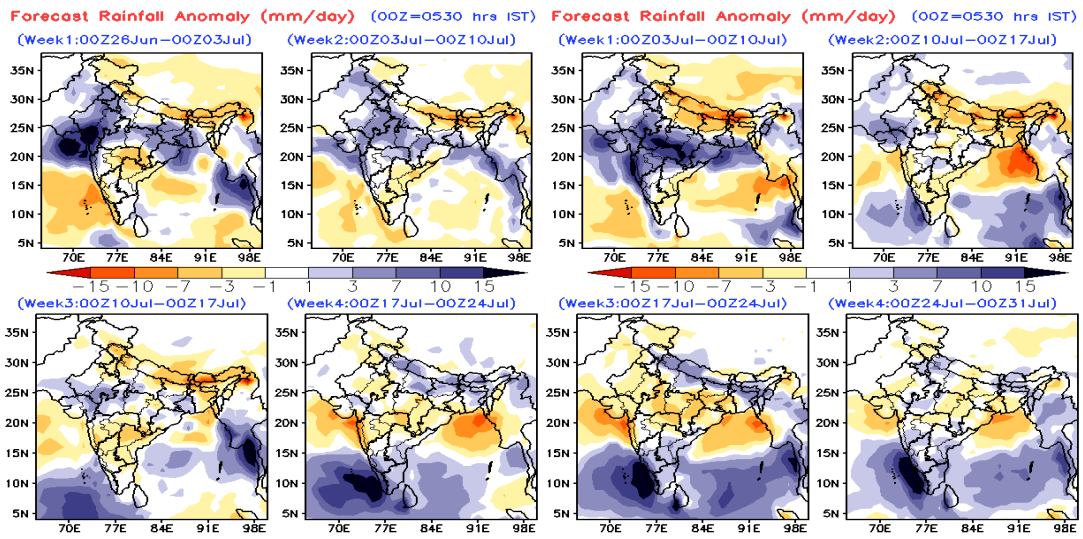
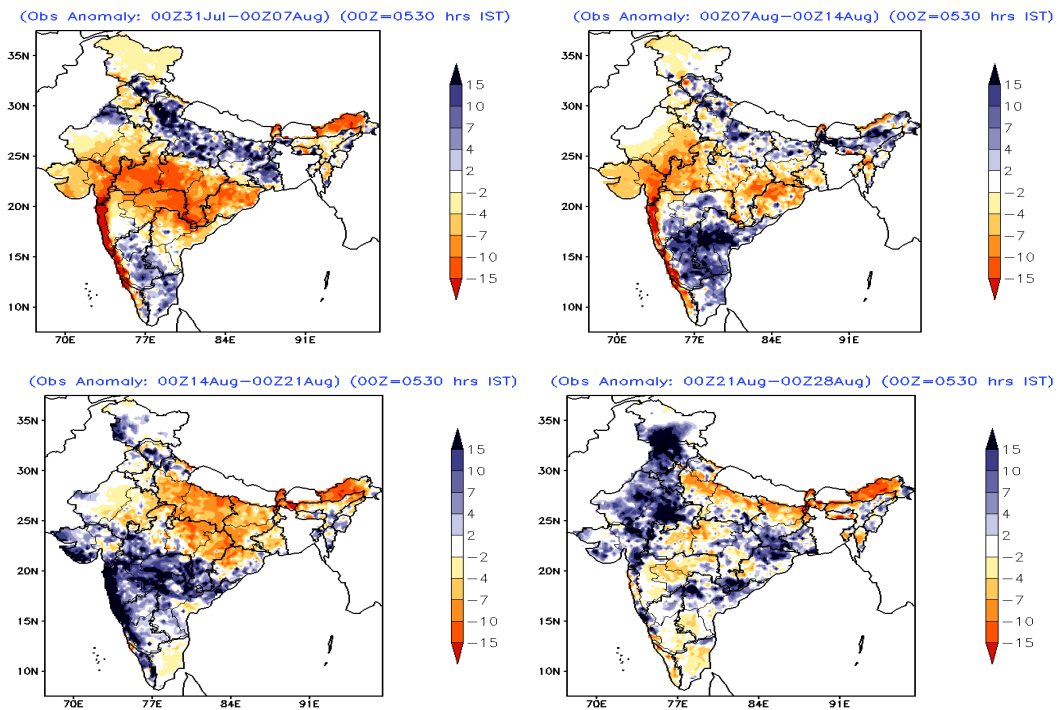


Fig. 12.5: (a) Weekly observed rainfall anomaly for four weeks from 26 June to 31 July, 2025. (b) The ERF rainfall anomaly for 4 weeks is based on 25 June and valid for 4 weeks (26 June-24 July, 2025). (c) ERF rainfall anomaly for 4 weeks is based on 02 July and valid for 4 weeks (03 July-31 July, 2025).

(a) Observed weekly rainfall anomaly for 4 weeks (31 July-26 August), 2025



(b) ERF, IC : 30 July, 2025

(c) ERF, IC : 06 Aug, 2025

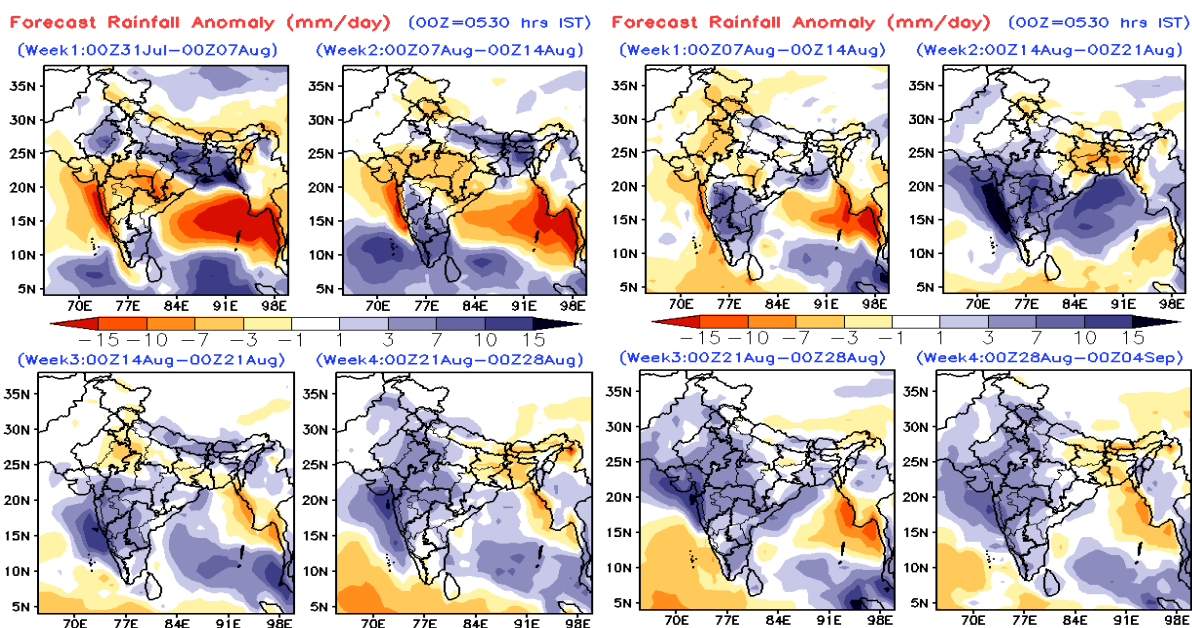


Fig. 12.6: (a) Weekly observed rainfall anomaly for four weeks for 02-29 Aug, 2025. (b) The ERF rainfall anomaly for 4 weeks is based on 31 Jul IC and valid for 02 Aug-29 Aug, 2025. (c) The ERF rainfall anomaly for 4 weeks is based on 07 Aug and valid for 09 Aug-05 Sep, 2025.

12.3.4 Monsoon during September

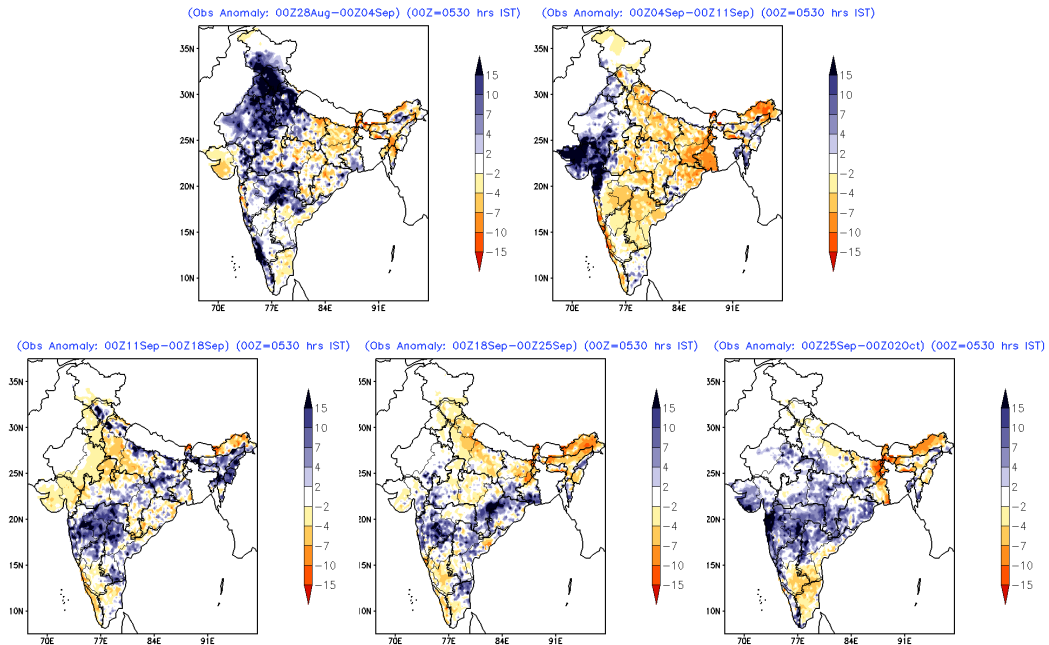
In the month of September 2025, positive rainfall anomaly can be seen over NW India in week 1, over Gujarat & Rajasthan in week 2, over Maharashtra in week 3-4, over Central and west India and Telangana in last week of September as can be seen in **Fig. 12.7**. The ERF based on 27th August, 2025 IC is able to predict positive rainfall anomaly over northwest India in week 1 forecast while not able to capture rainfall anomaly over Gujarat in second week of September. ERF based on 03rd September able to predict positive rainfall anomaly over Gujarat & Rajasthan in second week of September, positive anomaly over Maharashtra in week 3 & week 4 and last week of September while it is not able to predict rainfall anomaly pattern over south India in week 2.

12.4 Quantitative verification of ERF during monsoon 2025

To see the quantitative verification of real-time ERF over the country, the observed weekly rainfall departure averaged over India during the 2025 monsoon season is correlated with the corresponding forecast ERF rainfall departure for four weeks averaged over India. The observed weekly rainfall departures over India during the 2025 monsoon season along with the corresponding ERF rainfall departure with different lead times is shown in **Fig. 12.8** with the correlation coefficients (CC). As seen from **Fig. 12.8**, the ERF did capture the

observed pattern of monsoon rainfall during different phases of monsoon with significant CCs observed up to three weeks.

(a) Observed weekly rainfall anomaly for 4 weeks (28 Aug-02 Oct), 2025



(b) ERF, IC : 27 Aug, 2025

(c) ERF, IC : 03 Sep, 2025

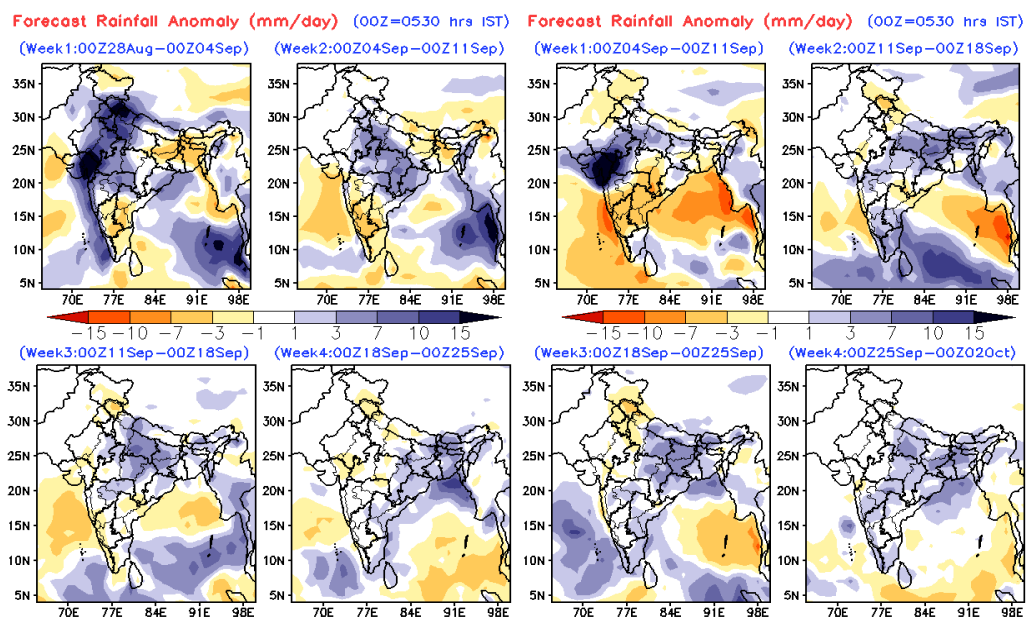


Fig. 12.7: (a) Weekly observed rainfall anomaly for 5 weeks from 28 Aug-02 October, 2025. (b) The ERF rainfall anomaly for 4 weeks is based on 27 Aug IC and valid for 28 Aug-25 Sep, 2025 (c) The ERF rainfall anomaly for 4 weeks is based on 03 Sep IC and valid for 04 Sep-02 Oct 2025.

To see the forecast skill over the four homogeneous regions (Fig. 12.9a), the observed and forecast rainfall departure is compared and plotted in Fig. 12.9b-e over Central India, south Peninsular India, Northwest India and Northeast India respectively.

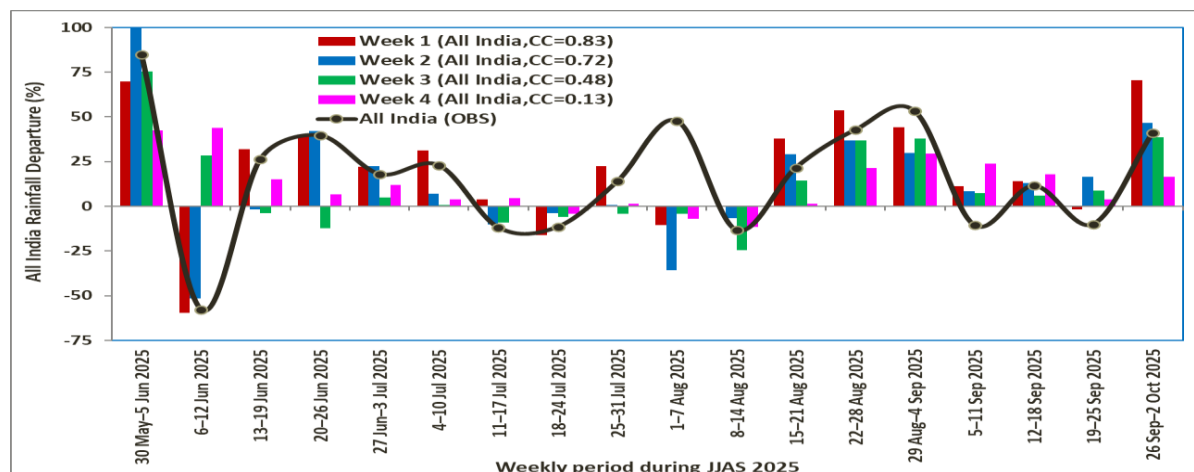


Fig. 12.8: The observed and ERF rainfall over India during the 2025 monsoon season from June to September with lead times of 4 weeks.

As it is seen the three homogeneous regions viz., central India, northwest India, and northeast India performed well by properly capturing the phases of monsoon with a correlation coefficient significant up to 2 weeks, whereas, over south India CC is low in week 2 forecast.

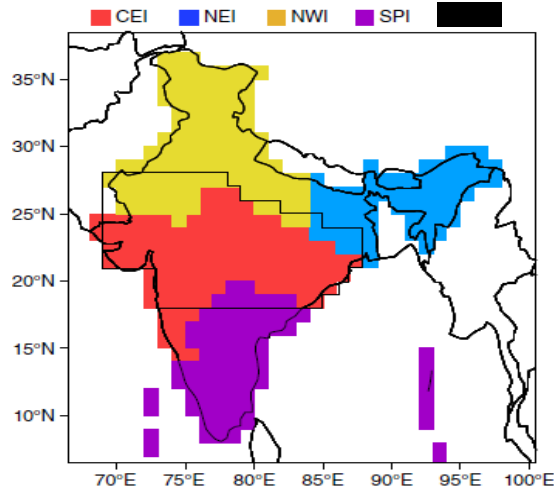
12.5 Forecast skill at Meteorological sub-division level forecast for application in Agriculture

On every week the met sub-division-wise rainfall forecast departure over 36 different met-subdivisions of India is prepared. As per the classification, a met-subdivision is considered to be above normal (AN) if rainfall departure $\geq 20\%$; Normal (NN) if it is between $+19\%$ to -19% and Below Normal (BN) if it is $\leq -20\%$ as given below as given in **Table 12.1**. **Table 12.1a** is the classification of met-subdivision level forecast under three categories as normal, above normal and below normal based on rainfall departure in a week, whereas, **Table 12.1b** is the verification contingency table considered for verification of sub-division level categorical forecast into Correct (C), Partially Correct (PC) and Wrong (W) categories.

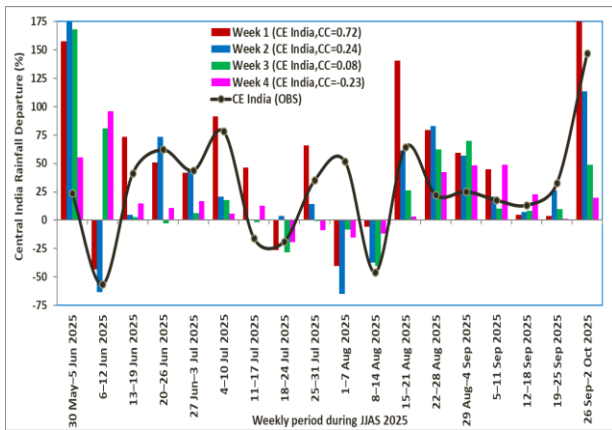
Before considering the categorical verification of the met-subdivision level forecast, the correlation coefficient between forecast rainfall departure and observed rainfall departure

during the 19 weeks of monsoon season 2025 during June to September for the operational ERF with a lead time of one week to four weeks has been calculated.

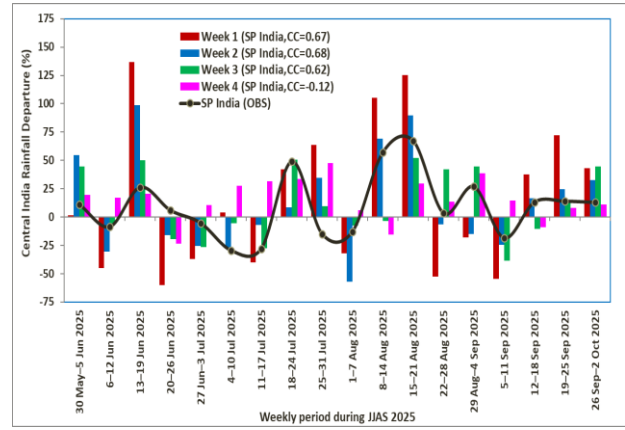
(a) Homogeneous regions of India



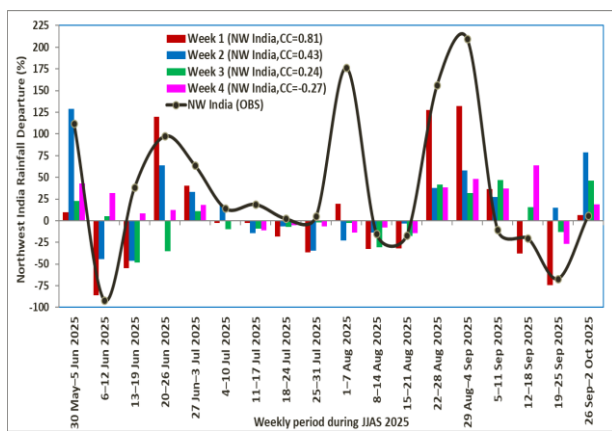
(b) CE, India



(c) SP India



(d) NW India



(e) NE India

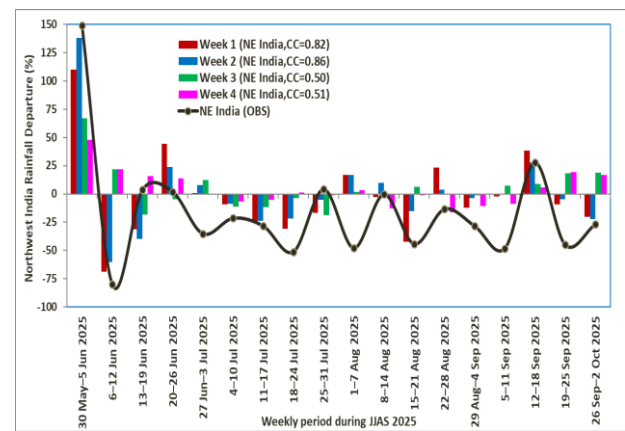


Fig. 12.9: The observed and ERF rainfall over 4 homogeneous regions of India as shown in (a) during the 2025 monsoon season from June to September with lead times of 4 weeks over (b) Central India, (c) South Peninsular India, (d) Northwest India and (e) Northeast India.

The met-subdivision level CC for four weeks is shown in **Fig. 12.10a-d**. As shown in **Fig. 12.11a** the CCs are highly significant for almost the entire India in week 1 forecast (**Fig. 12.10a**). The week 2 forecast show, higher CCs over the majority of subdivisions whereas lower CC can be seen in many subdivisions in east coast, J&K and Gujarat state (**Fig. 12.10b**). In week 2 south Peninsula and NE India show higher CC.

Table 12.1a-b: (a) Classification of met-subdivision as normal, above normal and below normal based on rainfall departure in a week (b) Contingency table considered for verification of sub-division level categorical forecast.

(a)

Categories	Subdivision Rainfall Departure	Classification
Excess (E)	+ 20% or more	Above Normal (AN)
Large Excess (LE)	+ 60% or more	
Normal (NN)	-19 % to + 19 %	Normal (NN)
Deficient (D)	- 20% or less	Below Normal (BN)
Large Deficient (LD)	- 60% or less	
No Rain (NR)	-100 %	

(b)

Forecast Categories → Observed Categories ↓	Above Normal (AN)	Normal (NN)	Below Normal (BN)
Above Normal (AN)	Correct (C)	Partially Correct (PC)	Wrong (W)
Normal (NN)	Partially Correct (PC)	Correct (C)	Partially Correct (PC)
Below Normal (BN)	Wrong (W)	Partially Correct (PC)	Correct (C)

In week 3, majority of met-subdivisions show higher CC whereas lower CC can be seen many subdivisions in east India, Arunachal Pradesh, Gujarat state, Konkan-Goa and south interior Karnataka (**Fig. 12.10c**). In week 4 many subdivisions in northwest India, Central India, northeast India show higher CC. By using the contingency **Table 12.1b**, the verification of sub-division level categorical forecasts for 4 weeks using three rainfall categories (Above normal, normal and below normal) at met-subdivision level are calculated for all 36 met-subdivisions. The correct categories forecast and the wrong categories

forecasts are shown in **Fig. 12.11** and **Fig. 12.12**, respectively. As seen from **Fig. 12.11**, the correct category is mostly between 50-70% with many met-subdivisions, 5 sub-divisions fall in 70 to 100% correct category and 10 subdivisions with 30 to 50% of correct categories which indicates skilful ERF in week 1 forecast. Similarly, the week 2 forecast also performed well over most of the sub-divisions except 2 met-subdivisions (Uttarakhand and Andaman Nicobar Islands) indicating only 10 to 30% of correct category forecast. The category forecast also performed well in case of week 3 forecasts, with a probability of 30 to 70% of correct category forecast over 30 met- subdivisions out of total 36. In week 4, 68 % of sub-divisions show correct category. The ‘Wrong’ category forecast as shown in **Fig. 12.12** indicates wrong category forecast percentage is less than 30 % in most of the sub-divisions in week 1 forecast with number of sub-divisions with wrong category above 30% show slight increase in week 2 to week 4 forecasts.

The mean probability of 36 met-subdivisions with percentage of correct and wrong categories forecasts during the 2025 monsoon season as shown in **Fig. 12.11**, **Fig. 12.12** and also for the partially correct categories (figure not shown here) is given in **Table 12.2**. As seen from **Table 12.2**, the “wrong” categories are only about 11% in week 1 forecast and between 12 to 18% in week 2 to week 4 forecasts.

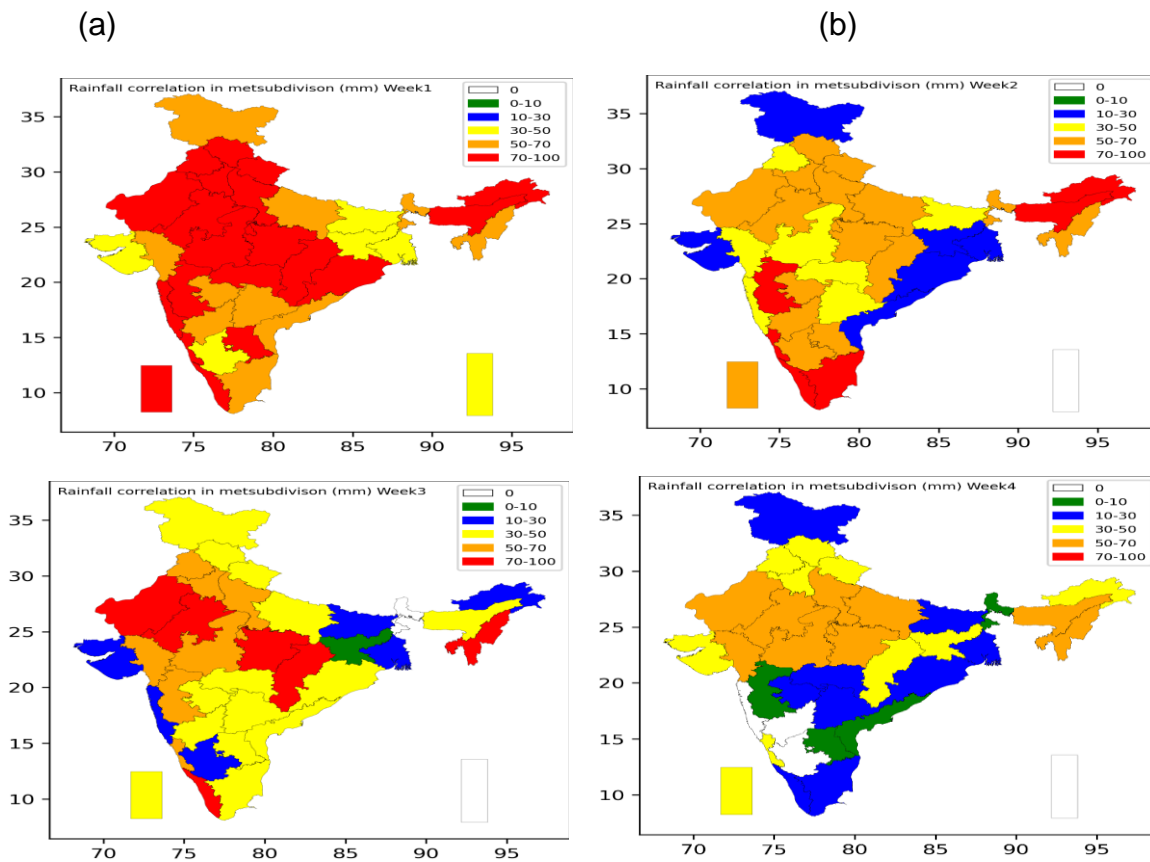


Fig. 12.10 a-d: Correlation coefficient between forecast rainfall departure and observed rainfall departure during the 19 weeks of monsoon season 2025 from June to September

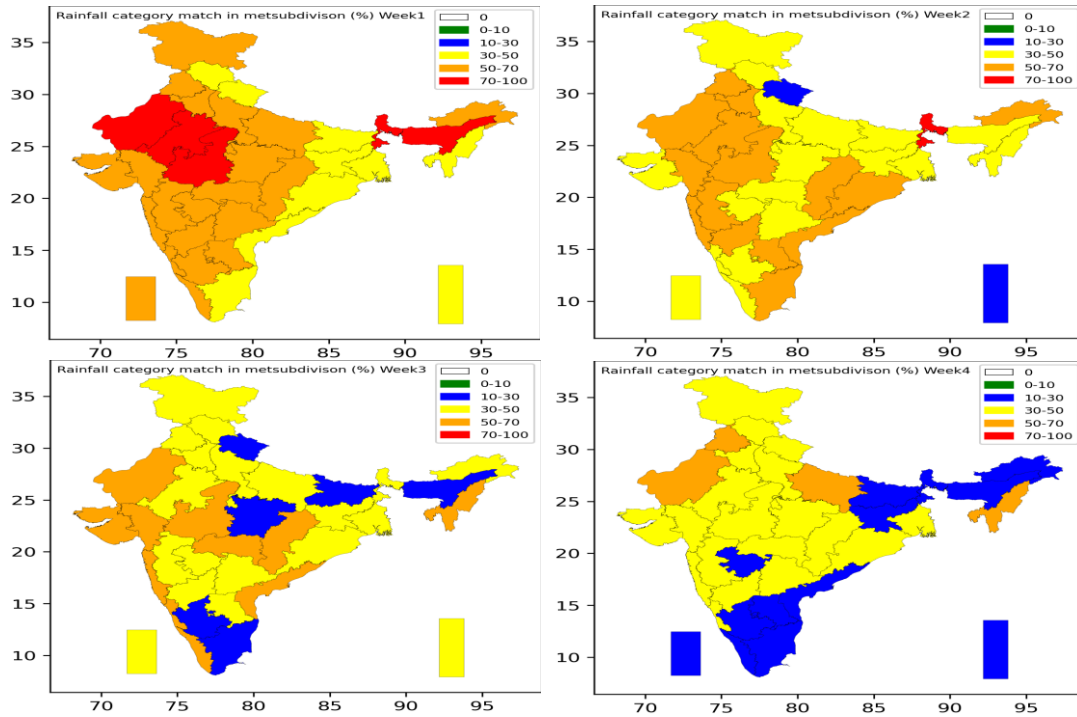


Fig. 12.11: Met-subdivision based percentage of correct category forecasts (Week 1 to Week 4)

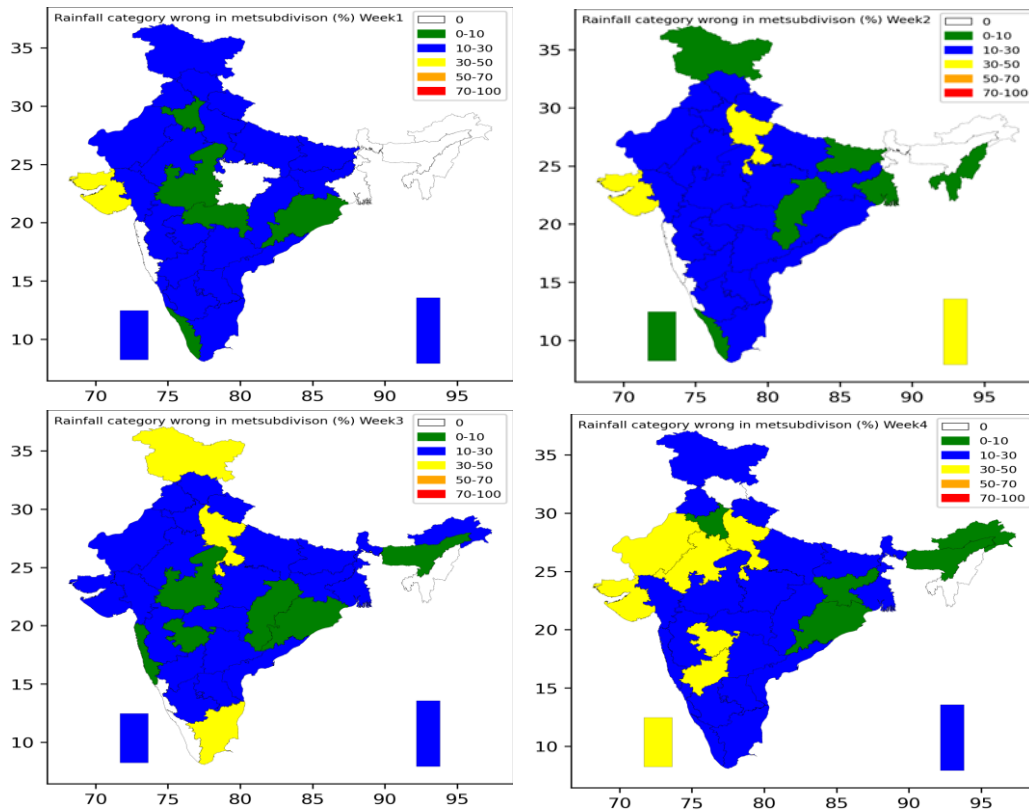


Fig. 12.12: Met-subdivision based percentage of wrong category forecasts (Week 1 to Week 4)

Thus, equivalently there is 89% probability of Correct to Partially correct categories cases for week 1 forecast and is between 86 to 83% probability of Correct to Partially correct categories cases for week 2 to week 4 forecasts. It is also seen from Table 2 that the percentage of correct categories in case of week 1 forecast is about 56% (19 Met-subdivisions out of 36) in case of week 1 forecast and is about 48% for week 2, 43% for week 3 and 33% for week 4 forecasts. This indicates that the forecast for two weeks at met-subdivision level are very skilful and can be utilised for agro-advisory purposes.

Table 12.2: Average of 36% met-subdivisions with percentage of correct, partially correct and wrong categories as per the classification given in Table 12.1b.

Week1			Week2		
Category	% of Met sub	No of Met sub	Category	% of Met sub	No of Met sub
Correct (C)	56	20	Correct (C)	48	17
Partially (PC)	33	12	Partially (PC)	40	14
Wrong (W)	11	4	Wrong (W)	12	5
Week3			Week4		
Category	% of Met sub	No of Met sub	Category	% of Met sub	No of Met sub
Correct (C)	43	15	Correct (C)	33	12
Partially (PC)	41	15	Partially (PC)	49	18
Wrong (W)	16	6	Wrong (W)	18	7

12.6 Met-subdivision level forecast for application in Agriculture

To use the extended range forecast for Agromet applications the category forecast for 36 met subdivisions of India is prepared for two weeks with the met-subdivisions as below normal, normal or above normal depending on the rainfall departure during the week. During the second half of June relatively good monsoon condition observed as shown in **Fig. 12.2b**. The corresponding met-subdivision level forecast for the period June 20-26 based on ICS 18th June and 11th June is shown in (**Fig. 12.13 a & b**). Normal to above normal rainfall is captured reasonably well in many of the regions in the extended range forecast, which is being used for Agromet advisory purposes.

(a) Week 1 forecast (IC 11th June)

(b) Week 2 forecast (IC 18th June)

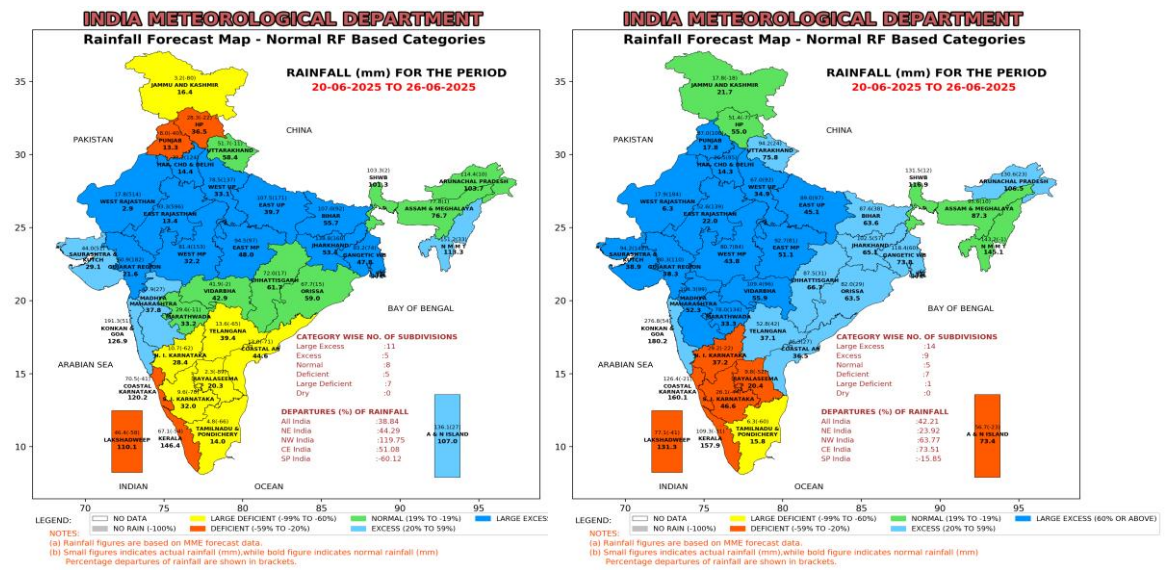


Fig. 12.13: (a) Met-subdivision wise week1 forecast valid for June 20 - 26 based on 18th June 2025 (b) Met-subdivision wise week2 forecast valid for June 20 - 26 based on 11th June 2025.

12.7 Districts level extended range forecast

The ERF at smaller spatial scales viz., at the met-subdivision level and district level are also being prepared operationally for application in agriculture (Pattanaik and Asish, 2024). As we have seen ERF is skilful and useful for two to three weeks. In order to prepare the forecast at smaller spatial domain at district level for Agromet application, IMD is also preparing district level forecast on experimental basis in terms of above normal, normal and below normal categories. The district level forecast valid for the first week of August based on ICS 18th June and 11th June and forecast is also seen in **Fig. 12.14a-b**. These products are available on NWP's website.

(a) Week 1 forecast (IC 18 June)

(b) Week 2 forecast (IC 11 June)

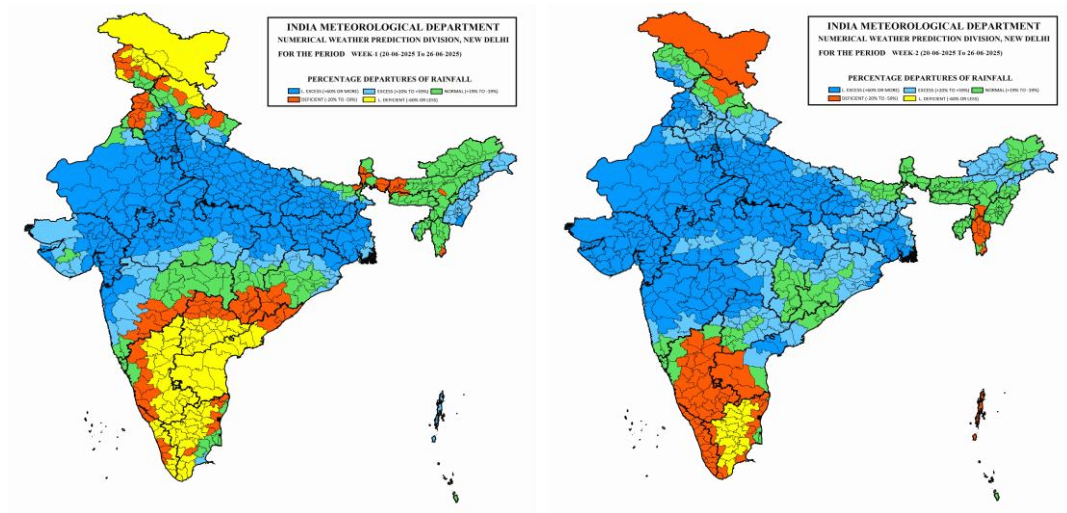


Fig. 12.14: (a) District-level forecast valid for 20-26 June based on 18th June 2025 (b) District-level forecast valid for 20-26 June based on 11th June.

12.8 Summary

The real time extended range forecast during different phase of monsoon 2025 have captured the observed intra-seasonal variability very well with 2 to 3 weeks lead time for all the target weeks covering:

- (i) Early onset with the weak phase of monsoon in June
- (ii) Active monsoon phase in second half of June, weak phase in middle of July and active phase in the end of July.
- (iii) Weak phase of monsoon phase in early August and active phase in second half of August.
- (iv) Active September with a short weak phase during the middle of September

Quantitatively, the ERF did capture the observed intra-seasonal variability of monsoon rainfall during different phases of monsoon with significant CCs observed up to three weeks over the country as a whole. The forecast skill over the four homogeneous regions between the observed and forecast rainfall departure is computed. The CCs over the three homogeneous regions viz., central India, northwest India, and northeast India performed well by properly capturing the different phases of monsoon with a CC significant up to 2 weeks, whereas, the performance over south India was with significant CC, only for week 1 forecast.

The met-subdivision level CC for week 1 forecast is highly significant for most of met-subdivisions of India. During the week 2 higher CCs over the majority of the met-subdivisions except east coast, J&K and Gujarat state. In week 3 forecasts, majority of the

sub-divisions show higher cc except over east India, Arunachal Pradesh, Gujarat state, Konkan-Goa and south interior Karnataka. In week 4 forecast, many subdivisions in northwest India, Central India, northeast India show higher CC. The verification of sub-division level categorical forecasts for 4 weeks using three categories (Above normal, normal and below normal) at met-subdivision level shows the correct category is mostly between 50-70% with many subdivisions, some subdivisions indicating a 70 to 100% and some subdivisions falls in 30 to 50% categories in case of week 1 forecast. Thus, it indicates a skilful ERF at sub-division level in week 1 forecast. Similarly, week 2 forecast also performed well over most of the sub-divisions with only 2 met-subdivisions (Uttarakhand and Andaman Nicobar Islands) indicating 10 to 30% correct category forecast.

It is also seen that the “wrong” categories forecast is only about 11% in week 1 and between 12 to 18 % in week 2 to week 4 forecasts. Thus, equivalently there is 89% probability of Correct to Partially correct categories cases for week 1 forecast and is between 86 to 83% probability of Correct to Partially correct categories cases for week 2 to week 4 forecasts. It is also observed that the percentage of correct categories in case of week 1 forecast is about 56% (19 Met-subdivisions out of 36) in case of week 1 forecast and is about 48% for week 2, 43% for week 3 and 33% for week 4 forecasts. This indicates that the forecast for two weeks at met-subdivision level are very skilful and can be utilised for agro-advisory purposes.

Acknowledgement

The authors are thankful to the Director General of Meteorology, Dr. M. Mohapatra for providing all facility in IMD in carrying out this research work. Thanks are also due to the IITM's ERF Group, NCMRWF and INCOIS for collaborating with IMD in enhancing the extended range forecast activity of IMD in running the coupled model.

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13



Verification of Long-Range Forecast of Monsoon 2025

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This chapter reviews the operational monthly and seasonal rainfall forecasts issued by the India Meteorological Department (IMD), including the forecast and verification of the 2025 southwest monsoon onset over Kerala. It further discusses dynamical seasonal forecasts generated using IMD's Monsoon Mission Coupled Forecasting System (MMCFS), in comparison with forecasts from leading national and international climate research centres.

13.1. Introduction

Since 2021, IMD has adopted a new strategy for issuing monthly and seasonal operational forecasts for the southwest monsoon rainfall over the country by modifying the existing two stage forecasting strategy. The new strategy is based on the existing statistical forecasting system and the newly developed Multi-Model Ensemble (MME) based forecasting system. The MME approach uses the coupled global climate models (CGCMs) from different global climate prediction and research centers including IMD's Monsoon Mission Climate Forecasting System (MMCFS) model. The spatial distribution of probabilistic forecasts for tercile categories (above normal, normal and below normal) for the seasonal rainfall (June to September) over the country was issued. In addition to that, IMD has also issued seasonal forecasts for four homogeneous regions and monsoon core zone (MCZ). In addition to the MME-based forecasts, the India Meteorological Department (IMD) also employed monthly and seasonal southwest monsoon rainfall forecasts derived from models based on advanced statistical techniques that have demonstrated useful predictive skill (Rajeevan et al., 2007; Pai et al., 2011).

A brief description of IMD's operational statistical and experimental dynamical forecasting systems is discussed in this chapter along with the verification of the forecasts generated by these forecasting systems. The forecasts for seasonal rainfall over the country, generated using the Monsoon Mission CFS (MMCFS) and various national and international research institutes, were discussed as guidance before issuing operational forecasts by the IMD.

13.2 Models Used

13.2.1 Multi Model Ensemble (MME) Forecasting System

For generating April MME forecast for 2025 southwest Monsoon season rainfall, April initial conditions have been used. Climate models with the highest forecast skills over the Indian monsoon region including MMCFS have been used to generate MME forecasts. The MME forecast suggested that the monsoon rainfall during the 2025 monsoon season (June to September) averaged over the country as a whole is likely to be above normal (104-110% of LPA). The spatial distribution of probabilistic forecasts for tercile categories (above normal, normal and below normal) for the seasonal rainfall (June to September) using April initial condition is shown in **Fig. 13.1a**. The spatial distribution suggested above-normal seasonal rainfall is very likely over most parts of the country except some areas over Northwest India, Northeast India and South Peninsular India, where below-normal rainfall is likely.

The updated MME forecast for 2025 southwest Monsoon season rainfall has been computed using various coupled global model forecasts with May initial conditions (**Fig. 13.1b**). Climate models with the highest forecast skills over the Indian monsoon region including MMCFS have been used to prepare the MME forecast. The updated MME forecast also suggested that the monsoon rainfall during the 2025 monsoon season (June to September) averaged over the country as a whole is likely to be above normal (104-110% of LPA). The spatial distribution of probabilistic forecasts for tercile categories (above normal, normal and below normal) for the seasonal rainfall (June to September) is shown in **Fig. 13.1b**. The spatial distribution indicated that normal to above normal rainfall is very likely over most parts of the country except some areas of Northwest and East India and many areas of Northeast India where normal to below normal rainfall is very likely. There is no signal by the model over the white shaded areas within the land region of the country.

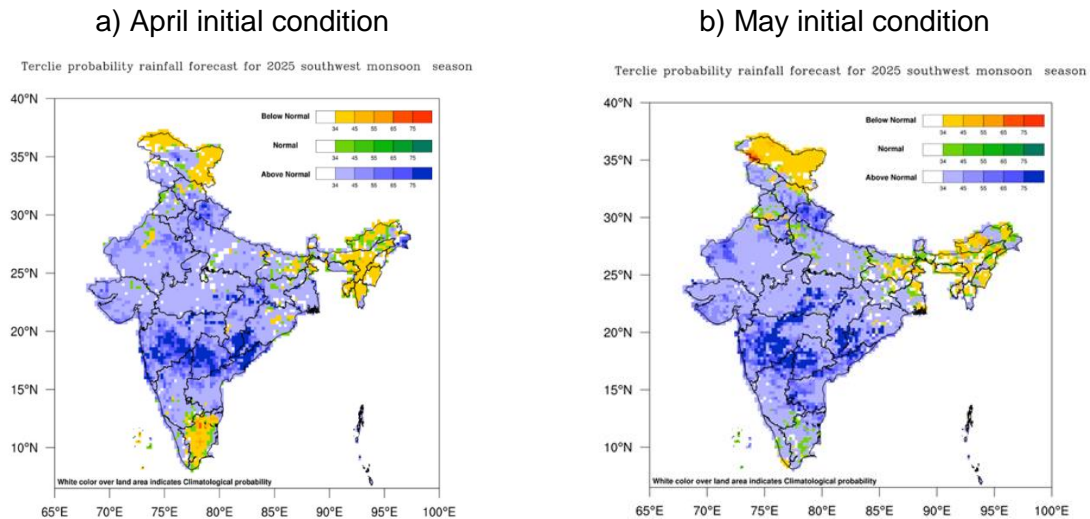


Fig. 13.1: The spatial distribution of probabilistic forecasts for tercile categories (above normal, normal and below normal) for the seasonal rainfall (June to September) using (a) April initial condition (b) May initial condition.

13.2.2 Statistical Ensemble Forecasting System for the Seasonal Rainfall over the Country as a Whole

The statistical ensemble forecasting system (SEFS) was used for the forecast for the seasonal rainfall over the country as a whole. For this a set of 10 predictors (**Table 13.1**) that having stable and strong physical linkage with the Indian south-west monsoon rainfall were used. The geographical domains of the predictors are shown in the **Fig. 13.2**. For the April SEFS, first five predictors listed in the **Table 13.1** were used. For June SEFS, the last six predictors listed in the **Table 13.1** were used that include 1 predictor used for April forecast. The standard errors of the 5-parameter and 6-parameter SEFSs were taken as $\pm 5\%$ and $\pm 4\%$ respectively. A schematic diagram of the statistical ensemble forecasting system is shown in the **Fig. 13.3**. As depicted in the **Fig. 13.3**, the forecast for the seasonal rainfall over the country as a whole is computed as the ensemble average of best few models out of all possible models constructed using two statistical methods; multiple regression (MR) technique and projection pursuit regression (PPR) - a nonlinear regression technique. In each case, models were constructed using all possible combination of predictors. Using 'n' predictors, it is possible to create $(2^n - 1)$ combination of the predictors and therefore as many numbers of models. Thus with 5 (6) predictors respectively for April (June) SEFS, it is possible to construct 31 (63) models. Using sliding fixed training window (of optimum period of 23 years) period, independent forecasts were prepared by all possible models for the period 1981-2024.

Performance of the April and June SEFS for the independent test period of 1981-2024 is shown in the **Fig. 13.4a & b** respectively. The RMSEs of the April and June SEFS for the period 1981-2024 are 7.58% of LPA and 7.25% of LPA respectively. The C.C. between observed and forecast rainfall of the April and June SEFS for the period 1981-2024 are 0.52 and 0.57 respectively.

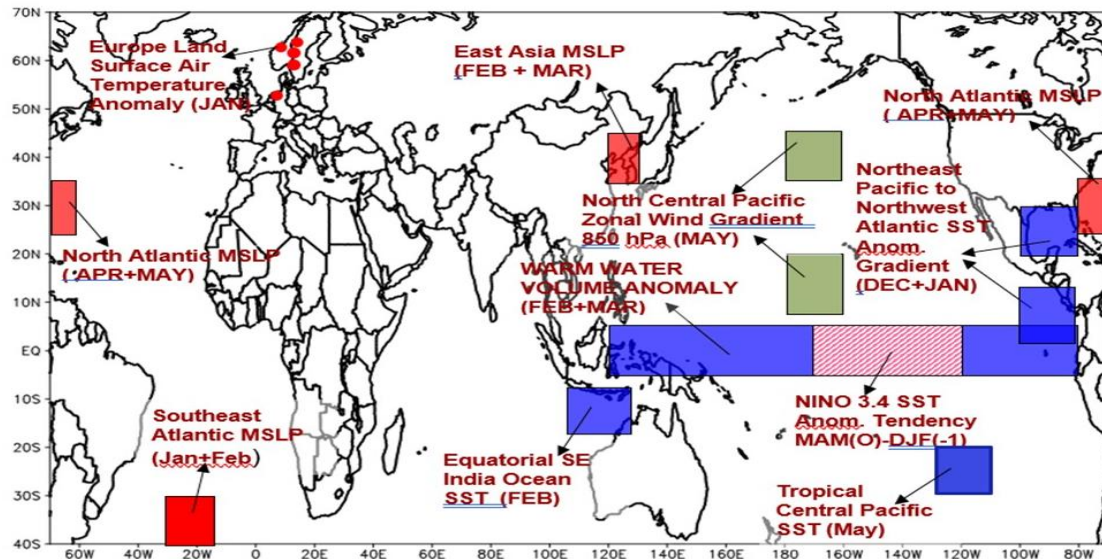


Fig. 13.2: Geographical domains of the predictors used in the statistical ensemble forecasting system for the seasonal rainfall forecast over the country as a whole.

Table 13.1: Details of the 10 predictors used for the new ensemble forecast system

No.	Predictor	Used for forecasts in	Correlation Coefficient (1981-2010)
1.	Europe Land Surface Air Temperature Anomaly (January)	April	0.39
2.	Equatorial Pacific Warm Water Volume Anomaly (February + March)	April	-0.37
3.	SST Gradient Between Northwest Pacific and Northwest Atlantic (December +January)	April	0.43
4.	East Asia MSLP (FEB + MAR)	April	0.53
5.	Equatorial SE India Ocean SST (FEB)	April and June	0.55
6.	Southeast Atlantic MSLP (Jan+Feb)	June	-0.41
7.	Tropical Central Pacific SST (May)	June	-0.44

8.	NINO 3.4 SST (MAM+(MAM-DJF) Tendency)	June	-0.42
9.	North Atlantic MSLP (APR+MAY)	June	-0.43
10.	North Central Pacific Zonal Wind Gradient 850 hPa (MAY)	June	-0.59

In addition to the quantitative forecast, the ensemble forecasting system has also been used to generate a five-category probabilistic rainfall forecast based on the forecast error distribution of the ensemble forecasting system. The five rainfall categories defined based on the observed data for the period 1901-2005 are deficient (< 90% of LPA), below normal (90-96% of LPA), normal (96-104% of LPA), above normal (104-110% of LPA) and excess (> 110% of LPA). The climatological probabilities of these five categories are 16%, 17%, 33%, 16% and 17% respectively. The five-category probability forecast is prepared using normal probability distribution with the ensemble average of the forecast from the ensemble forecasting system as the mean and the RMSE of the independent test period as the standard deviation. For verification purpose, the most probable category is one that has highest forecast probability compared to its climatological value. A forecast validating within the same category was considered as “correct (C)”, within one category as “usable (U)” and beyond one category as “unusable/not usable (NU)”. The 5 category probability forecasts based on the April and June SEFS for the 2025 monsoon season are given in the **Table 13.2**.

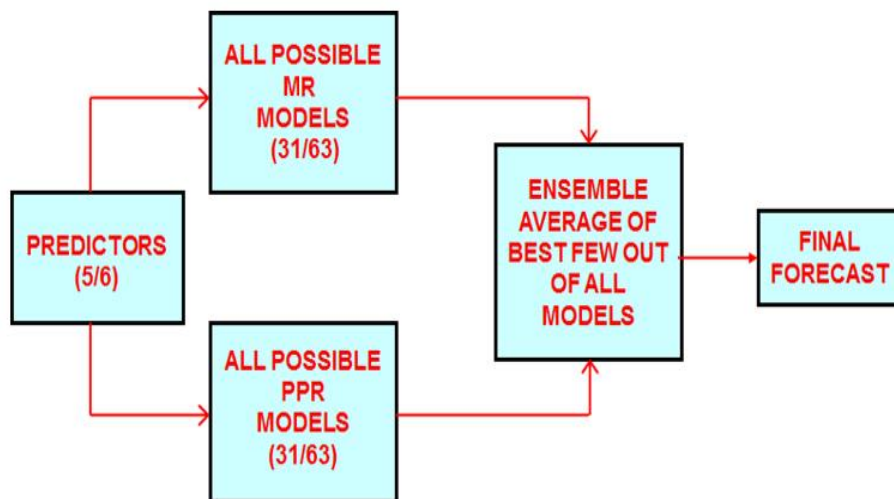


Fig. 13.3: A Schematic diagram of the new ensemble forecasting system for the monsoon seasonal rainfall over the country as a whole. The average of the ensemble forecasts from best out all possible MR (multiple regression) and PPR (projection pursuit regression) models gives the final forecast.

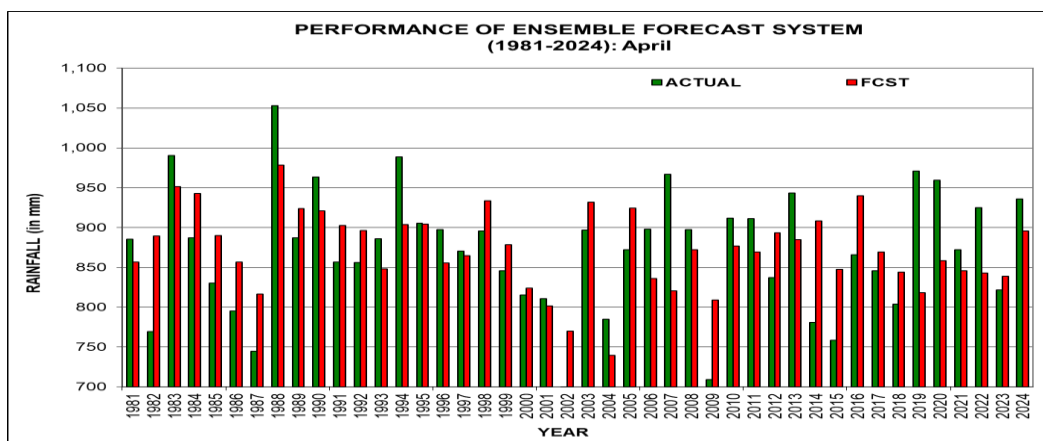


Fig. 13.4a: Performance of the April ensemble forecasting system for the seasonal rainfall over the country as whole for the period 1981-2024.

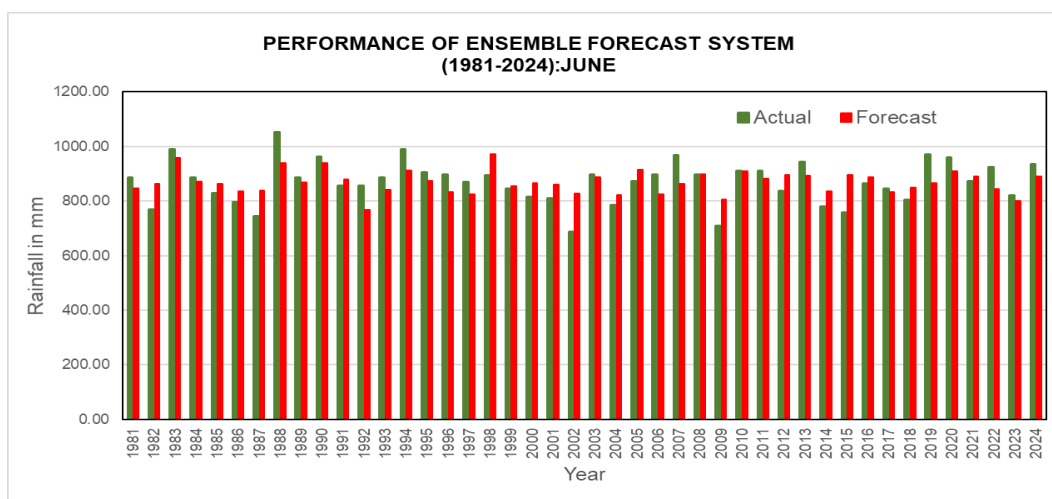


Fig. 13.4b: Performance of the June ensemble forecasting system for the seasonal rainfall over the country as a whole for the period 1981-2024.

Table 13.2: Probability forecasts for the 2025 Seasonal (June to September) rainfall over the country as a whole based on the SEFS forecast

Category	Rainfall Range (% of LPA)	Forecast Probability (%)		Climatological Probability (%)
		April SEFS	June SEFS	
Deficient	less than 90	2	2	16
Below Normal	90 - 96	9	8	17
Normal	96 -104	30	31	33
Above Normal	104 -110	33	32	16
Excess	more than 110	26	27	17

13.2.3 Operational Forecast Model for the Date of Monsoon Onset over Kerala

An indigenously developed statistical model (Pai and Rajeevan, 2009) was used for preparing the operational forecast of the onset of monsoon over Kerala. The model based on 6 predictors used the principal component regression (PCR) method for its construction. Independent forecasts were derived using the sliding fixed window period of length 22 years. The model for 2025 was trained using data for the period 2002-2024. The forecast for the onset of the monsoon in Kerala was issued on May 10, 2025, predicting that the monsoon would begin on May 27, with a model error of ± 4 days. The actual date of the monsoon's onset in Kerala was May 24. **Fig. 13.5** shows the performance of the forecast for the period 1997-2024. The RMSE of the model is about 4 days.

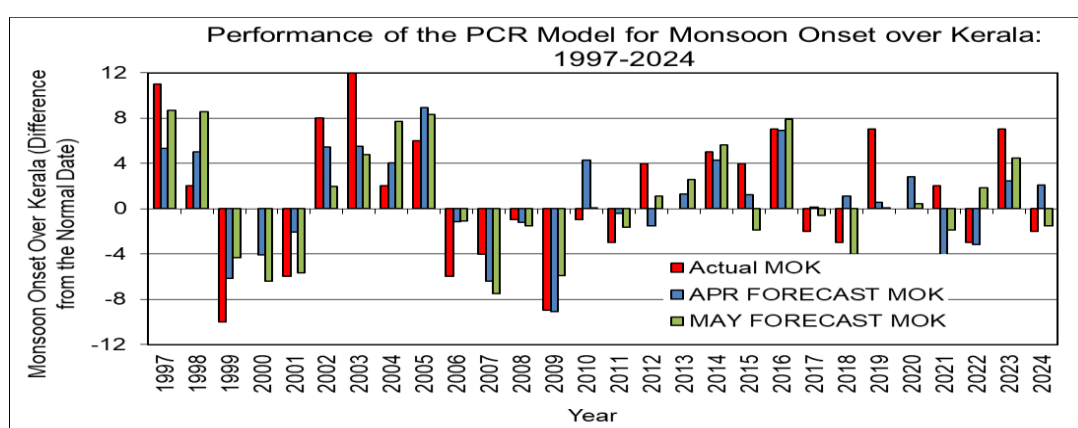


Fig. 13.5: Actual dates of monsoon onset over Kerala and their predictions from the PCR model for the period 1997-2024

13.2.4 Probabilistic Forecast for Rainfall for homogeneous region and Core Monsoon Zone (CMZ)

The probabilistic forecast for the southwest monsoon season (June–September 2025) indicated that the seasonal rainfall was most likely to be above normal over Central India and the South Peninsular region ($>106\%$ of the Long Period Average, LPA), normal over Northwest India ($92\text{--}108\%$ of LPA), and below normal over Northeast India ($<94\%$ of LPA). Over the Monsoon Core Zone (MCZ) comprising most of the country's rainfed agricultural areas the seasonal rainfall was also forecasted to be above normal ($>106\%$ of LPA). The observed seasonal rainfall during the 2025 southwest monsoon was 127% of LPA over Northwest India, 115% over Central India, 110% over the South Peninsula, and 80% over Northeast India. The rainfall over Northwest India (746.4 mm) was the highest since 2001 and the sixth highest since 1901, whereas rainfall over East and Northeast India (1089.9 mm) was the second lowest since 1901.

The tercile category forecasts for the four homogenous regions and MCZ for the 2025 southwest monsoon seasonal (June-September) rainfall based on the MME forecast generated using May initial conditions are given below in **Table 13.3**.

Table 13.3: Tercile category forecasts for the four homogenous regions and MCZ for the 2025 southwest monsoon seasonal (June-September) rainfall

Range (% of LPA)	NW India		Central India		South Peninsula	
	Range (% of LPA)	Forecast Probability (%)	Range (% of LPA)	Forecast Probability (%)	Range (% of LPA)	Forecast Probability (%)
Below Normal	<92	12	<94	11	<94	6
Normal	92-108	43	94-106	31	94-106	18
Above Normal	>108	45	>106	58	>104	76

Rainfall Category	Northeast India		Monsoon Core Zone (MCZ)	
	Range (% of LPA)	Forecast Probability (%)	Range (% of LPA)	Forecast Probability (%)
Below Normal	<94	54	<94	12
Normal	94-106	38	94-106	32
Above Normal	>106	8	>106	56

The MME monthly and spatial probability distribution forecasts issued during the 2025 are mentioned below:

The MME probability forecast indicates that the average June 2025 rainfall for the country as a whole is most likely to be above normal (>108 % of LPA). The LPA of the June rainfall over the country as a whole for the period 1971-2020 is 165.4 mm. The spatial distribution suggests that Normal to above normal monthly rainfall is very likely over most parts of the country, except some southern parts of peninsular India and parts of Northwest and Northeast India, where below normal rainfall is likely.

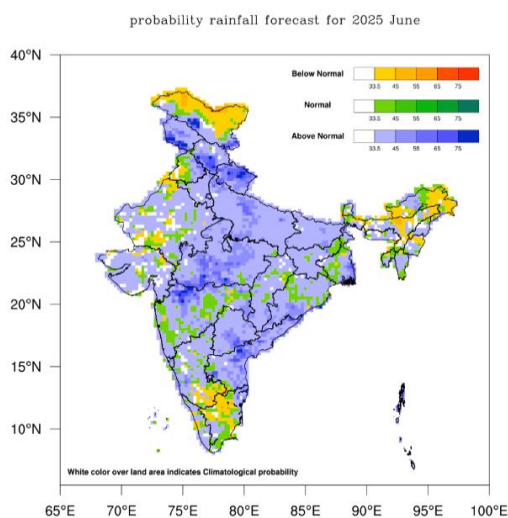
The MME forecast suggests that the monsoon rainfall averaged over the country as a whole during July 2025, is most likely to be above normal (>106 % of LPA)). The LPA of the July rainfall over the country as a whole for the period 1971-2020 is 280.4 mm. The spatial distribution suggests that the most parts of the country are likely to experience normal to above-normal rainfall. However, most parts of Northeast & East India, many areas of extreme South Peninsular India and some areas of Northwest India, are likely to receive below-normal rainfall.

For the 2025 August rainfall averaged over the country as a whole is most likely to be normal (94% - 106% of LPA). The LPA of the August rainfall over the country as a whole for the period 1971-2020 is 254.9 mm. The spatial distribution suggests that Normal to above normal rainfall is very likely over many parts of the country except many parts of central India, western parts of peninsular India, northeast India and some parts of east and northwest India where it is likely to be below normal.

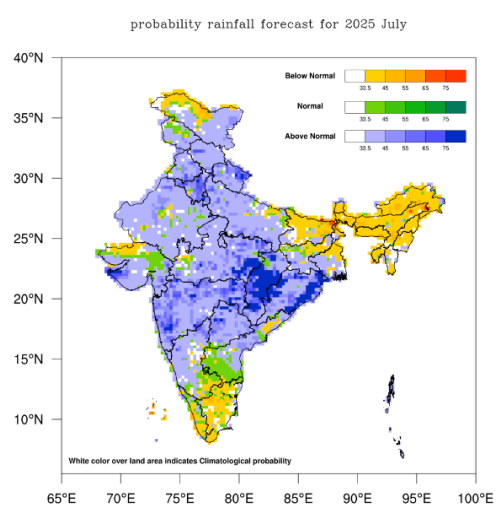
The 2025 August to September rainfall averaged over the country as a whole is most likely to be above normal (>106% of the Long Period Average (LPA)). The LPA of the August to September period rainfall over the country as a whole for the period 1971-2020 is 422.8mm. The spatial distribution suggests that normal to above normal rainfall is most likely over most parts of the country except many parts of northeast and adjoining areas of east India, some isolated regions of central India and south western parts of peninsular India where below normal rainfall is likely.

The rainfall averaged over the country as a whole during the September 2025 is most likely to be above normal (>109 % of LPA). The LPA of rainfall during September based on the data of 1971-2020 is about 167.9 mm. The forecast suggests that most parts of the country are likely to receive normal to above-normal rainfall. However, some parts of Northeast and East India, many areas of extreme South Peninsular India and some parts of northernmost India, are likely to receive below-normal rainfall.

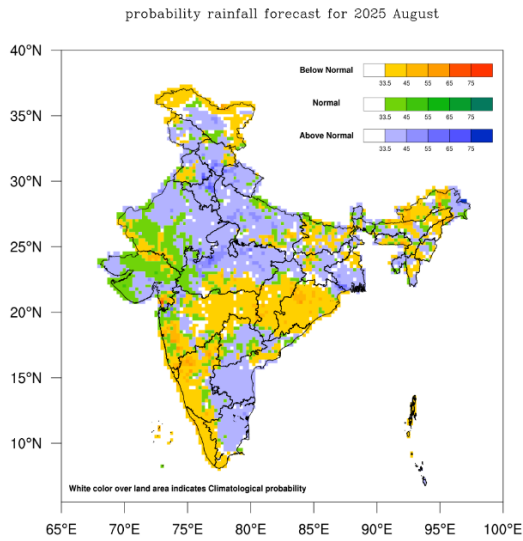
13.6a



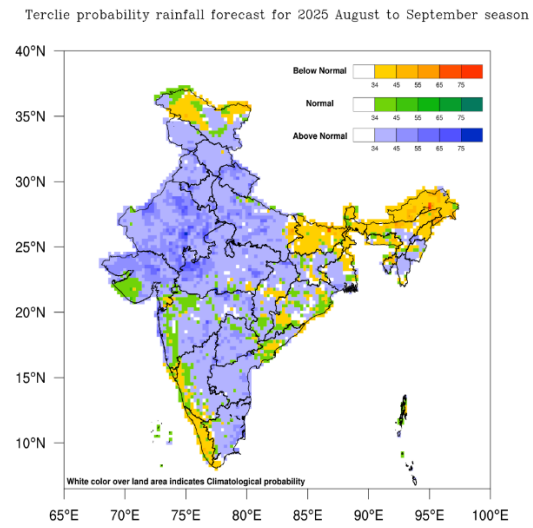
13.6b



13.6c



13.6d



13.6e

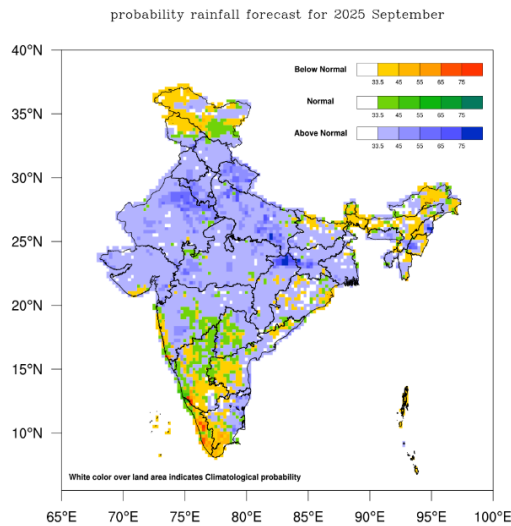


Fig. 13.6a to 13.6e: Probability forecast of tercile categories* (below normal, normal, and above normal) for the rainfall over India during June, July, August, Aug-Sept & September rainfall respectively.

The spatial distribution of probabilistic forecasts for tercile categories (above normal, normal and below normal) for the June, July, August, Aug-Sept and September rainfall are shown in **Fig. 13.6a to 13.6e** respectively. The white shaded areas within the land area represent climatological probabilities. The probabilities were derived using the MME forecast prepared from a group of coupled climate models. (* Tercile categories have equal climatological probabilities of 33.33% each).

13.3 Verification of Operational Forecasts

Based on an indigenously developed statistical model, it was predicted on 10th May 2025 that monsoon will set in over Kerala on 27th May with a model error of ± 4 days. The actual monsoon onset over Kerala was on 24th May and therefore the forecast was correct.

Table 13.4 gives the summary of the various operational long-range forecasts issued for the 2025 Southwest monsoon rainfall along with the realized rainfall.

The first stage forecast for the season (June-September) rainfall over the country as a whole issued in April was 105% of LPA with a model error of $\pm 5\%$ of LPA. The update issued on 27th May for this forecast was (106% of LPA) with a model error of $\pm 4\%$ of LPA. The actual season rainfall for the country as a whole was 108% of LPA. Thus the both the forecasts were within forecast limits and therefore the forecast was correct.

Considering the four broad geographical regions of India, the forecasts issued on 27th May, the southwest monsoon seasonal (June to September 2025) rainfall is most likely to be above-normal over Central India and South Peninsular India ($>106\%$ of LPA), above normal over Northwest India ($>108\%$ of LPA) and below normal over Northeast India ($<94\%$ of LPA). The southwest monsoon seasonal rainfall over the monsoon core zone consisting of most of the rainfed agriculture areas in the country was most likely to be above Normal ($>106\%$ of LPA). The actual rainfall over Northwest India, Central India, Northeast India, South Peninsula and Monsoon Core Zone were 27%, 15%, -20%, 10% and 22% of the LPA, respectively. The forecasts for monthly rainfall over the country as a whole for the months of June, July, August, and September were: Above Normal ($>108\%$ of LPA), Above Normal ($>106\%$ of LPA), Normal (94-106% of LPA), and Above Normal ($>109\%$ of LPA), respectively. The observed rainfall for these months was 109%, 105%, 105%, and 115%, respectively. All the monthly outlooks were within the forecast limit, except the July. The forecast for the second half of the monsoon season (August –September) for the country as a whole also was in the forecast limit.

Table 13.4: Performance of the operational forecast issued for the 2025 southwest monsoon rainfall

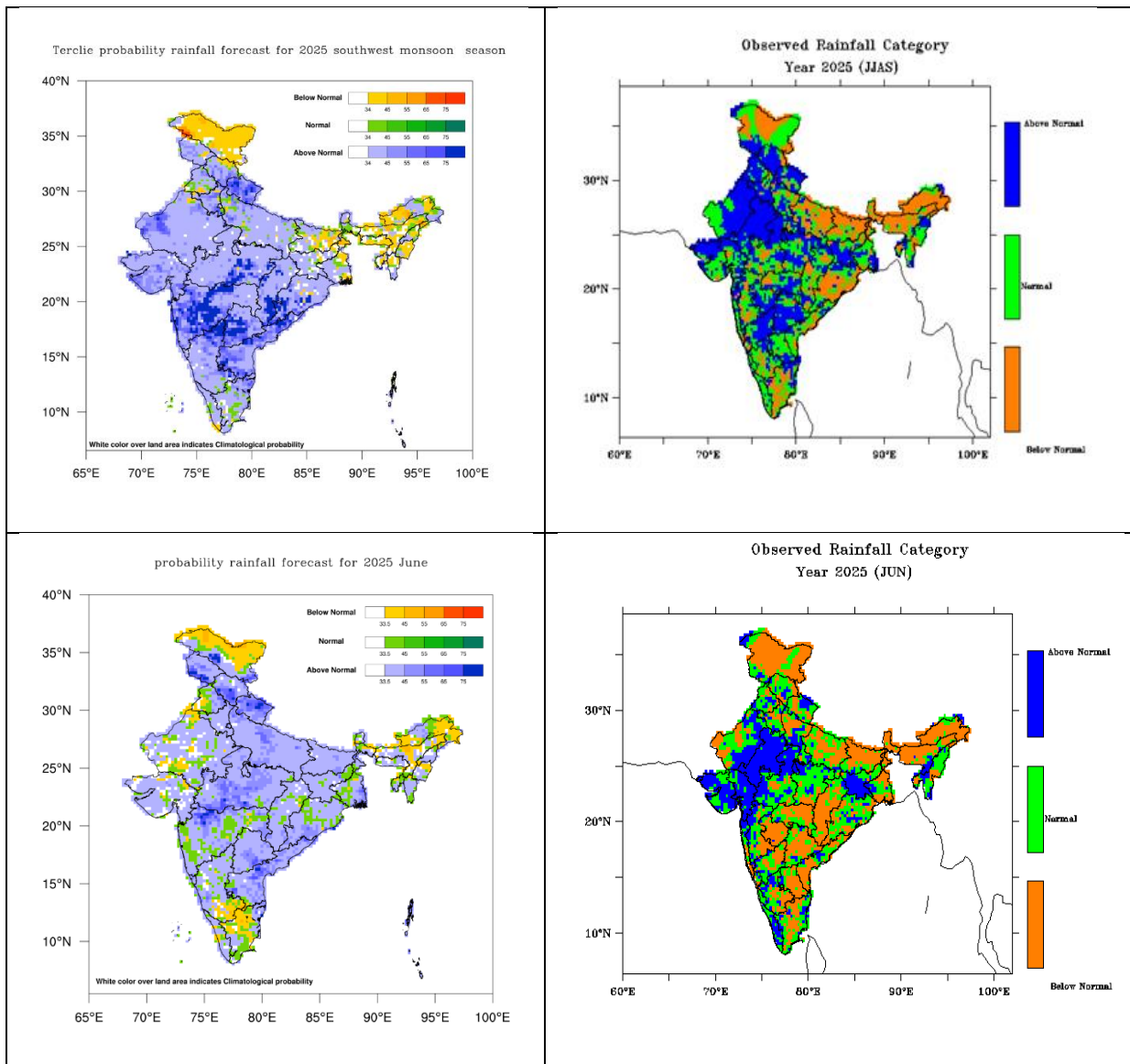
Seasonal Forecast		Observed
15 April 2025-1st Stage for Season as a whole	27th May 2025-2nd stage -	
<ul style="list-style-type: none"> • The Neutral ENSO condition is likely to continue during the monsoon season. • The Neutral IOD conditions are likely to continue during the southwest monsoon season. • The snow cover areas of northern hemisphere and Eurasia during the last three months (January to March, 2025) were below normal. The winter and spring snow cover extent over Northern Hemisphere as well as Eurasia has in general an inverse relationship with the subsequent Indian summer monsoon rainfall. • The southwest monsoon seasonal (June to September) rainfall over the country as a whole during 2025 is most likely to be above normal (>104% of the Long Period Average (LPA)). Quantitatively, the seasonal rainfall over the country as a whole is likely to be 105% of LPA with a model error of $\pm 5\%$. 	<ul style="list-style-type: none"> • Same ENSO forecast. • A weak negative IOD conditions are likely to develop during the southwest monsoon season. • Quantitatively, the southwest monsoon seasonal rainfall over the country as a whole is likely to be 106% of the Long Period Average (LPA) with a model error of $\pm 4\%$, indicating that above normal rainfall is most likely over the country as a whole during the monsoon season (June to September), 2025. 	<ul style="list-style-type: none"> • Neutral El Nino Southern Oscillation (ENSO) conditions are prevailing over the equatorial Pacific region till September. • IOD remained neutral till July and a weak negative IOD conditions are developed towards the end of the monsoon season. • Rainfall is (108% of LPA).
31st July -3rd Stage (For 2nd half of Monsoon 2025 (Aug- Sept))		Observed
<ul style="list-style-type: none"> • Neutral El Nino-Southern Oscillation (ENSO) conditions are prevailing over the equatorial Pacific region. These neutral ENSO conditions are likely to continue during remaining part of the monsoon season. • At present, neutral Indian Ocean Dipole (IOD) conditions are observed over the Indian Ocean. These neutral IOD conditions are likely to turn into weak negative IOD conditions at the end of the 		<ul style="list-style-type: none"> • Neutral El Nino-Southern Oscillation (ENSO) conditions prevailed. • A weak negative IOD conditions are developed towards the end of the monsoon season.

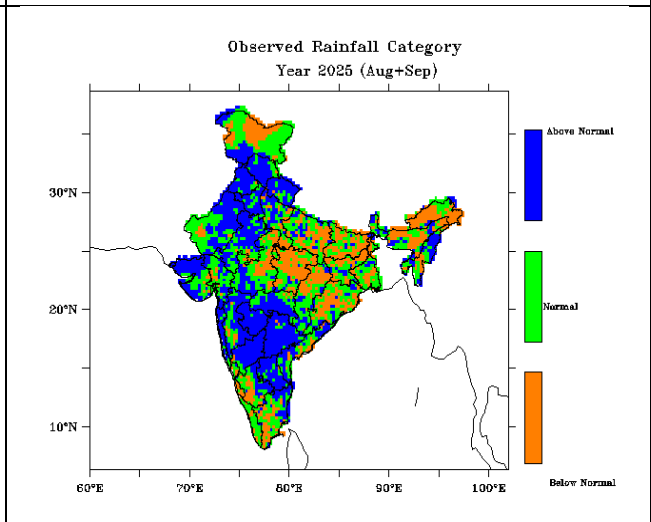
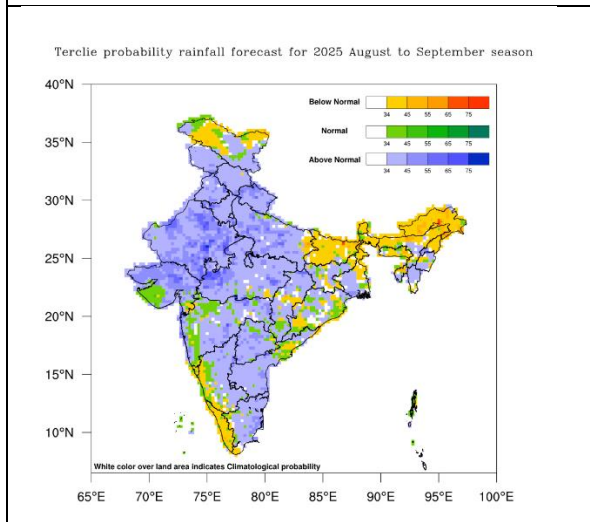
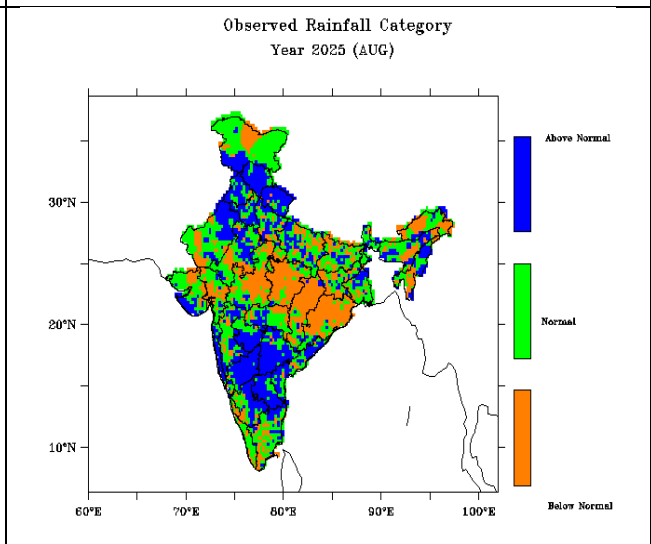
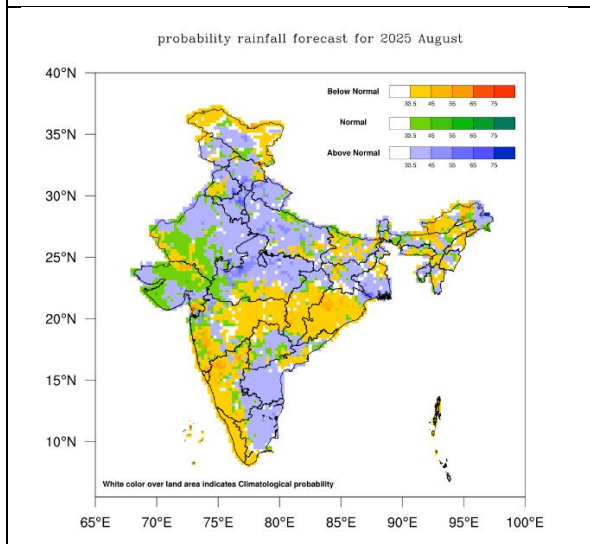
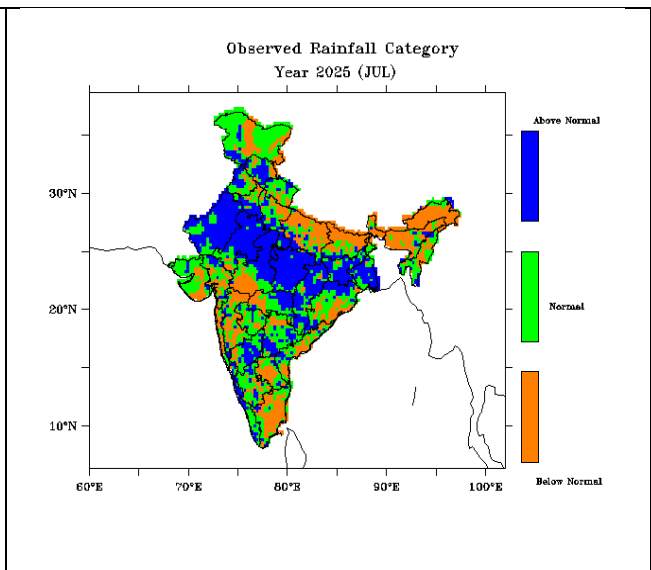
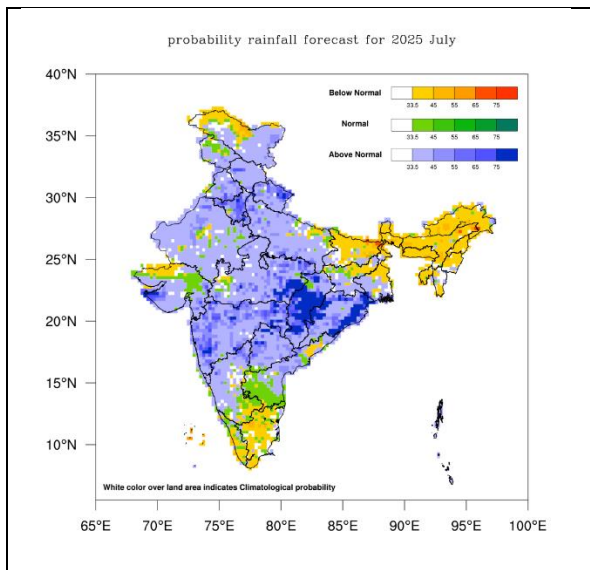
monsoon season.

- Rainfall is most likely to be above normal (>106% of LPA) for Second half of the monsoon season.

- Above normal Rainfall received for Both 1st half (106% of LPA) & second half (110% of the LPA of the monsoon season 2025).

The verification of the spatial probability rainfall forecast that was issued by IMD during the 2025 Southwest monsoon season is presented in **Fig. 13.7**.





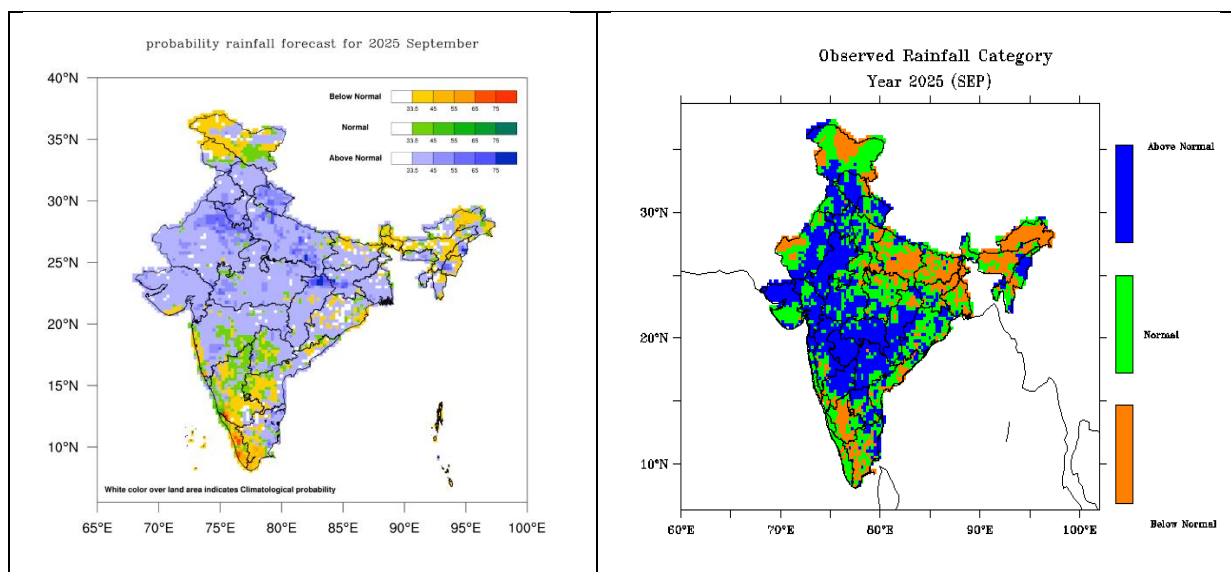


Fig. 13.7: Forecast verification of spatial seasonal and monthly probability forecast (left panel) with observed rainfall category (right panel)

Table 13.5 provides a summary of the spatial verification for each rainfall category (Above Normal, Normal, Below Normal) during both the first and second stages.

Table 13.5: Spatial verification for each rainfall category (Above Normal, Normal, Below Normal) during both the first and second stages

Verification of First stage (issued in April) Spatial Forecast (2025)						
		Observation				Correct forecast in each category (%)
		Below Normal	Near Normal	Above Normal	Total points	
Forecast	Below Normal	316	274	86	676	47%
	Normal	160	69	65	294	23%
	Above Normal	862	1366	1766	3994	44%
	Total points	1338	1709	1917	4964	

Verification of Second stage (issued in May) Spatial Forecast (2025)						
		Observation				Correct forecast in each category (%)
		Below Normal	Near Normal	Above Normal	Total points	
Forecast	Below Normal	382	250	67	699	55%
	Normal	139	106	66	311	34%
	Above Normal	817	1353	1784	3954	45%
	Total points	1338	1709	1917	4964	

13.4 Dynamical Seasonal Forecasting System

13.4.1 Monsoon Mission Coupled Forecast System (MMCFS)

The National Monsoon Mission (NMM) project was launched by the MoES in 2012 for developing a state-of-the-art dynamical prediction system for monsoon rainfall on different time scales. Climate Forecast System version 2 (CFSv2) of National Centers for Environmental Prediction (NCEP), USA was identified as the basic modeling framework for this purpose. The latest version of the high resolution (horizontal resolution of approximately 38km (T382)) MMCFS for the seasonal forecasting of monsoon rainfall was recently implemented at the Climate Research and Services, IMD, Pune and it has been used to generate the experimental forecast for southwest monsoon rainfall from 2017 onward. This high resolution MMCFS represents a significant improvement over the original version, which had a resolution of about 100 km.

The model climatology was prepared using retrospective forecasts generated for 27 years (1982-2008). The retrospective forecasts were prepared based on average of ten (10) ensemble members with different initial conditions (ICs). The model hindcasts and forecasts were bias corrected using the z-score transformation (correction for both mean and variance) method (The long period average (LPA) was calculated based on the 1961-2010 normal). The skill scores of the MMCFS model for the forecasting of seasonal rainfall over the country as a whole with different Initial conditions are given in the **Table 13.6**. The performance of the model for the period 1982-2008 is given in the **Fig. 13.8**. The seasonal forecasts from MMCFS for the 2025 southwest monsoon rainfall over the country as a

whole are also given in the **Table 13.6**. The spatial pattern of the forecast for 2025 JJAS rainfall anomaly based on April initial conditions is given in the **Fig. 13.9**. The spatial pattern of the updated forecast issued for JJAS generated with May initial conditions consisting of 21 ensemble members are given in **Fig. 13.10**. As seen in the **Table 13.4**, the forecast based on April conditions was 5% more than LPA whereas the actual JJAS rainfall was 108% of LPA. The updated forecast based on May conditions was 116% less than the LPA. This suggests that the model forecast for the 2025 southwest monsoon season over the country as a whole was correct in MMCFS using April initial condition, whereas it is overestimated and was not within forecast limits in May initial condition.

Table 13.6: Skill scores of the Monsoon Mission CFS model for the forecasting of seasonal rainfall over the country as a whole at two different initial conditions April and May, respectively. The forecast for the 2025 season rainfall over the country as a whole is given in the last column.

Initial conditions (IC) of	JJAS		Forecast for 2023 (% of LPMA)
	C.C. (1982-2008)	RMSE (mm/day) (1982-2008)	
April	0.35	1.43	105
May	0.23	1.01	116

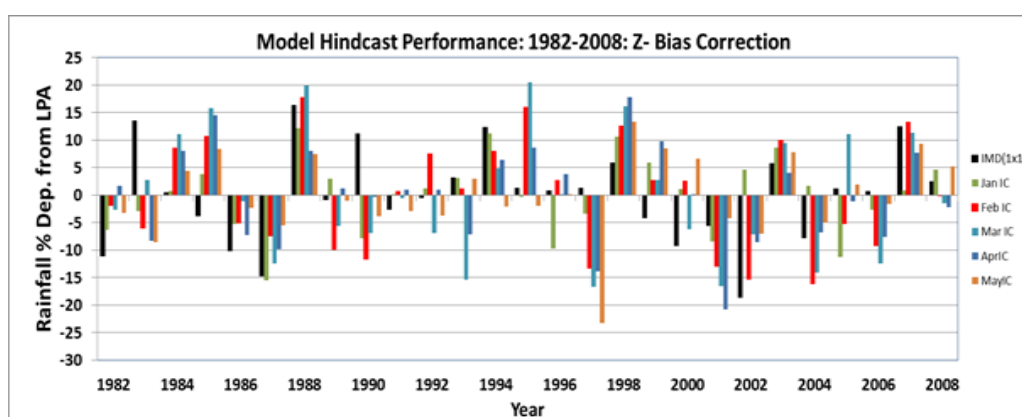


Fig. 13.8: Performance of the model hindcast for the southwest monsoon season (June-September) rainfall over the country as a whole based on various initial conditions. The model hindcasts were bias corrected using the z-score transformation (correction for both mean and variance) method.

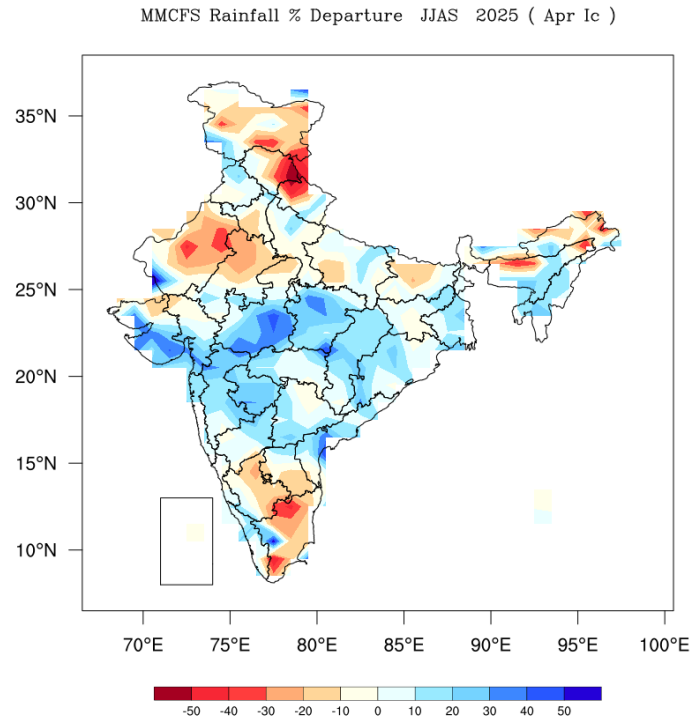


Fig. 13.9: Rainfall anomaly forecast over Indian region for the 2025 monsoon season computed from the MMCFS model based on April IC

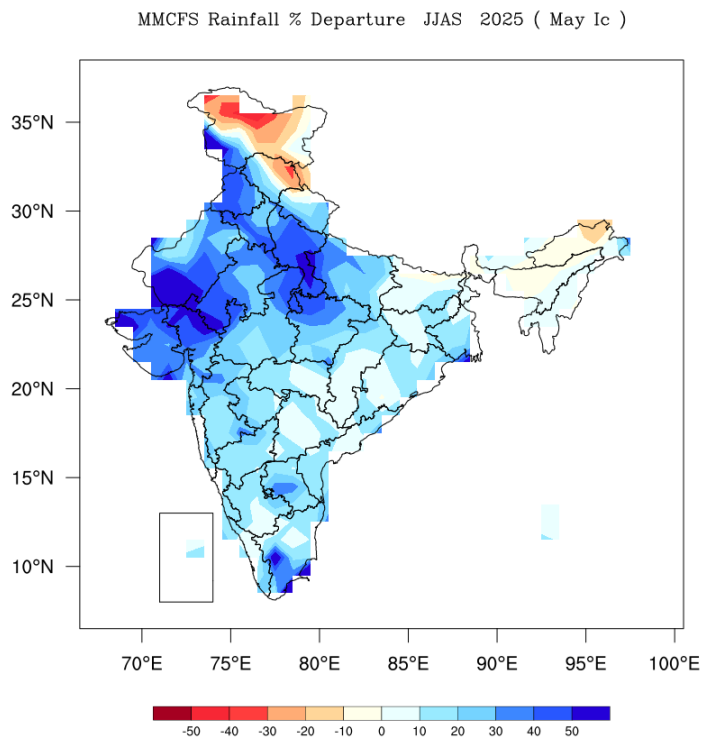


Fig. 13.10: Rainfall anomaly forecast over Indian region for the 2025 monsoon season computed from the MMCFS model based on May IC

13.5 Conclusions

The forecast for monsoon onset over Kerala for this year was correct, which is the nineteenth consecutive correct forecast for this event except the year 2015 since the commencement of this forecast in 2005. The Forecast date of onset of monsoon over Kerala was 27th May with a model error of ± 4 days and realized date of onset of monsoon over Kerala was 24th May.

The first stage forecast for the season (June-September) rainfall over the country as a whole issued in April was 105% of LPA with a model error of $\pm 5\%$ of LPA and the update forecast issued in the end of May 2025 was 106% of LPA with a model error of $\pm 4\%$ of LPA. The actual season rainfall for the country as a whole was 108% of LPA. Thus, the seasonal rainfall forecast for the country as a whole was correct.

Considering the four broad geographical regions of India, the forecasts issued on 27th May, the southwest monsoon seasonal (June to September 2025) rainfall is most likely to be above-normal over Central India and South Peninsular India ($>106\%$ of LPA), above normal over Northwest India ($>108\%$ of LPA) and below normal over Northeast India ($<94\%$ of LPA). The southwest monsoon seasonal rainfall over the monsoon core zone consisting of most of the rainfed agriculture areas in the country was most likely to be above Normal ($>106\%$ of LPA). The actual rainfall over Northwest India, Central India, Northeast India, South Peninsula and Monsoon Core Zone were 27%, 15%, -20%, 10% and 22% of the LPA, respectively. The seasonal forecast issued for homogeneous regions during the season was within the range of the forecast limit except the Northwest India. All the monthly outlooks were within the forecast limit, except the July. The forecast for the second half of the monsoon season (August –September) for the country as a whole also was in the forecast limit.

This year, Monsoon Mission Climate Forecast System (MMCFS) as well as other climate model forecasts correctly indicate that the Neutral ENSO condition are likely to continue during the monsoon season and a weak negative IOD conditions are likely to develop during the southwest monsoon season. However, La Niña-like conditions in atmosphere helps to get good monsoon rainfall over most of the Indian region except NE India. Large Intra-seasonal variation was also observed during the 2025 SW monsoon season rainfall. However, the Monthly rainfall outlook correctly indicates these variations. The favorable Madden–Julian Oscillation (MJO) activity during the July and August also helps to get good rainfall during the season. In summary, the 2025 monsoon season was marked by La Niña-like large-scale atmospheric circulation patterns and significant modulation of intraseasonal convective variability over the Indian region by the Madden–Julian Oscillation (MJO).

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14



THUNDERSTORM EVENTS DURING SUMMER MONSOON SEASON OF 2025

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This chapter discusses the performance of operational short-term forecasts and nowcast issued by India Meteorological Department (IMD) for thunderstorm events during the 2025 southwest monsoon season.

14.1 Introduction

The Indian summer monsoon season (June–September) is the principal rainy season over much of the Indian subcontinent and contributes nearly 75–80% of the annual rainfall over India. The majority of monsoon rainfall is associated with Mesoscale Convective Systems (MCSs), which are organized cloud systems characterized by large horizontal scales (of the order of several hundred kilometers) and long lifetimes (typically 6–12 hours or more). These systems generally consist of intense convective cores embedded within broader regions of stratiform cloud and precipitation (Houze et al., 2007; Sen Roy et al., 2015).

However, the relative contributions of convective and stratiform rainfall exhibit substantial intraseasonal variability within the monsoon season. During the transition toward active monsoon conditions, the fraction of convective cloudiness generally increases first, followed by an increase in the stratiform fraction after a lag of about 1–2 days, suggesting the progressive organization and maturation of convective cloud systems over the region. In contrast, the evolution toward break monsoon conditions is often associated with negative

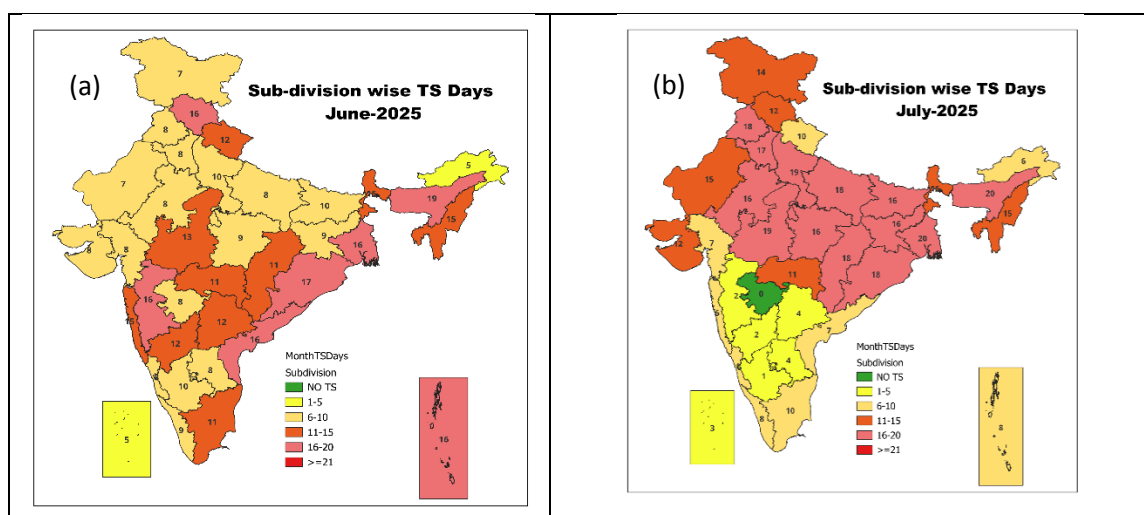
anomalies in both convective and stratiform cloud fractions, which tend to occur more in phase, indicating a weakening of organized deep convection over the monsoon trough region. These variations are linked to changes in large-scale circulation, thermodynamic structure, and regional heating patterns that modulate cloud organization and rainfall characteristics (Rajeevan et al., 2013; Saha et al., 2014).

Thunderstorms embedded within the monsoon environment are also accompanied by lightning activity, which poses a serious hazard to life and property across India. Lightning-related fatalities in India are estimated to be of the order of ~2,000 deaths per year, although the impacts vary considerably across regions and seasons (Nag et al., 2017; Yadava et al., 2020).

The pronounced intraseasonal variability in thunderstorm structure, organization, and associated hazards during the monsoon season presents a major challenge for operational weather forecasting across timescales ranging from nowcasting to subseasonal prediction. Improved understanding of the evolving balance between convective and stratiform processes is therefore essential for better prediction of rainfall intensity, thunderstorm organization, and lightning occurrence over the Indian monsoon region.

14.2 Models Used

The reports of Thunderstorm occurrence are available from a network of 141 full time observatories of IMD. **Figure 14.1 (a) to (d)** display the state wise monthly frequency of thunderstorm days from this network. As may be noted, the thunderstorm frequency was high in all months over east India. Frequency was less over west peninsular India. This may partly be on account of fewer full time observatories over the interior parts of western India, compared to the scale of the thunderstorms.



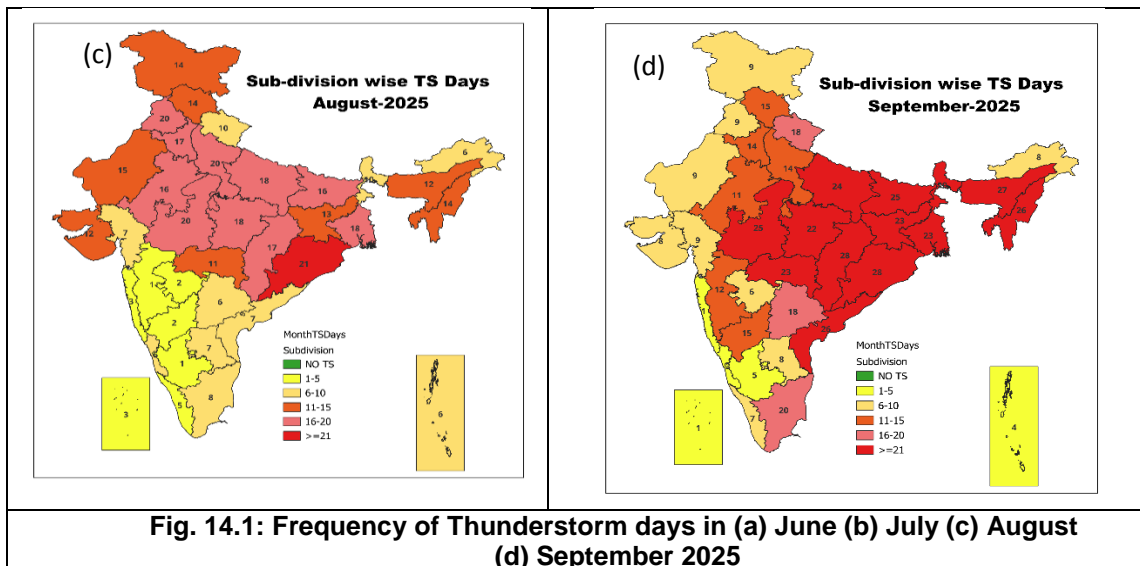


Fig. 14.1: Frequency of Thunderstorm days in (a) June (b) July (c) August (d) September 2025

However, the mesoscale nature of the events as well as their damage potential in terms of lightning is not adequately captured by the data. The lightning dataset from the IITM network comprising 118 sensors all over India is an important source of this information in this respect. **Figure 14.2 (a) to (d)** displays the district wise monthly statistics of Total lightning from this network. As may be noted from the figure the lightning flash density was highest over Rajasthan and Gujarat during June 2025, similar trend continue to July and August 25 as well, top Lightning count associated districts are in Rajasthan. In September the trend changes and Max Lightning count observed districts over Gujarat, Maharashtra, West Bengal, Chhattisgarh and Himachal Pradesh as well. In July and August lightning flash density increased over parts of east India and Maharashtra but continued to be high over Rajasthan. By September, lightning flash density decreased over the entire country, with relatively higher flash density over Gujarat and Maharashtra. However, the district wise count does not give the full picture of the vulnerability associated with lightning.

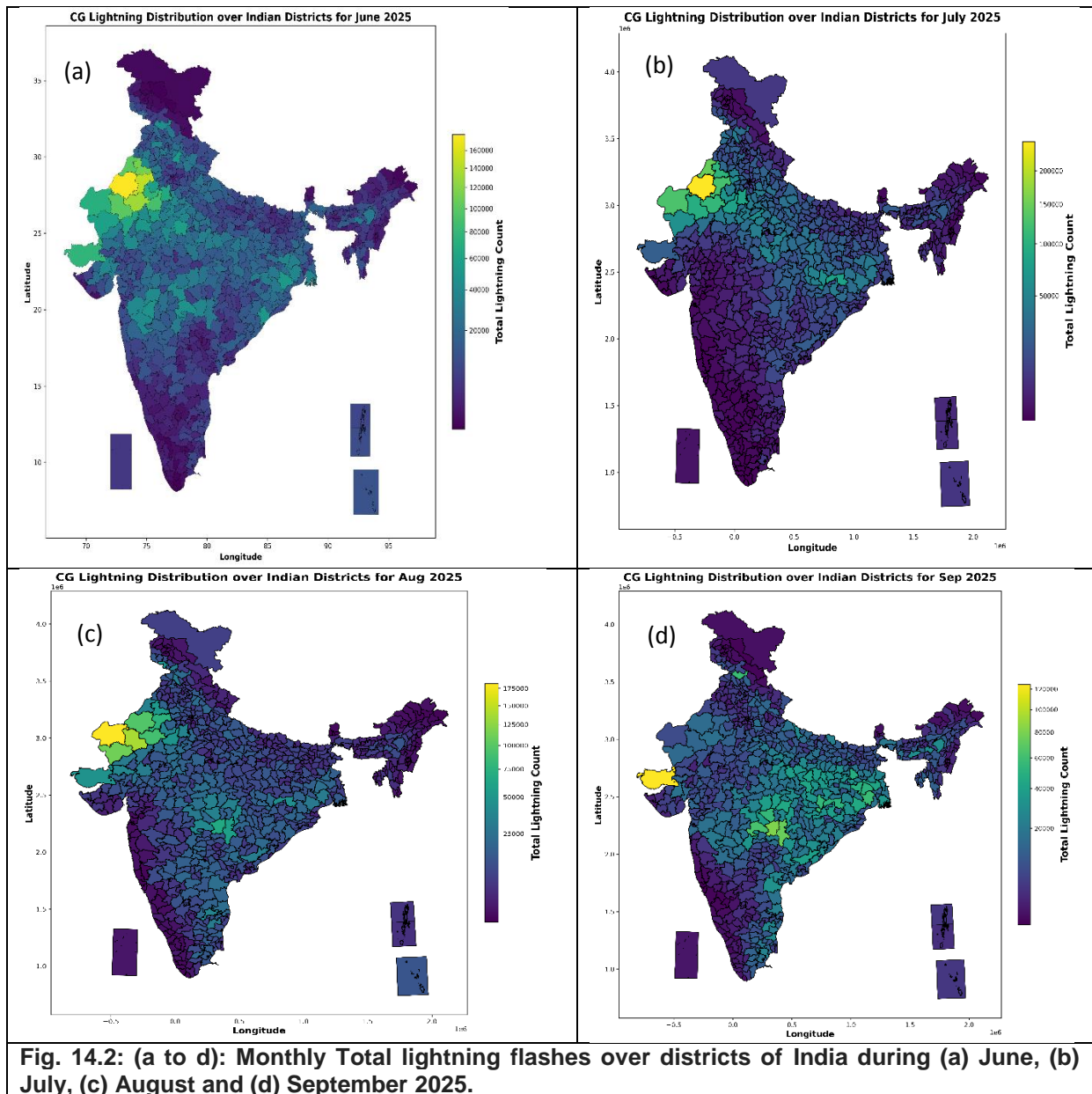


Fig. 14.2: (a to d): Monthly Total lightning flashes over districts of India during (a) June, (b) July, (c) August and (d) September 2025.

Table 14.1 lists the top ten districts throughout India in terms of total lightning count during June, July, August and September 2025. As may be noted, the district of west India (Rajasthan & Gujarat) had the highest lightning flash count in June. In July and August, lightning flash count was highest over districts in Rajasthan Odisha and Maharashtra, while in September the highest flash count districts were spread out throughout east, central, North and west India. On a seasonal scale, districts of Rajasthan generally reported the highest flash count during the season.

Table 14.1: Top ten districts in terms of total lightning flash count during June, July, August and September 2025.

	Name Of Districts	State	Total Lightning Count	Area Avg Lightning Density
June	BIKANER	RAJASTHAN	178637	5.82
	CHURU	RAJASTHAN	146414	10.45
	NAGOUR	RAJASTHAN	131076	7.28
	HANUMANGARH	RAJASTHAN	111816	11.41
	GANGANAGAR	RAJASTHAN	100962	9.14
	JODHPUR	RAJASTHAN	99722	4.32
	JAIPUR	RAJASTHAN	88807	7.92
	KACHCHH	GUJARAT	76642	1.85
	SIKAR	RAJASTHAN	75370	9.69
	JAISELMER	RAJASTHAN	71977	1.82
July	BIKANER	RAJASTHAN	249199	8.11
	GANGANAGAR	RAJASTHAN	146240	13.24
	JAISELMER	RAJASTHAN	128509	3.26
	CHURU	RAJASTHAN	124562	8.89
	NAGOUR	RAJASTHAN	109324	6.07
	HANUMANGARH	RAJASTHAN	104855	10.70
	JODHPUR	RAJASTHAN	96999	4.20
	ALWAR	RAJASTHAN	83593	9.91
	SUNDARGARH	ODISHA	80849	8.27
	JAIPUR	RAJASTHAN	80285	7.16
August	JAISELMER	RAJASTHAN	182105	4.62
	JODHPUR	RAJASTHAN	137682	5.97
	BARMER	RAJASTHAN	111902	3.85
	BIKANER	RAJASTHAN	97017	3.16
	NAGOUR	RAJASTHAN	89291	4.96
	CHURU	RAJASTHAN	75167	5.36
	CHANDRAPUR	MAHARASHTRA	66058	5.81
	GADCHIROLI	MAHARASHTRA	56990	3.92
	HANUMANGARH	RAJASTHAN	51589	5.26
	JAIPUR	RAJASTHAN	48625	4.33
September	KACHCHH	GUJARAT	124562	3.00
	CHANDRAPUR	MAHARASHTRA	81060	7.13
	GADCHIROLI	MAHARASHTRA	73766	5.07
	YAVATMAL	MAHARASHTRA	62393	4.58
	KANGRA	HIMACHAL PRADESH	57733	10.01
	PASHCHIM MEDINIPUR	WEST BENGAL	57632	6.09
	NAGPUR	MAHARASHTRA	55469	5.60
	RAIGARH	CHHATTISGARH	55122	7.82
	BANKURA	WEST BENGAL	51464	7.40
	SUNDARGARH	ODISHA	51217	5.24

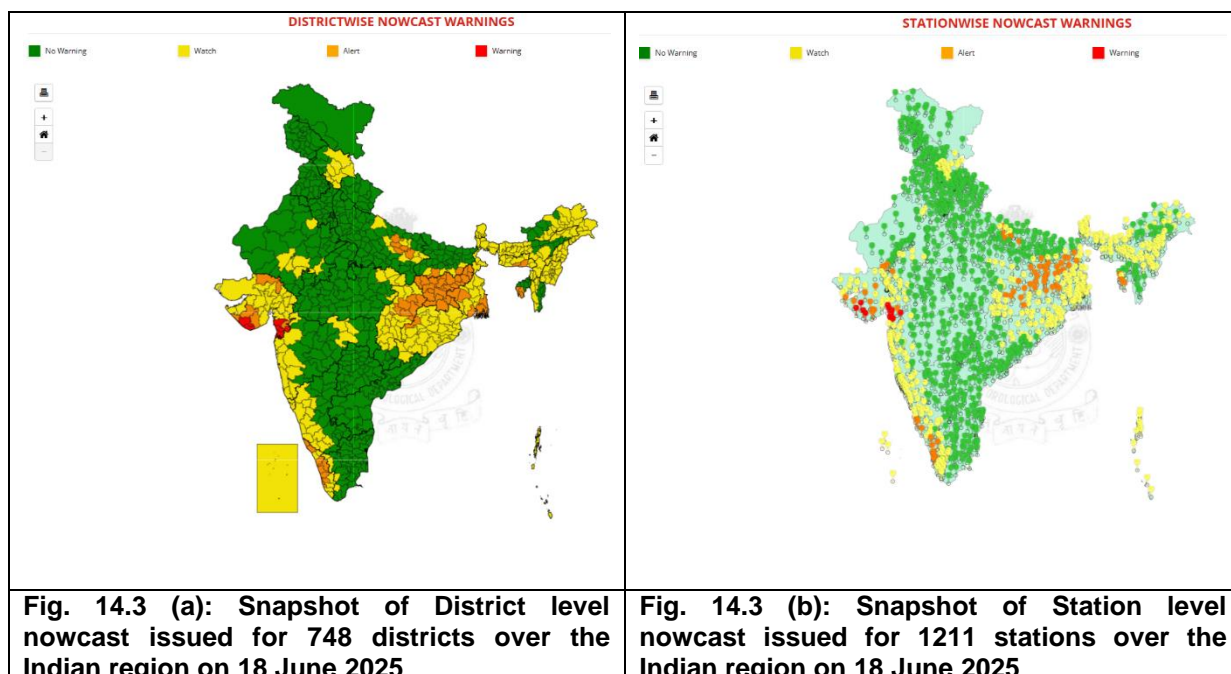
14.3 Nowcasting Strategy for the Indian region

Since 2018, IMD issues district level nowcasts severe weather round the clock at three hour intervals for all the 748 districts of India. Nowcasts are also issued for important cities or towns which may be district headquarters or places important for tourism or commercial importance. Currently nowcasts are issued for 1211 stations around the country. Nowcasts are issued every three hours round the clock throughout the year by Meteorological Centres throughout the country. These nowcasts are displayed on an interactive map on the IMD website for district level nowcasts at (https://mausam.imd.gov.in/imd_latest/contents/districtwisewarnings.php) and for station level nowcasts at (https://mausam.imd.gov.in/imd_latest/contents/stationwise-nowcast-warning.php). The impact expected due to the severe weather has also been added to the nowcast warnings in terms of colour codes following WMO Technical Note, 2015 (WMO, 2015) and National Disaster Management Authority (NDMA) guidelines (<https://ndma.gov.in/images/pdf/Draft-Guidelines-thunderstorm.pdf>) as follows:

- i) **Green colour** (No severe weather)
- ii) **Yellow colour** (Light rain: < 5 mm/hr, Light snow < 5cm/hr, Light Thunderstorms with maximum surface wind speed up to 40 kmph, Slight dust storm with wind speed up to 40 kmph and visibility is less than 1,000 metres but more than 500 meters due to dust, Low (< 30%) probability of cloud to ground lightning occurrence.

i) No weather
ii) Light rain: < 5 mm/hr
iii) Light snow < 5cm/hr
iv) Light Thunderstorms with maximum surface wind speed upto 40 kmph
v) Slight dust storm: If the wind speed is up to 40 kmph and visibility is less than 1,000 metres but more than 500 meters due to dust
vi) Low cloud to ground Lightning probability (< 30% probability of lightning occurrence)
vii) Moderate rain: 5-15 mm/hr
viii) Moderate snow: 5-15 cm/hr
ix) Moderate Thunderstorms with maximum surface wind speed between 41 – 61 kmph (In gusts).

x) Moderate dust storm: If the wind speed is between 41- 61 kmph and visibility is between 200 and 500 metres due to dust
xi) Moderate cloud to ground Lightning probability (30 - 60% probability of lightning occurrence)
xii) Heavy rain: >15 mm/hr
xiii) Heavy snow: >15 cm/hr
xiv) Severe Thunderstorms with maximum surface wind speed between 62 -87 kmph (In gusts).
xv) Very Severe Thunderstorms with maximum surface wind speed > 87 kmph (In gusts).
xvi) Thunderstorms with Hail
xvii) Severe dust storm: If surface wind speed (in gusts) exceeding 61 kmph and visibility is less than 200 metres due to dust
xviii) High cloud to ground Lightning probability (> 60% probability of lightning occurrence)
xix) Other warnings (to be filled by the user MC)
Table 14.2: Nowcast Warning categories on IMD website



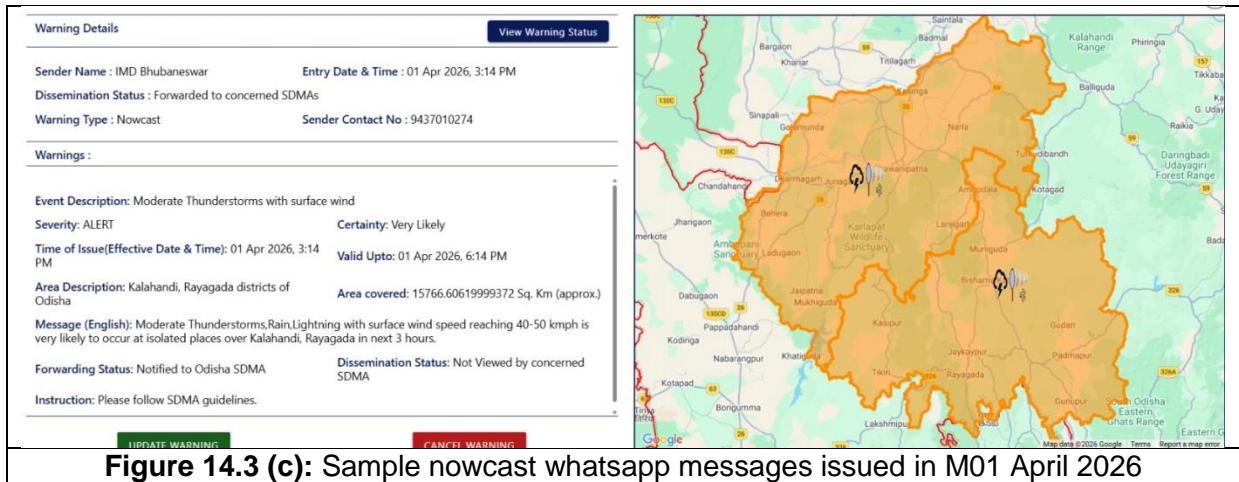


Figure 14.3 (c): Sample nowcast whatsapp messages issued in M01 April 2026

iii) **Orange colour** (Moderate rain: 5-15 mm/hr, Moderate snow: 5-15 cm/hr, Moderate Thunderstorms with maximum surface wind speed between 41 – 61 kmph (In gusts), Moderate dust storm with wind speed between 41- 61 kmph and visibility between 200 and 500 metres due to dust, Moderate (30 – 60%) probability of cloud to ground lightning occurrence)

iv) **Red colour** (Heavy rain: >15 mm/hr, Heavy snow: >15 cm/hr , Severe Thunderstorms with maximum surface wind speed between 62 -87 kmph (In gusts), Very Severe Thunderstorms with maximum surface wind speed > 87 kmph (In gusts), Thunderstorms with Hail, Severe dust storm with surface wind speed (in gusts) exceeding 61 kmph and visibility is less than 200 meters due to dust /High (> 60%) probability of cloud to ground lightning occurrence).

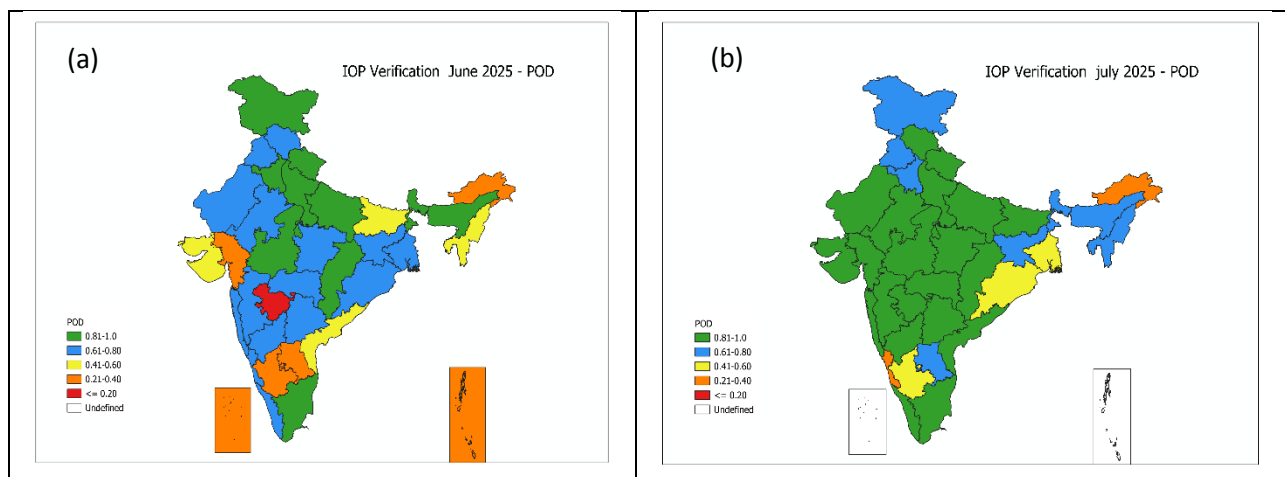
The colour coded warnings are given in **Table 14.2. Figure 14.2 (a) and (b)** display the stationwise and districtwise nowcast warnings for the Indian region.

When severe weather is expected, for maximum effectiveness of the warning, detailed SMS/Whatsapp messages and e-mails are issued to district collectors, State Disaster Management Authorities and local administration of the district concerned apart from print and electronic media. **Figure 14.3 (c)** displays some sample nowcast message generated by IMD Bhubaneswar office and disseminated through Common Alert Protocol and displayed in the SACHET portal issued during April 2026.

14.4 Verification of 24 hour IOP forecasts and 3 hourly Nowcasts of thunderstorms:

Thunderstorm reports from Class I observatories of IMD (about 148 stations all over India with round the clock observations), some Class II and Class III observatories that regularly report thunderstorm information, as well as observatories of the Indian Air Force are used as the observation dataset for verifying nowcasts. This total number limits realtime

and near real-time thunderstorm reports to less than 150 stations all over India. For verification purposes, a yes-no criterion (2x2 contingency table) is applied for occurrence-non-occurrence of thunderstorms. When a thunderstorm report is obtained for a station within the three hour period for which thunderstorms are nowcast to occur, it is taken as a yes-yes. Similarly the other categories of the contingency table are scored depending upon the occurrence and forecast for thunderstorms over the station. This data is used to compute various categorical skill scores in terms of (a) Probability of detection (POD) which measures the success of the forecast in correctly predicting the occurrence of thunderstorm, (b) False Alarm Ratio (FAR) which measures the number of false alarms per total number of thunderstorm predictions. (c) Critical Success Index (CSI) which is defined as the ratio of the number of hits (correct thunderstorm forecasts) to the number of events which occurred plus the number of false alarms. (d) Equitable Threat Score (ETS) which is a modification to the CSI, takes into account the number of correct forecasts of events (hits) that would be expected purely due to chance. The CSI is somewhat sensitive to the climatology of the event, tending to give poorer scores for rare events. It should be used in combination with other contingency table statistics (e.g., POD, FAR). The ETS is often used in the verification because its “equitability” allows scores to be compared more fairly across different regimes. However, it is not truly equitable. It is sensitive to hits and does not distinguish the source of forecast error and penalizes both misses and false alarms in the same way and is better for rare events.



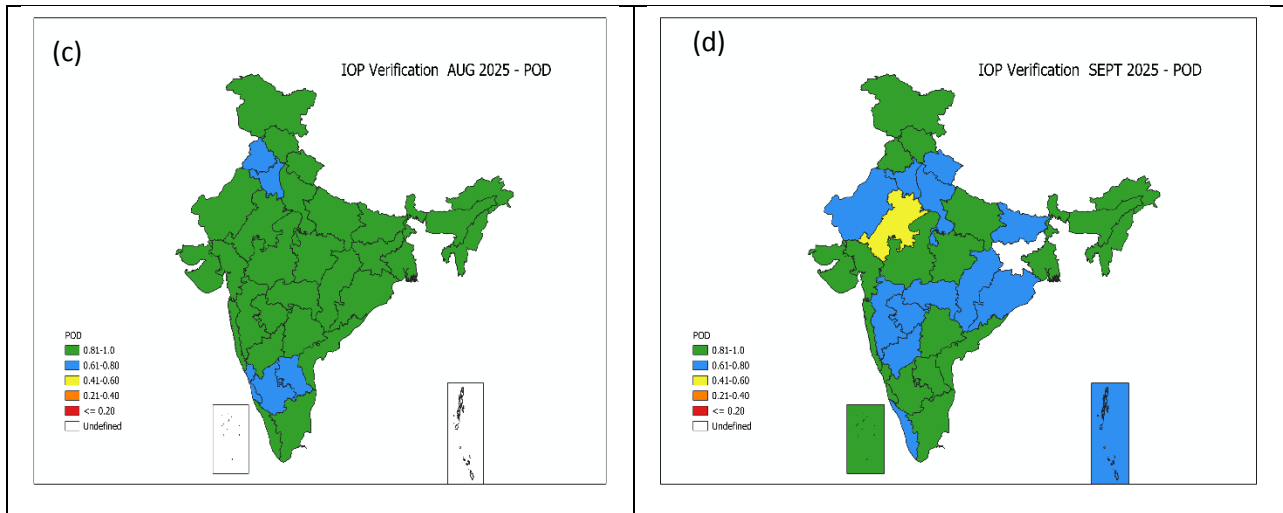


Fig. 14.4: Probability of Detection (POD) score for 24 hour Thunderstorm IOP forecast in (a) June (b) July (c) August (d) September 2025.

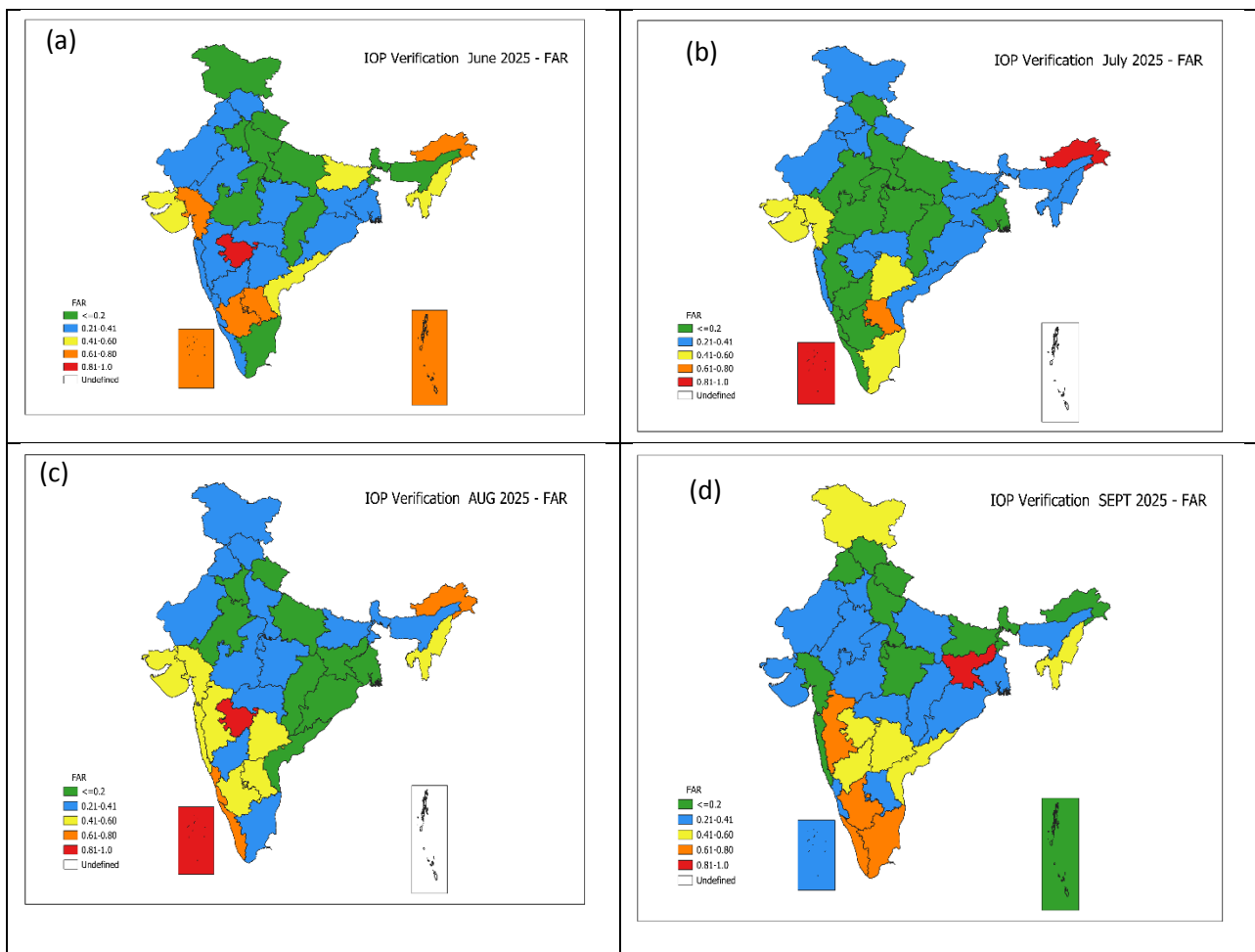
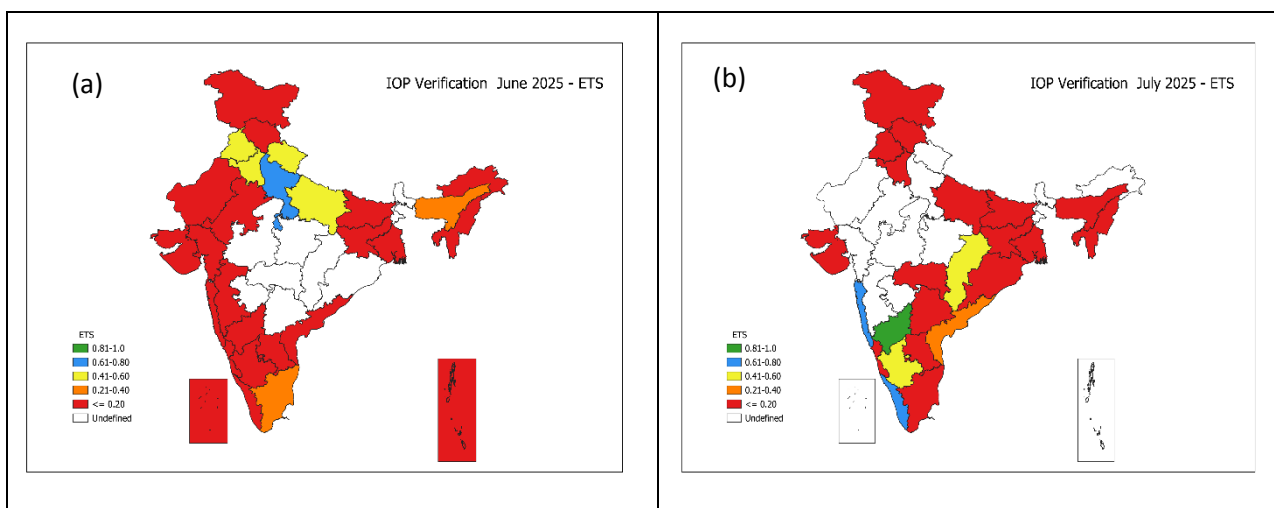
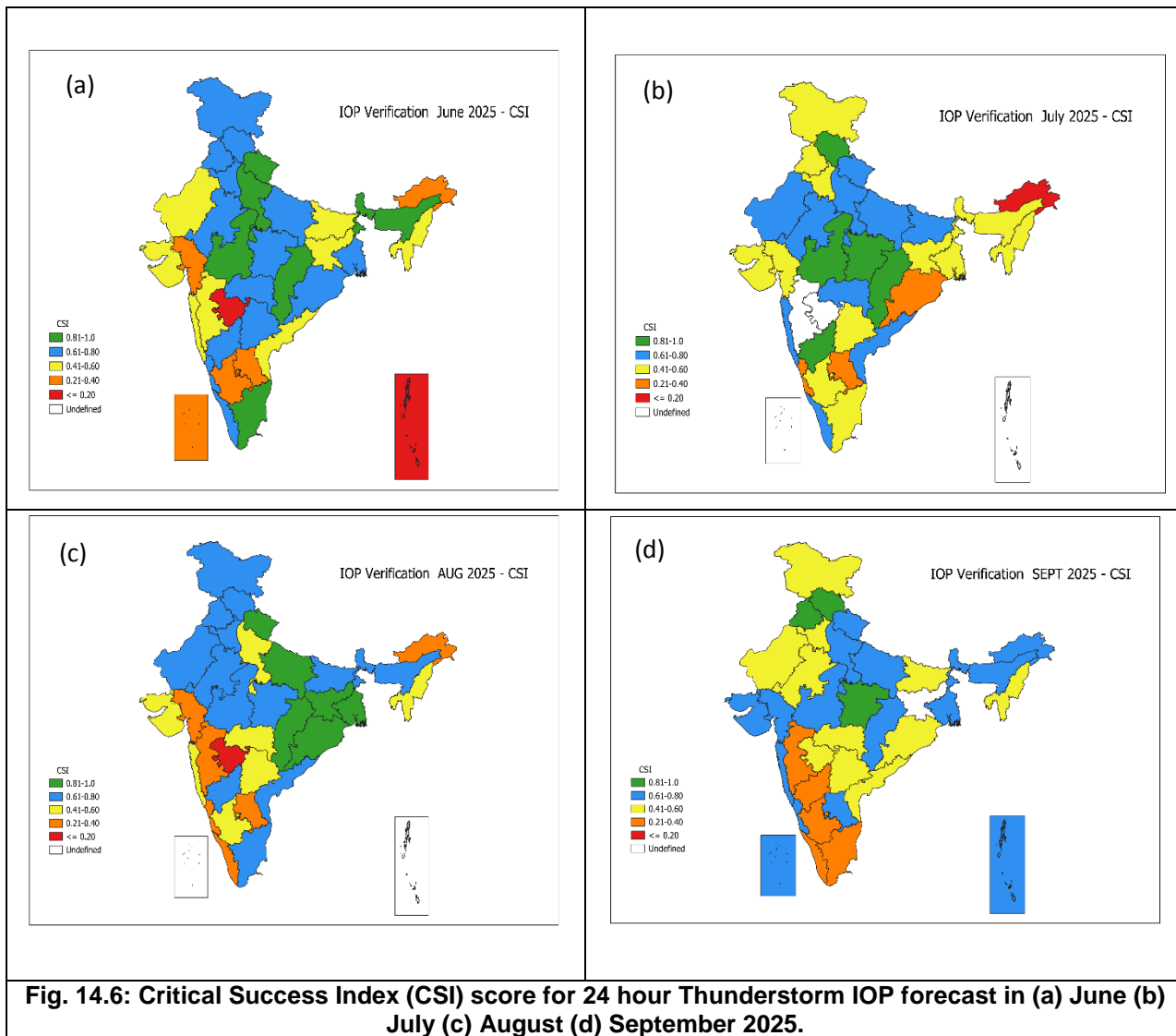
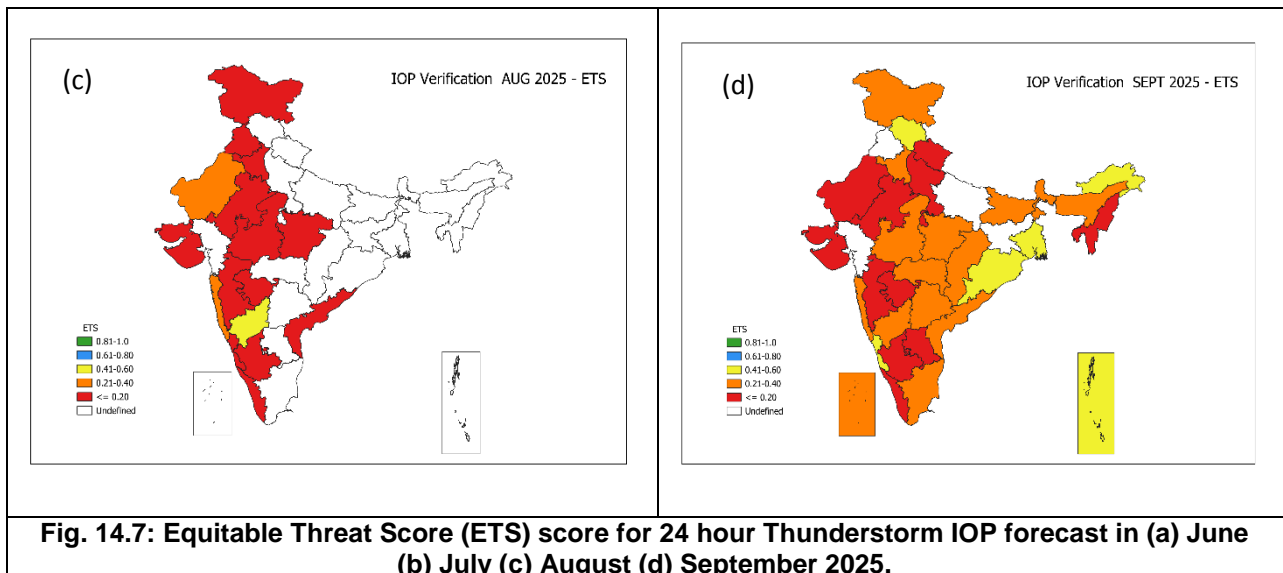


Fig. 14.5: False Alarm Ratio (FAR) score for 24 hour Thunderstorm IOP forecast in (a) June (b) July (c) August (d) September 2025.





For a good forecast, the FAR should approach zero and the rest of the variables should approach unity. In the present study, forecasts at two time scales have been verified. The 24 hour IOP for thunderstorm occurrence has been verified at the subdivision scale and spatial results are displayed in **Figure 14.4 (a to d)** to **Figure 14.7 (a to d)**. As may be noted the POD score (**Figure 14.4 a**) was high for all subdivisions in July and August. The score is comparatively poor over few met-subdivision during June, July and September, especially Marathwada, South Interior Karnataka (SIK), Rayalaseema, Lakshadweep, Gujarat, Arunachal Pradesh, Andaman & Nicobar Island in June and Arunachal Pradesh, Coastal Karnataka (CK), SIK, Odisha, Gangetic West Bengal (GWB), during July, and East Rajasthan during September. FAR follows a similar trend, with one difference. FAR score is poor over west and west peninsular India and northeast India from June to September, with better performance during June and July (**Figure 14.5 a to d**). The CSI (**Figure 14.6 a to d**) and ETS score (**Figure 14.7 a to d**), which provide a measure of accuracy taking both POD and FAR scores, indicates similar pattern, with higher and better scores over north, east and east peninsular India in all months compared to the west, west peninsular and northeast India. Incidentally, the poorer scores were over the same region where the frequency of thunderstorm days was less- according to the observatory data. Hence as discussed earlier, the accuracy may be a problem with observations rather than lack of expertise of forecasters. The scores varies month to month, specifically over South peninsular India the FAR increases during September and comparatively better during June, July & August. **Figure 14.8 a to d** display all India monsoon season verification scores for 24 hour thunderstorm forecast IOP and their comparison with previous years 2022 to 2025. The monthly scale all India forecast verification scores are similar to the spatial pattern discussed earlier. Compare to the last year, POD & ETS over the season

increases for 24 hour IOP verification over India by 01 percent, FAR decreases & CSI value increases by 2 percent.

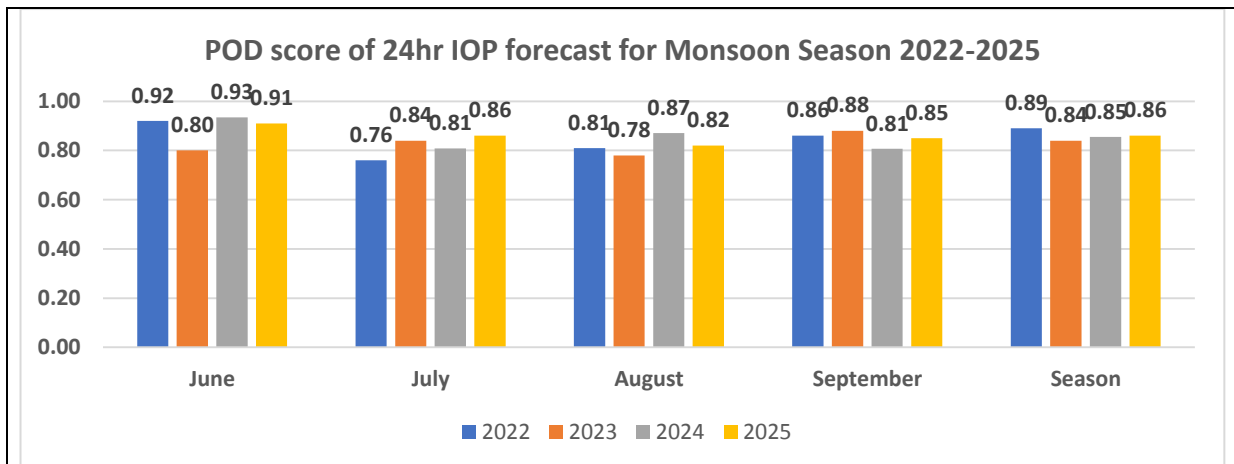


Fig. 14.8 (a): Comparison of POD score of 24 hour IOP forecasts for Monsoon 2022-2025

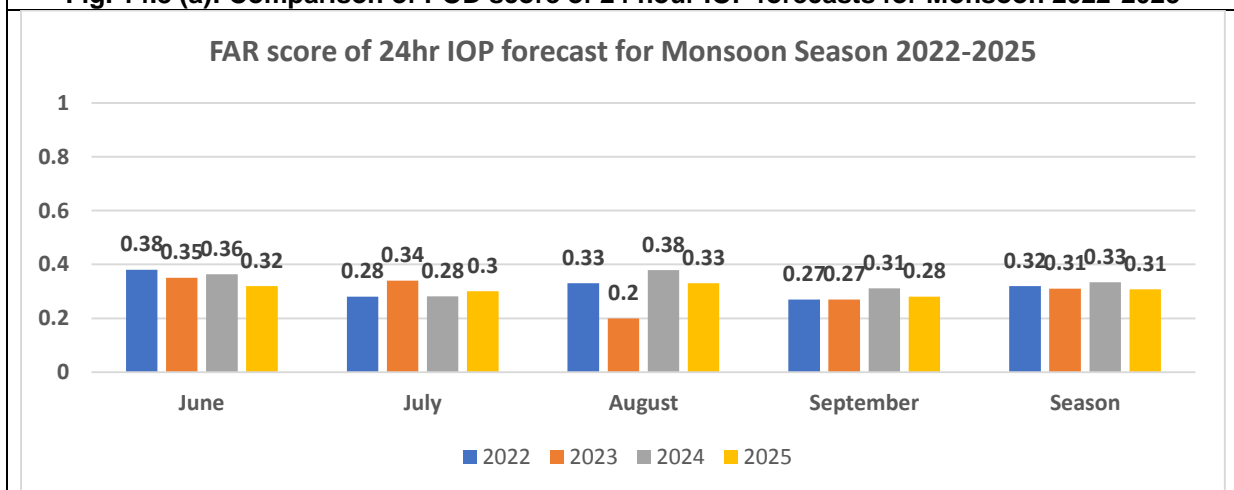


Fig. 14.8 (b): Comparison of FAR score of 24 hour IOP forecasts for Monsoon 2022-2025

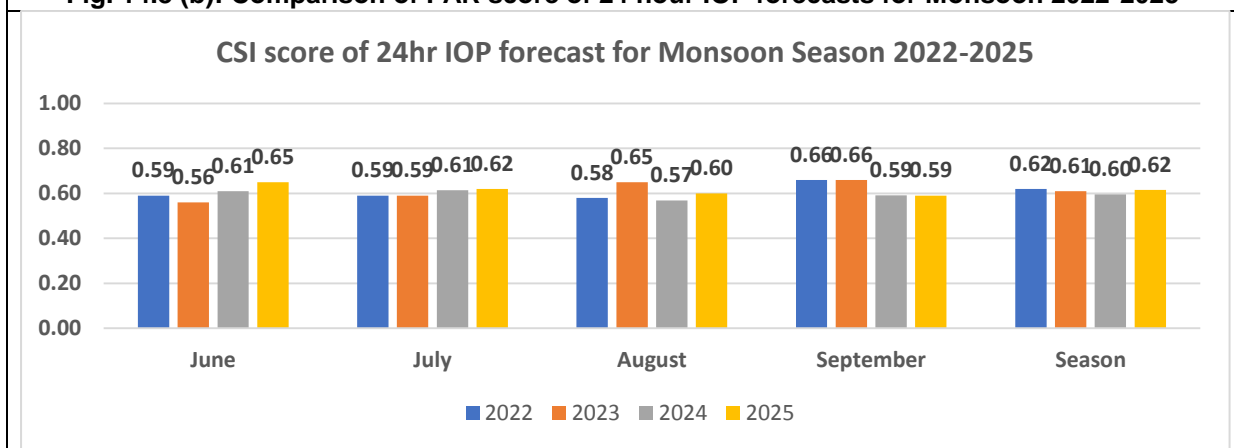


Fig. 14.8 (c): Comparison of CSI score of 24 hour IOP forecasts for Monsoon 2022-2025

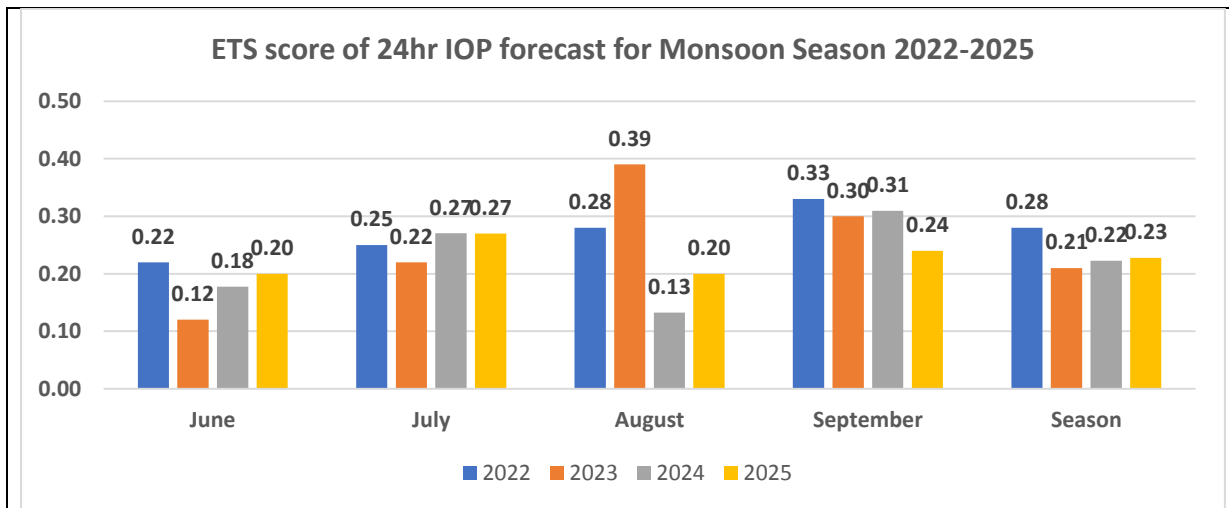


Fig. 14.8 (d): Comparison of ETS score of 24 hour IOP forecasts for Monsoon 2022-2025

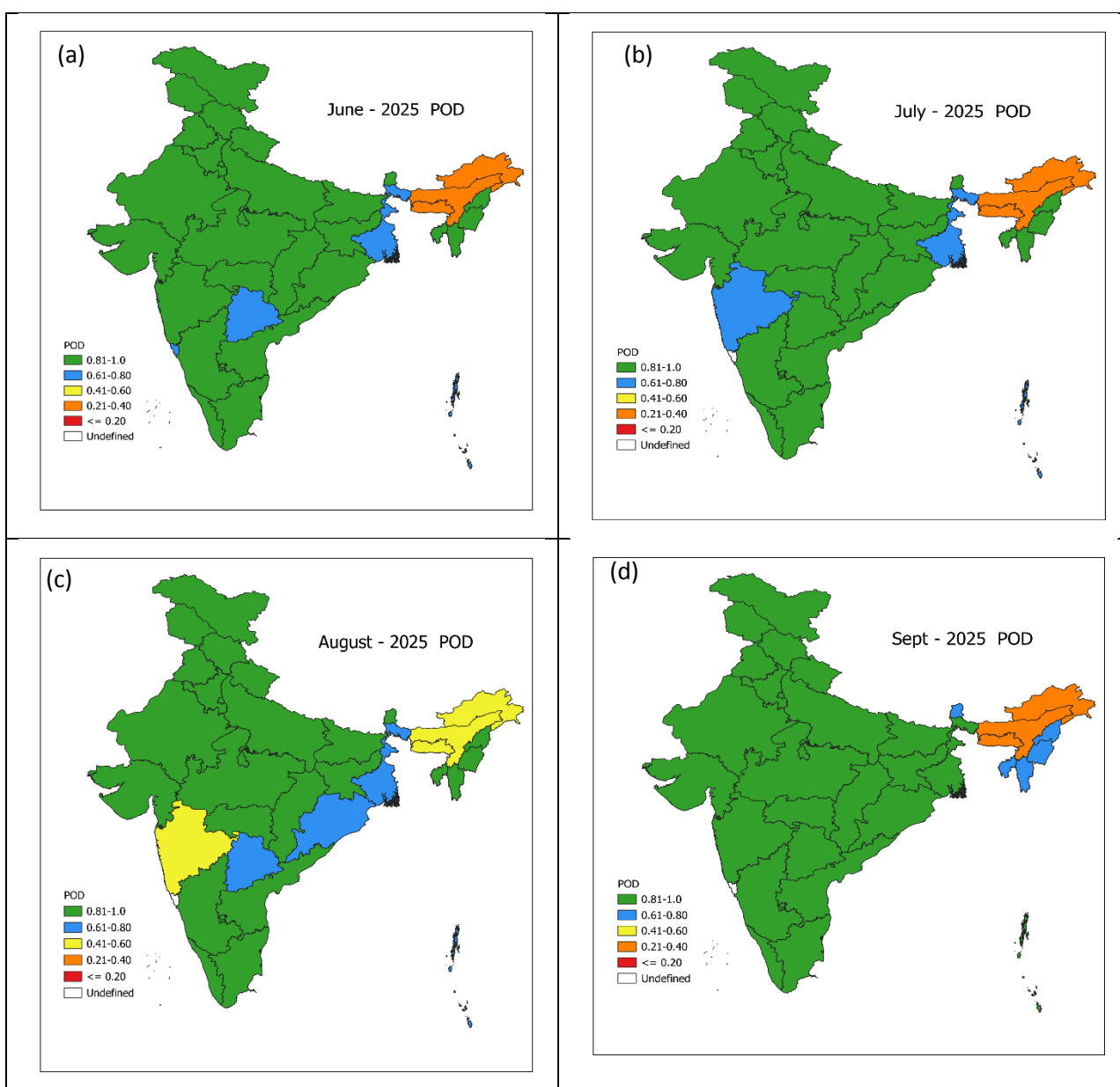


Fig. 14.9: Probability of Detection (POD) score for 3 hour Thunderstorm nowcast in (a) June (b) July (c) August (d) September

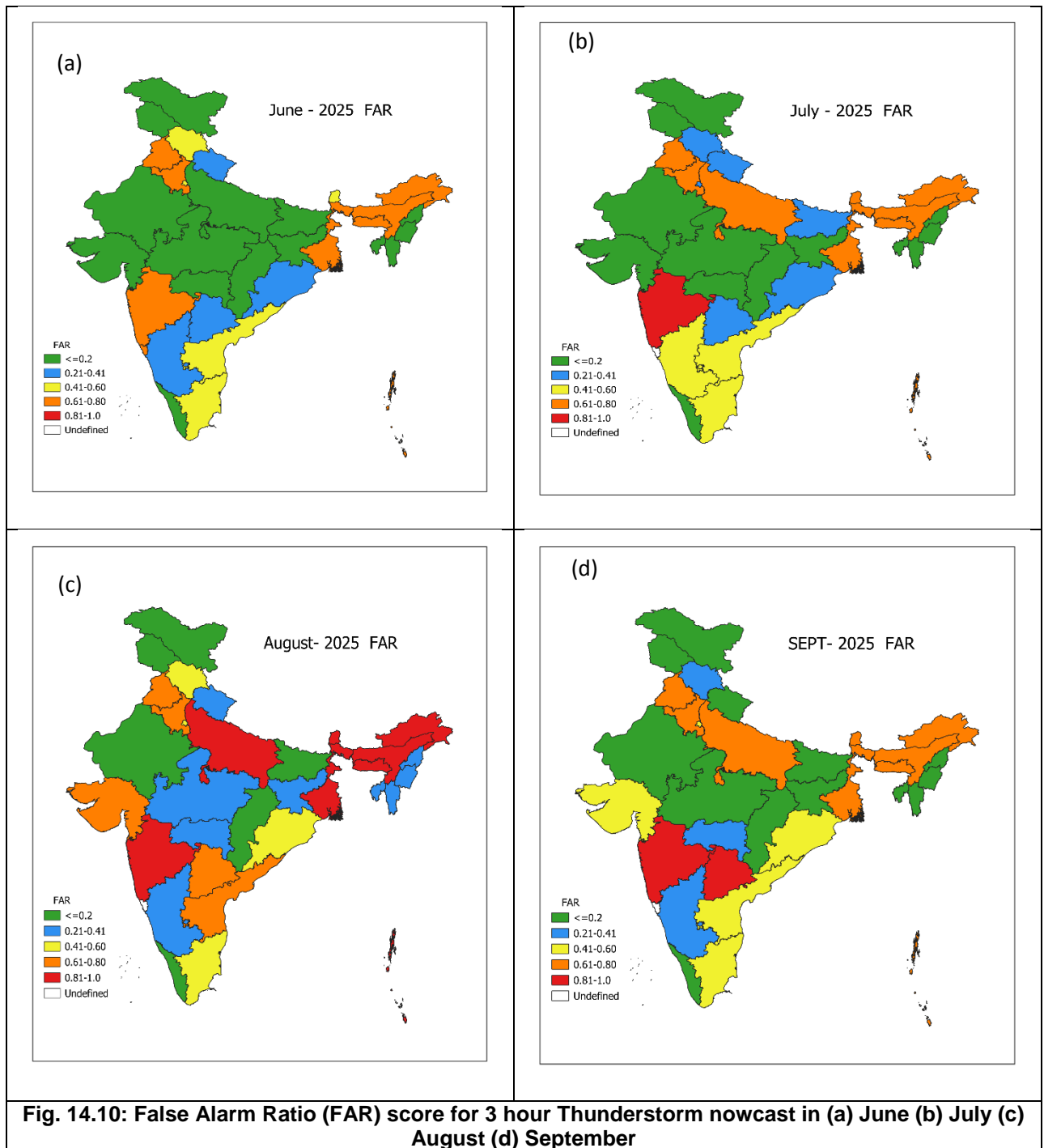


Fig. 14.10: False Alarm Ratio (FAR) score for 3 hour Thunderstorm nowcast in (a) June (b) July (c) August (d) September

Figure 14.9 (a to d) to Figure 14.12 (a to d) display state-wise verification scores of three hourly nowcasts. Unlike the 24 hour IOP forecasts, the POD of 3 hourly nowcasts (Figure 14.9 a to d) for thunderstorms score significantly well over most parts of the country except the Northern Eastern Part of India. The False Alarm Ratio FAR score (Figure 14.10 a to d) was better over west India (Rajasthan and Madhya Pradesh, Chhattisgarh, Jammu & Kashmir and Kerala) compared to the remaining parts of the country. There was no significant change in the score as the season progressed, but over peninsular India from June to September FAR alarm ratios are significant. The CSI and

ETS scores (**Figure 14.11 and 14.12 a to d**) follow a pattern similar to the FAR, with high accuracy over West India, Madhya Pradesh, Jammu and Kashmir, Bihar & Kerala (in the range of 0.8-1.0) and poorer scores over the remaining parts of the country. As the season progressed, scores improved or maintain similar scores over east India – like GWB, Odisha.

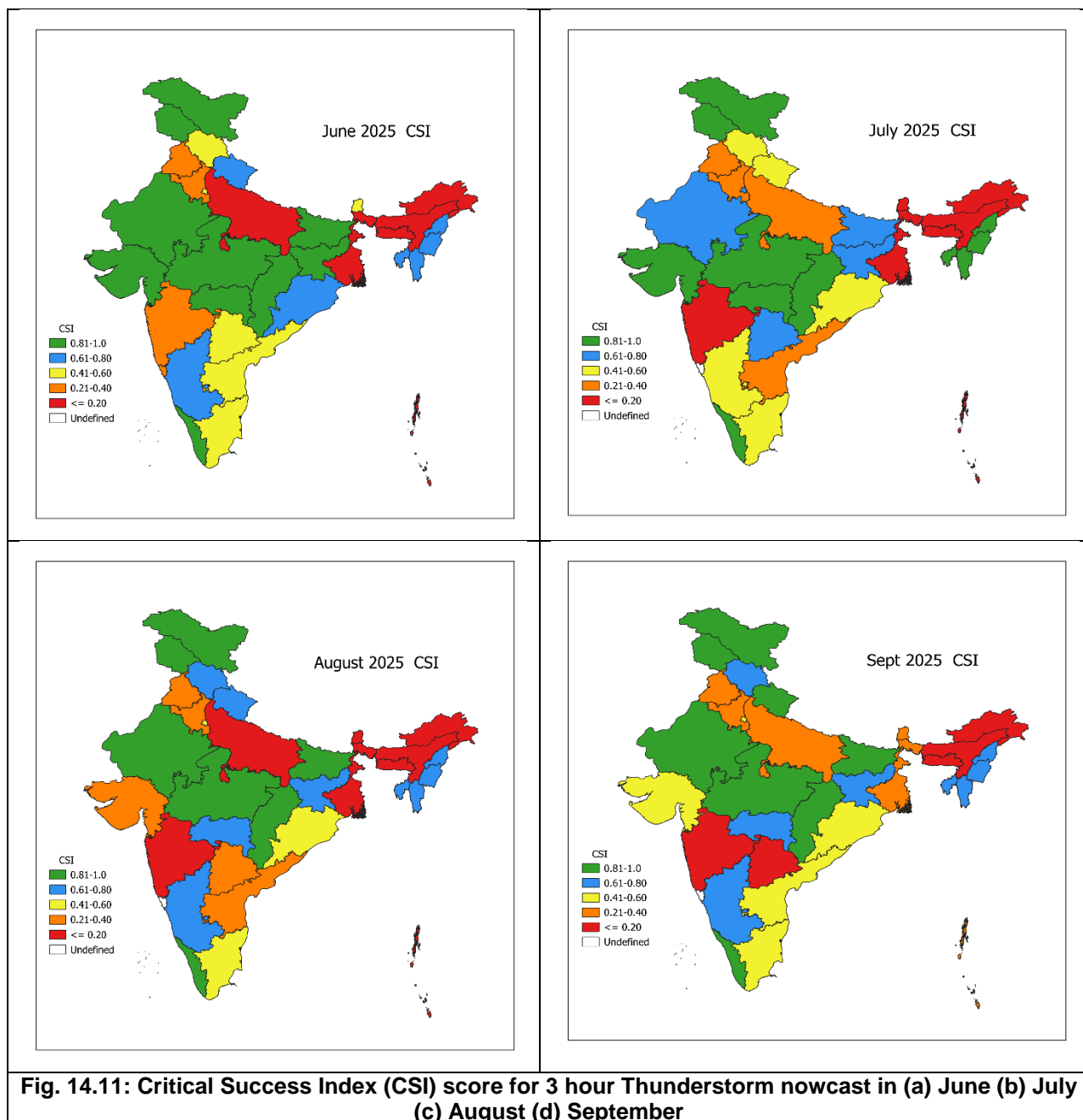
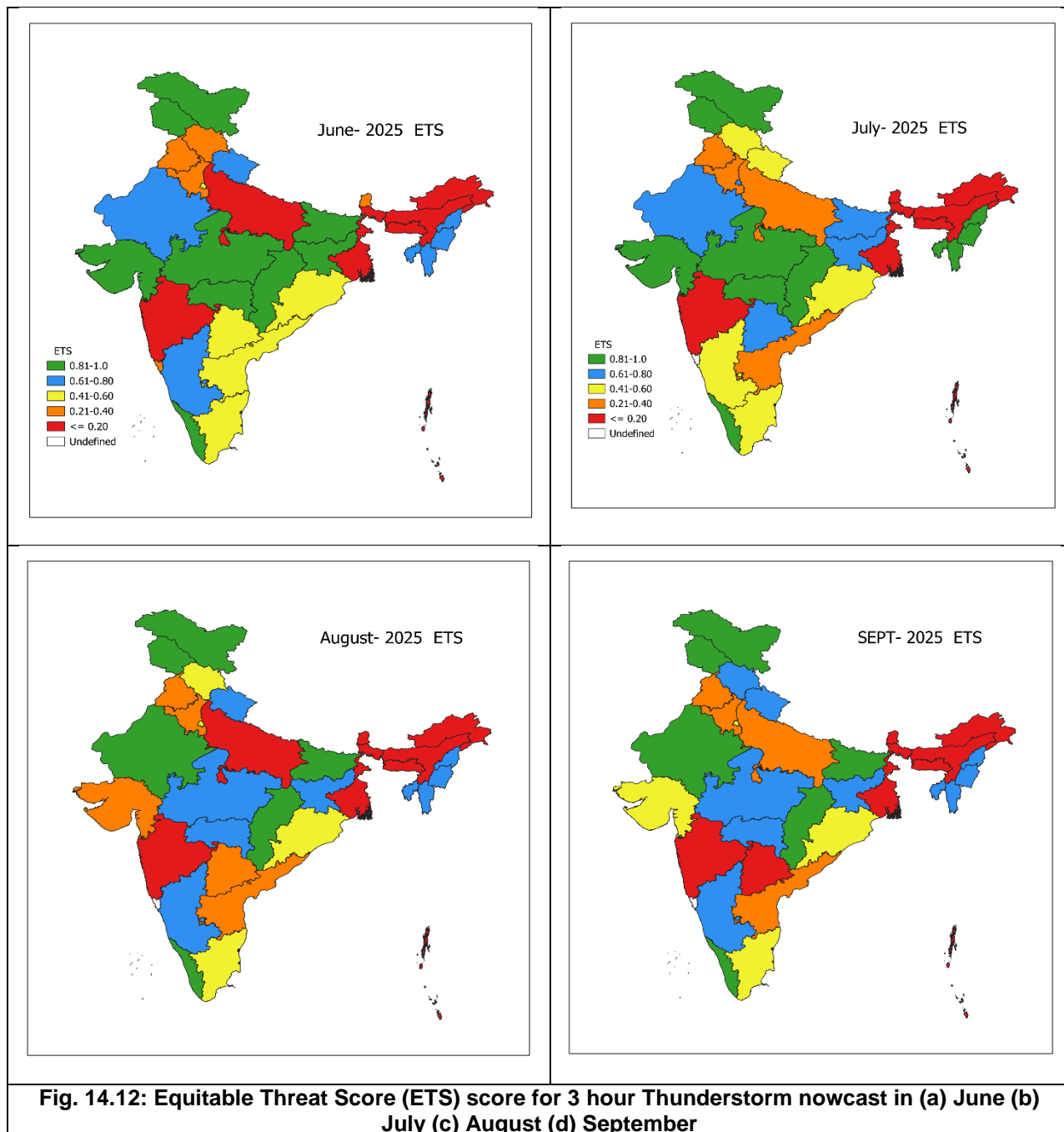


Figure 14.13 (a to d) display all India monsoon season verification scores for 3 hourly nowcasts and their comparison with previous years 2020 to 2025. As may be noted, the POD score for June and September shows consistently same value as the last year, whereas July

indicated improvement and August indicated slide decrease in POD value compare to the last year. Season wise POD value indicated consistently same during the last two consecutive tears. Interestingly, even if POD value is same, the FAR decreases drastically during 2025 compare to 2024 as indicated in Figure 12 (b). CSI and ETS also indicated significant increment during 2025 compare top the last year.



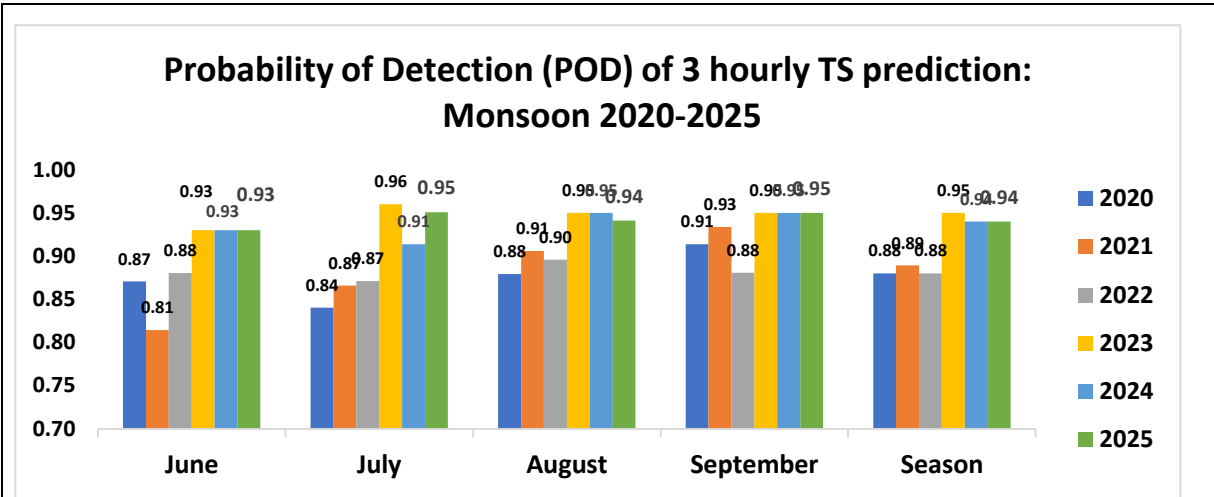


Fig. 14.13 a: Comparison of POD score of 3 hour nowcasts for Monsoon 2020 to 2025

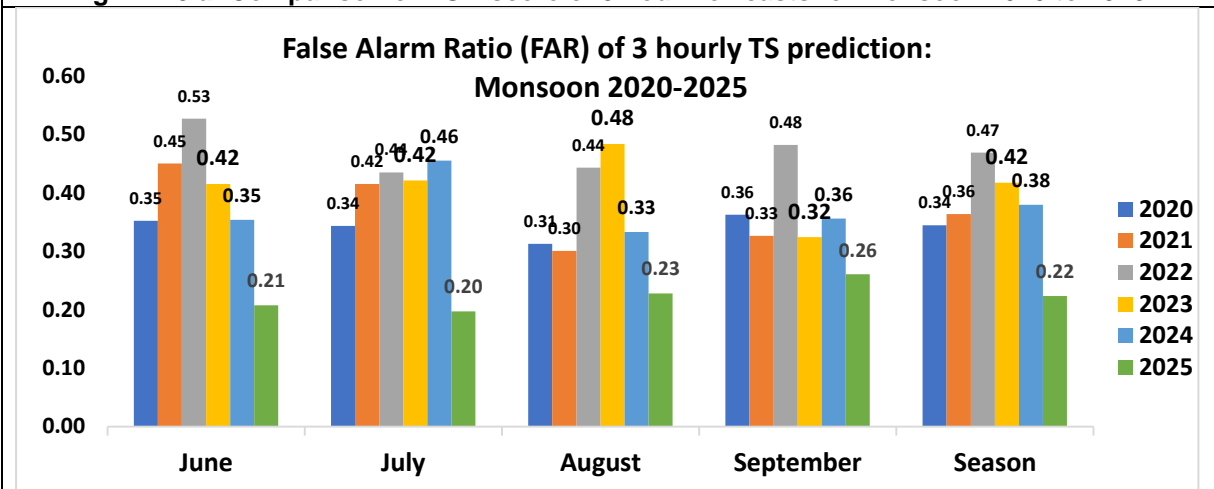


Fig. 14.13 b: Comparison of FAR score of 3 hour nowcasts for Monsoon 2020 to 2025

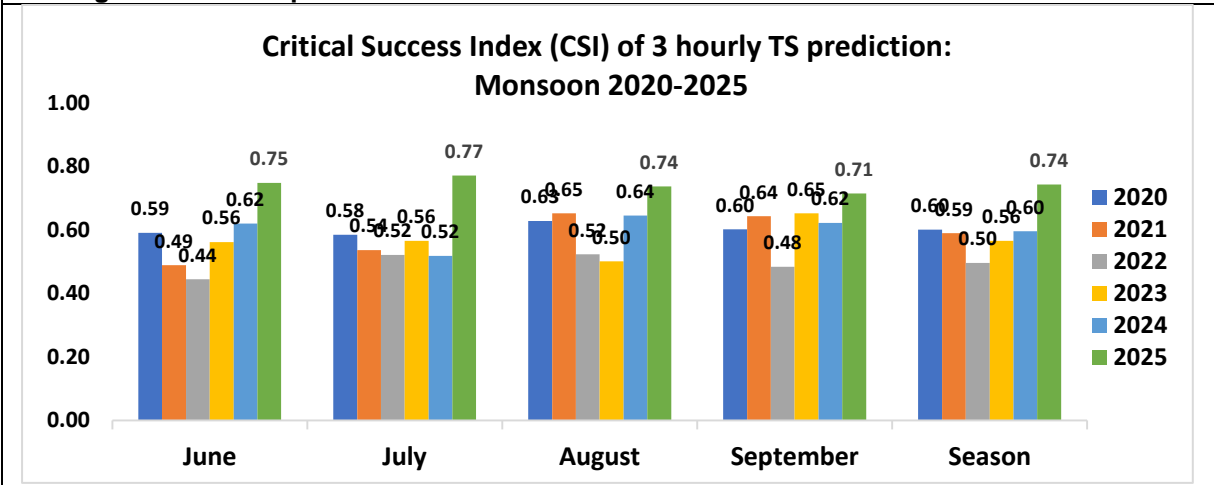


Fig. 14.13 c: Comparison of CSI score of 3 hour nowcasts for Monsoon 2020 to 2025

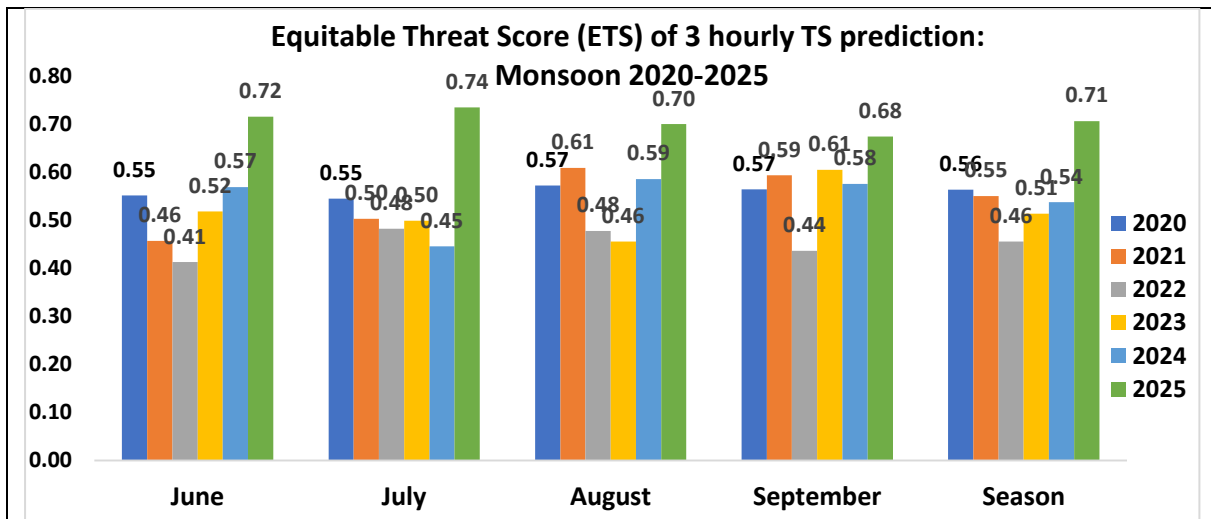


Fig. 14.13 d: Comparison of ETS score of 3 hour nowcasts for Monsoon 2020 to 2025

14.5 Conclusions

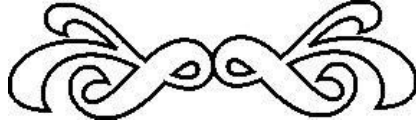
The 2025 southwest monsoon season over India was marked by an early onset, above-normal seasonal rainfall, and pronounced intraseasonal and regional variability in convective activity. The monsoon set in over Kerala on 24 May 2025, significantly earlier than the normal onset date, and its initial advance over parts of the country was relatively rapid. Seasonal rainfall over India as a whole during June–September 2025 was reported to be about 108% of the Long Period Average, indicating an overall favorable monsoon season. Nevertheless, the distribution of rainfall and associated thunderstorm activity was not homogeneous in space or time. While several regions experienced active monsoon spells with enhanced convection and widespread rainfall, some parts of northwest, east and northeast India witnessed relatively subdued rainfall and convective activity during selected phases of the season. Such fluctuations in organized convection and thunderstorm frequency likely influenced forecast skill at shorter timescales, particularly for 3-hourly nowcasts, whereas larger-scale rainfall systems remained comparatively better represented in 24-hour forecasts. Thus, the 2025 monsoon season over India can be characterized as a season with favorable large-scale rainfall conditions but substantial subseasonal variability in convective organization and forecast performance.

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15



PERFORMANCE OF AGRO-METEOROLOGICAL SERVICES DURING SOUTHWEST MONSOON 2025

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This chapter discusses the performance of agro-meteorological services of India Meteorological Department (IMD) during the 2025 southwest monsoon season.

15.1 Introduction

The southwest monsoon season is crucial to Indian agriculture, significantly shaping the country's farming calendar, crop planning and crop yields. India receives around 70% of its annual rainfall during the southwest monsoon period, which occurs from June to September, making it indispensable for irrigation in a country where about 51% of the net sown area relies on rain-fed systems (Singh & Prabhakar, 2025). The timely arrival and spatial distribution, and intensity of monsoon rains directly affect the cultivation of key *Kharif* crops, including rice (paddy), maize, millets (jowar, bajra), pulses (arhar/tur, moong, urad), cash crops like cotton, sugarcane, and oilseeds like groundnut and soybean, thereby playing a vital role in ensuring food security for millions and supporting rural livelihoods.

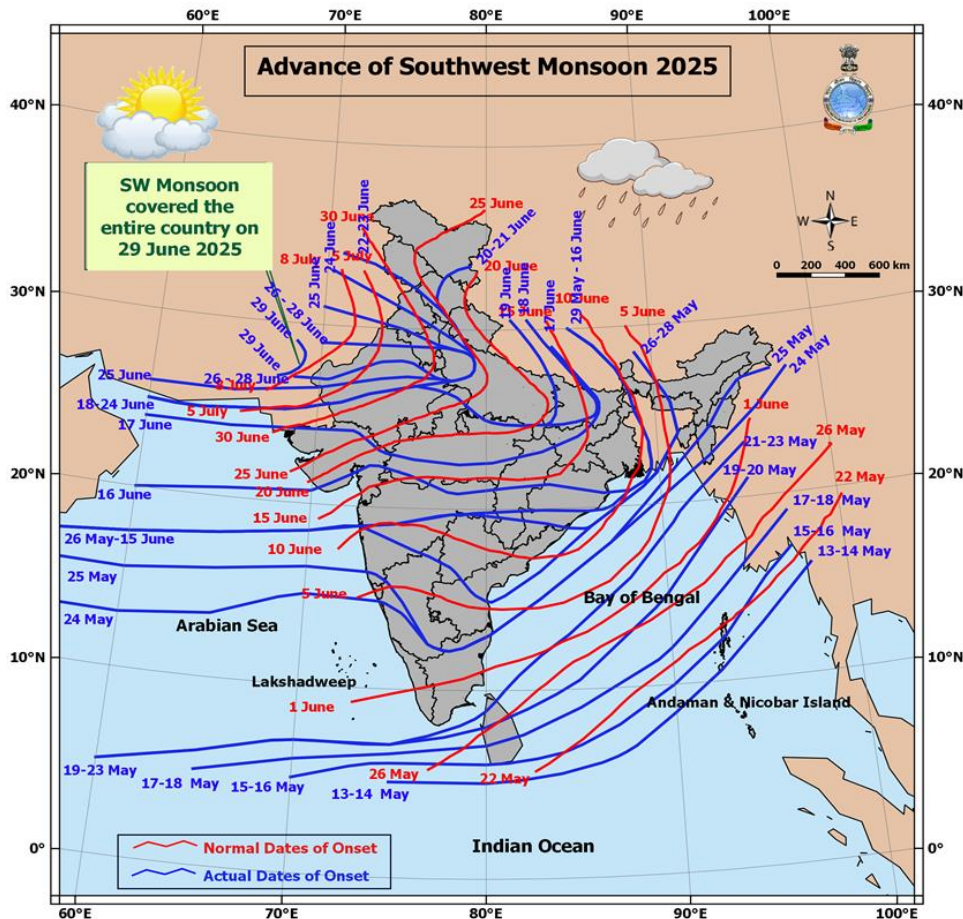


Fig. 15.1: Advancement of Southwest Monsoon 2025

In 2025, Southwest Monsoon set in over Kerala on 24th May 2025, eight days earlier than the normal date of 1 June. The further progression of the southwest monsoon was notably quicker as it advanced in South Maharashtra on 25th May, 11 days before normal date i.e. 5th June. From 30th May to 15th June 2025, its progress stalled for nearly 20 days, affecting early *kharif* sowing operations in some rainfed areas. The monsoon resumed its advance on June 16, reaching entire Konkan, Madhya Maharashtra; some parts of Gujarat state, southwest Madhya Pradesh, Sub-Himalayan West Bengal & Sikkim; some more parts of Vidarbha, Chhattisgarh, Odisha. Finally, by June 29, it covered remaining parts of Rajasthan, West Uttar Pradesh and Haryana and entire Delhi and hence covered the entire country, 9 days before the normal date of 8th July (**Fig. 15.1**).

The total rainfall during the monsoon season was above the normal amount, amounting to 937.2 mm on an all-India basis, indicating a positive departure of 8% from the Long Period Average (LPA). Among the four distinct homogeneous regions, season rainfall was above normal over three geographical regions of the country viz., Central India, Northwest India and South Peninsula and was below normal over East & Northeast India (**Fig. 15.2**).

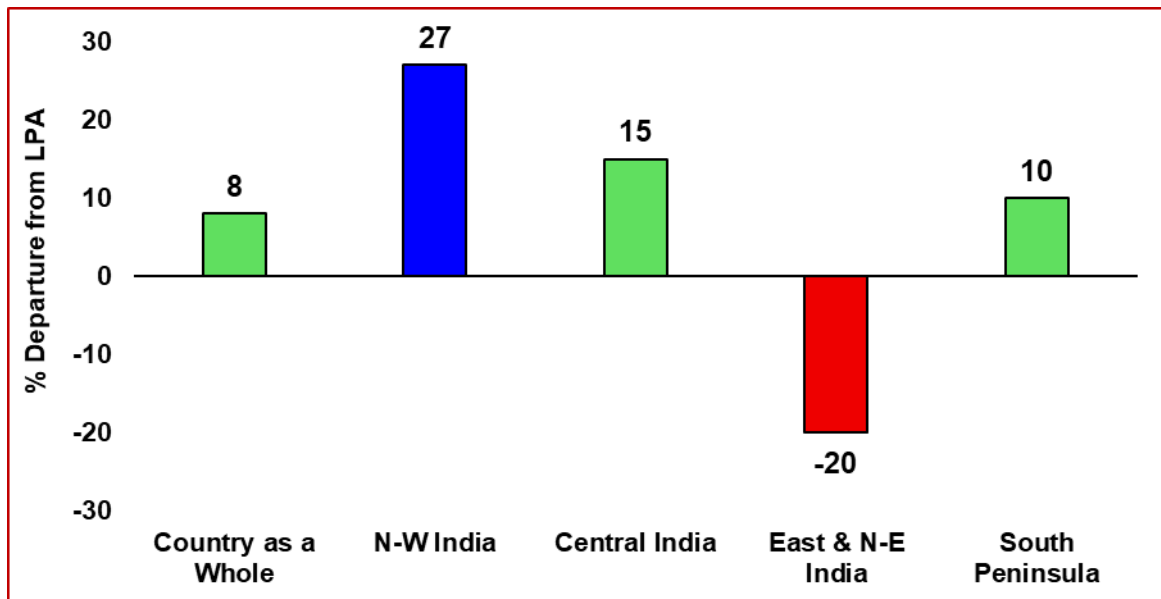


Fig. 15.2: Percentage departure of seasonal rainfall from the Long Period Average (LPA) during Southwest Monsoon 2025 over four homogeneous regions of India and the country as a whole.

Out of the total 36 meteorological subdivisions in the country, 2 subdivisions covering 10% of the total area, experienced a significant surplus of rainfall. Meanwhile, 12 subdivisions, representing 35% of the area, received above-average rainfall. Furthermore, 19 subdivisions, accounting for 46% of the total area, received normal rainfall. Lastly, 3 subdivisions, which make up 9% of the total area, faced below-normal rainfall. The subdivisions with deficient rainfall are Arunachal Pradesh, Assam & Meghalaya and Bihar.

Under the 'Gramin Krishi Mausam Sewa' project of the India Meteorological Department (IMD), targeted agrometeorological advisories were provided to farmers across India through an extensive network of Agromet Field Units (AMFUs) and District Agromet Units (DAMUs). These advisories were designed to help farmers to adopt suitable farming practices to reduce losses during adverse weather conditions. Various satellite data derived Agromet products, such as Standardised Precipitation Index (SPI), Normalised Difference Vegetation Index (NDVI), Vegetation Condition Index (VCI), and Temperature Condition Index (TCI), were operationally used to identify areas experiencing crop stress and moisture deficit/excess and were integrated into district-level agrometeorological advisories for recommending irrigation scheduling, sowing decisions, and other crop management practices (**Fig. 15.3**).

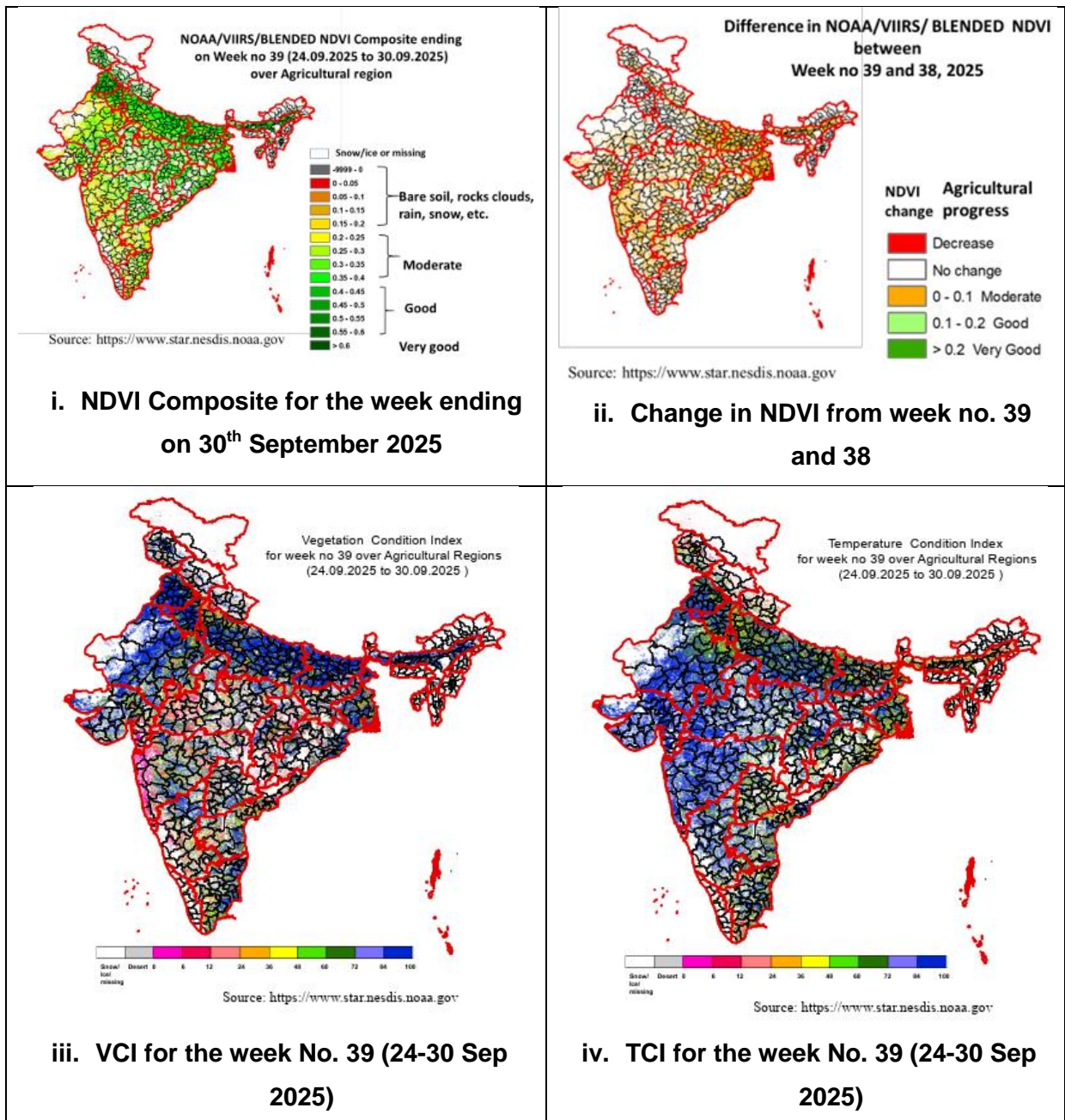


Fig. 15.3: Satellite-based agrometeorological products used during the Southwest Monsoon season (June–September) of 2025.

15.2 Major weather events during southwest Monsoon 2025 and their effects over various parts of the country

15.2.1 Impacts on crops and Agromet Advisory Services (AAS) under various rainfall situations

a. Dry spells / deficient rainfall and related Agromet services

Sowing and transplanting of *kharif* crops commenced within the regular sowing window in Kerala. The total sown area exceeded last year's, driven by good early rainfall, particularly for rice, pulses, and maize, though some regions faced issues with excess rain. By early

August 2025, sowing covered around 995.6 lakh hectares (Ministry of Agriculture & Farmers' Welfare, MoA&FW), up from the previous year, with strong increases in rice and coarse cereals. By early October, the total area surpassed 1121 lakh hectares (Ministry of Agriculture & Farmers' Welfare, MoA&FW), showing overall resilience, with significant expansion in rice, maize, sugarcane, and pulses.

Bihar

Bihar experienced a significant shortfall in monsoon rainfall during the 2025 monsoon season, resulting in an overall rainfall deficit of approximately 31% for the season. The deficit was more prominent in July, when rainfall was about 41 % below normal. Out of 38 districts, 25 reported deficient rainfall, ranging from 20% to 59% below normal, while 13 districts received rainfall closer to normal levels. Districts such as Sitamarhi, East and West Champaran, Muzaffarpur, and Saharsa were among those with pronounced shortfalls as evident from district-level rainfall analysis (**Fig. 15.4**).

The deficient monsoon adversely affected *Kharif* crop operations, notably for paddy, the principal rain-fed crop in Bihar. Delayed and inadequate rainfall hindered timely paddy transplanting and seedling establishment across several districts, particularly in northern Bihar, where dry conditions persisted into critical planting windows. Fields remained dry, forcing farmers to rely on groundwater extraction and pump irrigation, a cost-intensive option that many smallholder cultivators struggle to afford. Prolonged dry spells increased the risk of drought-like conditions and heightened concerns over potential reductions in crop yields and overall production.

To mitigate the impacts of rainfall deficiency in Bihar, a range of climate-adaptive interventions were recommended, including adoption of crop varieties with higher tolerance to drought stress, along with cultivation of short-maturity rice varieties in low- and medium-lying areas where residual moisture is available. Strengthening field bunds to improve in-situ rainwater harvesting and moisture retention was also emphasized. In addition, farmers were advised to diversify cropping systems by shifting towards coarse cereals such as sorghum, pearl millet, finger millet, little millet, and kodo millet, as well as drought-resilient pulse crops, which are better suited to withstand moisture stress while maintaining reasonable productivity. The implementation of soil moisture-conserving agronomic practices, including organic mulching and the use of cover crops, was further recommended to reduce evaporative losses, enhance soil health, and improve crop resilience under prolonged dry conditions.

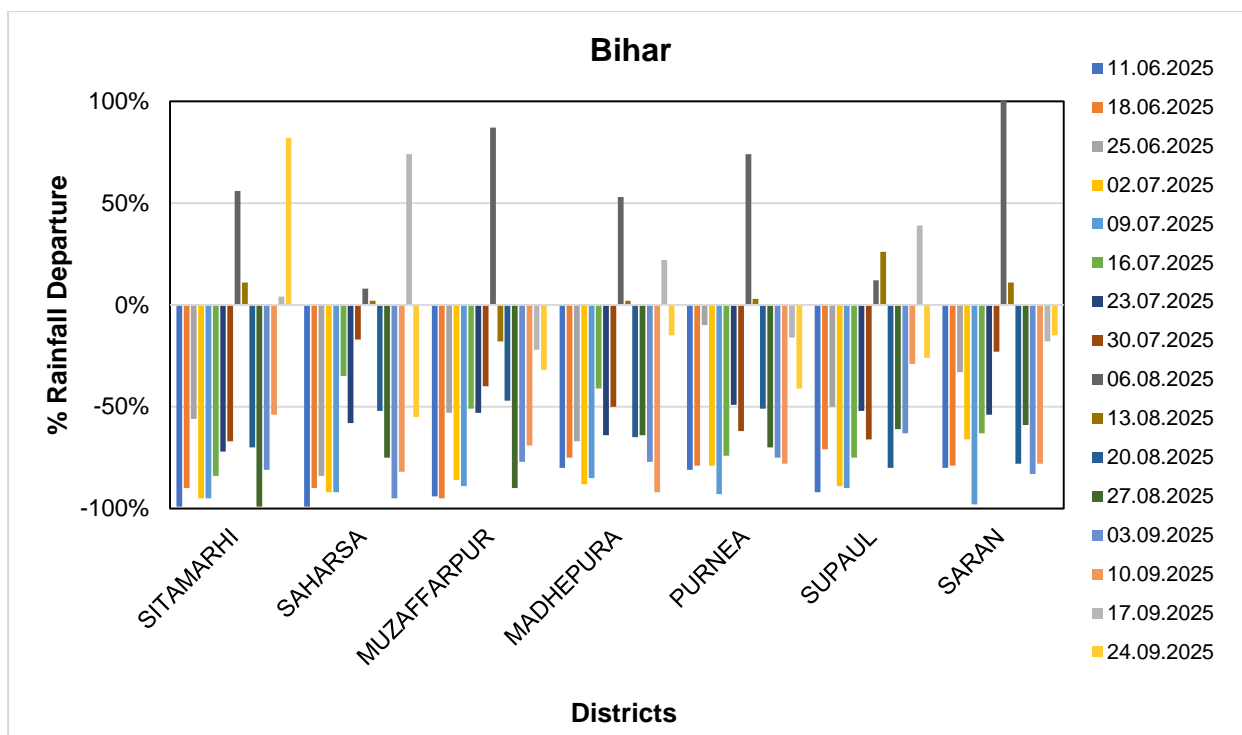


Fig. 15.4: Percentage departure of rainfall from normal in some districts of Bihar

North East Region

During the Southwest Monsoon 2025, large parts of North-Eastern India experienced intermittent rainfall deficiency, particularly during June–early July (delayed onset / weak active phases), and September (early withdrawal / long dry spells). Although cumulative seasonal rainfall in parts of the region appeared near normal, the long dry spells, delayed onset, and uneven temporal distribution had a clear adverse effect on *Kharif* crop performance. The impact was driven more by moisture stress at critical crop stages than by outright loss of cropped area.

In Assam, delayed and irregular rainfall affected timely transplanting of *Sali* rice, especially in rainfed and char areas. Reduced soil moisture during the vegetative and tillering stages led to lower yield potential, while *Ahu* rice and rainfed maize were more severely affected. Overall, cropped area was largely maintained, but yields declined in many districts. In Arunachal Pradesh, cumulative rainfall was relatively adequate in hill districts, but poor distribution caused moisture stress during sowing and early growth of maize and millets in lower valleys. Terrace rice systems showed better resilience due to residual moisture, resulting in only localized yield reductions. In Meghalaya, despite high average rainfall, prolonged dry spells during July and August affected upland rice and maize. Lowland paddy performed comparatively better, but overall *Kharif* yields declined due to stress during vegetative growth stages. Manipur experienced one of the more severe impacts. Deficient rainfall during the transplanting window resulted in delayed and staggered paddy

transplantation, which reduced the plant population in rainfed areas. Pulses and oilseeds also faced moisture stress during flowering, resulting in both area and yield losses and a sharper production decline compared to other North-Eastern states. In Mizoram, jhum-based rice cultivation was sensitive to delayed and erratic rainfall, which affected early crop establishment and biomass accumulation. Wetland rice systems, however, were relatively protected due to better water retention. A similar pattern was observed in Nagaland, where jhum rice and rainfed maize experienced significant yield losses due to prolonged dry spells, which reduced crop growth and productivity. In Tripura, early monsoon deficiency delayed paddy transplanting, and although August rainfall provided partial recovery, it was insufficient to fully offset earlier stress. Pulses and rainfed crops experienced yield reductions, while irrigated and low-lying fields performed better. Sikkim remained largely unaffected, as orographic rainfall ensured near-normal moisture conditions throughout the season.

Across the North-East region as a whole, rainfed rice, maize, pulses, and jhum crops were the most affected during *Kharif* 2025. Production losses were driven primarily by yield reductions rather than large-scale area loss, highlighting the vulnerability of rainfed and upland farming systems to monsoon variability. The season underscored that even in traditionally high-rainfall regions, deficient and poorly timed monsoon rainfall can substantially impact *Kharif* crop production, reinforcing the need for improved contingency planning, moisture conservation, and timely agrometeorological advisories.

During periods of deficient and erratic monsoon rainfall, rice-growing areas of Assam were advised to delay nursery sowing and transplanting until receipt of adequate rainfall, and to use short-duration or stress-tolerant rice varieties where the transplanting window was shortened. Farmers were advised to maintain shallow water levels in lowland fields, undertake field leveling and bund repair to conserve moisture, and provide protective irrigation at tillering and panicle initiation stages wherever water was available. Basal nitrogen application was advised to be postponed during dry spells, with split or foliar nutrient application recommended after rainfall to sustain crop growth.

In Nagaland, where jhum cultivation predominates, advisories emphasized timely sowing only after effective rainfall, along with retention of crop residues and adoption of contour-wise sowing to reduce moisture loss. Farmers were advised to avoid early weeding during dry periods to reduce soil evaporation and to apply organic mulches to conserve soil moisture. Across both states, advisories highlighted close monitoring of crops for pest incidence under moisture stress and urged farmers to follow district-specific weather forecasts and contingency advisories for re-sowing, gap filling, or crop substitution when prolonged dry spells persisted.

Marathwada region of Maharashtra

Due to subdued rainfall activity over Marathwada region of Maharashtra during first fortnight of July, sowing of principal *kharif* crops were delayed. After 15th July, farmers of Marathwada region were advised to sow intercrops instead of sole crops, soybean + pigeon pea (4:2), pearl millet + pigeon pea (3:3), castor + coriander (1:1), on unsown area after receipt of 75 to 100 mm cumulative rainfall. They were also advised to undertake intercultural operations like hoeing, weeding, soil mulching in already sown cotton, pigeon pea, groundnut, green gram and black gram. Farmers were advised to use available water judiciously through micro-irrigation systems to manage moisture stress. For crops around 30 days old, a foliar spray of 1% potassium nitrate (13-0-45) at 100 g per 10 litres of water was recommended to support growth under stress conditions. Irrigation in vegetable crops and orchards was advised strictly according to water availability. In addition, farmers were encouraged to continue transplanting 45-day-old seedlings of brinjal, tomato, and chilli where field conditions permitted.

b. Heavy rainfall / Flood situation and related Agromet services

Excessive monsoon rainfall accompanied by repeated flooding disrupted agricultural operations by postponing crop sowing and transplanting, while also degrading soil conditions through erosion, prolonged water stagnation, and nutrient loss. Waterlogged fields further created favourable conditions for the spread of pests and crop diseases, resulting in notable damage to standing crops. During the 2025 monsoon season, rainfall extremes and flood events affected several states, including Punjab, Rajasthan and Maharashtra, resulting in significant losses to *Kharif* crops. To cope with these impacts, farmers in vulnerable areas were supported with timely weather information and appropriate agrometeorological advisories, which enabled them to make informed management decisions and reduce potential losses.

i) Impact of heavy rainfall and flood on crops

Punjab

Punjab state has experienced several spells of heavy rainfall, leading to widespread flooding across the state, particularly from mid-August to early September 2025. Intense rainfall over short durations in the upper catchments of the Sutlej, Beas, and Ravi rivers caused rivers to overflow and floodplains to remain inundated for prolonged periods. As a result, all 23 districts of Punjab were officially affected to varying degrees (**Fig. 15.5**), with the most severe impacts reported from Gurdaspur, Pathankot, Amritsar, Kapurthala, Hoshiarpur, Ferozepur, Fazilka, Patiala, and Sangrur (Bagha, 2025). The flooding coincided with critical stages of *Kharif* crops, particularly the tillering to maturity and pre-harvest

stages. Large areas of agricultural land remained underwater or experienced prolonged waterlogging, which severely disrupted crop growth and field operations. Paddy suffered the maximum damage due to lodging, root damage, reduced grain filling, and increased incidence of diseases such as sheath blight. Cotton crops in southwestern districts, such as Bathinda, Mansa, and Fazilka, were adversely affected during the boll formation and opening stages, leading to boll rot and partial crop failure. Maize, fodder crops, vegetables, and horticultural plantations also experienced significant losses, particularly in low-lying and poorly drained areas.

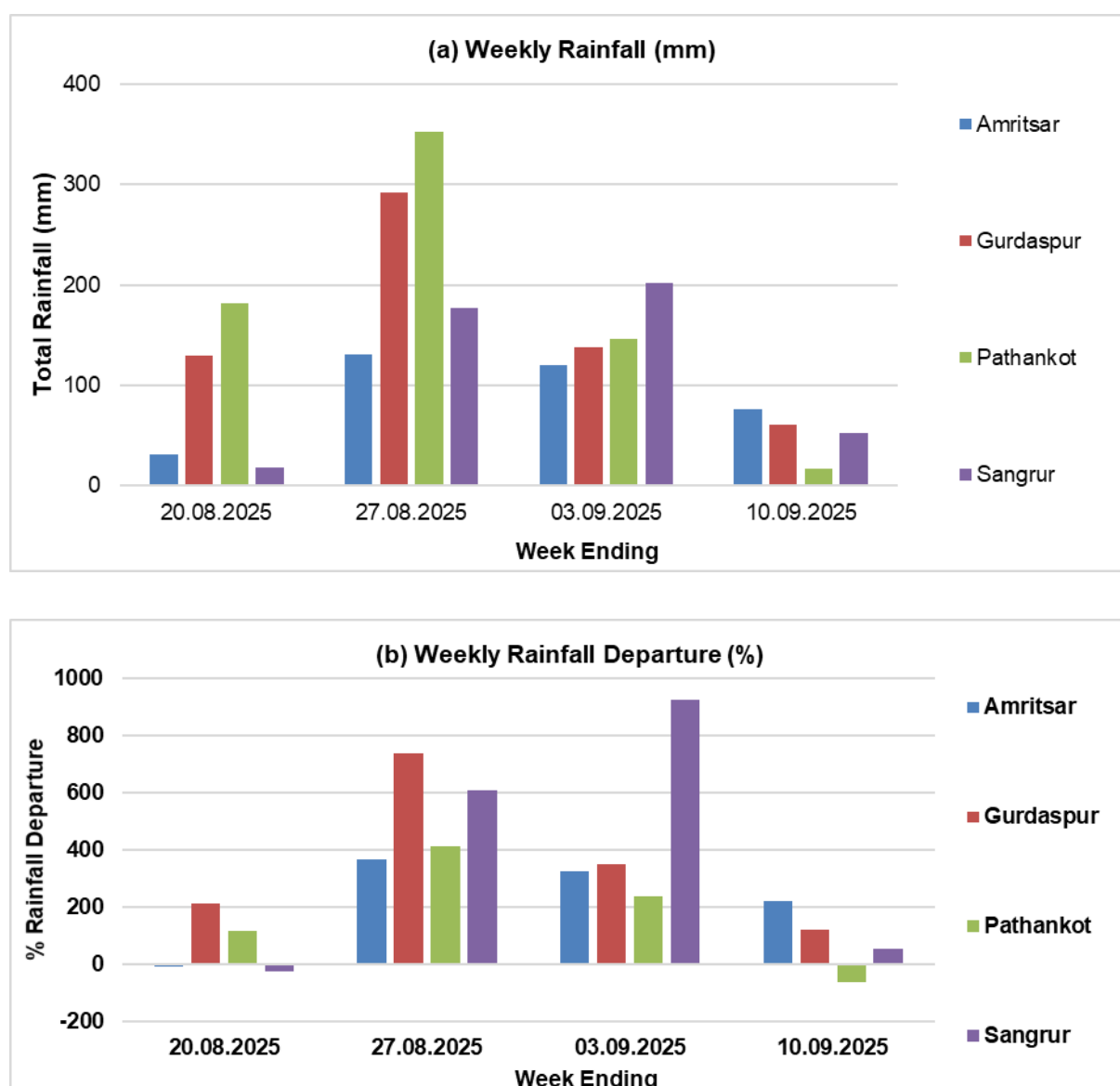


Fig. 15.5: Weekly Rainfall and departure in some of the flood-affected districts of Punjab

Preliminary assessments by various agencies and media reports indicate that approximately 1.76 lakh hectares of cropped area were affected across Punjab (Sphere

India, 2025). Paddy alone accounted for nearly 80–85 percent of the damaged area, reflecting the dominance of rice in the *Kharif* season and its exposure during the flood period. In districts such as Gurdaspur and Amritsar, tens of thousands of hectares of standing crops were reported damaged due to prolonged inundation. Overall, the estimated production losses for major *Kharif* crops ranged between 20 and 35 percent compared to a normal monsoon year, with losses being higher in flood-prone riverine belts and canal-command areas (The New Indian Express, 2025a; The Statesman, 2025).

Beyond direct crop damage, the floods also caused soil erosion, nutrient leaching, and damage to field bunds and irrigation infrastructure, which further increased input costs for farmers. Submerged fodder fields and contamination of water sources affected livestock health, compounding the economic stress on farming households. The cumulative impact of crop loss, infrastructure damage, and delayed agricultural operations placed considerable financial pressure on small and marginal farmers.

In the flood-affected districts of Punjab, farmers were advised to temporarily stop irrigation and drain excess water from fields to reduce prolonged waterlogging. Crop-stage-specific advisories were issued for paddy to strengthen weak tillers and manage lodging through balanced nitrogen and potassium application. Farmers were advised to monitor and manage pest and disease outbreaks, particularly sheath blight and boll rot, by using targeted plant protection measures. Advisory services also recommended re-sowing or gap-filling in severely damaged patches and timely harvesting where crops had reached maturity. Special advisories were issued for cotton and vegetables to prevent fungal infections after floods, and for fodder conservation to support livestock during the recovery phase.

Haryana

In Haryana, during August and early September 2025, heavy monsoon showers inundated fields in 22–24 districts, with Hisar, Bhiwani, Mahendragarh, Sirsa, Charkhi Dadri, Jind, Jhajjar, Fatehabad and Rohtak among the worst affected areas, where extended waterlogging and submerged fields were widely reported (**Fig. 15.6**). Paddy, cotton, bajra, moong and guar crops suffered severe damage due to prolonged water standing, root rot and delayed crop development, and yields were reported to be adversely impacted, particularly for water-sensitive and mid-season crops. Estimates from compensation registration data indicate that nearly 30 lakh acres of crops were reported damaged by more than 5.8 lakh farmers across the state, with 8.66 lakh acres of crop loss reported in 2,687 villages alone in some accounts, reflecting the scale of the agricultural impact (The Times of India, 2025). The state government's crop loss verification led to compensation payments totaling around ₹116 crore credited to tens of thousands of farmers for verified losses in paddy, millet, cotton and guar, although the total affected area reported on the portal was

much larger, indicating that many areas may still be under assessment (Hindustan Times, 2025).

To help farmers reduce crop damage under such heavy rainfall conditions, advisories issued in affected districts included monitoring weather forecasts and avoiding field operations during forecast heavy rain, implementing effective field drainage and removing excess water quickly, adjusting fertilizer and irrigation schedules once waterlogging receded, vigilant pest and disease management under saturated conditions, and guidance on damage reporting, insurance claims and re-sowing or gap filling where crop stands were completely lost. These measures aimed to support crop recovery and reduce further yield losses following flood events.

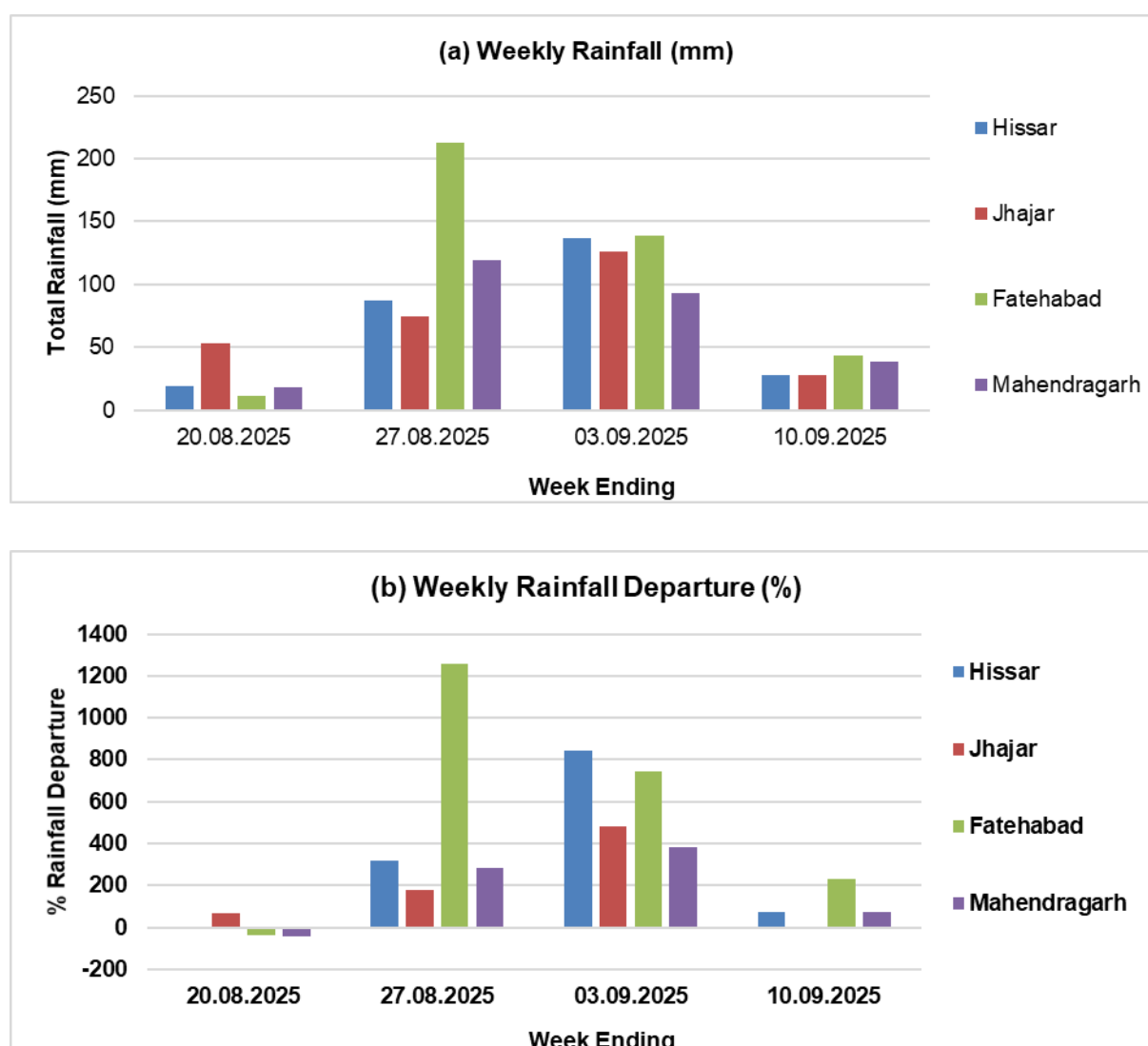


Fig. 15.6: Weekly Rainfall and departure in some of the flood-affected districts of Haryana

Rajasthan

In Rajasthan, intense rainfall during late August and early September 2025 created flood-like conditions in districts such as Kota, Bundi, Baran, Jhalawar, Tonk, Chittorgarh, and Sawai Madhopur (**Fig. 15.7**), disrupting normal agricultural activities and leading to waterlogging and crop damage especially for soybean, guar, moong, bajra, moth, and groundnut. Average losses in *Kharif* crops across many areas have been estimated at 30–40 percent, with localized losses as high as 90 percent in Sawai Madhopur and Hanumangarh regions (Business Standard, 2025). The intense rains washed away sowing efforts and flattened standing crops, necessitating repeated reseeded and further delaying crop establishment.

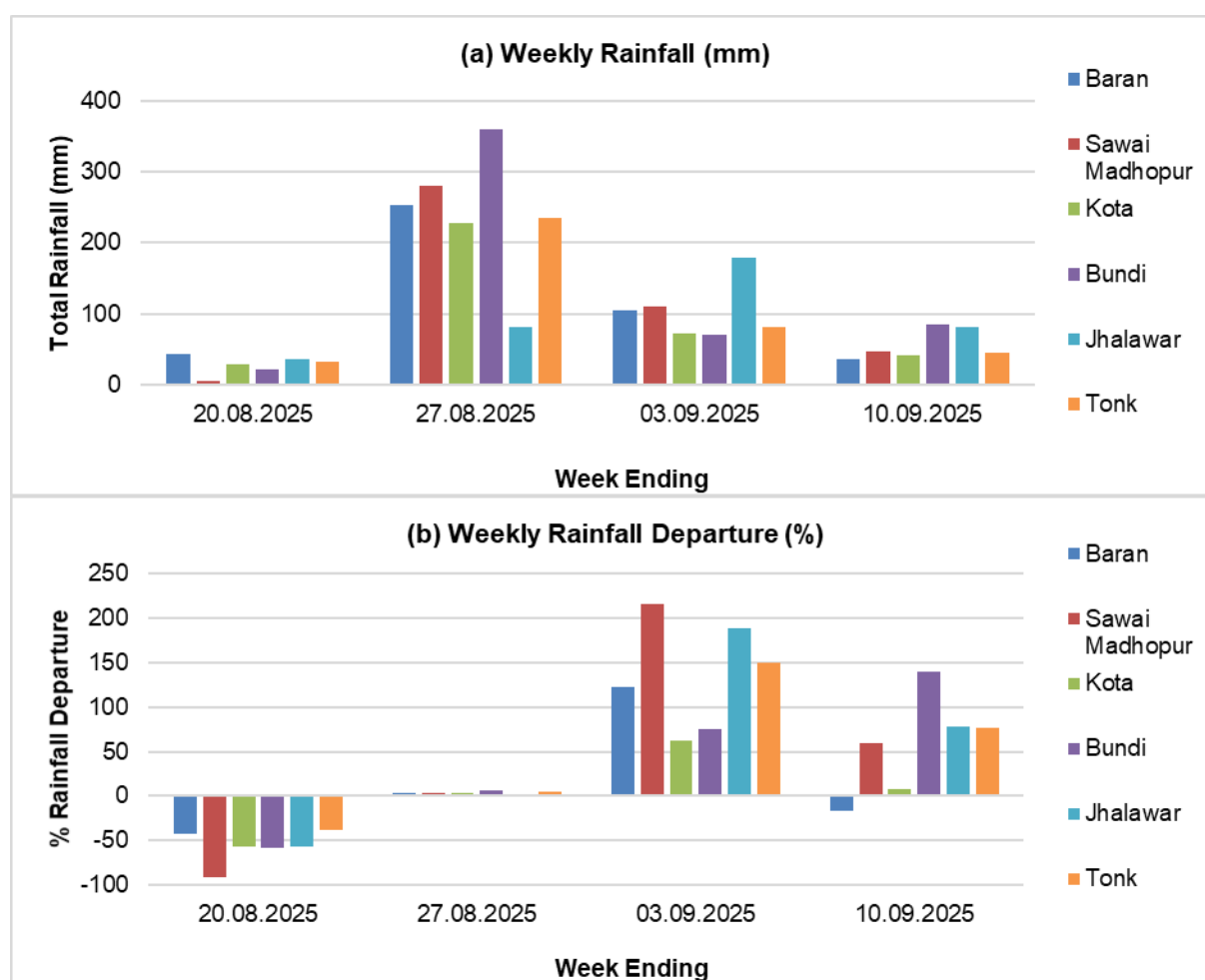


Fig. 15.7: Weekly Rainfall in some flood affected districts of Rajasthan

To mitigate impending crop damage, agricultural advisories issued to farmers in these affected districts emphasized timely drainage and water management practices to reduce prolonged waterlogging, avoiding sowing during heavy rainfall episodes, and monitoring for

pest and disease outbreaks under saturated soil conditions. Farmers were advised to adjust fertilizer and irrigation scheduling based on field moisture once flooding receded and to consider gap filling or re-sowing where feasible after water levels dropped.

Maharashtra

Maharashtra experienced extreme and persistent heavy rainfall and flooding from August through September, which caused widespread agricultural devastation across the state. Preliminary estimates from the Maharashtra agriculture department indicate that crops over nearly 70 lakh acres (about 28 lakh hectares) were damaged due to excess rain and inundation in 30 districts, with the worst impacts reported in Nanded, Beed, Solapur, Yavatmal, Dharashiv (Osmanabad), Buldhana, Washim, Ahilyanagar (Ahmednagar), Jalna, Hingoli, Akola, and Amravati (**Fig. 15.8**). Nanded alone saw damage on more than 18.20 lakh acres, while Solapur and Yavatmal recorded losses on roughly 9.95 lakh acres and 8.56 lakh acres respectively, reflecting the severity of the flooding and waterlogging that occurred between early August and late September 2025 (India Today, 2025). Major *Kharif* crops including soybean, maize, cotton, urad, tur (pigeon pea), bajra, sugarcane, onion, and turmeric suffered severe yield losses due to prolonged excess moisture, root rot, and disrupted phenological stages during peak growth periods. Preliminary assessments point to significant production reductions and widespread crop loss across these rain-affected areas, with final loss figures still under verification but already amounting to millions of hectares of impacted crop area. The state government reported ongoing damage surveys and has sanctioned relief measures, underlining the scale of the crisis facing farm households.

To reduce potential crop damage under such extreme rainfall, agricultural advisories issued to farmers emphasized timely weather forecasts and alerts, avoiding sowing or field operations during forecast heavy rain periods, and implementing effective drainage and water-management practices to alleviate waterlogging. Farmers were guided to monitor and manage pest and disease risks associated with saturated soil conditions following flooding, adjust fertilizer and irrigation scheduling once excess water receded, and undertake gap filling or strategic re-sowing where crops were completely lost.

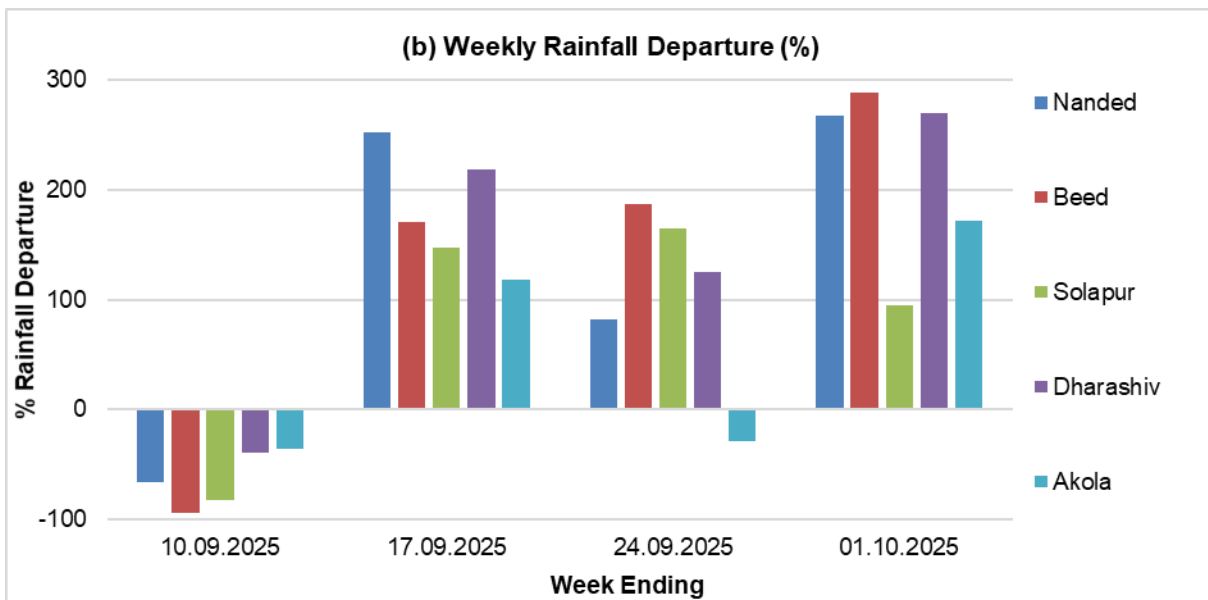
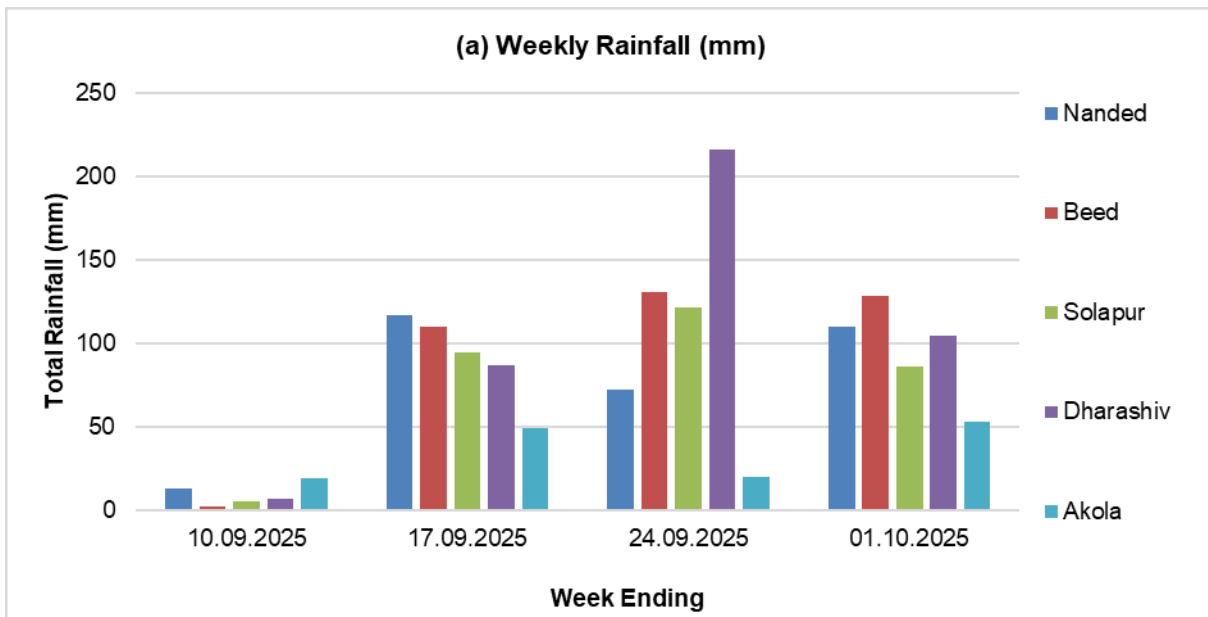


Fig. 15.8: Weekly Rainfall in some flood-affected districts of Maharashtra

Telangana

Telangana endured episodes of heavy rainfall and flooding, particularly in August and September 2025, as IMD issued alerts for intense rain across several districts. These downpours led to waterlogging and field inundation in districts such as Adilabad, Nirmal, Nizamabad, Medak, Kamareddy, Siddipet, as well as parts of Karimnagar, Mahabubabad and Hyderabad, disrupting agricultural activity (**Fig. 15.9**). In Adilabad district alone, about 11,900 acres of predominantly cotton and rainfed crops were damaged by floods and standing water early in the heavy rainfall phase. In Nizamabad’s Balkonda area, heavy rains over several days reportedly damaged more than 1,162 acres of paddy, along with maize

and soya, reflecting localized but significant crop losses as per media reports (Telangana Today, 2025). Broader state government assessments estimate that about 415,000 acres of crops were damaged due to heavy rains and floods, with associated crop loss valued at roughly Rs 415 crore, primarily in paddy, cotton, and maize, as per an official damage report (The New Indian Express, 2025b). Overall economic losses due to the rain-related damage in Telangana, including agriculture and infrastructure, were preliminarily assessed at Rs 5,438 crore by the state government (The Hindu, 2025).

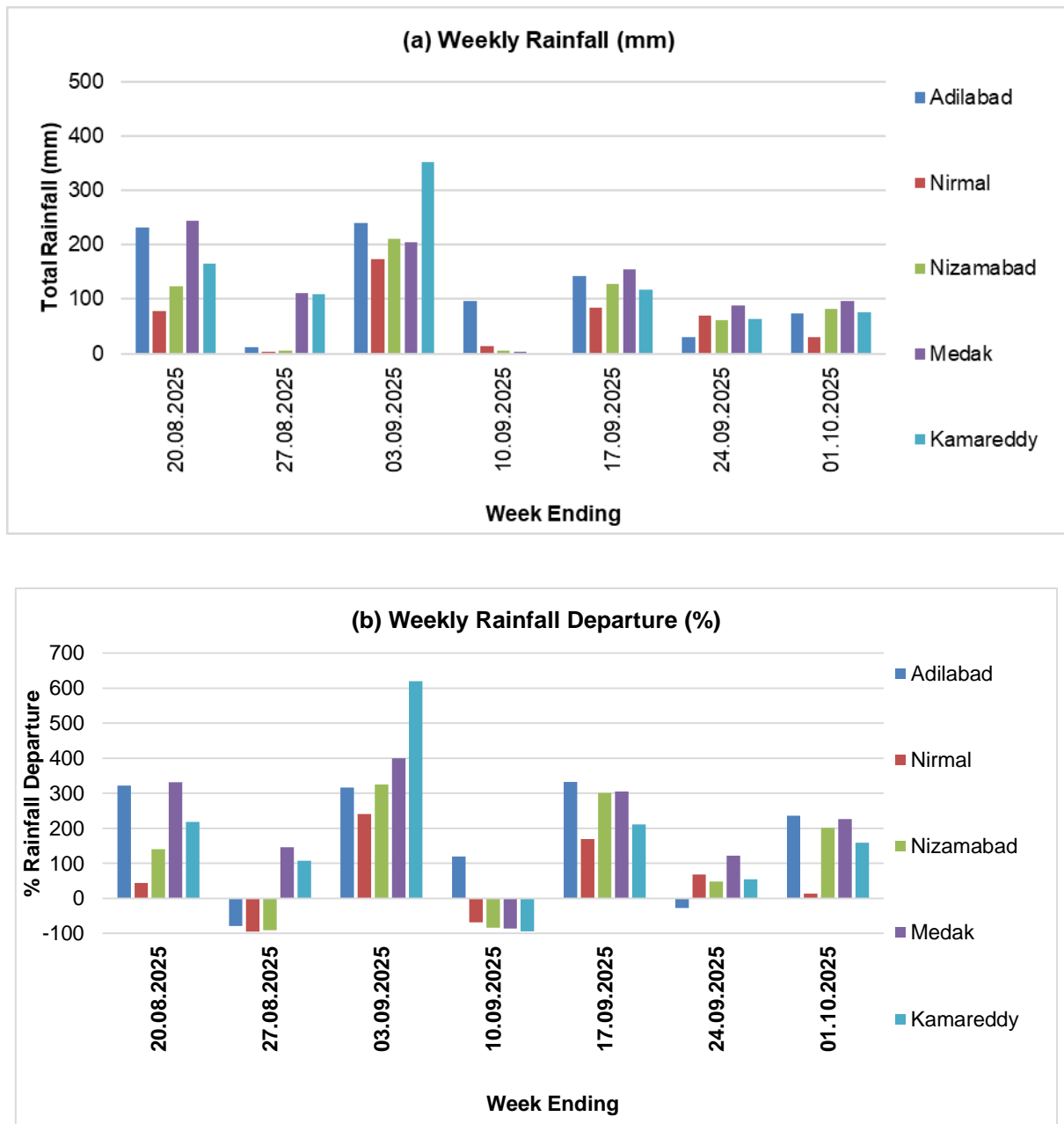


Fig. 15.9: Weekly Rainfall in some flood affected districts of Telangana

To mitigate potential crop damage during these extreme rainfall events, agricultural advisories issued to farmers in affected districts emphasized the importance of monitoring and responding to official weather forecasts and alerts, adopting effective drainage practices to remove excess water quickly from fields, adjusting irrigation and fertilizer scheduling once waterlogging receded, and carrying out pest and disease surveillance under saturated soil conditions. Farmers were also encouraged to undertake gap filling or re-sowing where standing crops were completely lost once safe field conditions returned.

15.2.2 Impact based Forecast (IBF) for Agriculture

Impact-Based Forecasting (IBF) for agriculture is an approach that integrates information on weather hazards with the exposure and vulnerability of crops to evaluate risk and strengthen decision-making, with the objective of reducing losses caused by extreme weather events. By focusing on likely impacts rather than only on weather parameters, IBF delivers essential inputs for managing weather-related risks in the agricultural sector. At the district level, the India Meteorological Department (IMD), through its Regional Meteorological Centres and Meteorological Centres, issues warnings for events such as heavy rainfall, hailstorms, cold waves, ground frost, heatwaves, and strong surface winds. These warnings are subsequently interpreted and converted into practical, crop-specific advisories by Agricultural Meteorological Field Units, taking into account the dominant crops in the district, their stage of growth, and the expected effects of the forecast weather on crop condition and productivity.

The compiled and consolidated IBF advisories are shared with District Collectors and Agriculture Department officials, enabling timely implementation of suitable preparedness and mitigation measures. During episodes of heavy rainfall across different states, AMFUs issue district-specific IBF advisories within their operational areas, guiding farmers on appropriate actions to protect standing crops and reduce potential damage. An illustrative example of such an IBF, prepared for Kodagu, Chamarajanagara, Mysuru and Mandya districts of Karnataka demonstrates how forecast-based, impact-oriented information is translated into clear, actionable guidance to support farmers in managing weather-induced risks to agriculture (**Fig. 15.10**).

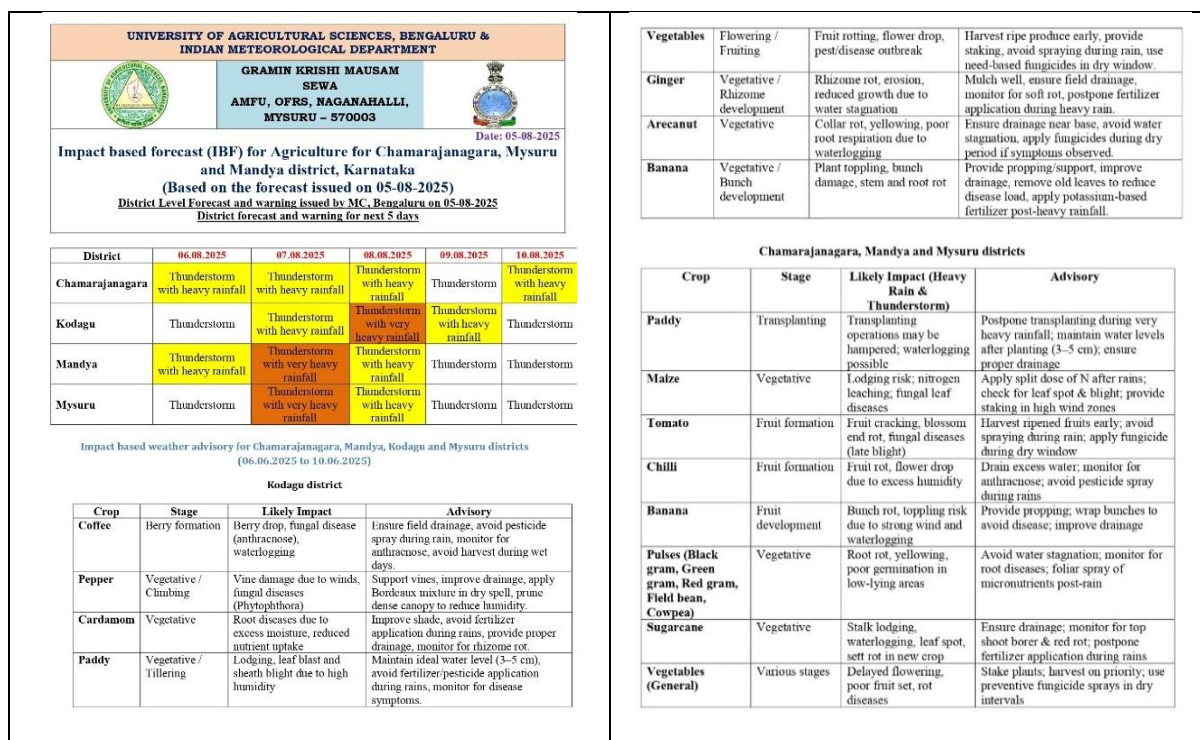


Fig. 15.10: Sample IBF issued by AMFU Naganahalli, Mysuru (Karnataka) on 05-08-2025

15.2.3 Incidence of pest and disease during southwest Monsoon (*kharif* season) 2025

Although overall intensity of pests and diseases remained below Economic Threshold Level (ETL) in most parts of the country, some incidences were reported, which have been presented in **Table 15.1**. Appropriate advisories have been issued by AMFUs on likely occurrence of pests & diseases and timely plant protection measures.

Table 15.1: Major pest and disease incidence during the Southwest Monsoon 2025

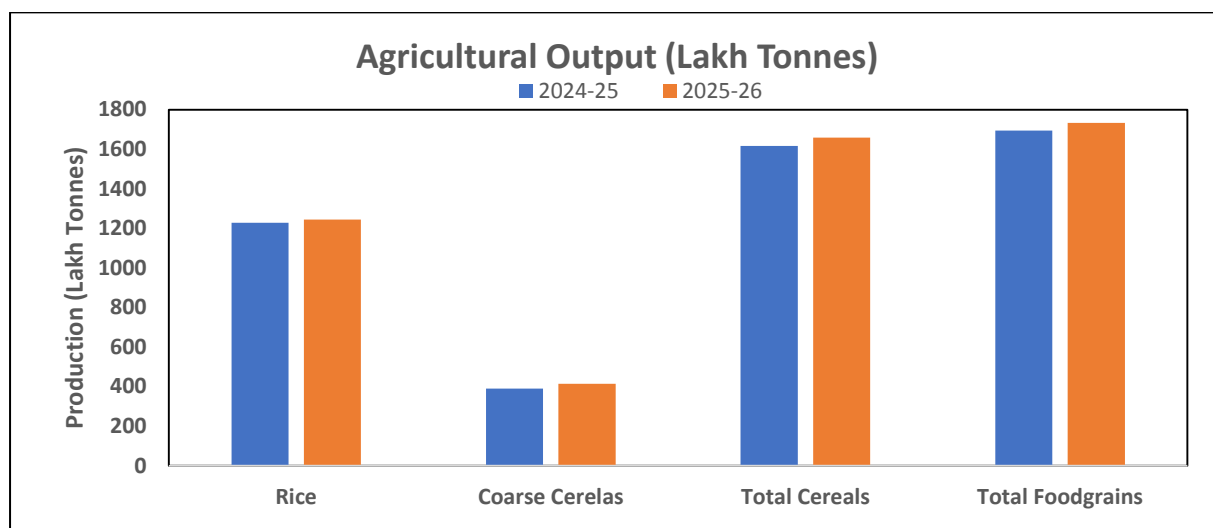
Crop	State(s) / Region(s) affected	Major pest/disease reported	Period of incidence (2025)	Intensity / Status as per CWWG
Rice	Assam	Rice hispa, swarming caterpillar, leaf folder	July–August	Localized incidence; some pockets above ETL
Rice	Haryana, Punjab	Southern Rice Black Streaked Dwarf Virus (SRBSDV)	August–September	Above ETL in limited areas; under close surveillance
Rice	Chhattisgarh	Yellow stem borer, brown plant hopper	August–September	Sporadic incidence; managed through advisories

Rice	Jharkhand	Caseworm	July–August	Localized, marginally above ETL
Rice	Jammu & Kashmir, Meghalaya	Mixed pest pressure	August	Below ETL; monitoring advised
Soybean	Maharashtra	Girdle beetle, tobacco caterpillar, white grub	July–September	Above ETL in pockets; crop-specific advisories issued
Soybean	Madhya Pradesh	Yellow mosaic virus, defoliators	August–September	Localized outbreaks; overall moderate intensity
Green gram (moong)	Rajasthan	White grub, tobacco caterpillar	July–August	Short-duration outbreaks; controlled through interventions
Cotton	Haryana	Pink bollworm, bacterial leaf blight	August–September	Above ETL in select fields
Maize	Karnataka	Downy mildew	July–August	Localized disease pressure; below epidemic level
Maize	Jammu and Kashmir	Fall armyworm	August–September	Sporadic incidence; vigilant monitoring advised
Groundnut	Maharashtra	White grub	July–August	Localized infestation; managed with timely advisories
Arecanut	Tamil Nadu	Inflorescence caterpillar	August–September	Crop-specific incidence; controlled

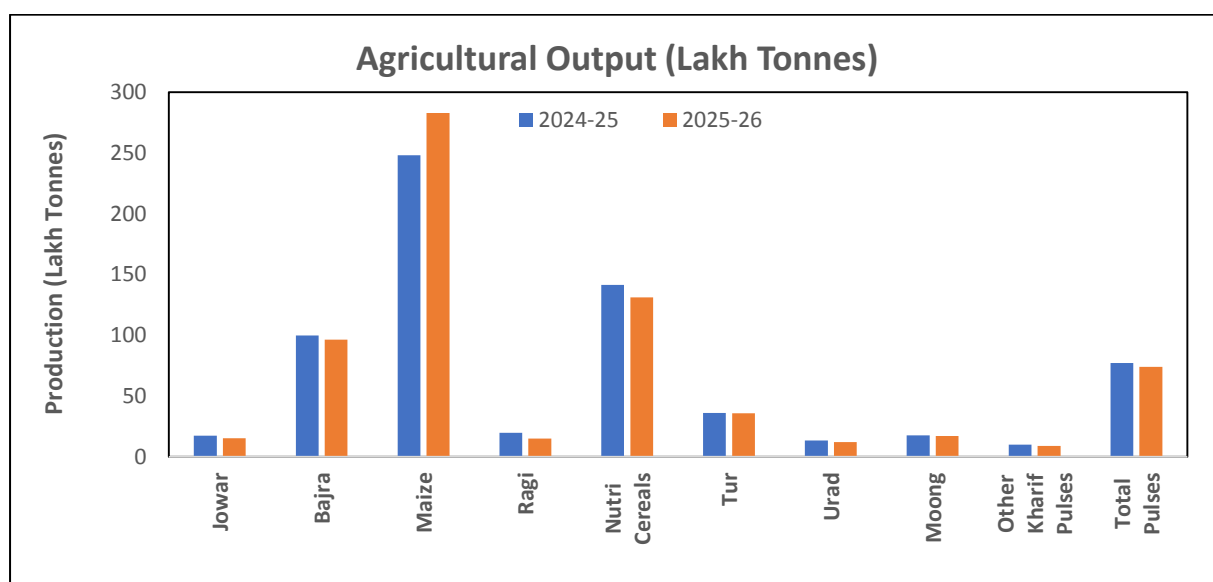
15.3 Impact of Monsoon 2025 on Crop Production

The Southwest Monsoon 2025 was characterized by considerable spatial and temporal variability, resulting in differentiated impacts on *Kharif* crop performance across regions. While near-normal to above-normal rainfall over large parts of Central and Peninsular India supported timely sowing and crop establishment, rainfall deficits in eastern India and episodic excess rainfall in north-western and western regions caused localized stress to *Kharif* crops.

As shown in **Fig. 15.11**, the First Advance Estimates for the agricultural year 2025–26 indicate that total *Kharif* foodgrain production is projected at 1,659.18 lakh tonnes, compared to 1,617.28 lakh tonnes in 2024–25, reflecting an increase of about 2.6 percent. Rice and maize account for much of this increase, supported by improved performance in major producing states. Production of coarse cereals shows mixed trends, with marginal increases in bajra and jowar and slight declines in ragi and small millets.



(a)



(b)

Fig. 15.11: Production of major *kharif* crops in India during 2024-25 and 2025-26 (Source: MoA&FW 2025)

Kharif pulses production during 2025–26 is estimated at 110.93 lakh tonnes, higher than the previous year, primarily due to improved output of tur and urad. In contrast, *Kharif*

oilseed production is projected to decline marginally to 275.63 lakh tonnes, mainly due to reduced soybean production in states affected by excess rainfall and waterlogging. Among commercial crops, sugarcane production is estimated to increase, whereas cotton production shows a slight decline, influenced by pest pressure and unfavourable weather during critical growth stages.

National-level crop production outcomes reflect the combined influence of monsoon behaviour, irrigation support, crop management practices, and policy and market factors. In this context, agrometeorological advisory services supported farm-level decision-making by enabling timely operational adjustments under both deficit and excess rainfall conditions. However, changes in aggregate production, as depicted in **Fig. 15.11**, represent the integrated outcome of multiple drivers and should not be attributed solely to advisory interventions.

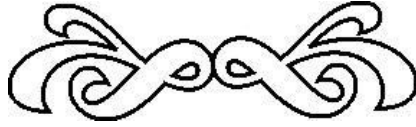
15.4 Success Stories of Farmers

 <p>Mr. Jaspal Singh Village- Lehra Begha, Block - Nathana District- Bathinda, Punjab</p>	<p>In late <i>Kharif</i>, particularly during September, Bathinda district in Punjab experienced episodes of heavy rainfall accompanied by strong winds, posing a high risk of lodging in standing paddy crops. Jaspal Singh benefitted from GKMS impact-based advisories that warned of these conditions in advance. By postponing irrigation, strengthening field drainage, and avoiding unnecessary field operations, he minimized lodging and crop damage. These timely actions helped preserve grain quality and avoided yield losses commonly associated with late-season weather extremes.</p>
 <p>Mr. Manoj Kumar Village- Narol Block - Kullu District-Kullu, Himachal Pradesh)</p>	<p>Across the monsoon and fruit development period in Kullu district of Himachal Pradesh, Manoj Kumar relied on GKMS advisories related to rainfall, hailstorms, and temperature drops. Timely alerts enabled him to plan orchard operations such as irrigation, spraying, and protective measures, thereby reducing weather-induced damage to apple and stone fruits and ensuring stable production over successive seasons. He has realized a remarkable increase in his annual farm income, from ₹1.5 lakh to ₹4.7 lakh in three years, directly attributing this success to agro-advisory guidance.</p>

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16



FORECAST PERFORMANCE OF LOW PRESSURE SYSTEMS DURING MONSOON 2025

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This chapter discusses the low pressure systems formed during the southwest monsoon 2025 and performance of extended and short-to-medium range forecasts for prediction of these low pressure systems.

16.1 Introduction

The monsoon low pressure systems (LPSs) are the fundamental components of the monsoon circulation, which play crucial roles in delivering monsoonal rainfall to various regions of the South Asia especially in India. This process not only brings much-needed rainfall to agriculture-dependent areas but also influences weather patterns of the large-scale monsoon. Monsoon LPSs are known for their ability to produce heavy rain, strong winds, and occasionally severe weather, making them a significant and closely monitored aspect of meteorology. LPSs are synoptic scale cyclonic disturbances that typically develop in the quasi-stationary monsoon trough during the southwest monsoon season (June–September). The study by Jadhav and Munot (2004) analysed the occurrence and duration of LPS during the summer monsoon season over the Indian region from 1891-2000. It highlighted the frequency and distribution of LPS and their impact on rainfall. Jadhav (2002) also examined the relationship between LPS and sub-divisional rainfall in India. The study by Mohapatra (2008) investigated the impact of LPS over the Bay of Bengal and adjoining land regions on sub-divisional rainfall during the summer monsoon season from 1982-1999. It provided insights into how LPS influence rainfall patterns in different meteorological sub-divisions. The study by Thomas et al. (2021) analysed the characteristics of LPS in the

Indian subcontinent and their association with extreme precipitation events. It highlighted that around 60-70% of monsoon rainfall in north, east, and central India is associated with LPS.

Using the NCAR Community Earth System Model (CESM1.2.2), Thomas et al. (2023) investigated how LPS characteristics might change with global warming. It suggested a slight weakening in the monsoon circulation but an increase in mean summer monsoon precipitation. The research study (Krishnamurthy and Ajayamohan, 2010) examined the structure of LPS and their relation to the Indian rainfall. It finds that LPS significantly contribute to the seasonal monsoon rainfall and are closely related to the phases and propagation of the dominant intraseasonal modes of Indian rainfall. The study by Krishnamurthy et al. (1975) is a significant piece of research on monsoon depressions. Godbole (1977) provides a detailed analysis of monsoon depressions using data from five cases during the monsoon season of 1973. The study discussed about composite characteristics of a few key parameters of monsoon depression e.g., Central Pressure, Wind Speed, Horizontal Scale, Temperature, Rainfall, Vertical Extent and Cyclonic Vorticity. The study by Suhas et al., (2024) assessed the historical performance of Global Forecast System (GFS) and Global Ensemble Forecast System (GEFS) models in forecasting LPS genesis, position, intensity, and precipitation rates for lead times of 1 to 5 days. The research by Deoras et al. (2022) explored the role of LPS in sub-seasonal-to-seasonal forecasts. Good forecasts of LPS activity can help mitigate flooding and local water resource crises, as well as develop mitigation strategies for the agricultural sector. This study by Suhas et al. (2024) also evaluated the performance of global ensemble models like GEFS and the European Centre for Medium-Range Weather Forecasts (ECMWF) Ensemble Prediction System in predicting LPS genesis. The study found that these models captured about half of the observed LPS genesis events one to two days in advance. In this chapter, the verification results of operational forecasting of low pressure systems during 2025 summer monsoon season over India has been described including all cyclonic disturbances.

Over the oceanic region, wind strength is used as a criterion for define intensities as well as for the classification of the LPSs. As per criteria of India Meteorological Department (IMD), the LPS is a low-pressure area (LPA) if the wind speed associated with the system is < 17 knots (kt), a depression if the wind speed is 17–27 kt, a deep depression if the wind speed is 28–33 kt, a cyclonic storm if the wind speed is more than or equal to 34 kt. However, over the land and adjoining sea area, the number of closed isobars at 2 hPa interval around the central area of the LPS within 5° (6°) latitude/longitude over the sea (land) is used as a criterion for classification of the intensity of LPS. The LPS is identified as (i) a low, if there is a single closed isobar, (ii) a depression, if there are two closed isobars, (iii) a deep depression, if there are three closed isobars and (iv) a cyclonic storm, if there are

four or more closed isobars. The LPS either form over the Indian subcontinent, the Bay of Bengal and Arabian Sea or develop from the remnants of depressions/storms, over South China Sea and move westwards/northwestwards into the Bay of Bengal (BoB). According to India Meteorological Department (IMD, 2024a) and Sharma & Mohapatra (2017), the cyclonic disturbances have been classified into various categories based on associated maximum sustained wind speed (**Table 16.1**).

These systems usually move west-northwestwards and have a life period of about 3 to 5 days (Sikka, 1978). These are the major rain bearing systems and they contribute to about 50% of the summer rainfall over India and up to 70% of the rainfall along the east coast (Hunt and Fletcher, 2019). The realised seasonal rainfall is presented in **Fig. 16.1**. While low pressure areas (LPAs) help recharge groundwater, cyclonic disturbances (CDs) including depressions, deep depressions and cyclones can cause severe floods, leading to major economic and social problems. The IMD follows a seamless flow of warnings and advisories to predict the genesis, movement, intensity and associated adverse weather including rainfall, winds and storm surge of these LPSs.

Table 16.1: Criteria for classification of cyclonic disturbances over the North Indian Ocean

Type of disturbance	Maximum sustained wind (MSW)
1. Low Pressure Area (LPA)	17 knots (<31 kmph)
2. Depression (D)	17 to 27 knots (31-49 kmph)
3. Deep Depression (DD)	28 to 33 knots (50-61 kmph)
4. Cyclonic Storm (CS)	34 to 47 knots (62-88 kmph)
5. Severe Cyclonic Storm (SCS)	48 to 63 knots (89-117 kmph)
6. Very Severe Cyclonic Storm (VSCS)	64 to 119 knots (118-221 kmph)
7. Super Cyclonic Storm (SuCS)	120 knots and above (≥ 222 kmph)

16.2 Low Pressure Systems of Southwest Monsoon 2025

During 2025 monsoon season, **19 LPSs** including **12 LPAs**, **7 depressions/deep depressions (D/DD)** developed over the North Indian Ocean region and Indian landmass. During the season, the region witnessed formation of LPS on 68 days and 18 hrs. Climatologically, about 13.2 LPSs form over the Indian region per monsoon season and there are about 57 LPS days over the region out of the total of 122 days (Mohapatra, 2007). Increased number of LPSs during monsoon season 2025 led to above normal rainfall (exceeding 104% of the Long Period Average (LPA)). Regionally, three of the four geographical zones recorded above-normal rainfall: Central India (>106% of LPA), Northwest India (>108% of LPA), and the South Peninsula (>106% of LPA). In contrast, East and Northeast India experienced below-normal rainfall, receiving less than 94% of the LPA.

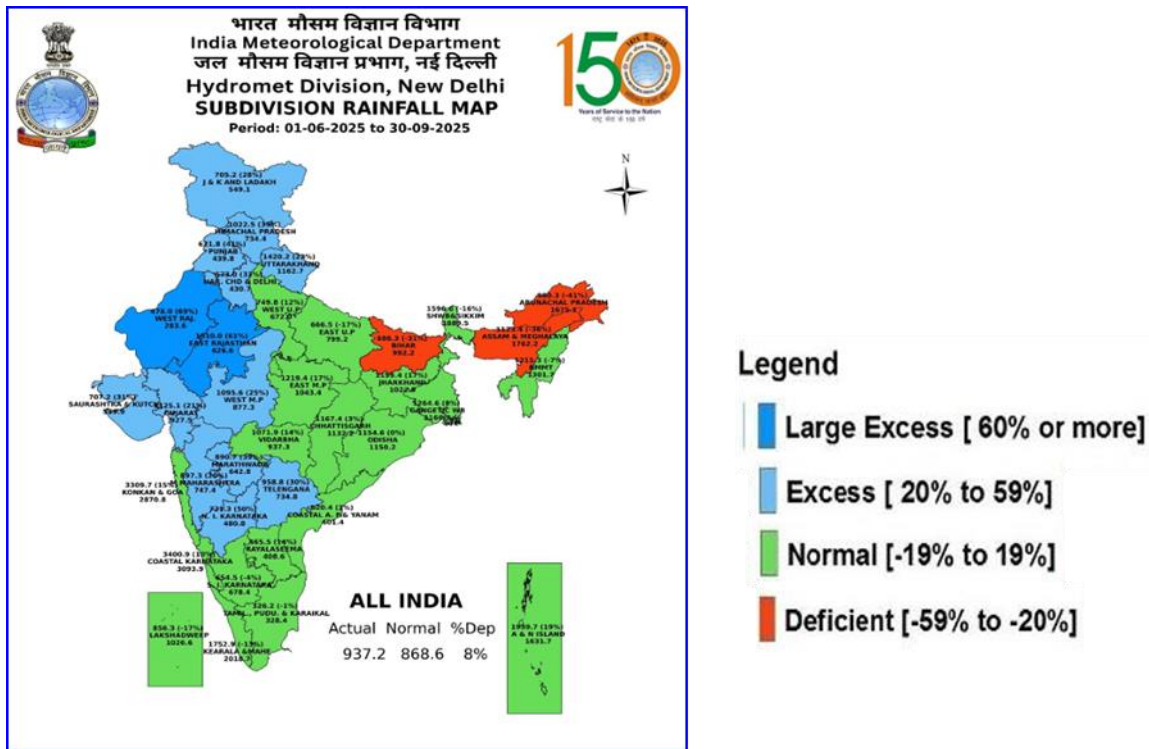


Fig. 16.1: Sub-divisionwise realised rainfall

Following LPSs were observed during the monsoon season 2025 and their details are given in **Table 16.2**:

- i) WML over Gangetic West Bengal during 17th - 23rd June
- ii) LPA over Gujarat region and neighbourhood during 17th - 19th June
- iii) LPA over northwest BoB and adjoining coastal areas of north Odisha and West Bengal during 26th - 27th June
- iv) LPA over Kutch and neighbourhood during 28th - 29th June
- v) LPA over Northwest Bay of Bengal and adjoining West Bengal and Bangladesh coasts during 29th June - 2nd July
- vi) LPA over Gangetic West Bengal and neighbourhood during 6th - 11th July
- vii) Depression over southeast Gangetic West Bengal & adjoining Bangladesh during 13th - 15th July
- viii) Depression over central parts of north Rajasthan during 13th - 17th July
- ix) Depression over southeast Uttar Pradesh during 15th - 21st July
- x) Depression over northwest BoB and adjoining areas of coastal West Bengal and Bangladesh during 24th - 29th July

- xi) LPA over westcentral & adjoining northwest BoB off north coastal Andhra Pradesh and south Odisha coasts during 13th – 18th August
- xii) Depression over northwest & adjoining westcentral BoB off north Andhra Pradesh - south Odisha coasts during 17th – 18th August
- xiii) LPA over Gangetic West Bengal and neighbourhood during 22nd - 25th August
- xiv) WML over northwest BoB off Odisha coast during 26th – 29th August
- xv) WML over Northwest BoB during 2nd – 4th August
- xvi) DD over North Gujarat and adjoining Southwest Rajasthan during 5th – 12th September
- xvii) LPA over northwest & adjoining westcentral BoB off south Odisha-north Andhra Pradesh coasts during 12th 15th September
- xviii) LPA over northeast BoB and neighbourhood during 22nd – 24th September
- xix) Depression over northwest and adjoining westcentral BoB off South Odisha-North Andhra Pradesh coasts during 25th September – 1st October

Table 16.2: Details of LPS (LPA to LPA) during the monsoon season June to September

S. No.	Systems	Period	Date/ Time/Area of Genesis of LPA	Date/ Time/Area of weakening	Life Period
1	WML over Gangetic West Bengal	17-23 June	17.6.25/0530 hrs IST / Southwest Bangladesh and adjoining Gangetic West Bengal.	23.6.25/0530 hrs IST / central parts of south Uttar Pradesh	6 days
2	LPA over Gujarat region and neighbourhood	17-19 June	17.6.25/0530 hrs IST / Gujarat region and neighbourhood	19.6.25/0530 hrs IST / South Rajasthan	2 days
3	LPA over northwest BoB and adjoining coastal areas of north Odisha and West Bengal.	26-27 June	26.6.25/0830 hrs IST / northwest BoB and adjoining coastal areas of north Odisha and West Bengal	27.6.25/0830 hrs / north Odisha and adjoining Gangetic West Bengal	1 day
4	LPA over Kutch and neighbourhood	28- 29 June	28.6.25/0830 hrs IST / Kutch and neighbourhood.	29.6.25/0830 hrs / Saurashtra & Kutch and adjoining south Rajasthan.	2 days
5	LPA over Northwest BoB and adjoining West	29 June – 02 July	29.6.25/0530 hrs IST / Northwest BoB and adjoining	02.07.25/ 0530 hrs / Southwest Jharkhand and	3 days

	Bengal & Bangladesh coasts.		West Bengal & Bangladesh coasts.	neighbourhood	
6	LPA over Gangetic West Bengal and neighbourhood	06-11 July	06.7.25/0830 hrs IST/ Gangetic West Bengal and neighbourhood	11.07.25/ 0530 hrs / South Jharkhand & neighbourhood	4 days and 21 hrs
7	Depression over southeast Gangetic West Bengal & adjoining Bangladesh	13-15 July	13.7.25/1730 hrs IST/ North BoB and adjoining coastal areas of Bangladesh, West Bengal & north Odisha	15.07.25/ 0830 hrs / north Jharkhand & adjoining south Bihar (maintained its intensity of WML and re-intensified into a depression as given at SN 9)	1 day and 15 hrs
8	Depression over central parts of north Rajasthan	13 –17 July	13.7.25/1730 hrs IST/ northwest Madhya Pradesh & neighbourhood	17.7.25/0530 hrs IST/ Central Pakistan & adjoining northwest Rajasthan	3 days and 12 hrs
9	Depression over southeast Uttar Pradesh	15-21 July	15.07.25/ 0830 hrs IST as WML (remnant of SN7) southwest Bihar & adjoining southeast Uttar Pradesh	21.7.25/0530 hrs IST/ West Rajasthan and adjoining Pakistan	5 days and 21 hrs
10	Depression over northwest BoB and adjoining areas of coastal West Bengal & Bangladesh	24 – 29 July	24.07.25/ 0530 hrs IST North BoB	29.7.25/1730 hrs IST/ Northwest Madhya Pradesh and neighbourhood	5 days and 12 hrs
11	LPA over Westcentral and adjoining northwest BoB off north coastal Andhra Pradesh & south Odisha coasts	13-18 August	13.8.25/0530 hrs IST / Westcentral and adjoining northwest BoB off north coastal Andhra Pradesh and south Odisha coasts	18.8.25 / 0530 hrs IST/ Vidarbha & neighbourhood	5 days
12	Depression over Northwest & adjoining Westcentral BoB off north Andhra Pradesh - south	17 - 18 August	17.8.25/ 0830 hrs IST / Westcentral and adjoining Northwest BoB off north coastal Andhra Pradesh and south Odisha	20.8.25 / 0830 hrs IST/ southeast Madhya Pradesh & neighbourhood	3 days

	Odisha coasts		coasts		
13	LPA over Gangetic West Bengal and neighbourhood	22– 25 August	22.8.25/01730 hrs IST/ Gangetic West Bengal and neighbourhood	25.8.25 / 0830 hrs IST/ central parts of south Uttar Pradesh & adjoining north Madhya Pradesh	3 days and 12 hrs
14	WML over Northwest BoB off Odisha coast	26-29 August	26.8.25/0530 hrs IST/ northwest BoB off Odisha coast	29.8.25 / 0530 hrs IST/ southeast Madhya Pradesh and neighbourhood	3 days
15	WML over Northwest BoB	02- 04 September	02.9.25/0530 hrs IST/ Northwest BoB	04.9.25 / 0530 hrs IST/ North Chhattisgarh & neighbourhood	2 days
16	DD over North Gujarat and adjoining Southwest Rajasthan	05 – 12 September	05.9.25 / 0830 hrs IST/WML over central parts of West Madhya Pradesh and adjoining East Rajasthan	12.9.25 / 0530 hrs IST/ northwest Arabian Sea	6 days and 21 hrs
17	LPA over northwest & adjoining westcentral BoB off south Odisha-north Andhra Pradesh coasts	12 -1 5 September	12.9.25/0830 hrs IST LPA over northwest & adjoining westcentral BoB off south Odisha-north Andhra Pradesh coasts	15.9.25 / 0530 hrs IST/ north Telangana & adjoining Vidarbha	2 days and 21 hrs
18	LPA over northeast BoB and neighbourhood	22 - 24 September	22.9.25/0530 hrs IST/ northeast BoB & neighbourhood	24.9.25/1730 hrs IST/ north Odisha and adjoining areas of northwest Bay of Bengal & Gangetic West Bengal	2 days and 12 hrs
19	D Depression over northwest and adjoining westcentral BoB off South Odisha-North Andhra Pradesh coasts	25 September- 1 October	25.9.25/1730 hrs IST/ central parts of north and adjoining central BoB	01.10.25/0830 hrs IST WML over Northeast AS and then intensified into SCS Shakhti	5 days and 15 hrs

16.3 Monitoring and Forecasting Mechanism

Every Thursday, IMD issues an extended range outlook which provides information about likely formation of LPS and cyclogenesis (formation of depression) valid for next 2 weeks. This serves as the first triggering mechanism to the forecasters and disaster managers. It is followed by regular 6 hourly bulletins issued by National Weather Forecasting Centre (NWFC) for national users and daily Tropical Weather Outlook for the member countries of World Meteorological Organisation/Economic and Social Commission for Asia & Pacific (WMO/ESCAP) Panel on Tropical Cyclones (PTC) and severe weather guidance under WMO's Severe Weather Forecasting Programme (SWFP) by Regional Specialised Meteorological centre (RSMC) New Delhi.

On formation of low-pressure area, a special message is issued daily by NWFC, concerned Meteorological Centres (MCs), Cyclone Warning Centres (CWCs) and Area Cyclone Warning Centres (ACWCs) with information about the LPS, associated adverse weather, impact-based warnings, damage expected and subsequent action suggested. In case there is likelihood of intensification of this LPS into a cyclonic storm, pre-genesis track & intensity forecast is issued for next 72 hours from the stage of LPA. On its intensification into a depression, the frequency of advisories and warnings is further increased and advisories are issued 5 times a day based on 0530, 0830, 1130, 1730 and 2330 hrs IST. On further intensification into a cyclonic storm every 3 hourly updates are issued based on 0230, 0530, 0830, 1130, 1430, 1730, 2030 and 2330 hrs IST. On the day of landfall, hourly updates are issued till the system maintains the intensity of cyclonic storm after landfall (IMD, 2024).

During monsoon season 2025, all cyclonic disturbances were monitored round the clock. IMD utilised all available resources including observations from various national & international satellites, radars, conventional & automatic weather stations & rain-gauges, ships, buoys, coastal & island observations to monitor the LPSs. For prediction of track and intensity, multi-model ensemble (MME) approach was adopted. IMD utilised all available models global & regional, deterministic and ensemble based and cyclonic specific model blended with forecasters experience & expertise to predict the path and intensity of these LPSs.

16.4 Life history of LPSs during 2025 southwest monsoon season

16.4.1 WML over Gangetic West Bengal during 17th –23rd June

A cyclonic circulation formed over westcentral BoB off north Coastal Andhra Pradesh coast on 14th June, 2025. It merged with the upper air cyclonic circulation over Northwest BoB & neighbourhood on 15th June, 2025. Under its influence, a low-pressure area formed over Southwest Bangladesh and adjoining Gangetic West Bengal on 17th June 2025. It

further intensified into a well-marked low pressure area over Gangetic West Bengal on 18th June 2025. It moved slowly northeastwards across Northeast Jharkhand on 19th and weakened into a low pressure area over south Bihar & neighborhood on 20th June 2025. It further moved northwestwards and lay over central parts of south Uttar Pradesh on 22nd June 2025 and became less marked on 23rd June 2025.

The extended range outlook (EROC) issued on 5th June for week 2 (13th June–19th June) indicated likely formation of a cyclonic circulation/low pressure area over north and adjoining central BoB during first half of week 2. Similarly, the EROC, issued on 12th June for week 1 (13th June–19th June) indicated likelihood of the formation of an upper-air cyclonic circulation over the northwest BoB towards the middle of week 1.

16.4.2 LPA over Gujarat region and neighbourhood during 17th -19th June

An upper air cyclonic circulation formed over central parts of Konkan and adjoining eastcentral AS on 15th June 2025. Under its influence, a low-pressure area formed over Gujarat region & neighbourhood on 17th June 2025. It moved nearly northwards and became less marked over south Rajasthan on 19th June 2025.

The EROC issued on 12th June for week 1 (13th June–19th June) indicated likelihood of the formation of an upper air cyclonic circulation over eastcentral AS. However, formation of low pressure area was not predicted. The Tropical Weather Outlook (TWO) issued on 16th June indicated likely formation of low pressure area over south Gujarat & neighbourhood around 17th June.

16.4.3 LPA over northwest BoB and adjoining coastal areas of north Odisha and West Bengal during 26th – 27th June

Under the influence of an upper-air cyclonic circulation over northwest BoB and adjoining coastal areas of north Odisha and West Bengal, an LPA formed over the same region at 0830 hrs IST of 26th June 2025. It became less marked over north Odisha and adjoining Gangetic West Bengal at 0830 hrs IST of 27th June 2025. It was not predicted in extended and medium range forecast.

16.4.4 LPA over Kutch and neighbourhood during 28th – 29th June

An upper air cyclonic circulation lay over Saurashtra & Kutch & adjoining northeast AS at 0530 hrs IST and under its influence, an LPA formed over Kutch & neighbourhood at 0830 hrs IST of 28th June, 2025. It became less marked over Saurashtra & Kutch and adjoining south Rajasthan at 0830 hrs IST of 29th June 2025. It was not predicted in extended and medium range forecast.

16.4.5 LPA over Northwest BoB and adjoining West Bengal & Bangladesh coasts during 29th June – 02nd July

An upper air cyclonic circulation formed over southwest Bangladesh & adjoining Gangetic West Bengal on 28th June, 2025. Under its influence an LPA formed over Northwest BoB and adjoining West Bengal and Bangladesh coasts at 0530 hrs IST of 29th June. It moved slowly west-northwestwards across North Odisha, Gangetic West Bengal & Jharkhand and became less marked over South Jharkhand at 0530 hrs IST of 2nd July.

The EROC issued on 19th June for week 2 (27th June–03rd July) indicated likelihood of formation of an upper-air cyclonic circulation over North BoB and adjoining West Bengal & Bangladesh towards end of week 1 (around 26th June) and an LPA over the same region around 27th June. The same was not reiterated in subsequent EROC issued on 26th June. In medium range forecast, the TWO issued on 27th June indicated likely development of an upper-air cyclonic circulation over north BoB and adjoining coastal Bangladesh & West Bengal around 29th June, 2025 and formation of LPA over the same region around 30th June.

16.4.6 LPA over Gangetic West Bengal and neighbourhood during 6th – 11th July

An upper air cyclonic circulation lay over northern parts of Gangetic West Bengal & neighbourhood at 0830 hrs IST of 05th July 2025 and under its influence, an LPA formed over Gangetic West Bengal & neighbourhood at 0830 hrs IST of 06th July. It moved west-northwestwards and lay over Gangetic West Bengal and adjoining Jharkhand at 0830 hrs IST of 09th July and over south Jharkhand & neighbourhood at 0830 hrs IST of 10th July and became less marked at 0530 hrs IST of 11th July 2025.

The EROC issued on 26th June for week 2 (04th -10th July) indicated formation of an upper-air cyclonic circulation/low pressure area over the north BoB with west-northwestwards movement during the week. Subsequent EROC issued on 03rd July for the week 1 (04th -10th July) indicated likelihood of the formation of an upper-air cyclonic circulation over north BoB and adjoining coastal West Bengal & Bangladesh around 6th July. In the medium range, the TWO issued on 5th July, indicated likely formation of low pressure area over Gangetic West Bengal & neighbourhood around 06th July, 2025.

16.4.7 Depression over southeast Gangetic West Bengal & adjoining Bangladesh during 13th – 15th July

An upper air cyclonic circulation formed over northwest BoB and adjoining West Bengal-North Odisha coasts at 1730 hrs IST of 12th July. Under its influence, an LPA formed over the same region at 1730 hours IST of 13th July. It lay as a Well-Marked Low-Pressure Area over southwest Bangladesh and adjoining Gangetic West Bengal at 0530 hrs IST of 14th

July. It concentrated into a Depression over the same region at 1130 hrs of 14th July. It moved west-northwestwards across Gangetic West Bengal and Jharkhand on 14th and 15th July and weakened into a WML over north Jharkhand and adjoining south Bihar at 0830 hrs IST of 15th July 2025. It moved west-northwestwards across southwest Bihar and Uttar Pradesh and was monitored further for re-intensification.

The EROC issued on 3rd July, indicated likely formation of an upper-air cyclonic circulation over the north BoB and adjoining coastal West Bengal-Odisha and Bangladesh during the week (11th – 17th July). The first special message issued at 1230 hrs IST of 14th July indicated further intensification of the system into a depression on 14th July. Thus, formation of cyclonic circulation over northwest BoB and adjoining West Bengal-North Odisha was predicted well in week 2 forecast (about 9 days ahead) with some spatial variations. However, formation of depression was not captured.

16.4.8 Depression over central parts of north Rajasthan during 13th – 17th July

The low pressure system over northeast Rajasthan and adjoining northwest Madhya Pradesh lay as a well-marked low pressure area over North Rajasthan at 0830 hrs IST of July 14, 2025. It intensified into a depression over the central parts of northern Rajasthan at 0530 hrs IST of 15th July. It moved nearly north-northwestwards and weakened into a WML on 16th July over northwest Rajasthan and into a low pressure area over central Pakistan & adjoining Northwest Rajasthan at 1730 hrs IST of 16th July. It became less marked over central Pakistan on 17th July, 2025. It was not predicted in the extended or medium range forecast.

16.4.9 Depression over southeast Uttar Pradesh during 15th- 21st July

It developed from the remnant WML over southeast Uttar Pradesh of the depression that developed over Southeast Gangetic West Bengal and adjoining Bangladesh on 14th July. It moved nearly west-northwestwards and intensified into a depression over Southeast Uttar Pradesh by 0530 hrs IST 17th July. It continued to move west-northwestwards and reached over northwest Madhya Pradesh at 0530 hrs IST of 18th July. It moved westwards across northwest Madhya Pradesh till 1130 IST of 18th July. Thereafter, it moved again nearly west-northwestwards and reached upto northwest and adjoining northeast Rajasthan as a depression by 0830 hrs IST of 19th July. Then, it moved westwards across west Rajasthan nearly for a day and weakened into a WML over west Rajasthan and adjoining Pakistan at 0530 hrs IST of the 20th July.

16.4.10 Depression over northwest BoB and adjoining areas of coastal West Bengal and Bangladesh during 24th - 29th July

An upper air cyclonic circulation (remnant of WIPHA) emerged into the North BoB and it intensified into an LPA over the same region at 0530 hrs IST of 24th July. It lay as a WML over North BoB at 1730 hrs IST of 24th July. It intensified into a Depression over Northwest BoB and adjoining areas of coastal West Bengal and Bangladesh at 0530 hrs IST of 25th July. It moved west-northwestwards and crossed West Bengal & adjoining Bangladesh coasts between 0730 and 0830 hrs IST of 25th July. It moved west-northwestwards across Gangetic West Bengal, North Odisha, Jharkhand, then moved nearly westwards across Madhya Pradesh and weakened into a WML over northwest Madhya Pradesh and neighbourhood at 0530 hrs IST of 27th July. It then moved across Madhya Pradesh and weakened into an LPA over northwest Madhya Pradesh & adjoining east Rajasthan at 0530 hrs IST of 28th July and less marked over northwest Madhya Pradesh & neighbourhood at 1730 hrs IST of 29th July.

The EROC issued on 17th July for week 2 (25th -31st July) indicated likelihood of the formation of an LPA over North BoB and adjoining coastal Bangladesh & West Bengal towards the beginning of week 2 (around 24th/25th July) with low probability of its intensification into a depression in the beginning of week 2 and its likely west-northwestwards during subsequent 2-3 days. Subsequent forecast issued on 24th July for the week 1 (25th -31st July) indicated west-northwestwards movement of the low pressure area over North Bay of Bengal and its intensification into a depression over coastal areas of West Bengal and Bangladesh on 25th July. Hence, the formation of Depression over northwest Bay of Bengal and adjoining areas of coastal West Bengal and Bangladesh was predicted well, two weeks in advance. In the medium range, the first information about likely formation of a low pressure area over north BoB around 24th July, 2025 was indicated in the daily TWO on 19th July. The TWO issued on 22nd July indicated low probability of formation of depression around 25th-26th July.

16.4.11 LPA over westcentral & adjoining northwest BoB off north coastal Andhra Pradesh and south Odisha coasts during 13th – 18th August

An upper air cyclonic circulation lay over the central parts of BoB on 12th August. Under its influence, an LPA formed over westcentral & adjoining northwest BoB off north Andhra Pradesh & adjoining south Odisha coasts on 13th August. It moved west-northwestwards and lay over South Odisha & adjoining North Andhra Pradesh coasts at 0830 hrs IST of 15th August. It further moved across south Chhattisgarh & Vidarbha and became less marked over Vidarbha & neighbourhood at 0530 hrs IST of 18th August 2025.

The EROC issued on 7th August (about 6 days prior) for week 1 (08.08.2025-14.08.2025) indicated likely formation of an LPA over the northwest BoB off the Odisha coast around 13th August, 2025. In the medium range, the TWO issued on 8th August further reiterated the forecast and indicated formation of an LPA over northwest & adjoining westcentral BoB around 13th August, 2025.

16.4.12 Depression over northwest & adjoining westcentral BoB off north Andhra Pradesh - south Odisha coasts during 17th – 18th August

An LPA formed over westcentral and adjoining northwest BoB off north Andhra Pradesh & south Odisha coasts at 0300 UTC of 17th August. It became a WML over westcentral & adjoining northwest BoB and north Andhra Pradesh - south Odisha coasts at 0530 hrs IST of 18th August. It moved northwestwards and concentrated into a depression over northwest & adjoining westcentral BoB and north Andhra Pradesh at 1730 hrs IST of 18th August. It crossed South Odisha coast close to Gopalpur during early morning of 19th August and weakened into a WML over central parts of Chhattisgarh & neighbourhood at 1730 hrs IST of 19th August. It further moved west-northwestwards and weakened into a low-pressure area over central parts of Chhattisgarh and adjoining east Madhya Pradesh at 0530 hrs IST and became less marked at 0830 hrs IST of 20th August.

The EROC issued on 14th August indicated likely development of an upper air cyclonic circulation /low pressure area over north BoB around 17th August. In the medium range, the tropical weather outlook (TWO) issued on 16th August further reiterated the forecast. The formation of LPA over northwest and adjoining westcentral BoB around 17th August and its west-northwestwards movement, intensification into a WML in the morning of 18th August, and its further intensification into a depression during subsequent 12 hours was predicted. On 17th/ 0830 hrs IST, it was also predicted to cross south Odisha-north Andhra Pradesh coasts around 0830 hrs IST of 19th August, 2025. Hence all the features including formation of LPA, its intensification, landfall time and location and its weakening were well predicted.

16.4.13 LPA over Gangetic West Bengal and neighbourhood during 22nd - 25th August

An upper air cyclonic circulation lay over northwest BoB & adjoining areas of north Odisha and Gangetic West Bengal at 0530 hrs IST of 21st August, 2025. It lay over north Odisha and adjoining Gangetic West Bengal at 0830 hrs IST of 21st August. Under its influence, an LPA formed over Gangetic West Bengal & neighbourhood at 1730 hrs IST of 22nd August, 2025. It moved west-northwestwards and lay over northeast Madhya Pradesh & neighbourhood at 0830 hrs IST of 24th August and became less marked over central parts of south Uttar Pradesh & adjoining north Madhya Pradesh at 0830 hrs IST of 25th August, 2025.

The EROC issued on 14th August for week 2 (22.08.2025-28.08.2025) indicated the likelihood of formation of cyclonic circulation/low pressure area over Gangetic West Bengal-north Odisha coasts and adjoining areas of northwest BoB during the end of week 2 (around 27th August) with gradual west-northwestwards movement across Jharkhand.

16.4.14 WML over northwest BoB off Odisha coast during 26th – 29th August

An LPA formed over northwest BoB off Odisha coast in the morning of 26th August. It became a WML over the same region at 0530 hrs IST of 27th August. It further moved slowly west-northwestwards and weakened into an LPA over South Odisha and adjoining Chhattisgarh at 0530 hrs IST of 28th August 2025. It became less marked over southeast Madhya Pradesh & neighbourhood at 0530 hrs IST of 29th August 2025.

The EROC issued on 21st August for week 1 (22.08.2025-28.08.2025) indicated likelihood of the development of an LPA over northwest BoB off Odisha-West Bengal coasts around 25th August with low probability of its intensification into a depression over north Odisha and adjoining northwest Bay of Bengal & Gangetic West Bengal around 27th August and its likely west- northwestwards movement across north Odisha & adjoining Jharkhand, North Chhattisgarh and east Madhya Pradesh during subsequent 2 days. Further, the formation of low-pressure area over the northwest BoB off Odisha coast and its low probability of intensification into a depression was predicted over the same region around 27th August. However, the Low-pressure area intensified into WML on 27th August and weakened into a low-pressure area over South Odisha adjoining Chhattisgarh.

In the medium range, formation of an LPA over northwest BoB off Odisha-West Bengal coasts around 25th August 2025 was predicted in the TWO issued on 22nd August. Further the forecast was updated / reiterated on 25th August, indicating formation of an LPA over northwest BoB off Odisha-West Bengal coasts by 27th August.

16.4.15 WML over Northwest BoB during 2nd – 4th August

Under the influence of the upper air cyclonic circulation over northeast BoB & adjoining Myanmar coast, an LPA formed over Northwest BoB at 0530 hrs IST of 02nd September. It became a WML over the same region at 0530 hrs IST of 03rd September. It moved west-northwestwards and weakened into an LPA over north Chhattisgarh and neighbourhood at 0530 hrs IST of 04th September.

The EROC issued on 21st August for week 2 (29.08.2025-04.09.2025) indicated likelihood of formation of a cyclonic circulation/low pressure area over northwest BoB off Odisha-West Bengal coasts during week 2. Subsequent EROC issued on 28th August for week 1 (29.08.2025-04.09.2025) indicated the likelihood of formation low pressure area over the north BoB around 3rd September. In the medium range, First information regarding likely

formation of an LPA over northwest BoB around 2nd September was issued on 1st September and it becoming marked over the same region was indicated on 2nd September.

16.4.16 DD over North Gujarat and adjoining Southwest Rajasthan during 5th – 12th September

Remnant of the WML over Northwest Bay of Bengal moved west-northwestwards weakened into a low-pressure area over north Chhattisgarh and neighbourhood at 0530 hrs IST of 04th September. It further moved west-northwestwards and lay as a WML over central parts of West Madhya Pradesh and adjoining East Rajasthan at 0830 hrs IST of 5th September, thereafter into a depression at 2330 hrs IST of 06th September and further into a deep depression over North Gujarat and adjoining Southwest Rajasthan at 1130 hrs IST of 07th September. It weakened into a depression at 2330 hrs IST of 08th September over Southeast Pakistan and adjoining Rajasthan. The system moved south-southwestwards across south Pakistan and emerged into northeast AS & adjoining south Pakistan at 0530 hrs IST of 10th September. It further moved nearly westwards and weakened into a WML over northwest AS and adjoining southwest Pakistan at 0530 hrs IST of 11th September and into an LPA over the same region at 1730 hrs IST of 11th September. It became less marked over northwest Arabian Sea at 0530 hrs IST of 12th September.

The EROC issued on 28th August, indicated an LPA over the north BoB around 3rd September, 2025. Thereafter, the system was indicated to move west-northwestwards across the northwest BoB, the coastal areas of West Bengal & north Odisha, and intensify into a depression around 5th September. Subsequent EROC issued on 4th September, indicated west-northwestwards movement of the system along the seasonal monsoon trough during next 48 hours with high probability of its intensification into a well-marked low pressure area over South Rajasthan & adjoining North Gujarat during middle of week 1 and low probability of its further intensification into a depression over Gujarat & neighbourhood. In the medium range forecast, the TWO based on 0830 hrs IST of 05.09.2025 (2 days prior), formation of Depression over South Rajasthan and adjoining North Gujarat was indicated.

16.4.17 LPA over northwest & adjoining westcentral BoB off south Odisha-north Andhra Pradesh coasts during 12th - 15th September

A low-pressure area formed over northwest & adjoining westcentral BoB off south Odisha - North Andhra Pradesh coasts at 0830 hrs IST of 12th September. It moved west-northwestwards and became less marked over north Telangana & adjoining Vidarbha at 0530 hrs IST of 15th September.

The EROC issued on 4th September for week 2 (12.09.2025-18.09.2025) indicated likelihood of formation of a fresh LPA over northwest & adjoining westcentral BoB during first

half of week 2 (around 13th September). Subsequently the forecast was updated regarding likely formation of an LPA over westcentral BoB and adjoining areas of north Andhra Pradesh & south Odisha coasts during next 2 days.

16.4.18 LPA over northeast BoB and neighbourhood during 22nd – 24th September

An upper air cyclonic circulation formed over north Andaman Sea & adjoining Myanmar coast on 18th September/ 1730 hrs IST. It became an LPA over northeast BoB and neighbourhood on 22nd September/0530 hrs IST. It became less marked on 24th September/ 1730 hrs IST over North Odisha and adjoining areas of Northwest Bay of Bengal & Gangetic West Bengal.

The EROC issued on 18th September indicated, that the upper air cyclonic circulation over North Andaman Sea and adjoining Myanmar coast is likely to move slowly north-northwestwards along Myanmar coast and reach eastcentral & adjoining northeast BoB off Myanmar coast by 21st September. Thereafter, it is likely to move northwestwards across north BoB and under its influence, an LPA is likely to form over north BoB around 23rd September. The forecast was reiterated in medium range indicating likely formation of an LPA over north BoB around 22nd September

16.4.19 Depression over northwest and adjoining westcentral Bo B off South Odisha-North Andhra Pradesh coasts during 25th September – 1st October

An upper air cyclonic circulation formed over coastal areas of central Myanmar and adjoining eastcentral Bay of Bengal in the middle tropospheric levels at 0830 hrs IST of 24th September. Under its influence, an LPA formed over central parts of north and adjoining central Bay of Bengal at 1730 hrs IST of 25th September. Moving westwards, it lay as a WML over northwest and adjoining central BoB at 0530 hrs IST of the 26th September. It further moved west-northwestwards and concentrated into a depression over northwest and adjoining westcentral Bay of Bengal off South Odisha- North Andhra Pradesh coasts at 1730 hrs IST of 26th September. It crossed south Odisha coast close to Gopalpur around 0430 hrs IST of 27th September. It moved nearly westwards across south Chhattisgarh & Vidarbha and weakened into a WML over West Vidarbha and adjoining North Madhya Maharashtra at 0830 hrs IST of 28th September 2025 and emerged into Gulf of Cambay at 0530 IST of 29th September. It delayed the withdrawal of monsoon from northwest & central India. It caused vigorous rainfall activity over Odisha, Andhra Pradesh, Telangana, Rayalaseema, Vidarbha, Maharashtra, Konkan & Goa, Madhya Pradesh, Rajasthan, Gujarat during 26th - 28th September.

The EROC issued on 11th September indicated likelihood of formation of a fresh upper air cyclonic circulation/low-pressure area over westcentral & adjoining northwest BoB

during first half of week 2 (around 20th September). Subsequently, on 18th September, it was indicated that, an LPA would form over northwest BoB around 26th with moderate (34-67%) probability of formation of depression during 26th-29th September. The advisory was further reiterated and the daily tropical weather outlook issued on 21st September, indicated low probability (1-33%) of formation of depression by 26th/ 0830 hrs IST and moderate probability (34-67%) by 27th/0830 hrs IST. Similar forecast was reiterated in the TWO issued on 20th and 21st September. The TWO issued on 20th September indicated, emergence of an LPA into eastcentral & adjoining northeast BoB off Myanmar- Bangladesh coasts around 25th September, 2025 and its cyclogenesis (formation of Depression) over northwest and adjoining westcentral Bay of Bengal off South Odisha- North Andhra Pradesh coasts around 26th September with its crossing on 27th September.

16.5 Forecast Performance

The verification of the genesis of LPSs during the monsoon season 2025 in extended range scale is presented in Section 16.5.1 and verification of heavy rainfall (≥ 7 cm) during LPS days is presented in Section 16.5.2.

16.5.1 Verification of Genesis

The skill scores in the extended range scale for week 1 and week 2 in predicting the genesis of LPSs are presented in **Fig. 16.2**. The results are presented below:

- (a) The frequency bias index (FBI) which is a measure of over-estimation or under-estimation shows that during 2025, the FBI was 0.85 in week 1, indicating a tendency to under-forecast events, whereas it increased to 1.08 in week 2, suggesting slight overestimation of event frequency.
- (b) The Probability of Detection (POD) which represents the fraction of observed events that are correctly predicted, was 0.69 in week 1, indicating that about 69% of observed events were correctly forecast. It improved to 0.77 in week 2, reflecting a better detection of events.
- (c) The False Alarm Ratio (FAR) which is a measure of the proportion of forecast events that did not actually occur, i.e., how often the forecast gives a false alarm was 0.18 in week 1, indicating relatively fewer false alarms, and it increased to 0.29 in Week 2,
- (d) The Critical Success Index (CSI) measures the overall accuracy of event forecasts, considering hits, misses, and false alarms, while excluding correct negatives. The CSI was 0.60 in week 1 and slightly decreased to 0.59 in week 2, indicating almost similar overall forecast skill, with a marginal decline in performance in week 2.

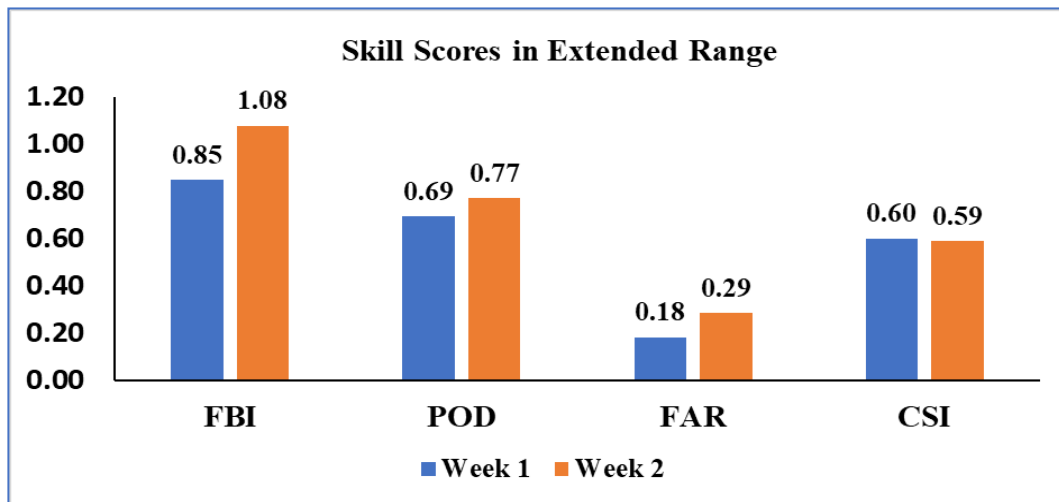


Fig. 16.2: Skill scores in the extended range forecast of genesis of LPSs during southwest monsoon season 2025

The skill scores in medium range forecast of LPSs for day 1 to day 5 is presented in Fig. 16.3. Results indicate that in medium range, the day 2 forecast (24-48 hrs ahead) has FBI of 1 (indicating unbiased forecast), POD as 0.78 (indicating 78% events are successfully detected) with a FAR of 22% and highest CSI of 0.64 among the forecast of all lead periods.

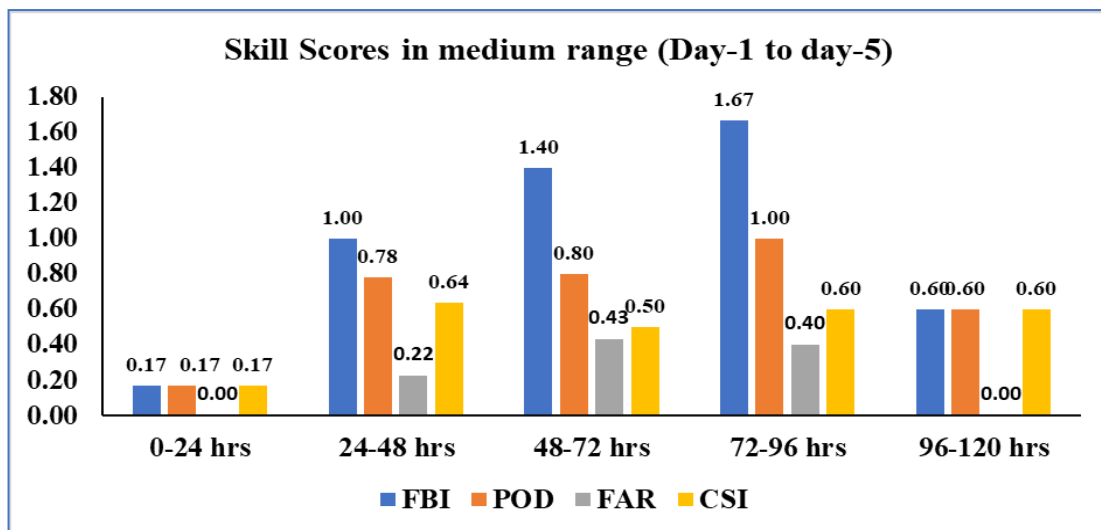


Fig. 16.3: Skill scores in the medium range forecast of genesis of LPSs during southwest monsoon season 2025

16.5.2 Verification of heavy rainfall

The verification of heavy rainfall predicted during LPS days has been carried out and results indicate that operationally, the probability of detection of heavy rainfall was 84%,

77%, 71%, 68% and 63% with percentage correct of 74%, 73%, 71%, 71% and 68% for lead periods of 24, 48, 72, 96 and 120 hrs, respectively (Fig. 16.4).

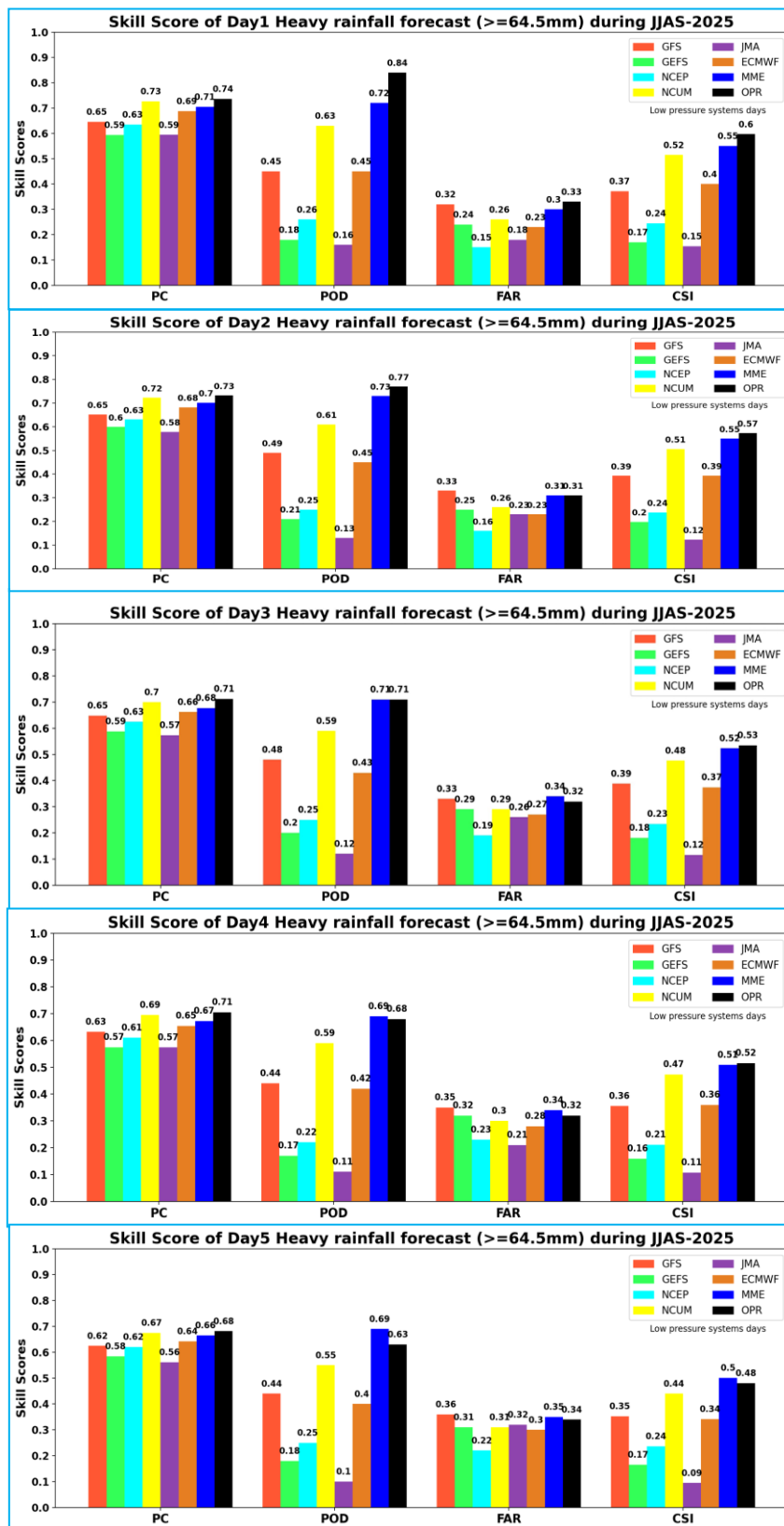


Fig. 16.4: Heavy rainfall verification skill score during LPS days in the southwest monsoon season 2025

16.6 Gap areas and challenges

Though there has been significant improvement in forecast accuracy of track, intensity and landfall point & time predictions of TCs in recent decades, there are still gaps and challenges in predicting the genesis, movement and intensity of weaker LPSs including LPA and depression/DD. Following are the major gap areas and challenges:

- (i) Predicting genesis of LPAs and depressions is still a challenge
- (ii) Understanding the internal dynamics of an LPS is still a challenge due to insufficient data. Predicting rapid intensity changes and landfall events, including heavy rainfall and storm surge, is still a global challenge due to the complexities near the coast.
- (iii) Predicting heavy rainfall is still a challenge. Despite all developments in models, the FAR is still 33% for all lead periods upto 5 days.
- (iv) IMD's risk-based warning systems face integration challenges, and there is a strong need for more localized, personalized warnings to improve accuracy and meet community needs.

16.7 Future Plans

No LPS should go undetected and unpredicted at least 7 days in advance and 20 days ahead by 2047 (IMD, 2024b). To improve the accuracy in prediction of genesis, track, intensity, landfall and associated adverse weather the following initiatives are required:

- i. Enhancement of observational network including radars, ships & buoys, automated weather stations, automated rain gauges, wind profilers, RS/RW and wind profilers.
- ii. Implementation of Artificial Intelligence and Machine Learning (AI/ML) approaches for reliable probabilistic forecasting of genesis, intensity, track, and associated adverse weather. These technologies would support the country's Early Warning & Early Action initiative.
- iii. Development of an automated prediction system using numerical, statistical, and AI/ML approaches to assist forecasters.
- iv. Development of interoperability in operational set up so that no LPS goes undetected and unpredicted 15 days in advance.
- v. Enhancement of cooperation & collaboration among the meteorologists, researchers, disaster managers, social scientists, and workers for effective disaster management related to LPS.
- vi. Enhancement of research through a Research Test Bed to improve understanding of the conditions, precursors and processes leading to LPS intensity changes and the landfall process throughout the its lifecycle (from pre-formation to decay)
- vii. Study of climate change-related variations in LPS characteristics in particular associated heavy rainfall.

- viii. Development of customized, sector-specific, risk-based warnings for industries, ports, coastal stations, offshore and onshore industries, air force bases, airports, tourist spots, railways, highways, etc.
- ix. Development of a national repository for all-hazard event and loss data (associated with LPSs), improving decision-making about where and how to prioritize resilience investments.

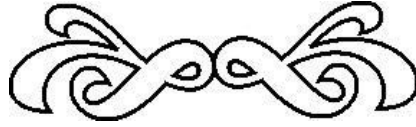
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17



CONCLUSIONS

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The southwest monsoon current made its advance on 13th May, 2025 over parts of Nicobar Islands and South Andaman Sea, aided by strengthened westerly and southwesterly winds (up to 20 knots) in the lower troposphere. The monsoon entered this region 9 days earlier than its climatological date and subsequently advanced rapidly into additional parts of the Bay of Bengal, as well as the entire Maldives and most of Sri Lanka. The monsoon made a swift and expansive progression over the remaining parts of the South Arabian Sea, Westcentral and Eastcentral Arabian Sea, the entire Lakshadweep region, Kerala, Mahe, parts of Karnataka, the Comorin area, many parts of Tamil Nadu, and large sections of the Southwest, Eastcentral, Westcentral, and North Bay of Bengal, extending also into parts of Mizoram by 24th May, 2025. The monsoon onset over Kerala occurred on 24th May, 8 days earlier than the normal date of 1st June. Following its establishment over Kerala, the monsoon advanced rapidly across South India and the Northeastern region by 29th May. After this accelerated phase, the monsoon experienced a hiatus of approximately 17 days, with its further northward progress resuming on 16th June. The monsoon covered the entire India by 29th June, 9 days earlier than its normal date of 8th July, bringing widespread rainfall across the country. The withdrawal of the southwest monsoon 2025 commenced on 23rd September from west Rajasthan, delayed by 6 days from its normal date of 14th September, three days earlier than the normal date of 17th September, following a reduction in rainfall and the formation of an anti-cyclonic circulation in the lower troposphere. The southwest monsoon withdrew from the entire country on 16th October, one day later than the normal date.

The seasonal monsoon rainfall (June to September) over the country as a whole was 936.8 mm, which is 108% of Long Period Average (LPA; 1971-2020) of 868.6 mm. Regional wise, the seasonal rainfall was above normal over three of the four homogeneous regions of

the country. The central India received seasonal rainfall 115% of its LPA, Northwest India received 127% of its LPA, and South Peninsular India received 110% of its LPA, while East & Northeast India received 80% of its LPA during this season. The seasonal rainfall over the monsoon core zone, which consists of most of the rain-fed agriculture regions in the country, was also above normal (122% of LPA). Out of the total 36 meteorological sub-divisions, 2 sub-divisions (West Rajasthan and East Rajasthan) covering 10% of the total area of the country received large excess seasonal monsoon rainfall, 12 sub-divisions constituting 35% of the total area received excess rainfall, 19 sub-divisions covering 46% of the total area of the country received normal rainfall, and 3 sub-divisions (Arunachal Pradesh, Assam & Meghalaya and Bihar) constituting 9% of the total area received deficient seasonal rainfall. During the season, out of 738 districts for which data were available, 67 districts received large excess rainfall, 187 districts received excess rainfall, 327 districts received normal rainfall, 134 districts received deficient rainfall and 12 districts received large deficient rainfall. Monthly rainfall over the country as a whole was 109% of LPA in June, 105% of LPA each in July and August, and 115% of LPA in September.

During the 2025 monsoon season, the El Niño-Southern Oscillation (ENSO) condition was neutral. However, repeated upwelling Kelvin waves and the associated Walker circulation pattern indicated a continuation of La Niña-like conditions in atmosphere, with enhanced ascent over the Indo-Pacific Warm Pool and subsidence over the central and eastern Pacific. Over the Indian Ocean, a negative Indian Ocean Dipole (IOD) developed from July onward, producing a strong east-west SST gradient that enhanced convection over the eastern Indian Ocean while suppressing it over the western basin. The Madden-Julian Oscillation (MJO) was weak in June, strengthened in July, remained active in August, and turned weak again in September, providing intermittent support to monsoon activity.

The major heavy rainfall episodes across the country and intense rainfall activities over Jammu & Kashmir, Himachal Pradesh and Uttarakhand states during the monsoon 2025 have been comprehensively analysed in this report. The heavy rainfall episodes consists of 31 May – 05 June over northeast India, 16 – 25 July over Gujarat state, and heavy rainfall activities over Rajasthan state. The hydro-meteorological conditions and synoptic weather systems responsible for these heavy rainfall events along with realized rainfall and associated impacts have been discussed in detail. The performance of IMD operational forecasts, warnings, impact-based forecast bulletins and flash flood guidance provided during these episodes have also been analysed for further improvement in multi-hazard early warning system. These case studies also highlight the effectiveness of collaboration among meteorological agencies, local authorities, and communities in ensuring better preparedness, disaster prevention and mitigation strategies, and safeguarding lives and resources in vulnerable regions. The satellite-based, particularly using INSAT-3DR and

INSAT-3DS satellites, large-scale monsoon features and associated rainfall during the season have also been analysed.

The verification of heavy rainfall forecasts from various NWP models, MME, and operational forecast at meteorological sub-divisional scale during the southwest monsoon of 2025 highlighted a strong dependence of heavy rainfall forecast skill on regional rainfall characteristics. The verification results indicate a systematic degradation of forecast skill with increasing lead time upto Day-5, evident across most meteorological subdivisions. This decline is characterized by a gradual reduction in the Probability of Detection (POD) and Critical Success Index (CSI), accompanied by an increase in the False Alarm Ratio (FAR), reflecting reduced forecast confidence in the medium range. While the Operational Forecast performs reasonably well over climatologically active monsoon regions up to Day-5, there is a need for region-specific calibration, improved representation of local processes, and targeted bias correction to enhance forecast accuracy over climatologically challenging and less predictable areas.

The real-time extended range forecasts during different phases of monsoon 2025 have captured the observed intra-seasonal variability very well up to 3 weeks lead time. The extended range forecasts over three homogeneous regions viz., central India, northwest India, and northeast India performed well by properly capturing the different phases of monsoon with significant forecast skill upto two weeks lead time, whereas the performance over South Peninsular India was significant only for week 1. Overall, forecasts for two weeks lead time at meteorological sub-divisional scale are shown to be skilful and can be utilised for agro-advisory purposes. The forecast at district level also indicated encouraging results upto two weeks lead time.

The operational forecast of IMD for the monsoon onset over Kerala for this year was correct as the forecast date of monsoon onset over Kerala was 27th May with a model error of ± 4 days and monsoon set in over Kerala on 24th May. The forecast for the rainfall over the country as whole during the season as a whole was correct as the realized rainfall was 108% of LPA against the forecast of $106\% \pm 4\%$. The seasonal forecast issued for homogeneous regions during the season was within the range of the forecast limit except for the Northwest India. All the monthly outlooks were within the forecast limit, except for the July. The forecast for the second half of the monsoon season (August –September) for the country as a whole also was in the forecast limit.

The IMD agro-meteorological advisories during this monsoon season for wet and dry spells, impact-based forecasts for agriculture have been critically assessed. In deficit-hit states, the delay and insufficiency of rain stressed major *Kharif* crops like paddy, maize, and pulses, leading to delayed sowing, inadequate irrigation, etc. Conversely, surplus rainfall in some states caused localized flooding, damaging standing crops and delaying harvesting.

The weather-based advisories enhanced the abilities of the farmers to take appropriate farm management decisions in time which has improved agricultural situations under extreme weather conditions resulting in higher crop production.

During the monsoon season of 2025, 19 Low Pressure Systems including 12 Low Pressure Areas, 5 Depressions, and 2 Deep Depressions developed over the Indian region. During the season, the region witnessed formation of LPS on 68.8 days. Climatologically, about 13.2 LPSs form over the Indian region during the monsoon season, and there are about 57 LPS days over the region out of the total of 122 monsoon days. The assessment of extended range forecast showed CSI of 0.60 in week 1 and 0.59 in week 2, indicating almost similar forecast skill in prediction of genesis of LPSs. The verification of heavy rainfall predicted during LPS days showed that operationally, POD of heavy rainfall was 84%, 77%, 71%, 68% and 63% with percentage correct of 74%, 73%, 71%, 71% and 68% for lead periods of 24, 48, 72, 96 and 120 hours, respectively.

Monsoon

A Report ²⁰²⁵

