A Brief Report on unprecedented weather including Fog, Cold wave & Cold Day during December, 2019 over northern parts of India

1. Introduction:

The plains of north India and adjoining Central India experienced unusual Cold Day Conditions during second half of December, 2019 following an active Western Disturbance (WD), which affected the above region during 11^{th}-14^{th} December, 2019. The salient features of the severe weather during December, 2019 are given below:

I. An active Western Disturbance (WD) and its interaction with lower level easterlies caused fairly widespread (between 51 to 75% stations) to widespread (> 75% stations) precipitation over entire northwest India accompanied with hailstorm and isolated heavy falls (≥ 64.5 mm) during 12-13 December, 2019. Western Himalayan region (WHR) received maximum rain/snow upto 100 mm and plains received upto 90 mm rainfall during this period **(Annexure 1).**

II. After passage of this system, there was dense (visibility between 50 to 200 meter) to very dense fog (visibility less than 50 meter) over northern parts of the country starting from Punjab to Bihar from 14^{th} December, 2019 onwards with most intense spell of fog during 28^{th} to 31^{st} December. On 30^{th} December, season's worst dense fog was reported all over Delhi with visibility of 000-200 meter for a very prolonged period from 0230 to 1200 hours IST.

III. Due to dense to very dense fog and low level clouds, fairly widespread to widespread cold day to severe cold day conditions occurred over North India from 15^{th} to 31^{st} December, 2019. **(Annexure IV)**

IV. In addition, cold wave to severe cold wave conditions conditions were also observed at scattered to fairly widespread places over Punjab, Haryana, Chandigarh & Delhi, Uttar Pradesh and Bihar during 28^{th}-30^{th} December. **(Annexure IV)**

2. Realized Weather:

Widespread cold day conditions (CDCs) were observed over Punjab, Haryana, Chandigarh &

Delhi and Uttar Pradesh on 16th December. It intensified further over Punjab, Haryana, Chandigarh & Delhi and Uttar Pradesh were taken into the grip of severe cold day conditions (SCDCs) at most places with Severe Cold Day Conditions in isolated pockets over Bihar from 17th-19th December. The situation improved slightly with Severe Cold Day Conditions only in isolated pockets over Punjab, Haryana, Chandigarh & Delhi, Uttar Pradesh and Bihar during 20th-22nd December (**Annexure II**).

The Cold Day Conditions re-aggravated from 23rd with observance of Severe Cold Day Conditions in most places over Punjab, Haryana, Chandigarh & Delhi, Uttar Pradesh and in isolated pockets over Bihar till 25th December. Aggravating further from 26th December onwards, Severe Cold Day conditions were observed at most places over Punjab, Haryana, Chandigarh & Delhi, Uttar Pradesh and Bihar till 30th December. Also, during the period 26th-30th December scattered to fairly widespread Severe Cold Day Conditions were observed over Rajasthan, Madhya Pradesh and isolated to scattered over Chhattisgarh, West Bengal, and Jharkhand (**Annexure II**).

Interestingly, during this period (15th-30th December) Cold Wave Conditions were observed at scattered to fairly widespread places over Punjab, Haryana, Chandigarh & Delhi, Uttar Pradesh and Bihar only during 28th-30th December (**Annexure II**).

30th December was the severest day in view of Cold Day Condition observance. On this day Maximum temperature departures of upto -15°C were observed over the North Indian region. From 31st December lower level westerlies started weakening and lower level easterlies had begun their incursion into the plains of north India. Hence, severity of Cold Day Conditions started decreasing from 31st December onwards when only scattered to fairly widespread Severe Cold Day Conditions were observed over Punjab, Haryana, Chandigarh & Delhi and only Cold Day Conditions in most places over Uttar Pradesh and isolated pockets over Bihar were observed. No Cold Day Conditions were observed over Punjab, Haryana, Chandigarh & Delhi, Uttar Pradesh and Bihar from 01st January, 2020 onwards.

There was dense to very dense fog over northern parts of the country starting from Punjab to Bihar from 14th December, 2019 onwards with most intense spell of fog during 28th to 31st

December. On 30th December, season's worst dense fog was reported all over Delhi (**Annexure II**).

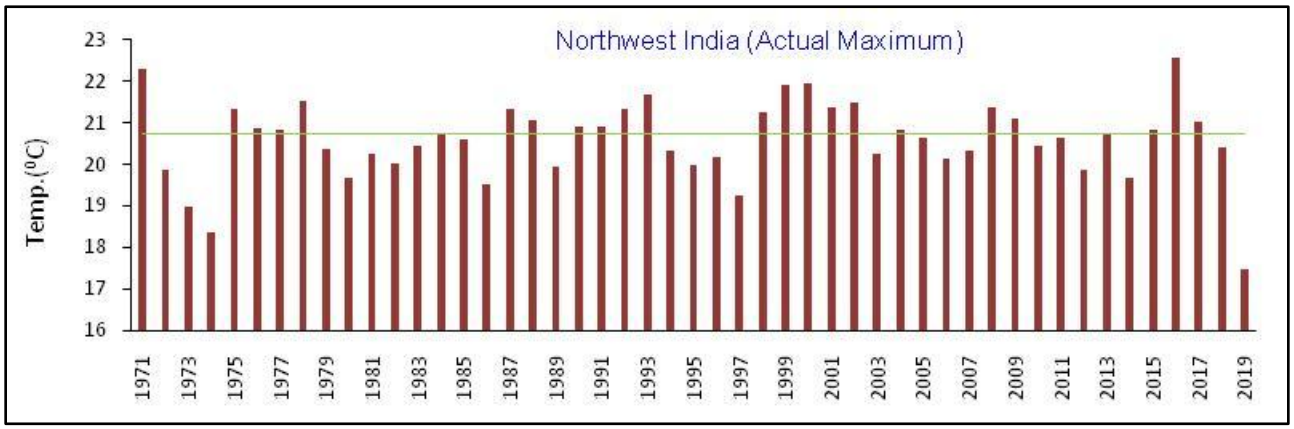

Fig. 1: Maximum temperatures for the month of December from 1971-2019

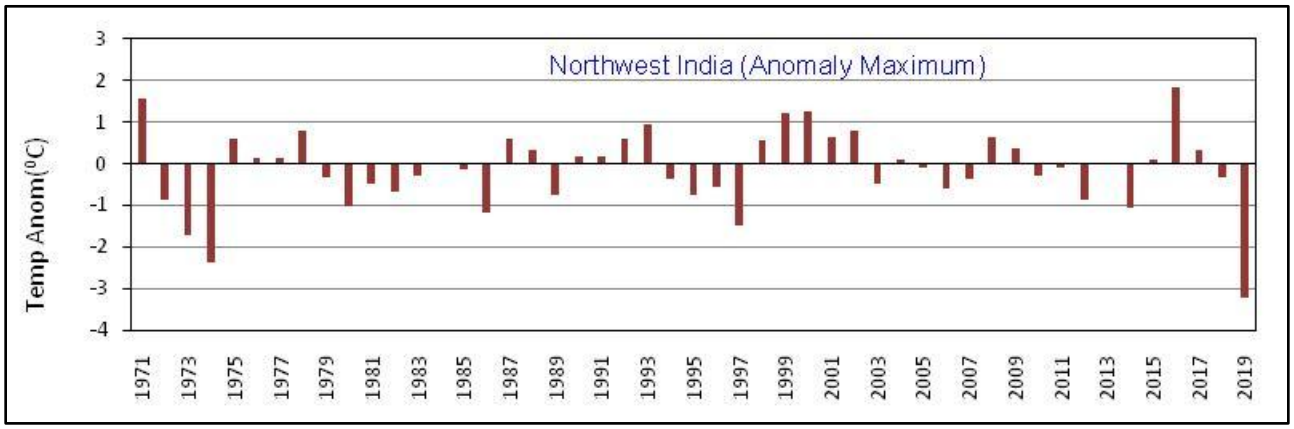

Fig. 2: Maximum Temperature anomalies for the month of December from 1971-2019

These Cold Day conditions led the December maximum temperature of 17.5°C to be the lowest over Northwest India since 1971 (**Fig. 1**). Also December 2019 maximum temperature anomaly (-3.2°C) is the lowest over Northwest India since 1971. Second lowest anomaly is that of December 1974 (-2.4°C) against the normal December Maximum Temperature of 20.7°C over Northwest India since 1971 (**Fig. 2**).

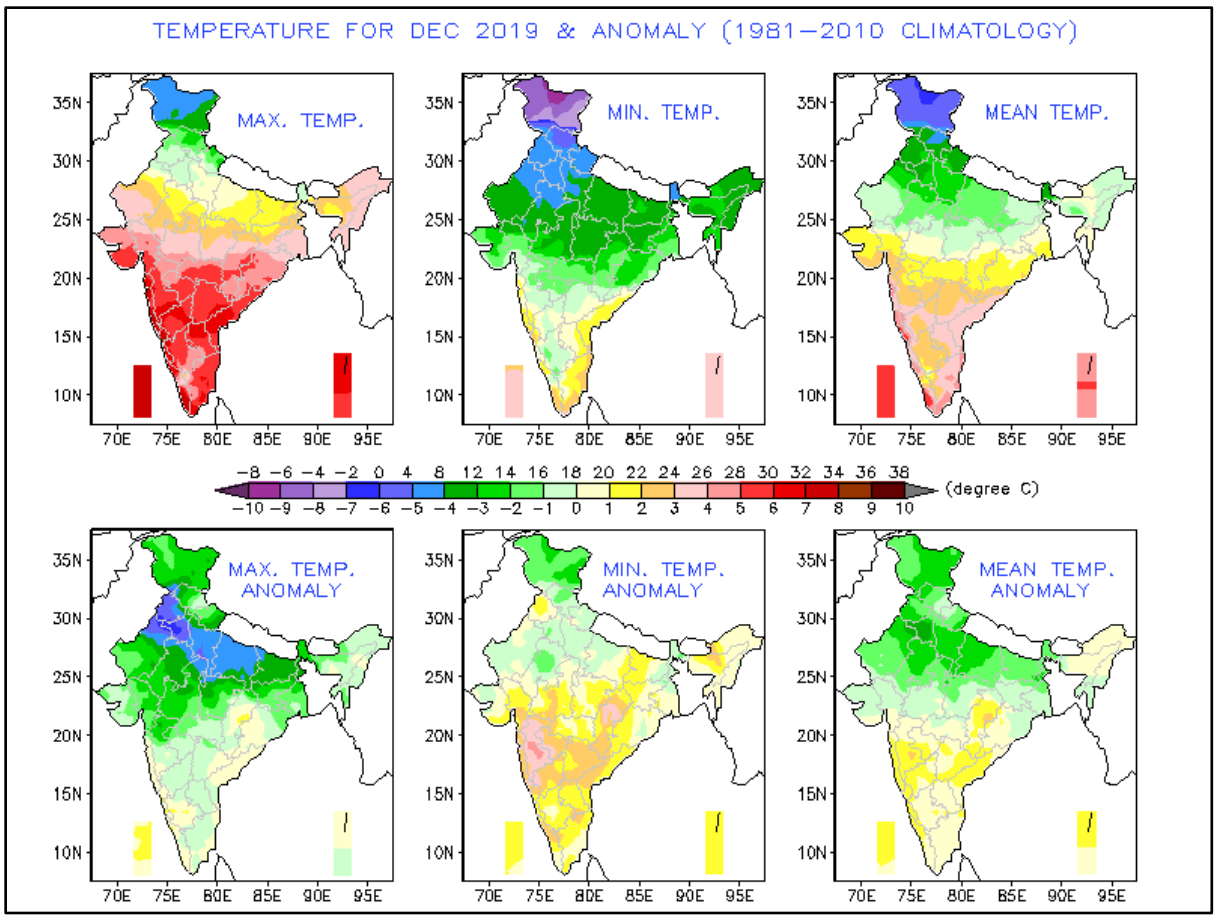

Fig. 3: Spatial Distribution of Maximum Temperature & their anomalies for the month of December, 2019 based on climatology from 1981-2010

From spatial distribution of the maximum temperatures' anomaly, it is clear that the coldest anomaly (-6°C to -7°C) is over south Punjab, northwest Rajasthan and west Haryana region (**Fig. 3**). Minimum temperature anomalies were near normal over Northwest India region. But mean temperature anomalies are colder which is due to the large colder anomalies in the maximum temperatures. This itself is an indicator of lower level clouding over the region during daytime.

3. Brief History (Meteorological Analysis):

3.1 The Western Disturbance:

- This Western Disturbance (WD) originated as a Cyclonic Circulation over North Atlantic Ocean. Moving initially east-southeastwards and then eastwards across Iran and Afghanistan, it started affecting Western Himalayan Region in the night of 11th December.

- This WD was seen as a cyclonic circulation extending upto mid-tropospheric levels over eastern parts of Iran and adjoining Afghanistan on 09th & 10th December. It moved eastwards and laid as a cyclonic circulation over north Afghanistan & neighbourhood at mid-tropospheric levels on 11th. Under its influence, an induced cyclonic circulation formed over west Rajasthan & neighbourhood at lower tropospheric levels on same day.

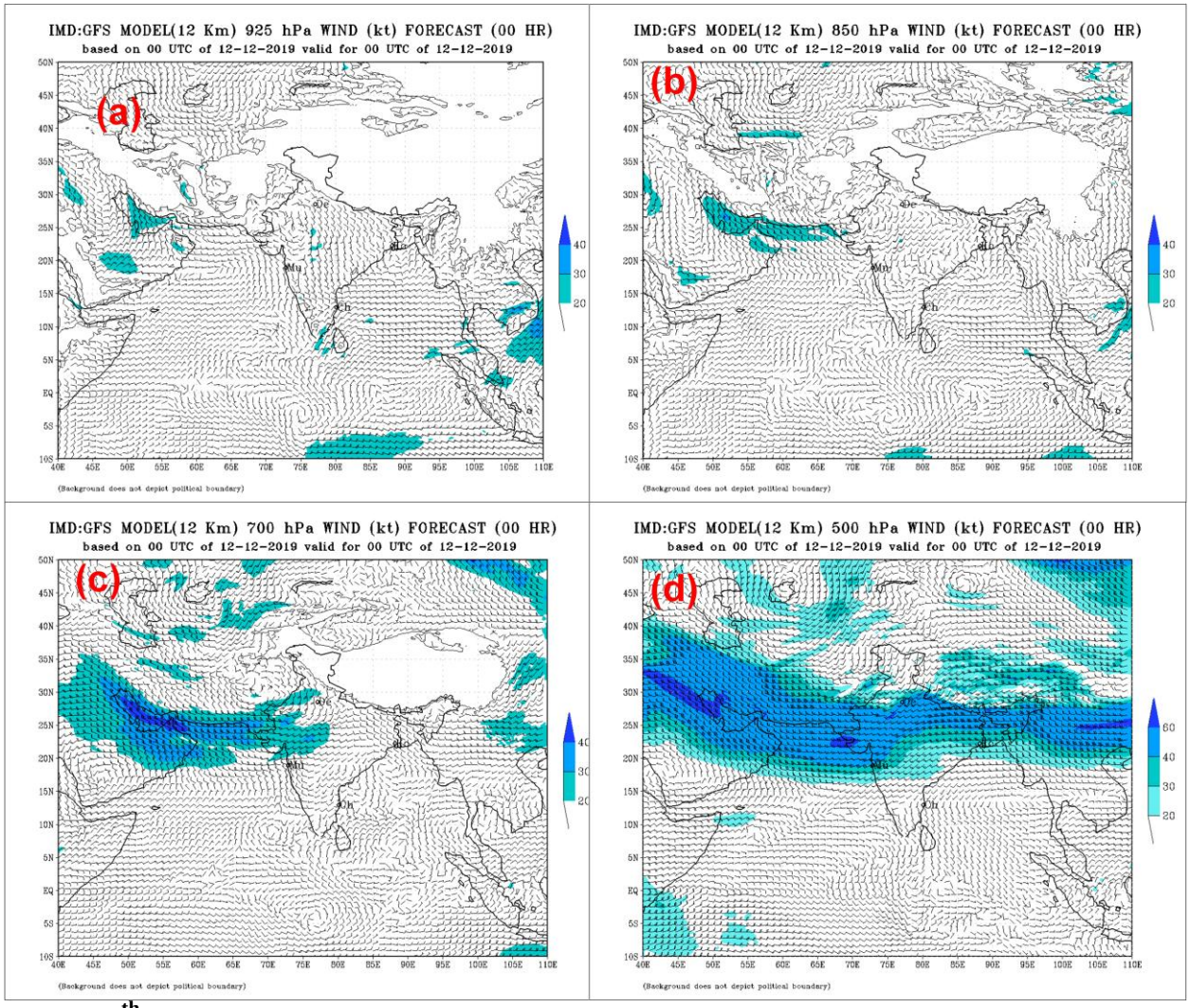

Fig. 4: 12th December IMD-GFS Analysis charts based on 0000 UTC a) 925 hPa b) 850 hPa c) 700 hPa d) 500 hPa

- Thereafter, it was seen as a cyclonic circulation over central Afghanistan & adjoining Pakistan between 3.1 & 4.5 km above mean sea level with a trough aloft in mid & upper tropospheric levels with its axis at 5.8 km above mean sea level roughly along Long. 62°E to the north of 24°N on 12th. The induced cyclonic circulation persisted over west Rajasthan & neighbourhood at lower tropospheric levels.

- Thereafter, the system laid as a cyclonic circulation over north Pakistan and adjoining Jammu & Kashmir between 3.1 & 4.5 km above mean sea level with the trough aloft in mid & upper tropospheric levels with its axis at 5.8 km above mean sea level roughly along Long. 70°E to the north of 22°N on 13th. The induced cyclonic circulation laid over northeast Rajasthan & neighbourhood at lower tropospheric levels.

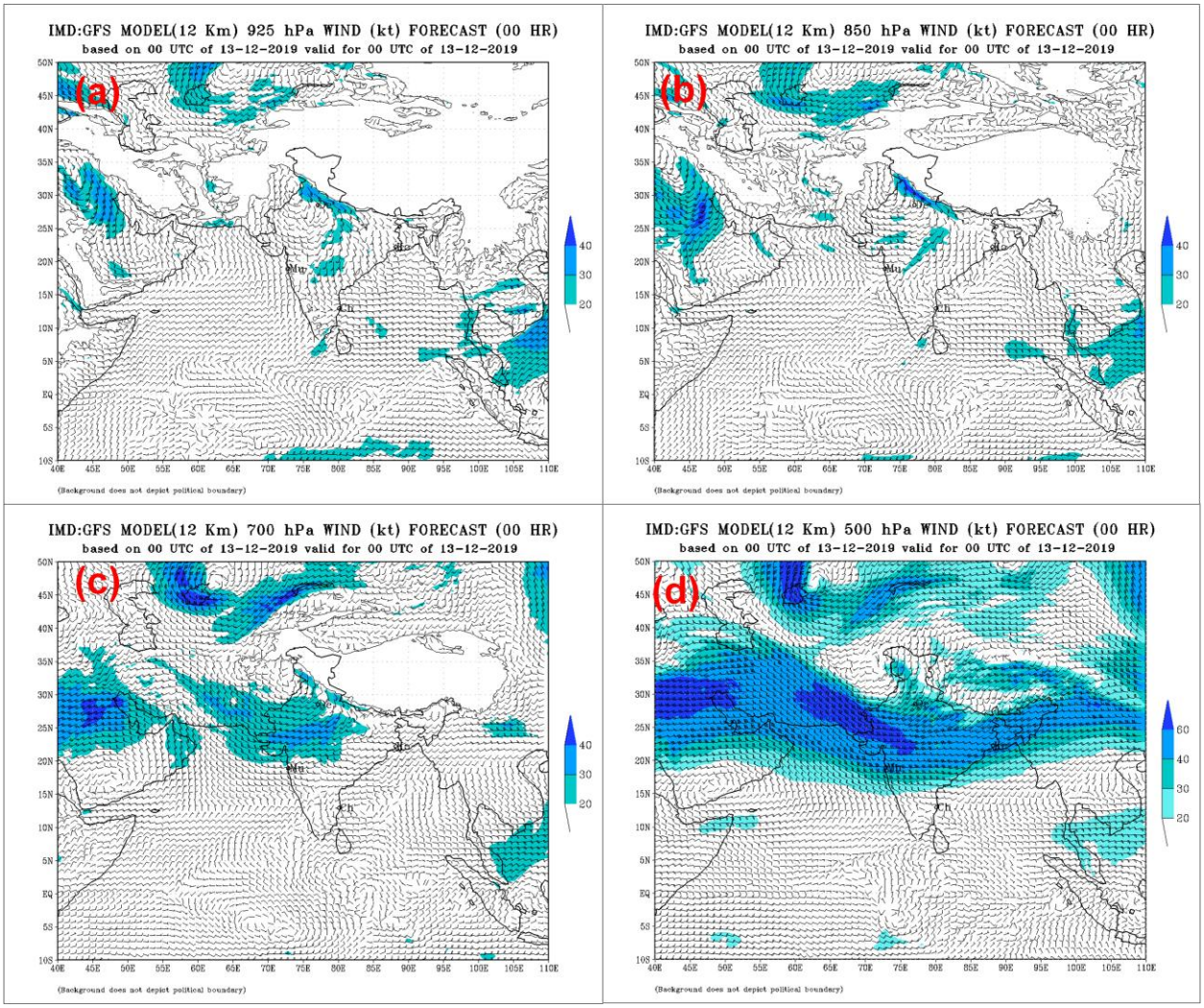

Fig. 5: 13th December IMD-GFS Analysis charts based on 0000 UTC a) 925 hPa b) 850 hPa c) 700 hPa d) 500 hPa

3.2 Confluence Zone and Moisture Feeding:

- There was high moisture feeding from the Arabian Sea over the region at lower & mid-tropospheric levels along with high wind convergence. The system is supported by high jet stream winds (> 100 knot) mainly in the right entrance of the trough in upper tropospheric

levels which provided high divergence of order $20X10^{-5}$ sec^{-1} and maintained its maximum intensity on 12^{th} & 13^{th}.

- Along with above favourable meteorological features, there was wind confluence zone over plains of northwest India & adjoining central India at lower tropospheric levels between easterlies & westerlies (**Fig. 4 & 5**), which contributed in the thunderstorm along with hailstorm activity over the region. Thereafter, the system has moved away east-northeastwards.

3.3 Factors leading to Severe Cold Day Conditions:

The above active WD and its interaction with lower level easterlies caused widespread rain/snow accompanied with isolated hailstorm over north India during 12-13 December, 2019. This supplied abundant surface moisture to the plains of Northwest India. After passage of this WD, strong lower level westerlies continued over the plains of north India for subsequent 15-16 days. Left entrance region of the Sub-Tropical Westerly Jet (STWJ) also continued to be over the region of Punjab, Haryana, Chandigarh & Delhi, north Rajasthan and West Uttar Pradesh. As the Left entrance region of STWJ is associated with upper level convergence it subsequently resulted into sinking motion over the region.

In lower level geo-potential height analysis, it has been observed that an anomalous high was developed over north Pakistan region around 15^{th} December which caused consistent lower level clouds over north Indian plains preventing short wave solar insolation from reaching the earth surface. Also, there took place no lower level easterlies incursion into the north Indian plains and that no active WD affected the Indian region during the period 15^{th}-30^{th} December.

These were the crucial factors, which caused abysmal fall in maximum temperature leading to Severe Cold Day Conditions (SCDCs) over the plains of north India. These Cold Day Conditions (CDCs) were historic in the way that maximum temperatures records were broken at many stations one of which being Delhi (Safdarjung), which recorded lowest maximum temperature of 9.4°C in the history of 119 years of climatological history of Delhi since 1901. Delhi (Safdarjung) maximum temperature of 9.4°C recorded on 30^{th} December, 2019 was lowest in the country since 1971 and second lowest since 1901.

4. Monitoring and forecasting process:

IMD utilized all its resources to monitor round the clock forecast with a lead period of 05 days and warn against adverse weather to the general public, disaster managers, media and other stake holders.

For monitoring the weather systems, IMD used all type of Synoptic charts, INSAT-3D Rapid half hourly imagery, every 10 minutes DWR products for Srinagar, Patiala, Delhi, Lucknow, Jaipur and Bhopal. Various Numerical Prediction Models like IMD GFS, WRF, ECMWF, NCMRWF NCUM, GEFS and various international models were utilized for this purpose.

The digitized decision support system known as SYNERGIE was utilized for decision making and for development of consensus forecast.

5. Verification of forecast & Warnings:

Regarding active WD, which widespread precipitation with isolated heavy falls on 12th & 13th December, 2019, the 1st indication about heavy spell was given in Forecasting Demonstration Project (FDP) Winter Weather Bulletin issued on 03.12.2019. Thereafter, National Weather Forecasting Centre (NWFC), IMD New Delhi continued in their national bulletins till 13th. In this regard, IMD issued four Press Releases well in advance on 08th, 09th, 12th and 13th December.

Six Press Releases were issued about intense Cold Day to Severe Cold Day Conditions, dense fog and severe cold wave conditions on 17th, 24th, 26th, 27th and 30th December, 2019. In 1st & 2nd Press Release issued on 17th & 24th December respectively persistence of cold day and dense fog conditions over north India were predicted. Thereafter in the 3rd Press Release issued on issued on 26th December, Wet spell over northwest, central & east India during 31st December, 2019 to 3rd January, 2020 and abatement of ongoing severe cold day and dense fog conditions over northern parts of India from 31st December was predicted.

Similar forecast & warnings were issued in the bulletins which are issued four times daily by NWFC, IMD New Delhi. These bulletins were emailed regularly to higher officials of Central & State government including disaster Managers and Print & Electronic media with different colour coded warnings as shown below.

Different Verifications scores for Day 1 (D1), Day 2 (D2) & Day 3 (D3) for Fog, Cold Day & Cold Wave are also calculated for December 2019 for northern parts of the country (Table 1). Probability of Detection (PoD) of **Fog warning** for D1, D2 & D3 are 80%, 68% & 46% respectively; Critical Success Index (CSI) for D1, D2 & D3 are 58%, 52% & 40% respectively; False Alarm Rate (FAR) for D1, D2 & D3 are 27%, 22% & 10% respectively. For detailed formulae of FAR, MR, CSI, HSS and POD (refer **Annexure III**).

Probability of Detection (PoD) of **Cold day warning** for D1, D2 & D3 are 84%, 63% & 38% respectively; Critical Success Index (CSI) for D1, D2 & D3 are 73%, 59% & 38% respectively; False Alarm Rate (FAR) for D1, D2 & D3 are 7%, 4% & 0% respectively.

Probability of Detection (PoD) of **Cold wave warning** for D1, D2 & D3 are 88%, 65% & 38% respectively; Critical Success Index (CSI) for D1, D2 & D3 are 56%, 48% & 36% respectively; False Alarm Rate (FAR) for D1, D2 & D3 are 6%, 4% & 0% respectively.

Table 1: Different Skill scores for Fog, Cold Day and Cold Wave Forecast for northern parts of the country:

FOG	FAR	MR	CSI	HSS	POD
D1	0.27	0.20	0.58	0.52	0.80
D2	0.22	0.32	0.52	0.46	0.68
D3	0.10	0.54	0.40	0.38	0.46
COLD DAY	FAR	MR	CSI	HSS	POD
D1	0.07	0.16	0.73	0.77	0.84
D2	0.04	0.37	0.59	0.64	0.63
D3	0.00	0.62	0.38	0.45	0.38
COLD WAVE	FAR	MR	CSI	HSS	POD
D1	0.06	0.13	0.56	0.68	0.88
D2	0.04	0.35	0.48	0.61	0.65
D3	0.00	0.63	0.36	0.50	0.38

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Annexure I

Chief amount of 24 hours accumulated precipitation (≥50mm) recorded at 0830 hours IST:

Sl No.	Sub-Division	13.12.2019		14.12.2019	
1.	**Jammu & Kashmir**	PAHALGAM	80.1	PAHALGAM	86.3
		BADARWAH	69.4	QAZI GUND	70.2
		JAMMU	97.4	BANIHAL	70.2
		KATHUA	59.2	BATOTE	59.0
		RAJHANI AWS	50.0	KATRA	51.9
		QAZI GUND	62.2		
		BANIHAL	79.6		
		BATOTE	79.4		
		GOVINDPURA AWS	51.0		
		KATRA	101.6		
		SAMBA AWS	60.0		
		KAWA AWS	75.0		
2.	**Himachal Pradesh**	KHERI	52.2	NAINA DAVI	58.2
		DHARMSALA	66.4	CHAMBA AWS	62.0
		KANGRA AERO	50.5	DHARMSALA	86.4
		BANJAR	52.3	KANGRA AERO	56.6
		KHADRALA	57.0	PALAMPUR	56.0
				BANJAR	55.4
				GOHAR	56.0
				UNA	50.6
3.	**Uttarakhand**	DEOPRAYAG	71.0	DWARHAT	50.5
				KARNAPRAYAG	56.2
				BANBASA	50
				DEOPRAYAG	79
				HALDWANI	53
				MUKTESHWAR	60
				NAINITAL	52
4.	**Punjab & Haryana, Chandigarh & Delhi**	DHANSA	57.8	PHANGOTA	51.8
		MADHOPUR	54.0	NANGAL	69.2
		MALAKPUR	59.2	ROPAR	52.0
		PATHANKOT IAF	63.6		
		PHANGOTA	52.2		
		TIBRI	60.0		
5.	**East Uttar Pradesh**	MEJA	71.0	NANPARA	55.0
				MUHAMMADI	54.4
				NIGHASAN	81.2

6.	**West Uttar Pradesh**	BILARI 51.0 RAMPUR 51.2 SUAR 50.2 SAMBHAL 78.0 SHAHJAHANPUR (T) 84.2	BAHERI 69.0 HAPUR 58.0 MORADABAD 71.4 MORADABAD OBSY 89.2 THAKURDWARA 65.4 SHAHJAHANPUR (T) 89.3 SHAHJAHAPUR OBSY 63.0

Annexure II

Realized Fog, Cold Day and Cold Wave in December, 2019:

Date	Dense Fog	Cold Day	Cold Wave
15	Very dense fog observed in isolated pockets over West Uttar Pradesh; dense fog in isolated pockets over East Uttar Pradesh, Himachal Pradesh and Uttrakhand; moderate to dense fog in isolated pockets over Punjab	Nil	Nil
16	**Dense to very dense fog** observed in isolated pockets over Jammu & Kashmir, Punjab, Haryana, Chandigarh & Delhi, Chhattisgarh, West Rajasthan, Sub-Himalayan West Bengal & Sikkim and West Madhya Pradesh;	**Cold day conditions** observed in Most places over Rajasthan, Haryana, Chandigarh & Delhi and Punjab; in many pockets over West Madhya Pradesh; in isolated pockets over Jammu & Kashmir, Uttarakhand and Himachal Pradesh.	Nil
17	**Very dense fog** observed in isolated pockets over Rajasthan; **dense fog** in isolated pockets over Punjab	**Severe Cold Day conditions** observed in most pockets over Punjab, Haryana, Chandigarh & Delhi, West Uttar Pradesh and north Rajasthan; in some pockets over West Madhya Pradesh and in isolated pockets over East Uttar Pradesh, East Madhya Pradesh, Jammu & Kashmir and Himachal Pradesh. **Cold Day conditions** observed in most pockets over	Nil

		south Rajasthan and in some pockets over West Madhya Pradesh.	
18	**Dense to Very Dense fog** observed in isolated pockets over North Rajasthan; **Dense Fog** in many places over Haryana, Chandigarh & Delhi and in isolated pockets over Jammu & Kashmir, Punjab	**Severe Cold Day conditions** observed in many pockets over Punjab, Haryana, Chandigarh & Delhi, Uttar Pradesh and in isolated pockets over Madhya Pradesh. **Cold Day conditions** observed in isolated pockets over Rajasthan and Bihar.	Nil
19	Dense to very dense fog observed in many pockets over Haryana, Chandigarh & Delhi and in isolated pockets over Punjab, West Rajasthan, West Uttar Pradesh, Jharkhand and Sub-Himalayan West Bengal & Sikkim and dense fog in isolated pockets over East Uttar Pradesh, East Madhya Pradesh, Himachal Pradesh, Uttarakhand	**Severe Cold Day conditions** observed in most pockets over Haryana, Chandigarh & Delhi, Uttar Pradesh, Bihar; in many pockets over East Madhya Pradesh and Punjab and in isolated pockets over West Uttar Pradesh, West Madhya Pradesh, Jammu & Kashmir and Himachal Pradesh; **Cold day** condition in isolated pockets over North Chhattisgarh.	Nil
20	**Very dense fog observed** isolated pockets over Rajasthan, Punjab and Haryana, Chandigarh & Delhi; **dense fog** in isolated pockets over Uttar Pradesh, Bihar, Tripura and Assam & Meghalaya.	**Cold day conditions** observed in many pockets with **severe cold day** in isolated pockets Punjab, Haryana, Chandigarh & Delhi, Uttar Pradesh, Bihar and Jammu & Kashmir, **Cold day conditions** observed in	**Cold wave conditions** observed in isolated pockets over Jharkhand, Gangetic West Bengal and

		isolated pockets over West Bengal & Sikkim, Jharkhand and northern parts of Rajasthan, Madhya Pradesh.	Odisha.
21	Dense to very dense fog reported in isolated pockets over Rajasthan, Punjab and East Uttar Pradesh; Dense fog in isolated pockets over Haryana, Chandigarh & Delhi, Himachal Pradesh, West Uttar Pradesh, Bihar and Gangetic West Bengal	**Cold Day conditions** in some pockets with **severe cold day** in isolated pockets observed over East Uttar Pradesh and Bihar; **Cold day to severe cold day conditions** in isolated pockets over Gangetic West Bengal and West Uttar Pradesh; **Severe cold day conditions** in isolated pockets over northwest Rajasthan and **Cold day conditions** in some pockets over Punjab.	Nil
22	Very Dense fog reported in few places over East Uttar Pradesh and in isolated pockets over Uttarakhand, West Rajasthan, Haryana and Assam & Meghalaya; Dense fog in isolated pockets over Punjab and Bihar.	**Cold Day conditions** in some pockets with **severe cold day** in isolated pockets observed over Punjab, Haryana, Chandigarh & Delhi, West Uttar Pradesh and Bihar; **Cold day conditions** in some pockets over Sub-Himalayan West Bengal & Sikkim and at isolated places over Gangetic West Bengal and East Uttar Pradesh.	Nil
23	**Very dense fog** in isolated pockets over West Rajasthan; **Dense fog** in	**Severe cold Day conditions** observed in most pockets over	Nil

	isolated pockets over Haryana, Chandigarh & Delhi, East Madhya Pradesh, East Uttar Pradesh, West Bengal & Sikkim and Tripura	Punjab, Haryana, Chandigarh & Delhi , north Rajasthan and West Uttar Pradesh; **Cold day to severe cold day conditions** observed in isolated pockets over Himachal Pradesh and East Uttar Pradesh and **Cold day conditions** in isolated pockets over Jammu & Kashmir.	
24	**Very dense fog** reported at isolated pockets over West Rajasthan, East Uttar Pradesh and Assam & Meghalaya; **Dense fog** reported at isolated places over Punjab, Haryana & Chandigarh, Uttarakhand, West Rajasthan, West Madhya Pradesh, Uttar Pradesh, Bihar	**Severe cold Day conditions** observed in most pockets over Punjab, Haryana and Chandigarh and East Uttar Pradesh; **Cold day to severe cold day conditions** in most pockets over West Uttar Pradesh; in isolated pockets over Delhi, north Rajasthan and north Madhya Pradesh and **Cold day conditions** in isolated pockets over Bihar and Gangetic West Bengal.	Nil
25	**Dense to very dense fog** observed in isolated pockets over Rajasthan, East Madhya Pradesh and East Uttar Pradesh; **dense fog** in isolated pockets over Jammu & Kashmir, south Haryana and northwest Madhya Pradesh	**Severe cold Day conditions** observed in most pockets over Punjab, Haryana, Chandigarh & Delhi and West Uttar Pradesh; in some pockets over East Uttar Pradesh and north Rajasthan; **Cold day to severe cold day conditions** in	Nil

		isolated pockets over Bihar and **Cold day conditions** in isolated pockets over north Madhya Pradesh.	
26	**Very Dense Fog** observed in isolated pockets over extreme north Rajasthan and north Madhya Pradesh; **Dense Fog** in isolated pockets over Jammu & Kashmir and Bihar; **Moderate Fog** in isolated pockets over Himachal Pradesh, Uttarakhand, Haryana, Chandigarh & Delhi, Uttar Pradesh	**Severe cold Day conditions** observed in most pockets over Punjab, Haryana, Chandigarh & Delhi, Uttar Pradesh and Bihar; in isolated pockets over north Rajasthan and north Madhya Pradesh.	Nil
27	Very dense fog in isolated pockets at northwest Rajasthan, northwest Madhya Pradesh; Dense fog in most places over Haryana, Chandigarh & Delhi and East Uttar Pradesh; in many pockets over West Uttar Pradesh; in isolated pockets over Himachal Pradesh, Uttarakhand & Bihar.	**Severe Cold Day conditions** observed in most pockets over Punjab, Haryana, Chandigarh & Delhi, Uttar Pradesh and Bihar; in isolated pockets over north Rajasthan; **Cold Day to Severe Cold Day conditions** in many pockets over Madhya Pradesh; in isolated pockets over West Bengal and **Cold Day conditions** in some pockets over Jharkhand and north Chhattisgarh.	Nil
28	**Very dense fog** in some pockets over Punjab and in isolated pockets over northwest Rajasthan, northeast Madhya Pradesh, Madhya Maharashtra and Tamilnadu; **Dense**	**Severe Cold Day conditions** was observed in most pockets over Punjab, Haryana, Chandigarh & Delhi, Uttar Pradesh and Bihar; in isolated	**Severe cold wave conditions** observed in many pockets over Haryana,

	fog in isolated pockets over Uttarakhand, Haryana, Chandigarh & Delhi, East Rajasthan, Bihar and Manipur	pockets over north Rajasthan; **Cold Day to Severe Cold Day conditions** in many pockets over Madhya Pradesh; in isolated pockets over West Bengal and **Cold Day conditions** in some pockets over Jharkhand and north Chhattisgarh.	Chandigarh & Delhi; in isolated pockets over north Rajasthan & Vidarbha; **Cold wave conditions** in many pockets over East Madhya Pradesh and Bihar; in some pockets over West Madhya Pradesh & Odisha; in isolated pockets over Jammu & Kashmir, Uttar Pradesh, Jharkhand and West Bengal & Sikkim.
29	**Dense to Very dense fog** in many pockets over Punjab and Haryana, Chandigarh & Delhi and in isolated pockets over Rajasthan, Uttar Pradesh and East Madhya Pradesh; **Moderate to Dense fog** in isolated pockets over Madhya Maharashtra, Bihar and West Madhya Pradesh	**Severe Cold Day conditions** observed in most pockets over Punjab, Haryana, Chandigarh, Uttar Pradesh and Bihar; in isolated pockets over Uttarakhand, northeast Rajasthan, northwest Madhya Pradesh and north Jharkhand; **Cold Day to Severe Cold Day conditions** in many pockets over Delhi; **Cold Day**	**Severe cold wave conditions** were observed in some pockets over Haryana, Chandigarh & Delhi, Himachal Pradesh and Jammu & Kashmir; in isolated pockets

		conditions in many pockets with **Severe Cold Day** is isolated pockets over West Rajasthan and East Madhya Pradesh and **Cold Day conditions** in some pockets over northern parts of Madhya Maharashtra and Vidarbha.	over Rajasthan and West Madhya Pradesh; **Cold wave conditions** in many pockets over Uttarakhand; in some pockets over Odisha; in isolated pockets over Punjab, East Uttar Pradesh, East Madhya Pradesh and Assam & Meghalaya.
30	**Very Dense Fog** observed in many pockets over East Uttar Pradesh and in isolated places over East Madhya Pradesh; **Dense Fog** in many pockets over Bihar; **Moderate to Dense Fog** in isolated pockets over Rajasthan, West Madhya Pradesh, West Uttar Pradesh	**Severe Cold Day conditions** observed in most pockets over Punjab, Haryana, Chandigarh & Delhi, Uttar Pradesh and Bihar; in isolated pockets over Jammu & Kashmir, Uttarakhand, north Rajasthan and north Madhya Pradesh; **Cold day conditions** in isolated pockets over north Jharkhand and West Bengal.	**Severe cold wave conditions** were observed in isolated pockets over Punjab, Haryana, Chandigarh & Delhi,Rajasthan, Uttar Pradesh, Madhya Pradesh, Vidarbha, Odisha, Chhattisgarh, Bihar and Jammu & Kashmir. **Cold wave conditions** observed in some

			pockets over Saurashtra & Kutch and West Bengal & Sikkim.
31	Dense to Very Dense Fog observed in isolated pockets over West Rajasthan, Haryana, West Madhya Pradesh and Tamilnadu, Puducherry & Karaikal; Dense Fog observed in isolated pockets over Punjab & East Madhya Pradesh Moderate Fog in isolated pockets over Delhi, Uttar Pradesh and Bihar.	**Severe cold day conditions** observed in most pockets over Haryana & Delhi, south Uttar Pradesh and north Madhya Pradesh; in many pockets over Rajasthan and in isolated pockets over north Punjab and Jammu and **Cold day conditions** in most pockets over north Uttar Pradesh; in many pockets over south Madhya Pradesh; in some pockets over Chandigarh and rest parts of Punjab and in isolated pockets over Bihar and rest parts of Rajasthan.	**Severe Cold Wave conditions** observed in many pockets over East Uttar Pradesh and at isolated places over North Madhya Pradesh and **Cold Wave conditions** in isolated pockets over Punjab, Odisha, North Rajasthan, Saurashtra & Kutch, Bihar and Gangetic West Bengal.

Annexure III

Forecast	Observed		
	Yes	**No**	**Total**
Yes	Hits (a)	False alarms (b)	**Forecast yes (a+b)**
No	Misses (c)	Correct negatives (d)	**Forecast no (c+d)**
Total	**Observed yes (a+c)**	**Observed no (b+d)**	**Total (n=a+b+c+d)**

Using above 2x2 contingency table and following Doswell, et al. (1990), Mohapatra et al. (2009 a & b), Ram et al., (2007) and Yadav et al. (2015), given below measures are calculated:

a) Probability of Detection/ Hit Rate $POD = H = \frac{a}{(a+c)}$, [Hits/ Total observed Yes]

Range: 0 to 1, Perfect score = 1

b) Miss Rate $MR = 1 - POD$, **Range**: 0 to 1, Perfect score = 0

c) False Alarm Ratio, $FAR = \frac{b}{(a+b)}$, [False alarms / Total forecast Yes]

Range: 0 to 1, Perfect score = 0

d) Threat Score/Critical Success Index, $TS = CSI = \frac{a}{(a+b+c)}$,

Range: 0 to 1, Perfect score = 1

e) Heidke Skill Score, $HSS = \frac{2(ad-bc)}{\left[(a+c)(c+d)+(a+b)(b+d)\right]}$, Range: $-\infty$ to 0

Annexure IV

Cold Wave & Cold Day Criteria:

(A) Cold Wave:
It should be based on the actual minimum temperature of a station.

Cold Wave is considered when minimum temperature of a station is 10^0C or less for plains and 0°C or less for Hilly regions.

Based on Departure

Cold Wave: Negative Departure from normal is 4.5°C to 6.4°C

Severe Cold Wave: Negative Departure from normal is more than 6.4°C

Based on Actual Minimum Temperature (For plain stations only)

Cold Wave: When minimum temperature is ≤ 04°C

Severe Cold Wave: When minimum temperature is ≤ 02°C

Cold Wave conditions for coastal stations

When minimum temperature departure is -4.5°C or less over a station, *"Cold Wave"* may be described if the minimum temperature is 15^0C or less.

(B) Cold Day:
It should be considered when minimum temperature is 10^0C or less for plains and 0°C or less for Hilly regions.

Cold day: Maximum Temperature Departure is -4.5°C to -6.4°C

Severe Cold day: Maximum Temperature Departure is < -6.4°C