सत्यमेव जयते

Ministry of Earth Sciences

Standard Operation Procedure - Weather Forecasting and Warning Services

India Meteorological Department

Ministry of Earth Sciences

Government of India

2021

Standard Operation Procedure
Weather Forecasting and Warning

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MISSION

To effectively forecast High Impact Weather events to strengthen Disaster Preparedness Mechanism

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Foreword

The India Meteorological Department (IMD) is principal government agency in the country in all matters relating to meteorology and allied subjects. It has continuously ventured into new areas of application and services, and steadily built upon its infra-structure in its history of 146 years. It has simultaneously nurtured the growth of meteorology and atmospheric science in India and is poised at the threshold of an exciting future. India, being a tropical country, experiences various severe weather events like cyclones, severe thunderstorms, squalls, flash floods, snow avalanches, heat wave, cold wave, heavy rainfall etc. These severe weather events can cause wide spread loss to life and property.

Owing to high impact of severe weather events and its consequential influence on social, cultural, commercial, health, defence, transport etc. and the increased public awareness, it is felt that there is a requirement of a well laid out system/methodology for monitoring of these weather events by India Meteorological Department (IMD). Considering these, IMD has brought out Standard Operation Procedure (SOP), to provide uniform monitoring of weather especially disastrous weather events. The manual contains chapters on General Forecasting Organization of IMD, Satellite Application in Weather Forecasting, Radar Application in Weather Forecasting, Public Weather Services, Heavy Rainfall Warning Services, Thunderstorm Warning Services, Heat & Cold Wave Warning Services, Fog Warning Services, Nowcasting Services, Multi-hazard Early Warning System , Urban Meteorological Services, Marine Weather Forecasting Services , Meteorological Communication and Early Warning Dissemination, Post Event survey and Forecast Verification. This manual will prove to be very helpful to the operational forecasters and will serve as a valuable document for carrying out research activities.

The reduction of damage due to a disastrous weather event depends on several factors viz. the skill in their prediction, timely dissemination of warnings and the public perception about the credibility of the official predictions and warnings. While formulating these guidelines, we have involved experts from various forecasting units of IMD so that a standard procedure is followed throughout the country for effective analysis, monitoring and dissemination of warning to minimize damage to life and property from disastrous weather events.

I express my deep appreciation to all the experts and the officials involved for their commitment and dedication in bringing out this publication.

Mrutyunjay Mohapatra
New Delhi
March, 2021

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I sincerely compliment and appreciate Dr. S. I. Laskar for his significant contribution in coordinating with authors and reviewers, editing, compiling and hence the timely publication of this SOP.

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New Delhi
March, 2021

Mrutyunjay Mohapatra

Chapter 1

GENERAL FORECASTING ORGANISATION OF INDIA METEOROLOGICAL DEPARTMENT

1.1. Introduction

Weather forecasting in India commenced with the establishment of India Meteorological Department (IMD) in 1875 and over a period of time, a network of forecasting organizations has been developed in IMD. Being a tropical country, India experiences severe weather events like cyclones, severe thunderstorms, flash floods, snow avalanches etc. To understand the science behind such weather systems there is need to understand tropical meteorology in different space and time scales. With the development of science and technology and advancements in computers together with induction of observational aids like Doppler weather radars and satellites, there has been better understanding of weather phenomena in all the scales leading to improvement in daily operational weather forecasts. Recent modernization of IMD's activities including commissioning of newly acquired modern observing equipments, induction of high resolution numerical weather prediction models and the utilisation of high power computing systems for running numerical models etc. has lead to further improvements in the quality of forecasting services. The forecasting service has also gained importance in sector specific applications and demands have increased for providing sector specific tailor made high resolution forecast products in both spatial and temporal scale. These demands are met through a strong organisational set up of the forecasting services. Details of the same are given in this chapter.

The forecasting organisation is set up with the following objectives:

- To improve coordination between all relevant operational centres across the country in the national, regional and state level, in matters related to daily forecasting.
- To update the products & warnings several times a day to meet user expectations.
- To increase consistency and accuracy of all the forecast products for different services viz. general weather, agromet, marine, aviation, mountain weather etc. through use of better fitted techniques, collaborative work, and complementary roles.
- To issue district level forecast and nowcasts and bring out further improvements in the system. This is a challenge as it deals with downscaling short range forecasts to district level.
- To improve city forecast which require location specific assessment of the weather scenario.
- To provide marine forecast (for both high seas and coastal areas) and Fishermen Warning and further improvements in the system.
- To provide Cyclone warning services for the Low pressure systems forming over the North Indian Ocean through modernized tropical cyclone tracking modules/systems.
- To provide impact based warning services related to different weather scenario.
- To provide impact based weather forecast for heavy rainfall for the capital cities.
- To take into account the new requirements of forecasting Services.
- To do Research & Development work to support betterment of the services.

1.2. Current Forecasting Organization

National Weather Forecasting Centre (NWFC) at IMD New Delhi is coordinating IMD's forecasting activities for the entire country and the Weather Central, IMD, Pune functions as the standby Centre for NWFC. While the Regional Meteorological Centres (RMCs) carry out weather monitoring and forecasting for their respective regions, the Meteorological Centers (MCs) at the state capitals do the same for their respective states. Cyclone related operational activities are being monitored and coordinated by Cyclone Warning Directorate (CWD), IMD, New Delhi in the headquarters' level. This unit also functions as the Regional Specialized Meteorological Centre (RSMC) for tropical cyclones for the WMO region. Area Cyclone Warning Centres (ACWCs) and Cyclone Warning Centres (CWCs) take care of the cyclone warning services of the coastal states as well as marine weather services, as per their area of responsibility. The Hydrometeorology Division, IMD, New Delhi coordinates the Flood forecasting related services being carried out through Flood Meteorological Offices (FMOs) and collects the data and prepares rainfall statistics for the entire country. Agromet Forecasting Services are coordinated by Agricultural Meteorology Division, IMD Pune whereas the liaisoning work related to Agromet services are carried out by Agro Advisory Service Division (AASD), IMD, New Delhi.

1.2.1. General Forecast

- National Weather Forecasting Centre (NWFC) at IMD New Delhi provides procedural and technical coordination related to forecasting services. The centre coordinates the forecasting/nowcasting work at the national, regional and state levels, prepares documentation on realized weather with contributions from Weather Central, IMD, Pune, RMCs and MCs, issues forecasting related circulars, organizes Annual Monsoon and Cyclone review meetings every year to review the previous year's forecast performance, analyses user feedback and forecasting appraisal by various centres so as to deliberate and device methodologies for improvement of the services.
- NWFC, IMD New Delhi acts as the main operational interface for all weather related matters to the Government of India and provides suitable information / briefing on realized and forecasted weather for the country as a whole to different government agencies including National Disaster Management Authority (NDMA).
- NWFC provides forecast and warning related information to Press & Media, All India Radio, Doordarshan and other users. It also provides forecasts for Western Himalayan Region and issues special forecasts for various activities including sports, tourism, mountain expeditions, VVIP movements, Independence and Republic day celebrations etc.
- NWFC prepares, finalizes and provides inputs for parliament questions, grievances and RTI queries related to weather forecasting services in the national level.
- Regional Weather Forecasting Centres (RWFCs) in RMCs/ State Weather Forecasting Centres (SWFCs) in MCs act as the operational interface for the weather forecast and warning services extended to the respective State Government and various government departments and provide necessary information/briefing on realized and forecasted weather at the district level and also for the important cities in the state. It provides the weather information to all the users related to state disaster management and also to electronic and print media etc.
- Warnings related to Heavy rainfall, Heat wave, Cold wave, Fog, Thunderstorm and associated phenomena viz., Lightning, Squall, Gusty winds, Hail etc. are issued by all the forecasting centres as and when the required conditions arise. Guidelines for the purpose are available in the form of Forecaster's Guide. For Standard Operational Procedures for those high impact weather phenomena, the chapters related to the same in this document may be referred to.

1.2.2. Marine Forecast

Forecasts and warning services for high seas are coordinated by Marine Service Division of NWFC, IMD New Delhi with contributions from ACWC Kolkata for Bay of Bengal and ACWC Mumbai for Arabian Sea. This division issues Global Maritime Distress Safety System (GMDSS) Bulletin for the Area VIII N as well as Fleet Forecast for Indian Ocean between Latitude 5^{0} N to 10 ^{o} S and Longitude 60^{0} to 100^{0} E .This division also issue Fishermen Warning for coastal as well as for deep sea areas of North Indian Ocean in both text and pictorial format. ACWCs/ CWCs issue coastal bulletins and fishermen warnings for their respective areas of responsibility in consultation with NWFC, IMD New Delhi. Details of the area of responsibility (pertaining to coastal areas) for ACWCs/CWCs are given in Table 1.1.

Table 1.1

Area of responsibility of ACWCs/CWCs

Area of Responsibility			
Centre	**Sea Area**	**Coastal Area**	**Coastal states**
ACWC Kolkotta	Bay of Bengal	West Bengal, Andaman & Nicobar islands	West Bengal, Andaman & Nicobar islands
ACWC Chennai	-	Tamil Nadu & Puducherry	Tamil Nadu & Puducherry
ACWC Mumbai	Arabian Sea	Maharashtra, Goa	Maharashtra, Goa
CWC Bhubaneshwar	-	Odisha	Odisha
CWC Visakhapatnam	-	Andhra Pradesh	Andhra Pradesh
CWC Thiruvananthapuram	-	Kerala, Karnataka	Kerala, Karnataka & Lakshadweep
CWC Ahmedabad	--	Gujarat, Diu, Daman, Dadra & Nagar Haveli	Gujarat, Diu, Daman, Dadra & Nagar Haveli

1.2.3. Cyclone Warning

The Cyclone Warning Organization of the Department is given in Figure 1.1.

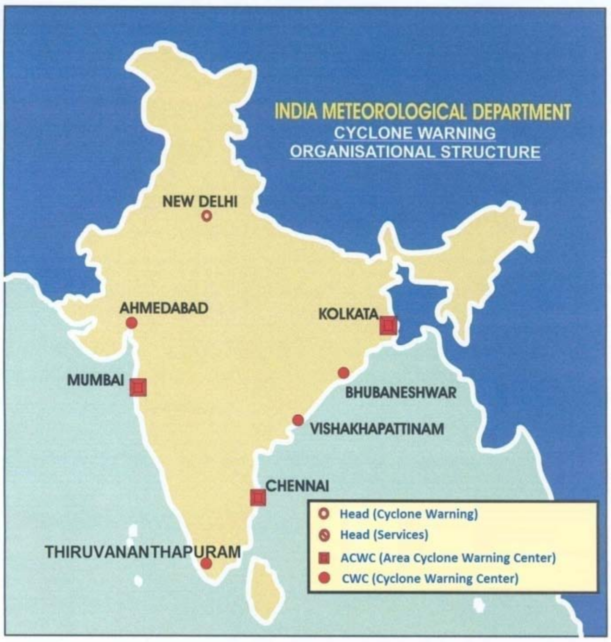


Figure 1.1. Cyclone Warning Organisational Structure of IMD

Cyclone warning procedures are well structured, through the so called *"red book"* at national level and *"Cyclone Manual*" at IMD level. Crisis Disaster Management related to cyclones is taken care through efficient coordination at various levels. At national level, National Disaster Management Council (chaired by Prime Minister's Office) interacts with DGM or other senior officer concerned of IMD Headquarters. At State level, State Disaster Management Council (chaired by Chief Minister of State) interacts with Head of RMC/ACWC/CWC and at district level, District Disaster Management Council (chaired by District Collector or magistrate), interacts with Head of RMC/MC / CWC. The ACWCs, located in Kolkata, Chennai, and Mumbai in coordination with the CWCs located at Bhubaneshwar, Visakhapatnam, Thiruvananthapuram and Ahmedabad take care of the operational cyclone warning related work as per their area of responsibility given in Table 1.1., under the guidance of CWD, IMD, New Delhi.

With respect to cyclone warning services, the department has international responsibilities also and thus functions also as Regional Specialized Meteorological Centre (RSMC) for tropical cyclone forecasting for the region. The area of responsibility of RSMC New Delhi is given in Figure 1.2.

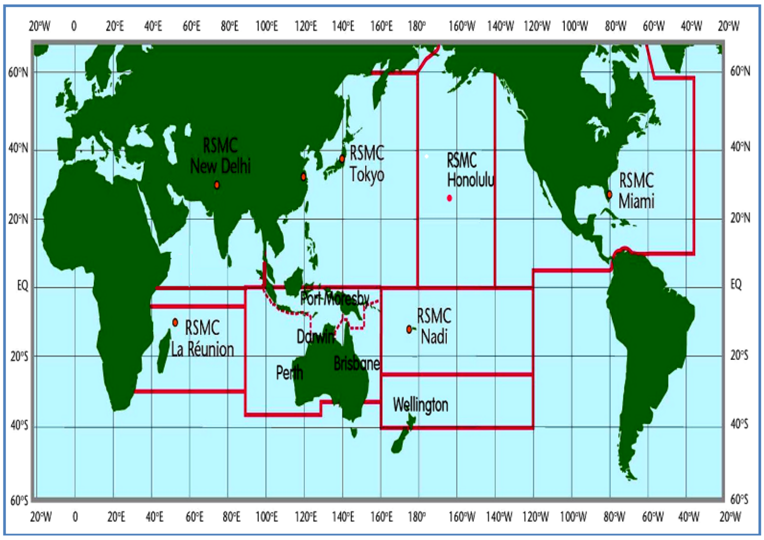


Figure 1.2. Area of responsibility for RSMC, New Delhi

1.2.4. Agrometeorological Services

Weather forecasts for agriculture are issued at RMC/MC level through their Agromet Advisory Service (AAS) units. Five days' quantitative district level forecasts are issued by RMCs and MCs twice a week using Numerical Weather Prediction model products, after carrying out value addition based on synoptic analysis. The final forecast is forwarded from AAS units of RMCs/MCs to various Agro Meteorological Field Units (AMFUs) and District Agro-Met Units (DAMUs) of the states. Based on these forecasts, AMFUs and DAMUs in turn issue agromet advisories for the farmers of their respective areas/districts. The coordination with RMCs/MCs and AMFUs/DAMUs is managed jointly by Head (AASD), IMD New Delhi and Head (Agromet), IMD, Pune.

1.2.5. Flood Meteorological Offices

For flood related services, IMD has established Flood Meteorological Offices (FMOs) at thirteen locations, viz., Agra, Ahmedabad, Asansol, Bhubaneshwar, Guwahati, Hyderabad, Jalpaiguri, Lucknow, New Delhi, Patna, Srinagar, Bengaluru and Chennai and also supports Damodar Valley Corporation (DVC) for their flood forecasting activities for Damodar river basin areas. Through these FMOs, IMD provides meteorological support to Central Water Commission (CWC) for issuing flood warnings in respect of the 43 rivers of India covering 153 river basins. CWC issues flood forecasts 6 hrs. to 30 hrs. in advance for about 176 locations using the Quantitative Precipitation Forecast (QPF) as well as the hydro meteorological data received from IMD.

1.2.6. Nowcast Services

The weather phenomena like thunderstorms, hailstorms etc. are short lived but are highly disastrous due to the associated weather elements like squalls and lightning. Hence continuous monitoring and issue of warning for these severe weather events are necessary. Since they develop and dissipate within a short period, they can be better covered by nowcasts than short range forecasts.

To support nowcast services, the Nowcast Division of NWFC issues nowcast guidance bulletin on daily basis which gives the details of the expected severe weather phenomena and its intensity along with the area of occurrence, so that the concerned RWFC/SWFC can keep continuous watch for the development of those severe weather and issue nowcasts accordingly. These nowcasts are uploaded in the nowcast page of the IMD website and are disseminated through SMS and social media also for the benefit of general public and disaster managers.IMD at present issue nowcast for about 897 locations across the countries which are coming under radar range.

1.2.7. Mountain Meteorological Services

The Mountain Meteorology Division of NWFC issues weather forecast bulletins for Western Himalayan Region twice daily, based on 0830 & 1430 hours observations. These bulletins contain observed weather as well as forecast and warnings for Jammu, Kashmir and Ladakh divisions of J&K, High hills and lower hills regions of Himachal Pradesh and Garhwal & Kumaon regions of Uttarakhand for seven days .These bulletins are disseminated through emails to Meteorological Centres at Srinagar, Shimla, Dehradun and to Snow& Avalanche Study Establishmet (SASE) through email and are uploaded in IMD Website also.

NWFC also provides weather forecast service on demand to various government agencies and defence services to support their mountain expeditions related requirements through this division.

1.2.8. Forecast Services for Sectorial Applications

Requirement of weather information and forecast for specific sectors viz., sports, tourism, pilgrimage, transport (highway), railways, aviation, power Sector, health, urban and environment services etc. are taken care of by designated units located in IMD, New Delhi and in RMCs/MCs.

1.3. Revision of SOP

From the modest beginning in 1875, IMD has progressively expanded its infrastructure with respect to meteorological observations, forecasting services and meteorological communications. The Standard Operating Procedures (SOP) for handling operational aspects of weather forecast services was first published by IMD in 2012. Thereafter many changes, addition and improvements in various aspects of the service have come into effect under modernization programme. Revision of old SOP has thus become essential to take care of those changes.

1.4. Responsibility of Forecasting Centres

In order to deliver effective forecast and related services to general public and different user agencies including disaster management authority, India Meteorological Department (IMD) has a **three-tier** structure for providing weather forecasts and warnings for natural calamities like heavy rainfall, snowfall, thunderstorm, hailstorm, heat wave, cold wave etc. The National Weather Forecasting Centre (NWFC) at IMD Headquarters, New Delhi issues All India Weather Bulletin for 36 meteorological sub-divisions of the country as a whole on daily basis and the same is updated three times within twenty four hours. This bulletin more or less serve as a guidance bulletin for the subordinate offices and based upon that bulletin, the forecasting centres of Regional Meteorological Centres (RMCs) and State Meteorological Centres (SMCs) issue forecast and warning in the district level. NWFC also issues nowcast guidance bulletin for the severe weather elements like thunderstorm, heavy rainfall, fog etc. based on which the RWFCs and the SWFCs issue nowcast in every three hours or as and when required related to the concerned severe weather phenomena. In additional to this, Mountain Weather Bulletins for Western Himalayan Region and Global Maritime Distress and Safety System (GMDSS) bulletins for Area VIII N as well as Fleet Forecast for Indian Ocean between Latitude 5 ^{0}N to 10 ^{0}S and Longitude 60^{0} to 100^{0} E related to marine weather are also issued from NWFC two times respectively in a day. NWFC also issue special forecasts for events like Independence Day and Republic Day celebrations and extends forecast and warning support to mountain expedition teams and for Amarnathji Yathra etc., every year.

The three tier structure of the forecasting services is summarised below.

1.4.1. National Weather Forecasting Centre (NWFC) : Functions from IMD New Delhi and is responsible for weather monitoring and forecast for the entire country. Forecasts are issued in the sub divisional scale from this centre four times a day. The different subdivisions of the country are shown with serial numbers in Figure 1.2 and their corresponding details are given in Table 1.2.

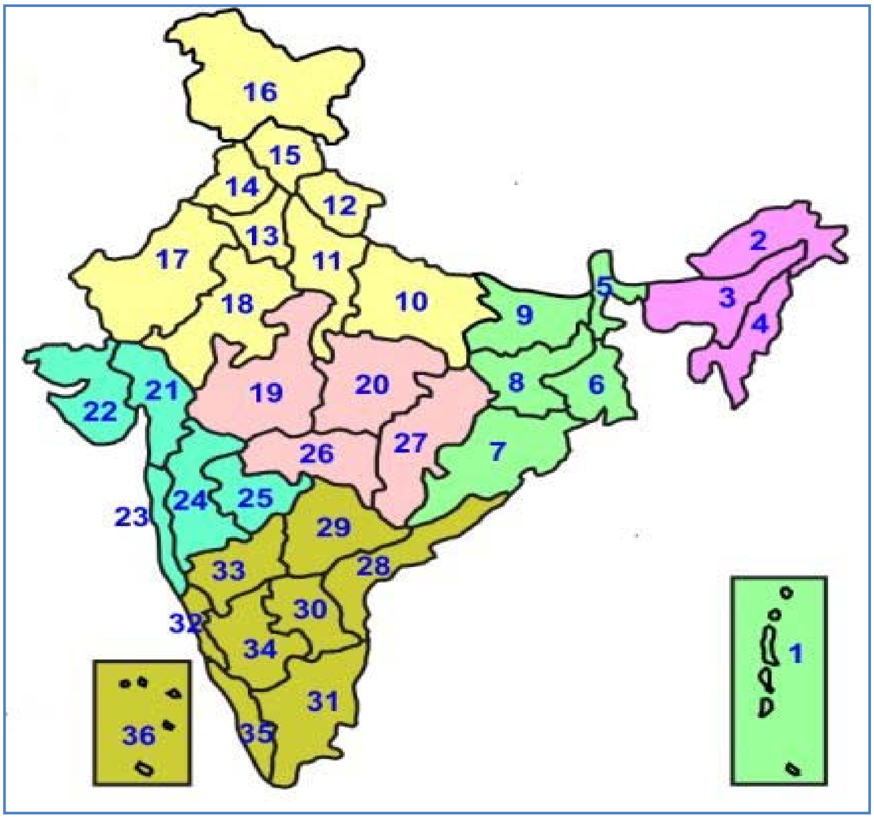


Figure 1.2. Meteorological sub-divisions of the Country

Table 1.2.

Details of the Meteorological sub-divisions of the Country

S. No.	Name of Sub-division	S. No.	Name of Sub-division
1.	Andaman & Nicobar	19.	West Madhya Pradesh
2.	Arunachal Pradesh	20.	East Madhya Pradesh
3.	Assam & Meghalaya	21.	Gujarat Region
4.	Nagaland, Manipur, Mizoram & Tripura	22.	Saurashtra & Kutch
5.	Sub-Himalayan West Bengal & Sikkim	23.	Konkan & Goa
6.	Gangetic West Bengal	24.	Madhya Maharashtra
7.	Odisha	25.	Marathwada
8.	Jharkhand	26.	Vidarbha
9.	Bihar	27.	Chhattisgarh
10.	East Uttar Pradesh	28.	Coastal Andhra Pradesh & Yanam
11.	West Uttar Pradesh	29.	Telangana
12.	Uttarakhand,	30.	Rayalaseema
13.	Haryana, Chandigarh & Delhi	31.	Tamilnadu & Puducherry & Karaikal
14.	Punjab	32.	Coastal Karnataka
15.	Himachal Pradesh	33.	North Interior Karnataka
16.	Jammu, Kashmir & Ladakh	34.	South Interior Karnataka
17.	West Rajasthan	35.	Kerala & Mahe
18.	East Rajasthan	36.	Lakshadweep

1.4.2. Regional Weather Forecasting Centre (RWFC) : The RWFCs function from the Regional Meteorological Centres (RMCs) situated at New Delhi, Mumbai, Nagpur, Kolkota, Guwahati and Chennai. They monitor weather and issue forecasts/warnings for their area of responsibility in sub divisional scale/parts of the subdivisions. A region normally consists of a few meteorological subdivisions. The Regional Meteorological Centre also has the responsibility to issue district wise forecast and warnings, district wise/location specific nowcasts and city/tourism forecast for the state in which it is located. In case of Maharashtra, this responsibility is however shared between RWFC Mumbai and RWFC Nagpur. Among the different RWFCs, those located at Kolkota, Chennai and Mumbai function also as ACWCs and carryout the marine forecast services and cyclone warning services for their respective areas of responsibility.

1.4.3. State Weather Forecasting Centre (SWFC) : The SWFCs situated at the state capitals carry out weather monitoring and issue district level forecasts/warnings and districtwise/location specific nowcasts for the state for which they are responsible. It also has the responsibility to issue city forecast for important cities /tourist places within the state. The SWFCs at Ahmedabad, Thiruvananthapuram and Bhubaneshwar function also as CWCs and carryout the marine forecast services and cyclone warning services for their respective areas of responsibility.

1.4.4. Weather Central (WC), Pune : The functioning of Weather Central, Pune is similar to that of NWFC in respect of technical analysis and finalization of forecast. The centre archives past weather data, prepares Indian Daily Weather Report (IDWR) and carries out analysis and documentation of seasonal weather for publication purpose. The centre also regularly carry out analysis of surface and upper air weather charts of both morning and evening and do its archival in digital format for its future use. These digitized charts are circulated to different forecast centres also immediately after their preparation on daily basis for their display and archival for future use. In additional to this, the centre conducts map discussion on every Friday in which the realized weather of the previous meteorological week and the forecast for the running week is discussed in detail. These map discussions are attended by officials from IITM, students from Universities and also by retired officials of IMD and IITM etc.

The weather forecasting organization of the department is given in Figure 1.3.

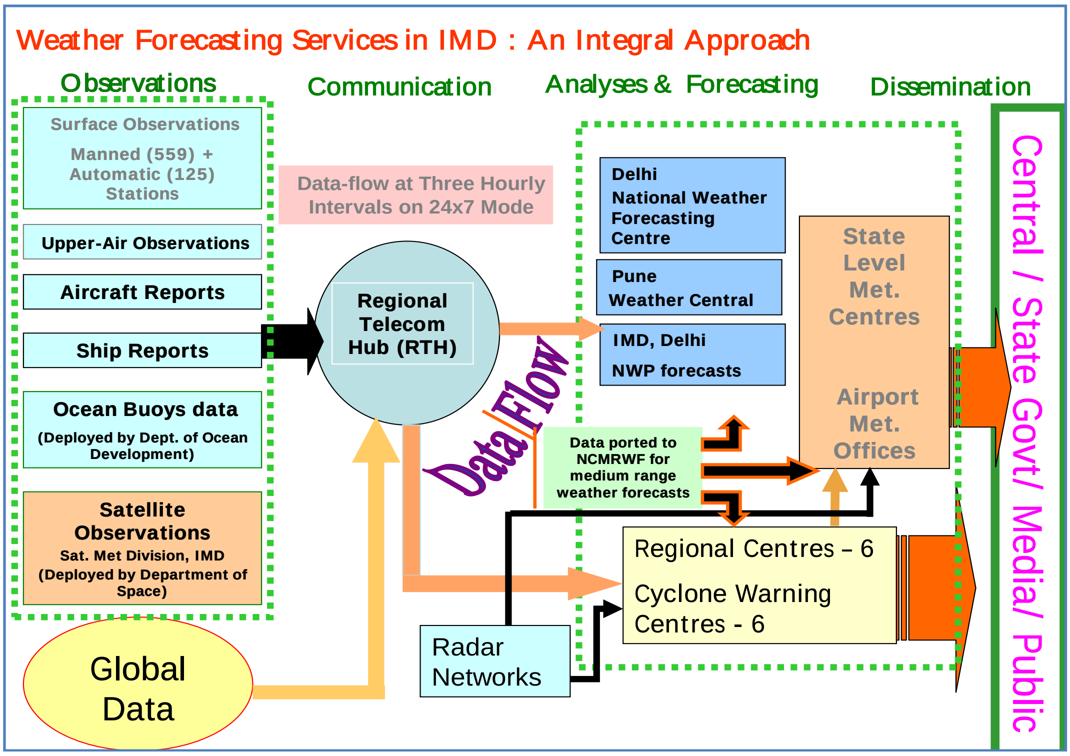


Figure 1.3. Weather forecasting organization of IMD

1.5. Forecast scheme

The scheme for issue of forecast by various offices is shown in Table 1.3.

(i) Forecasts will be issued 4 times a day by NWFC. It includes one main weather bulletin around mid day and remaining three are updates of the same. RWFCs/SWFCs will issue forecast two times a day; one main bulletin around mid day and an update in the night.

(ii) All the bulletins should include time of issue and time of observations based on which it is issued which forms the basis of bulletin, validity period of the bulletin and next time of issue of update.

(iii) Meteorological day is considered from 0830 hrs IST of any day concerned to 0830 hrs IST of the next day. The forecasts issued from NWFC/RWFCs/SWFCs on any day are valid for 120 hours (five days) from the date and time of issue. Thus, forecasts issued for Day 1 on say 11th of a month in the morning, midday, evening and night all would be valid upto 0830 hrs of 12th only. And the forecast issued for Day 5 on 11th in all the above bulletins will be valid from 0830 hrs IST of 15th upto 0830 hrs of 16th. Thus the validity period is not exactly 120 hrs with respect to the time of issue of every forecast bulletin within a day.

(iv) The outlook will be valid for a subsequent period of 48 hrs (2 days). For example, forecasts issued on say 11th of a month in the morning, midday, evening and night will contain the outlook for 16th and 17th valid from 0830 hrs IST of 16th upto 0830 hrs of 18th.

(v) Forecasts issued for Day 1 cover the weather expected during 24 hrs period, Day 2 for the period between 24 to 48 hrs, Day 3 for the period between 48 to 72 hours, Day 4 for the period between 72 to 96 hours and Day 5 for the period between 96 to 120hrs.

(vi) Warnings for severe weather expected are also included in the bulletins as per the ongoing season. For example warning for fog/cold wave etc are included during the winter season whereas warning for heatwaves are included during the summer/pre monsoon season as per the criteria followed.

(vii) The forecast and warnings issued from NWFC are in the subdivisional scale for the country as a whole whereas the same from SWFC are in the district scale for the state concerned. Forecast and warning issued from RWFC are for the subdivision as whole or for sectors of subdivision while it also issue district level forecast and warning for the state in which it is located.

(viii) The weather bulletin contains a brief summary of the observations, description of the prevailing synoptic situations and significant features in addition to the forecast, warnings and the outlook.

(ix) The Daily Weather Bulletin (Mid Day) issued from RWFCs/SWFCs includes a brief advisory for farmers which are generally broadcasted by All India Radio.

The Example for Multi Hazard Warning Bulletin issued by NWFC is given in Appendix I and the same for forecast and warning bulletin issued from SWFC Bhubaneshwar are given in Appendix II and III respectively.

Table 1.3.

The scheme for issue of forecast

Forecast Centre	Type of weather bulletin	Time of issue	Time of Observation
NWFC	All India Daily Weather Bulletin (i) Mid Day (Main Bulletin) (ii) Evening (Update Bulletin) (iii) Night (Update Bulletin) (iv) Morning (Update Bulletin)	(i)Around 1300Hrs IST (ii)Around 1630Hrs IST (iii)Around 2000Hrs IST (iv)Around 0800Hrs IST of the next day	(i) based on 00Z and 03Z Observations (ii) based on 06Z and 09Z Observations (iii) based on 12Z Observation (iv) based on 00Z Observation
RWFC	a)Regional weather Bulletin (i) Mid Day (Main Bulletin) (iii) Night (Update Bulletin) b) District level forecast Bulletin i) Mid Day (Main forecast)	a) (i)Around 1300Hrs IST (ii)Around 2000 Hrs IST b) (i)Around 1400Hrs IST	(i) based on 00Z and 03Z Observations (ii) based on 12Z Observations based on 00Z and 03Z observations and Mid day bulletin
SWFC	a)State daily weather Bulletin (i) Mid Day (Main Bulletin) (ii) Night (Update Bulletin) b) District level forecast Bulletin Mid Day (Main forecast)	a) (i)Around 1300Hrs IST (ii)Around 2000Hrs IST b) (i)Around 1400Hrs IST	(i)based on 00Z and 03Z observations (ii)based on 12Z observations (i)based on 00Z and 03Z observations and Mid day bulletin

Note : The forecast from RWFC/SWFC will be updated as and when required other than the scheduled timings mentioned above in case of necessity and the same needs to be communicated to all concerned and to be updated in the website also.

1.6. Forecast Generation

Forecasting services is a three tier system with NWFC New Delhi at the headquarters, RWFC at the regional level and SWFC at the state level. Thus forecast for a meteorological subdivision would be issued by at least three centres. e.g., For Telengana subdivision, forecasts will be issued by SWFC Hyderabad, RWFC Chennai and NWFC New Delhi. Such forecasts originating from different centres should be consistent in their contents and should not differ from centre to centre.

(i) To ensure consistency in the forecasts issued from different centres, the operational forecasters of NWFC, RWFC and SWFC carryout discussion about the ongoing and impending weather scenario in detail through Video Conference or teleconference between 1030 hrs to 1200 hrs IST on daily basis before the issue of main bulletin (Mid Day bulletin) and based upon the final decision all centres will issue the forecast and warnings as per the forecast scheme of each centre.

(ii) While updated bulletins are issued, In case of any significant change required to be made for any area, the same is carried out after telephonic discussion with the concerned RWFC/SWFC. For example, if SWFC Bhubaneswar wants Heavy rainfall warning is to be included in Night Bulletin then the same is incorporated after discussing with NWFC, New Delhi and RWFC Kolkata so that the corresponding modifications are carried out in the bulletins issued from that centres also. Any centre can suggest incorporation of modifications in the updated bulletins and the same is finalised after discussing and taking the consent from all concerned in the national, regional and state levels.

1.7. Terminology used in Forecasts

Description of spatial distribution of rainfall or its intensity over any subdivision/district for any day is based on the 24 hr accumulated rainfall ending at 0830 hrs IST of that day. Similar criteria are applicable for the forecasted rainfall also, viz., the forecasted spatial distribution and intensity of rainfall for Day 1 is based on the rainfall expected from 0830 hrs IST of that day to 0830 hrs IST of the next day.

1.7.1. Spatial distribution of Rainfall

For description of the spatial distribution of rainfall in observed as well as forecasted weather, categories used are given in Table 1.4.

Table 1.4.

Terminology for Spatial Distribution of rainfall

Spatial Distribution of Rainfall	Descriptive term used	Criteria for observed/forecastweather
Dry	Dry	No station reported/expecting rainfall
Isolated	One or two Places	≤25% of stations get/expected to get rainfall
Scattered	At a few Places	(26–50)% of stations get/expected to get rainfall
Fairly Widespread	At many Places	(51–75)% of stations get/expected to get rainfall
Wide spread	At most places	(76–100)% of stations get/expected to get rainfall

Note : Only daily rainfall of at least 2.5mm is taken into consideration in the monsoon months. During non-monsoon period, rainfall less than 2.5 mm also may be considered for distribution / verification as per existing practice. Rainfall realised in the category of trace, viz., less than 2.5 mm in monsoon season and less than 0.1 mm in other seasons in a subdivision, the weather for that sub division will be described as mainly dry.

1.7.2. Intensity of 24-hour Accumulated rainfall

For the description of intensity of 24-hour accumulated rainfall, the criteria used are given in Table 1.5.

Table 1.5.

Terminology for intensity of 24 hour accumulated rainfall

S. No.	Terminology	Rainfall (mm)	Rainfall (cm)	Percentile
1.	Very light rainfall	Trace -2.4		
2.	Light rainfall	2.5-15.5	Upto 1	Upto 65
3.	Moderate rainfall	15.6-64.4	2-6	65-95
4.	Heavy Rainfall	64.5- 115.5	7-11	95-99
5.	Very Heavy Rainfall	115.6-204.4	12-20	99.0-99.9
6.	Extremely heavy rainfall	Greater than or equal to 204.5 mm	21 cm or more	>99.9
7.	Exceptionally Heavy Rainfall	When the rainfall observed is a value near about the highest recorded rainfall at or near the station for the month or the season. However, this term will be used only when the actual rainfall amount exceeds 12 cm		

1.7.3. Intensity of 24-hour Accumulated snowfall

For the description of intensity of 24-hour accumulated snowfall, the criteria used are given in Table 1.6.

Table 1.6

Terminology for intensity of 24 hour accumulated snowfall

S. No.	Terminology	Snowfall depth in cm	Percentile
1.	Light Snowfall	10.4 cm or less	Less than 50th Percentile
2.	Moderate Snowfall	10.5-64.4 cm	50-95
3.	Heavy Snowfall	64.5- 115.5 cm	95-99
4.	Very Heavy Snowfall	115.6-204.4 cm	99.0-99.9
5.	Extremely heavy Snowfall	204.5 cm or more	>99.9

Note : For the description of spatial distribution of weather events other than rainfall, viz., heat wave, cold wave, fog, thunderstorms etc., the criteria given in Table 1.4 itself are used. The criteria used for the description of intensity of those weather events are separately dealt in the Chapters related to them.

1.7.4. Probability of Occurrence of the Weather event

In order to mention the probability of occurrence of the expected weather, the terminology given in Table 1.7 is used.

Table 1.7

Terminology for probability of occurrence of weather event

Term	Probability of occurrence
Unlikely	Less than 25%
Likely	25% to 50%
Very likely	50% to 75 %
Most likely	more than 75%

1.7.5. Description of Temperature departure from normal

Terminology used for description of maximum and minimum temperature departures from normal in weather bulletin are given in Table 1.8.

Table 1.8

Terminology for Temperature departure from normal

Terminology	Departures from normal
Markedly below normal	- 5.0^{O} C or less
Appreciably below normal	- 3.1^{O} C to –5.0^{O}C
Below normal	-1.6^{O} C to -3.0^{O}C
Normal	- 1.5^{O} C to 1.5^{O}C
Above normal	1.6^{O} C to 3.0^{O}C
Appreciably above normal	3.1^{O} C to 5.0^{O} C
Markedly above normal	5.0^{O} C or more

1.7.6. Description of temperature tendency

Terminology used for description of maximum and minimum temperature tendency (change in twenty four hours) in weather Bulletin is given in Table 1.9.

Table 1.9

Terminolgy for temperature tendency

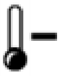
Terminology	Change in twenty four hours
Marked fall	- 4.1^{O}C or less
Appreciable fall	- 2.1^{O}C to – 4.0^{O}C
No Large Change	- 2.0^{O} C to + 2.0^{O}C
Appreciable rise	2.1^{O}C to 4. 0^{O}C
Marked rise	4.1^{O}C or more

1.7.7. Symbols for Severe weather Representation

The symbols used for representing the severe weather phenomena in weather warnings are given in Table 1.10.

Table 1.10

Symbols for severe weather representation in warnings

S. No.	Weather Type	Symbol
1.		Heavy Rain
2.		Heavy Snow
3.		Thunderstorm
4.		Dust storm
5.		Strong Wind
6.		Visibility
7.		Cyclone
8.		Squall/Hail
9.		Frost
10.		Cold Wave
11.		Heat Wave
12.		Sea State

1.7.8. Colour code for Weather warnings

The following colour codes are used in weather warnings for bringing out the severity of the weather phenomena expected. This mainly serves as a signal for the disaster management authority about the impact of the weather expected so as to keep them ready for necessary action related to disaster risk reduction.

WARNING (TAKE ACTION)
ALERT (BE PREPARED)
WATCH (BE UPDATED)
NO WARNING (NO ACTION)

In order to decide upon the colour to be assigned to a given weather warning situation under the 5-day forecast scheme, the matrix given in Figure 1.4. is followed, giving thrust on the probability of occurrence of the event as well as its impact assessment.

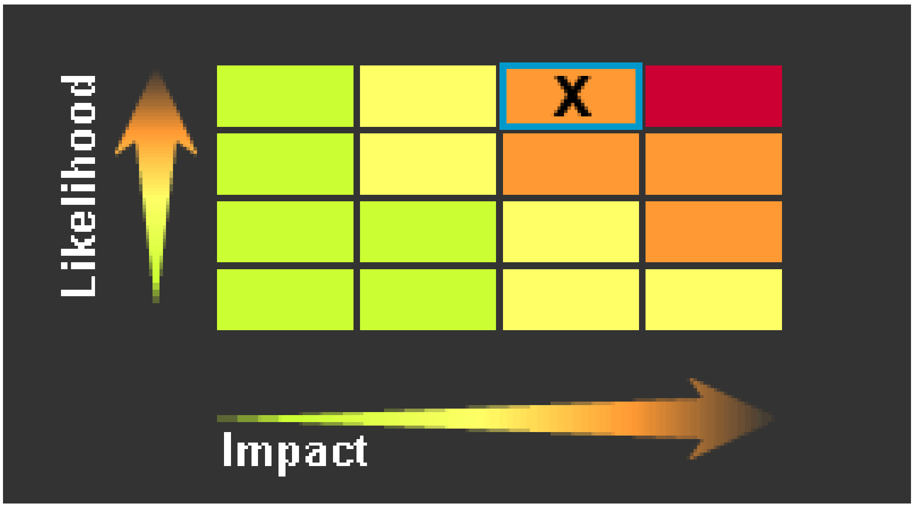


Figure 1.4. Matrix for Decision of Colour Code for Warning

The probability of occurrence of severe weather for Day1 to Day5 may be decided based upon the inference derived from the synoptic analysis of Observations, analysis of model forecasts (including probabilistic outputs) and diagnostic products available with respect to different weather phenomena. For impact assessment, the conceptual model of the weather associated with the disaster events from past and the impact caused by them along with the topography, land-use pattern, socio-economic factors and livelihood of the region needs to be taken into consideration.

The colour code for impact based warning for a district or subdivision depends upon many factors including (i) meteorological factors (ii) hydrological factors (iii) geophysical factors etc. which may interact with each other to determine the impact and risk. Hence the forecaster will decide the impact considering all these factors and colour code for the warning will be decided accordingly.

For more details on Impact Based Forecasting, Chapter on Heavy Rainfall Warning may be referred to.

1.8. District level forecasts

(i) District level forecast and warning shall be issued by all SWFC and RWFC for their area of responsibility. The validity period of district level forecast will be five days with an outlook of subsequent two days.

(ii) The probability of occurrence of heavy rainfall alongwith qualitative description regarding the intensity of rainfall expected viz. heavy rainfall, very heavy rainfall etc. are mentioned for each district as and when required in each forecast and updates. Rainfall intensity less than that of heavy rainfall, viz., Light to moderate rainfall etc. should also be given as and when necessary in probabilistic terms.

(iii) A district is a compact area hence spatial distribution of individual district may be different from the spatial distribution of cluster of districts comprising a sub division. For example, if scattered distribution is predicted for a subdivision, some of the districts of that subdivision can have dry weather also.

(iv) Appropriate colour code (Green, Yellow, Orange, and Red) for warning is to be assigned for each district taking into consideration of the probability of occurrence of severe weather and its impact for all the five days.

The criteria of colour coding of heavy rainfall warning at district level are given in Table 1.11 for each day of the forecast, valid up to five days.

Table 1.11

Colour coding criteria for heavy rainfall warning in the district level

Category	Colour Coding
Isolated extremely heavy rainfall	Red
Scattered heavy to very heavy rainfall	Red
Isolated heavy to very heavy rainfall (consecutively for 3 days)	Orange for Day 1 and Day 2 and Red for Day 3
scattered heavy rainfall/Isolated heavy rainfall	Yellow
If it is already flood situation and heavy rainfall is expected	Orange/Red
No heavy rainfall	Green

(v) The criteria given above are of general nature. Considering the location, period of occurrence of heavy rainfall expected and the ongoing flood scenario if any, the impact may be different. Hence, MCs/RMCsto decide the colour code for district level warnings accordingly.

(vi) Even though colour code criteria used by all the centres are same, it is not necessary that the colour code used for subdivisional warning will be same as the colour code used for any district in that subdivision. Thus, the colour code used by NWFC for the subdivision as a whole may be yellow but the colour code used by RWFC/SWFC for any district within that subdivision can be orange or red as per the weather situation expected and its impact.

1.9. City/Local Forecast

Local Forecasts for the Capital and other cities/towns are very important for management of urban activities. In addition to this, location specific forecasts are provided also for important functions like Independence Day, VVIP movements and tourism requirements etc.

(i) Location specific city forecasts/tourism forecasts are to be issued by RWFC/SWFC for the main cities under their area of jurisdiction and it will consists of local weather report and forecast for seven days.

(ii) In case of VVIP movements, depending upon the location for which forecast is required, the concerned RWFC/SWFC prepares the forecasts and send it to NWFC for approval and after verification of the same and incorporating modifications needed if any, the final forecast is issued from NWFC.

(iii) The local weather report includes the maximum and minimum temperature realized and their departure from normal, twenty four hours accumulated rainfall ending at 0830 hrs IST of the day, relative humidity recorded in the morning and evening and time of sunrise, sunset, moon rise and moon set for the location.

(iv) The forecast part includes the expected maximum and minimum temperature and weather for the seven days. If no weather is expected for a particular day, then expected sky condition will be given instead.

(v) The local forecast is issued four times a day, around 0200 hrs, 0800 hrs, 1400 hrs and 2000 hrs IST respectively,

(vi) The categories used in local forecast for expected rainfall characteristics are given in Table 1.12 below.

Table 1.12

Categories of rainfall in Local forecasts

Weather phenomena	Description
One or two spells of Rain	During 24 hour period, rainfall occurring with a frequency of one or two spells.
A few spells of rain	During 24 hrs period, rainfall occurring with a frequency Of more than two spells but with well defined dry spells in between.
Intermittent rain	During 24 hrs period, rainfall occurring with a frequency more than that defined in "A Few Spells" but is discontinuous and without presenting the character of a Shower
Continuous rain	Rain occurring almost throughout the 24-hour period.
Drizzle	Liquid precipitation in the form of water drops of very small size (by convention, with radius of water drops between about 100 and 500 µm)
Shower	Liquid precipitation in the form of water drops, with radius of water drops more than 2500 µm. Showers are in general characterized by short duration with fluctuating intensity.

(vi) The categories used for describing the sky conditions in local forecast are given in Table 1.13. The sky condition is reported in terms of Octa wherein the sky is divided into eight equal parts.

Table 1.13

Categories for Sky condition in Local Forecast

Sky condition	Portion of sky covered with clouds (in Octa)
Clear sky	0
Mainly clear sky	1-2
Partly cloudy sky	3-4
Generally cloudy sky	5-7
Cloudy sky	>7

Here the terminology used in Local Forecasts for rainfall and sky conditions are discussed. When there are possibilities of occurrence of severe weather elements like thunderstorms, fog, heatwave, cold wave etc. affecting the city/location, the same are to be mentioned in the local forecast.

1.10. Forecasting Organisational Structure

To cater to the needs of forecasting activities in the national, regional and state levels, the General Forecasting system preferably have the following organizational structure with respect to NWFC in the national level with Weather Central, IMD, Pune as its standby, RWFC in the regional level and SWFC in the state level.

1.10.1. National Level

- General Forecasting and Public Weather Service (PWS) Division

  a. General Weather Forecasting Unit
  b. Public Weather Services Unit
  c. Weather Summary Unit
  d. Unit dealing with Parliament Questions/RTI/Grievances

- Cyclone Warning Division
- MarineWeather Service Division
- Nowcast Division
- Mountain Meteorology Division
- Satellite Application Division

All these divisions of NWFC are shown schematically in Figure.1.5 below.

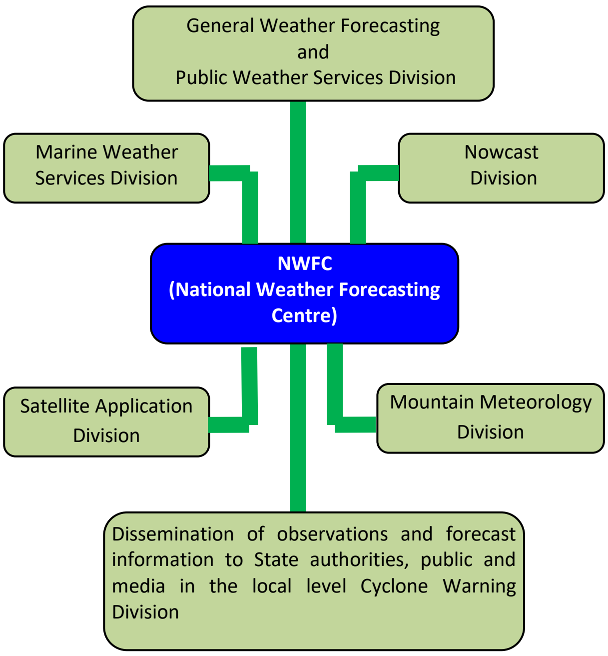


Fig. 1.5. Organisational Structure of National Weather Forecasting Centre

1.10.2. Weather Central, IMD, Pune

Weather Central, Pune will have the following Cells.

- Standby Operational Forecast Cell for NWFC operations to manage the operational work in the event of any major contingency at NWFC.

- Documentation Cell for preparation of IDWR, WWR, Monthly and Seasonal Reports.

- Verification Cell for monitoring of procedures followed by all operational offices and verification of forecasts (in collaboration with NWFC).

- Communication Cell.

The organisational structure of Weather Central, Pune is shown in Figure 1.6.

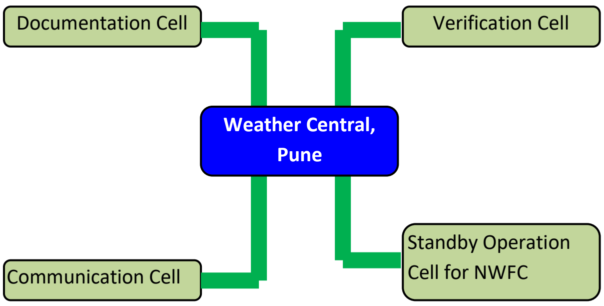


Fig. 1.6. Organisational Structure of Weather Central Office, Pune

1.10.3. State level/Regional level

The RWFC/SWFC will have following cells:

- General Forecasting / Nowcasting Cell
- PWS Cell
- Documentation Cell
- DRMS Cell
- Communication Cell
- Agromet Service Cell
- Aviation Co-ordination Cell
- FMO's Co-ordination Cell

The organisational structure of RWFC/SWFC is shown in Fig.1.7.

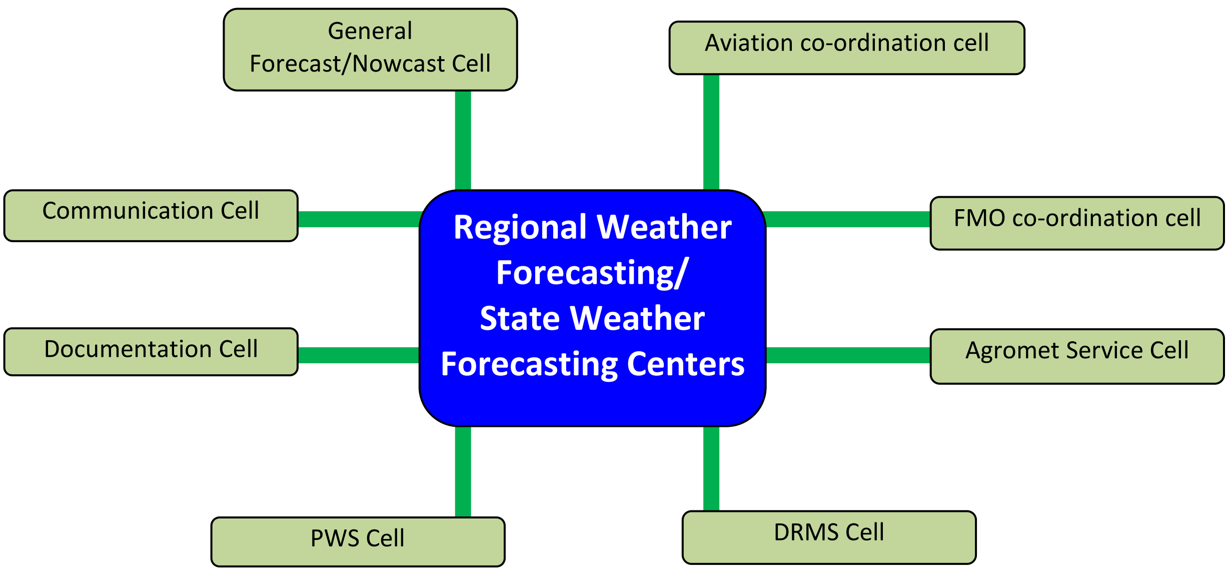


Fig. 1.7. Organisational Structure of Regional/State Weather Forecasting Centres

1.10.4. Meteorological Offices

The Meteorological Offices will have the organisational structure for the activities related to their responsibilities shown in Fig. 1.8.

- Regular weather Observations and their communication
- Survey and reporting of adverse weather
- Dissemination of observations and forecast informations to local authorities, public and media
- Maintenance of surface observatory/AWS/ARG
- Preparation of Station climatology

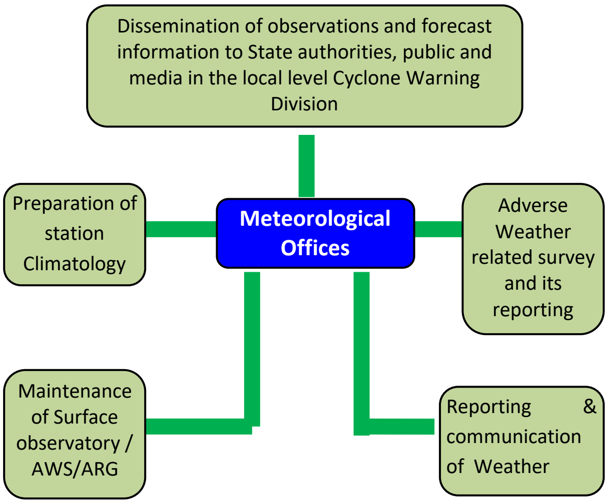


Fig. 1.8. Organisational Structure of Met Offices

1.11. Mandate of Different Forecasting Centres

1.11.1. NWFC

(A) General forecasting cell

(i) This cell will monitor the weather situation over the country.

(ii) It will issue sub-divisional wise short and medium range forecasts for next five days and outlook for subsequent two days in consultation with RWFCs and SWFCs.

(iii) It will issue All India weather forecasts 4 times a day as per forecast scheme.

(iv) It will issue forecast related to sports, VVIP movements, Independence /Republic day functions etc. with copies endorsed to concerned SWFC and RWFCs .

(v) It will monitor Global Weather that would have implications on Indian weather.

(vi) This cell will function round the clock.

(B) Cyclone Warning and Marine Cell

(a) Marine cell will be responsible for the issue of

- (i) GMDSS Bulletin for area VIII (N)
- (ii) Fleet Forecast
- (iii) Fishermen warning in text as well as pictorial format for coastal as well as high sea areas of North Indian Ocean on daily basis
- (iv) All weather related enquiries pertaining to high sea areas will be handled by the marine cell in co-ordination with ACWCs/CWCs.

(b) Cyclone Warning Cell will issue Tropical Weather Outlook for North Indian Ocean on daily basis and extended range outlook for cyclogenesis in North Indian Ocean on weekly basis.

(c) Cyclone warning cell will be functioning round the clock once a low pressure system over the North Indian Ocean concentrates into a depression.

(d) Cyclone Warning cell shall continue to follow the existing practices for monitoring and forecast as per the latest cyclone manual.

(C) Nowcasting cell

(i) This cell would monitor and forecast severe weather events with shorter life span of a few hours such as: Thunderstorm, Thunder squall, Tornado, Hail storm, Lightning, Dust storm, Fog, Heavy spells of rain etc.

(ii) Nowcast guidance bulletin related to severe weather events is issued by the Nowcasting cell after the daily discussion through video conference and the same is updated as and when required.

(iii) The nowcasting cell continuously monitors the nowcasts being issued from the RWFCs/SWFCs and carryout the scrutinisation of the verification of the nowcasts issued from these centres.

(iv) This cell prepares thunderstorm reports on yearly basis.

(D) PWS Cell

(i) This cell will provide end user services at national level.

(ii) PWS unit will furnish inputs for providing material to media and to stake holders

(iii) This cell will prepare multi hazard maps with colour code for the warnings issued.

(iv) This cell will take care of weather product generation and dissemination of all types of bulletins/ warnings to different State and Central Government users, All India Radio, Television channels including Door Darshan, Registered Users and the electronic and print media.

(v) It will carry out periodic website updating, dissemination of weather information through different social media viz., Facebook, Twitter, Whatsapp etc.

(vi) This cell will function round the clock.

(E) Satellite Application Unit

(i) The SATMET Application Unit is collocated with NWFC and function round the clock to facilitate the interpretation of satellite images and data required for forecasting.

(ii) The satellite application cell monitors and interprets the satellite imageries. This cell issues satellite bulletins for use by various users. The satellite bulletins are issued at three hourly intervals on regular basis and at hourly/half hourly interval during the period of intense Low pressure systems like cyclones.

All the above cells of NWFC will function under a Senior Scientist as overall in charge & all above duties are to be carried out under the guidance and approval of overall In charge.

1.11.2. Weather Central, Pune

(i) The WC, Pune will generate the daily forecast in the same format as it is done by NWFC, Delhi on All India level in the subdivisional scale, but will not issue it to the users.

In the event of a major contingency at NWFC, Delhi (HQ Office) resulting into disruption of operational services for a few days, Weather Central Pune will immediately take over all the operational responsibilities of NWFC. All the work stations available at Weather Central*,* Pune and at the Meteorological Training institute at Pune will be used, as required, to support the essential operational services.

When normal conditions are restored at NWFC New Delhi, regular operational activities will be shifted from Weather Central, Pune to NWFC, New Delhi.

(ii) This centre also provides technical guidance in operational matters and carry out preparation of related manuals, guides etc. in collaboration with NWFC.

(iii) WC Pune is also responsible for documentation and preservations of IDWR, WWR and seasonal weather summaries etc.

(iv) WC Pune would prepare and disseminate local forecast for Pune and neighbourhood, four times a day.

(v) WC Pune carryout digitization of analysed weather charts and their preservation.

(vi) WC Pune also carries out forecast verification and its documentation for some of the forecasts issued by forecasting centres.

1.11.3. RWFC /SWFC

(A) General forecasting Cell

(i) Round the clock weather monitoring for the area of responsibility.

(ii) Preparation and issue of Daily Weather Report (DWR) in district level with forecast and warning for five days (120hrs) and outlook for subsequent 2 days. SWFC will prepare the same for the concerned state whereas RWFC will prepare the same for the state in which it is located.

(iii) Forecasting cell of RWFC will prepare the DWR in subdivision/sectors of subdivision level also for its area of responsibility.

(iv) SWFC will prepare and issue of Local Forecast /City Forecast and its update in every 6 hours for the stations of the concerned state whereas RWFC will prepare the same for the stations of the state in which it is located.

(v) SWFC/RWFC will prepare and issue all user specific bulletins viz., bulletin for All India Radio, Door Darshan, Press, State disaster management authorities etc related to weather information and warnings for the state concerned.

(vi) Preparation of draft inputs for VVIP movements, special events etc. and its dissemination to NWFC for its finalisation and issue will also be carried out by SWFC/RWFC as per their area of responsibility.

(vii) Preparation and issue of Fishermen Warning 4 times a day for the area of responsibility (only by those RWFC/SWFC which functions also as ACWC/CWC respectively).

(viii) Preparation and issue of Routine Coastal bulletin, Sea area bulletin, Port warning for the concerned area of responsibility (only by those RWFC/SWFC which function also as ACWC/CWC respectively). Thus RWFC (ACWC) Kolkata will issue Sea area bulletin for Bay of Bengal and RWFC(ACWC) Mumbai will issue Sea area bulletin for Arabian Sea. Similarly SWFC (CWC) Thiruvananthapuram will issue Coastal bulletin for Kerala-Karnataka coasts.

(ix) Preparation and issue of Cyclone related bulletins, viz., Alert/Warning, Port and Fisheries bulletins, and Coastal bulletins during Cyclone / Depression period as per SOP of cyclone(only by those RWFC/SWFC which functions also as ACWC/CWC).

(x) This cell will also do the monitoring of severe weather developments over its area of responsibility and issue nowcasts as and when required as per the nowcast guidance bulletin from now casting Cell of NWFC.

Note : This cell would be headed by a Senior Scientist. It will always be manned by a Class I officer or a trained forecaster and will function round the clock.

(B) Agro Advisory Service Unit

(i) Preparation and issue of value added district level forecast and its issue to AMFUs/DAMUs two times a week; on Tuesdays and Fridays so as to enable them to issue agromet advisories to the farmers.

(ii) This unit issue quantitative district wise forecast for five parameters, viz., rainfall, maximum & minimum temperature, maximum & minimum relative humidity, cloudiness, wind speed and wind direction.

(iii) Multi-Model Ensemble (MME) technique is used to generate district level forecast in terms of quantitative numbers and the final forecast is issued after carrying out value addition.

(iv) This forecast would be issued only once per day (at about 1200 hrs IST) on both the days. The forecaster can make use of medium range forecast products generated by IMD, NCMRWF, ECMWF and also the district rainfall climatology to do value addition.

(D) Communication cell

(i) This cell would monitor and ensure the flow of observational data and forecast products between the forecasting centres at the national, regional and state level and also with Weather Central, Pune for the smooth functioning of operational work.

(ii) This cell will also be responsible for collection and transmission of data from all observatories for the concerned area of Jurisdiction.

(E) Daily Rainfall Monitoring Scheme (DRMS) Cell

This cell will do collection of all rainfall data from concerned area/state, process and analyse the data and prepare rainfall statistics for the area of responsibility in both tabular and map form.

(F) FMO Coordination

In RWFC New Delhi and RWFC Gauhati and MCs at Ahmedabad, Bhubanaeshwar, Hyderabad, Lucknow, Patna, Srinagar and Bangalore FMOs are collocated with the forecasting centre and hence the same unit will do the co-ordination work with Central Water Commission (CWC) and issue Quantitative precipitation forecast for concerned basins under their area of responsibility. When the FMOs are in a different location, a coordination cell shall work within the concerned RWFC/SWFC under which the FMO is situated.

(G) Aviation Coordination

This cell within RWFC/SWFC will monitor/co-ordinate the operational forecast activities of all the aviation meteorological offices located within the jurisdiction of concerned RWFC/SWFC.

A Senior Scientist preferably in the rank of Scientist E/D will function as the chief forecaster in RWFC and SWFC. The daily video conference will be attended and the main weather bulletin (mid day bulletin) will be issued by the chief forecaster or in his absence by the batch In charge in consultation with the chief forecaster. The updated weather bulletin will be issued by the batch In charge in consultation with the chief forecaster.

All the above cells will function under the Head of RMCs/MCs as overall in charge and all the decisions related to operational activities are to be carried out with the approval of overall In charge.

1.11.4. Meteorological Offices (Observatories)

(i) The Meteorological offices should be the integral components of the forecast organisation even though they do not perform any forecast related activities.

(ii) They will collect and provide the current observations to all concerned to support forecast activities. Additional (special) observations needs to taken and reported to the concerned as and when required during severe weather phenomena like cyclone affecting the area.

(iii) Field survey will be conducted by the staff in case of adverse weather conditions prevailing in their region as and when required or on instruction from RWFC/SWFC. Any adverse weather conditions will be reported promptly to SWFC/RWFC and a report based on field survey will also be submitted via email followed by hard copy.

Appendix I

All India Multi Hazard Warning Bulletin issued by NWFC

Tuesday 21 July 2020
Time of Issue: 1345 hours IST

(MID-DAY)

21 July (Day 1): ♦ Heavy to very heavy rainfall at isolated places with **extremely heavy falls** at isolated places very likely over Assam & Meghalaya; **heavy to very heavy rainfall** at isolated places over Himachal Pradesh, Uttarakhand, Punjab, Bihar, Sub-Himalayan West Bengal & Sikkim, Arunachal Pradesh and Nagaland, Manipur, Mizoram & Tripura and **heavy rainfall** at isolated places over Jammu & Kashmir, Ladakh, Gilgit-Baltistan, Muzaffarabad, North Haryana, Chandigarh & Delhi, Uttar Pradesh, Rajasthan, Madhya Pradesh, Jharkhand, Gangetic West Bengal, Madhya Maharashtra, Marathwada, Coastal Andhra Pradesh & Yanam and Lakshadweep.

♦ **Thunderstorm accompanied with lightning** very likely at isolated places over Jammu & Kashmir, Ladakh, Gilgit-Baltistan, Muzaffarabad, Himachal Pradesh, Uttarakhand, Punjab, Haryana, Chandigarh & Delhi, Uttar Pradesh, Rajasthan, Madhya Pradesh, Vidarbha, Chhattisgarh, Bihar, Jharkhand, Gangetic West Bengal, Odisha, Arunachal Pradesh, Assam & Meghalaya, Nagaland, Manipur, Mizoram & Tripura, Coastal Andhra Pradesh & Yanam, Telangana and Interior Karnataka.

♦ **Strong Wind** (speed reaching 50-60 kmph) very likely over Southwest and adjoining westcentral Arabian Sea. **Squally weather** (wind speed reaching 40-50 kmph) over Eastcentral & adjoining southeast Arabian Sea. Fishermen are advised not to venture into Sea over these areas.

22 July (Day 2): ♦ Heavy to very heavy rainfall at isolated places over Assam & Meghalaya, Nagaland, Manipur, Mizoram & Tripura and Lakshadweep and **heavy rainfall** at isolated places over Uttarakhand, East Uttar Pradesh, East Madhya Pradesh, Chhattisgarh, Bihar, Jharkhand, Sub-Himalayan West Bengal & Sikkim, Odisha, Arunachal Pradesh, Madhya Maharashtra, Telangana, Rayalaseema, South Interior Karnataka and Kerala & Mahe.

♦ **Thunderstorm accompanied with lightning** very likely at isolated places over Bihar, Jharkhand, Gangetic West Bengal, Odisha, Coastal Andhra Pradesh & Yanam and Rayalaseema.

♦ **Strong Wind** (speed reaching 50-60 kmph) very likely over Southwest and adjoining westcentral Arabian Sea. **Squally weather** (wind speed reaching 40-50 kmph) over Lakshadweep area & adjoining southeast Arabian sea; along & off Kerala coast and Eastcentral Arabian Sea & off Karnataka coast. Fishermen are advised not to venture into Sea over these areas.

23 July (Day 3): ♦ Heavy to very heavy rainfall at isolated places with **extremely heavy falls** at isolated places very likely over Assam & Meghalaya; **heavy to very heavy rainfall** at isolated places over West Uttar Pradesh and Nagaland, Manipur, Mizoram & Tripura and **heavy rainfall** at isolated places over Uttarakhand, East Madhya Pradesh, Vidarbha, Chhattisgarh, Bihar, Jharkhand, West Bengal & Sikkim, Odisha, Arunachal Pradesh, Madhya Maharashtra, Marathwada, Konkan & Goa, Telangana, Rayalaseema, Karnataka, Tamilnadu, Puducherry & Karaikal, Lakshadweep and Kerala & Mahe.

♦ **Thunderstorm accompanied with lightning** very likely at isolated places over Bihar, Jharkhand, Gangetic West Bengal, Coastal Andhra Pradesh & Yanam,Tamilnadu, Puducherry & Karaikal and Rayalaseema.

♦ **Strong Wind** (speed reaching 50-60 kmph) very likely over Southwest and adjoining westcentral Arabian Sea. **Squally weather** (wind speed reaching 40-50 kmph) over Lakshadweep area & adjoining southeast Arabian sea; along & off Kerala coast and Eastcentral Arabian Sea & off Karnataka-Goa-South Maharashtra coasts. Fishermen are advised not to venture into Sea over these areas.

24 July (Day 4): ♦ Heavy rainfall at isolated places over Himachal Pradesh, Uttarakhand, East Uttar Pradesh, East Rajasthan, Madhya Pradesh, Bihar, Jharkhand, Sub-Himalayan West Bengal & Sikkim, Assam & Meghalaya, Madhya Maharashtra, Marathwada, Konkan & Goa, Telangana, Rayalaseema, Coastal Karnataka, Tamilnadu, Puducherry & Karaikal and Kerala & Mahe.

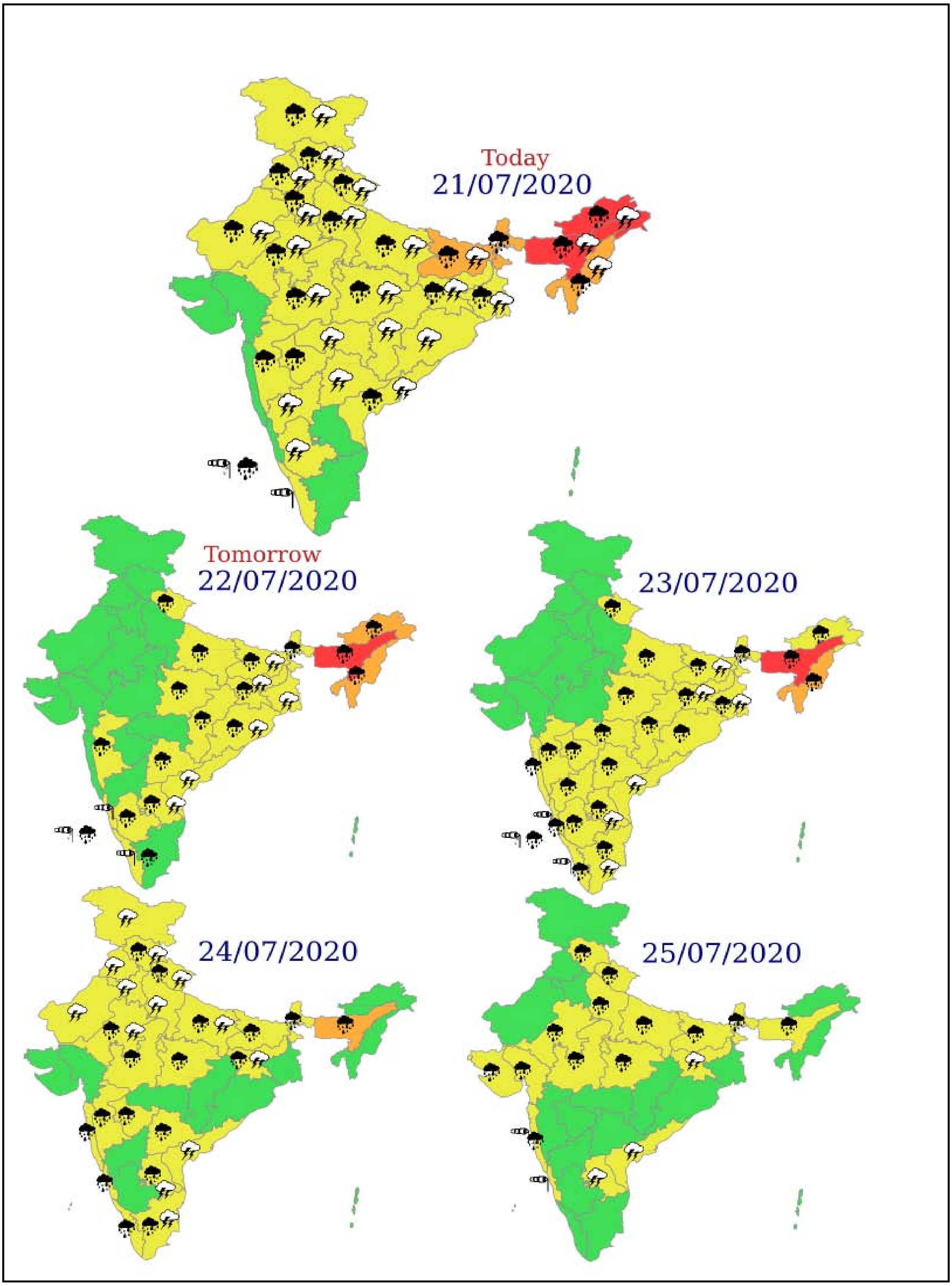
♦ **Thunderstorm accompanied with lightning** very likely at isolated places over Jammu & Kashmir, Ladakh, Gilgit-Baltistan, Muzaffarabad, Himachal Pradesh, Uttarakhand, Punjab, Haryana, Chandigarh & Delhi, Uttar Pradesh, Rajasthan, Jharkhand, Coastal Andhra Pradesh & Yanam, Rayalaseema and Tamilnadu, Puducherry & Karaikal.

♦ **Strong Wind** (speed reaching 50-60 kmph) very likely over Southwest and adjoining westcentral Arabian Sea. **Squally weather** (wind speed reaching 40-50 kmph) over Lakshadweep area & adjoining southeast Arabian sea; along & off Kerala coast and Eastcentral Arabian Sea & off Karnataka-Goa-Maharashtra coasts. Fishermen are advised not to venture into Sea over these areas.

25 July (Day 5): ♦ Heavy rainfall at isolated places over Himachal Pradesh, Uttarakhand, Uttar Pradesh, East Rajasthan, Madhya Pradesh, Bihar, Sub-Himalayan West Bengal & Sikkim, Assam & Meghalaya, Gujarat State and Konkan & Goa.

♦ **Thunderstorm accompanied with lightning** very likely at isolated places over Jharkhand, Coastal Andhra Pradesh & Yanam and Rayalaseema.

♦ **Strong Wind** (speed reaching 50-60 kmph) very likely over Southwest and adjoining westcentral Arabian Sea. **Squally weather** (wind speed reaching 40-50 kmph) over Eastcentral & Northwest Arabian Sea and along & off Karnataka-Maharashtra coasts. Fishermen are advised not to venture into Sea over these areas.


Today
21/07/2020
Tomorrow
22/07/2020
23/07/2020
24/07/2020
25/07/2020

Appendix II

District Level Forecast issued from SWFC Bhubaneshwar

भारत सरकार
पृथ्वी विज्ञान मंत्रालय
भारत मौसम विज्ञान विभाग
मौसम विज्ञान केंद्र
भुवनेश्वर, ओडिशा -751020

Government of India
Ministry of Earth Sciences
India Meteorological Department
Meteorological Centre
Bhubaneswar, Odisha-751020

District Level Weather Forecast for Odisha

Date: 15.07.2020
MIDDAY

Region	Name of the Districts	Weather Forecast for 5 days					Weather outlook for subsequent 2 days valid from 0830 hrs of 20.07.2020 to 0830 hrs of 22.07.2020
		DAY 1 valid from 1330 hrs IST of 15.07.2020 to 0830 hrs IST of 16.07.2020	DAY 2 valid from 0830 hrs IST of 16.07.2020 to 0830 hrs IST of 17.07.2020	DAY 3 valid from 0830 hrs IST of 17.07.2020 to 0830 hrs IST of 18.07.2020	DAY 4 valid from 0830 hrs IST of 18.07.2020 to 0830 hrs IST of 19.07.2020	DAY 5 valid from 0830 hrs IST of 19.07.2020 to 0830 hrs IST of 20.07.2020	
North Coastal Odisha	Balasore	FWS LIGHT TO MOD RA/TS	FWS LIGHT TO MOD RA/TS	SCT LIGHT TO MOD RA/TS	SCT LIGHT TO MOD RA/TS	FWS LIGHT TO MOD RA/TS	LITTLE CHANGE
	Bhadrak	FWS LIGHT TO MOD RA/TS	FWS LIGHT TO MOD RA/TS	SCT LIGHT TO MOD RA/TS	SCT LIGHT TO MOD RA/TS	FWS LIGHT TO MOD RA/TS	LITTLE CHANGE
	Jajpur	FWS LIGHT TO MOD RA/TS	FWS LIGHT TO MOD RA/TS	SCT LIGHT TO MOD RA/TS	SCT LIGHT TO MOD RA/TS	FWS LIGHT TO MOD RA/TS	LITTLE CHANGE
	Kendrapara	FWS LIGHT TO MOD RA/TS	FWS LIGHT TO MOD RA/TS	SCT LIGHT TO MOD RA/TS	SCT LIGHT TO MOD RA/TS	FWS LIGHT TO MOD RA/TS	LITTLE CHANGE
	Jagatsinghapur	FWS LIGHT TO MOD RA/TS	FWS LIGHT TO MOD RA/TS	SCT LIGHT TO MOD RA/TS	SCT LIGHT TO MOD RA/TS	FWS LIGHT TO MOD RA/TS	LITTLE CHANGE
	Cuttack	FWS LIGHT TO MOD RA/TS	FWS LIGHT TO MOD RA/TS	SCT LIGHT TO MOD RA/TS	SCT LIGHT TO MOD RA/TS	FWS LIGHT TO MOD RA/TS	LITTLE CHANGE
North Interior Odisha	Sundargarh	WS LIGHT TO MOD RA/TS	FWS LIGHT TO MOD RA/TS	FWS LIGHT TO MOD RA/TS	FWS LIGHT TO MOD RA/TS	FWS LIGHT TO MOD RA/TS	LITTLE CHANGE
	Jharsuguda	WS LIGHT TO MOD RA/TS	FWS LIGHT TO MOD RA/TS	FWS LIGHT TO MOD RA/TS	FWS LIGHT TO MOD RA/TS	FWS LIGHT TO MOD RA/TS	LITTLE CHANGE
	Bargarh	WS LIGHT TO MOD RA/TS	FWS LIGHT TO MOD RA/TS	FWS LIGHT TO MOD RA/TS	FWS LIGHT TO MOD RA/TS	FWS LIGHT TO MOD RA/TS	LITTLE CHANGE
	Sambalpur	WS LIGHT TO MOD RA/TS	FWS LIGHT TO MOD RA/TS	FWS LIGHT TO MOD RA/TS	FWS LIGHT TO MOD RA/TS	FWS LIGHT TO MOD RA/TS	LITTLE CHANGE
	Deogarh	WS LIGHT TO MOD RA/TS	FWS LIGHT TO MOD RA/TS	FWS LIGHT TO MOD RA/TS	FWS LIGHT TO MOD RA/TS	FWS LIGHT TO MOD RA/TS	LITTLE CHANGE
	Angul	WS LIGHT TO MOD RA/TS	FWS LIGHT TO MOD RA/TS	FWS LIGHT TO MOD RA/TS	FWS LIGHT TO MOD RA/TS	FWS LIGHT TO MOD RA/TS	LITTLE CHANGE
	Dhenkanal	WS LIGHT TO MOD RA/TS	FWS LIGHT TO MOD RA/TS	FWS LIGHT TO MOD RA/TS	FWS LIGHT TO MOD RA/TS	FWS LIGHT TO MOD RA/TS	LITTLE CHANGE
	Keonjhar	WS LIGHT TO MOD RA/TS	FWS LIGHT TO MOD RA/TS	FWS LIGHT TO MOD RA/TS	FWS LIGHT TO MOD RA/TS	FWS LIGHT TO MOD RA/TS	LITTLE CHANGE
	Mayurbhanj	WS LIGHT TO MOD RA/TS	FWS LIGHT TO MOD RA/TS	FWS LIGHT TO MOD RA/TS	FWS LIGHT TO MOD RA/TS	FWS LIGHT TO MOD RA/TS	LITTLE CHANGE

भारत सरकार
पृथ्वी विज्ञान मंत्रालय
भारत मौसम विज्ञान विभाग
मौसम विज्ञान केंद्र
भुवनेश्वर, ओडिशा -751020

Government of India
Ministry of Earth Sciences
India Meteorological Department
Meteorological Centre
Bhubaneswar, Odisha-751020

	Sonepur	WS LIGHT TO MOD RA/TS	FWS LIGHT TO MOD RA/TS	FWS LIGHT TO MOD RA/TS	FWS LIGHT TO MOD RA/TS	FWS LIGHT TO MOD RA/TS	LITTLE CHANGE
	Boudh	WS LIGHT TO MOD RA/TS	FWS LIGHT TO MOD RA/TS	FWS LIGHT TO MOD RA/TS	FWS LIGHT TO MOD RA/TS	FWS LIGHT TO MOD RA/TS	LITTLE CHANGE
	Nuapada	WS LIGHT TO MOD RA/TS	FWS LIGHT TO MOD RA/TS	FWS LIGHT TO MOD RA/TS	FWS LIGHT TO MOD RA/TS	FWS LIGHT TO MOD RA/TS	LITTLE CHANGE
	Bolangir	WS LIGHT TO MOD RA/TS	FWS LIGHT TO MOD RA/TS	FWS LIGHT TO MOD RA/TS	FWS LIGHT TO MOD RA/TS	FWS LIGHT TO MOD RA/TS	LITTLE CHANGE
	Kalahandi	WS LIGHT TO MOD RA/TS	FWS LIGHT TO MOD RA/TS	FWS LIGHT TO MOD RA/TS	FWS LIGHT TO MOD RA/TS	FWS LIGHT TO MOD RA/TS	LITTLE CHANGE
	Kandhamal	WS LIGHT TO MOD RA/TS	FWS LIGHT TO MOD RA/TS	FWS LIGHT TO MOD RA/TS	FWS LIGHT TO MOD RA/TS	FWS LIGHT TO MOD RA/TS	LITTLE CHANGE
	Nawrangpur	WS LIGHT TO MOD RA/TS	FWS LIGHT TO MOD RA/TS	FWS LIGHT TO MOD RA/TS	FWS LIGHT TO MOD RA/TS	FWS LIGHT TO MOD RA/TS	LITTLE CHANGE
	Rayagada	WS LIGHT TO MOD RA/TS	FWS LIGHT TO MOD RA/TS	FWS LIGHT TO MOD RA/TS	FWS LIGHT TO MOD RA/TS	FWS LIGHT TO MOD RA/TS	LITTLE CHANGE
	Koraput	WS LIGHT TO MOD RA/TS	FWS LIGHT TO MOD RA/TS	FWS LIGHT TO MOD RA/TS	FWS LIGHT TO MOD RA/TS	FWS LIGHT TO MOD RA/TS	LITTLE CHANGE
	Malkangiri	WS LIGHT TO MOD RA/TS	FWS LIGHT TO MOD RA/TS	FWS LIGHT TO MOD RA/TS	FWS LIGHT TO MOD RA/TS	FWS LIGHT TO MOD RA/TS	LITTLE CHANGE
South Coastal Odisha	Gajapati	FWS LIGHT TO MOD RA/TS	FWS LIGHT TO MOD RA/TS	SCT LIGHT TO MOD RA/TS	SCT LIGHT TO MOD RA/TS	FWS LIGHT TO MOD RA/TS	LITTLE CHANGE
	Ganjam	FWS LIGHT TO MOD RA/TS	FWS LIGHT TO MOD RA/TS	SCT LIGHT TO MOD RA/TS	SCT LIGHT TO MOD RA/TS	FWS LIGHT TO MOD RA/TS	LITTLE CHANGE
	Puri	FWS LIGHT TO MOD RA/TS	FWS LIGHT TO MOD RA/TS	SCT LIGHT TO MOD RA/TS	SCT LIGHT TO MOD RA/TS	FWS LIGHT TO MOD RA/TS	LITTLE CHANGE
	Khurda	FWS LIGHT TO MOD RA/TS	FWS LIGHT TO MOD RA/TS	SCT LIGHT TO MOD RA/TS	SCT LIGHT TO MOD RA/TS	FWS LIGHT TO MOD RA/TS	LITTLE CHANGE
	Nayagarh	FWS LIGHT TO MOD RA/TS	FWS LIGHT TO MOD RA/TS	SCT LIGHT TO MOD RA/TS	SCT LIGHT TO MOD RA/TS	FWS LIGHT TO MOD RA/TS	LITTLE CHANGE

N.B: Probability of Occurrence is Very Likely for all forecast

Appendix III

District Level Warning issued from SWFC Bhubaneshwar

भारत सरकार
पृथ्वी विज्ञान मंत्रालय
भारत मौसम विज्ञान विभाग
मौसम विज्ञान केंद्र
भुवनेश्वर, ओडिशा -751020

Government of India
Ministry of Earth Sciences
India Meteorological Department
Meteorological Centre
Bhubaneswar, Odisha-751020

District Level Weather Warnings for Odisha

Date: 15.07.2020
MIDDAY

Region	Name of the Districts	Weather Warnings for 5 days				
		DAY 1 valid from 1330 hrs IST of 15.07.2020 to 0830 hrs IST of 16.07.2020	DAY 2 valid from 0830 hrs IST of 16.07.2020 to 0830 hrs IST of 17.07.2020	DAY 3 valid from 0830 hrs IST of 17.07.2020 to 0830 hrs IST of 18.07.2020	DAY 4 valid from 0830 hrs IST of 18.07.2020 to 0830 hrs IST of 19.07.2020	DAY 5 valid from 0830 hrs IST of 19.07.2020 to 0830 hrs IST of 20.07.2020
North Coastal Odisha	Balasore	NIL	NIL	NIL	NIL	NIL
	Bhadrak	NIL	NIL	NIL	NIL	NIL
	Jajpur	NIL	NIL	NIL	NIL	NIL
	Kendrapara	NIL	NIL	NIL	NIL	NIL
	Jagatsinghapur	NIL	NIL	NIL	NIL	NIL
	Cuttak	NIL	NIL	NIL	NIL	NIL
North Interior Odisha	Sundargarh	ISOL HEAVY RAIN	NIL	NIL	NIL	ISOL HEAVY RAIN
	Jharsuguda	NIL	NIL	NIL	NIL	ISOL HEAVY RAIN
	Bargarh	NIL	ISOL HEAVY RAIN	NIL	NIL	ISOL HEAVY RAIN
	Sambalpur	ISOL HEAVY RAIN	ISOL HEAVY RAIN	NIL	NIL	ISOL HEAVY RAIN
	Deogarh	NIL	NIL	NIL	NIL	NIL
	Angul	NIL	ISOL HEAVY RAIN	NIL	NIL	ISOL HEAVY RAIN
	Dhenkanal	NIL	NIL	NIL	NIL	NIL
	Keonjhar	NIL	NIL	NIL	NIL	ISOL HEAVY RAINS
	Mayurbhanj	NIL	NIL	NIL	NIL	NIL
South Interior Odisha	Sonepur	NIL	ISOL HEAVY RAIN	NIL	NIL	NIL
	Boudh	NIL	ISOL HEAVY RAIN	NIL	NIL	NIL
	Nuapada	ISOL HEAVY RAIN	NIL	NIL	NIL	NIL

भारत सरकार
पृथ्वी विज्ञान मंत्रालय
भारत मौसम विज्ञान विभाग
मौसम विज्ञान केंद्र
भुवनेश्वर, ओडिशा -751020

Government of India
Ministry of Earth Sciences
India Meteorological Department
Meteorological Centre
Bhubaneswar, Odisha-751020

	Bolangir	ISOL HEAVY RAIN	NIL	NIL	NIL	NIL
	Kalahandi	ISOL HEAVY RAIN	NIL	NIL	NIL	NIL
	Kandhamal	NIL	ISOL HEAVY RAIN	NIL	NIL	NIL
	Nawrangpur	ISOL HEAVY TO VERY HEAVY RAIN	NIL	NIL	NIL	NIL
	Rayagada	ISOL HEAVY TO VERY HEAVY RAIN	NIL	NIL	NIL	NIL
	Koraput	ISOL HEAVY RAIN	NIL	NIL	NIL	NIL
	Malkangiri	ISOL HEAVY TO VERY HEAVY RAIN	NIL	NIL	NIL	ISOL HEAVY RAIN
South Coastal Odisha	Gajapati	ISOL HEAVY RAIN	NIL	NIL	NIL	NIL
	Ganjam	NIL	NIL	NIL	NIL	NIL
	Puri	NIL	NIL	NIL	NIL	NIL
	Khurda	NIL	NIL	NIL	NIL	NIL
	Nayagarh	NIL	NIL	NIL	NIL	NIL

N.B: Probability of Occurrence is Very Likely for all warnings.

Spatial Rainfall distribution category(in terms percentage number stations rainfall reporting)			
% Stations	Category	% Stations	Category
> 75	Widespread (WS) / Most Places	00-25	Isolated (ISOL) / One or two places
51-75	Fairly Widespread (FWS) / Many Places	25-50	Scattered(SCT)/ A few places
No Rain	DRY		

-: LEGEND :-

Probabilistic Forecast (%)		Color Code for WARNING	Legend for Weather			
Unlikely	< 25	WARNING (TAKE ACTION)	RA	Rain	TSQ	Thunder Squall
Likely	25 - 50	ALERT (BE PREPARED)	TS	Thunder Shower	HW	Heat Wave
Very Likely	50 - 75	WATCH (BE UPDATED)	SQ	Squall	CW	Cold Wave
Most Likely	> 75	NO WARNING (NO ACTION)	HR	Heavy Rain		

Heavy Rain	Very Heavy Rain	Extremely Heavy Rain
64.5 to 115.5 mm(in 24 hours)	115.6 to 204.4(in 24 hours)	>204.4 mm(in 24 hours)

Chapter 2

Satellite Application in Weather Forecasting

2.1. Introduction

Satellite Meteorology Division started functioning in India Meteorological Department since early 70's. From 1972 to 1982, IMD used to receive the Satellite imageries of NOAA and NASA meteorological satellites through Secondary Data Utilization Centre (SDUC) and images were printed on photographic paper for using in weather forecasting. Advances in satellite technology have led to improved observational capabilities. The first generation of the Indian National Satellite (INSAT) programme started in 1982, is a series of multipurpose geo-stationary satellites by ISRO to meet requirement of the telecommunications, broadcasting, meteorology, and search and rescue operations. In 1983 IMD has established its first satellite data receiving and processing system to receive & process the data from INSAT-1B, as a full-fledged satellite Meteorological Division for providing satellite Metrological services to the nation. Since then, IMD is providing the Meteorological Satellite Services to the Forecasters using the data from Meteorological payloads of INSAT-1, INSAT-2, and INSAT-3 series satellites. During both INSAT-1 and INSAT-2 series satellites, the temporal resolution of scan acquisitions was on 3 hourly basis & satellites Imageries were developed on a photographic sheet through photographic process till 1992 and later on Imageries were printed on photographic sheets through thermal Kodak printers. IMD had started dissemination of the satellite imageries through IMD website from 1996. The division has made a steady progress in satellite data reception and generation of several new products which are quite useful in weather forecasting and the division now plays an important role in supporting weather forecasting. Now days, the satellite technology is of great use in meteorology and plays a very significant role in the improvement of weather forecasting. At present IMD is using Indian Meteorological Geostationary satellites (INSAT-3D&INSAT-3DR), Polar Satellite (Scatterometer Satellite-1 (SCATSat-1), Oceansat-2 & Mega-Tropiques) and International Geostationary Meteorological Satellites (METEOSAT-8 of EUMETSat, Himawari-8 of JMA) data in near real time for weather forecasting through terrestrial EUMETCast system.

INSAT-3D and INSAT-3DR are dedicated meteorological geostationary satellites and located at 82-degree and 74-degree East longitude respectively. INSAT-3D& 3DR carries a multi spectral six channel Imager, 19 channel Sounder, Data Relay Transponder and Search& Rescue Transponder payloads.

The Imager payload of INSAT-3D and INSAT-3DR is being used in staggered mode so that effectively 15 minutes temporal resolution is achieved. Sounder payloads of INSAT-3D & INSAT-3DR are used in integrated manner so that INDIAN land region sector data become available on hourly basis and Indian Ocean region data become available on one and half hourly basis either from INSAT-3D or INSAT-3DR satellite.

Recently, IMD has established Multi-Mission Meteorological Data Receiving and Processing System (MMDRPS) for INSAT-3D, INSAT-3DR and INSAT-3DS satellites through a MoU with M/s Antrix Corporation Ltd, ISRO and existing IMDPS system is phasing-out. Dedicated New Earth stations have been setup under MMDRPS [Multi-Mission Meteorological Data Reception and Processing System] Project, which have the capability to receive the data from INSAT-3D, INSAT-3DR and upcoming INSAT-3DS satellite. MMDRPS systems consist of advance & latest state of art servers capable to process the complete set of data within 7 minutes after completion of scanning along with the storage capacity of order 2.0/2.0PB (Main/ Mirror) & 324TB SSD which will facilitate online sharing of processed data for all Indian meteorological satellites to the registered users as per IMD data policy through Web based secured satellite Data Supply System. All available past satellite datasets starting from 1983 will be kept in online mode in due course of time.

2.1.1. INSAT-3D & 3DR Satellite

a. Six channel Imager
b. Nineteen channel Sounder
c. Data Relay Transponder(DRT)
d. Satellite aided Search and Rescue(S&SR) System

(a) INSAT-3D/3DR-Imager

It is multi-spectral (optical radiometer) capable of generating the images of the earth in six wavelength bands significant for meteorological observations, namely, visible, shortwave infrared, middle infrared, water vapor and two bands in thermal infrared regions. The Imager generates images of the earth disk from geostationary altitude of 36,000 km every 26 minutes and provide information on various parameters, namely, outgoing long-wave radiation, quantitative precipitation estimation, sea surface temperature, snow cover, cloud motion winds, etc.

The salient features of INAST-3D Imager are as follows:

1. Blackbody calibration sequence is modified as compared to VHRR of earlier satellites.

2. In the Fast Scan direction IFOVs are over sampled by 1.75 times.

3. Satellite is flip after every six months that is a biannual rotation of yaw by 180 degree has been introduced to maintain proper cold patch temperature.

4. Two flexible mode of operation:

- Full frame mode scans 18-degree EW x18 degree NS covering the entire Earth disc in 26 minutes.
- Program mode covering 18 degree in EW direction NS coverage can be defined in terms of number of lines to be scanned.

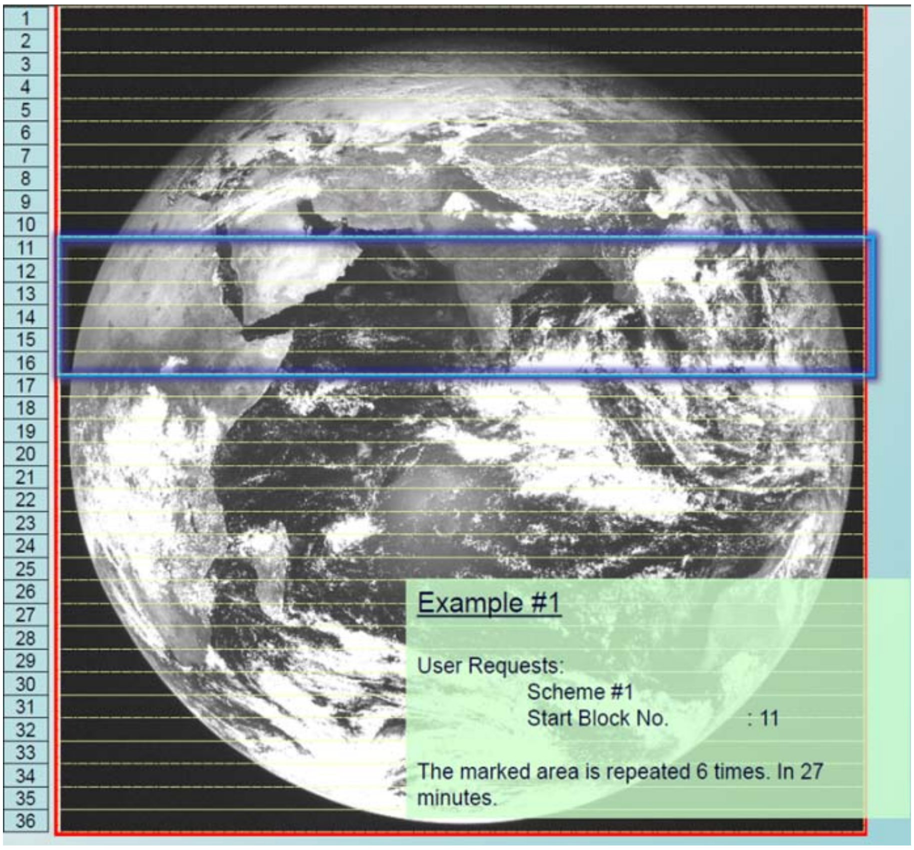
➢ **INSAT-3DR Imager can also be operated in RAPID SCAN Mode**

INSAT-3DR Imager can also be operated in RAPID SCAN Mode to monitor the severe weather events like Cyclone and Thunder Storms, the IMAGER instruments have been built with the flexible scanning feature named as ‘Program Mode’, where the number of scan lines over a given coverage region and the number of repetitions of thus selected region could be programmed for scanning. In order to simplify and standardize the usage of this feature, the following operational strategy has been worked out for Rapid scan:

INSAT-3DR will provide rapid Scans during severe weather conditions, while INSAT-3D will continue to provide Full frame Mode Scan covering full globe. In rapid scan mode the globe is divided into 36 blocks in North-South directions such that, each block covers 0.50 in N-S direction and consist of 40 scan lines.

One rapid scan covered up 240 no. of scan lines and took 4.7 minutes to complete it. MCF Hassan ISRO is intimated to start the rapid scan whenever there is request from NWFC with following information :

- Start Block Number
- No. of blocks to cover and
- No. of repetitions



The spectral band and products images of rapid scan mode can be assessed through the following link: http://satellite.imd.gov.in/rapid/rapid_scan.htm

Imager Channel Specification

Channel no.	Spectral Band	Spectrum (µm)	Ground Resolution (km)	Purpose
1	Visible	0.55 – 0.75	1 × 1	Clouds, Surface features
2	SWIR	1.55 – 1.70	1 × 1	Snow, Ice and water phase in clouds
3	MIR	3.80 – 4.00	4 × 4	Clouds, Fog, Fire
4	WV	6.50 – 7.10	8 × 8	Upper-Troposphere Moisture
5	TIR1	10.2 – 11.3	4 × 4	Cloud top and surface temperature
6	TIR2	11.5 – 12.5	4 × 4	Lower-Troposphere Moisture

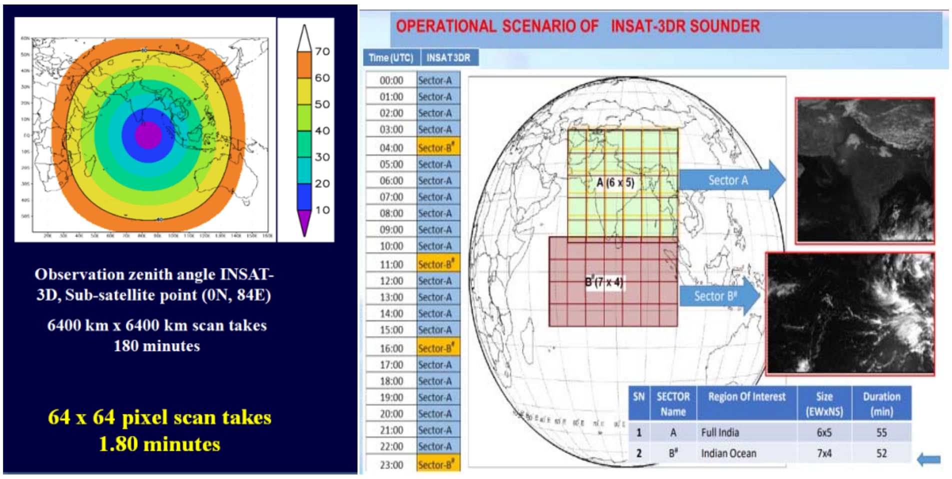
(b) INSAT-3D/3DR-Sounder

INSAT-3D/3DR carries a newly developed 19 channel sounder, which is the first such payload to be flown on an ISRO satellite mission. The Sounder has eighteen narrow spectral channels in shortwave infrared, middle infrared and long wave infrared regions and one channel in the visible region. The ground resolution at nadir is nominally 10 × 10 km for all nineteen channels. Atmospheric Sounding System, provide vertical profiles of temperature 40 levels (surface to 70 km), Humidity 21 levels (surface to 15 km) and integrated ozone from surface to top of the atmosphere. The specification of Sounder is as follows.

Sounder Channel Specification

Detector	Ch. No.	Central Wavelength (mm)	Principal absorbing gas	Purpose
Long wave	1	14.67	CO_2	*Stratosphere temperature*
	2	14.32	CO_2	*Tropopause temperature*
	3	14.04	CO_2	*Upper-level temperature*
	4	13.64	CO_2	*Mid-level temperature*
	5	13.32	CO_2	*Low-level temperature*
	6	12.62	water vapor	*Total precipitable water*
	7	11.99	water vapor	*Surface temp., moisture*
Mid wave	8	11.04	window	*Surface temperature*
	9	9.72	ozone	*Total ozone*
	10	7.44	water vapor	*Low-level moisture*
	11	7.03	water vapor	*Mid-level moisture*
	12	6.53	water vapor	*Upper-level moisture*
Short wave	13	4.58	N_2O	*Low-level temperature*
	14	4.53	N_2O	*Mid-level temperature*
	15	4.46	CO_2	*Upper-level temperature*
	16	4.13	CO_2	*Boundary-level temp.*
	17	3.98	window	*Surface temperature*
	18	3.76	window	*Surface temp., moisture*
Visible	19	0.695	visible	*Cloud*

The Sounder measures radiance in eighteen IR and one visible channel simultaneously over an area of 10 km × 40 km at nadir every 100 ms. Using a two-axes gimballed scan mirror, this footprint can be positioned anywhere in the FOR [24º (E-W) × 19º (N-S)]. A scan program mode allows sequential sounding of a selected area with periodic space and calibration looks. In this mode, a ‘frame' consisting of multiple ‘blocks' of the size 640 km × 640 km, can be sounded. The selected frame can be placed anywhere within a FOR 24º (E-W) × 19º (N-S). As with the Imager, the Sounder provides an adequate radiometric resolution for the intended science applications. The full frame mode of sounder scan covered up 6400 Km × 6400 Km in size and will take 3 hours to complete this scan. However, it is operated over Indian region as per IMD requirement. These profiles are available over Indian landmass on hourly basis and Indian Ocean Region on one and half hourly basis. INSAT 3D Sounder has reached its end of life and accordingly a modified scan strategy of INSAT-3DR sounder payload has been implemented with effect from 23rd September, 2020. Sounder payload of INSAT-3DR is operated in such a way that INDIAN land region sector data is covered up twenty times and Indian Ocean region data is covered up four times (04, 11, 16 & 23 UTC) on hourly basis.



(c) Data Relay Transponder (DRT)

Data Relay Transponder (DRT) on-board INSAT-3D/3DR is used for receiving meteorological, hydrological and oceanographic data from remote, uninhabited locations over the coverage area from Data Collection Platforms (DCPs) like Automatic Weather Station (AWS), Automatic Rain Gauge (ARG) and Agro Met Stations (AMS). The data is relayed back for down linking in extended C-Band.

(d) Satellite Aided Search and Rescue (SAS & R) Transponder

INSAT-3D/3DR is equipped with a Search and Rescue payload (operating in 406 MHz) that picks up and relays the alert signals originating from the distress beacons of maritime, aviation and land-based users to the Indian Mission Control Centre (INMCC) located at ISRO Telemetry, Tracking and Command Network (ISTRAC), Bangalore. The major users of Satellite Aided Search and Rescue service in India are the Indian Coast Guard, Airports Authority of India (AAI), Directorate General of Shipping, Defence Services and fishermen. The Indian service region includes a large part of the Indian Ocean region covering India, Bangladesh, Bhutan, Maldives, Nepal, Seychelles, Sri Lanka and Tanzania for rendering distress alert services.

2.1.2. Scatsat-1 Satellite

SCATSAT-1 is a continuity mission for Oceansat-2 Scatterometer payload to provide wind vector data products over ocean for weather forecasting, cyclone detection and tracking services to the users. The satellite carries Ku-band Scatterometer similar to the one flown onboard Oceansat-2. Scatsat-1 satellite was launched on 2016 ataltitude 720 km in polar sun synchronous orbit, with mission life of 5 years.

Specifications of Scatterometer Payload

Parameter	Specifications	
Altitude	720 km	
Frequency	13.515 G Hz(Ku-band)	
Wind speed range	3 to 30 m/s, accuracy of 1.8 m/s (rms) or 10%	
Wind speed	0 – 360 degreesaccuracy of 20º rms	
Scanning rate	20.5 rpm	
Antenna Diameter	1 meter	
Nominal PRF	193 Hz	
Transmit pulse width	1.35 ms	
	Inner beam	Outer beam
Polarisation	HH	VV
Swath	1400 km	1800 km
Footprint	27 km × 46 km	30 km × 70 km
Beam width in degrees	1.47 × 1.63	1.39 × 1.72
Wind vector cell size	50 km × 50 km grid and 25 km × 25 km grid	

https://www.mosdac.gov.in/data/init.do?mode=initexecute

2.1.3. EUMETCast

EUMETCast is a multi-service dissemination system based on multicast technology sustained by EUMETSAT. IMD has established a dedicated terrestrial EUMETCast system at NCMWRF Noida through a MoU with EUMETSAT to receive the Geostationary and Polar meteorological satellites data for assimilating in NWP models and Weather forecasting.

2.1.3.1. METEOSAT-8 Satellite

Meteosat-8 is a Meteosat Second Generation (MSG)spin-stabilized Geostationary Meteorological satellite located at 41.5°E and consist of 12 spectral channels with capability to performed ‘Full-Earth Scan’ in 15 minutes. The scan region for Full-Earth scanning is covered up the area from approximately 40°W to 120°E i.e., it cover up the full European continent, Africa and central Asia. It carried the 12-channel imager, known as the spinning enhanced visible and infrared imager (SEVIRI). It also provides for better retrieval of wind fields which are obtained from the tracking of clouds, water vapour and ozone features.

Specification of SEVIRI payload

Channel No.	Spectral Band (µm)	Characteristics of Spectral Band (µm)			Main observational application
		□cen	□min	□max	
1	VIS0.6	0.635	0.56	0.71	Surface, clouds, wind fields
2	VIS0.8	0.81	0.74	0.88	Surface, clouds, wind fields
3	NIR1.6	1.64	1.50	1.78	Surface, cloud phase
4	IR3.9	3.90	3.48	4.36	Surface, clouds, wind fields
5	WV6.2	6.25	5.35	7.15	Water vapor, high level clouds, atmospheric instability
6	WV7.3	7.35	6.85	7.85	Water vapor, atmospheric instability
7	IR8.7	8.70	8.30	9.1	Surface, clouds, atmospheric instability
8	IR9.7	9.66	9.38	9.94	Ozone
9	IR10.8	10.80	9.80	11.80	Surface, clouds, wind fields, atmospheric instability
10	IR12.0	12.00	11.00	13.00	Surface, clouds, atmospheric instability
11	IR13.4	13.40	12.40	14.40	Cirrus cloud height, atmospheric instability
12	HRV	Broadband (about 0.4 – 1.1 µm)			Surface, clouds

2.1.3.2. Himawari Satellite

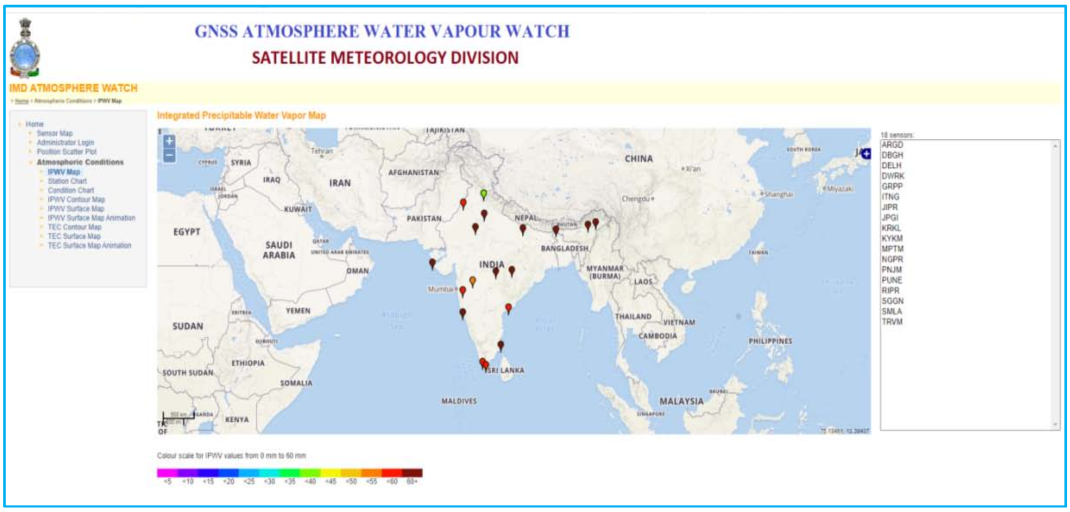
Himawari-8 is a Geostationary Meteorological satellite located at 140°E longitude of JMA with capability to performed ‘Full-Earth Scan’ in 10 minutes. The scan region for Full-Earth scanning is covered up the area of the East Asia and Western Pacific. It carried the 16-channel imager, known as the Advanced Himawari Imager (AHI) for multi-purpose imagery for weather watch, NWP utilization and environment monitoring and wind derivation by tracking clouds and water vapour features.

Specification of AHI payload

Central wavelength	Bandwidth	Resolution at s.s.p.
455 nm	50 nm	1.0 km
510 nm	20 nm	1.0 km
645 nm	30 nm	0.5 km
860 nm	20 nm	1.0 km
1610 nm	20 nm	2.0 km
2260 nm	20 nm	2.0 km
3.85 µm	0.22 µm	2.0 km
6.25 µm	0.37 µm	2.0 km
6.95 µm	0.12 µm	2.0 km
7.35 µm	0.17 µm	2.0 km
8.60 µm	0.32 µm	2.0 km
9.63 µm	0.18 µm	2.0 km
10.45 µm	0.30 µm	2.0 km
11.20 µm	0.20 µm	2.0 km
12.35 µm	0.30 µm	2.0 km
13.30 µm	0.20 µm	2.0 km

2.1.4. GNSS

IMD has set up a countrywide network of 25 nos. Global Navigation Satellite System (GNSS) stations for "Earth and Atmospheric studies" to drive integrated precipitable water vapour (IPWV) in real time. The IPWV data is being used for now casting, monsoon studies, thunderstorms observation, and climate research and assimilated in NWP models to improve the accuracy of weather forecasting. Unlike Radar, GNSS covers 20 to 30 KM radius.



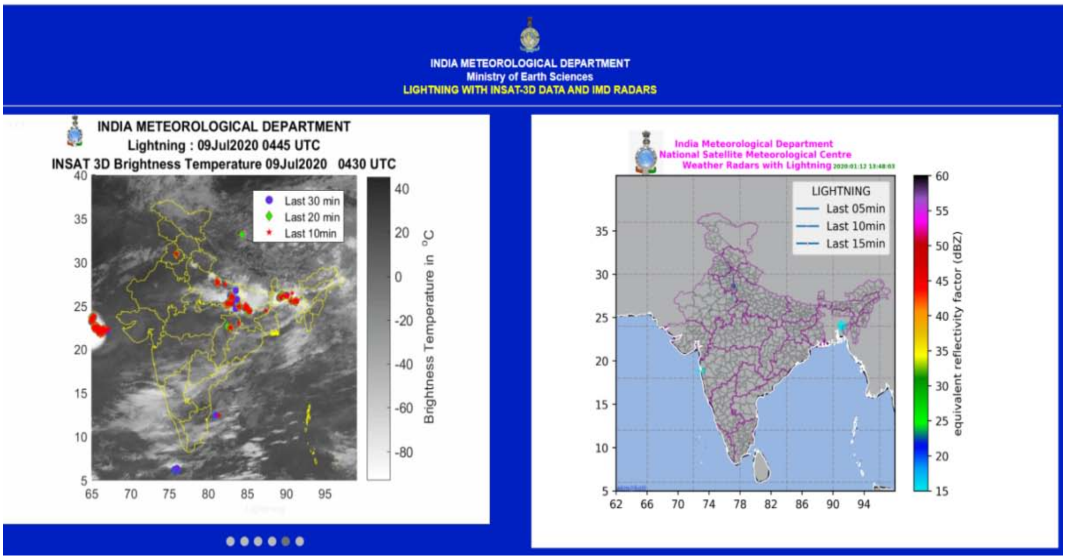
A dedicated website has been developed to access IPWV data of 25 GNSS site in real time (http://gnss.imd.gov.in/TrimblePivotWeb/MemberPages/AtmosphericConditions/IpwvMap.aspx)

Graphical user Interface was also provided to visualize 15 minutes, hourly, daily, weekly and monthly IPWV data along with Meteorological parameters (Pressure, Temperature and Relative Humidity) and minimum and maximum values of IPWV etc.

2.1.5. Visualization of surface Lighting network Data over satellite images

IITM Pune and IAF have set up lighting network across the country. IITM Pune collect the data at frequency of 2-minutes interval and IAF every 15 minutes and provide this lighting data to IMD in real time basis. The merged product of lightning and satellite-based cloud with INSAT-3D data product is generated at real-time basis with half an hour animation. The animation, lightning data is divided into the 3 different time categories 10, 20 and 30 minutes in different colours and it is updated every 15-minutes.The time gap between satellite and lightning data will be around 1 hours. This is due to the satellite scan strategy. The timing of 10, 20 and 30 minutes have been considered from the lightning data received and shown in the image. For example, in the image shown below, Last 10 minutes = 0959 UTC to 0949 UTC, Last 20 minutes = 0949 UTC to 0939 UTC and Last 30 minutes = 0939 UTC to 0929 UTC, observation of lightning are merged with INSAT-3D imagery of 0900 UTC. The points are lightning flashes/strikes (cloud-to-ground) which is being generated by the ground networks. These flashes/strikes are also superimposing on INSAT-3D cloud top temperature. User can access this data through a dedicated link on IMD website:

http://internal.imd.gov.in/section/satmet/lightning/ https://srf.tropmet.res.in/srf/ts_prediction_system/index.php



2.2. Cloud Imageries

2.2.1. Cloud Imagery of INSAT-3D & INSAT-3DR IMAGER

IMD generating different type cloud imageries of different domain using INSAT-3D& 3DR imager data for issuing weather forecast as one input along with other observation inputs. The different spectral band images are generated using the grey count /digital numbers values transmitted by the sensor of different locations of scan areas. The values of grey count/ digital number are lies between (0 to 1023) depending upon the quantized energy level by the sensors. In case of imager channel (MIR, TIR1, TIR2 & WV) images are generated by the inverting the grey count values (1024-Actual grey count), So that cloud appears brighter similar to Visible & SWIR images. Normal Images are generated by resampling of the grey count at coarser resolution and high-resolution images are generated at channel resolution. The details of different type of images generated are giving below:

Normal Images

Globe/Sector	Bands/parameter	Resolution of Image	Format/ Size of Image	Domain	Frequency of Updation
Standard Full Disk	Visible, SWIR, MWIR, WV, TIR1, TIR2, IR-1 Brightness Temperature, Day Microphysics/& Night Microphysics	13 × 13 Km	240-500 KB	70°S to 70°N, 10°E to 150°E.	Every Fifteen minutes either from INSAT-3D or INSAT-3DR
Asiamer Sector	Visible, SWIR, MIR, WV, TIR1, TIR2 & Day Microphysics & Night Microphysics RGB, IR-1 Brightness Temperature	6 × 6 Km	200-500 KB	10°S to 45°N, 40°E to 110°E.	Every Fifteen minutes either from INSAT-3D or INSAT-3DR

High Resolution Images with District boundaries

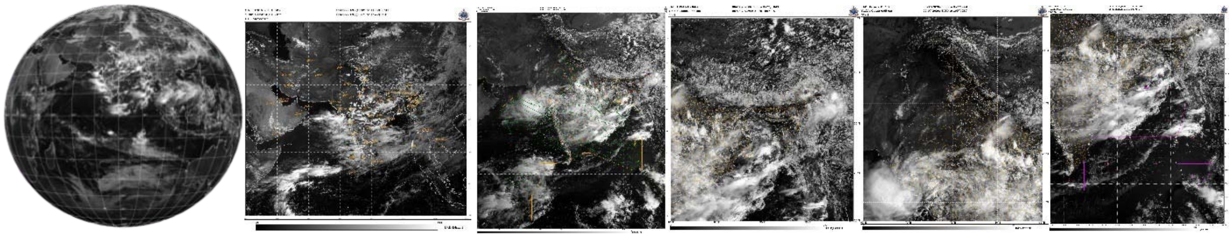
Globe/ Sector	Bands/parameter	Resolution of image	Format/ Size of Image (Jpeg)	Domain	Frequency of Updation
Asiamer Sector	Visible,SWIR	1 x 1 Km	5MB	0°N to 40°N, 40°E to 110°E.	Every Fifteen minutes either from INSAT-3D or INSAT-3DR
	MIR, TIR1, TIR2, WV, IR-1-BT Blended Image,IR-1- BT & Visible Sandwich Image	4 x 4 Km	300-500 KB		
North East-Sector	Visible, SWIR	1 x 1 Km	1.2MB	15°N to 35°N, 80°E to 100°E.	Every Fifteen minutes either from INSAT-3D or INSAT-3DR
	MIR, TIR1, Day Microphysics &Night Microphysics	4 x 4 Km	80-120KB		
North West-Sector	Visible, SWIR	1 x 1 Km	1.5 MB	18°N to 38°N, 65°E to 85°E.	Every Fifteen minutes either from INSAT-3D or INSAT-3DR
	MIR, TIR1, Day Microphysics & Night Microphysics	4 x 4 Km	100KB		
South East-Sector	Visible, SWIR	1 x 1 Km	2MB	0°N to 30°N, 74°E to 100°E.	Every Fifteen minutes either from INSAT-3D or INSAT-3DR
	MIR ,TIR1	4 x 4 Km	200KB		
	Day Microphysics &Night Microphysics		213KB		
South West-Sector	Visible, SWIR	1 x 1 Km	2.5MB	0°N to 30°N, 40°E to 82°E.	Every Fifteen minutes either from INSAT-3D or INSAT-3DR
	MIR ,TIR1	4 x 4 Km	303KB		
	Day Microphysics & Night Microphysics	4x4Km	275KB		

Special Sector Images

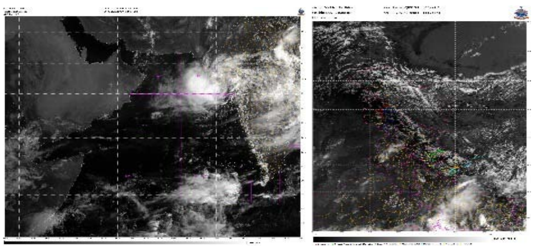
Globe/Sector	Bands/parameter	Resolution of image	Format/ Size of Image	Domain	Frequency of Updation
Aviation Sector	Visible	1 x 1Km	3MB	0°N to 40°N, 55°E to 100°E	Every Fifteen minutes either from INSAT-3D or INSAT-3DR Every Fifteen minutes either from INSAT-3D or INSAT-3DR
	TIR-1, Cloud top BT (< -30 Deg. C)	4 x 4 Km	150KB		
Cyclone Enhancement SW Sector	TIR-1BT using Cyclone enhancement LUT (BD curve & IMD Curve)	4 x 4 Km	300KB	0°N to 30°N, 40°E to 82°E	
SE Sector				0° N to 30° N, 74° E to 100° E	
Pilgrimage Sectors	Visible, SWIR	1 x 1 Km	750KB	0° N to 40° N, 70° E to 85° E	Every Fifteen minutes either from INSAT-3D or INSAT-3DR
	TIR1	4 x 4 Km	330KB		

Visible Band

The Visible Band (0.55 – 0.75µm) is reflective type of band and hence its use is limited to day. Visible images obtained during day time and depend on albedo of the target surface. Thus cloud, which is having high value of albedo than land surface appears brighter and land appears darker in the visible image. These Images are used for monitoring mesoscale weather features such as cloud cover, air mass boundaries, convergence zones, cyclone movement, thunderstorms, fog, dust storms and snow coverage. Limited to daytime use.



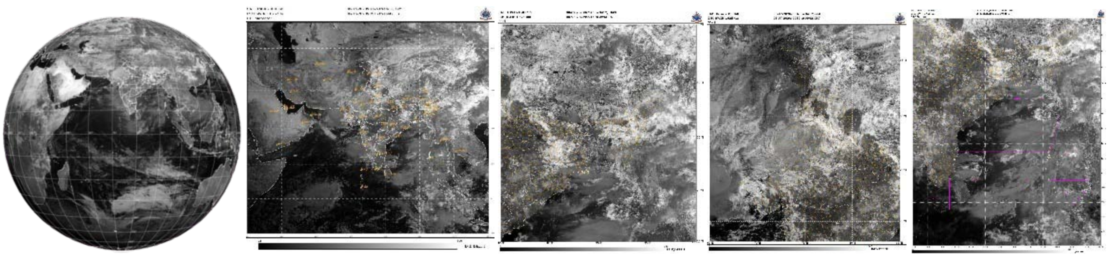
Globe Asiamer Aviation Sect NE NW SE



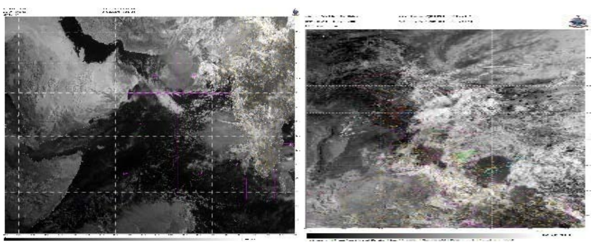
SWQ Pilgrim Sector

Shortwave Infra-Red (SWIR)

The SWIR Band (1.55 – 1.70µm) is reflective type of band and hence its use is limited to day time only. Incident radiation in SWIR, strongly absorbed by water, ice, snow and reflected by cloud, while in case of visible spectrum these objects essentially transparent. Therefore, melting snow patches or lake, ice is seen bright in the visible image while these appears dark in SWIR images and therefore SWIR images are used to differentiate the cloud, rain given cloud and snow. The SWIR band is sensitive to the moisture content soils recently irrigated field therefore appears in darker tones in SWIR images. These Images are used for monitoring local snow cover, day time Fog, Convective R/F estimation, Cloud radiative properties, NDSI.



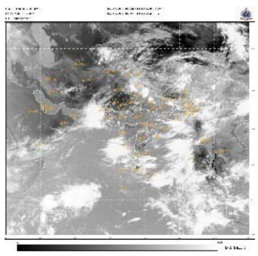
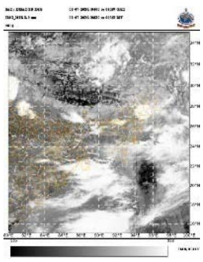
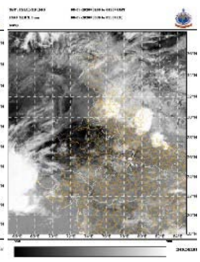
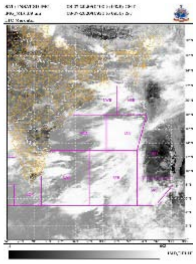
Globe Asiamer NE NW SE



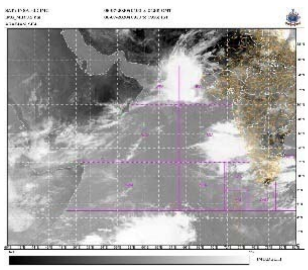
SW Pilgrim Sector

Midwave Infra-Red (MIR)

The Mid IR window channel (3.9um) has more temperature sensitivity than thermal infrared and has many applications in conjunction with thermal infrared channels. It is almost impossible to detect fog or low clod in conventional IR (10-12 µm) images in night if the fog top has a similar temperature to that of the adjacent ground. In this 3.9 µm channel, however the water droplets in fog can be differentiated from a land or sea surface at the same temperature because of emissivity difference. It is also used to identify night time fire/hotspot, volcanic eruption and ash detection in conjunction with thermal infrared window channel. During day time, this channel is modulated by reflected sunlight, the day time image is warmer than night time image. The sun glint by the sea surface produces glow in this channel and shows sea brighter than small cirrus cloud.

Globe Asiamer NE NW SE

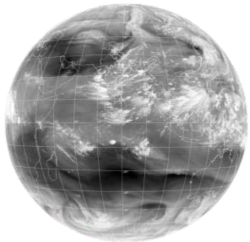
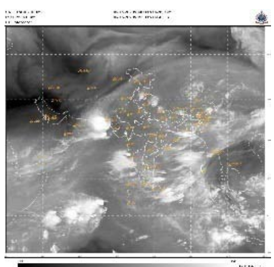


SW

Water Vapour (WV)

The band 6.5 -7.1um is called water vapour band. This is not an atmospheric window but is a part of the IR spectrum where water vapour is dominant absorbing gas. So naturally baseline information will not be available for this channel. In a normal moist atmosphere, most of the radiation received by the satellite originates between mid and upper part of the troposphere. Moist air or cloud in the lower half of the troposphere is not depicted well in WV imagery. But thick high clouds, such as cumulonimbus, anvils stand out prominently.

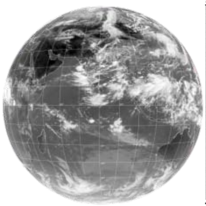
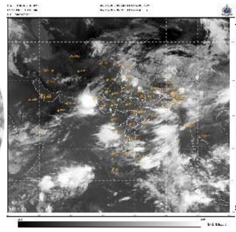
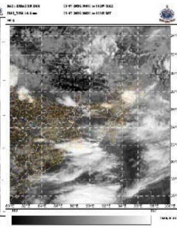
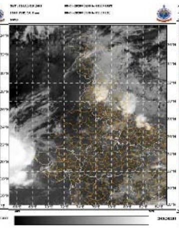
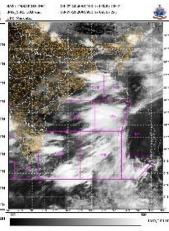
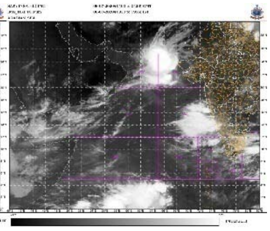
Broad scale flow patterns of moisture, upper tropospheric cyclone, raising and subsidence of moisture appears bright and dark respectively. The jet streams are delineated by sharp gradients in moisture, with dry air on the pole ward side. The atmospheric motion vector derived from WV imagery is directly used in NWP models.

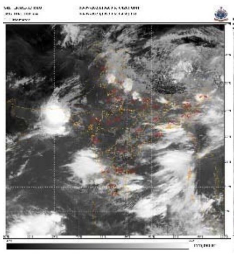
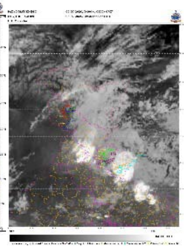
Globe Asiamer

Thermal Infra-Red (TIR-1)

The band between 10.3 – 11.3 µm are called thermal infrared band-1. Around the 10.7 um region, most of the energy radiated from the surface reach's the sensor, because the radiances emitted by the surface is less affected by the atmospheric components thus the band known as “clear atmospheric window". Since the temperature measured is close to scene temperature. Used for monitoring cloud top and surface temperature, cloud cover, air mass boundaries, convergence zones, surface lows and thunderstorms both day and night. Because cloud top Brightness temperature decreases with height, thermal IR images show good contrast between clouds at different levels unlike visible image.

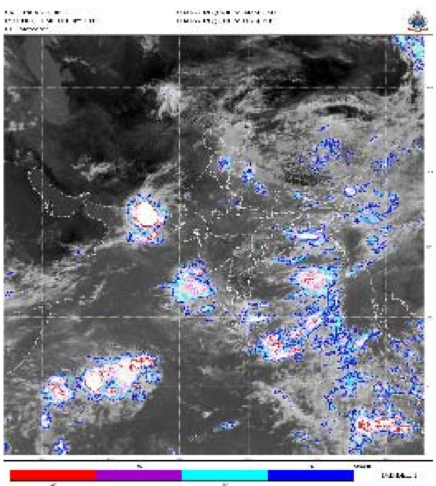
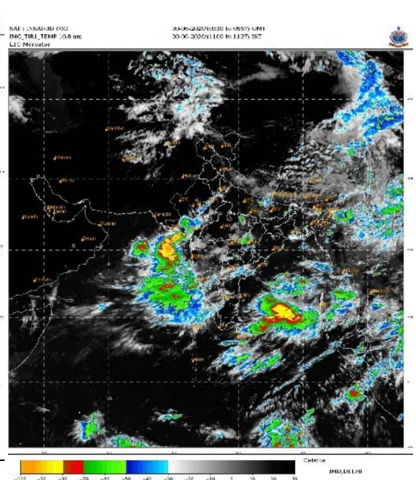
Globe Asiamer NE NW SE SW

Aviation Pilgrim

Cloud Top Brightness Temperature/IR-1 BT Blended Image

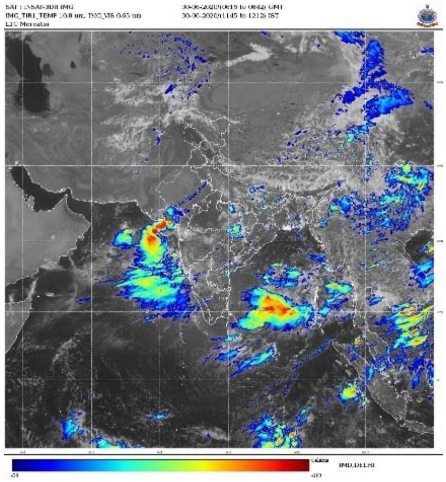
Brightness Temperature (BT) is the temperature of that body when it is assumed as a perfectly black body (i.e., Emissivity=1). Though Cloud is not a perfectly black body, however for derivation of Cloud Top Brightness Temperature (CTBT), cloud is assumed as a black body. In CTBT contour image, the CTBT contours are plotted over the grey count of thermal infrared (IR-1) band of imager payload. These contours provide the quantitative measurement of CTBT. The value of CTBT corresponds to the vertical growth and intensity of convective clouds. The more negative value of CTBT corresponds to higher vertical growth and intensity. Another IR1 BT blended image prepared using two different type of LUT in a single image that is grey scale for the range of +30 to -30-degree BT values and coloured scale for the range -30 to -100-degree Celsius BT to identify well developed convective cells.

CTBT IR-1 BT Blended Image

IR-1 BT & Visible Sandwich Image

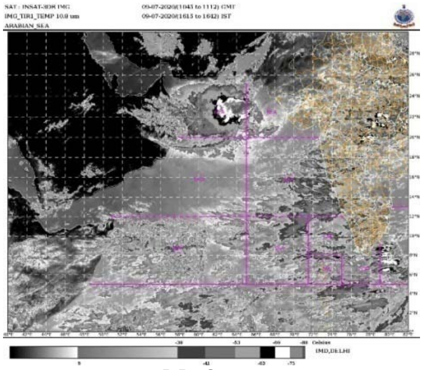
The overshooting tops usually resemble “bubbles” of several image pixels across, seen either in visible and near infrared spectral bands due to their texture and shadows they cast, or in thermal bands as local brightness temperature minima, with steep gradients surrounding them. Under favourable conditions the overshooting tops are accompanied by smaller-scale warm spots or larger and longer-lived embedded warm areas, forming downwind of the overshooting tops, easily observed in the colour-enhanced thermal IR imagery. Usually the overshooting tops and their downwind warm spots are observed independently, in the two stand-alone bands – the Visible band, and colour-enhanced IR10.8 brightness temperature imagery. Here we present a new image product, which merges the two bands together, allowing to observe all of these features simultaneously, in one single product.



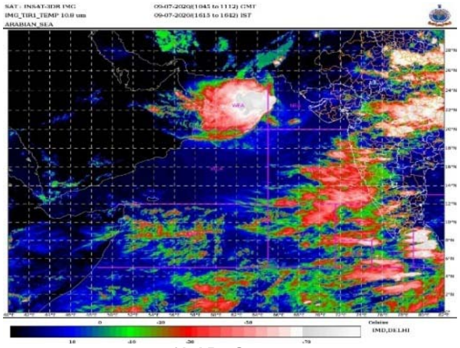
BD Curve and IMD curve Enhancement images for cyclone

Infrared-1BT images using INSAT-3D & 3DR imager payload data are generated &displayed that have been enhanced using two primary enhancement curves. These enhancements are used to highlight various different features within the imagery, with each enhancement used for different purposes. These two enhancements are named the "BD Curve" and "IMD Curve" enhancements.

The BD curve enhancement is used a great deal in the research and tropical cyclone forecasting communities who are interested in determining the intensity of these storms. This enhancement is otherwise known as the "Dvorak Hurricane Curve for Tropical Cyclone Classification", and is applied only to infrared (10.8µm) imagery. The different black/white/gray ranges represent different intensity classifications in the Subjective Dvorak Intensity Classification Technique (NOAA Technical Report NESDIS 11, 1984). The temperature values displayed on the image above are approximate, with the absolute temperature ranges for each gray shade. The IMD curve enhancement is mainly utilized for enhancement of infrared (10.8µm) imagery for television, newspaper, and internet displays. This enhancement is typically provided for/by the media since they prefer to work with colour imagery rather than simple black & white enhanced imagery.



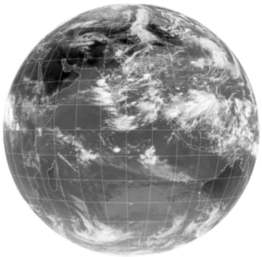
BD Curve

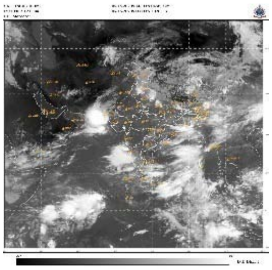


IMD Curve

Thermal Infra-Red (TIR-2)

The band between 11.5 – 12.5 µm are called thermal infrared band-2. TIR-2 window region around 12 µm, is contaminated by low level water vapor, and thus is called the "dirty window" and it is used to identify the Lower-Troposphere Moisture.


Globe


Asiamer

INSAT-3D RGB Composite Images : Description

RGB composite images are produced by composing satellite images colored in red, green and blue (RGB). In the multi-spectral imager era RGB composites are an excellent addition to the tools available at the forecasters' bench. In an operational environment it is important of course, to judiciously select the RGB composites and limit their number to a strict minimum in accordance with the problems at hand. At the same time one should strive for composites being available night and day and maximizing feature identification.

Two application specific RGB products Day Microphysics RGB, Night Microphysics RGB are generated in IMD by using data from INSAT-3D Imager.

Day Microphysics RGB Imagery

Channel combination "recipes" of the Day Microphysics RGB

- **In the RED beam** - The visible reflectance at 0.64 µm approximates the cloud optical depth (thickness) and amount of cloud water and ice. Typically, water cloud is more reflective than ice cloud and thus will have a stronger red beam component. This channel also gives information about the surface of the earth.

- **In the GREEN beam** – The 1.67 µm SWIR (shortwave infrared) solar reflectance gives a qualitative measure for cloud particle size and phase. Typically smaller water droplets or small ice particles have a higher reflectivity, resulting in a stronger green beam component. A sandy earth surface also has a strong reflectance in this channel.

- **In the BLUE beam** - The 10.8 µm TIR1 brightness temperature is a function of surface and cloud top B. temperatures. The scaling for this beam results in a strong blue beam component for warm surfaces, whereas cold cloud tops will not have any contribution in this beam.

This colour scheme is useful for cloud analysis, convection, fog, snow, and fires.

Day microphysics RGB scheme

Beam	Channel	Range	Gamma
Red	VIS(0.55-0.75 µm)	0 ...+100 %	1.0
Green	SWIR(1.67µm)	0 ... +60 %	1.0
Blue	IR(10.8 µm)	+203 ... +323 ºK	1.0

This product is used during the daytime because a solar reflectance component is adopted. Colors and their interpretation are based on I. M. Lensky and D. Rosenfeld : Clouds-Aerosols- Precipitation Satellite Analysis Tool (CAPSAT), Atmos. Chem. Phys.,8, 6739-6753, 2008i.

INSAT-3D RGB Composite Images : Description

The Night Microphysics RGB product is designed and tuned for monitoring the evolution of night time fog and stratus clouds. Other secondary applications include detecting fires, classification of clouds in general, snow and low-level moisture boundaries.

The distinction between low clouds and fog is often a challenge. While the difference in the TIR1 10.8µm and MIR 3.9µm channels is applied to meet this challenge, the Night-time Microphysics RGB adds TIR2 12.0µm channel difference to indicate cloud thickness and enhance areas of warm clouds where fog is more likely.

Other applications of Night-time Microphysics RGB include analysis of cirrus and contrail clouds, fire hot spots, and snow.

Channel combination recipe of the Night Microphysics RGB

- **In the RED beam:** The channel differencing gives an indication of optical depth. It uses TIR2 – TIR1. There is a strong signal in this beam for thick clouds. For thin meteorological cloud there is greater absorption by ~~the "dirty window"~~ 12 µm channel. In addition, the 12 µm radiation is absorbed more strongly in ice phase cloud compared to water phaseclouds.

- **In the GREEN beam:** This channel differencing is used in fog/low cloud detection method. It uses TIR1 – MIR. The 3.9 µm radiation has lower emissivity compared to the 10.8 µm radiation for small water droplet clouds. Therefore, there is a large contribution to the green beam in this RGB product for water clouds with small droplets. There is also a significant contribution from desert surfaces.

- **In the BLUE beam:** The 10.8 µm infrared brightness temperature is a function of surface and cloud top temperatures. The scaling for this beam results in a strong blue beam component for warm surfaces.

Night-time microphysics RGB scheme

Beam	Channel	Range	Gamma
Red	IR12.0 µm - IR10.8 µm(TIR2-TIR1)	-4 … +2 K	1.0
Green	IR10.8 µm - IR3.9 µm (TIR1-MIR)	-4 … +6 K	1.0
Blue	IR10.8 µm (TIR1)	+243 … +293 K	1.0

Some of the identified clouds and features are listed below for reference,

Fog can also be detected through **Night-time Microphysics RGB Imagery.** Fog and low clouds in warm climates tend to have aqua or light blue areas in the RGB. This appears very light green in colder climates because the 10.8 µm thermal channel used for the blue band contributes less.

Table

Lists the DMP and NMP thresholds along with their resolution and time of use for identification of fog and low clouds

Product	Pixel Resolution	Time	Source	Use (Conditions)
Night Time RGB (3.9, 10.8 µm)]	1 to 4Km	13 to 02 UTC (of next day) Half Hourly	RAPID rapid.imd.gov.in	1.TIR2-TIR1 BT DIFF > must be negative and -4 to 1.5K 2. TIR1-MIR BT must be -26K to -1, if positive = Ice/Snow clouds 3. TIR1 BT < 255K ===>Thunderstorm with Rain i) TIR2-TIR1 BT DIFF>becoming positive and -2 to 2K ii) TIR1-MIR BT must be -26K to 25 iii) TIR1 BT < 250K ===>Thunderstorm with Hail
Day Time RGB (TIR,SWIR, Vis)	1-4 Km	02:30 to 12:30 UTC Half Hourly	RAPID rapid.imd.gov.in	i) TIR1 BT Rate of Change is (in consecutive hours) -5 to -15 K ii) VIS 26-55% (Increasing trend) iii)SWIR < 28% (Decreasing trend) and iv) VIS>SWIR ==>Thunderstorm with Rain i) TIR1 BT Rate of Change (in consecutive hours) is -5 to -38 K ii) VIS 18-58% (Increasing trend) iii) SWIR < 25% (Decreasing trend) and iv) VIS>SWIR ==>Thunderstorm with Hail

Table

DMP and NMP thresholds along with its pixel resolution and time of use for thunderstorms prior to the event

Product	Resolution	Time	Source	Use (Conditions)
Night Time RGB (3.9, 10.8 µm)]	1 to 4Km	13 to 02 UTC (of next day) Half Hourly	RAPID rapid.imd.gov.in	1.TIR2-TIR1 BT DIFF>must be +1 to -1 K 2. TIR1-MIR BT >2.5K 3. TIR1 BT> 279K ===> Fog 1.TIR2-TIR1 BT DIFF> -1 to 0 K 2. TIR1-MIR BT >2.5K 3. TIR1 BT< 275K ===> Low cloud/Mist/Haze
Day Time RGB	1 to 4Km	02:30 to 12:30 UTC Half Hourly	RAPID rapid.imd.gov.in	TIR1 BT between 255-275K & VIS 30-45% & SWIR 31-60% ==>Low Cloud TIR between 276-290K & VIS 16-55% & SWIR 31-60% ===> FOG

2.2.2. Imager Products from INSAT-3D & 3DR Satellite

Product	Temporal Resolution	Horizontal Resolution	Format	Domain	Unit
Upper Tropospheric Humidity (UTH)	Half hourly, Daily, Weekly, Monthly	Per pixel	HDF/JPEG	Globe coverage	Percentage (%)
Total Precipitable Water Vapour (New Product)	Half hourly	Per Pixel	HDF/JPEG	Globe (Ocean)	cm
Sea Surface temperature (SST)	Half Hourly	$0.5^0 \times 0.5^0$	HDF/JPEG	Globe (Ocean)	degree Celsius
LST (Land Surface Temperature)	Half Hourly	Per pixel	HDF/JPEG	Globe (Land)	Kelvin
Cloud Products					
Cloud Mask	Half Hourly	Per pixel	HDF/JPEG	Globe	0-Pixel is clear, 1- pixel is cloudy, 2- pixel is probably clear 3- pixel is probably cloudy
CTT (Cloud top temperature)	Half Hourly	50 km	HDF/JPEG	Globe	Kelvin
Cloud top pressure	Half Hourly	50 km	HDF/JPEG	Globe	hPa
Effective cloud emissivity	Half hourly	50 km	HDF/JPEG	Globe	percentage (%).
Cloud Fraction	Half Hourly	50 km	HDF/JPEG	Globe	Expressed in **fractions**
Cloud Particle Effective Radius	Half hourly	Per Pixel	HDF/JPEG	30^0E-130^0E 50^0S-50^0N	Microns
Cloud Optical Thickness	Half hourly	Per Pixel	HDF/JPEG	30^0E-130^0E 50^0S-50^0N	percentage (%)
Rain Fall products (Quantitative Precipitation Estimation)					
Hydro Estimator Precipitation (HEM)	Half hourly, Daily, Weekly, Monthly	Per pixel	HDF/JPEG	Globe	mm/hr (mm-Daily, Weekly, Monthly)
Insat Multispectral Rainfall (IMSRA)	Half hourly, Daily, Weekly, Monthly	$0.1^0 \times 0.1^0$	HDF/JPEG	30^0E-120^0E 40^0S-40^0N	mm/hr (mm-Daily, Weekly, Monthly)
Global precipitation Index (GPI)	Three Hourly Accumulated	$1^0 \times 1^0$	HDF/JPEG	30^0E-120^0E 40^0S-40^0N	mm
IMSRA (Improved)	Half hourly, Daily, Weekly, Monthly	Per Pixel	HDF/JPEG	Globe	mm/hr (mm-Daily, Weekly, Monthly)

Atmospheric MotionVectors (AMV) and wind Derived products					
Cloud Motion Vector (CMV/IR1-wind)	Half Hourly at Levels (100-400mb 401-700mb 701-975mb)	Point	Gif/JPEG	30^0E-130^0E 40^0S-40^0N	Knots
Water vapour Winds (WVW)	Half Hourly at Levels (100-250mb 251-350mb 351-500mb)	Point	Gif/JPEG	30^0E-130^0E 40^0S-40^0N	Knots
Visible (during day) /MIR (during night) Winds	Half Hourly at levels (600-800mb 801-975mb)	Point	Gif/JPEG	30^0E-130^0E 40^0S-40^0N	Knots
IRW –Merged winds	Half hourly	Point	Gif/JPEG	30^0E-130^0E 40^0S-40^0N	Knots
WVW-Merged winds	Half hourly	Point	Gif/JPEG	30^0E-130^0E 40^0S-40^0N	Knots
Vis-HR winds	Half hourly	Point	Gif/JPEG	30^0E-130^0E 40^0S-40^0N	Knots
Vorticity (850,700,500 & 200 hPa)	Half hourly	0.5^0 X0.5^0	Gif/JPEG	30^0E-130^0E 40^0S-40^0N	10^{-5} x /sec
Low Level Convergence (850-925 hPa):	Half hourly	0.5^0 X0.5^0	Gif/JPEG	30^0E-130^0E 40^0S-40^0N	10^{-5} x /sec
Upper level Divergence (150-300 hPa):	Half hourly	0.5^0 X0.5^0	Gif/JPEG	30^0E-130^0E 40^0S-40^0N	10^{-5} x /sec
Wind Shear:	Half hourly	0.5^0 X0.5^0	Gif/JPEG	30^0E-130^0E 40^0S-40^0N	Knots
Mid-Level wind Shear	Half hourly	0.5^0 X0.5^0	Gif/JPEG	30^0E-130^0E 40^0S-40^0N	Knots
Wind Shear Tendency	Half hourly	0.5^0 X0.5^0	Gif/JPEG	30^0E-130^0E 40^0S-40^0N	Knots
Miscellaneous Geophysical Products					
Snow cover	0500,0530, 0600,0630 UTC	Per pixel	HDF/JPEG	20^0E-110^0E 50^0S-50^0N	Unit-less
Fire	Half Hourly	Point	HDF/JPEG	60^0E-100^0E 0^0N-40^0N	Unit-less
Smoke	Half Hourly	Point	HDF/JPEG	60^0E-100^0E 0^0N-40^0N	Unit-less
Fog (Night Time/Day Time)	Half Hourly	Per pixel	HDF/JPEG	45^0E-110^0E 10^0S-45^0N	Unit-less
Fog Intensity	Half Hourly	Per pixel	HDF/JPEG	45^0E-110^0E 10^0S-45^0N	Unit-less (1,2,3,4)
Aerosol Optical Depth (AOD)	0500 to 0830 UTC on half hourly basis	Per pixel for clear sky	HDF/JPEG	45^0E-100^0E 10^0S-45^0N	Unit-less

Radiation Products/ Agromet Products					
Outgoing Long Wave Radiation (OLR)	Half hourly, Daily, Weekly, Monthly	Per pixel	HDF/JPEG	Globe	Watt/m^2
Net Radiation	Half hourly	Per Pixel	HDF/JPEG	60^0E-100^0E 5^0N-40^0N	Watt/m^2
Land surface Albedo	Half hourly	Per Pixel	HDF/JPEG	60^0E-100^0E 5^0N-40^0N (land)	Unit - less
Short Wave Radiation	Half hourly	Per Pixel	HDF/JPEG	40^0E-110^0E 15^0S-25^0N (Ocean)	Watt/m^2
Evapotranspiration (PET)	Half hourly	Per Pixel	HDF/JPEG	50^0E-105^0E 5^0S-41^0N (land)	mm
Actual Evapotranspiration	Half hourly	Per Pixel	HDF/JPEG	60^0E-100^0E 5^0N-40^0N	mm/day
Insolation	Half Hourly	Per pixel	HDF/JPEG	45^0E-110^0E 10^0S-45^0N	Watt/m^2

2.2.3. Sounder Products

S. No.	Data Product	Processing Level	Code	Format	Remarks
Standard Products					
	Standard Product	L1B	STD	HDF	Per Pixel Lat & Lon as viewed by Satellite
Geo-Physical Parameters					
	Vertical Profiles and Derived products	L2B	PFL	HDF	Profile on 3x3 Pixels (Average)

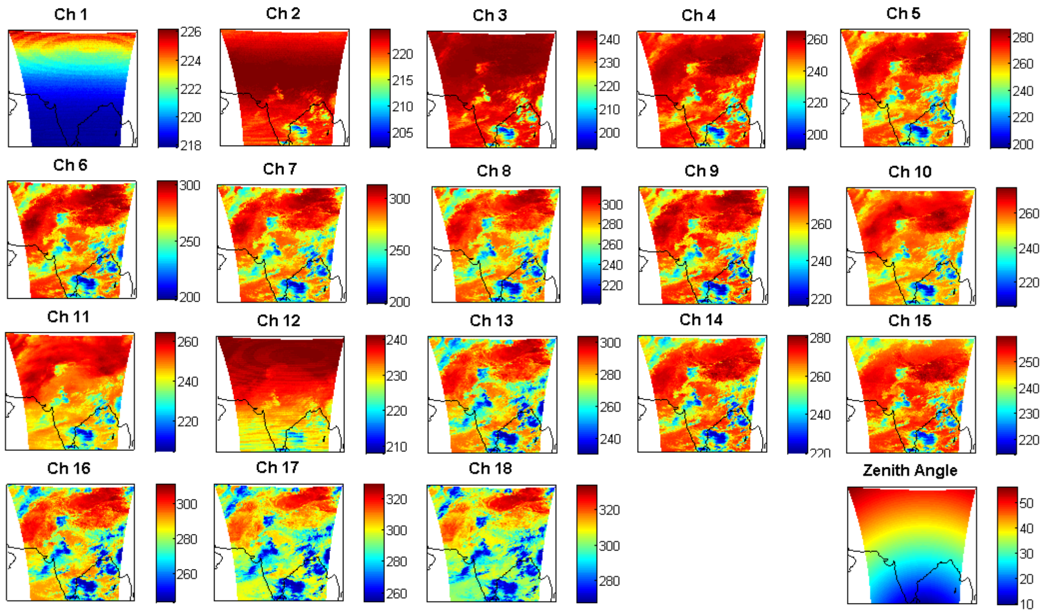
The algorithm of sounder products is designed for retrieving vertical profiles of atmospheric temperature and moisture along with total column ozone content in the atmosphere from clear sky infrared radiances in different absorption bands observed through INSAT-3D/3DR.

Sounder derived profiles include temperature at 40 vertical pressure levels from surface to about 70 km and water vapor in 21 levels from surface to around 15 km. Following application products are derived from sounder derived atmospheric profiles.

The profiles generated include:
(i) Temperature
(ii) Humidity
(iii) Total Ozone

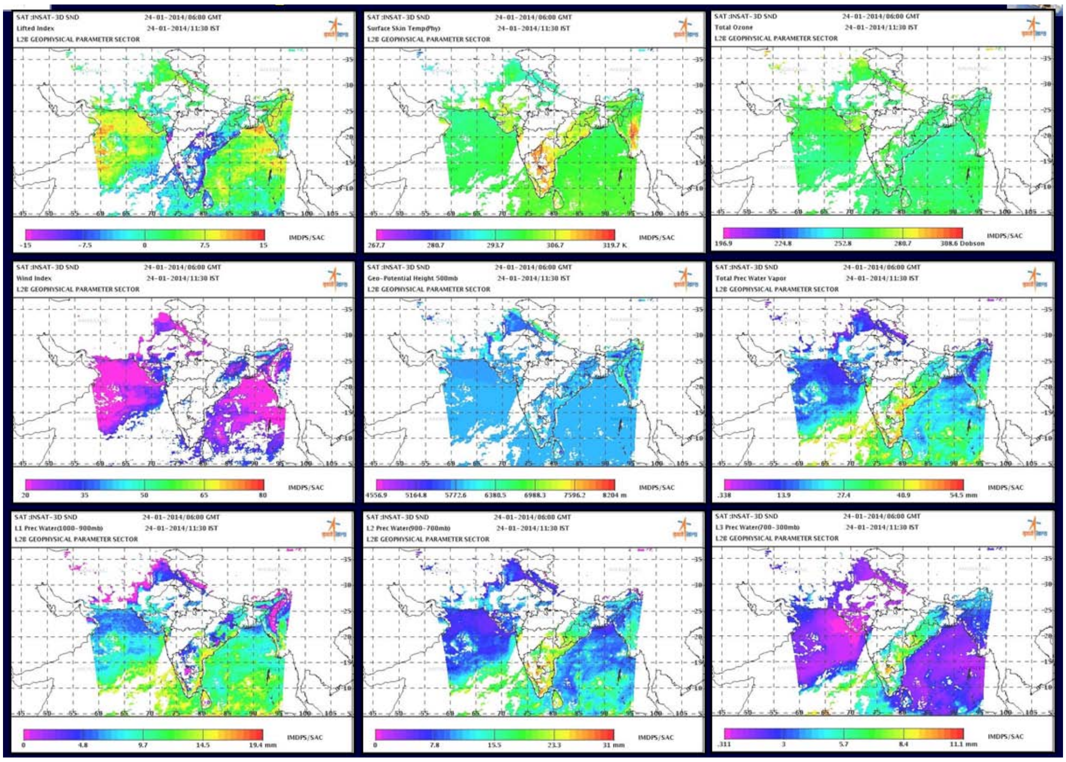
These derived products include:

(iv) Geopotential height
(v) Layer and total precipitable water
(vi) Lifted index from sounder
(vii) Dry microburst index
(viii) Maximum vertical theta-e differential
(ix) Wind index



INSAT-3D Sounder Channels Brightness Temperature (10-AUG-2013 0331Z)

Sample INSAT-3D/3DR Sounder L2 Products



Geopotential Height: Calculate layer thickness between pressure levels starting from surface.

LIFTED INDEX : LI >2 –No Significant Activity
-2<LI<0 -Thunder storm possible
LI < -4 -Severe thunder storm possible

Dry microburst index (DMI) : Dry microburst occurs in situations characterized by high convective cloud bases and strong evaporation cooling in the sub-cloud layer, resulting in little or no precipitation at the surface. Such conditions occur in mountainous and high plain regions.

Wind Index : Wind index provide guidance on the maximum possible wind gusts that can occur with given atmospheric conditions, if convection were to occur. This is useful for generating short-range warnings and forecasts.

Maximum vertical theta-e (θ_e) differential : The equivalent potential temperature (θe) is a measure of the total static energy (sensible heat, latent heat and geopotential) in an atmospheric column. Due to its strong dependence on moisture, θe decreases rapidly with height above the boundary layer reaching a minimum in the middle troposphere, then θe increases again into the upper troposphere. The maximum vertical θe differential from boundary layer to the middle troposphere is a useful quantity in calculating microburst potential etc.

Total precipitable water : The TPW may be used for monitoring the mesoscale to synoptic-scale convective activity, monsoonal activities, and moisture gradients. It has shown a significant improvement in precipitation forecasts when TPW is incorporated in the numerical weather prediction models.

Accuracy with Radiosondes

Temperature : There is a consistently negative bias (~ 0.2 to 0.8°C) in temperature below 850 hPa and positive bias (~1 to 2 °C) in the upper troposphere and lower stratosphere in all stations is noticed. The root-mean-square error (RMSE) values between INSAT-3D and radiosonde station temperature profiles at each altitude level shows better agreement less than 4 °C except above 200 hPa more than 3 °C at all stations.
Humidity: 30%

Total precipitable water : The comparison of INSAT-3D TPW with RS TPW on monthly bases shows that the root means square error (RMSE) and correlation coefficients (CC) are ∼8 mm and 0.8, respectively. In general, INSAT-3D TPW corresponds well with rainfall observation; however, it has found that heavy rainfall events occur in the presence of high TPW values. It is found that the heavy and heavy-to-very-heavy rainfall correspond to the higher INSAT TPW values (60–80 and above 80 mm).

2.2.4. Dissemination

All the channel & specialized Images and Products Images being disseminated through dedicated webpages

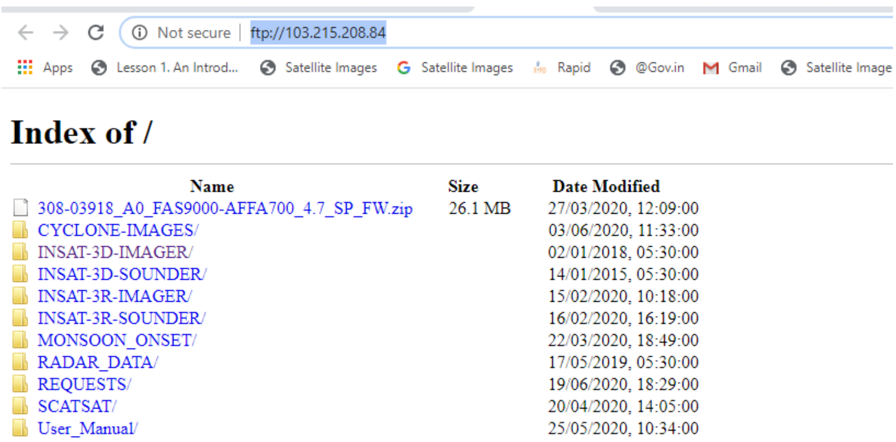
http://satellite.imd.gov.in/insat.htm

It can further be expanded by clicking RAPID SCAN, Agromet Product, SCATSAT-1 Wind and to see detailvarious products which ae not cover-up on main webpage on link click here.

https://www.satellite.imd.gov.in/rapid/rapid_scan.htm

The division is also maintaining the online archival of last six months channel and products Images on FTP Server which is also user name and password protected.

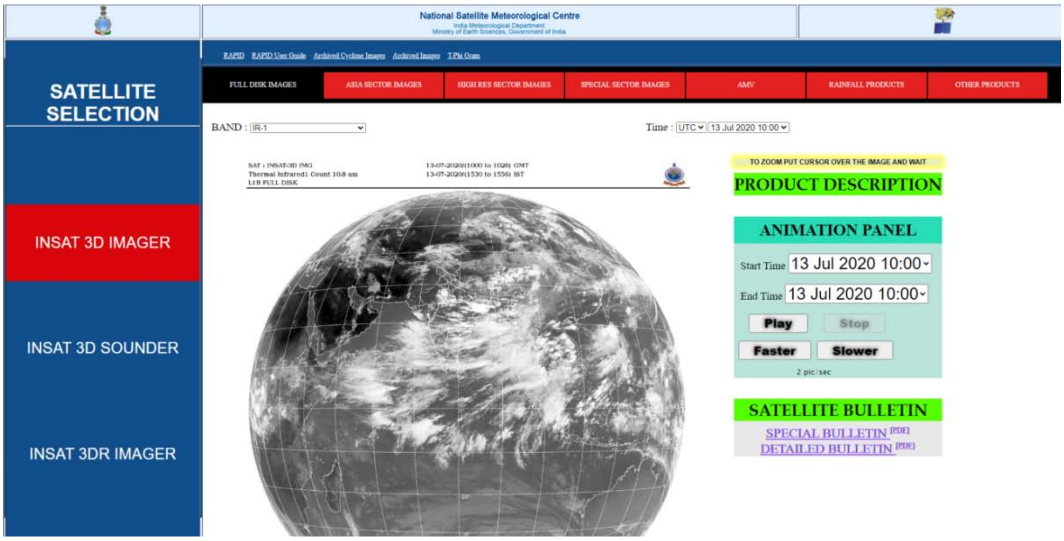
ftp://satmet@103.215.208.84/

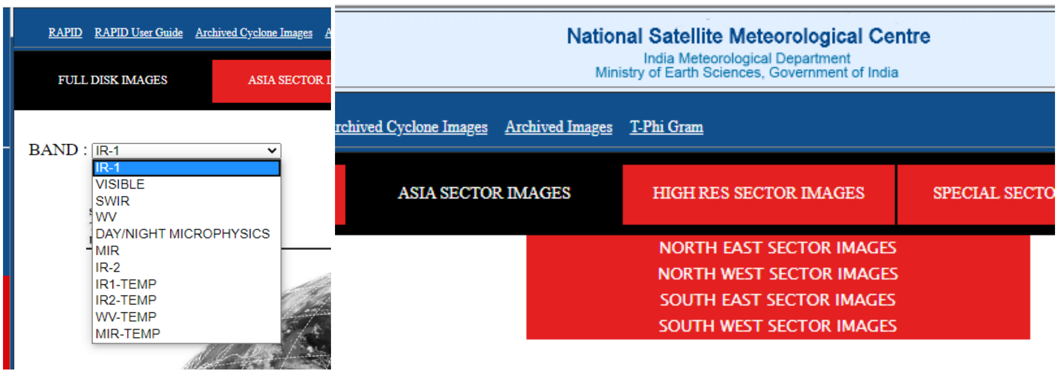


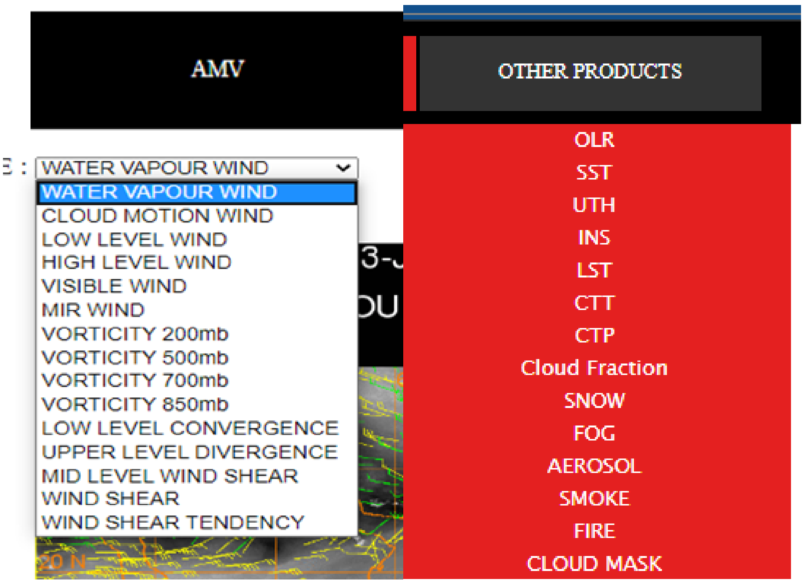
http://satmet.imd.gov.in/insat3d.htm

Features

- Selection via Drop down box.
- Auto Zooming facility.
- User defined Animation on all set of imageries and products.
- Imagery/Product description documents for all.
- Availability of last 24 hrs imageries/products for visualization.

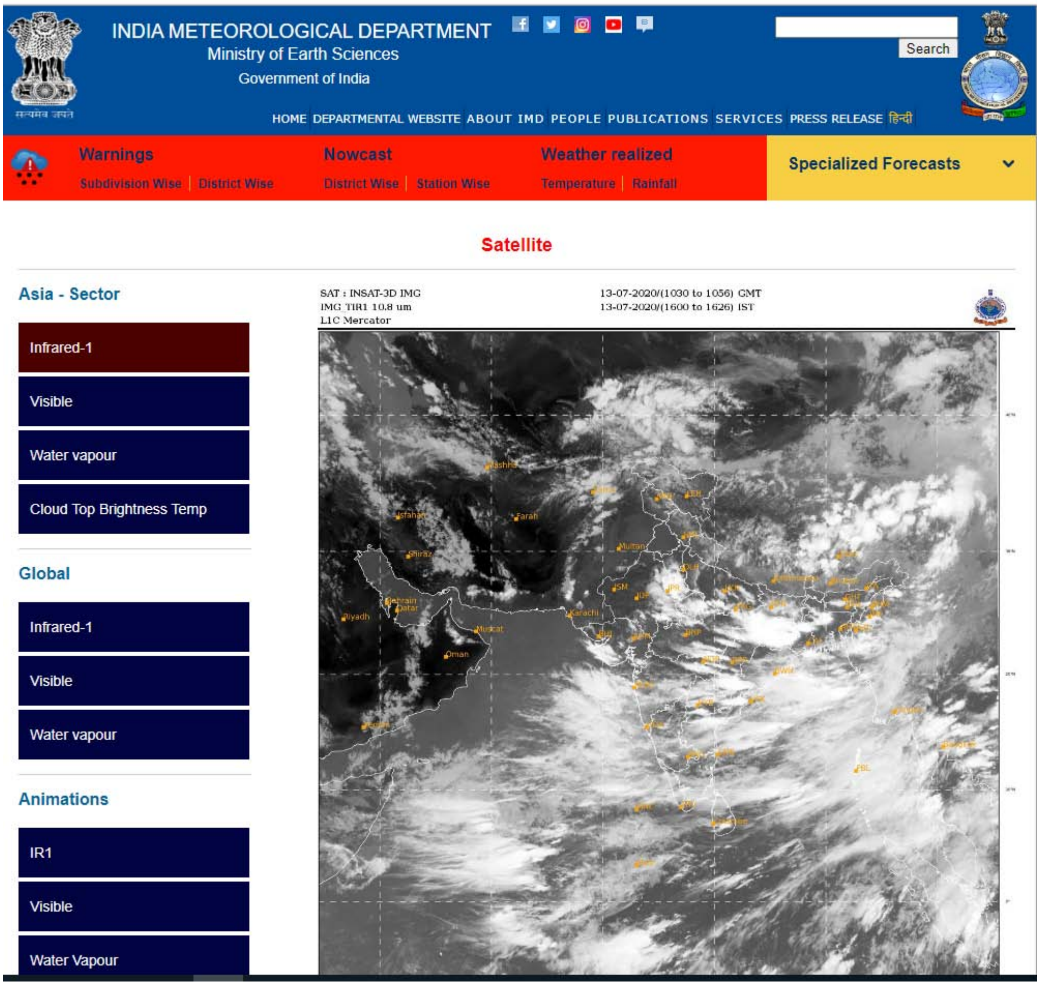






These Webpages are user name & password protected. International Meteorological services, National Government Agency and Research Institutions dealing with forecasting disaster management and research work can obtained the username and password information from virendra61.singh@imd.gov.in with the conditions that these will not be further shared with others.

For general users, limited satellites Images are disseminated through https://mausam.imd.gov.in/ and can be visualize by clicking Satellite.



2.2.5. Real-time Analysis of Product and Information Dissemination (RAPID)

With an increase in the number of Earth Observation satellites, large volume of data and types of data products available to users from meteorological satellites has created a requirement for a web-based interface, which can provide quick visualisation and analysis capabilities to end users and in-particular to meteorologists and decision makers.

RAPID introduces Next Generation Weather Data Access & Advanced Visualization Application that touches the life of common man in one or other way ranging from severe weather monitoring to various sectoral applications like agriculture, tourism, sports etc. For example, we can assess the fog over railway tracks and surface transportation highways, aviation, navigation & a pilot can monitor the location, intensity & movement of cumulonimbus clouds enroute.

This tool was conceptualized and developed by Satellite Application Centre (SAC), ISRO in collaboration with India Meteorological Department (IMD), New Delhi to enhance the visualization and analysis of INSAT Meteorological Satellite data on real time basis by the forecasting community. This system is operationally sustained by National Satellite Meteorological Centre (IMD), New Delhi. This tool is hosted at http://www.rapid.imd.gov.in/. User guide for operating this tool is available on http://satellite. imd.gov.in/desc/RAPID_User_Guide.pdf

2.2.6. METEOSAT SEVIRI (spinning enhanced visible and infrared imager) located at 41.5°E Meteosat 8- Channel Imageries

Bands (µm)	Domain	Resolution (at Nadir)	Approximate Size	Frequency of Updation
Vis 0.6	10S-50N, 40E-110E	3km x 3km	2.5mb	15 mins
Vis 0.8	10S-50N, 40E-110E	3km x 3km	2.5mb	15 mins
IR 1.6	10S-50N, 40E-110E	3km x 3km	2.5mb	15 mins
IR 3.9	10S-50N, 40E-110E	3km x 3km	2.5mb	15 mins
IR 8.7	10S-50N, 40E-110E	3km x 3km	2.5mb	15 mins
IR 9.7	10S-50N, 40E-110E	3km x 3km	2.5mb	15 mins
IR 10.8	10S-50N, 40E-110E	3km x 3km	2.5mb	15 mins
IR 12.0	10S-50N, 40E-110E	3km x 3km	2.5mb	15 mins
IR 13.4	10S-50N, 40E-110E	3km x 3km	2.5mb	15 mins
WV 6.2	10S-50N, 40E-110E	3km x 3km	2.5mb	15 mins
WV 7.3	10S-50N, 40E-110E	3km x 3km	2.5mb	15 mins

RGB recipes used to generate RGB products from METEOSAT-8

Product	Red	Green	Blue
Air-mass	WV6.2 -7.3	IR 9.7-10.8	WV 6.2
Convection	WV 6.2 – 7.3	IR 3.9 – 10.8	NIR 1.6 – VIS 0.6
Night Fog	IR 12.0 – 10.8 (-4K to +2k)	IR 10.8 – 3.9 (0 to +10K)	IR 10.8 (+243 to +293K)
Dust	IR 12.0 – 10.8	IR 10.8 - 8.7	IR 10.8
Day Microphysics	VIS0.8	IR3.9 solar reflectance	IR 10.8
True colour	NIR 1.6	VIS0.8	VIS 0.6

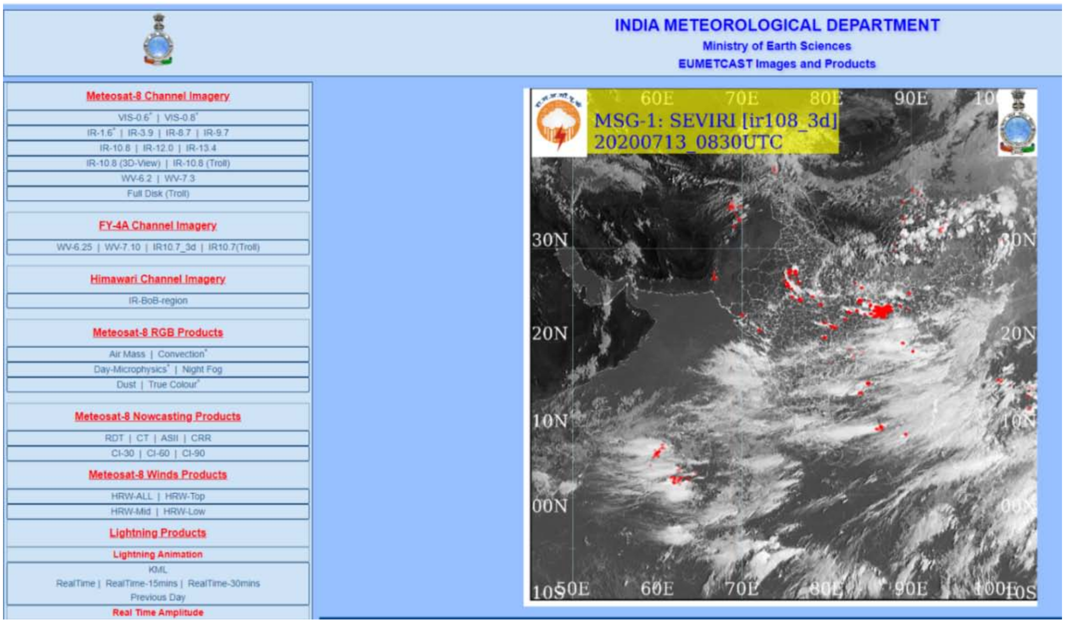
RGB Products

Name of Product	Domain	Resolution	Limitation	Frequency of Updation
Air-mass	10S-50N, 40E-110E	3km x 3km	Only mid-upper level information	15 mins
Convection	10S-50N, 40E-110E	3km x 3km	Only Day time product	15 mins
Day Microphysics	10S-50N, 40E-110E	3km x 3km	Only available during Day time	15 mins
Night Microphysics	10S-50N, 40E-110E	3km x 3km	Only available during Day time	15 mins
Dust	10S-50N, 40E-110E	3km x 3km	Concentration and height of dust cannot be ascertained.	15 mins
True Color	10S-50N, 40E-110E	3km x 3km	Only available during Day time	15 mins

Wind Products

Name of Product	Domain	Resolution	Limitation	Frequency of Updation
Winds- All levels	10S-50N, 45E-105E	3km x 3km	Winds are derived only wherever atmospheric tracers are available	15 mins
Winds- High levels	10S-50N, 45E-105E	3km x 3km	Only 400-100hPa level Winds	15 mins
Winds-Medium levels	10S-50N, 45E-105E	3km x 3km	Only 600-400hPa level Winds	15 mins
Winds- Low evels	10S-50N, 45E-105E	3km x 3km	Only 800-600hPa level Winds	15 mins

Imageries and products are available at http://foreignsat.imd.gov.in/



2.2.7. GNSS

IPWV derived product from GNSS Network is used for continuous monitoring the column precipitable water vapour and Meteorological parameters values (Pressure, Temperature, Relative Humidity) charts in real time basis through a dedicated web page (http://gnss.imd.gov.in/TrimblePivotWeb/MemberPages/AtmosphericConditions/IpwvMap.aspx). To watch these parameters user can use the following sequence selections-

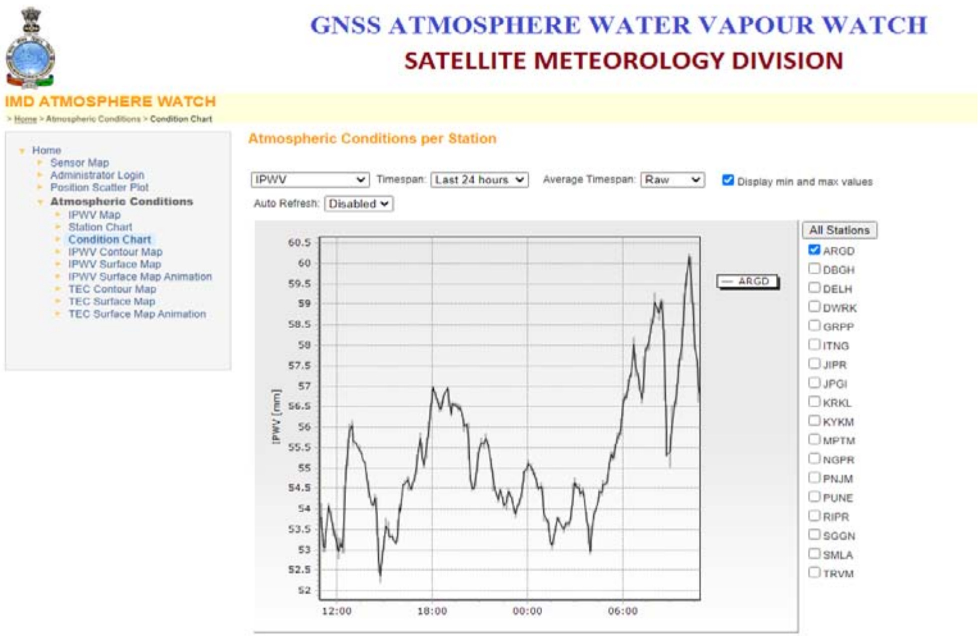
(i) Condition chart under Atmospheric conditions

(ii) Stations name may be selected from extreme right-hand drop-down box “All Stations” name.

(iii) Parameters selection in a first drop-down menu with a default “IPWV” name

(iv) For time periods selection to visualize every 15 minutes data curve in second drop-down menu with a default “last 2 hours” name.

(v) To watch average or current digital values of parameters user can opt third dropdown box with default “raw” name.



The following criteria of IPWV and surface temperature values may be used for predicting the rainfall occurrence associated with Synoptic system at Inland and Costal stations.

Inland Stations

Month	Surface Temperature (approximately)	IPWV (with Synoptic system)
Jan	10 – 15-degreeCelcius	15 – 18 mm
Feb	15 – 20 C	18 – 22 mm
March	15 - 25 C	20 – 25 mm
April	25 - 35	25 – 30 mm
May	35-40	>40 mm (less than this value dust storm)
June	38 – 45 Degree Celsius	>45 mm (less than this value dust storm)
Monsoon	30-38 degree	>60 mm
Break Monsoon		40 – 45 mm
Post Monsoon	30-35	30 – 40 mm

Costal station : South Peninsular India

Month	Surface Temperature	IPWV
JAN - FEB	20 – 30 C	40 mm and more
MAR - APRIL	30 – 35 C	45 and above
MAY,JUN,JULY,AUG,SEP,OCT	35 – 40 C	55 and above
NOV, DEC	30 - 35	60 and above

Further, If IPWV > 60 mm and maintains average value around 60 mm continuously for 2 to 3 days, then forecaster may use as favourable condition for monsoon arrival at that location. If IPWV values associated with synoptic systems lies between 65-68 mm will give heavy rainfall over costal stations. More than 70 mm IPWV associated with synoptic system will give heavy to very heavy rainfall provided IPWV value maintains this value at synoptic time scale. The IPWV normally increases and may go more than 80 mm in severe convective thunderstorms particularly NE, Bihar, UP, Delhi, Jharkhand region.

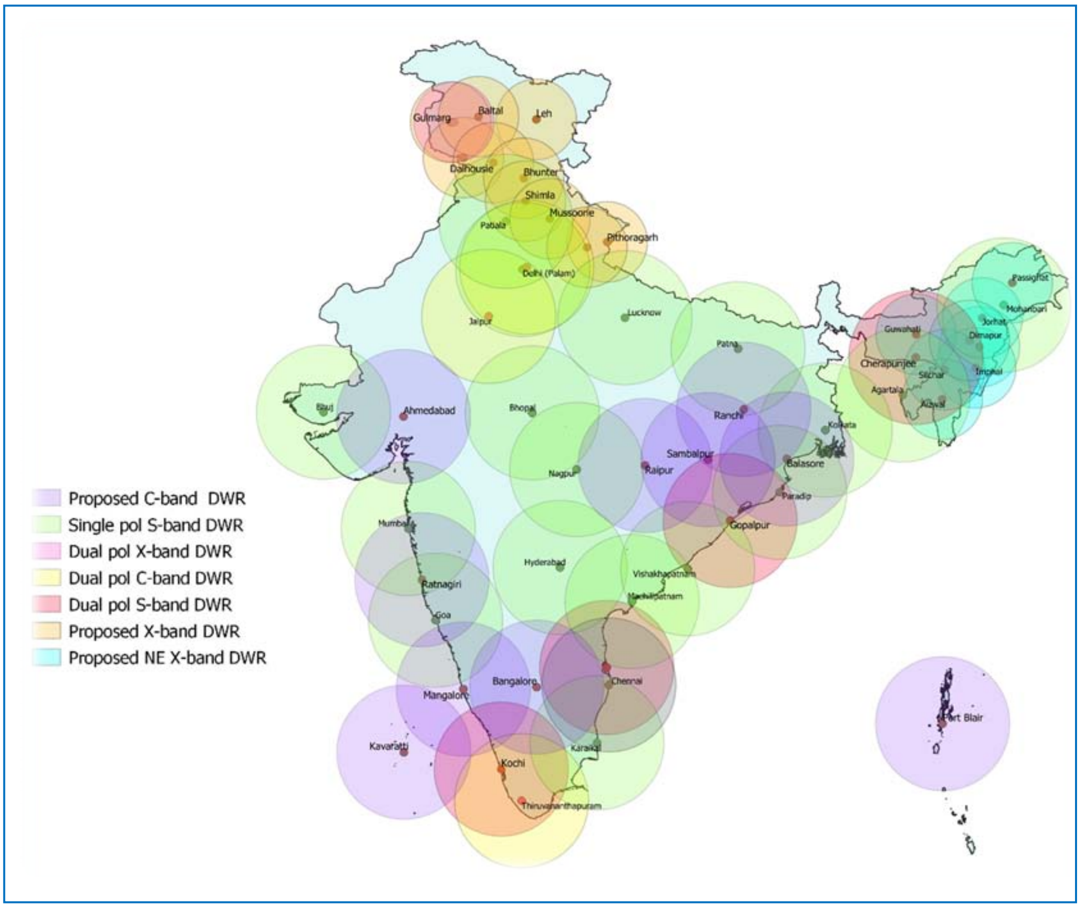
For Hilly region depending upon the elevation, the value of IPWV comparatively less than plain region. Example or Bengaluru, 40 mm is threshold value for Monsoon arrival. Similarly, for Shimla ranges between 30 - 35 mm. The IPWV values for nowcasting the TS and rainfall area site specific. However, forecaster may further refine these thresholds for different weather events, different seasons and stationsfor more accurate forecasting.

Chapter 3

DOPPLER WEATHER RADARS & ITS APPLICATION

3.1. Radar network in India Meteorological Department

The digital and Doppler capability increases the versatility of the radars several fold. Besides reflectivity factor which is the basic output of all radars, these give additional output of velocity and its variance. Using these outputs it is possible to derive several products of operational meteorological interest. Distribution of rainfall rates, accumulated rain over a period of time, vertical profile of wind, signatures of cyclones and tornadoes, maximum wind in cyclones, wind shear and turbulence, probability of severe weather and hail and the likely size of hailstones are among the important products.



- Installed at Chennai, Kolkata, Machilipatnam, Visakhapatnam, Paradip, Gopalpur, Hyderabad, Nagpur, Patna, Lucknow, Patiala, Karaikal, Kochi, Bhopal, Agartala, Mohanbari, Delhi (Palam) and Goa and 02 numbers C-band Polarimetric DWRs are installed at Delhi (HQ) and Jaipur and four X-band DWR has been installed at Srinagar, Sonamarg, Kufri and Mukteshwar.
- IMD's network consists of 27 DWR radars comprising of 21 S-band Radars (DWRs), 02 C-band Radars and 4 X-band DWR at Srinagar, Sonamarg, Kufri and Mukteshwar. Data is also being utilized from ISRO owned radars at Thiruvananthapuram and Cherrapunjee.
- IMD plans to install radars with state-of-art Doppler Weather Radars (DWRs) in a phased manner at Mumbai, Bangalore, Mangalore, Lakshadweep, Andaman Island (Port Blair), Balasore, Sambalpur, Raipur, Ranchi, Ratnagiri and Ahmedabad.
- Under scheme of Integrated Himalayan Meteorology Project (IHMP) IMD will install 10 X-band DWRs in Central and Western Himalayas to cover the hilly range of J&K, Himachal Pradesh and Uttarakhand.

3.2. Operational scan strategies and radar data flow

3.2.1. Operational scan strategy

DWR scans are designed so as to suit the prevailing weather situations and data requirements.

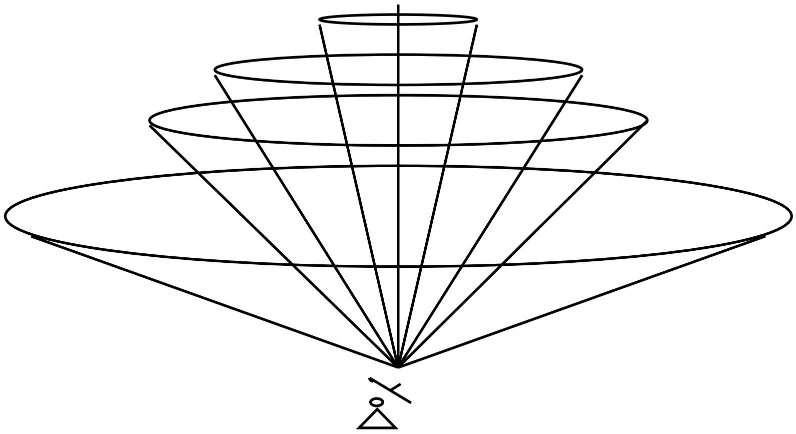


Fig. 2. Radar Volume scan

The scan schedules are as follows:

a) A long range single elevation scan, generally up to 500Km range, with lowest elevation angle possible is done to have general observation of the atmosphere around the radar site. Scan time maximum 2 minutes.

b) A medium range (upto 250Km) multiple elevations scan, called a volume scan is done for detailed probing of atmosphere. Scan time maximum 9 minutes.

c) A 10 minute temporal spaced scan strategy, to suit the periods of bad weather or expected bad weather, is adopted by all Indian DWRs.

3.2.2. Doppler Weather Data

Doppler Weather Radar produces mainly three kinds of data viz., Raw Data, Digital Products Data and Image Data.

3.2.3. Sharing of Doppler Weather Radar Data

The following products are considered most common and useful to weather forecasters and also to common man:

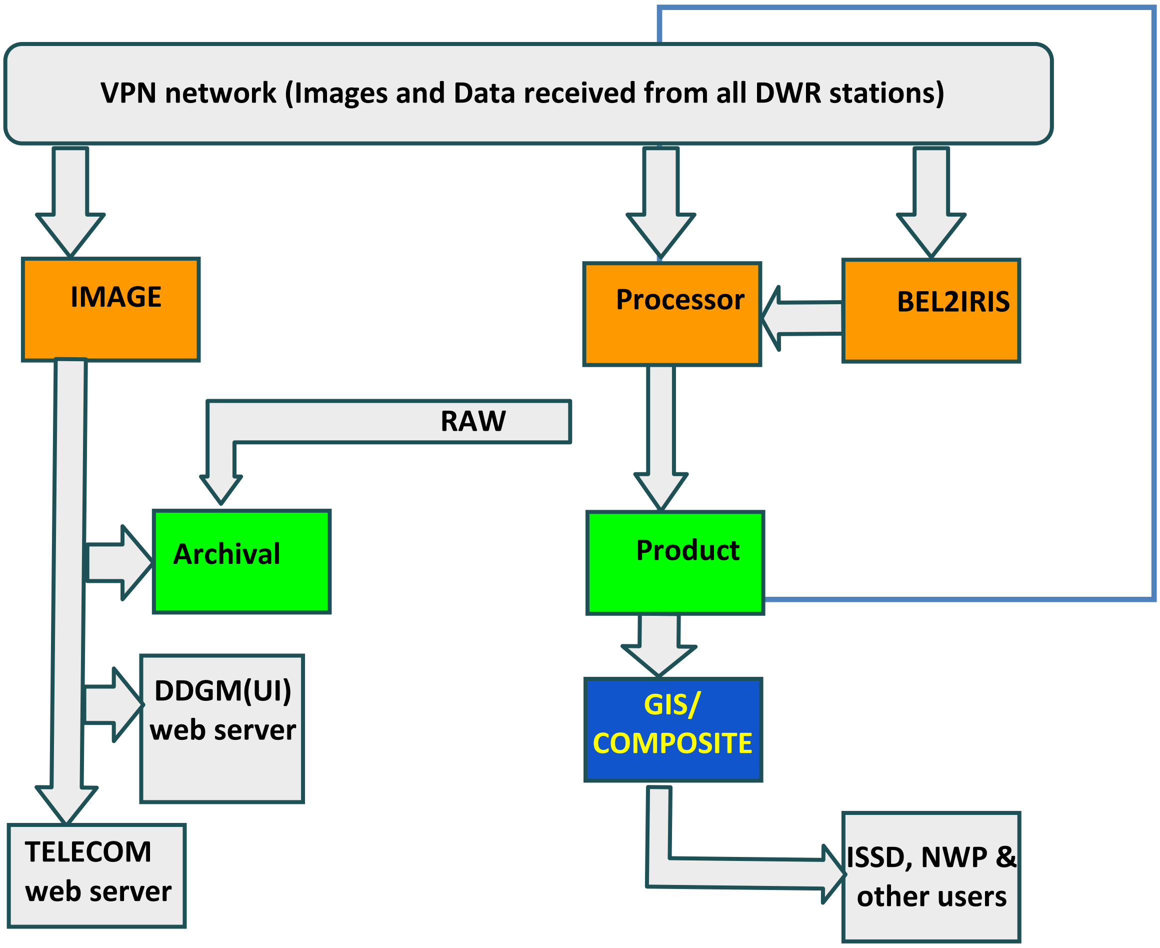
- Plan Position Indicator – Reflectivity (PPZ)
- Plan Position Indicator – Velocity (PPV)
- Plan Position Indicator – Surface Rainfall Intensity (SRI)
- Plan Position Indicator – 24 hours Precipitation Accumulation (PAC)
- Maximum Reflectivity -- (Max-Z)
- Vertical Wind Profile -- (VVP2)

3.2.4. Data Flow

- The RAW data of all DWRs are received via VPN / INTERNET in every 10 minutes.
- The Central server at Radar lab, HQ accepts data in IRIS, Rainbow and BEL format for processing. BEL and Rainbow format is converted to IRIS format for compatibility with IRIS software.
- The received/converted data is passed through the IRIS and any corrupted data gets filtered out.
- The filtered data is then used for generating various output products and format conversion to NetCDF, BUFR and HDF5

3.2.5. Networking, Power and other associated equipment

- All DWRs are having a number of servers that processes the radar data and provides data for products and images generation.



DWR Data flow at HQ.

There are number of servers used at DWR stations for processing radar data, images generation, archival of raw data and images etc.

- The data and images are shared by DWR stations with Radar Lab, HQ via VPN and broadband networks in real time.

3.3. Radar Operational details

- DWR stations operate radars 24X7 for detection of significant weather.
- Weather warnings and bulletins are being issued to state government authorities and other recipients using radar images by DWR stations.
- In case of cyclones, thunderstorms and extreme weather events, bulletins and earnings are also issued using emails, fax, SMS etc.
- Restricted Operations

Radar lab in consultation with station in charge can suggest reducing the operational hours of Radar to the Radar station based on any operational constraints arising due to technical or logistic reasons.

3.4. Basics of weather radar products & its interpretation

3.4.1. Introduction

Radar can only detect reflected energy when it is in listening mode. While radar is transmitting energy, it cannot detect reflected energy. Since radar alternates between transmitting and receiving energy, a term called the pulse repetition frequency (PRF) – defined as the rate at which the radar sends pulses. PRF is used to characterize radar. For example, a PRF of 1000 Hz, it means the radar is transmitting 1000 pulses per second, or one pulse every thousandth (0.001) of a second. The PRF has mathematical significance to reflectivity and velocity products also. Microwave energy emitted by radar has all the characteristics of waves. One of them is wavelength, defined as the distance between successive peaks or valleys in a wave. In the microwave portion of the electromagnetic spectrum, wavelengths may be varied between 1 millimetre and 1 meter. For Doppler weather radars, different wavelengths are being used like 10 centimetre (S-band), 5 centimetre (C-band), and 3 centimetre (X-band) radars. The wavelengths used for radar have three major effects:

a. How small of particles the radar can detect?

b. How much the beam is attenuated as it bounces off the reflectors?

c. How large a value of velocity can be measured?

The shorter the wavelength, the smaller the particles the radar can detect. Attenuation means weakening of the beam due to energy being deflected away or absorbed by particles as the beam travels away from the radar. A practical application of this effect is when a radar beam has to travel through several intense thunderstorms, or along a line of intense thunderstorms. The beam will encounter with a very large number of raindrops as it passes through the thunderstorms. The more raindrops the beam bounces off less energy is left to travel farther to more distant storms. The product called base reflectivity displays the amount of energy that has returned to the radar. If there is less energy emitted to reflect from particles, there will be less back reflected power to the radar. This will make it seem like the thunderstorms that are farther out are less intense, in fact they may be as intense as or more intense than the storms closer to the radar.

3.4.2. Interpretation of Basic Radar Images

The interpretation of radar images in terms of rainfall intensity at the ground is complicated due to several factors. These require the modification of observed patterns of radar echoes. Although useful corrections for these factors can be made automatically but they cannot be eliminated completely, hence understanding of their effects is important for improving the usefulness of the imagery to forecasters/users. Doppler Weather Radar is a very useful tool to provide a wealth of information but it needs proper interpretation. In the past, only meteorologists had access for Weather Radar data, but now a day, the Internet has enabled the general public to access the same data that is being used by meteorologists on a daily basis.

To understand “what is “it” when we look into the radar imagery, just looking at the radar return isn't always as simple as looking it. Though, there may be the thunderstorm and clouds, the experienced meteorologist will certainly be able to glance at a radar image and quickly be able to make out the important features, but most of us have to study the images quite a bit closer. The experienced meteorologist should always be the first source of information.

Meteorology and radar interpretation are different complex fields like other fields and require experience. It is easy and good to understand the concepts but when it comes right down to it this becomes a very complicated topic and the ability to interpret radar images and conclusion are always different from person to person even they have working experience with this technology.

The main difficulty is when looking at Doppler Weather Radar imagery especially differentiating between what is real and what isn't and what is important and what isn't. The DWRs are so sensitive that they are capable of picking up birds, insects, smoke or even dust, pollen, pollution and temperature inversions.

Therefore there are two primary points that needs to be considered when observing DWR images:

- Recognize real meteorological objects and be able to identify them.
- Identify known radar anomalies produced by birds, insects, smoke, dust, temperature inversions and radar data anomalies etc.

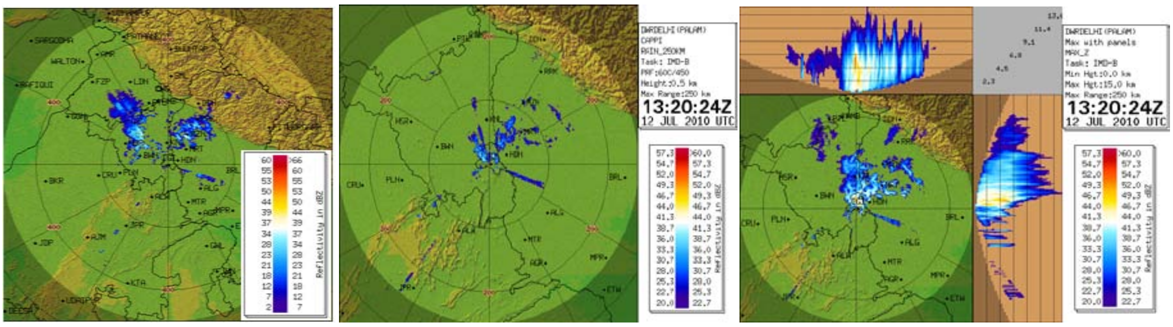
3.4.3. Types of base data

The Doppler Weather Radar initially generates three types of base data:

a. Reflectivity (i.e., the amplitude of the backscattered signal)

1. Reflectivity

Echo intensity (reflectivity) is measured in scale of dBZ. Reflectivity is the amount of transmitted power returned to the radar. The base reflectivity is essentially “raw” data usually seen from the lowest tilt angle, 0.50 degree, for example PPI-Z (Reflectivity) product is the Base Reflectivity. The Base Reflectivity Products are able to detect precipitation, evaluate storm structure, locate atmospheric boundaries and determine hail potential. The Several different elevation angles (tilts) of the radar can be used for composite reflectivity products, for example the CAPPI-Z and MAX-Z are the Composite Reflectivity products. The colours are the different echo intensities (reflectivity) measured in dBZ (decibels of Z). The dBZ values increase as the strength of the signal returned to the radar increases. Very Light rain will have dBZ values around 20dBZ with more intense thunderstorms having values of 50 dBZ or more. In the following figure some reflectivity products are shown.



(a) PPI-Z (b) CAPPI-Z (c) MAX-Z

Figure. Reflectivity Products of Doppler Weather Radar

There are three factors distinguish the Reflectivity Product.

(i) Weather radars can receive false echoes from ground objects such as buildings and towers. The Reflectivity product uses Doppler processing to edit out (filter out) most of these false echoes. This Doppler correction stops at about 110km. Because of the correction, the Reflectivity product is generally better and not affected with ground clutters.

(ii) Trees and hills around radars can block some or entire radar beam, resulting in decreased echoes returned at low angles. This is particularly seen on the Reflectivity product in winter when very low angles are used to detect precipitation at close range.

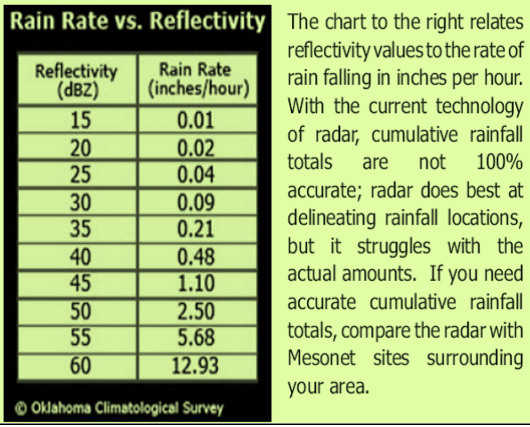
(iii) The Reflectivity product can appear to be less sensitive in Doppler mode. A ring of discontinuity may appear at the transition to the non-Doppler processing (CAPPI). This is especially evident if weak precipitation is occurring where the Doppler processing ends. Beyond this point, echoes may suddenly appear stronger as the radar's ability to detect those increases.

➢ **Reflectivity images for Precipitation of Rain.**

The relationship between precipitation intensity and reflectivity for "Rain" image correlates reflectivity to rainfall rate (in mm/h).

The radar reflectivity values can be interpreted in terms of possible precipitation type. As a general rule following values be used to interpret precipitation type. It may be remembered that the pattern may also tell something about the precipitation type.

In the following Tables (A) & (B) indicated rain rate and radar reflectivity values in dBZ Vs weather interpretation respectively.



Rain Rate vs. Reflectivity

Reflectivity (dBZ)	Rain Rate (inches/hour)
15	0.01
20	0.02
25	0.04
30	0.09
35	0.21
40	0.48
45	1.10
50	2.50
55	5.68
60	12.93

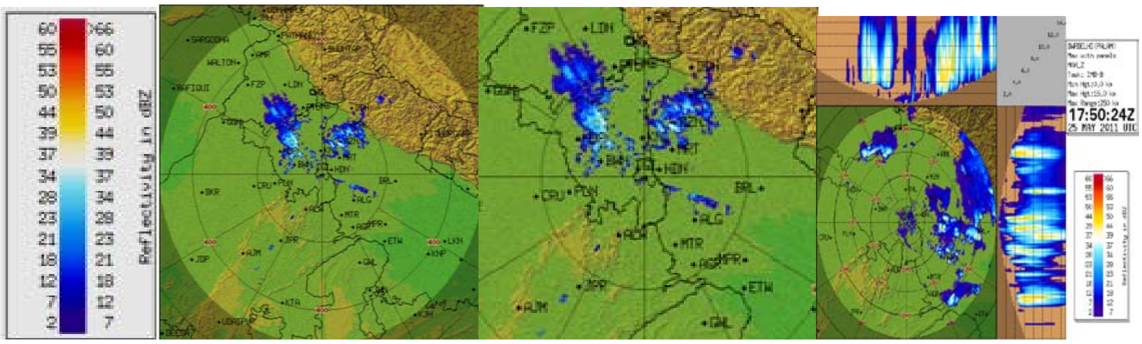
© Oklahoma Climatological Survey

The chart to the right relates reflectivity values to the rate of rain falling in inches per hour. With the current technology of radar, cumulative rainfall totals are not 100% accurate; radar does best at delineating rainfall locations, but it struggles with the actual amounts. If you need accurate cumulative rainfall totals, compare the radar with Mesonet sites surrounding your area.

dBZ Values	Interpretation
< 15	Clouds
15 to 20	Weak steady rain
30 to 40	Shower or heavier rain
>50	Strong thunderstorm

(A) (B)

The legend on the radar image is an important part of interpretation, above left is the color-codes scale for indication of the reflectivity values. By comparing with a given color in the legend (color-scale), the corresponding reflectivity values can be read for reflectivity radar image. The example may be seen in the following figure below:



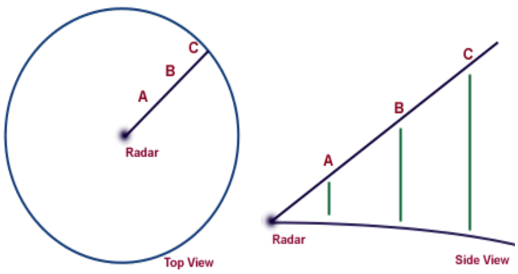
(a) (b) (c) (d)

Figure. (a) The IMD DWR Reflectivity colour coded Scale (b) Reflectivity PPI-Z image (c) The close range reflectivity PPI-Z image and (d) Reflectivity MAX-Z Image

b. Radial velocity (i.e., the rate of movement toward or away from the radar site);

i. Speed shear wind patterns

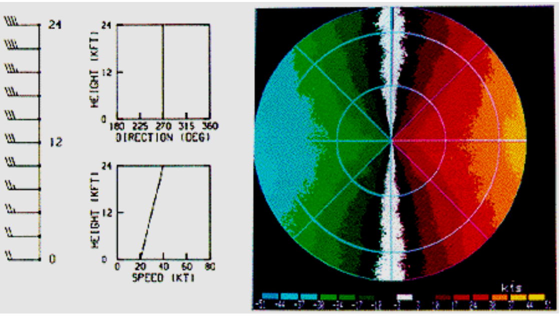
To understand Doppler radial velocity patterns, one first has to consider the geometry of a radar scan. Normally the radar beam is pointed at an elevation angle greater than zero so that the beam, as it moves away from the radar, moves higher and higher above the surface of the earth as shown in following figure-4.6. Therefore due to this radar beam geometry, radar returns originating from targets near the radar represent the low-level wind field, while returns from distant targets represent the wind field at higher levels.



On a radar PPI display, the distance away from the radar at the center of the display represents both a change in horizontal distance and a change in vertical distance. To determine the wind field at a particular elevation above the radar, one must examine the radial velocities on a ring at a fixed distance from the radar. The exact elevation represented by a particular ring depends upon the elevation angle of the radar beam.

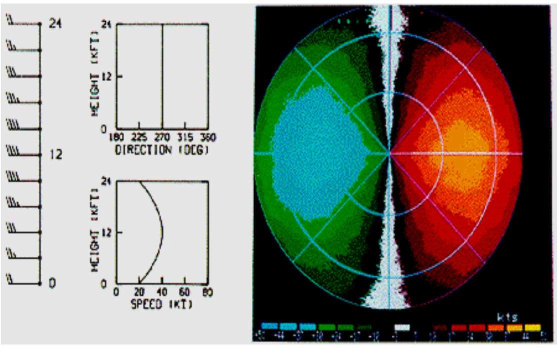
Figure. Radar beam Geometry

In examples (from figure 4.7 to 4.10) idealized Doppler radial velocity patterns were constructed with a computer assuming simple vertical wind field patterns. These simplified radial velocity patterns can help in to understand more complicated patterns that are associated with storm motions. Doppler velocity patterns (right) correspond to vertical wind profiles (left), where the wind barbs indicate wind speed and direction from the ground up to 24,000 feet. Negative Doppler velocities (blue-green) are towards the radar and positive (yellow-red) are away from radar. The radar location is at the center of the display.



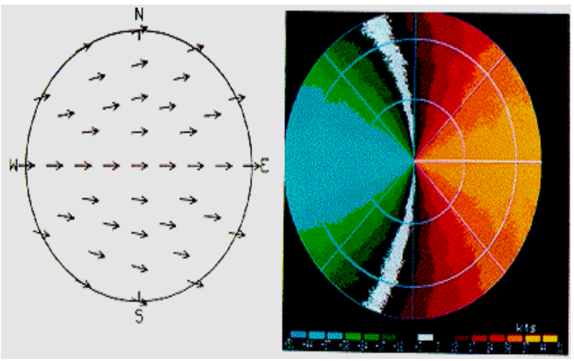
For this first example, wind is constant with height, but wind speed increases from 20 knots at the ground to 40 knots at 24,000 feet. Note on the velocity field the maximum inbound velocity is to the west and maximum outbound is to the east while to the north and south the radar measures zero radial velocity. This is because the winds are perpendicular to the radar beam when viewed to the northor south.

Figure. Curtsey Image : Brown & Wood



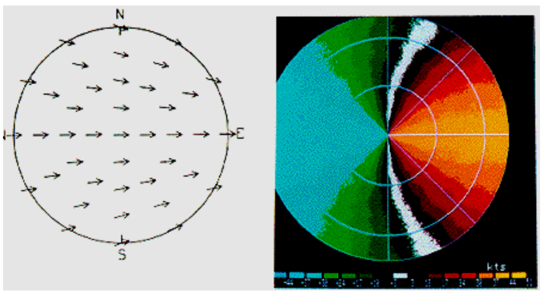
In the second example, the winds increase from 20 to 40 knots between zero and 12,000 feet and then decrease again to 20 knots at 24,000 feet. The wind direction again is constant. The radar beam intersects the 12,000 foot level along a ring half-way across the radar display. This is where we see the maximum inbound and outbound velocities.

Figure. Curtsey Image: Brown & Wood



In the third example, we see a wind field which changes direction from north to south but has a constant speed at all heights. The zero radial velocity line now bends so that it is everywhere perpendicular to the wind field. The maximum radial velocities are observed where the radar beam points directly toward or way from the wind direction.

Figure. Curtsey Image: Brown & Wood



In this fourth example, there is the same effect but in this case, hence the flow is confluent instead of diffluent.

Figure. Curtsy Image : Brown & Wood

ii. PPI-V Product

The PPI-V product s product is indicated some significant information about the local wind field pattern up to the range of 50 to 70 km only, in absence of clouds. It may be clear here that the Doppler Radars are reporting the radial wind, not actual winds. The radial wind is the component of wind seen by the antenna when facing it. If the angle between the actual wind and the antenna position is $\boldsymbol{\theta}$ and wind speed is **V** then radial wind **Vr** is computed as:

Vr = V cos θ

When wind and the antenna are in the same direction θ will be zero and the radial will be equal to actual wind (**Vr = V).** When wind and the antenna are in the opposite direction (facing each other) the θwill be180 degrees and **Vr = --V.**

When wind and the antenna are perpendicular to each other then θwill beis 90 degrees and **Vr = 0.** This property is used to interpret the wind flow patterns using the PPI-V images. As far as direction is concerned one has to imagine a line connecting the white areas which indicates that the radial wind is zero, in other words the antenna is not feelingany wind either into the antenna or away from it. Now imagine lines from blue/green colour areas to yellow/red colour areas perpendicular to while line (already imagined) at every point/ at regular intervals on it.

If we imagine lines from blue colour areas to yellow colour areas and perpendicular to while line (already imagined) at every point at regular intervals on it, these lines define the streamlines of wind field. If these lines are indicating that there is a convergence or divergence that can be easily inferred using the Synoptic chart or top-chart. In other words one can also see the sector angle of blue/ yellow coloured areas at the centre of the radar image (actually the radar station). If the sector angle of yellow colour is larger than blue colour we can infer that wind is entering the station from smaller areas and leaving into larger areas – a clear case of divergence. If the sector angle of yellow colour is smaller than blue colour we can infer that wind is entering the station from larger areas and leaving into smaller areas. A clear case of convergence can be in images given on next page (figure below).

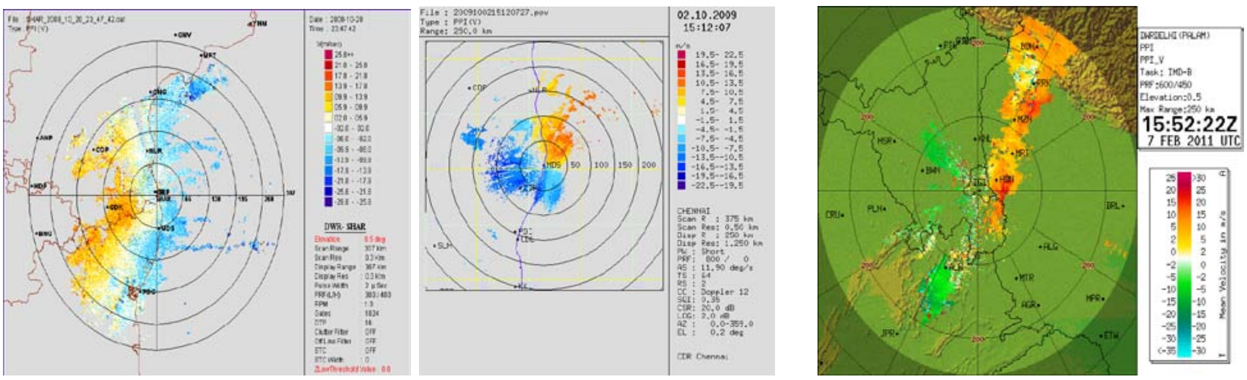


Figure. PPI-V DWR product images indicating Convergence in wind field

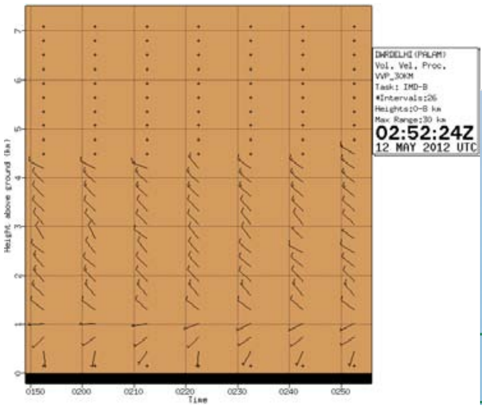
These type of information can be inferred particularly when a low is developing in the sea areas where there is inadequate synoptic data.

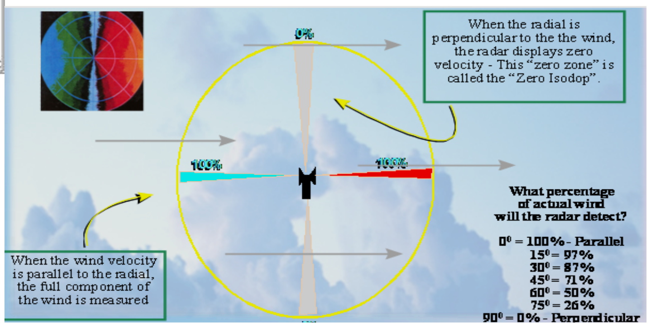
When cloud is present and wind echoes are recorded, with a north-south trough we can see the wind approaching the station on the left side of it and wind leaving the station on the right side.

For coastal stations, when sea breeze is approaching it brings in a large quantity of moisture over a long front. The refractive index variations cause the radar record special line like structures overseas and over the land in such situations with reflectivity up to 20 dBZ. If we follow these on half hourly to hourly basis, we can see that they move towards the station, and even the velocity of their movement can be computed. This helps to estimate the sea-breeze setting time, which is very useful particularly for cities on the coast during very hot summer days. Wind field in PPI-V supports this direction of movement.

iii. The VVP-2 Product

The VVP-2 product (Velocity images) of radar provides a picture of the basic wind field in the area surrounding 30 km and up to the height from the surface to the height of 7.5 km or user selectable, with respect to the radar station. Velocity images are useful for determining areas of strong wind from downbursts or detecting the speed of cold fronts. The VVP-2 product of DWR-Palam is shown in figure 4.12.





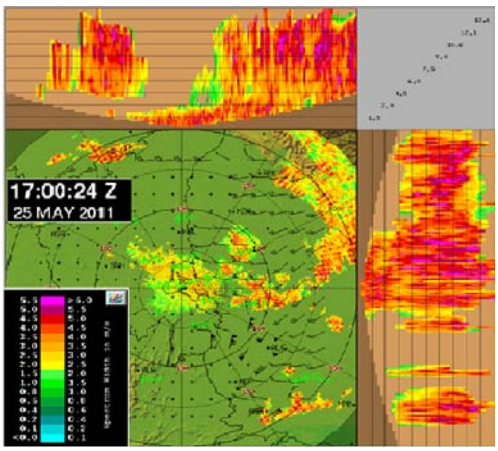
VVP-2 product of DWR. The concept of DWR radial wind & "Zero Isodop"

iv. Limitations in velocity detection with Doppler radars

The radar can "see" only motion of the target either directly towards or away from the radar, called radial velocity. The strength of the wind will always be less than what is actually occurring unless the wind is moving directly towards or away from the radar antenna or beam. This is explained in figure-4.13.

c. **Spectrum width** (i.e. the range of the Doppler shifts)

Aspectrum width estimate is the square root of the second moment about the mean velocity. The Dopplerweather radars are having the capabilities to detect and display turbulence in the form of Spectrum width products particularly convective activity. The areas of turbulence in the clear air situation can be pre cursors for convective developments. In stratiform cloud, areas of higher spectral width indicate the presence of embedded Thunder clouds. This spectrum width is based on the Doppler Effect and is sensitive to precipitation movement. The spectrum width function needs a minimum amount of precipitation to be effective. To help make safe flight path decisions, and especially when the weather ahead is represented as dense, the spectrum width products is useful to detect turbulence.



An area of light rainfall, depicted in green in normal mode, is shown in red or pink when there is high turbulence activity within the system.

The spectrum width products are only much effective within a range of 40 NM (Doppler measurement capability) and can only be used in wet weather.

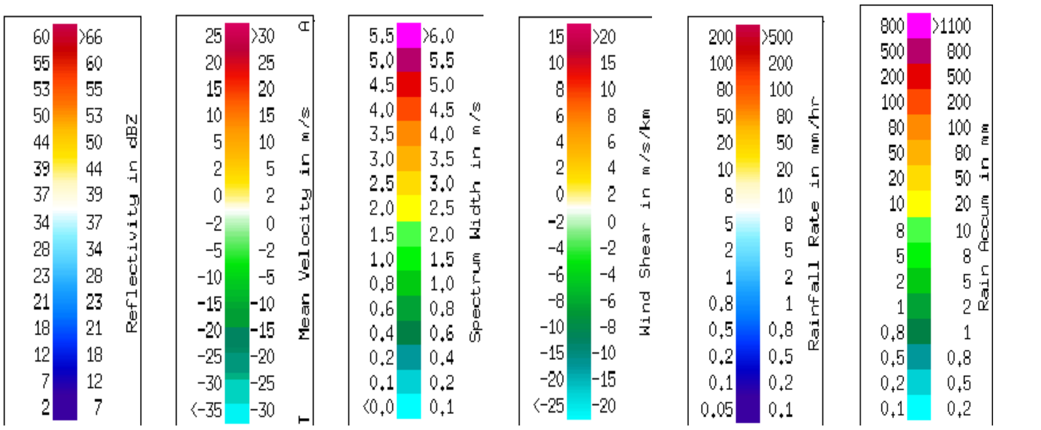
Note **:** Clear air turbulence and dry turbulence cannot be detected by the weather radar.

Figure. DWR Spectrum Width Product

3.5. IMD Doppler Weather Radar Products Colour Scales

The following colour scales are being used in IMD for various DWR products, shown in figure below:

(a) Reflectivity colour scale in the unit of dBZ
(b) Mean Velocity Colour scale in the unit of m/s
(c) Spectrum width colour scale in the unit of m/s
(d) Wind Shear products colour scale in m/s/km
(e) Rainfall intensity/ Rainfall Rate colour scale in the unit of mm/hr
(f) Precipitation Rainfall Accumulation colour scale in the unit of mm.



Reflectivity Radial Velocity Spectrum Width Wind Shea Rainfall intensity Rainfall Acc.
(PPI-Z/MAX-Z) (PPI-V/MAX-V) (PPI-W/MAX-W) (Shear) (SRI) (RAIN1/RAIN24)
(a) (b) (c) (d) (e) (f)

Figure (a to f). IMD Doppler Weather Radar "Colour enhancement Scales" for various products as mentioned below:

Digital data sets allow specific colours to be displayed for specific bands of dBZ value. This allows relatively easy visualization of the image details. This process is called *colour enhancement* and is used with many digital images including the satellite imagery. Figure (a) to (f) are the colour enhancement scale used by the IMD Doppler Weather Radar Network for some important reflectivity and velocity products. For reflectivity hotter colours (dark orange and red or combination of these) are used for stronger returns while cooler colours (blues and greens combinations) are used with weaker returns. All IMD Doppler Weather Radar display are using uniform colour scale for uniformity of all radar products for easy for interpretation. The following table-4.4 shows the approximate rainfall intensity w.r.t. colours and levels as a general view.

Level	Colour		Approx. Rainfall Intensity (mm/hr)
0	clear	Not visible	Under 0.2
1		Off-white	0.5
2		Sky-blue	1.5
3		Light Blue	2.5
4		Blue	4
5		Light Cyan	6
6		Cyan	10
7		Dark Cyan	15
8		Yellow	20
9		Yellow-orange	35
10		Orange	50
11		Orange-red	80
12		Red	120
13		Dark Red	200
14		Maroon	300
15		Dark Brown	over 360

Approximate Rainfall Rates

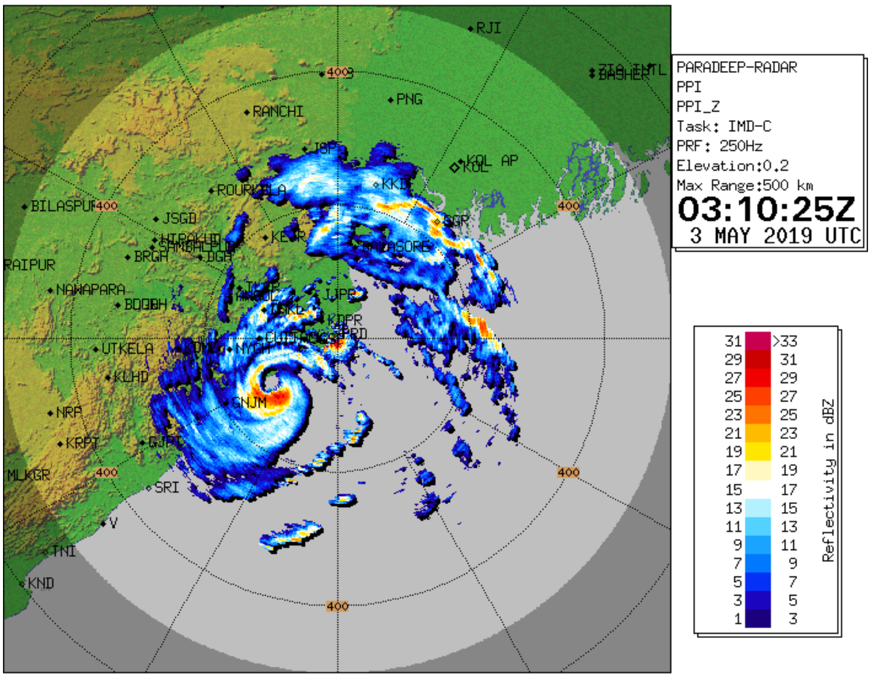
NOTE : These values can be used as a general guide lines & may vary.

3.6. Meteorological Products Displayed on IMD Website

3.6.1. PPI-Z product

The Base Reflectivity Products are the plot of the energy backscattered to the radar during a single Elevation Scan also known as PPI-Display or PPI Products.. It shows the distribution of the selected data parameter on a constant elevation angle. This is a display of echo intensity (reflectivity) measured in **dBZ.** The IMD DWR base reflectivity Products (images) are available at three different radar "tilt" angles, 0.5°, 1.0°, and 2.0°. The maximum range the PPI is user selectable, however as much as range is exceeded the product will show less reflectivity (intensity of the target)". The short range" base reflectivity product of approx. 250km from the radar location is showing more accurate results, but this view will not display echoes signatures more than the distance of 250km, even though precipitation may be occurring at greater distances. PPI products can be generated from 50 km to 500 km range but accuracy of data will be decreased with increasing range.

A constant elevation surface is extracted and converted to an output image. The displayed range is the slant range.



PPI-Display

Usage

- As an aid in the analysis of meteorological events.
- Primary use is for surveillance as well as a detailed interpretation on a storm-by-storm basis.
- The sensitivity of the radar allows the detection of ice crystals, some as cirri form and mid-level clouds. The range of detection is dependent on the ice crystal and snowflake composition of the cloud. Stratocumulus clouds will often contain precipitation aloft as raindrops or ice crystals and snowflakes, or both, large enough to be detected by the DWR.
- Stratus (and fog) usually will not be detected due to small droplet structure.
- Precipitations events can be monitored as they are evolve, develop or dissipate by observations of reflectivity patterns.
- Moisture or turbulent layers, or both, can be observed from backscatter from refractivity fluctuations.
- The evolution of the planetary boundary layer can be monitored from the backscatter from the refractivity structure or particulates (e.g., insects).
- Horizontal rolls and the evolution of cloud streets at the top of the planetary boundary layer can be monitored. The depth of the planetary boundary layer can be monitored during a diurnal cycle.
- Features such as the bright band may be observed.

Applications

- Observe precipitation intensity, movement, and trends.
- Evaluate environmental conditions and meteorological characteristics such as inversions or moisture layers, especially in the Clear Air Mode.
- Identify ice cloud layers and even very light precipitations characteristics.
- Identify and locate the freezing/melting level.
- To observe and track for identification of non-precipitation phenomena such as birds, bats, insects, smoke, volcanic ash, chaff, etc.
- Weak returns from refractive index gradients and small particulates such as insects reveal many characteristics of the boundary layer.
- Determine the location and motion of wind shear lines and boundaries such as gust fronts, synoptic fronts, sea breezes, and wind-shifts of all kinds.
- Determine significant convective storm structural features such as Weak Echo Regions (WER), Bounded Weak Echo Region (BWER), hook echoes, and even evidence for Rear Flank Downdraft (RFD) existence. Line Echo Wave Patterns (LEWP) and squall lines can be identified.

Limitations

- Data level values cannot be changed.
- Weak returns are not detected in Precipitation Mode.
- Residual ground and point clutter, and AP can contaminate data.
- Discrete elevation sampling of any Volume scan limits echo sampling only to the scanned elevation angles. Areas between non-contiguous beams and above the highest beam elevation are not sampled at all.
- Chaff echoes are often difficult to distinguish from precipitation echoes.
- Beam broadening with increasing ranges limits detection of features that are small compared to the beam width. This is referred to as "aspect ratio" or the ratio of the beam width to the feature size. Beam blocking is possible on lower elevation angles by nearby high-rise buildings or orographic features such as mountains.

3.6.2. Planned Position Indicator (PPI-V)

Overview

The PPI-V is planned position indicator velocity data. Using the Doppler Theory, the radar uses a Doppler Shift to determine the velocity of a reflector. In this product, a single elevation angle is scanned, and the velocity of the reflectors is returned. Negative values indicate reflectors moving towards the radar, while positive values indicate reflectors moving away from the radar. It should be noted that the further the radar beam extends from the radar, the higher it's elevation, thus it should report higher velocity values as winds are generally stronger at higher altitudes.

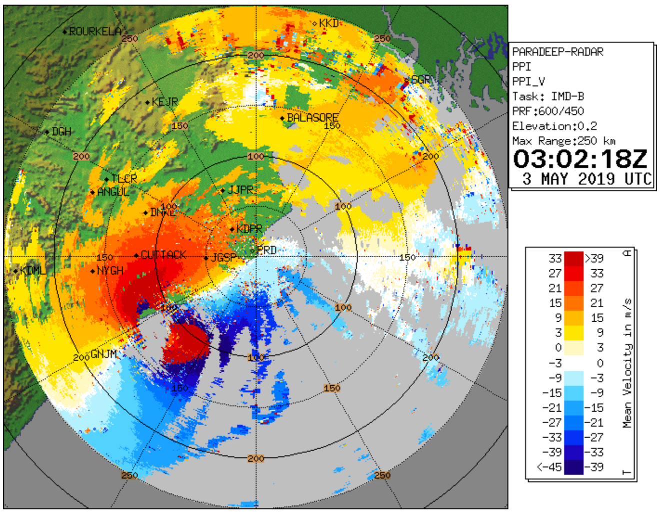


Fig. 4 (b). PPI product of velocity from Doppler Weather Radar Paradeep

Winds tangential to radar beam are shown as non-moving (white color). Negative value (Blue … White) of velocity shows that the winds are approaching the radar site. Positive value (White … Red) of velocity shows that the winds are moving away from the radar site.

Usage of Base Velocity

The PPI-V Product is basically used to determine the Wind Speed and Wind Direction of the movement of the system. It is an aid for the characterization of velocities in meteorological events. The high spatial resolution and largest number of data levels of this product enables detail detection of meteorological events like TVS/Mesocyclones, Microbursts, Storm kinematic structure, Gust fronts, Boundaries, Algorithm validation/quality control and Non-meteorological returns. Therefore this product is basically an aid to determine the wind flow structure and shear recognition of the atmosphere on various scales, local wind field characteristics and detection of location of tornadic circulations mesocyclones, and other atmospheric vortices.

Limitations

- Range folding may obscure data.
- Improper de-aliasing may result in erroneous velocity values.
- Product data file size is very large.
- Velocity aliasing can mask real velocities or shears.
- Velocities may exceed product data levels or even the signal processing specified velocity data levels.

3.6.3. MAX-Z (Maximum Reflectivity) Product

Overview

MAX Z is a maximum display of reflectivity data. After the radar has made a series of scans at different elevations, known as a volume scan, the maximum reflectivity values are returned to create this product. Thus, it shows us, the maximum reflectivity value for each pixel coordinate. To determine height, cross sections are included in the image. The cross section at the top of the image is taken is on a west to east axis, and the cross section on the right is on a north to south axis. The product is based on 10 angles volume scan TASK and is calculated by first constructing a series of CAPPI's to span the selectable layer, and then determining the maxima of reflectivity for the horizontal and two vertical projections East–West and North–South. Note, that the radar cannot see all the way to the surface of the earth, hence the curved boundaries at the bottom of the side panels are shown.

The Maximum Product takes a polar volume raw data set, converts it to a Cartesian volume, generates three partial images and combines them to the displayed image. The height and the distance between two Cartesian layers are user definable. The partial images are:

- A top view of the highest measured values in Z-direction. This image shows the highest measured value for each vertical column, seen from the top of the Cartesian volume.
- A north-south view of the highest measured values in Y - direction. This image is appended above the top view and shows the highest measured value for each horizontal line seen from north to south.
- An east-west view of the highest measured values in X - direction. This image is appended to the right of the top view and shows the highest measured value for each horizontal column seen from east to west.

Use

The MAX product provides an easy-to-interpret presentation of the echo height and intensity in a single display. It is especially useful for depicting areas of severe weather. This single product provides distribution of parameters measured by DWR in three dimensional spaces.This product is very useful to the forecasters.

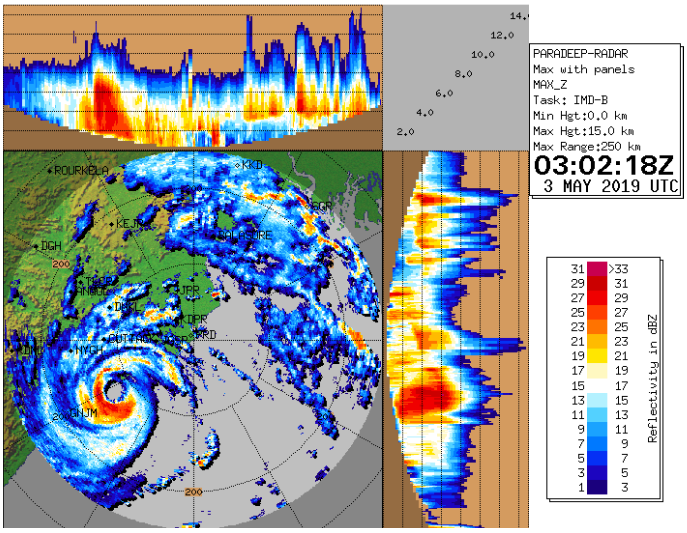


Fig. MAX-Z product from Doppler Weather Radar. Provides location as well as height of clouds

3.6.4. Volume Velocity Processing (VVP-2) wind profile:

Overview

VVP is the volume velocity processing product. This product comes from a volume scan of velocity data. VVP is a wind barb display of the horizontal wind velocity and direction in a vertical column above the radar site. In this product, north is oriented directly to the top of the image. The VVP or VVP-2 product displays wind velocity profile over the radar station. Wind velocities (speed direction are calculated at different vertical layers and are displayed in the form wind barbs. A Doppler radar can only measure the component of wind either towards or away from the radar. This is called the “radial wind.” However, by looking at the wind over all azimuths around a full circle, the average wind speed and direction can be determined.

The VVP (2) displays the horizontal wind velocity and the wind direction in a vertical column above the radar site. These quantities are derived from a volume raw data set with velocity data. A linear wind field model is used to derive the additional information from the measured radial velocity data. The algorithm calculates velocity and wind direction for a set of equidistant layers. A column of wind barbs shows velocity and direction for a time step, subsequent columns show the wind profile for subsequent VVP (2) product generations.

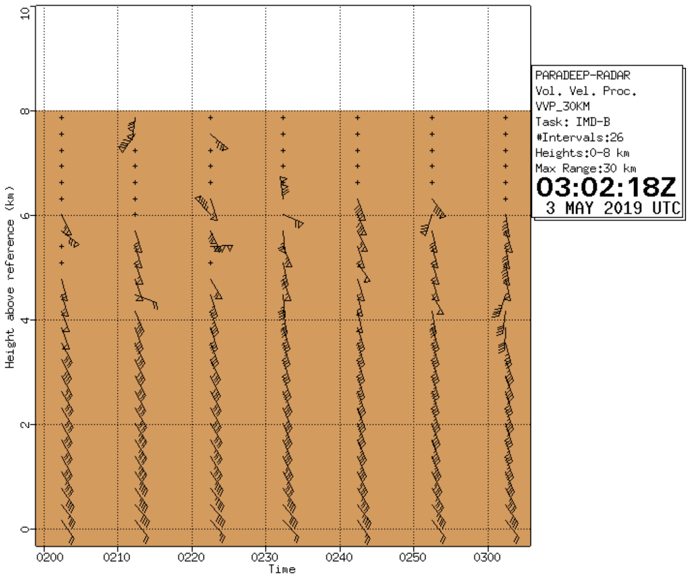


Fig. 7. VVP2 product. It provides vertical wind profile over DWR station

Use

- The VVP product can compute the vertical velocity, deformation and axis of dilatation of the wind field and the mean reflectivity profile above the radar.
- Time versus height profile plots for periods of one to six hours can be generated allowing the user to keep track of significant changes due to advection or other significant meteorological mechanisms.
- The VVP product provides a timely determination of the boundary layer wind profile.

Limitations

- Needs sufficient data points.
- May be unreliable in disturbed environments.
- Large flocks of migrating birds may produce anomalous wind data.

3.6.5. Surface Rainfall Intensity (SRI)

Overview

Surface rainfall intensity product displays rainfall rate in mm/s. It can be used as input into the RAIN1 product, to get the best possible estimates of accumulated precipitation even at longer ranges from the radar. The SRI generates an image of the rainfall intensity in a user selectable surface layer with constant height above ground. The product provides instantaneous values of rainfall intensity. The estimated values of reflectivity are converted to SRI by using $Z=AR^b$ relationship (Marshall et al. (1947) where R is the rainfall intensity and A and b are constants. The values of A & b vary from season to season and place to place.

Vertical reflectivity profile is the most important source of error in radar rainfall measurements in cool and moderate climate. Upper parts of precipitating clouds give typically weaker echo than the cloud base, except near melting layer where the echo is much stronger. Thus a correction is needed to estimate surface rainfall intensity.

SRI allows the user to apply local knowledge and provides several ways to input information of the actual reflectivity profile, as well as methods to make educated first guesses. It distinguishes convective cases from large scale precipitation, and applies the correction only to the later; while for convective precipitation the value of the lowest clutter free bin is presented. The reflectivity profile and melting level estimation will not be perfect, but they will improve the rainfall estimates as compared to performing no correction.

The typical corrections obtained will be of the order –10 dBZ to +5 dBZ (in mm/h scale up to factor of 4) depending on the melting level altitude, distance from radar and the lowest elevation angle.

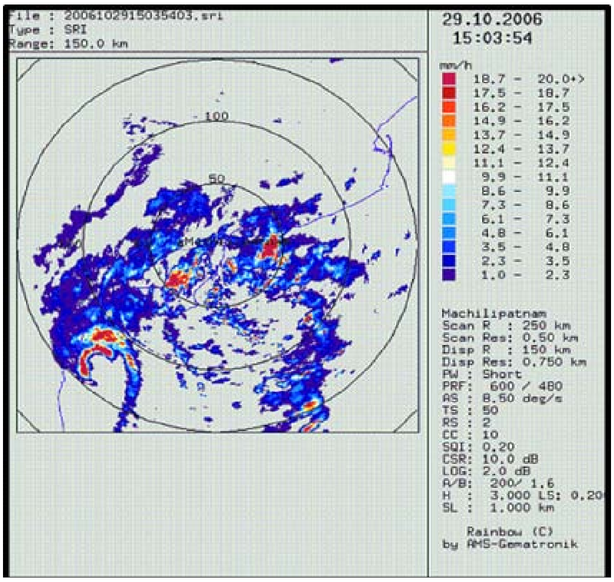


Fig. 8. SRI Product generated by DWR Chennai. Highest rainfall intensity observed in eyewall region

Use

- SRI is mainly used as an input product to generate rain1 (hourly rain accumulation) product.
- It gives the rough idea of rainfall at surface level from the cloud at a particular location in coming next hour.By defining the “catchment areas” with the range of SRI product, flood effected catchments can be identified.

3.6.6. Precipitation Accumulation (PAC)

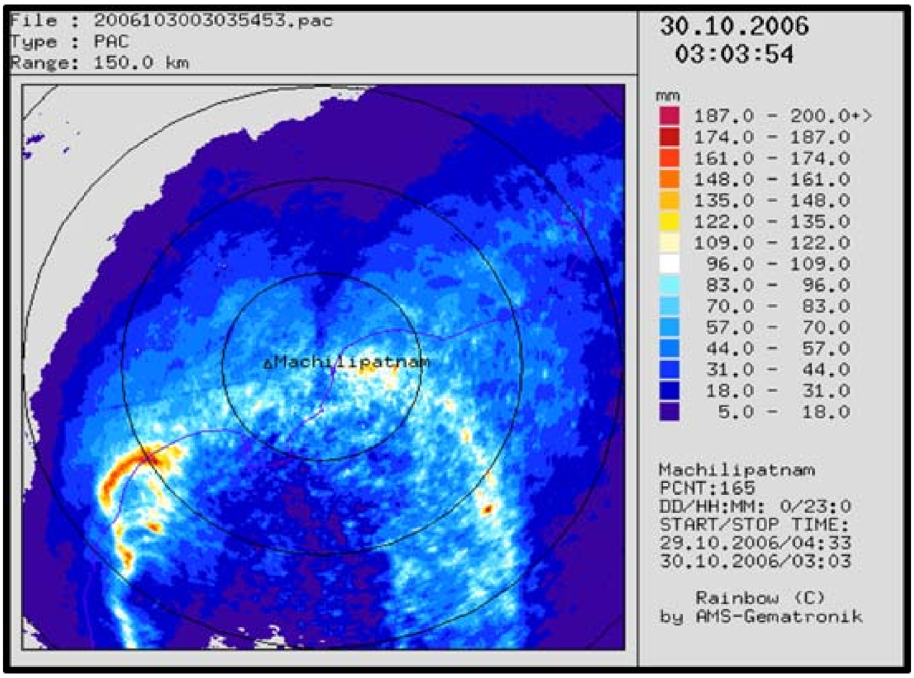


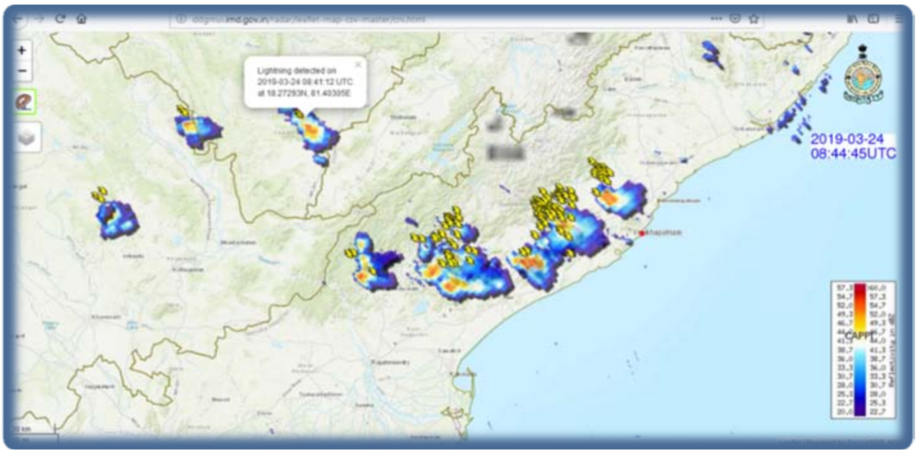
Fig. 9. Precipitation Accumulation Product

The PAC product is a second level product. It takes SRI products of the same type as input and accumulates the rainfall rates in a user-definable time period (look back time). The display shows the colour coded rainfall amount in [mm] for the defined time period. The display is similar to SRI product.

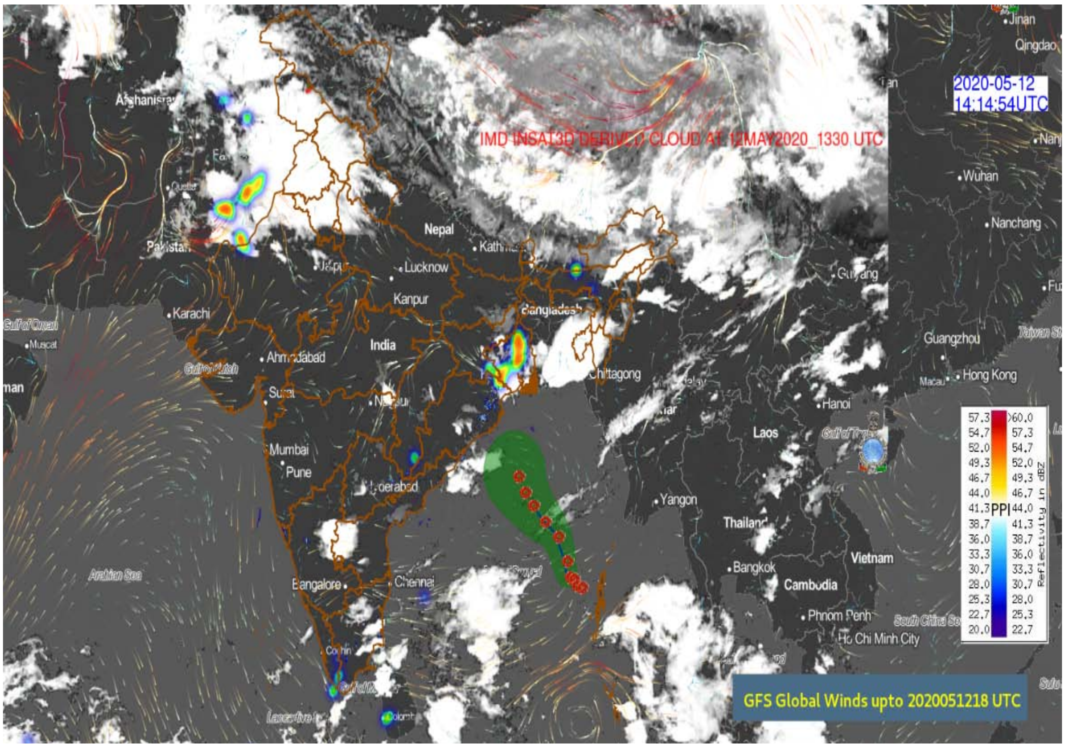
3.7. GIS Products

3.7.1. Integrated Display of Weather and Thunderstorm Warnings

An interactive GIS webpage is available for visualisation of real time lightning flashes overlaid along with several other weather observations such as radar images, radar wind, satellite images etc. as shown below.

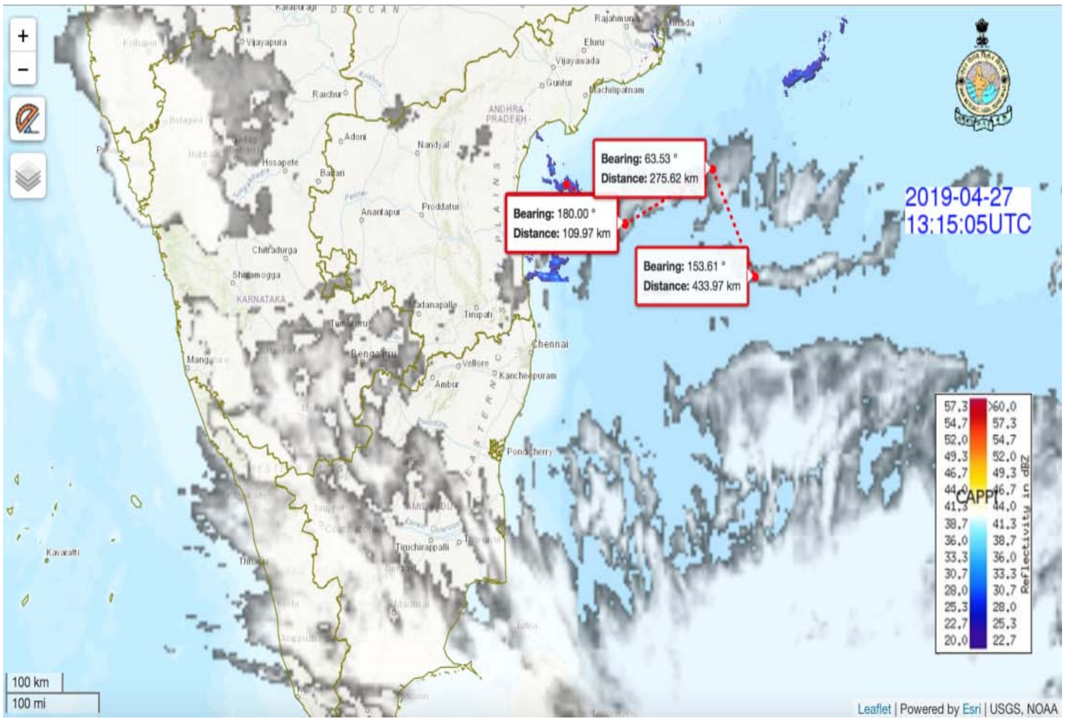


Current extreme weather observations with radar & lightning on Web-GIS platform



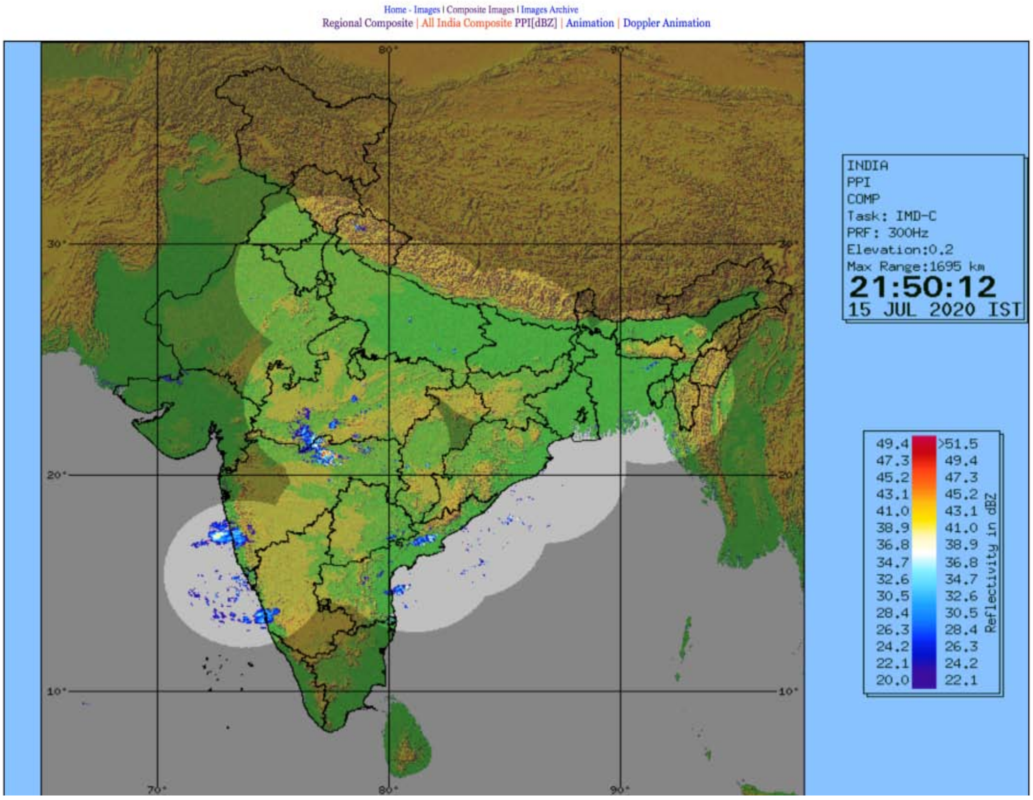
The product displays user selectable layers such as Lightning layer, Radar Reflectivity layer, Satellite data, Radar radial winds and State & District boundaries on a web-GIS platform. More than one layer can be selected simultaneously as per user requirements.

Cyclone forecast and observed track have also been plotted on web-GIS platform along with cone of uncertainty as shown for Cyclone Amphan



Among various applications, user can find out azimuth bearing as well as distance between two points on map (as shown in Fig. below) between any two user selectable points on the map.

3.7.2. All India Mosaic Product



Radar Mosaic images are available for whole India on website enabling user for visualizing all DWRs images on India map along with radar coverage range as can be seen.

In the central server, IRIS software converts the Gematronik format and BEL format data in to IRIS format and uses this data in conjunction with the IRIS format data from Metstar radars for generating National MOSAIC image. The Doppler Weather Radar data of different radars can be processed simultaneously and a product called MOSAIC image can be generated. The Radar Mosaic images are available for national as well as regional level at the url https://internal.md.gov.in.

3.8. Guidance for Bulletins from DWR Stations

a) Cyclone Radar Bulletin(CRB)

i. Strength of weather radar, as a cyclone tracking and prediction tool, lies in its capability to provide accurate, frequent and high-resolution observations even when the cyclones are situated as much as 300 km away (roughly about 20 hours lead time in case of cyclones heading coast from deep sea). As the cyclones approach closer the fineness and accuracy of data improve further. At range as close as 100 km, accuracy, resolution, and richness of radar data is superior to that from any other source.

ii. During Cyclones, DWRs issue Cyclone bulletins to IMD HQ every hourly or at less frequency depending on the intensity of cyclone and detection by radar. The bulletin includes the eye location, intensity of cyclone, maximum reflectivity in wall cloud region, location of eye region, maximum radial wind velocity etc.

iii. Cyclone Radar bulletin (CRB) is an important document which is issued during tracking of cyclones from Radar stations. The format of the CRB is given at Annexure-I sample cyclone bulletin issued by DWR Goa for Cyclone Nisarga is attached in Annexure-II.

iv. The issuing of CRB should commence when the eye of cyclone is visible in any of the main products/eye is within Radar range or as decided by the officer in charge whichever is earlier.

v. The CRB should contain the details of cyclone obtained from analysis of various different products.

vi. CRB should be issued every hourly through email only to the stakeholders within IMD, However, the frequency of bulletin can be increased to every 30 minutes as desired by officer in charge/HQ.

vii. In case the velocity values are folded in the Radar products, the bulletin should contain the unfolded velocities.

viii. The beam height calculation, speed of cyclone movement, direction of cyclone movement and unfolded velocity can be calculated with the help of Cyclone bulletin tool as mentioned in Annexure lII. And also the bearing and distances can be ascertained using the GIS webpage.

ix. Once Issue of CRB commences, it can be stopped once the eye of the cyclone goes beyond the range of Radar/ eye is not visible in the products or as desired by officer in charge.

x. CRB is an internal bulletin intended for use by trained meteorologist, it should not be shared or circulated to any stakeholders outside IMD.

b) FDP Thunderstorm Bulletins

A FDP (Forecast demonstration project) thunderstorm bulletin is being issued by DWR stations to IMD HQ during Mar-Jun period with radar based description of current weather conditions over region covered by particular radar.

The objective of FDP bulletin is to understand the genesis, development and propagation of severe thunderstorms. A sample FDP thunderstorm bulletin is attached as ANNEXURE-IV.

c) Radar weather Reports

Severe weather radar bulletins are issued by DWR stations in case of extreme weather event observed by a particular DWR.

The bulletin is being issued to IMD HQ and State government authorities. The sample radar weather report is given as ANNEXURE-III.

ANNEXURE-I

CYLONE REPORT-10

1. Name of the Station	: DWR Chennai
2. Date and Time (UTC) of observation (yyyymmddhhmm)	: 20190430_16UTC
3. Name of the cyclone (if declared a cyclone)	: FANI
4. Information about Eye of the cyclone	
a. Is the eye visible (yes/No)	: Yes
b. Shape of the Eye	: Circular
c. Diameter of the Eye (km)	: 20.68km
d. Estimation of centre of the cyclone based on Eye/spiral band observation	: 13.504N/84.374E/83.4deg/444.45km
e. Echo top (height 20 dBZ level) of rain bearing clouds around the cyclone within 100 Km radius (km)	:18km
f. (i) Maximum radar reflectivity (dBZ) & rainfall rate (mm/h) in the eye wall/spiral band region, its height (km) and position (azimuth and distance from the radar)	: 39.0dBZ/8.26km/86.7deg/437.7km
(ii) Maximum reflectivity at any other area (spiral/ streamers etc)	:57.0dBZ/4.23km/84.2deg/332.4km.
g. (i) Maximum radial velocity in eye wall/spiral band region (mps), its height (km) and its position (azimuth and distance from the Radar)	: 38.2 mps/7.95km/78.1deg/430.5 km
(ii) Maximum velocity in any other area (spiral / streamers / rain shields etc)	: 42.9 mps/8.24 km/68.0deg/437.2km
5. Tendency of the cyclone	: Decreasing
a. Intensity (Increasing/Decreasing)	
b. Duration for which the information on movement of the system pertains to	: 3hrs
c. Direction of movement	: WNW
d. Estimated speed of movement (km/h)	: 14.5
Any other significant feature(s)	: No Change.

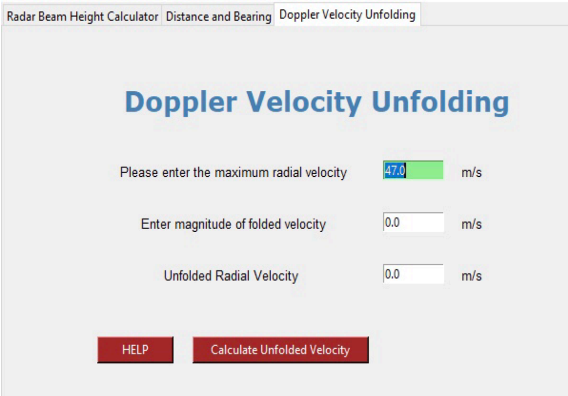
ANNEXURE-II

CYCLONE BULLETIN

Time: 02/06/2020 18:30 IST

1.	**Name of the Station**	DWR GOA
2.	**Date & Time of observation (UTC)**	02/06/2020 1300 Z
3.	**Name of Cyclone**	NISARGA
4.	**Information about the Eye of the Cyclone**	
	a)Is the Eye Visible	Yes (Visible from 1100Z)
	b)Shape of the Eye	Elongated Circle
	c)Diameter of the Eye (km)	21.1 km (Approx)
	d)Estimation of centre of the cyclone based on Eye/Spiral band observation	16.3024 N & 71.2409 E (Approx) Dist:- 290.1 km from the radar.
	e)Echo top (20 dBZ level) of rain bearing clouds around the cyclone within 100 km radius	
	f) Maximum radar reflectivity (dBZ) in eye wall and Spiral band region, its height (km) and position (azimuth and distance from the radar)	27.00 dBZ, 8.9 km (Height), Azimuth:291.4 Distance: 319.5 km
	g) Maximum reflectivity at any other area (spiral/ streamers etc)	47.0 dBZ / 0.3 km(Height) / 280.0 deg/ 19.5 km Max ref/height/bearing/range
	h) Maximum radial velocity in eye wall and Spiral band region observed (mps), its height (km) and its position (azimuth and distance from the Radar)	11.38 mps / 4.4 km / 282.5 deg./ 243.3 km From Radar
	i) Maximum velocity in any other area (spiral / streamers / rain shields etc)	26.56 mps / 0.9 km / 339.8 deg./ 93.4 km From Radar
5.	**Tendency of the Cyclone**	
	a. Intensity(Increasing/Decreasing)	Slight Intensification
	b. Duration for which the information on movement pertains to	1 hour (For the period from 1200 UTC of 02/06/2020 to 1300 UTC of 02/06/2020)
	c. Direction of Movement	Northwards
	d. Estimated speed of Movement	19.47 kmph
6.	**Any other Significant Feature**	Rainfall very likely at a few places over North Goa and South Goa district of Goa, Uttar Kannada district of Karnataka, and Ratnagiri & Sindhudurg districts of Maharashtra.
7.	**Confidence**	Good

ANNEXURE-III



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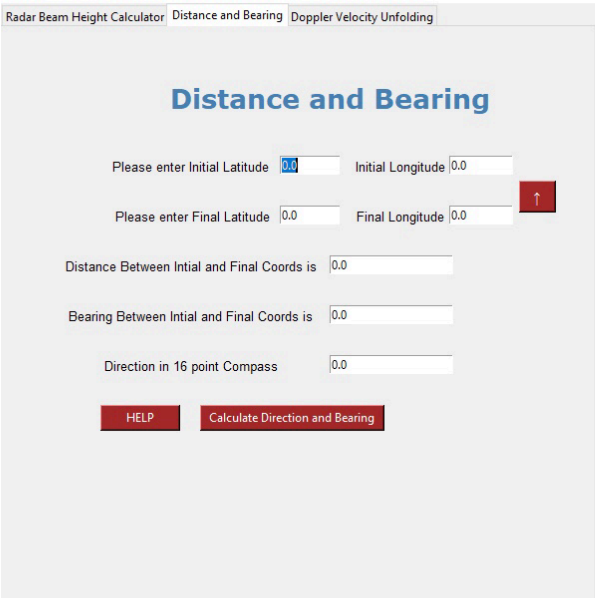
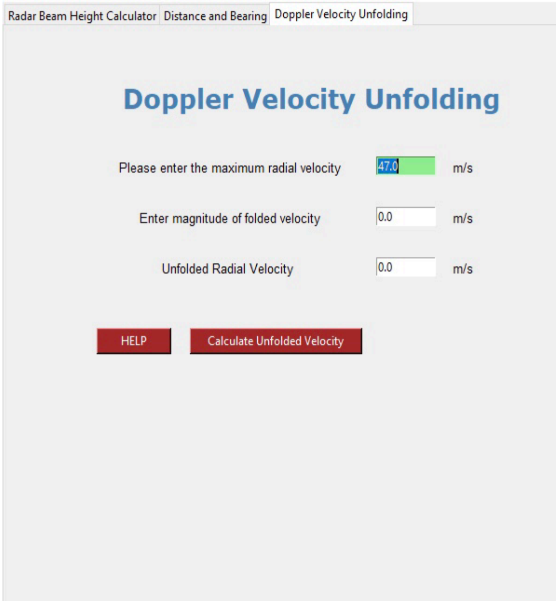




ANNEXURE-IV

Description of Convective Activity at DWR AGARTALA during past 24 hour sending at 0300 UTC 0f 30-06-2020

Radar Station name	Date	Time interval of observation (UTC)	Organization of the cells (Isolated single cells/multiple cells/ convective regions/ squall lines) with height of 20 dBZ echo top and maximum reflectivity	Formation w.r.t radar station and Direction of movement	Remarks	Associated severe weather if any	Districts affected
AGARTALA	30/06/2020	290302 - 292359	1) Multiple cells found over Bangladesh and Tripura at 0522 UTC with height of 12km at 1022 UTC and maximum reflectivity 50dBZ at 0952UTC.	Cells found about 20-250 km in all direction of DWR Agartala and moves in North East direction with speed 25kmph.	Cell dissipated over Bangladesh, Tripura, Mizoram and south Assam at 1502 UTC.	Rain	Tripura, Bangladesh, Mizoram and South Assam
			2) Multiple cells found over Bangladesh at 1922 UTC with height of 12km at 2322 UTC and maximum reflectivity 43dBZ at 2222UTC.	Cells found about 100-200 km in N, NE direction of DWR Agartala and moves in North East direction with speed 20kmph.	Cell still persists over Bangladesh and Meghalaya at 2352 UTC.	Rain	Bangladesh and Meghalaya
	300000 - 300302	Multiple cells found over Bangladesh and Meghalaya at 0002 UTC with height of 11km at 0012 UTC and maximum reflectivity 45dBZ at 0012UTC.	Cells found about 100-200 km in N, NE direction of DWR Agartala and moves in North East direction with speed 20kmph.	Cell still persists over Bangladesh and Meghalaya at 2352 UTC.	Rain	Bangladesh and Meghalaya	

ANNEXURE-V

Severe Weather Warning based on DWR observation

Name of issuing radar station		Doppler Weather Radar Mumbai
Geo-coordinates of issuing station (Lat, Long, Alt.)		Lat – 18˚54'04", Long-72˚48'32" Height AMSL – 3.22 meters.
Date & time of issue in UTC (yyyyMMddhhmm)		202007161000UTC
Nature of severe weather event expected		TS activity with Heavy Rain
i	Location (sectors w.r.t the radar and mean range in km)	1. 1 1. All around the station upto 150 Km range. NW sector 2. TS activity with heavy rain.
ii	Approx. Areal Extent (sq. km.)	
iii	Vertical extent (20dBz Echo Top)	6-15 km in NW sector & 6-9 Km in all around
iv	Direction of motion (bearing w. r. t radar towards which storm move)	NE
v	Speed of motion (m/s)	3-9 m/s in SW sector & 9-15 m/s in NW Sector
vi	Tendency (past half to one hour) Growing / Mature / Dissipating	Mature & Dissipating
vii	Max. Ref. Factor (dBz)	26-40 dBz
viii	Max. Radial velocity (m/s)	15 m/s
ix	Max. wind shear (radial and/or azimuthal) m/s/km	-------
x	Special features observed if any (TVS / Hail / Bow echo / BWER / hook echo / Micro burst / meso cyclone…)	-------
Districts / Talukas likely to be impacted with lead time if possible		Coast of Alibag, Raigad, Haranai, Dapoli, Mahabaleshwar. NW Sector of Arabian Sea, Mumbai City & Suburb, Thane, Kalyan, Palghar.
Description of the likely severe weather		---------
Warning validity		----------
Remarks		----------

Chapter 4

Public Weather Services

4.1. Introduction

Severe weather phenomena have life threatening potential depending upon their intensity, duration and persistence over any area hence timely dissemination of forecast and warnings related to the same to the stake holders is essential to support mitigation work. Providing weather related services and products to the public thus assume great significance. The importance of these products also lie in the inherent dynamics leading to continuously changing weather patterns and the impact it have on a spectrum of human activities. In the context of the socio economic impact a disastrous weather event can have in an agro-based country like India, an efficient Public Weather Services is the most essential requirement of the time. However, the weather information must be communicated and disseminated in a time bound manner to the users and general public, using whatever means of communication available. It therefore, becomes the most important function of every weather services.

The public weather services (PWS) of the department get critically monitored and evaluated by the media, general public and Government especially during severe weather events. A true assessment of the performance of national weather service can be derived from its importance felt by the user community and for this purpose the public weather services of the department has to be very strong and user friendly. When people find that utilization of weather information, forecasts and warnings, along with climatological and hydrological data can significantly improve their safety and protect their property, public as well as media support for the weather services become much stronger. There is much to be gained from a scientifically competent public servant working in tandem with the major stake holders. For the successful organization of mega events, a robust, efficient and accurate Public Weather Service System has to be put into practice .Weather forecast products like that of rainfall, maximum and minimum temperatures, winds, relative humidity etc and other indirect products like heat index, comfort index, chill factor etc would be of paramount importance to the public, officials as well as NGOs.

National Weather Services all over the world are now becoming increasingly aware of the need for an efficient PWS component for effective communication of all weather related information for benefit to the various sectors of national economy. Recognizing this importance and the need for world - wide coordination of such activities, the World Meteorological Organisation (WMO) had established a PWS programme in the year 1994 to assist all National Meteorological and Hydrological services in this endeavor. Lot of technical material and guidelines has since been generated by the WMO in coordination with the representatives of all major National Weather Services of the world. An efficient PWS not only increases the outreach of National Meteorological and Hydrological Services, but it also helps in improving the public image of the National Weather Service. India Meteorological Department, therefore has established a dedicated PWS component as an integral part of its service with the sole objective of improving outreach to the public and user agencies.

4.2. Requirement for Revision of SOP

After the recent modernization of observing and forecasting systems of IMD, the weather observations viz., Synop, Pilot, AWS, Buoys, satellite and radar images are available on a single platform namely Synergie on real time basis. These data can be viewed, analysed digitally and interpreted within a short period of time. This facility is available at present in the national and regional level and in two to three other forecasting centres. Weather products (in both Text and Graphical format) can be generated and disseminated from Meteofactory, a modernized PWS platformis available alongwith at selected forecasting centres. Thus generation of customized weather forecasts/warnings and reports in text form as well as in graphical form have become possible, to meet the user requirements. In those centres where this facility is not there, the district forecast and warning (with colour code) are prepared in tabular form.

Earlier, dissemination of the weather related messages to the concerned users were done using telefax and e mail. However with the advancements in mass communication, use of social media and bulk SMS also have been put into use in dissemination of weather forecast and warnings. In addition to this, user friendly website also has been created in the recent past in which the forecasts & warnings of different spatial and temporal scales are uploaded and updated.

Thus there have been considerable changes in the preparation, presentation and dissemination of forecast and warning related information by the forecasting centres due to which visible improvements had been there in the public weather services of the department and there is scope for further improvement also.

The facilities available with the present PWS with the scope for further improvements are brought forward in this document.

4.3. Major Objectives of PWS

- Providing customized weather services to the users.
- Improving early warning services and quality of related products and ensure their timely dissemination to the end users on routine basis for the safety and protection of life, livelihoods and property.
- Deliver warnings and information on climate extremes to government authorities for planning and decision-making on public safety and cost-efficiency in all social and economic activities affected by weather.
- Engage in capacity building, awareness programme and preparedness activities to help citizens make the best use of forecasts and warning information available to them.
- Improve outreach of National Weather Service and related products.
- Identification of new end users / stake holders and their additional requirements;
- Promoting the applications of the science of meteorology, climatology, hydrology and related technology to improve products and services through exhibitions, field visits by school/ colleges, disaster managers and display of posters.
- Engaging in demonstration projects, exchange visits and collaborative activities concerned to PWS with government agencies.
- Establishing an interactive channel of constant feedback from the end users who would help us to re-validate our products for further improvement in its quality.

4.4. Major Stake holders

- Government (both Central and State) organizations
- Electronic and print media;
- Industries/other autonomous bodies
- NGOs
- Farmers,Fishermen and General Public
- Research Institutes and Universities.

4.5. Main Products/Activities under PWS System

- Seamless flow of current weather, forecast and warning information from forecasting centres and special cells to end users to be ensured. These forecast and warnings will be issued in subdivisional scale by National Weather Forecasting Centre (NWFC) whereas Regional Weather Forecasting Centres (RWFCs) and State Weather Forecasting Centres (SWFCs) issue district level forecasts. The forecast will be issued for five days with an outlook for subsequent two days. In addition to this, nowcasts are issued form the RWFCs/SWFCs related to severe weather developments for their area of responsibility at least in every three hours. All these forecast and warning products are disseminated by different modes of communication to the user community and are uploaded in the website. The typical work flow in PWS is given in Figure 4.1.

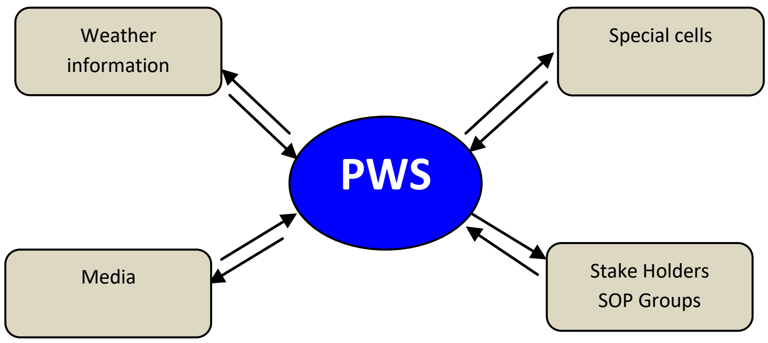


Figure 4.1. A typical work flow of PWS

- While issuing the warning, suitable colour code will be used to bring out the impact of the severe weather expected and to signal the disaster managers about the course of action to be taken with respect to the impending disaster weather event. While NWFC issues the warnings in both text and graphical form in the subdivision scale for the country as a whole, the RWFCs/SWFCs issue colour coded warning in tabular form in the district level. The colour code used in weather warning is given in Figure 4.2. Examples of the All India weather warnings issued from NWFC in text and pictorial form (with colour code) are given in Appendix 1(A) and 1(B) respectively and the warning issued in tabular form with colour code from SWFC, Bubaneshwaris given Appendix 2 as examples.

WARNING (TAKE ACTION)
ALERT (BE PREPARED)
WATCH (BE UPDATED)
NO WARNING (NO ACTION)

Figure 4.2. Colour code used in Weather warning

- For capital cities, impact based forecast along with guidelines to the public should be provided as and when a severe weather event is expected to strike the city and the same needs to be updated frequently till the cessation of the event. Once the event is over a dewarning message needs to be issued. These are done by RWFCs and SWFCs for their concerned areas of responsibility.

- A Weekly weather report bringing out the major weather features experienced during the previous week, analysis of the weather systems which were responsible for the weather realised, spatial and intensity of the rainfall and temperature scenario of the week, weekly and seasonal realised rainfall statistics and forecast and warning for the next week are prepared and disseminated to all the users and uploaded in the website at the beginning of every meteorological week. While NWFC prepares this report for the country as a whole, RWFC/SWFC prepares the same for their concerned areas of responsibility.

- Also a bulletin on current weather status and outlook for next two weeks bringing out the significant weather features of the past week, main synoptic situations and large scale features prevailing, weekly as well as seasonal realised rainfall statistics and the weather outlook for the next two weeks are prepared and disseminated to all the users and uploaded in the website, in the beginning of every meteorological week. In this case also, NWFC prepares the same for the country as a whole whereas RWFCs/SWFCs prepare the same for their areas of responsibility.

- Availability of historical data bank of climatological information of different meteorological parameters in an easily usable and regular format for the end users needs to be there. Mean Maximum, Mean Minimum, lowest and highest values of maximum and minimum temperatures realized along with the date, highest and lowest values of twenty four hours accumulated rainfall with date, total number of rainy days etc. has to be available in this data bank with respect to month, season and year and also with respect to location, district, subdivision, state and for the country as a whole in the spatial scale.

- The current weather situations as well as the forecast of the weather expected needs to be briefed to the press and media on routine basis so as to have its proper reporting. While briefing the media and press, the latest weather bulletin issued needs to be taken as the reference. Briefing can be done in English and Hindi in the national level however, the regional language can also be of used at the regional/state level for better understanding of the masses.

- When significant weather events are expected to occur within the forecast period, issuance of press release related to the same with update as and when required is preferred. At the time of severe weather occurrence, press conference to brief the press and media about the event and issue of special weather bulletins related to the event will be beneficial to the user community and stake holders.

- At RWFC/SWFC levels, audio/video capsules on the current and impending weather scenario of about two-minute duration, preferably in regional languages, should be made available to the media, disaster managers and other stake holders on daily basis through website and social media platform.

- Once in a week, similar audio/video capsule depicting the realised weather of the past week and the medium and extended range forecast for the next two weeks can be made available through the same platforms. While NWFC do the same for the country as a whole, RWFCs/SWFCs can do the same for their concerned area of responsibility.

- Monthly Weather bulletin should be prepared at the end of every month giving brief description and analysis of the realised weather of that month and giving weather outlook for the successive month based on the latest extended range forecast products available. This bulletin should be prepared and circulated to all concerned and also be uploaded in the website within a week from the commencement of the next month. Here also, NWFC prepare the same for the country as a whole whereas RWFC/SWFC prepares the same for their area of responsibility.

- Any achievement, (viz. increased forecast accuracy, correct prediction of a disastrous weather event, any new initiative etc.) should be proactively highlighted through audio/video capsules, press release, media briefing, briefing the disaster managers and other stake holders.

- In case of occurrence of any disastrous weather event over any area, post event reports for that need to be prepared within one week by the concerned RWFC/SWFC and it is to be submitted to NWFC. The report will include impact assessment forthe hazardous phenomena (like cyclone, tornado/thunder squall very severe TS, cloudburst, urban water logging disrupting normal life due to heavy precipitation) and will mainly consist of the meteorological analysis of the event, historical aspect of occurrence of such extreme events, impact analysis, details of the loss of life & property and a review of services extended in respect of the event. NWFC will review the report and after incorporating modifications if any, the same will be submitted to the Ministry, NDMA etc for their reference.

4.6. Functioning of PWS

The functioning of the PWS is given in Figure 4.3 below.

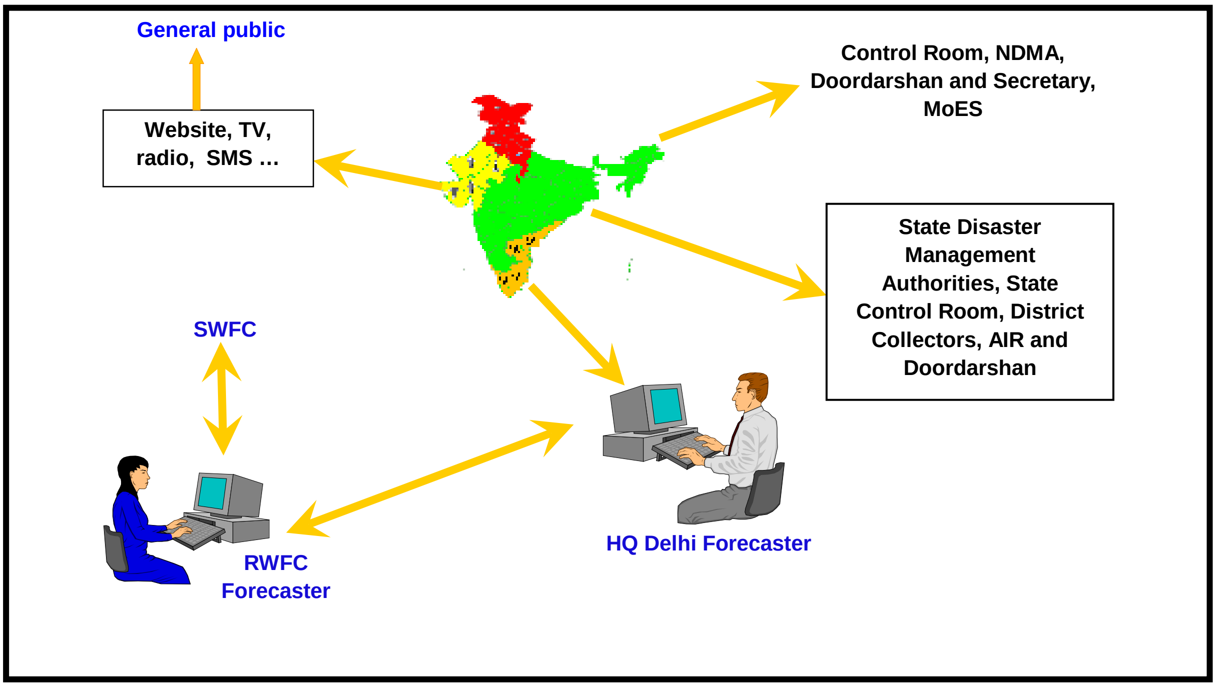


Figure 4.3. Functioning of PWS

The functioning of PWS involves forecasters in the national, regional and state levels, national and state disaster management authorities, media as well as general public.

4.6.1. Homogeneity in the contents of the Forecast and Warnings

- Based upon the discussion and decision made through video conference with RWFCs/SWFCs, the National Weather Forecasting Centre (NWFC) at IMD Headquarters, New Delhi issues the main All India Weather Bulletin for 36 meteorological sub-divisions of the country around noon on daily basis and the same is updated another three times within a day. This bulletin more or less serve as a guidance bulletin for the subordinate offices and based upon that bulletin, the Regional Meteorological Centres (RWFCs) and State Meteorological Centres (SWFCs) issue forecast and warning in the district level. NWFC also issues nowcast guidance bulletin for the severe weather elements like thunderstorm etc. based on which the RWFCs and the SWFCs issue nowcast in every three hours or as and when required related to severe weather phenomena and update the same in the dedicated web page for nowcast in the IMD website.

- The final weather products are prepared after discussion at length through video conference amongst NWFC, RWFCs and SWFCs forecasters. The video/audio conferencing is meant for removing the discrepancies in weather forecasting services especially during the occurrence of extreme weather events and have homogeneity in the contents.

- The product is designed and finalized incorporating suitable colour codeetc. specific to the needs of end users in consultation with the chief forecaster and then integrated into the system for dissemination to the designated end users.

- PWS cell prepares and disseminates customized products (forecasts/warnings) to media, disaster managers and other Government officials. These are also posted on IMD website and are made available through social media platform. It is to be checked and ensured that, dissemination of the forecast for a particular area from all the three levels are uniform in its contents to avoid creating confusion for general public.

4.6.2. Mode of Dissemination of Forecast & Warnings under PWS

Dissemination of weather forecast and warning were being carried through e mails and telefax earlier. In addition to that, the latest facilities of communication are also being used nowadays to disseminate the messages to the users.The various modes of communication used in PWS are given below.

i) Email : Weather forecast and warning in both text and pictorial form are being sent to Central & State government organisations and authorities, national & state disaster management agencies, media, other stake holders etc by National Weather Forecasting Center (NWFC) as well as by Regional Meteorological Centers (RMCs) and Meteorological Centers (MCs). For this purpose the e mail addresses of all concerned are maintained in the forecasting centres which are updated from time to time.

ii) SMS : Weather forecast and warnings especially agromet advisories and nowcasts related to thunderstorms etc. are disseminated to the registered users through SMS facility on mobile phones by different forecasting offices. Dissemination of these messages through SMS is carried out through Kisan Portal launched by Ministry of Agriculture and Farmers' Welfare and through private companies under Public Private Partnership (PPP) mode. This facility is widely used by farmers to get guidance on farming operations. Also Doppler Weather Radar centres across the country use SMS facility to issue SMS, related to the development of severe convection in their vicinity.

iii) Use of social media in dissemination : Dissemination of Weather forecast and warning through social media are being encouraged nowadays due to their wide publicity. Accordingly, all the offices of IMD have opened their facebook and twitter accounts to use the same for PWS. NWFC uploads All India forecasts and colour coded warning in India Meteorological Department facebook page (https://www.facebook.com/India.Meteorological. Department) and India Meteorological Department twitter page (https://twitter.com/Indiametdept) on regular basis. A weather capsule consisting of sub-division wise colour coded weather forecast & warnings, animation of satellite imageries, major synoptic features, temperatures of major cities and maximum & minimum temperatures of mega cities, highest maximum and lowest minimum temperatures recorded on the day across the country is being uploaded on India Meteorological Department youtube page (https://www.youtube.com/ channel/UC_qxTReoq07UVARm87CuyQw?view_as=subscriber) on regular basis in addition to its uploading on earlier mentioned platforms.These forecast products are disseminated through WhatsApp groups created with media personnel, disaster managers etc. also. In similar manner, RMCs and MCs have created their own facebook and twitter account and have formed WhatsApp groups so as to disseminate the district level forecast, colour coded warnings and nowcasts pertaining to their area of responsibility.

iv) Website : IMD offices in the national, regional and state level maintains websites with dedicated pages for weather forecasting services which contain both static as well as dynamic pages. The static pages contain general information about the weather forecasting services etc. for information and reference whereas the dynamic pages can be used to upload the latest forecast products for reference and use by all those interested. The website also contains dedicated pages for different services so as to upload weather information, forecast and reports related to that like monsoon, cyclone etc. Language used in these websites is generally English however some of the Regional Meteorological Centres/Meteorological Centres have websites in regional language also. In the national level, different products and bulletins including forecast and warning in the text and pictorial forms issued by NWFC are being uploaded on India meteorological Department's national website (https://mausam.imd.gov.in/) by the centre and the same is updated as and when required. Similarly, RWFCs and SWFCs upload and update the weather information for their respective area of responsibility in their website. The link 'Departmental Website' in the main page of the national website gives the links for the websites of other offices including regional and state level offices. Statistics show that these websites are widely visited and referred by general public, national & state disaster management authority, central & state government agencies, media and other stake holders.

v) Bulletin for All India Radio and Doordarshan : Bringing out the major features of realised weather, forecast and warnings, regular bulletins are issued to Doordarshan & All India Radio for broadcast purpose. The weather capsule mentioned in the previous section is also sent to Door Darshan on daily basis to be used for the display of weather information in DD news. The national bulletin is issued by NWFC whereas state level bulletins are issued by concerned RWFCs/SWFCs.

vi) Telefax : Weather forecast & warning especially those related to cyclone warnings are sent by fax also to State and Central Government authorities in addition to other modes of communication. VVIP forecasts issued by NWFC are also sent by telefax on dedicated fax numbers. Record of the telefax numbers are maintained in the forecasting centres which are verified and updated from time to time, especially before the commencement of cyclone season.

vii) Press &Media Briefing : Press and Media briefing about observed and impending weather are regularly done by senior officers of the forecasting centre. While NWFC officers give briefing on All India Weather, senior officers of RWFCs and SWFCs brief the weather scenario; both observed and expected, under their area of responsibility. While briefing press and media, the information provided should be with reference to the details of the latest weather bulletin issued.

viii) Mobile App : India Meteorological Department has prepared mobile App for the use by general public to get latest weather information on their mobile. The mobile App '**Meghdoot'** is meant for **Agromet Advisory Services** and it can be used by farmers for weather based farm management. It provides weather forecast, weather summary and crop advisory to farmers. The Mobile App '**DAMINI**' developed by Indian Institute of Tropical Meteorology, Pune gives details of realtime observation and forecast of lightning in close proximity .It also provides guidelines on lightning risk reduction while being outdoor. Recently, in May 2020, IMD has hosted seven of its services viz. current weather, rainfall information, nowcast, city forecast, tourism forecast, colour coded severe weather warning and cyclone warning in the Unified Mobile Application for New-Age Governace (**UMANG),** which is an all-in-one, single, unified, secure, multi channel, multi platform, multi lingual, multi service mobile App of Government of India. **In addition these, IMD's mobile App 'MAUSAM' has been launched on 27thJuly, 2020 and the same is available in both App store and Play store at present.**

4.7. Requirements for Efficient PWS

- Clear cut policy on the working domain, responsibility and dissemination of information to media and end users are needed for PWS. For this purpose, the PWS related work can be classified into three levels. The first level has to deal with the preparation of observation, climatology and forecast related products. The second level has to deal with explanation of the observed weather and forecast, reply to specific queries and give bytes/ interviews to electronic and print media in addition to handling the responsibilities and providing guidance to the first level. Level 3 has to deal with briefing related to weather forecasts, panel discussions, decision making, reply to high ranking officials, VIPs etc. in addition to handling and coordinating Level 1 and 2 activities.

- Proper database of the all the end-users and all major stake holders is to be maintained at all forecasting offices and the same needs to be updated from time to time.
- Flow of information to and from PWS needs to be well structured.
- User friendly language rather than highly technical wording to be used while communicating with the users.
- While preparing the forecast products, more thrust to be given on graphical contents rather than textual contents and colours must be used for the warnings to stand out clearly from the usual day to day forecast.
- A strict time schedule needs to be followed while issuing the general forecast / warning; preferably it should be synchronized with the broadcast time of weather bulltins.
- A multi channel communication network with inbuilt redundancy must be set up to avoid breaking of communication, especially during severe weather.
- In order to avoid repeated interviews to the media, it is proposed that a media hour should be followed at all the offices of IMD for daily routine briefings related to normal weather. However, during severe weather events, the media briefing can be done as per requirements.
- There needs to be continuous review of services extended and a robust feedback mechanism so as to improve the quality of services.
- A panel of resource persons/experts from operational forecasting and from supporting fields viz. Numerical Weather Prediction , Climate Change &Global Warming, Satellite Products , Doppler Weather Radar (DWR) Products needs to be made for taking part in important discussions, interaction with media and attending parliament sessions.
- Memorandum of Understanding is preferred with the end users especially with the media to avoid misuse / misinterpretation of information shared with them.
- Frequently Asked Questions (FAQs) on different fields of weather are to be prepared and posted on IMD website for reference by all interested so as to increase awareness.
- Pamphlets related to weather forecasting services needs to be prepared from time to time highlighting the latest development and achievements and distributed during field visits/exhibitions to increase awareness about the services.
- Setting up of dedicated network integrated with interactive Weather Display systems at public places and fixed space in newspaper/ scrolling space in TV channels / Dedicated Weather Channel will help in communicating the accurate weather information in real time basis.
- Workshop for media and disaster managers should be organized frequently. Basic training is to be organized for media personals about the meteorological conventions/terminologies so as to educate them.
- Provision of readymade audio-visual capsules to Doordarshan and other electronic media, AIR/FM Radios will help in avoiding wrong reporting.
- Work related to PWS is currently handled by the operational staff of IMD working in forecasting division, in addition to their routine work. Dedicated man power or monitoring cell needs to be there for PWS in the forecasting offices of IMD. Hence creation of PWS cell is advisable in all the forecasting centres for better coordination and management of PWS related work.

4.8. New Initiatives in PWS

New initiatives like implementation of impact based forecast, introducing Common Alert Protocol in dissemination of forecasts and warnings, initiatives to increase outreach etc. are being carried out due to which further improvement in the quality and effectiveness of PWS may become possible. In addition to these, formation of weather watch group and conduction of Forecast Demonstration Project with the involvement of agencies outside the department is also in vogue to improve the outreach. Sector specific services are also being encouraged nowadays to demonstrate the utility of weather services in different fields.

4.8.1. Implementation of Impact based forecast

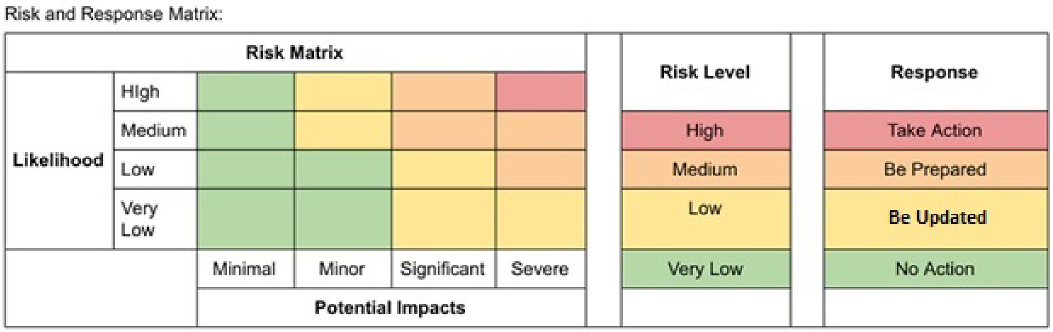


Figure 4.4. Risk Matrix for Impact based Forecast

Impact based forecast is given with the intention to project what the weather will do rather than what the weather will be. The weather forecast and warning products are being prepared with the incorporation of colour code already, so as to bring out the intensity and impact of the severe weather expected and to signal the disaster managers about the action to be initiated at their end for mitigation.The impact based forecast is issued with reference to the Risk and Response matrix given in Figure 4.4.

This matrix is used for selecting proper colour code in warning with respect to any impending severe weather event, taking into consideration of the probability of its occurrence and the potential impact expected from the event.

In the warnings related to cyclones, the impact based forecast had been introduced long before and thus severe weather expected during cyclones along with the impact it will have on public life and the guidelines for necessary action during the occurrence of severe weather are provided in the warning messages. The same pattern of warning messages had been extended to other severe weather elements like thunderstorm and associated severe weather phenomena like squall/lightning, heat wave etc. from 2019.For these weather elements, the guidelines prepared in collaboration with National Disaster Management Authority about the action to be taken had been referred and utilized while issuing impact based forecast.

From Monsoon season of 2020, impact based forecast for heavy rainfall had been introduced for major cities of the country. These forecasts are issued by RWFCs and SWFCs for the major cities under their area of responsibility. These forecasts are issued in four stages. First stage corresponds to heavy rainfall advisory (watch) issued 3 to 5 days in advance of the expected occurrence of the event and is updated in every twelve hours. In stage 2, heavy rainfall alert is issued with 1 to 3 days lead period and is updated in every six hours. Stage 3 corresponds to heavy rainfall warning issued with 12 to 24 hours lead period and is updated in every 1 to 3 hours. Stage 4 corresponds to the warning issued 12 hour prior to the occurrence of maximum rainfall. More details and SOP for this new initiative are separately available in another chapter this document.

4.8.2. Introduction of Common Alert Protocol in Dissemination of Forecast & Warnings

The Common Alerting Protocol (CAP) is a standard message format designed for communicationsover any and all media like television, radio, telephone, fax, highway signs, e-mail, Web sites; about any and all kinds of hazard viz., Weather, Fires, Earthquakes, Volcanoes, Landslides, Child Abductions, Disease Outbreaks, Air Quality Warnings, Transportation Problems, Power Outages; to any one viz., the public at large, designated groups like civic authority, responders, etc. or specific people simultaneously. As per WMO guidelines, the National Weather Services across the world have to introduce CAP in dissemination of weather messages at the earliest. The main purpose of CAP is to disseminate timely and meaningful warning information about the possible extreme events or disasters like Flood, drought, earthquake, volcanoes, landslides, tsunami, cyclone, gas leak, thunderstorm, fire etc. through the same platform through which information regarding other hazard situations like terror attack, child abductions, disease outbreaks, air quality warnings, beach closings, transportation problems, power outages etc. are disseminated using various dissemination mediums such as Indian Telecom Network, Indian Broadcasting network and other media.

National disaster management authority is introducing an **Integrated Disaster Management System (IDMS)** for dissemination of all type of warning using CAP and the same will be developed by **Centre for Development of**

Telematics(C-DOT). The outline of the system is given in Figure 4.5.The forecast and warnings received from IMD also will be disseminated through this system. The Standard Operating Procedure for the purpose is already finalized by Department of Telecommunication, Government of India in consultation with NDMA, all the stake holders and C-DOT.

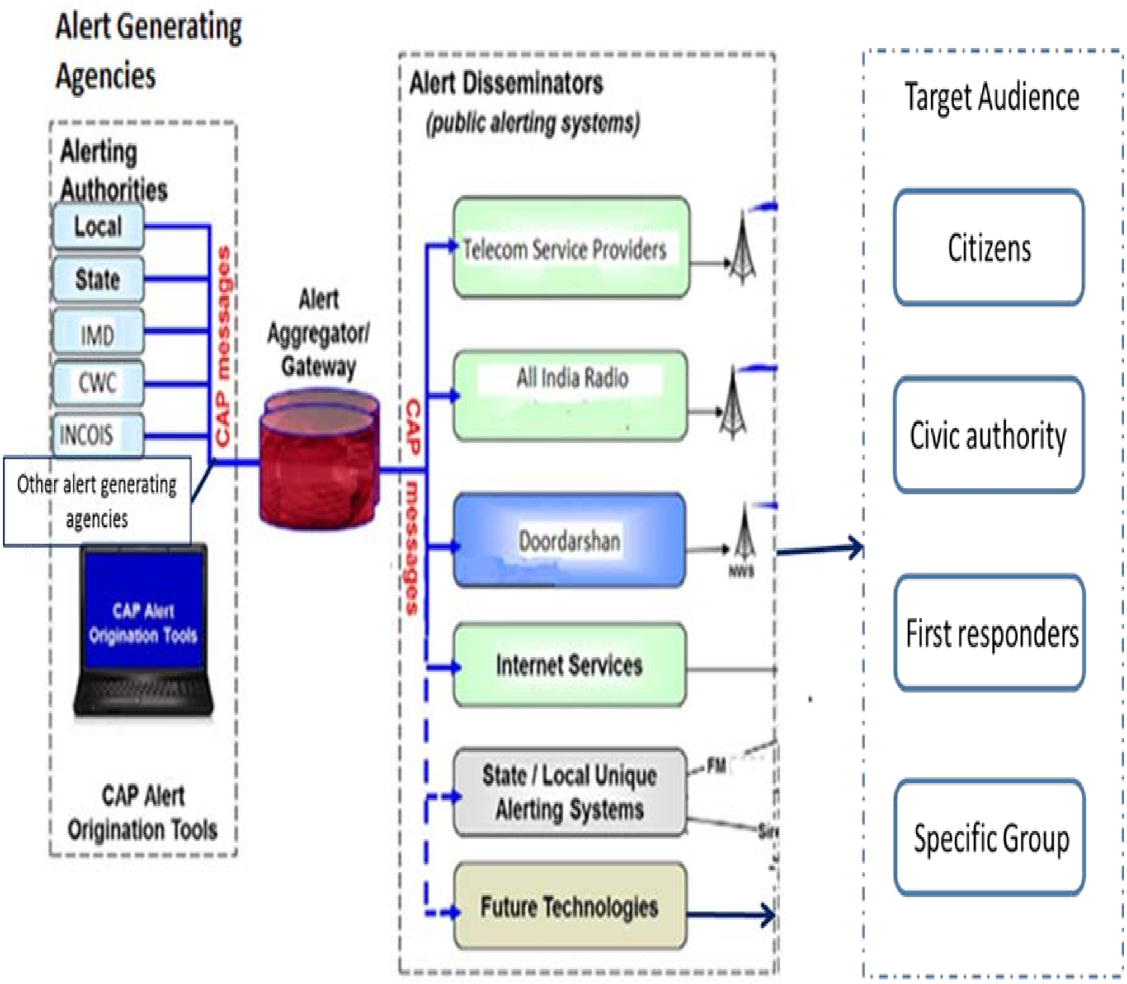


Figure 4.5. Outline of proposed IDMS of NDMA

Dissemination of weather warnings through this platform using SMS as the output had been tested by C-DOT on various severe weather occurrences in the recent past and satisfactory results were received. Hence a Pilot project had been started for the state of Tamil Nadu for dissemination of messages through the system which is in vogue at present. After successful completion of the same, the facility will be extended to all the states.

In addition to this, utilizing the procedures provided by WMO for implementation of CAP, IMD is independently trying to incorporate CAP format in dissemination of weather forecast and warning messages on trial basis which also has shown positive results.

4.8.3. Measures to improve the Outreach

To improve the outreach, joint exercises involving universities / IITs and other government agencies along with IMD professionals are being undertaken during projects like Forecast Demonstration Project (FDPs).

- At present IMD is having FDPs on different weather phenomena like cyclone, thunderstorm, heat wave, Fog etc. in which involvement of agencies working in the field of Atmospheric Sciences other than IMD are encouraged and their contributions and feed back is utilized in analyzing the phenomena, improving the forecast and warning services related to those events, preparation of guidelines for public use during such events, carrying out case studies of the events and their documentation for future reference etc.

- In addition to this, installation of Automatic Weather Stations in schools and involving the students in taking observations and reporting, extension of familiarization training to teachers etc. are being carried out in order to educate and familiarize them with the science and practices of weather forecasting.

- IMD is actively participating and providing lectures in the WEBINARS /Workshops/Symposium related with Meteorological services conducted by National Disaster Management Authority etc. by which the expertise and the facilities available with IMD and the achievements of the department in the field are getting highlighted. In the training workshops conducted by National Institute of Disaster Management, visit to NWFC and familiarisation of the work carried out by the centre is always included as a part of curriculum.

4.8.4. Provision of Sector Specific Services:

Since weather has its impact on almost all the sectors of public utilities, there is large demand for customized weather products for various sectors. The services of IMD for the sectors like aviation, agriculture, marine activities etc. are well established. IMD also supports the flood forecasting services of Central Water Commission by providing hydrological data and quantitative precipitation forecasts for river basins.

In addition to this IMD has extended its services in the recent past to Power, Health, Transport (both road and railway), urban services etc. and is in the process of improving the observational network to meet the requirements of these sectors in addition to providing customized weather forecast products through dedicated links. However, services to these sectors are extended after signing MOU with the agencies concerned.

Appendix I(A)

All India Weather Warning in text format issued from NWFC

Tuesday 21 July 2020
Time of Issue: 1345 hours IST

(MID-DAY)

21 July (Day 1): ♦ **Heavy to very heavy rainfall** at isolated places with **extremely heavy falls** at isolated places very likely over Assam & Meghalaya; **heavy to very heavy rainfall** at isolated places over Himachal Pradesh, Uttarakhand, Punjab, Bihar, Sub-Himalayan West Bengal & Sikkim, Arunachal Pradesh and Nagaland, Manipur, Mizoram & Tripura and **heavy rainfall** at isolated places over Jammu & Kashmir, Ladakh, Gilgit-Baltistan, Muzaffarabad, North Haryana, Chandigarh & Delhi, Uttar Pradesh, Rajasthan, Madhya Pradesh, Jharkhand, Gangetic West Bengal, Madhya Maharashtra, Marathwada, Coastal Andhra Pradesh & Yanam and Lakshadweep.

♦ **Thunderstorm accompanied with lightning** very likely at isolated places over Jammu & Kashmir, Ladakh, Gilgit-Baltistan, Muzaffarabad, Himachal Pradesh, Uttarakhand, Punjab, Haryana, Chandigarh & Delhi, Uttar Pradesh, Rajasthan, Madhya Pradesh, Vidarbha, Chhattisgarh, Bihar, Jharkhand, Gangetic West Bengal, Odisha, Arunachal Pradesh, Assam & Meghalaya, Nagaland, Manipur, Mizoram & Tripura, Coastal Andhra Pradesh & Yanam, Telangana and Interior Karnataka.

♦ **Strong Wind** (speed reaching 50-60 kmph) very likely over Southwest and adjoining westcentral Arabian Sea. **Squally weather** (wind speed reaching 40-50 kmph) over Eastcentral & adjoining southeast Arabian Sea. Fishermen are advised not to venture into Sea over these areas.

22 July (Day 2): ♦ **Heavy to very heavy rainfall** at isolated places over Assam & Meghalaya, Nagaland, Manipur, Mizoram & Tripura and Lakshadweep and **heavy rainfall** at isolated places over Uttarakhand, East Uttar Pradesh, East Madhya Pradesh, Chhattisgarh, Bihar, Jharkhand, Sub-Himalayan West Bengal & Sikkim, Odisha, Arunachal Pradesh, Madhya Maharashtra, Telangana, Rayalaseema, South Interior Karnataka and Kerala & Mahe.

♦ **Thunderstorm accompanied with lightning** very likely at isolated places over Bihar, Jharkhand, Gangetic West Bengal, Odisha, Coastal Andhra Pradesh & Yanam and Rayalaseema.

♦ **Strong Wind** (speed reaching 50-60 kmph) very likely over Southwest and adjoining westcentral Arabian Sea. **Squally weather** (wind speed reaching 40-50 kmph) over Lakshadweep area & adjoining southeast Arabian sea; along & off Kerala coast and Eastcentral Arabian Sea & off Karnataka coast. Fishermen are advised not to venture into Sea over these areas.

23 July (Day 3): ♦ **Heavy to very heavy rainfall** at isolated places with **extremely heavy falls** at isolated places very likely over Assam & Meghalaya; **heavy to very heavy rainfall** at isolated places over West Uttar Pradesh and Nagaland, Manipur, Mizoram & Tripura and **heavy rainfall** at isolated places over Uttarakhand, East Madhya Pradesh, Vidarbha, Chhattisgarh, Bihar, Jharkhand, West Bengal & Sikkim, Odisha, Arunachal Pradesh, Madhya Maharashtra, Marathwada, Konkan & Goa, Telangana, Rayalaseema, Karnataka, Tamilnadu, Puducherry & Karaikal, Lakshadweep and Kerala & Mahe.

♦ **Thunderstorm accompanied with lightning** very likely at isolated places over Bihar, Jharkhand, Gangetic West Bengal, Coastal Andhra Pradesh & Yanam,Tamilnadu, Puducherry & Karaikal and Rayalaseema.

♦ **Strong Wind** (speed reaching 50-60 kmph) very likely over Southwest and adjoining westcentral Arabian Sea. **Squally weather** (wind speed reaching 40-50 kmph) over Lakshadweep area & adjoining southeast Arabian sea; along & off Kerala coast and Eastcentral Arabian Sea & off Karnataka-Goa-South Maharashtra coasts. Fishermen are advised not to venture into Sea over these areas.

24 July (Day 4): ♦ **Heavy rainfall** at isolated places over Himachal Pradesh, Uttarakhand, East Uttar Pradesh, East Rajasthan, Madhya Pradesh, Bihar, Jharkhand, Sub-Himalayan West Bengal & Sikkim, Assam & Meghalaya, Madhya Maharashtra, Marathwada, Konkan & Goa, Telangana, Rayalaseema, Coastal Karnataka, Tamilnadu, Puducherry & Karaikal and Kerala & Mahe.

♦ **Thunderstorm accompanied with lightning** very likely at isolated places over Jammu & Kashmir, Ladakh, Gilgit-Baltistan, Muzaffarabad, Himachal Pradesh, Uttarakhand, Punjab, Haryana, Chandigarh & Delhi, Uttar Pradesh, Rajasthan, Jharkhand, Coastal Andhra Pradesh & Yanam, Rayalaseema and Tamilnadu, Puducherry & Karaikal.

♦ **Strong Wind** (speed reaching 50-60 kmph) very likely over Southwest and adjoining westcentral Arabian Sea. **Squally weather** (wind speed reaching 40-50 kmph) over Lakshadweep area & adjoining southeast Arabian sea; along & off Kerala coast and Eastcentral Arabian Sea & off Karnataka-Goa-Maharashtra coasts. Fishermen are advised not to venture into Sea over these areas.

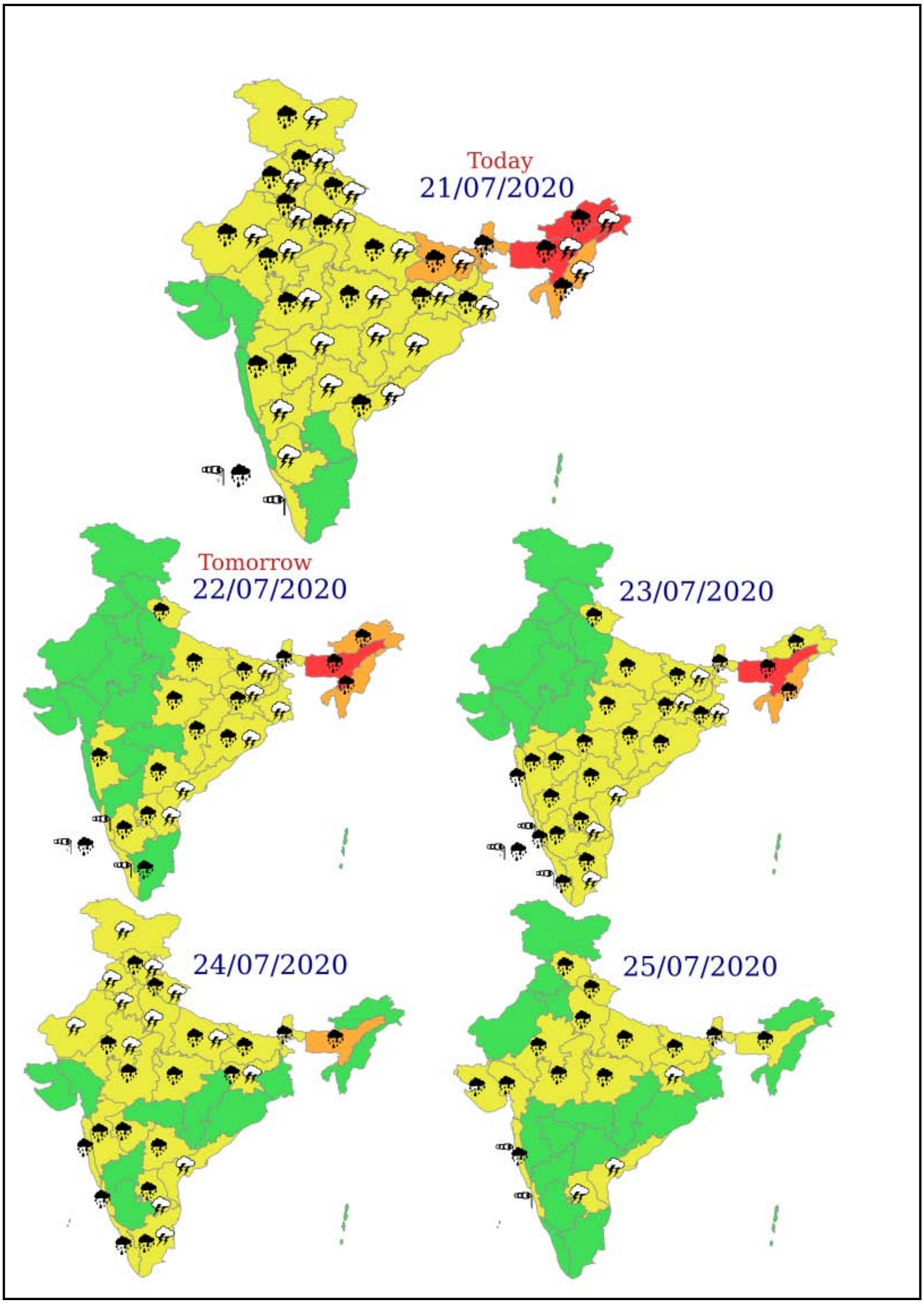
25 July (Day 5): ♦ **Heavy rainfall** at isolated places over Himachal Pradesh, Uttarakhand, Uttar Pradesh, East Rajasthan, Madhya Pradesh, Bihar, Sub-Himalayan West Bengal & Sikkim, Assam & Meghalaya, Gujarat State and Konkan & Goa.

♦ **Thunderstorm accompanied with lightning** very likely at isolated places over Jharkhand, Coastal Andhra Pradesh & Yanam and Rayalaseema.

♦ **Strong Wind** (speed reaching 50-60 kmph) very likely over Southwest and adjoining westcentral Arabian Sea. **Squally weather** (wind speed reaching 40-50 kmph) over Eastcentral & Northwest Arabian Sea and along & off Karnataka-Maharashtra coasts. Fishermen are advised not to venture into Sea over these areas.

Appendix I(B)

All India Weather Warning in pictorial format issued from NWFC



Appendix II

District level warning with colour code issued from M.C.(SWFC) Bhubaneshwar

भारत सरकार
पृथ्वी विज्ञान मंत्रालय
भारत मौसम विज्ञान विभाग
मौसम विज्ञान केंद्र
भुवनेश्वर, ओडिशा -751020

Government of India
Ministry of Earth Sciences
India Meteorological Department
Meteorological Centre
Bhubaneswar, Odisha-751020

District Level Weather Warnings for Odisha

Date: 21.07.2020
MORNING

Region	Name of the Districts	Weather Warnings for 5 days				
		DAY 1 valid from 0830 hrs IST of 21.07.2020 to 0830 hrs IST of 22.07.2020	DAY 2 valid from 0830 hrs IST of 22.07.2020 to 0830 hrs IST of 23.07.2020	DAY 3 valid from 0830 hrs IST of 23.07.2020 to 0830 hrs IST of 24.07.2020	DAY 4 valid from 0830 hrs IST of 24.07.2020 to 0830 hrs IST of 25.07.2020	DAY 5 valid from 0830 hrs IST of 25.07.2020 to 0830 hrs IST of 26.07.2020
North Coastal Odisha	Balasore	NIL	ISOL THUNDERSTORM WITH LIGHTNING	NIL	NIL	NIL
	Bhadrak	NIL	ISOL THUNDERSTORM WITH LIGHTNING	NIL	NIL	NIL
	Jajpur	NIL	ISOL THUNDERSTORM WITH LIGHTNING	NIL	NIL	NIL
	Kendrapara	NIL	NIL	NIL	NIL	NIL
	Jagatsinghapur	NIL	NIL	NIL	NIL	NIL
	Cuttak	NIL	NIL	NIL	NIL	NIL
North Interior Odisha	Sundargarh	NIL	ISOL THUNDERSTORM WITH LIGHTNING AND HEAVY RAIN	NIL	NIL	NIL
	Jharsuguda	NIL	ISOL THUNDERSTORM WITH LIGHTNING	NIL	NIL	NIL
	Bargarh	NIL	NIL	ISOL HEAVY RAIN	NIL	NIL
	Sambalpur	NIL	ISOL THUNDERSTORM WITH LIGHTNING AND HEAVY RAIN	ISOL HEAVY RAIN	NIL	NIL
	Deogarh	NIL	ISOL THUNDERSTORM WITH LIGHTNING AND HEAVY RAIN	NIL	NIL	NIL

Chapter 5

Heavy Rainfall Warning Services

5.1. Introduction

India is prone to heavy rainfall nearly all through the year. During monsoon, their frequencies of occurrences are very high. Study shows, under climate change scenario, the frequency of heavy rainfall is increasing in recent years (Fischer and Knutti 2017, Landerink and Fowler, etc). Occurrence of high monsoonal precipitation event over a much localized area in very short time span has been major cause of damage to lives and properties in India. Below listed, are some of the chronology of some of the High impact heavy rainfall events, which affected the Indian Mainland during the period 2005- 2020 while Figure 5.1 shows cumulative rainfall of these extremely heavy rainfall spells and lives lost for some of the major events during 2005-2020.

a. Mumbai 26-27 July 2005 - One of the worst ever observed unusual localized extreme rainstorm at Mumbai when a maxima of 94.6cm in 24-h with almost 60% of it observed during 1430-2030 IST of 26 July. The event was so localized that it was restricted to areas around Santcurze Airport, due to which 400 people lost their lives, and city was without phone, transport and electricity for a week, damage 5000 crores with closure of Mumbai airport was for almost a week.

b. Leh cloud burst on 6 August, 2010, leading to flash flood and mud slides causing loss of lives and damages to amenities and infrastructure.

c. Uttarakhand severe rainstorm (15-18 June 2013) - The devastating flash flood and series of landslides triggered by Uttarakhand severe rainstorm 15-18 June 2013, killed around 6000 people. Made 100,000 people stranded and were rescued by Govt.

d. Maharashtra Landslide event on 30 July 2014 - Malin, a Village in Maharashtra was hit by mud flow/land slide early in the morning while residents were asleep and it was caused by a burst of heavy rainfall and killed at least 134 people.

e. Jammu & Kashmir floods during 3-7 September 2014 - Jammu and Kashmir, had rainfall up to 30 to 61cm in 3 to 4 days with worst effect on the capital town of Srinagar. Around 250 lives lost and affected whole city for 15 days. Country's another biggest rescue operation by Govt for 250,000 people who were stranded.

f. Chennai Flood of 16-17 November and 1-2 December 2015 - Chennai city was hard-hit with more than 500 people losing their lives and damages and losses ranging from nearly 15000 crore. This had been one of the most severe urban flooding in Modern times.

g. Kerala Extreme rains and Floods of August 2018 - 14-16 Aug 2018 was the worst rain episode by which 483 people died, and 14 are missing. Property lost is ₹40,000 crore. Highest rain touched/number of stations reported>7cm and the respective numbers are 11cm/7, 27cm/50, 35cm/50, 19cm/30 and 11cm/3 for 12-13, 14-15, 15-16, 16-17 and 17-18 Aug, respectively with most extreme part of rainfall spell occurred in 14-16 Aug 2018.

h. Extreme heavy rainfall spells of 3-10 August 2019 at west coast of India: i) **Konkan and Madhya Maharashtra including Mumbai City during 3-7 Aug 2019** causing 40-80cm of cumulative rainfall due to which around 50 lives lost. The ever highest 24- hours rainfall for the period for the state was reported from Pen with value of 49.3cm with Mumbai airport closing partially. ii) **Kerala during 8-10 Aug 2019 -**Kerala received extreme rainfall(>20.4cm) spell during 7-10 Aug with cumulative 20-60cm. The ever highest reported was 33 cm in Ottapalam on 8th-9th August. This caused landslides and around 102 lives lost. Kochi airport was also closed for a day.

i. Extreme heavy rainfall spell of 4-7 July 2020 over Saurashtra and Kutch where 48.7cm was recorded at **Khambhalia**,of Dwarka district on 5-6 July and 47.67cm was over Okha on 7-8 July casuing flood over the region. Kokan coast covering Mumbai also experienced extremely heavy rain spell which have affected lives severely.

j. Extreme heavy rainfall spell amounting to 50-71cm hit Maharashtra, Karnataka, Kerala and adjoining Tamil Nadu during 3-8 August 2020 and major amounts during that spell are:

- 4 Aug- Mumbai (Dharavi)-38, Mumbai (Santacruz)-26; Mumbai (Colaba)-25, Hosanagar-21, Bhagamandala-19
- 5 Aug- Palghar-46, Talasari-39, Dahanu-38, Matheran-25, Ratnagiri-22, Kalyan-17, Thane-17, Santacruz-8, Colaba-5
- 6 Aug- Vaibhavwadi-71(Sindhudurg); Mumbai(Colaba)-33 Mumbai(Santacruz)-15, (All Konkan). Manantoddy-19, Vyttiri-18, Nilambur-10, Kuppady-9, Munnar Kseb-8(All Kerlal) Avalanchi-58(Nilagiri-TN); Bhagamandala-49 and Kottigehara-39, (Kodagu)(all south interior Karnataka)
- 7 Aug- Peermade to-26, Munnar Kseb-23, Idukki-23, Manantoddy-21, Vyttiri-19, Myladumpara-18, Kuppady-17, Palakkad-14(All Kerala) Bhagamandala-40, Kottigehara-36 (All south Interior Karnatak)

The latter extremely heavy rainfall spell of 3-8 August 2020 over west coast, have severely impacted the region and as a result, a huge land slide occurred near the tea plantation area at Pettimudi near Munnar in in the night of 6th Aug August caused 66 people lost their lives and 4 are missing due to this landslide. In south interior Karnataka, on the night of 5th August, five people missed and 40 cows have died in the heavy rainfall related devastation, after heavy rain caused a landslide near Talacauvery, Bhagamandala in Karnataka's Kodagu district. Bhagamandala has received about 147cm of rainfall during 3-8 Aug 2020.Pettimudi station affected by a huge landslide on 6 Aug 2020 and study shows it has recvied about had 61.6cm with 300cm rainfall cumulatively got during 1-11 Aug 2020 (data as accessed by Achu et al 2021 using data of Pettimudi division Neymakkad Tea Estate, KDHP Ltd.) while rainfall received by IMD at Munar KSEB, shows 88cm for the same period and on 6th Aug 2020, it was 23cm, being just 20km Northeast of Pettimudi.

As exemplified by the above data, heavy rainfall has been one of the most severe weather events among all other natural hazards that recently affected lives the most. It has been causing floods and inundations including riverine, local flash floods and urban flash floods and landslides and severely impacting agriculture and local infrastructures. In major urban pockets, it severely affects all service sectors and many times various service sectors get closed down including airports, hospitals and other basic municipality services like power supply, communications, surface transports.

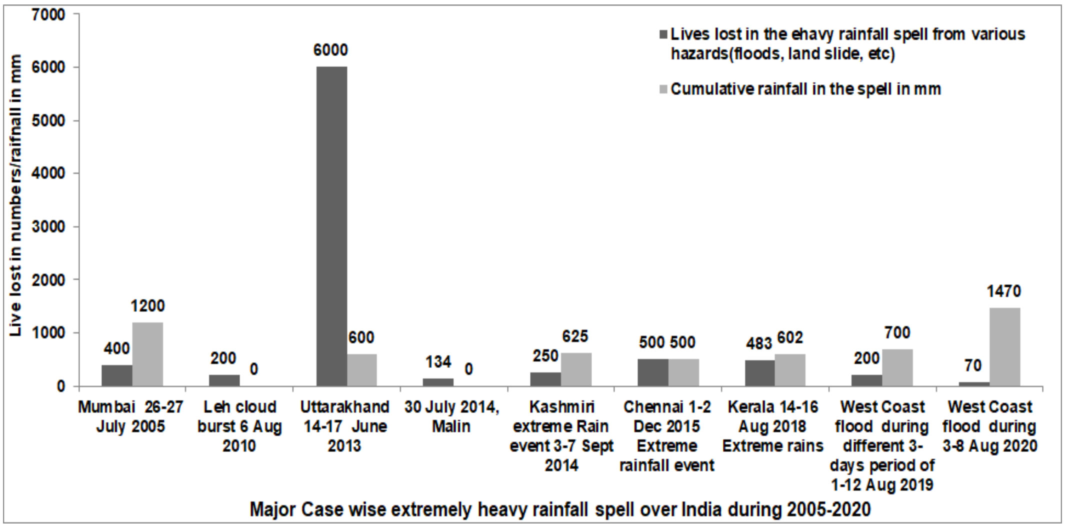


Figure 5.1. Rainfall cumulative highest vis-a-vis lives lost during various Major extremely heavy rainfall events of 2005-2020

So IMD on very high priority basis, has developed and adopted time to time various global and regional scientific integrated approach through various collaboration projects with FFGS-WMO, WCSSP-UKMO, SWFDP-WMO etc, via WMO, USA, EU, UK and adoption of indigenous techniques and technology available within country via ISRO and MoES institutions like NCCR, NCMRWF, IITM to improve its monitoring and early warning system including its timely outreach to minimize its impact. It covers improvement of real time monitoring through dense network of surface, RADAR and Satellite rainfall monitoring upto block level and sub-city levels and to generate a timely Heavy rainfall warning upto 5-7 days in lead time by adopting a suit of latest available NWP models at local to global scale called seamless approach at Nowcast to ERF time scale. Another objective has been to ***"adopt appropriate understandable***

warning format in both local regional languages and to use all the latest and best dissemination system like Social media, CAP based technology, Whatsapp, Website etc and other digital platform to timely disseminate these warnings to general public, media, Government and disaster managers as and when heavy rainfall is expected over a region". For better efficiency of the heavy rainfall warning system, IMD follows a Standard Operating Procedure (SOP) for monitoring, prediction and warning services.

5.2. Organisation and Area of responsibility

India Meteorological Department (IMD), Ministry of Earth Sciences is the Nodal National Meteorological agency mandated for issuing seamless operational weather forecast and warnings for weather hazards across the country. IMD has 3-tier structure, viz., National weather forecasting Center (NWFC) at Delhi for National level, Regional Meteorological Center (RMC) at regional level and Meteorological centers (MC) at state level. The weather forecasts are issued for different temporal and spatial domains. The spatial domain range from venue, city, District, State and country - each having different temporal domain. The temporal domains based on their validity periods are (i) Nowcasting – a few couple of hours ahead,(ii) Short Range - up to 3 days, (iii) Medium Range - 3 – 10 days, (iv) Extended range - 10 days to 1 month and (v) Long range – Months to a whole season. However, the warnings are issued only in nowcast to short/medium range valid upto five days at district level.

At the national level, NWFC will issue sub-division wise heavy rainfall warning four times in day valid for next 5 days with 2 days outlook based on 00, 03, 09 and 12 UTC observations for entire country. The warning will be issued to national agencies, national disaster management agencies, press & electronic media, public, users and all stakeholders by various modes. In addition the heavy rainfall warning is issued in text and colour coded graphical form by NWFC.

At regional level the heavy rainfall warning bulletin issued at district level and sub-division level for the concerned state by RMC/MC. The warning will be issued to state agencies, state disaster management agencies, press & electronic media, public, users and all stakeholders by various modes. In addition the heavy rainfall warning is issued in text and colour coded graphical form by RMCs.

At RMC/MC the HRW will be issued by duty officer under the supervision of RMC/MC In-charge for the state. At RWFC there should be round the clock duty headed by a Group-A officer if available, otherwise work may be managed by trained officials under the supervision of a Group-A Officer.

Table 5.1

Heavy Rainfall warning issued by different centres of IMD

S. No.	Centre	Area of responsibility	Update	Warning type
1.	National Weather Forecasting Centre (NWFC)	Meteorological Sub-division wise	4 times in a day	Text and colour coded form
2.	Regional Meteorological Centre (RMC)	Meteorological Sub-division and district wise	2-4 times in a day	Text and colour coded form
3.	Meteorological Centre (MC)	District wise	2-4 times in a day	Text and colour coded form

Forecast Ranges for Heavy Rainfall in India

- Medium range upto 7 days
- Short range upto 3 days
- Nowcasting range < 6 hours

5.2.1. Classification of Heavy Rainfall

IMD's classification of heavy rainfall(HRF) and terminology use for location specific rainfall ranges is given below. It defines HRF for a specific station based on daily rainfall. It is based on the rainfall realised for the past 24 hrs ending at 0830 hrs IST of a specific day. Various categories of HRF for a station defined by IMD are given below in table 5.2.

Table 5.2

Rainfall category

Category	Range of daily rainfall of a station
Very Light Rain	Trace - 2.4 mm
Light Rain	2.5 – 15.5 mm
Moderate Rain	15.6 – 64.4
Heavy rain	64.5-115.5 mm
Very heavy rain	115.6-204.4mm
Extremely heavy rain	≥ 204.5mm
Exceptionally heavy rain	When the amount is a value near about the highest recorded rainfall at or near the station for the month or season. However, this term will be used only when the actual rainfall amount exceeds 24cm.

For defining intensity of heavy rainfall event, IMD follows

1 - hourly rainfall amounts as defined in Table 5.3.

Table 5.3

Rainfall spell category

Category	Range of daily rainfall of a station
Light spell	1 cm/hour
Moderate spell	1-2 cm/hour
Intense spell	2-3 cm/hour
Very Intense spell	3-5 cm/hour
Extremely Intense spell	5-10 cm/hour
Cloud Burst(CB)	> 10 cm/hour

To define spatial distribution of heavy rainfall over a Meteorological Sub-division, criteria as defined in Table 5.4 is followed by IMD.

Table 5.4

Rainfall distribution category

Spatial Distribution	Percentage of Stations in a Meteorological Sub-division /Region recording heavy rainfall
Isolated Heavy Rainfall	25% or less
Scattered Heavy Rainfall	26-50%
Fairly Widespread Heavy Rainfall	51-75%
Widespread Heavy Rainfall	76-100%

5.3. Climatology of Heavy Rainfall and Cloud Burst (CB)

5.3.1. Climatology of Heavy Rainfall

IMD has got reasonable number stations over India with longer period data and Fig. 5.2 shows occurrences of heavy rainfall of different categories in terms of number of days in an year over different areas of India.

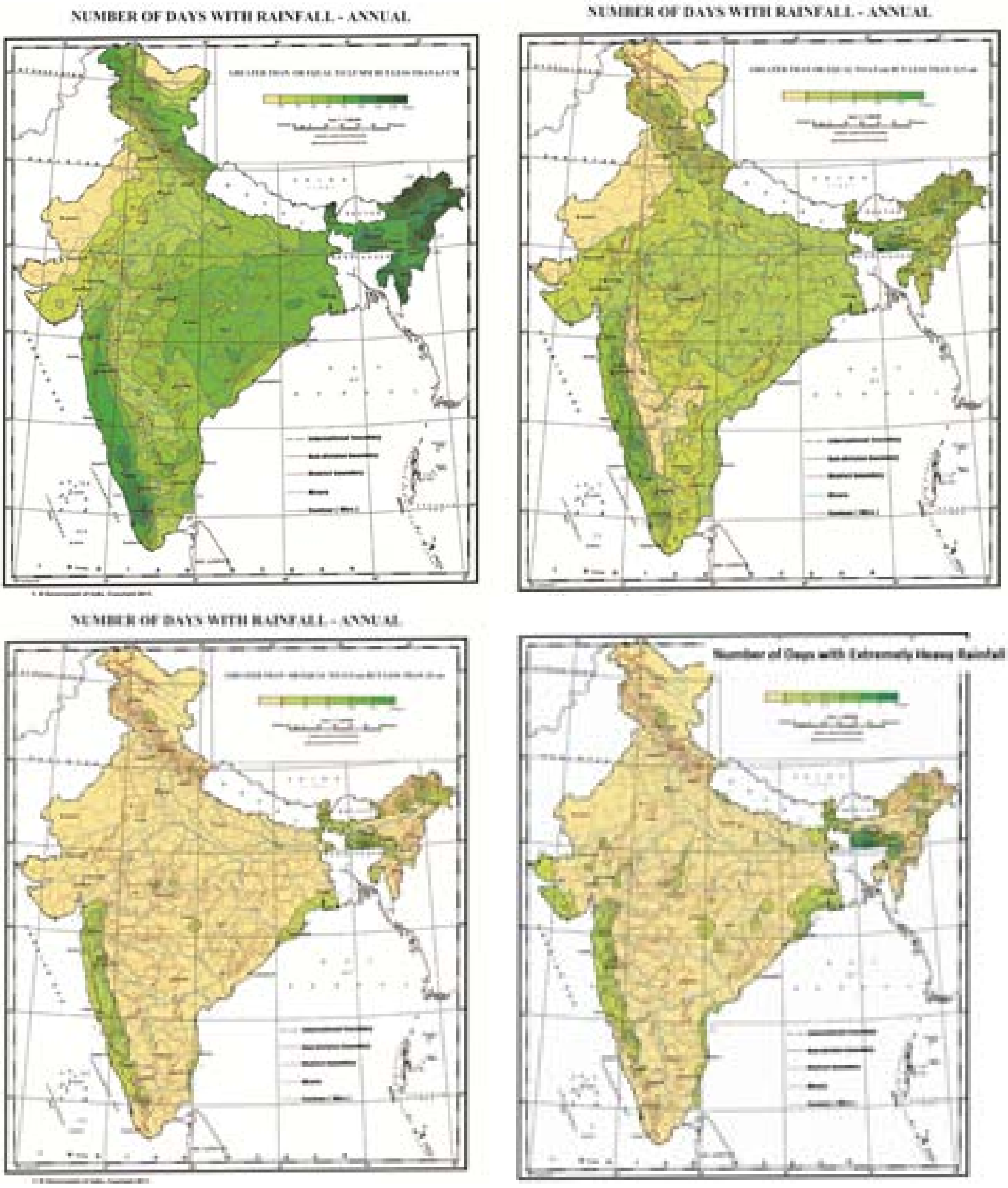


Fig. 5.2. Climatology of Annual number of Rainy days, Heavy rainfall, Very heavy rainfall and Extremely Heavy Rainfall days

5.3.2. Climatology of Cloud Burst (CB)

Cloud Burst (CB) occurrences are very local in nature and are normally observed in monsoon season over lower Himalayan region especially over from its western parts. CB have been well known to local people for their very higher impact as it causes very localized flash flood, landslides, debris flow, flash floods with huge damages to properties and human losses, irrespective of the rainfall amount. Lack of sufficient number of hourly recording rainfall data and observing system has put its detection a challenge. However, one may refer Figs 5.3 and 5.4 for finding areas climatologically vulnerable for CBs.

Some important characteristics of Cloudburst (CB)

- Extreme amount of rainfall realized in very short period of time
- IMD criteria-Any Precipitation event exceeding 100mm/h
- Frequencies over India

➢ Highest in and around the southern rim of the Indian Himalayas especially over Uttarakhand, HP and northeastern hill states

➢ Westcoast over windward side Western Ghats Hills from Goa to Saurashtra

- Areas vulnerable over western Himalayas

➢ At between elevation range of 1000 m and 2500 m occurred within a small geographic area of 20-30 km

➢ 30 cloud burst events have occurred over the southern rim of the Himalayas during 1970-2016, and around 17 cloud burst events among them occurred in Garhwal region of Uttarakhand

➢ Droplet size ranges from ~4 – 6 mm with fall speed of ~10 m/s

- Possible causes

➢ Orographic architecture of the mountain regions

➢ Monsoonal moist laden winds at lower levels from southeast/east towards the hills, coupled with vertical shear in wind and orographic uplifting leading to intensely precipitating convective systems

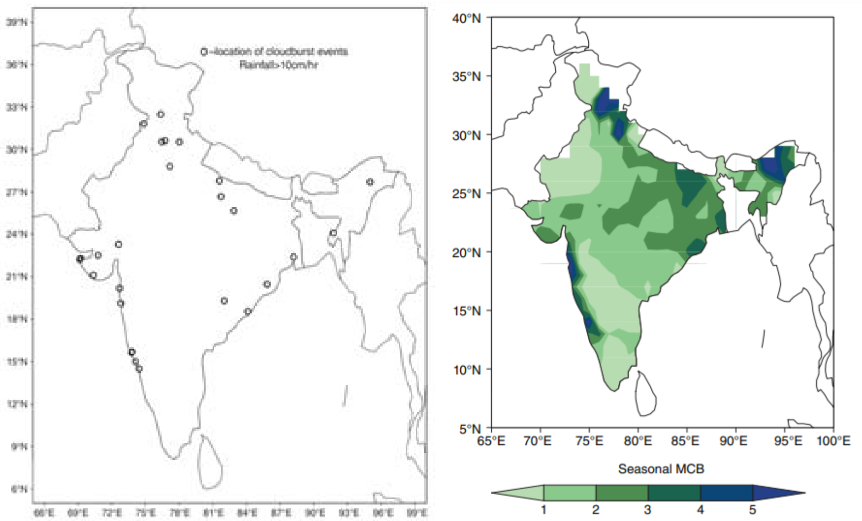


Fig. 5.3. Occurrences of CB events 1969-2015 –IMD SRG/ARG data(total of 28 events occurred during 1969-201) (left) while Right fig shows Rainfall of 3-5 cm per hour in the steep slope mountainous regions of Himalayas (both figs arefrom Deshpande et al., 2017

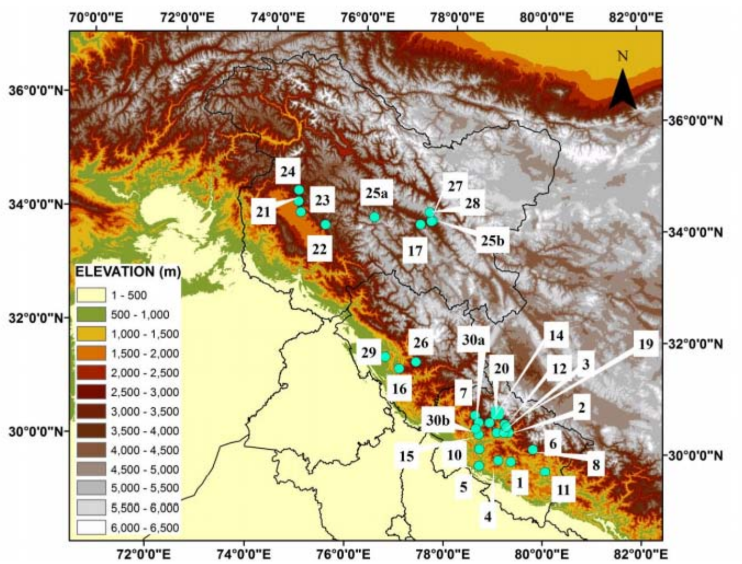


Fig. 5.4. CB over WR region as collected from various sources including Media and State govt (from Dimri et al., 2017)

Table 5.5

Record Highest one day rainfall reported over India as per IMD data in deadening order

S. No.	Station	State	1-day rainfall in cm	Date of occurrence
1.	Sohra (earlier Cherrapunji) Obsy	Meghalaya	156.3	16-Jun-1995
2.	Amini Divi	Lakshadweep	116.8	6-May-2004
3.	Sohra	Meghalaya	103.6	14-Jun-1876
4.	Ambarnath	Maharashtra	101.0	27-Jul-2005
5.	Sohra	Meghalaya	99.8	12-Jul-1910
6.	Mausynram	Meghalaya	99	10-Jul-1952
7.	Dharampur	Gujarat	98.7	2-Jul-1941
8.	Sohra	Meghalaya	98.5	13-Sep-1974
9.	Mawsynram	Meghalaya	98	4-Aug-1982
10.	Tamenlong	Manipur	98	10-Aug-1970
11.	Sohra	Meghalaya	97.4	5-Jun-1956
12.	Mawsynram	Meghalaya	94.5	7-Jun-1966
13.	Mumbai	Maharashtra	94.4	27-Jul-2005
14.	Tamenlong	Manipur	94	28-Jul-1970
15.	Sohra	Meghalaya	93	15-Jun-1995
16.	Guna	Madhya Pradesh	92.8	23-Aug-1982
17.	Sohra	Meghalaya	92.5	27-Jun-1934
18.	Sohra	Meghalaya	90.7	25-Jun-1970

5.4. Implementation of IBF and Risk based warning for Heavy rainfall event

Impact based forecast (IBF) is given with the intention to project what the weather will do rather than what the weather will be. The weather forecast and warning products are being prepared with the incorporation of colour code already, so as to bring out the intensity and impact of the severe weather expected and to signal the disaster managers about the action to be initiated at their end for mitigation. River flood, Urban flood, Land slide, Flash flood, Coastal Flood, water inundation, water logging in low lying areas etc. are the various impacts associated with heavy rainfall**.** (For more detail kindly go through Impact Based Forecasting SOP chapter).

Table 5.6

Highest ever rainfall record of a day over World

Rainfall (cm)	Station and country	Date
World		
184.1	Cilaos, Reunion Island	15–16 March 1952
179.6	Foc Foc, Reunion Island	7–8 January 1966
166.2	Belouvc, Reunion Island	27–28 February 1964
155.2	Aurere, Reunion Island	7–8 April 1958
137.8	Muuocaicang, Nei Mouggol China	1–2 August 1977
122.8	Paishih, Taiwan	10–11 September 1963
117.5	Halaho, Taiwan	9–10 September 1963
116.8	Amini Devi, India	5–6 May 2004
115.0	Bagerio, the Philippines	14–15 July 1911
112.3	Belledenker QLD, Australia	3–4 January 1979

5.5. Observation, Monitoring and Product generation of Heavy rainfall events

IMD presently using both surface and remote based observations and monitoring systems for detection and reporting of heavy rainfall events occurrences in terms of areas of occurrences and their timings . Followings are series of observational platforms at use presently for accurately detecting and monitoring heavy rainfall events.

i. Surface Observatories (both departmental and non- departmental (559)
ii. Pilot Balloon Observatories (62)
iii. RS/RW Observatories (43)
iv. ARG (1350)
v. AWS (701)
vi. Hydromet observatories (4241)
vii. Non-Dept. rainguages (3540)
viii. INSAT-3D
ix. INSAT-3DR
x. International Satellites-METEOSAT/ HIMWARI
xi. DWR-26

5.5.1. Rainfall products

Various observed rainfall products regularly updated and available in web page of IMD and other MoES centers are as follows:

i. District wise daily observed rainfall and seasonal cumulative observed rainfall from Hydromet division of IMD (refer Fig 5.5.)

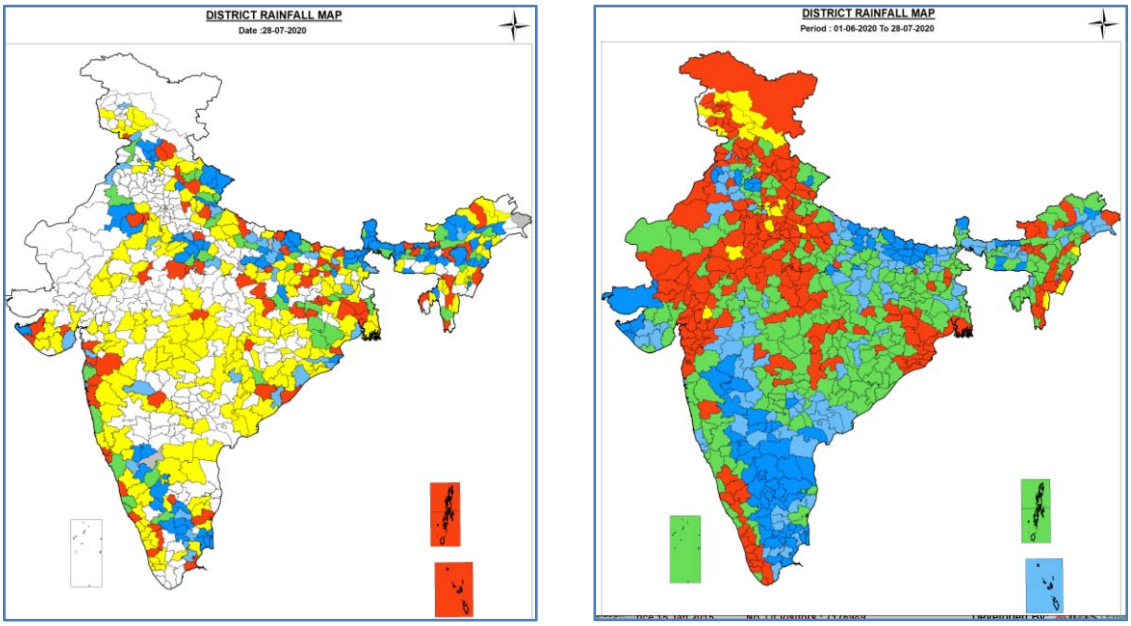


Figure 5.5. District wise daily observed rainfall (left) and Seasonal cumulative observed rainfall (right) prepared in Customized Rainfall Information System (CRIS) by Hydrology Div, IMD

ii. QPE of INAT 3D and INSAT 3DR

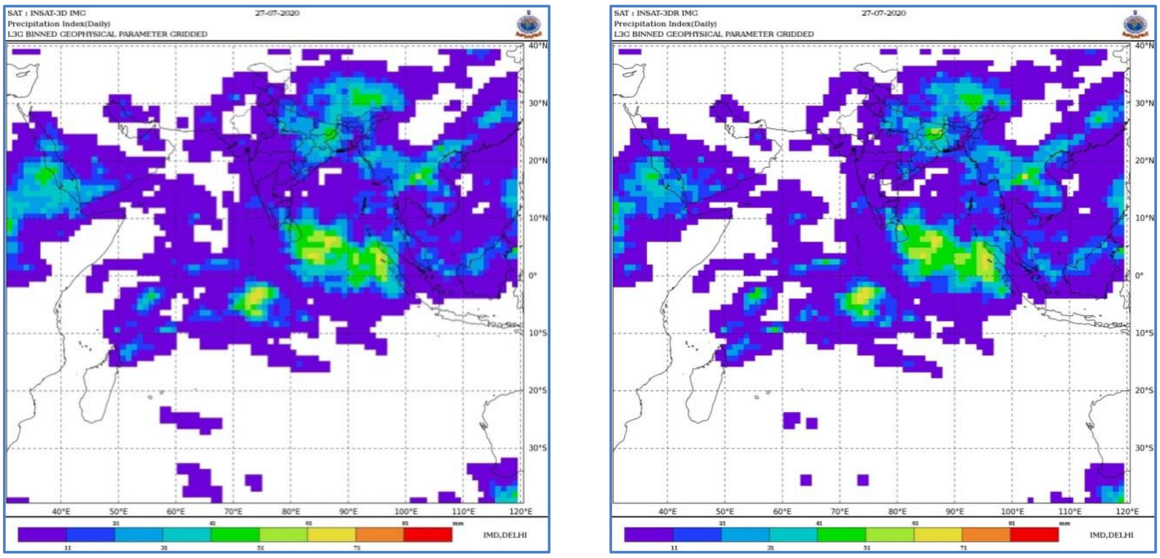


Figure 5.6. QPE of INSAT 3D (left) and QPE of INSAT 3DR (right)

iii. Rainfall product of DWR

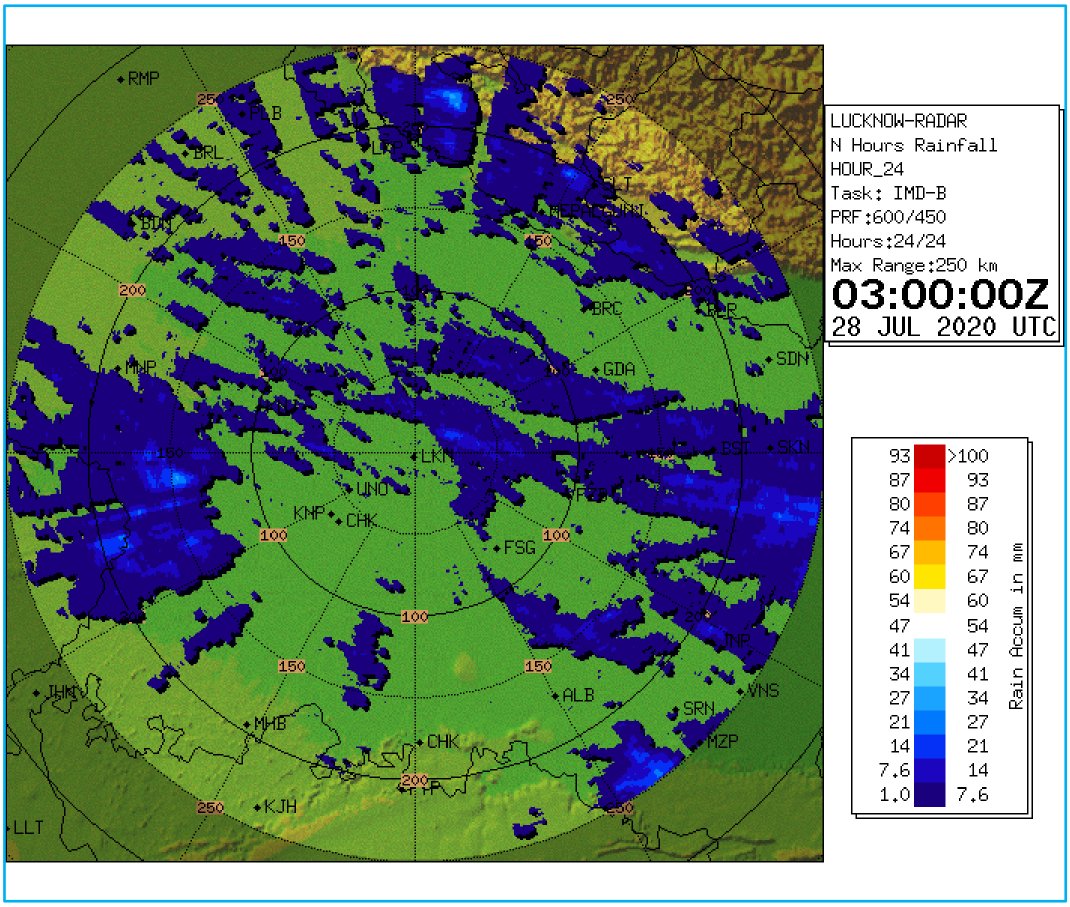


Figure 5.7. 24 hour Rainfall by DWR

iv. Gauge and satellite gridded rainfall product of NCMRWF

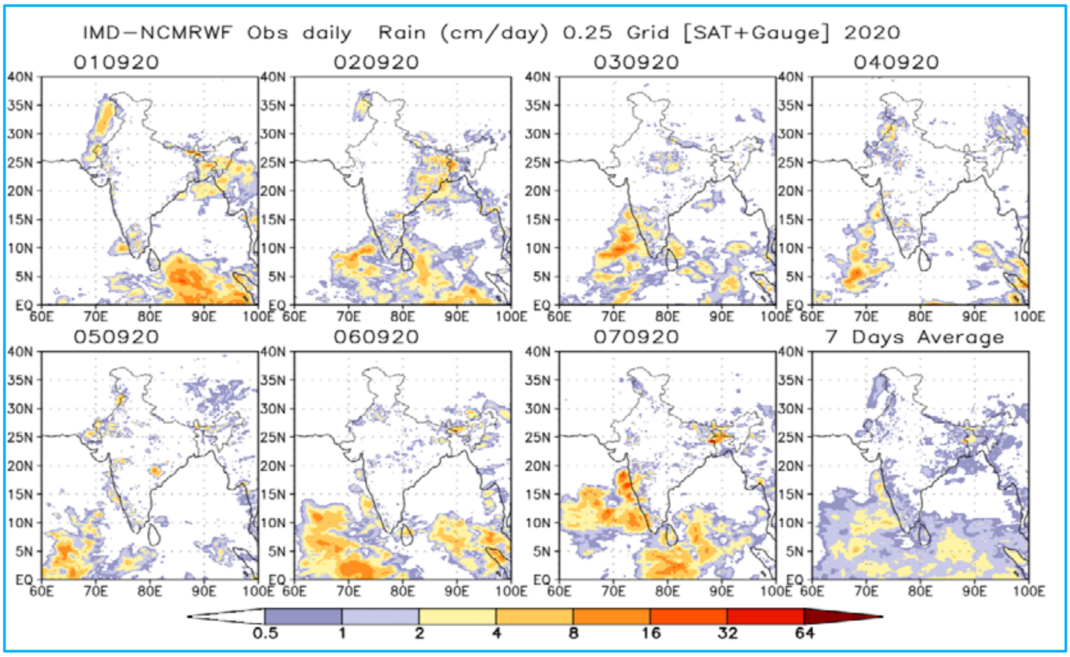


Figure 5.8. Rainfall products from NCMRWF- Daily Merged Satellite Gauge Real-Time Rainfall Dataset for Indian Region

v. Rainfall observation data at Synergie

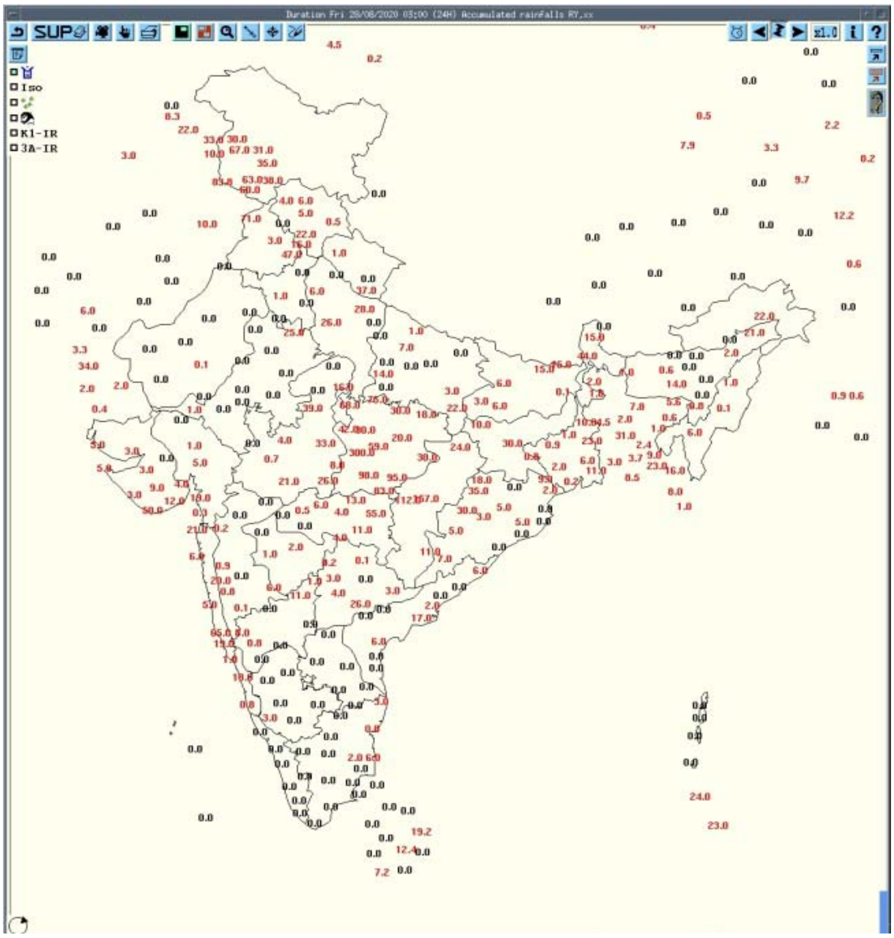


Figure 5.9. 24 hour observed rainfall in synergie

5.6. Forecasting Techniques of Heavy rainfall

At present, the heavy rainfall event over an area/location is predicted based on the diagnostic meteorology covering synoptic and upper air data analysis and preparing synoptic climatology or pattern matching, various NWP model products and satellite & radar observations.

5.6.1. Diagnostic Method

CLIPER, Synoptic, Synoptic analogues/Pattern matching are methods where past heavy rainfall cases are analyaed and various products are diagnosed synoptically and dynamically to find various conditions causes these events. NWP model analysis and forecasted winds, areas of stronger wind shear, moisture availability, dynamic features like vorticity, convergence and divergences at various levels of atmosphere (CIMMS and GFS diagnostic products) are also in use in this regard to get the pattern as was past cases are associated with earlier events. **Some of the major features diagnosed which are favourable to cause heavy rainfall event are:**

- Major cyclonic systems like CS/Dep, Monsoon Lows/Dep while moving, causes heavy rainfall events
- MTC and Active Monsoon trough/Off-shore trough with stronger moist laden Easterly/westerly, along west coast and Gujarat.
- Orographic lifting and Mid-latitude system and Monsoon system interaction over western Ghats and Himalayan region
- During break/revival phase of monsoon-Synoptic-Meso-scale Convective interaction leading to MCC/MCZ formation
- Features cause Extreme heavy rainfall events/CB/Intense to very Intense spell over Himalayas and west Coast
  - Eastern Himalaya- Convergence of moist southerly/southwesterly winds from Bay of Bengal across steep slope of orography where moist laden winds suddenly condensed and provide very high rainfall
  - Western Himalayas- Interaction of WD/mid-Latitude trough with LPS where southerly(southeasterly) moist monsoon winds from Arabian Sea or the Bay of Bengal aided by orographic uplift turning to severe convective events with CB grown upto 15km height.
  - West Coast and adj south Gujarat- MTC, east-west Shear zone, off shore trough and distance effect of LPS/Depression located over Odisha-Bengal coast or over eastern parts of Central India
- Besides above synoptic scale systems, **Large scale features of the day like low level jet, MJO, IOD, El-Nino, Ridge, easterly Jet position also enhance/supress convection in areas favourable of heavy rainfall over various parts of India over monsoon core zone along central India, west coast and east coast of India.**
- Dynamic features: Divergence, convergence, shear, shear tendency, vorticity etc
- Thermodynamic features: CAPE, CINE, Temperature gradient etc. are also used.

5.6.2. Based on NWP Models

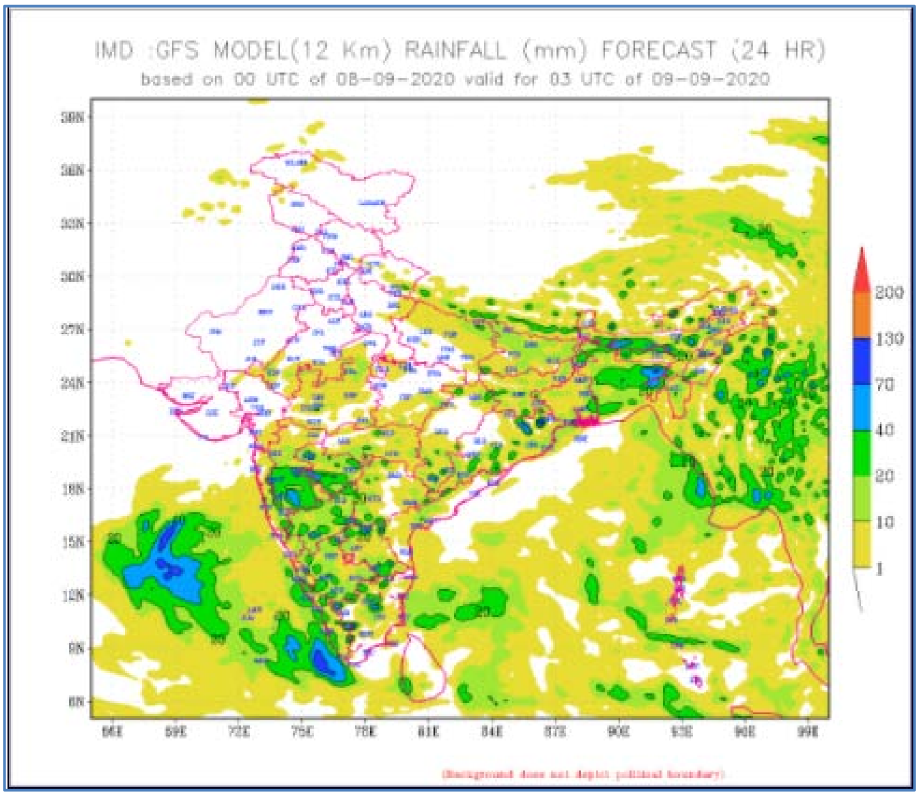
Presently Ministry of Earth Sciences runs around 10 regional and global models with various resolutions. Rainfall product of various models are given in Table 5.4.

Table 5.7.

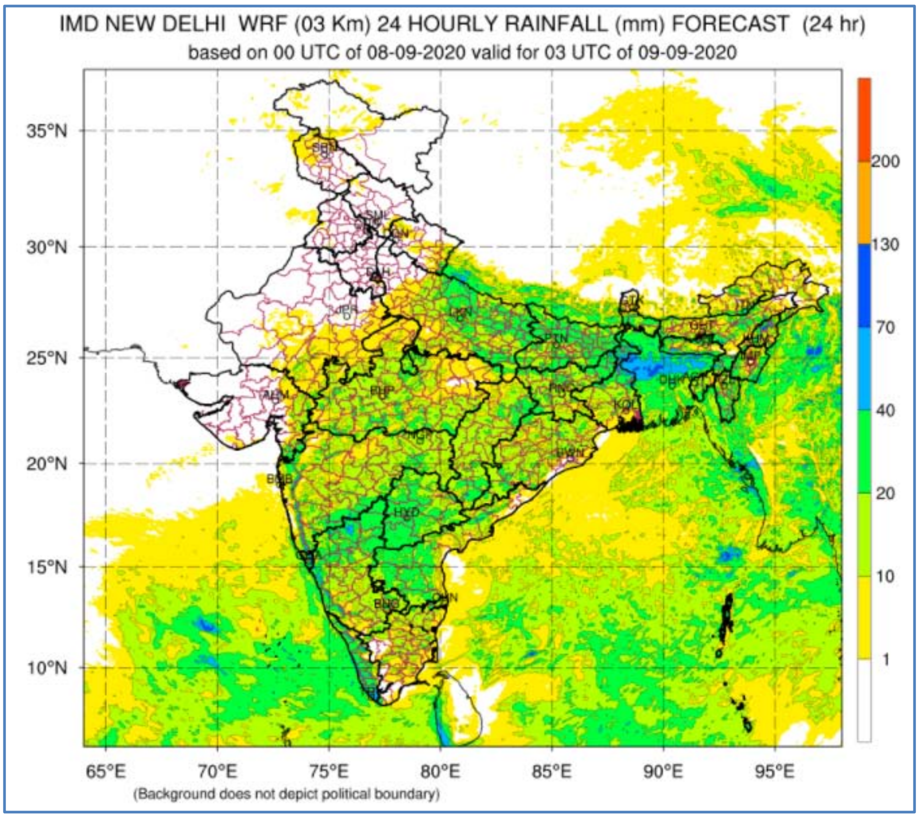
Brief of NWP Forecast models in use (individual Deterministic models, Ensemble forecast Models)

Type of nwpForecast models in use (individual Deterministic models, multi-model ensemble (MME) and single model ensemble prediction system (EPS) and Statistical Dynamical Models)	**Resolution and product Updates**
❖ **Medium Range Forecast : Global Model products from IMD and other MoES centers in 2018-19 :**	
Global forecasting system (GFS) global model-IMD-http://nwp.imd.gov.in/gfsproducts_cycle00.php	horizontal resolution of 12 km and forecast upto 10 days (0000 and 1200 UTC)
Unified model-NCMRWF-https://www.ncmrwf.gov.in/latest_charts.php	horizontal resolution of 12 km and forecast upto 10 days (0000 and 1200 UTC)
Global Ensemble Forecasting System (GEFS) global probabilistic model-IITM-https://www.tropmet.res.in/erpas/files/eps_initial_conditions.php Products at IMD(http://nwp.imd.gov.in/gefspro.php	horizontal resolution of 12 km and forecast upto 10 days (0000 UTC)
Global Unified model ensemble prediction system-NCMRWF- (Model in brief – https://www.ncmrwf.gov.in/NEPS_TR_Aug2018_Final.pdf Products at https://www.ncmrwf.gov.in/latest_charts.php	horizontal resolution of 12 km and forecast upto 10 days
Probabilistic Forecast Products from NCMRWF Ensemble Prediction System (NEPS)- (Model in brief- at https://www.ncmrwf.gov.in/Reports-eng/TR_12-km_ NEPS_Forecast_Products.pdf Products at https://www.ncmrwf.gov.in/latest_charts.php#	10-day probabilistic forecasts are issued daily using 23 ensemble members (1 control + 22 perturbed). The operational deterministic forecast running from 00 UTC is used as control forecast. One set of 11 perturbed members run from 00 UTC of current day and another set of 11 perturbed members run from 12 UTC of previous day to form 22 perturbed ensemble members. T
❖ **Global Model products available to IMD through WMO/Multi- institutional global collaboration:** IMD implemented JMA supported software for real-time TC forecast over North Indian Ocean (NIO) during 2011. The Ensemble and deterministic forecast products from ECMWF (50+1 Members), NCEP (20+1 Members), UKMO (23+1 Members) and MSC (20+1 Members) are available near real-time for NIO region for named TCs. The JMA provided software to prepare Web page to provide guidance of tropical cyclone forecasts in near real-time for the ESCAP/WMO committee Members. The forecast products are made available in real time.	
❖ **Short Range Forecast**	
Weather research forecast (WRF) Meso scale model	horizontal resolution of 3 and 9 km and forecast upto 3 days.
Unified Meso scale regional model	horizontal resolution of 4 km and forecast upto 3 days
Hurricane WRF (HWRF) for cyclone prediction	horizontal resolution of 2 km and forecast upto 5 days
High-Resolution Rapid Refresh (HRRR) WRF model with Satellite Application Center-Indian Space Research Organization (SAC-ISRO) for north India region. The experimental HRRR model is based on Weather Research and Forecasting (WRF) Model’s ARW core and takes the initial and boundary condition from the IMD-GFS global model. Using the WRF Data Assimilation system (WRF-DA), the RADAR data is assimilated in HRRR every 10-15 min over a 1-h period(from Feb 2021	The HRRR is hourly updated atmospheric model with horizontal resolution of 2km. The model is currently being integrated for 12hours to provide precipitation and maximum reflectivity products.The experimental HRRR model implementation uses Radar data of 6 radars namely Delhi, Jaipur, Chandigarh, Bhopal, Lucknow and Srinagar. The model completion time at present is approximately 1hr 45 min. Hence forecasted plot are available at 2-h gap

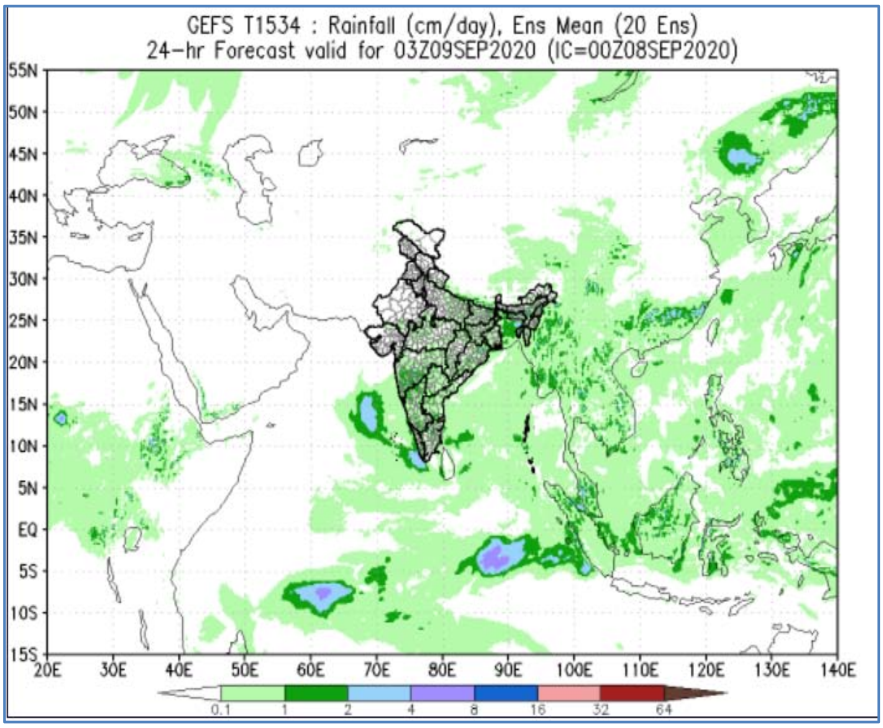
IMD GFS (12 km)

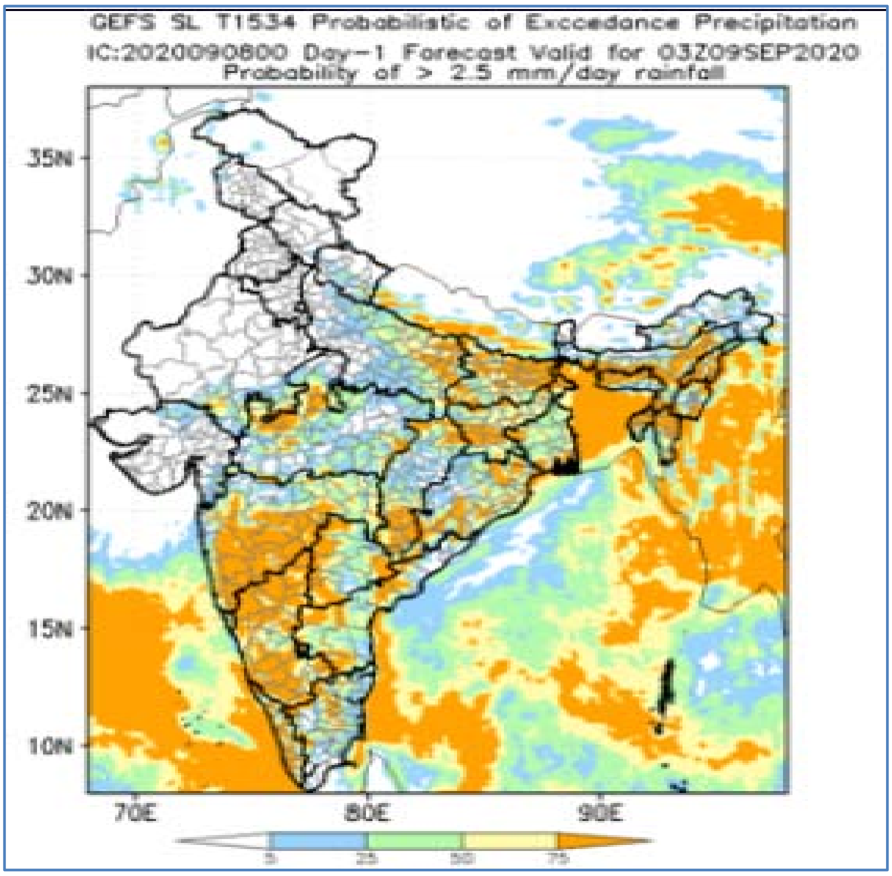


(i) IMD WRF (03 km)

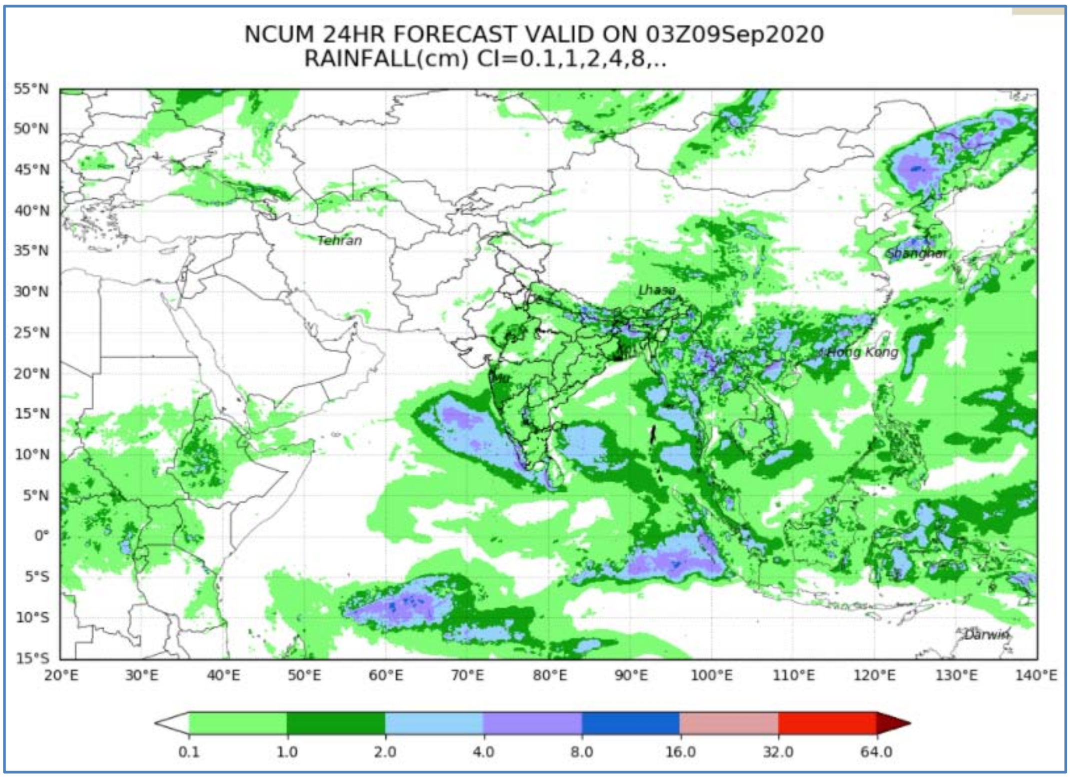


(ii) GEFS (12 km)

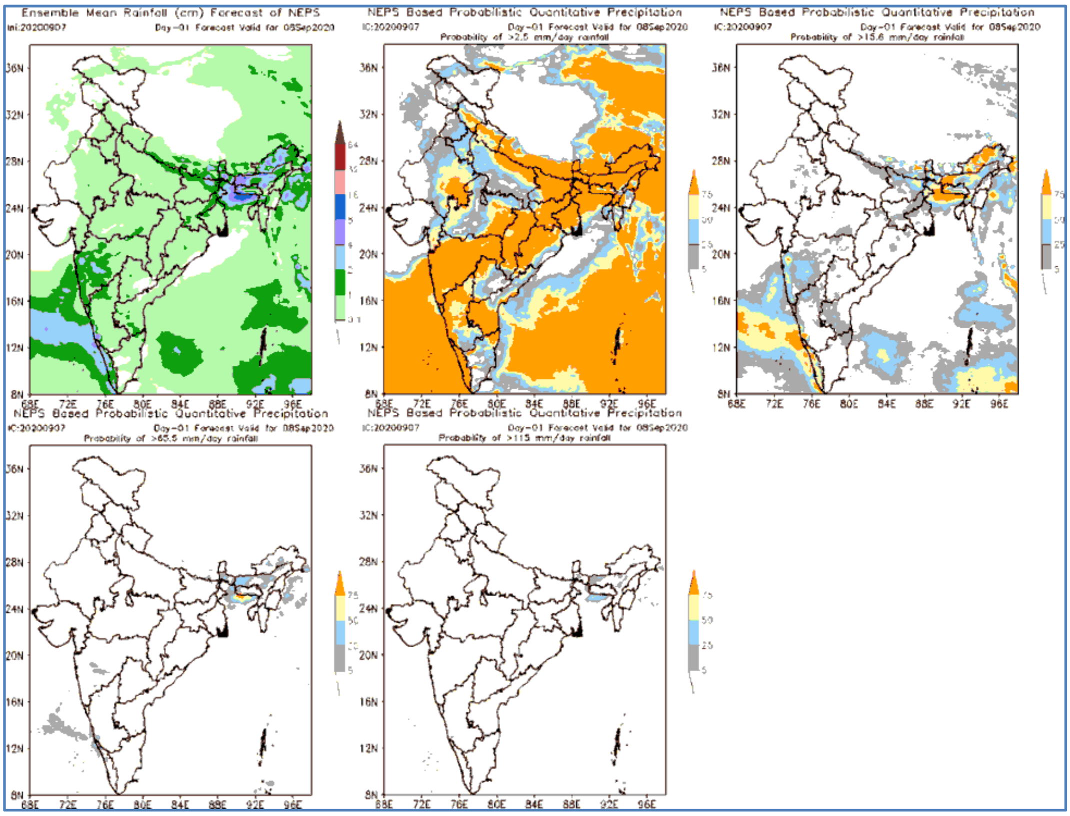

GEFS T1534 : Rainfall (cm/day), Ens Mean (20 Ens)
24-hr Forecast valid for 03Z09SEP2020 (IC=00Z08SEP2020)
55N
50N
45N
40N
35N
30N
25N
20N
15N
10N
5N
EQ
5S
10S
15S
20E
30E
40E
50E
60E
70E
80E
90E
100E
110E
120E
130E
140E
0.1
1
2
4
8
16
32
64


GEFS SL T1534 Probabilistic of Exceedance Precipitation
IC:2020090800 Day-1 Forecast Valid for 03Z09SEP2020
Probability of > 2.5 mm/day rainfall
35N
30N
25N
20N
15N
10N
70E
80E
90E

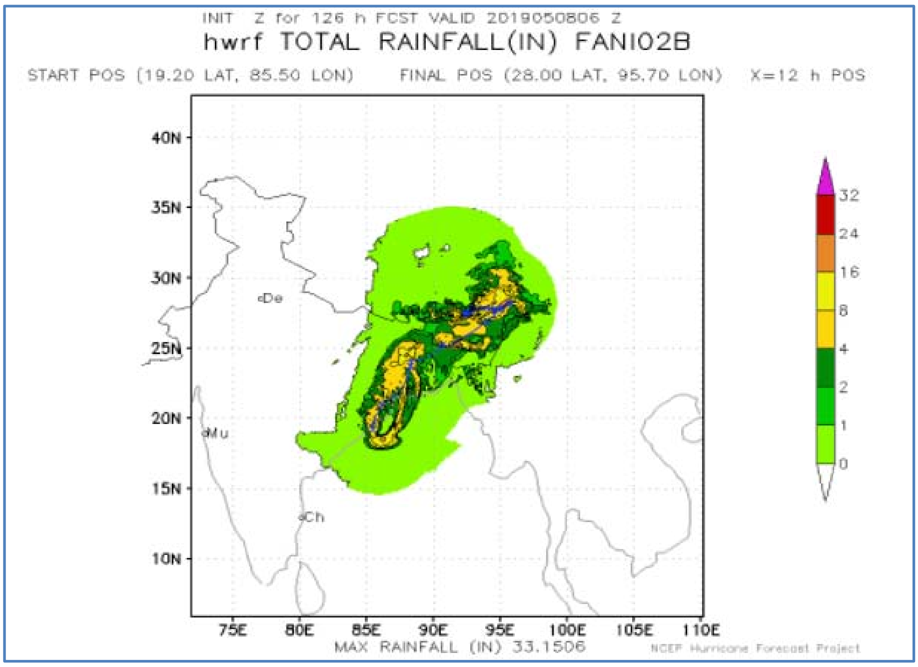
(iii) NCUM



(iv) NEPS



(v) HWRF



The most recent development of Heavy rainfall intensity forecast upto 5 days using NWP rainfall amounts, IMD has made arrangement to make available forecast of rainfall averaged over the met-sub-division wise from 5- different models available in a single click in tabular form as given below at https://nwp.imd.gov.in/models_intensity_05days.php.

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

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

DAY-01

S.NO.	SUB-DIVISION	DAY-01:GFS - FCST BASED ON :12032021 :VALID FOR:13032021	DAY-01:JMA - FCST BASED ON :12032021 :VALID FOR:13032021	DAY-01:NCUM - FCST BASED ON 12032021 :VALID FOR:13032021	DAY-01:NCEP - FCST BASED ON 12032021 :VALID FOR:13032021	DAY-01:GEFS - FCST BASED ON 12032021 :VALID FOR:13032021
		GFS	JMA	NCUM	NCEP_GFS	GEFS
01	A & N ISLAND	5	0	1	3	1
02	ARUNACHAL PRADESH	18	4	2	2	4
03	ASSAM & MEGHALAYA	0	0	1	0	0
04	N M M T	0	0	2	0	0
05	SHWB & SIKKIM	12	3	9	1	6
06	GANGETIC WEST BENGAL	6	1	3	6	5
07	ORISSA	4	1	4	1	3
08	JHARKHAND	22	4	20	6	4
09	BIHAR	9	0	14	5	4
10	EAST UTTAR PRADESH	12	11	22	3	3
11	WEST UTTAR PRADESH	19	25	30	12	6
12	UTTARAKHAND	2	0	19	4	0
13	HAR.CHD & DELHI	10	15	22	5	6
14	PUNJAB	43	13	20	12	11
15	HIMACHAL PRADESH	8	21	7	4	5
16	JAMMU & KASHMIR	40	20	28	25	17
17	WEST RAJASTHAN	2	0	4	0	0

5.7. SOP of Heavy rainfall Monitoring, Forecasting and Warning system

At present, the heavy rainfall is monitored and predicted based on the synoptic, satellite, radar and NWP model inputs (refer fig. 5.10). All these data/products are analysed and then discussed through video conferencing among all the forecaster across the country to arrive at a consensus decision on likelihood of heavy rainfall and its impact over a region or a part of it during next 5 days.

5.7.1. Steps for monitoring of Heavy rainfall

The monitoring for heavy rainfall basically involves the following steps.

- Routine retrieval and review of scheduled bulletins and products issued by SWFC/RWFC/AMO/ FMO/NWP Division/NWFC etc.
- Routine retrieval and review of all remotely sensed data (AWS, ARG, Satellite, Radar, Lightning etc.
- Maintenance of continuous watch for the arrival of unscheduled data like intense precipitation advisory reports of actual heavy rainfall occurring etc.

5.7.2. Heavy Rainfall Forecast Techniques

There are various techniques for predicting heavy rainfall over a region:

a. Synoptic
b. Radar
c. Satellite
d. NWP products
e. Checklist

- Synoptic features of the day
- Large scale features of the day like MJO, IOD, El-Nino, Ridge, Jet position.
- Systems in Indian Ocean
- Satellite guidance
- Radar guidance
- Dynamic features: Divergence, convergence, shear, shear tendency, vorticity etc
- Thermodynamic features: CAPE, CINE, Temperature gradient etc.
- Model Guidance

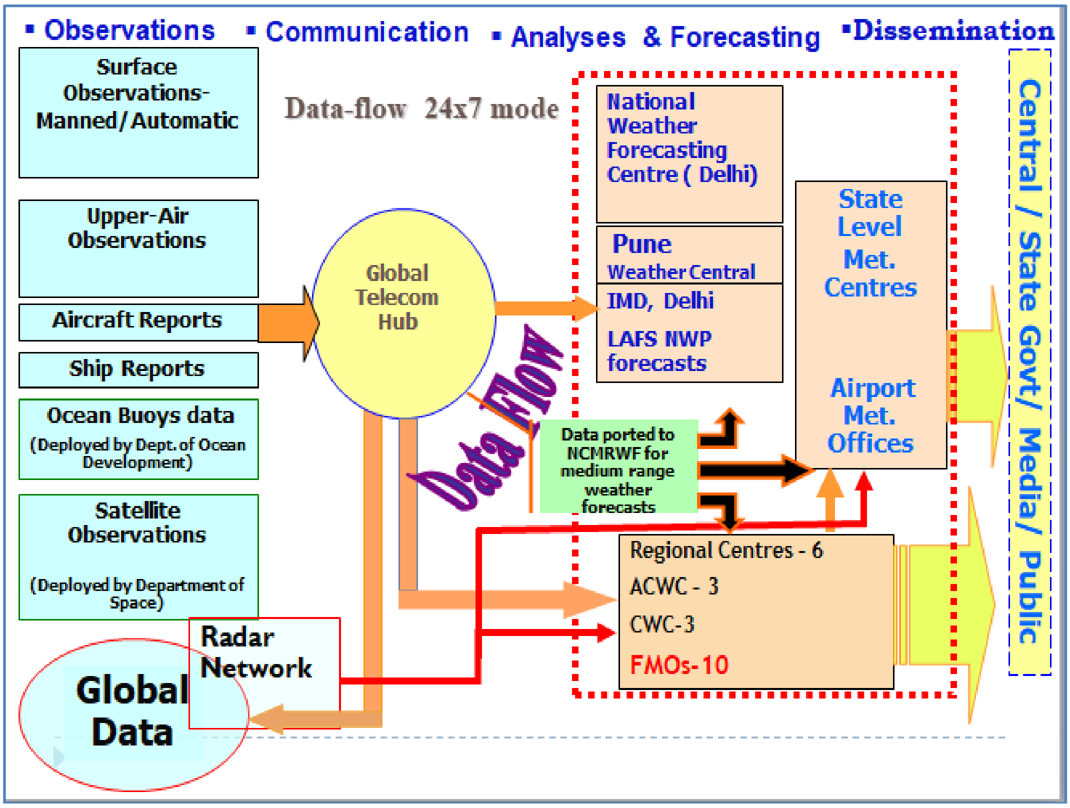


Figure 5.10. Flow charts of Heavy rainfall monitoring and warning

5.7.3. Analysis and Forecasting

Forecasters will analyse actual weather charts along with supporting NWP and satellite/Radar products to assess intensity, position, behaviour and direction of movement of the weather system(s). After processing all weather data duty officer will issue HRW over the area of responsibility if expected. Heavy rainfall warning should be issued without fail, when forecasters estimate that the weather system is likely to hit the area of responsibility 5 Days and may give heavy rain. In subsequent bulletin, the warning may be reviewed by referring the weather charts, NWP/Satellite/RADAR products, position of the system and its direction of movement. Basic steps are given below.

- Duty Forecaster will analyse all the received data on the workstation available to him continuously. For fulfilling it, a digital signature to record as the proof of his time of analysis should be provided at his work station. The MC/RWFC, where such facility is not available, a manual log book will be maintained for this purpose.
- Forecaster will issue a bulletin/warning on the basis of observations and messages received. In case of likelihood of heavy rainfall inferred from various inputs, for the region of forecast of the SWFC / RWFC, the forecaster will issue brief characteristics of the heavy rainfall and necessary warnings.
- In case no heavy rainfall expected, the concerned SWFC / RWFC will issue a “Warning : Nil”.

5.7.4. Decision making process

NWFC issue sub-division wise Heavy Rainfall Warning(HRW)for the whole county (Annex 1) while SWFC/ RWFC will issue HRW district-wise for the respective state (Annex 2) and these warnings are issued for 5-days validity period udapted 6-hourly basis**.** Issuing HRW is the sole responsibility of the concerned MC/RWFC. However, they will discuss the matter with NWFC by 1030 hrs. IST for issue of warning based on data of 0830 hrs. IST of the day through tele/video conferencing. In case of discrepancy, the view of SWFC /RWFC will prevail.

Decision making involves the following features:

- Routinely retrieval and review of scheduled bulletins and products issued by SWFC/RWFC/AMO, Satellite, Radar, upper air, synoptic divisions
- Forecaster should recognize impact of unrepresentative/erroneous observations. Once the error is recognized, it should be discounted. An observation can be suspected only by comparing it with observation of the surrounding station/stations. Also it should be seen whether the concerned observation has compliance/non-compliance of the conceptual models considered. Once the error is ascertained, the forecaster should take necessary action to collect correct information from the observatory and its further communication.
- Diagnose conditions along the boundaries. The duty forecaster will monitor forecast/warning issued for adjacent region. The duty officer will liaison with forecasters of adjacent region also.
- Noting weather nearing the predefined threshold of severity in the area of responsibility.
- Once a Duty forecaster detects any impending heavy rainfall event in the domain of responsibility, he/she will consult with RWFC/NWFC/Satellite/RADAR Centre to arrive at a decision of issuing a heavy rainfall warning. Duty forecaster, will contact the senior designated officer and discuss the input to arrive at the conclusion of issuing a heavy rainfall warning.
- Forecaster should use techniques appropriate for heavy rainfall warning. He/she should correctly use subjective (synoptic), NWP and statistical guidance. For heavy rainfall warning valid up to 24 hrs synoptic method supported by NWP guidance and other models observation tools/products like satellite and radars should be used. In this range the mesoscale WRF model guidance should take precedence of global NWP models. For 48 and 72 hrs validity period, mainly the suitable NWP models (both global and mesoscale) should be used. For this purpose the suitability of various models for the area of interest should be verified for daily use. In the absence of this information, the mosel which best suits the initial condition of the day of the day should be used for heavy rainfall forecast.
- The forecaster should commence with predicting the evolution and motion of the weather system for heavy rainfall.
- The duty forecaster will prepare the checklist for decision making based on the above guidelines. SWFC / RWFC should prepare their region specific checklist as per their own requirements and the local conditions under the broad framework of this SOP.

- The forecaster should proactively amend the forecast as and when the situation demands.
- The duty forecaster will respond in a timely manner when amendment criteria are reached.
- Entire process of decision making has to be logged precisely and methodically.

5.7.5. Time line for analysis, forecast and dissemination

All forecast/warnings will be issued at the time scale of 3 hours and spatial scale of districts from corresponding SWFC / RWFC. The time line for this purpose is given below.

HH: Appreciation of the scenario through synoptic and NWP analysis and forecast
↓
Analysis of hourly data and products (Satellite, Radar, AWS, ARG, Metar, Speci etc)
↓
HH+1: Preparation of Check list and decision making
↓
HH+2: Generation of warning bulletin and products
↓
HH+2.5 : Uploading and dissemination

The offices will issue HRW four times/two times a day according to infrastructure/ facilities available (like availability of Synergy) and depending upon requirements of various users.

Table 5.7.

Preparation & dissemination time of various charts/products

Charts/Product Time	Preparation Time	Dissemination Time
0600UTC	0900UTC	1000UTC
1200UTC	1500UTC	1600UTC
1800UTC	2100UTC	2200UTC
0000UTC (of next day)	0300UTC	0400UTC

5.7.6. Forecast/warning services

5.7.6.1. Directory/List of Warnees

(i) Complete upto date list of HRF warnees, with address and telephone numbers to be kept. List of warnees to be updated in the month of March every year.
(ii) The duty officer will ensure that HRW has been issued and has been passed on to all concerned.
(iii) Highest authorities of the State (Chief Secretary, Military, Relief commissioners etc.) to be kept informed telephonically by D/O or class I officer.
(iv) A log book to be maintained for this purpose.

5.7.7. HRW Products

5.7.7.1. Text of heavy rainfall warning in color code tabular form

The text to be adopted in operational use depending on spatial distribution of heavy rainfall is as follows:
Heavy/very heavy/extremely heavy rain would /will occur at isolated/scattered/ in the districts/subdivisions............. (name) during 12/24/36/48 hrs.
Heavy to very heavy rain would /will occur in districts/subdivisions ......(name) during 12/24/36/48 hrs.
Extreme heavy rain would /will occur in districts/subdivisions ....(name) during 12/24/36/48 hrs.
NWFC and state Format given in Annex I and II

5.7.7.2. In graphical form of Multi-hazard colour code maps

Annexure 3 is the forecast circular 2018 forecasting colour code while Annex 1 is the sample in multi-hazard map for upto Day 5 issued by NWFC and Annex 2 at districts level issued by MC.

5.7.8. SOP of Local Heavy rainfall forecast and Urban heavy Rainfall Monitoring and warning services

IMD has taken up the Urban Meteorological services as one of its priority project for providing location specific at sub-city based severe weather warning for major cities which also **includes impact based warnings for local heavy rainfall events** which causes flash flood. The SOP of heavy rainfall forecast over urbane areas, major cites and local forecast are available in respective SOP

5.7.8.1. SOP on Location specific heavy rainfall forecast - A consensus approach of all NWP model products and other checklist

- IMD issues various forecast and warnings routinely at sub-division, district and city scales. While the sub-divisional scale short to medium range weather forecast is issued by NWFC, 4 times a day the short to medium range forecast at district-wise scale is issued by MC/RMC and updated twice a day. The Nowcast are issued by MC/RMC every three hours for districts and cities/town, the short to medium range cities forecasts are issued by MC/RMC which are updated 4 times a day for different parts of the city.
- In addition to the general forecasts and warnings the **Local Forecasts for the Capital and other important cities/towns is very important for management of urban activities.** These forecasts are very important particularly for special occasion like 15th August, 26th January, festival/fair/tourism and also for VVIP movements.
- Though the Local Forecasts are issued for 7 days (or some time for special occasions the forecasts are issued 10 days to two weeks in advance) but its utility is increased manifold upto 48 hours so the forecasters need to be accurate in terms of time and space as the lead time decreases.

5.7.8.2. Objective of present SOP for issuing city/local forecast of heavy rainfall

- The objective of the present SOP is to integrate all available observed and forecast products (surface, upper-air, radar and satellite, etc) and NWP model forecasts to improve the location specific forecasts.

A. Issuing Authority

- Duty officers of MC/Head of MC/RMC forecasting offices will be issuing final local forecast over the major cities within their respective regions. For forecast in Delhi, NWFC will issue the forecast in consultation with RMC Delhi.

B. Stages of Local Forecast

Stage -1: 7 days or more before the event date (or as per the requirement)

NWP models are capable to provide indications and likelihood over a city or location about 5 days in advance. Also the extended range forecast will be able to capture the large scale condition prior to about 10 days of the event. The initial forecasts can be issued and updated once in a day by using the model products. Based on the various models guidance from deterministic and probabilistic NWP models the forecasters will decide the forecast weather element and their probability of occurrence and its intensity. Based on the various models guidance from deterministic and probabilistic models the forecasters will decide the forecast of weather elements and their probability of occurrence and intensity.

Following models and observations are to be used for this purpose.

- IMD Extended Range Forecast products & NCMRWF Extended Range Forecast products
- GFS & GEFS; UM & UMEPS; ECMWF, NCEP GFS
- Also the forecasters should use the climatological guidance

Stage -2: 3 to 6 days before the event date

Following models and observations are to be used for this purpose in this time scale. As the lead time decreases, the forecast need to be modified based on the local observations and updated models products.

Forecast products (both direct and derived) from various models such as:

a. GFS-T1534, WRF, GEFS, NCUM, NEPS, NCEP GFS, ECMWF &UKMO (Available through SWFP portal)

b. METEOGRAM, EPSGRAMS from all models are to be used.

https://nwp.imd.gov.in/login.php

http://www.ncmrwf.gov.in/All_times_ind_mihir_00.php

SWFP login (for ECMWF & UKMO models)

c. Climatological inputs (Normal, Extremes and Severe Weather)

Stage -3: 48 hours to 24 hours before the target date/event

This is the very crucial period of forecast. All inputs are to be considered based on synoptic observations, thermodynamic indices, dynamical parameters and NWP models outputs and all entries are to be documented in a specified tabular form.

Following inputs are to be considered.

i. Synoptic inputs

Surface synoptic charts – SYNERGIE SYSTEM / AMSS
METAR/SPECII observations– SYNERGIE SYSTEM/OLBS
Upper-air charts from OLBS (AMSS)/Synergy
Parameters : (MSLP, T, TD, RH, Wind, cloud type and cloud cover and their changes in past 24 hours)

ii.Observed thermodynamic indices & dynamical parameters for the location based on nearest GPS/RSRW observations.

CAPE & CINE
Low level wind direction & speed,
Low to mid level humidity
Warm air advection or veering of wind (Winds that rotate clockwise with height)
Cold air advection or backing of wind (Wind turning counter-clockwise with height)
Vertical wind shear at lower level
(The website of UAID may be referred)

iii.Satellite inputs

a. RGB of INSAT-3D, CTT and Skew-T charts from RAPID

http://www.rapid.imd.gov.in/

b. RGB of EUMETSAT

http://foreignsat.imd.gov.in/

c. Animation

http://foreignsat.imd.gov.in/, http://satellite.imd.gov.in/img/animation3d/sanew_3d.htm iv.Model forecasts

Forecast products (both direct and derived) from various models such as:

d. GFS-T1534, WRF, GEFS, NCUM, NEPS, NCEP GFS, ECMWF &UKMO (Available through SWFP portal)

e. METEOGRAM, EPSGRAMS from all models are to be used.
https://nwp.imd.gov.in/login.php
http://www.ncmrwf.gov.in/All_times_ind_mihir_00.php
SWFP login (for ECMWF & UKMO models)

v. .Climatological inputs (Normal, Extremes and Severe Weather)

Stage -4: On the day of the event before the target date/event

Surface observation as described in Stage 3 i on hourly basis at the location

A. Observed thermodynamic indices & dynamical parameters for the location based on nearest GPS/RS/RW observations. (Same as 3ii)

B. Satellite inputs (Same as 3iii)

C. Model forecasts (Same as 3iv). Additional Nowcast products are to be utilized.

D. Climatological inputs (Same as 3v)

E. Radar parameters

d. MaxZ

e. Wind
http://www.imd.gov.in/pages/radar_main.php

f. Animations
http://ddgmui.imd.gov.in/radar/leaflet-map-csv-master/mosaic.php

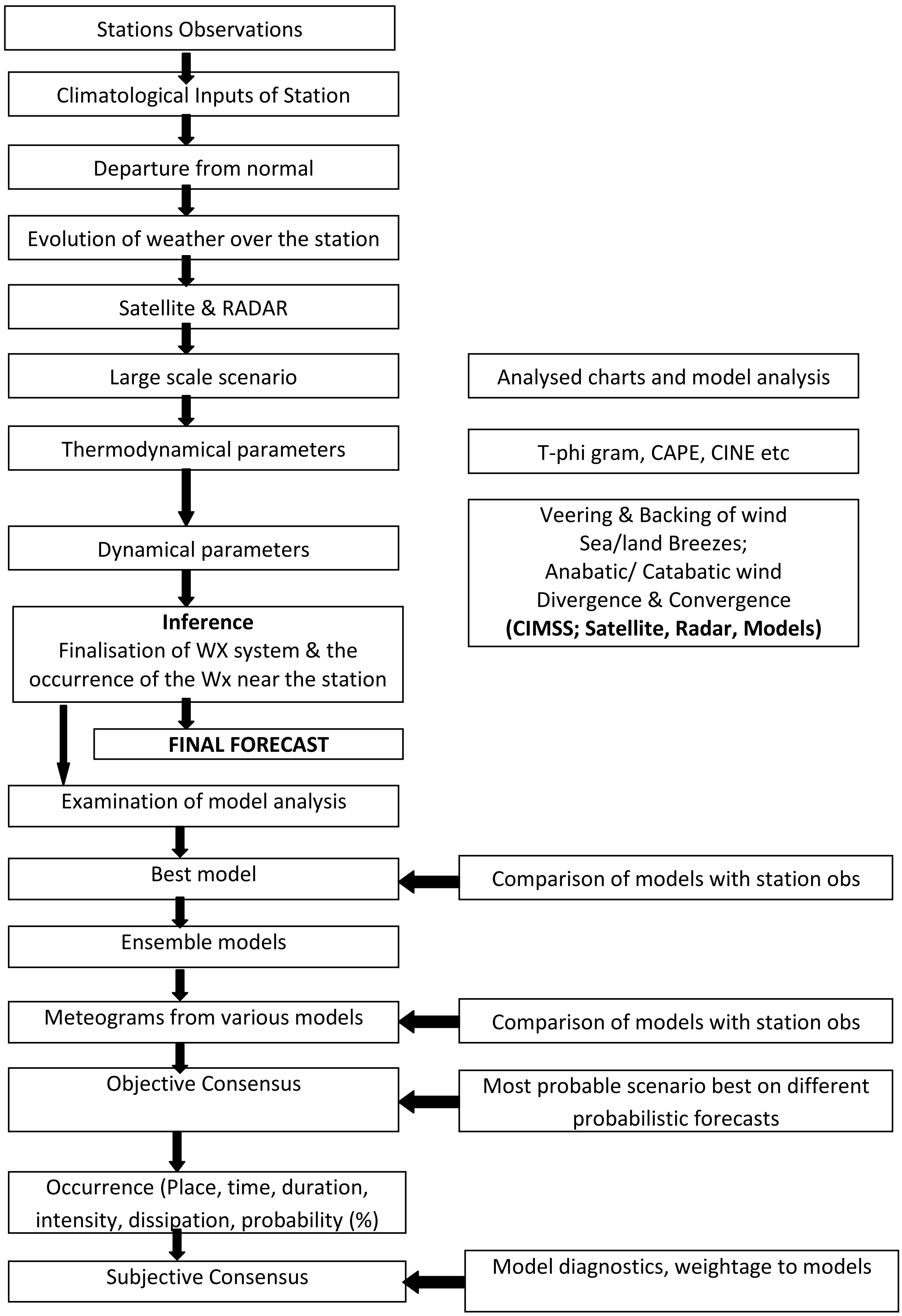
Stage -v: Before 6 hours of the event

SOP for Nowcast is to be followed.

Local Forecasts for the Capital and other important cities/towns is very important for management of urban activities.These forecasts are very important particularly for special occasion like 15th August, 26th January, festival/fair/tourism and also for VVIP movements.

Though the Local heavy rainfall Forecasts are issued for 7 days (or some time for special occasions the forecasts are issued 10 days to two weeks in advance) but its utility is increased manifold upto 48 hours so the forecasters need to be accurate in terms of time and space as the lead time decreases.

5.7.8.3. Decision Making Process for Local heavy rainfall Forecast

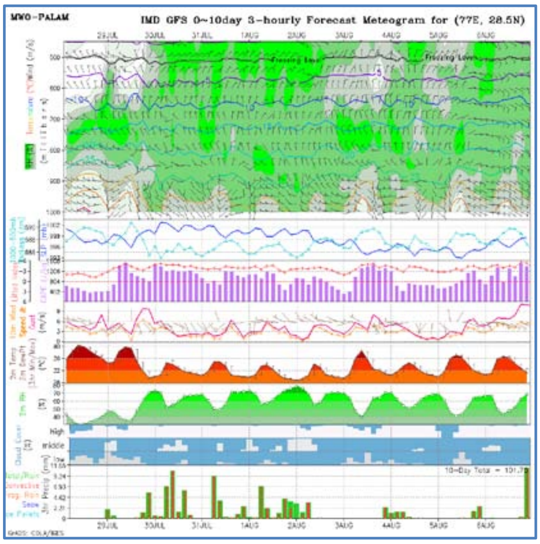


5.7.8.4. Decision making & preparation of final forecast

- Based on all these inputs from NWP models an objective consensus will be drawn with respect to occurrence/non occurrence of the event (Both deterministic and probabilistic), its time of occurrence, its duration, its dissipation.
- Based on model diagnostic/prognostics and the observations from Satellite/Radar/AWS/ARG and synoptic station, a subjective guidance will be developed to moderate the objective consensus. For this purpose the individual model analysis for that station will be compared with the actual observation and hence the initial value of the model can be modified and hence the forecast can also be modified. The available forecasters will consult with each other to exchange their knowledge, expertise, experience to arrive at subjective consensus.
- In case of forecast for VVIP user for Delhi, it has to be approved by Director General of Meteorology 2 days prior to the target date.

5.7.8.5. Meteograms of Location

Meteograms of various locations are also available based on GFS, WRF, NCUM and NEPS model now available at single click display



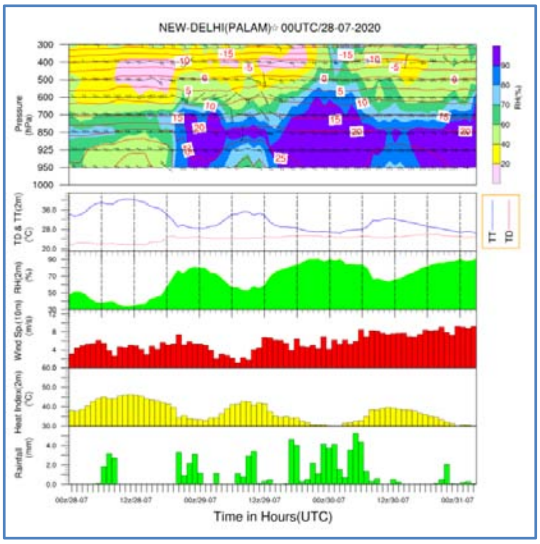


Table 5.11.

Sample of Objective Consensus for Location specific rainfall

DATE	METEOGRAMS	RAINFALL	AMOUNT of Rainfall (mm) valid for 15th August			
			0_6 UTC	6_12 UTC	12_18 UTC	18_24 UTC
15-08-2020	ECMWF	YES	1.5 (Max=3)	4.5 (Max=10)	1 (Max=11)	3 (Max=7)
	GEFS	YES	8 (Max=19)	0 (Max=1)	2 (Max=4)	3 (Max=12)
	GFS	--				
	UKMO	YES	4 (Max=6)	2 (Max=4)	1 (Max=3)	4.5 (Max=12)
	NCUM	YES	3	0	0	1
	NCUM-EPS	YES	5 (Max=8)	4 (Max=7)	0 (Max=2)	3 (Max=13)
	Mean Rainfall		4	2	1	3
			(Max=19)	(Max=10)	(Max=11)	(Max=13)

5.7.9. SOP of Heavy rainfall- Impact Based Forecast(IBF) and risk based warning

A SOP on IBF is already implemented in IMD since June 2020 and its objective is to integrate all available observed and forecast weather and climate information of heavy rainfall event forecasts using all observations (surface, upper-air, ship, buoys, aircraft, radar and satellite) and NWP model forecasts for issuing IBF at met sub-division, district wise and at sub-city levels.. The Continuous monitoring through hourly/sub-hourly rainfall observations, RADAR & SATELLITE observations will be the basis of nowcast in real time while alert has already been given in the forecasts for the day.The frame procedures based on IBF from heavy rainfall, covering variant of services with lead time, types of bulletin, graphics and etc are in its SOP. The SOP includes formats and types of bulletins/forecasts and warnings along with provisions to include location and intensity of the heavy rainfall appended with hourly to 3 hourly rainfall updates from AWS/ARG and SYNOP stations available in the city as well as QPE from the satellite/radar. The features of weather system using RADAR and Satellite pictures along with alert/warning message will be added to bring necessary attention of the disaster manages and general public. This section discussed IBF concepts and IMD SOP.

5.7.9.1. What is IBF-Heavy rainfall

Impact based forecast: *Reorient Focus from what the weather will be to what the weather will do*. Weather Ready Nations (WRNs) program is implementing an Impact-based forecast system following the WMO, 2015 guidelines (Ref: WMO guidelines on multi-hazard impact based forecast and warning services).

Heavy rainfall over an area or over a location has following types basic impact:

- Flash Flood and Riverine flood
- Urban Flash Flood and Flash flood over Hilly areas with steep topography
- landslides and debris flow
- Local Inundation, Road and Traffic disruption
- Agriculture
- Infrastructural Damage-Houses, roads, Airport, Hospitals, City center
- Emergency Services gets affected- Electricity, Phone/Internet and water
- Socio- economic Impact like- Human lives and health and Livestock

The various components of impact based forecast system are shown in following charts

- Assessing Risks
- Monitoring and Early Warning
- Dissemination and Communication
- Response Capability

.

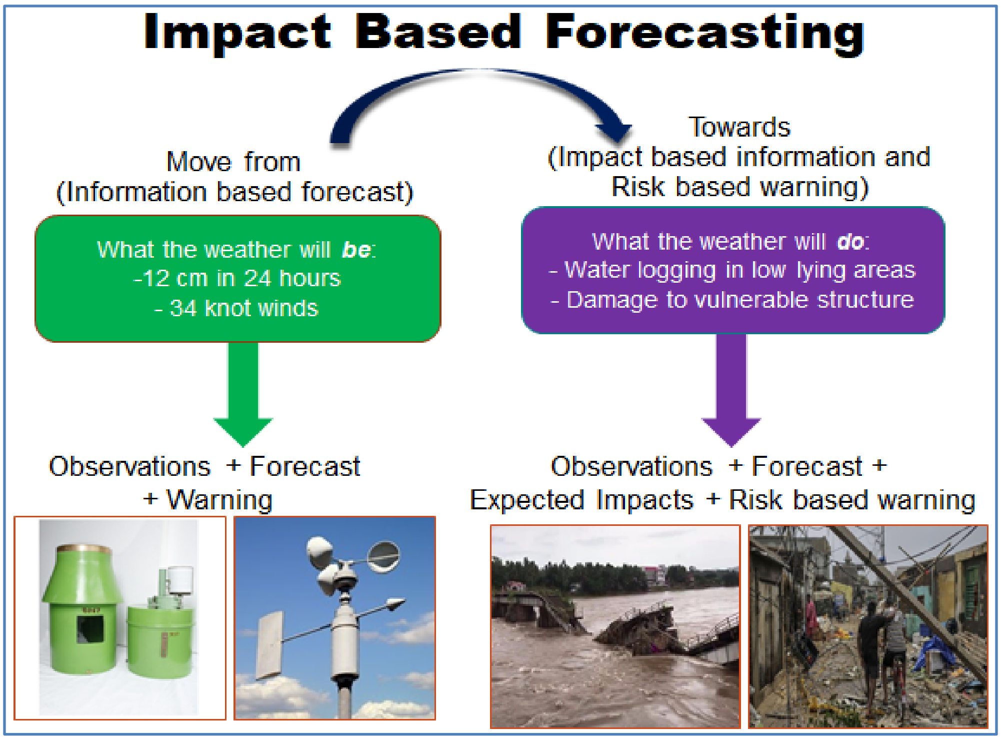


Figure 5.12. Impact based forecast component

5.7.9.2. Stages of IBF-Heavy rainfall development and implementation in IMD

In India, IMD has been developing IBF and warning, stage wise, for various severe weather as per WMO, 2015 methods. It covers cyclone, heat wave, fog, cold wave, and heavy rainfall, thunderstorm. Stages of developments for IBF are:

Stage-I: Threshold Method
Stage-II: Qualitative combination method
Stage-III: Impact Model method
Stage-IV: Climate Sensitivity Method

Threshold Method : In threshold method, color code warning is given based on meteorological threshold. It is based on WMO guideline and depends upon two factors i.e. likelihood of weather event and potential impact of hazard. It was implemented in IMD since 2013 for all type of weather hazard affecting Indian region with gradual development.

Qualitative combination method : In this method in addition to threshold method, a generalized impact is developed for each severe weather type through consensus among the forecasters based on subjective assessment of potential impacts corresponding to weather warning threshold. Generalized impact is implemented for all type of weather hazard.

Impact Model method : In this method in addition to qualitative combination method, climatological data of past impact corresponds to different severe weather hazard is collected and then a threshold is fixed for each hazard. Thereafter a climatological impact is prepared for different type of hazard based on threshold. Currently, various climatological data of different hazard and impact is collected and data is supplied to NCCR for analysis and in house analysis of data is under process.

Climate Sensitivity Method : In climate sensitivity method in addition to climatological impact, Real time impact based forecast and risk based warning will be given by considering the real time information of meteorological hazard, vulnerability and exposure in geo reference coordinate and a decision support system will also be established. Meteorological data has been collected and being analysed. However exposure date is being collected.

5.7.9.3. Stages of implementation of IBF

IMD implemented generalized Impact based forecast for heavy rainfall since 2018 Monsoon season with further development in 2020 Monsoon season. From 2018, as per forecast circular (Annex 3), colours are assigned based on vulnerability of past data.

The impacts are finalized through VC consultation for issuing real time impact Based warnings at met sub-division/district upto 5 days. It has completed the Stage I and Stage II of development and implemented it at all India.

Color code for IBF graphics/table

Risk and Response Matrix:

Risk Matrix					
Likelihood	HIgh				
	Medium				
	Low				
	Very Low				
		Minimal	Minor	Significant	Severe
		Potential Impacts			

Risk Level	Response
High	Take Action
Medium	Be Prepared
Low	Be Aware
Very Low	No Action

Figure 5.13. Risk & Response Matrix

The existing colour code as prescribed by WMO and reproduced here will be utilized to provide impact based forecasting & response action.

From monsoon of 2020 Data of past impact has been collected and analyzed for major cities of India and IBF for 20 major cities was also started since Monsoon 2020 season. Exposure data is being collected for Real time IBF and Risk based matrix. However Chennai Flood warning system (C-Flows) and Mumbai Flood warning system (i-Flows, since 2020) is in place and Kolkata flood warning system is under process for real time IBF.The format of IBF given in Annex IV where heavy rainfall warning issued via Multi-Hazard map and tabular form both for Met sub-division wise and district wise. The impact and response action will be provided in the warning table corresponding to heavy rainfall warning. The standard impact & response table are given below. The generalized impact is classified and suggested actions are given below which have been implemented at me sub-division/district levels while Table 5.8 shows city based matrix derived using past impact and heavy rainfall data for 1991-2020-30 years.

Heavy rainfall- Impact based warning & Action suggested (Met sub-dvsion wise and district wise) - implemented in IMD at real time since July 2019

A. Impact

- Localized Flooding of roads, water logging in low lying areas and closure of underpasses mainly in urban areas of the above region.
- Occasional reduction in visibility due to heavy rainfall.
- Disruption of traffic in major cities due to water logging in roads leading to increased travel time.
- Minor damage to kutcha roads.
- Possibilities of damage to vulnerable structure.
- Localized Mudslides(for plain areas) and Landslides (for hill and vulnerable areas)
- Damage to horticulture and standing crops in some areas due to inundation.
- It may lead to riverine flooding in some river catchments (for riverine flooding please visit Web page of CWC)

B. Action Suggested

a. Check for traffic congestion on your route before leaving for your destination.
b. Follow any traffic advisories that are issued in this regard.
c. Avoid going to areas that face the water logging problems often. Avoid staying in vulnerable structure.

Table 5.8

Impact Based Forecast Matrix for Mumbai

S. No.	Heavy rainfall Intensity	Expected Impact	Action Suggested
1.	**Moderate rainfall (<6cm)**	▪ Slippery roads ▪ Localised traffic congestions	• Nil
2.	**Heavy rainfall (>=7 cm) with moderate to intense spell**	▪ Localized flooding/water logging of low lying areas ▪ Traffic congestions	• Traffic may be regulated effectively
3.	**Cumulative rainfall (>= 12 cm in 48 hours)**	▪ Localized flooding/water logging of low lying areas ▪ Traffic congestions ▪ Possibility of danger to very old buildings and unmaintained structures	• Traffic may be regulated effectively ▪ People living in very old buildings and unmaintained structures may take caution
4.	**Very heavy rainfall (>=12 cm)**	• Water logging/ flooding in many parts of low lying area and river banks • Localized and short term disruption to municipal services (water, electricity, etc.) • Major disruption of traffic flow. Major roads/local trains affected. • Possibility of danger to very old buildings and unmaintained structures, falling of trees etc ▪ Closure of roads crossing low water bridges	• Traffic may be regulated effectively • People in the affected area may restrict their movement
5.	**Heavy to very heavy rainfall with isolated extremely heavy rainfall at isolated places (>=20cm)**	Widespread and severe water logging/ flooding in most parts of low lying area and also on river banks. • Major disruption of traffic flow. Major roads/local trains and travel routes severely affected. • Localized and short term disruption to municipal services (water, electricity, etc.) • Possibility of danger to old and unmaintained structures, falling of trees etc • Possibility of local landslides in elevated hilly areas • Possibility of inundation of coastal areas when coincided with high tide • Closure of roads crossing low water bridges	• Traffic may be regulated effectively • People in the affected area may restrict their movement

5.7.9.4. SOP on IBFand Risk based warning of Heavy Rainfall Warning

NWFC will issue IBF for met sub-division wise while Concern Duty officers of MC/Head of MC/RWFC forecasting offices will be issuing final impact based forecasts for all heavy rainfall events over the major cities and districts within their respective regions.

Stages of IBF based heavy rainfall warning

Stage -1 : Heavy rainfall Advisory(Watch)-(3-4 days lead time with 12-h udpates)

Heavy rainfall (Intensity, location, day/time of occurrence, onset, duration and cessation) remain a challenge to forecast world-wide. However, NWP models are capable to provide indications and likelihood over a city at 2-5 Days in advance especially in case it is associated with some well-defined monsoon systems**. In latter case, a preliminary bulletin in terms of heavy rainfall outlook can be issued and updated time to time (format enclosed as Annex V). It can be disseminated mainly to disaster managers for the city.**

Stage-2 : Heavy rainfall Alert (48 hours prior to the occurrence of the event at 12 hourly updates)

Model consensus mostly develops when event lead time is within 1-3 days. Hence Color coded messages in tabular form with Impact types(**format encld as Annex Ib**) can be issued at this lead time with likely rainfall amounts and duration of the event. Probability based forecast guidance should be issued considering its likelihood of occurrences. Based on potential impact, risk should be decided using color matric. This forecast has to be **disseminated using e-mails, web page, various social media, WhatsApp, etc. Expected Impact may be accordingly included as per Annex VI.**

Stage-3 : Heavy rainfall Warning (24 hours prior to the occurrence of the event at 06/12-hourly updates)

At this stage 3, a complete diagnostic and prognostic feature from available RADAR, Satellite, NWP and Convective products needs to be evaluated. After all critical analysis, bulletin can be further modified including IBF and a concise color code warning can be issued by including all features of the event and likely impact over the city/part of that city. The format **of this bulletin is enclosed in Annex vii.**This bulletin has to be **disseminated to all user communities including local media using web page, e-mails, various social media, WhatsApp, etc.**

Stage-4 : 12-Hours prior to occurrences of maximum rainfall spell

By this time heavy rainfall event can be under intense monitoring using RADAR, Satellite, ARG/Synop hourly/half-hourly current weather information and GFS/WRF/NOWCAST models. The warnings and it's all features should be updated in every hour/3-hours. It is final and crucial stage of IMD warning system and all attempts must be made by the concerned MC/RWFC to make its monitoring, forecasting and warning reasonably correct and timely. The time to time coordination with concerned disaster management and media should be carried out with telephonic conversations, SMS and WhatsApp etc. To carry out such task smoothly from the start of the event as captured by RADAR/Satellite, a complete diagnostic and prognostic features of the event along with associated cloud characteristics and rainfall distribution as available from RADAR, Satellite and surface data e.g. AWS/ARG/SYNOP have to be made available to the duty forecasters. The format of the bulletin in stage 4 is given in Annex VIII. It is impact based warning with a color code for different parts of the city. This bulletin has to be disseminated to all user communities including local media using web page, e-mails, various social media, WhatsApp, etc.

5.7.9.5. SOP IBF and Risk based warnings for city, District and Met Sub-Division

It covers guidelines regarding spatial and temporal resolutions of forecasting

- Impact based forecasting & warning should be provided at meteorological city level initially by MC/RMCs, later on the area of the impact will be demarcated with different color without restricting to city boundaries.
- At the MC/RMC level the impact based forecast will be provided at the district level initially (within the city), later on the area of impact will be specified specially, as and when the decision support system will be available to the forecaster.

- The impact based forecast will be issued for next 5 days like existing severe weather warning e.g. D1, D2, D3, D4 & D5. With the availability of the advanced tools for severe weather prediction, Impacts Based Forecast will be issued for the city during the time scale of nowcast/very short range forecast.

5.7.9.6. Decision making on IBF and warning

The decision regarding expected impact will be taken by analyzing the severity & likelihood of weather event on daily basis. The decision will be taken through video conferencing to decide the impact (very low, low, medium or high) at sub-divisional level. Correspondingly the expected impact for a given severe weather will be described from pre-defined table. Also the suggested response action will be decided accordingly following the response action mentioned in response table with respect to expected category of impact. The decision for district level impact & response forecast will be issued by MC/RMC for their area of responsibility considering all the above factors.

In view of low skill of heavy rainfall forecast at 3-5 days lead time over a location by the NWP models and for providing a Red color in IBF matrix needs high skill score so, Red color IBF warning cannot be given beyond 48 hours and for lead time higher than 48 hours yellow & orange color can be given.

Viz: For any extremely heavy rainfall on Day 5: Give yellow color on Day 4 & 5, orange color on Day 3 and give Red color on Day 2 & 1. Even though we may be confident sometimes about the occurrence on day 5 on first day itself, red color warning we will not be given beyond 3 days.

Upload of bulletins: Impact based forecast will be uploaded 4 times in a day in NWFC and 2 times in a day in MC/RMC normally. However in case of repeat **development or cessation of extreme weather or false alarm the bulletin may be updated immediately**. Day-1 forecast will be valid till 0830 hours IST of next day for all forecast issued that day.

5.7.9.7. Real time Customized Heavy rainfall monitoring and IBF system operational over Mumbai and Chennai

IMD has taken up the Urban Meteorological services as one of its priority project for providing location specific at sub-city based severe weather warning for major cities which also **includes impact based warnings for local heavy rainfall events** which causes flash flood.

The present Urban met services of IMD functional at most cities in India. It can be classified as:

i) 6-h local forecast updates issued routinely at sub-city level that includes temperature and rainfall observations.

ii) Sub-city level during potential severe weather development at least 3 hourly .

iii) Impact Based Forecast for City heavy rainfall forecast.

To improve services during heavy rainfall events for vulnerable cities, a 5- years plan has already been implemented for 2019-2024 for improving both the monitoring systems with installation of more dense network of ARG/AWS at various cities as well as other modern monitoring facilities covering DWR, Radiometers, wind profilers etc and work is in progress through collaboration with its other institutions of MoES like IITM, NCMRWF, NCCR, INCOIS and with local administration authority like Municipal and disaster authorities.

Chennai Flood Warning System (C-FLOWS)

- A multi-institutional project involving institutions of MOES (IMD, INCOIS, NCCR, NCMRWF), IIT-Bombay, IIT-Madras, IRS-Anna University.
- A tools for relief and mitigation operations especially during flooding
- A disaster preparedness decision support system for coastal flooding in urban areas
- C-FLOWS : first operational system for urban flooding in country

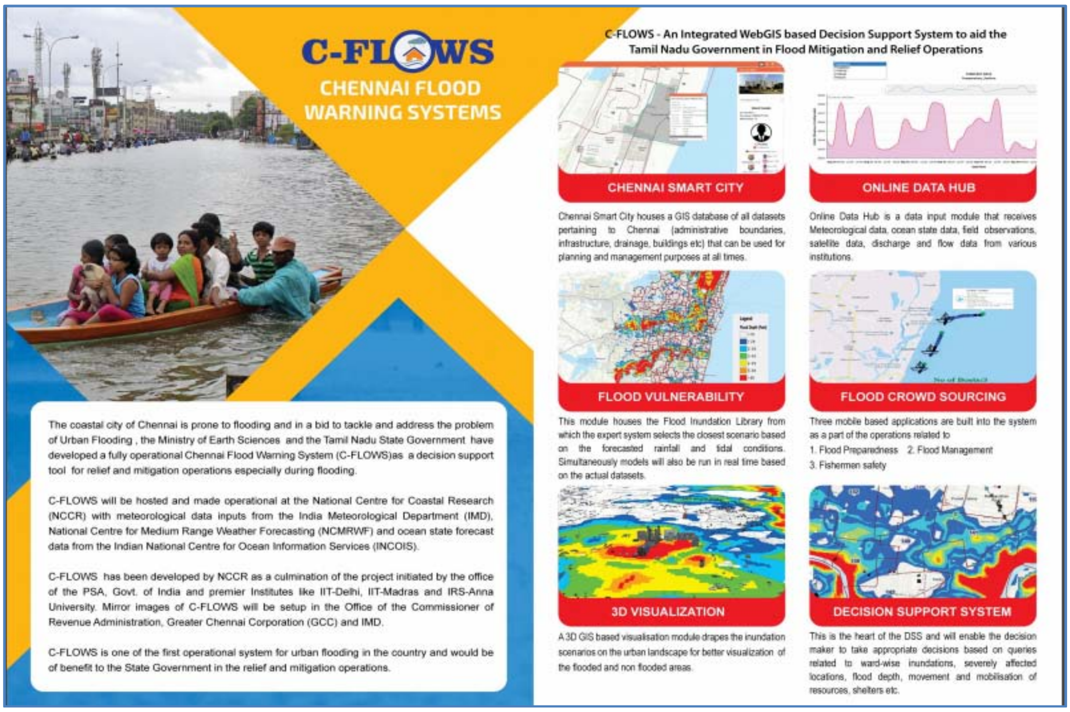


Figure 5.14. C-FLOWS

(i) Integrated Mumbai Flood Warning System (I-FLOWS)

Extreme precipitation events are on the rise in India driven by warming temperatures and changes in the monsoon due to climate change. The capital of the state of Maharashtra, Mumbai, a megapolis and the financial capital of India has been experiencing floods with increased periodicity and recent flood in 29 August, 2017, brought the city to a standstill. The flood during 26th July, 2005, is probably etched in the memory of every Mumbai citizen, when the city received a rainfall of 94cm, a 100 year high in a span of 24 hours paralyzing the city completely. As a preparedness for floods before they occur, people to be warned so that they can be prepared in advance for flooding conditions.

In a bid to aid in the mitigation activities of the flood prone city, Municipal Corporation of Greater Mumbai, Govt of Maharashtra approached the Ministry of Earth Sciences (MoES) to develop an Integrated Flood Warning System for Mumbai referred to as, IFLOWS-Mumbai. MoES initiated the development of IFLOWS-Mumbai in July 2019 using the inhouse expertise available within the Ministry of Earth Sciences in close coordination with Municipal Corporation of Greater Mumbai. IFLOWS-Mumbai is developed as a state of art Integrated Flood Warning system for Mumbai to enhance the resilience of a city of Mumbai by providing early warning for flooding specially during high rainfall events and cyclones.

I-FLOWS is built on a modular structure and comprises of seven modules, namely Data Assimilation, Flood, Inundation, Vulnerability, Risk, Dissemination Module and Decision Support System. The system incorporates weather models from National Centre for medium Range Weather Forecasting (NCMRWF), India Meteorological Department (IMD), field data from the rain gauge network stations setup by Indian Institute of Tropical Meteorology (IITM), Municipal Corporation of Greater Mumbai (MCGM) and IMD, thematic layers on land use, infrastructure etc provided by MCGM. Based on inputs from weather models, Hydrologic models are used to transform rainfall into runoff and provides inflow inputs into the river systems. Hydraulic models are used to solve equations of fluid motion to replicate the movement of water to assess flooding in the study area. Since, Mumbai is an island city with its connectivity to sea, hydrodynamic models and storm surge model are used to calculate the tide and storm surge impacts on the city. The system has provisions to capture the urban drainage within the city and predict the areas of flooding, which will be incorporated in the final system. The data on river bathymetry was collected in all rivers namely Mithi, Dahisar, Oshiwara, Poisar, Ulhas, lakes and creeks by NCCR in association with MCGM and IMD, Mumbai. The land topography, land use, infrastructure, population etc., was provided by MCGM and it was integrated into a Decision Support System to accurately estimate flood levels at ward level using thematic layers in GIS. A web GIS based decision supports system is build to calculate the vulnerability and risk of elements exposed to flood.

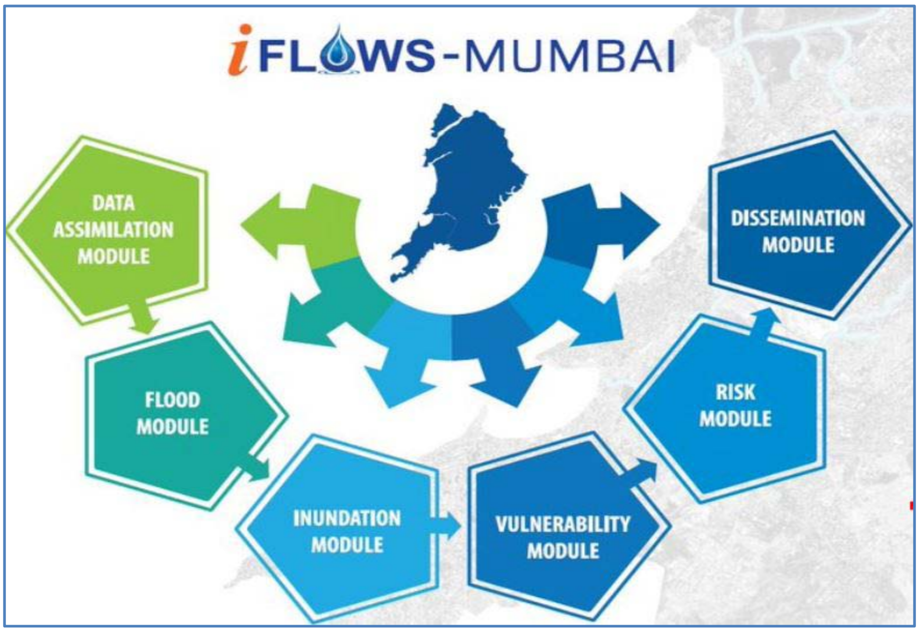


Figure 5.15. Mumbai I-FLOWS

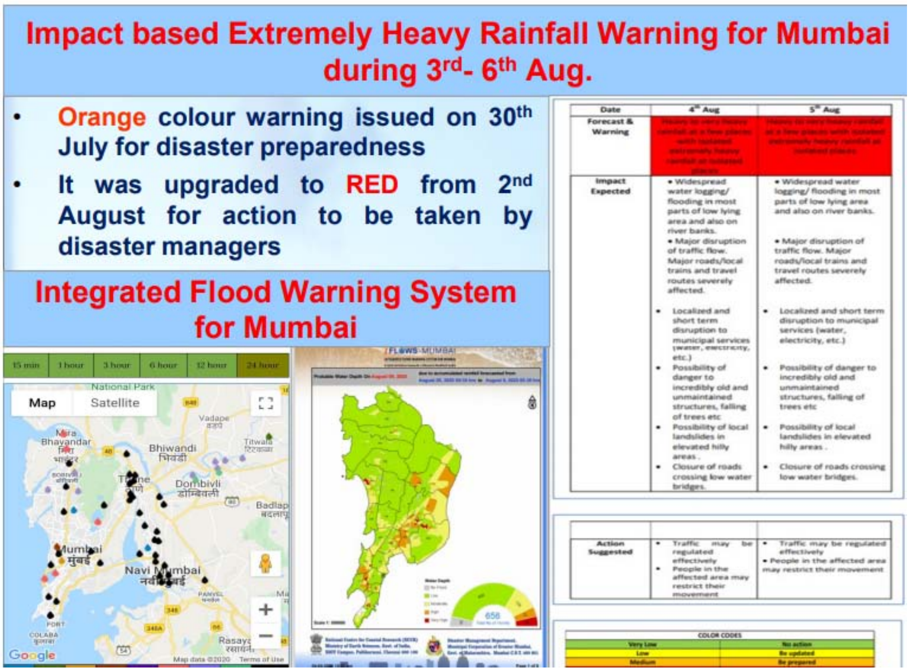


Fig. 5.16. Mumbai city-Impact based warning issued on 3 August, 2020

5.7.9.8. Heavy rainfall impact-Flood inundation forecast from FFGS

World Meteorological Organization (WMO), in partnership with the U.S. Agency for International Development/ Office of the U.S. Foreign Disaster Assistance (USAID/OFDA), the National Weather Service (NWS) of the U.S. National Oceanic and Atmospheric Administration (NOAA), and the Hydrologic Research Center (HRC) started a Global Flash Flood Guidance System project to cater services for hydro meteorological events occurring in short duration time. Global Flash Flood Guidance System (FFGS) is recognized as one of the **Impact Based Forecast and Warning Service (IBFWS)** tool.

The use of this tool in IBFWS has the ability to improve the synergy between NMHSs, NDMAs and citizens that play a role in hazard mitigation (e.g. flash floods), by bridging the gaps between the four components for effective early warning systems: ‘risk knowledge’, ‘monitoring and warning service’, ‘dissemination and communication’ and 'response capability'. The adoption of such a robust approach is identified as a high priority in the WMO Guidelines on Multi-hazard Impact-based Forecast and Warning Services (2015, WMO-No 1150) as well as in the Multi-hazard Early Warning Systems: A Checklist (2018). These support the Sendai Framework for Disaster Risk Reduction 2015-2030 (United Nations, 2015). The aim of the FFGS is to provide a diagnostic value (known as flash flood guidance refer Fig 5.17) that estimates the amount of rainfall of a given duration within a watershed that is required to produce flooding at the outlet of the catchment. The FFGS is designed to update its values in time and space and to "remember" rainfall that has already occurred in the catchment. In this way, the FFGS takes account of antecedent catchment conditions and can calculate the amount of additional rainfall that is needed in order to produce flooding. When these values are used in real time with nowcasts or in a forecasting capacity, they provide an objective basis to generate flash flood warnings.

The FFGS provides global coverage to 3 billion people or 40% of the world's population. The countries using the FFGS have a combined land surface area of around 25 million square Kilometers, which is equivalent to 18% of the total land surface area of the world. Specifically, the South Asia Flash Flood Guidance System (SAsiaFFGS) provides coverage for nearly 51% of the world's population.

Presently, ***SAsiaFFGS is in experimental operation catering services to India, Nepal, Bhutan, Srilanka and Bangladesh this 2019*** and it is active through two servers (Computational & Dissemination) hosted at **India Meteorological Department (IMD), India, as Regional Centre of SAsiaFFGS**. Upon verification of cases and validation on different temporal and spatial scales, the same has been on real time operation mode implemented in IMD since August 2020 and outputs are supplied to CWC and MCS/NWFC for improving IBF and warnings.

Salient features of **South AsiaFFGS operational in IMD**

- FFGS is a robust system to provide support for flash floodswarnings.
- Uses precipitation data from radar & satellite and hydrological models.
- IMD supports Bangladesh, Bhutan, India, Nepal & Sri Lanka.
- Provides flash flood guidance for about 30000 watersheds delineated with 30m DEM & other terrain parameters.
- System is currently pre-operational
- **IMD issuing bulletins 4 times a day i.e., 0530, 1130, 1730 and 2330 IST to Central Water Commission.**

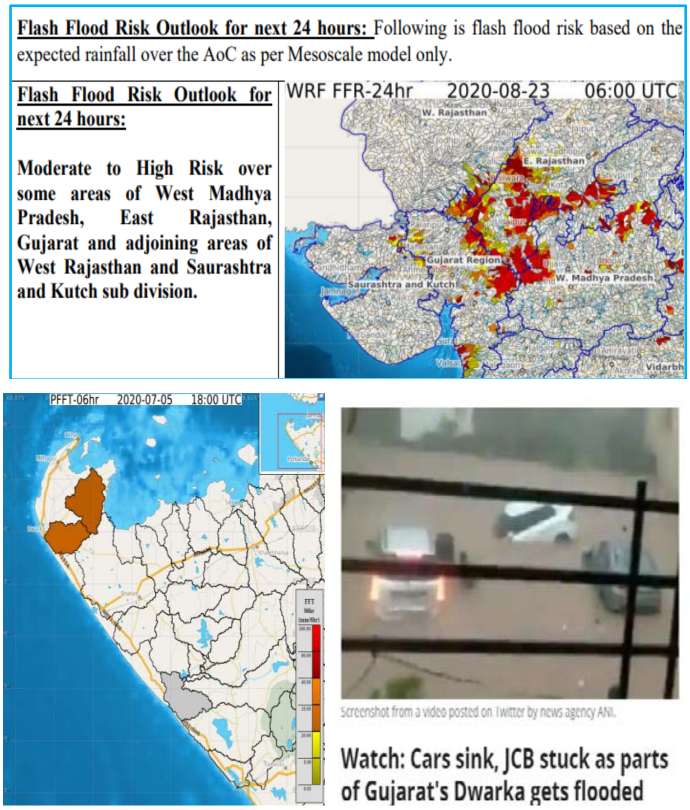


Figure 5.17. FFGS Real time products.(Top figure) 27 cm rainfall resulting in flash floods in Dwarka on 05 July, 20 casued local flodding captured by FGGS (left products) and photo (right)

5.8. Forecast and Warning dissemination of Heavy rainfall

- Weekly video in YouTube and social media
- Press release National, regional & State levels
- WhatsApp Group : National/Regional/State/district/city level for quick outreach
- Briefing/ Interaction via phone/VC with disaster managers at national, state & district levels
- Warning to sectoral users : CWC, NHAI, Aviation, Indian Railways, municipal corporation, Agriculture Officials, Farmers, Fishermen
- Public Website (mausam.imd.gov.in)
- IMD Apps like Mausam/DAMINI/RAIN ALARM
- Social Media : Facebook, Twitter, Instagram, BLOG
- Common Alert Protocol, Global Multi-hazard Alert System (GMAS)

Figure 5.18. Dissemination system for heavy Rainfall

Annexure 1

Annexure I-on bulletin of 21 and 23 Aug over extremely heavy rainfall over ODSIHA

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भारत मौसम विज्ञान विभाग
पृथ्वी विज्ञान मंत्रालय

National Weather Forecasting Centre
India Meteorological Department
Ministry of Earth Sciences

Friday 21 August 2020
MID-DAY
Time of Issue: 1315 hours IST

ALL INDIA WEATHER SUMMARY AND FORECAST BULLETIN

Significant Weather Features

♦ The **Well Marked Low Pressure Area** lies over central parts of East Madhya Pradesh & neighbourhood. It is very likely to move nearly westwards across West Madhya Pradesh during next 3-4 days.

♦ The monsoon trough is active and south of its normal position. An east-west shear zone runs roughly along Lat. 22°N across central India between 3.1 km & 7.6 km above mean sea level tilting southwards with height.

♦ Under the influence of above systems:

(i) Widespread rainfall **with isolated heavy to very heavy falls** very likely over Madhya Pradesh, Vidarbha, Telangana, Gujarat, Maharashtra and Rajasthan during next 3-4 days.

(ii) Isolated extremely heavy falls are likely over East Rajasthan and Gujarat region during 21st-23rd; over West Madhya Pradesh during 21st-22nd; over East Madhya Pradesh and Vidarbha on 21st; over Madhya Maharashtra during 21st-22nd; over Saurashtra & Kutch during 23rd-24th August, 2020.

♦ Under the influence of likely formation of the Low Pressure Area over Northwest Bay of Bengal, rainfall activity is likely to increase over east & adjoining central India from 23rd August. Isolated heavy to very heavy falls very likely over Odisha during 23rd-25th August, over Gangetic West Bengal on 24th & 25th and over Jharkhand on 25th August.

♦ **Moderate thunderstorm accompanied with lightning** at isolated places very likely over south Rajasthan, East Uttar Pradesh and Coastal Andhra Pradesh & Yanam during next 12 hours.

राष्ट्रीय मौसम पूर्वानुमान केन्द्र
भारत मौसम विज्ञान विभाग
पृथ्वी विज्ञान मंत्रालय

National Weather Forecasting Centre
India Meteorological Department
Ministry of Earth Sciences

Sunday 23 August 2020
MID-DAY
Time of Issue: 1330 hours IST

ALL INDIA WEATHER SUMMARY AND FORECAST BULLETIN

Significant Weather Features

♦ The Well Marked Low Pressure Area now lies as a Low Pressure Area central parts of East Rajasthan & neighbourhood. It is very likely to move nearly westwards across Rajasthan during next 2 days and become less marked thereafter. However, the associated cyclonic circulation is likely to meander over south Rajasthan neighbourhood region for subsequent 2-3 days. The monsoon trough is active and south of its normal position. It is likely to remain active during next 2-3 days.

♦ Under the influence of the above systems, **Isolated extremely heavy falls are very likely over Southwest Rajasthan and Gujarat state on 23rd & 24th and over Southeast Rajasthan on today, the 23rd August, 2020. Isolated heavy to very heavy falls** very likely over East Rajasthan on 24th & over West Rajasthan on 25th & 26th August, 2020.

♦ Due to likely formation of the Low Pressure Area over North Bay of Bengal around 24th August, 2020; rainfall activity is likely to increase over east & adjoining central India thereafter. **Isolated extremely heavy falls** are likely over Odisha on 25th August and Isolated Very heavy falls over Gangetic West Bengal and Jharkhand during 25th-27th August.

♦ Due to convergence of lower level easterlies from Bay of Bengal and south-westerlies from Arabian Sea, rainfall activity is very likely to increase over Northwest India from 25th August:

i) Jammu, Kashmir, Gilgit, Baltistan, Muzaffarabad & Ladakh and Himachal Pradesh are very likely to receive fairly widespread rainfall with ***isolated heavy falls*** *and Uttarakhand* ***isolated heavy to very heavy falls*** during 25th-27th August.

ii) Punjab, Haryana, Chandigarh & Delhi and Uttar Pradesh are likely to receive fairly widespread rainfall with ***isolated heavy falls*** on 26th & 27th August.

Annexure I

Press-NWFC heavy rainfall bulletin

Press on 25 Aug: 2020

Government of India
Earth System Sciences Organization
Ministry of Earth Sciences
India Meteorological Department

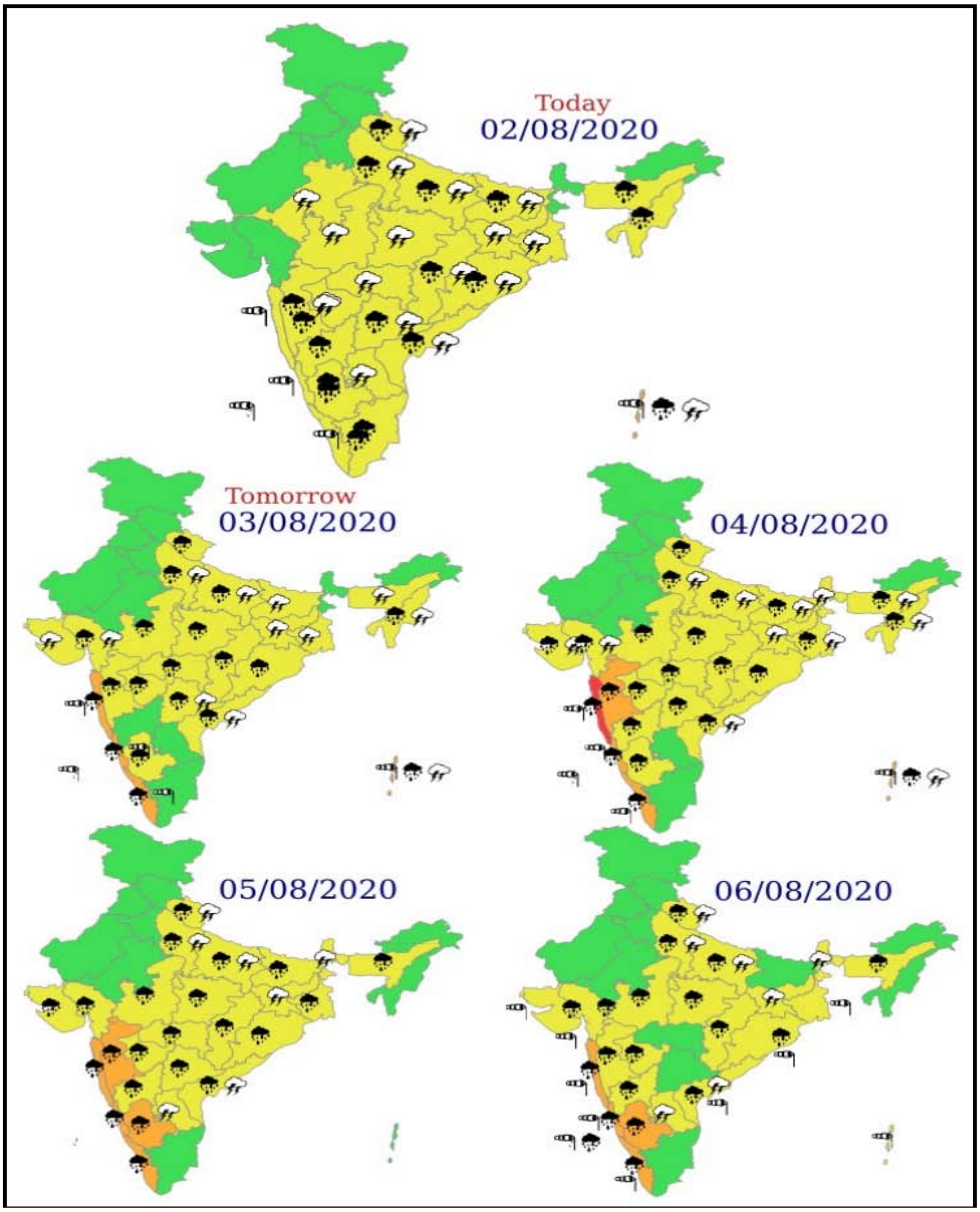
Press Release
Date: 25 August, 2020
Time of Issue: 1630 hrs IST

Subject: Heavy spell of rainfall over east and northwest India during 25 to 28 August, 2020

- A **well marked low pressure area** lies over North Bay of Bengal & neighbourhood. It is very likely to move west-northwestwards across Odisha, Gangetic West Bengal, Jharkhand, north Chhattisgarh, north Madhya Pradesh and south Uttar Pradesh during next 5 days.
- The monsoon trough is active and is very likely to remain active during next 2-3 days. In addition, there is a convergence of strong lower level southwesterly winds from Arabian Sea over northwest India till 28 August.
- Under the influence of above systems:
  a) Widespread rainfall with **isolated heavy to very heavy falls** very likely over Odisha, Gangetic West Bengal & Jharkhand till 28 August; over Chhattisgarh, Madhya Pradesh & West Rajasthan during 26 to 28 and over East Rajasthan on 28 & 29 August, 2020.
  b) **Isolated extremely heavy falls also very likely over Odisha on 25 & 26 and over Chhattisgarh on 27 August, 2020.**
  c) Widespread rainfall with **isolated heavy falls** very likely over northwest India till 28 August, 2020. **Isolated heavy to very heavy falls** are also very likely over Himachal

Annexure I

(Multi-hazard maps upto day 5)



Annexure II

District wise Colour Coded Warnings issued for Heavy Rainfall to Extremely Heavy Rainfall events for 8th August 2019 for Kerala

Date of Issue / Districts	4th August (8th Aug as Day 5)	5th August (8th Aug as Day 4)	6th August (8th Aug as Day 3)	7th August (8th Aug as Day 2)	8th August (8th Aug as Day 1)
Thiruvananthapuram	Light to Moderate Rainfall	Light to Moderate Rainfall	Light to Moderate Rainfall	Light to Moderate Rainfall	Heavy Rainfall
Kollam	Light to Moderate Rainfall	Light to Moderate Rainfall	Light to Moderate Rainfall	Light to Moderate Rainfall	Heavy Rainfall
Pathanamthitta	Light to Moderate Rainfall	Light to Moderate Rainfall	Light to Moderate Rainfall	Light to Moderate Rainfall	Heavy to Very Heavy rainfall
Alappuzha	Light to Moderate Rainfall	Heavy Rainfall	Light to Moderate Rainfall	Light to Moderate Rainfall	Heavy to Very Heavy rainfall
Kottayam	Light to Moderate Rainfall	Light to Moderate Rainfall	Light to Moderate Rainfall	Light to Moderate Rainfall	Heavy to Very Heavy rainfall
Ernakulam	Light to Moderate Rainfall	Heavy Rainfall	Heavy Rainfall	Heavy Rainfall	Heavy to Very Heavy rainfall
Idukki	Light to Moderate Rainfall	Extremely Heavy Rainfall	Extremely Heavy Rainfall	Extremely Heavy Rainfall	Extremely Heavy Rainfall
Thrissur	Light to Moderate Rainfall	Heavy to Very Heavy rainfall	Heavy to Very Heavy rainfall	Heavy to Very Heavy rainfall	Heavy to Very Heavy rainfall
Palakkad	Light to Moderate Rainfall	Heavy Rainfall	Heavy to Very Heavy rainfall	Heavy to Very Heavy rainfall	Heavy to Very Heavy rainfall
Malappuram	Light to Moderate Rainfall	Extremely Heavy Rainfall	Extremely Heavy Rainfall	Extremely Heavy Rainfall	Extremely Heavy Rainfall
Kozhikode	Heavy Rainfall	Extremely Heavy Rainfall	Extremely Heavy Rainfall	Extremely Heavy Rainfall	Extremely Heavy Rainfall
Wayanad	Light to Moderate Rainfall	Heavy Rainfall	Heavy to Very Heavy rainfall	Heavy to Very Heavy rainfall	Extremely Heavy Rainfall
Kannur	Heavy Rainfall	Heavy to Very Heavy rainfall	Heavy to Very Heavy rainfall	Heavy to Very Heavy rainfall	Heavy to Very Heavy rainfall
Kasaragode	Heavy Rainfall	Heavy to Very Heavy rainfall	Heavy to Very Heavy rainfall	Heavy to Very Heavy rainfall	Heavy to Very Heavy rainfall
Lakshadweep	Light to Moderate Rainfall	Heavy Rainfall	Heavy Rainfall	Heavy Rainfall	Heavy Rainfall

Annexure 3

MO : Port Blair
CR&S Pune/ CATC Bamarauli

Forecasting Circular No. 1/2018

Sub: Issuance of District level weather forecast and warnings based on ensemble model outputs

Annexure-I

Colour coding of Heavy Rainfall Warning

Category	Colour Coding
Extremely Heavy Rainfall	Red
Scattered heavy to very heavy	Red
Isolated heavy to very heavy (consecutively for 3 days)	Red on 3rd day
Heavy to very heavy rainfall observed at least for 2 days and is expected again.	Red (on day 1)
Isolated heavy to very heavy (for consecutive 2 days)	Orange (on 2nd day)
Isolated/scattered heavy rainfall/Isolated heavy to very heavy rainfall	Yellow (on day 1)
If it is already flood situation and heavy rainfall is expected.	Orange/red
No heavy rainfall	Green

Note : This is a general guideline. Considering the location and the day and period of occurrence, the impact may be different. Hence, concerned MC/RMC may decide the colour code accordingly.

Annexure IV (IBF)

राष्ट्रीय मौसम पूर्वानुमान केन्द्र
भारत मौसम विज्ञान विभाग
पृथ्वी विज्ञान मंत्रालय

National Weather Forecasting Centre
India Meteorological Department
Ministry of Earth Sciences

Impact expected over Madhya Pradesh and Vidarbha on 28th August due to Extremely Heavy rainfall

- Localized Flooding of roads, water logging in low lying areas and closure of underpasses mainly in urban areas of the above region.
- Occasional reduction in visibility due to heavy rainfall.
- Disruption of traffic in major cities due to water logging in roads leading to increased travel time.
- Minor damage to kutcha roads.
- Possibilities of damage to vulnerable structure.
- Localized Mudslides.
- Damage to horticulture and standing crops in some areas due to inundation.
- It may lead to riverine flooding in some river catchments (for riverine flooding please visit website of center water commission (http://www.cwc.gov.in/))

For specific district wise impact kindly visit IMD's sate level meteorological center websites (https://mausam.imd.gov.in/imd_latest/contents/departmentalweb.php) and national website (https://mausam.imd.gov.in/).

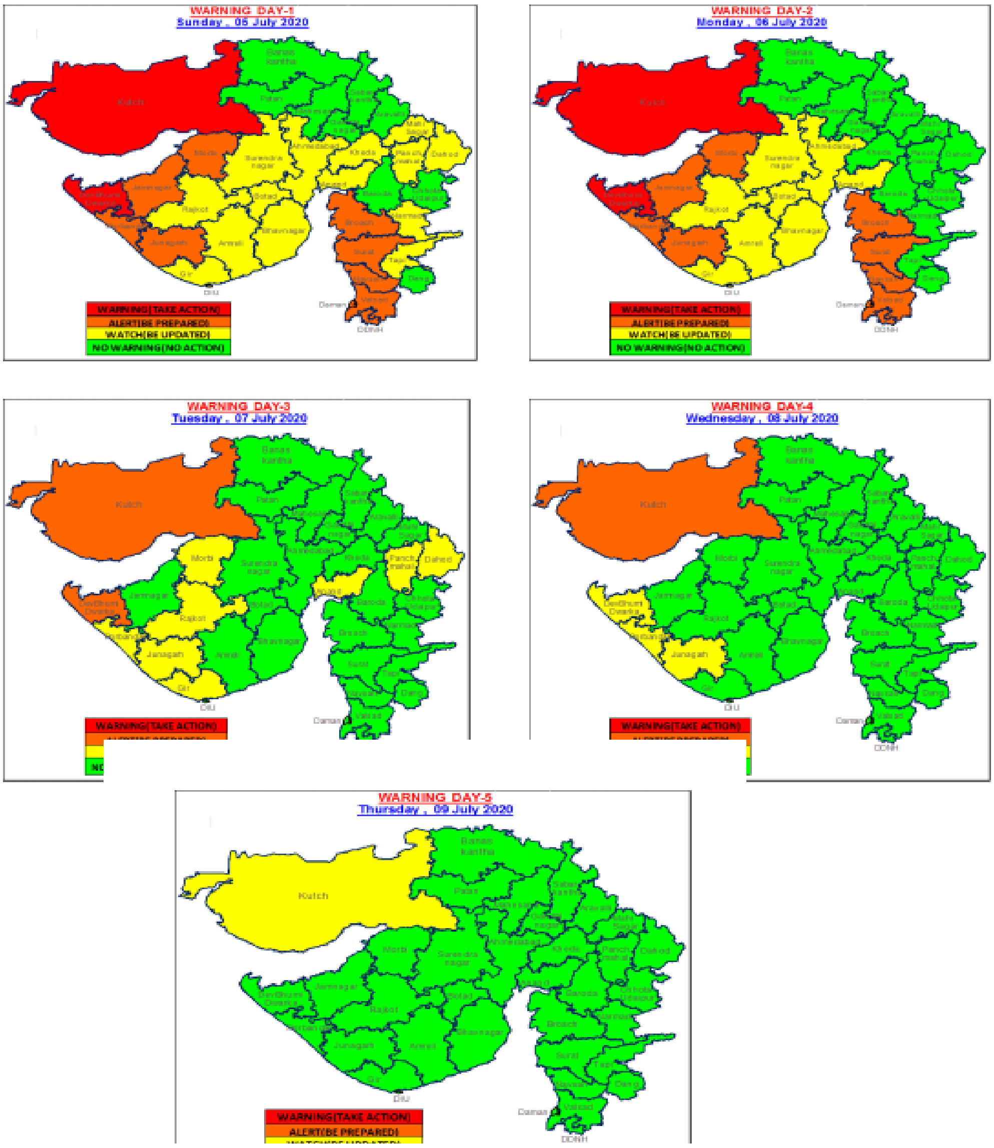
Action Suggested

- Check for traffic congestion on your route before leaving for your destination.
- Follow any traffic advisories that are issued in this regard.
- Avoid going to areas that face water logging problem often.
- Avoid staying in vulnerable structure.

Annexure IV (IBF)

District based IBF heavy rainfall warnings

(WARNING)



Field Level Forecast-District wise and Sub-City based IBF and Color coded warnings

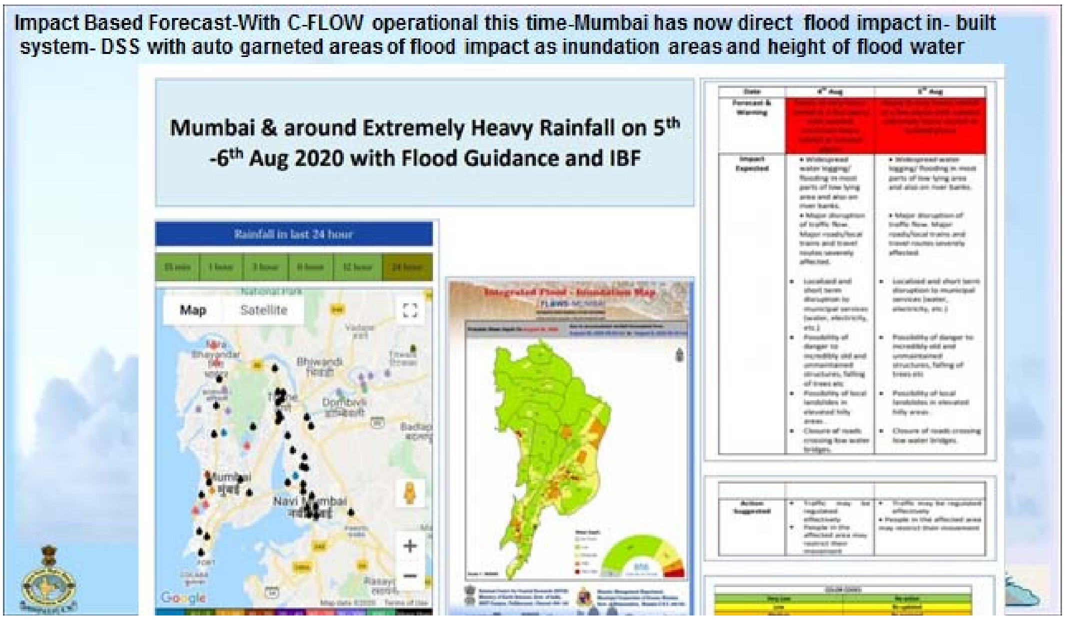
IMPACT BASED FORECAST

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

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

Annexure IV (IBF)

City based IBF heavy rainfall warnings-Mumbai



Annexure V

Met Center……..
India Meteorological Department
Ministry of Earth Sciences

MUMBAI HEAVY RAINFALL ADVISROY WITH 12-Hourly UPDATE

ADVISROY NO. 1

DATE:18-07-2020 TIME OF ISSUE: 12:00 HRSIST

Forecast based upon	**11:30 HRS IST OF 18-07-2020 / 06:00 UTC OF 18.07.2020**
06:00UTC of 18 July	Mumbai city is likely to get heavy/very heavy/extremely heavy rainfall on 20 July 2020

Next bulletin will be issued at 00:30UTC (06:00IST)

Annexure-VI

Met Center Name……..
India Meteorological Department
Ministry of Earth Sciences

MUMBAI HEAVY RAINFALL ALERT WITH 12-Hourly UPDATE

ALERT NO. 1

DATE:19-07-2020 TIME OF ISSUE: 12:00 HRSIST

Forecast alert based upon	**11:30 HRS IST OF 19-07-2020 / 06:00 UTC OF 19.07.2020**
06:00UTC of 19 July	Some areas of Mumbai City (if possible specify region like west, east, north, south, central etc) are likely to experinces heavy/ very heavy rainfall/extremely heavy rainfall on 20 July 2020 most likely during evening/night in the date.
Impact expected	

Figure 1 RADAR products over map with location details of the city
Figure 2 Satellite Images zoomed over a region for the city

Next bulletin will be issued at 00:30 UTC (06:00IST)

Annexure-VII

Met Center……..
India Meteorological Department
Ministry of Earth Sciences

3 HOURLY UPDATE OF ONGOING MUMBAI HEAVY RAINFALL EVENT

WARNING NO. 1
DATE:20-07-2020 TIME OF ISSUE: *12:00 HRS IST*

DATE/TIME (IST) OF OBSERVATION	**11:30 HRS IST OF 20-07-2020 / 06:00 UTC OF 20.07.2020**
Rainfall realized **a)**RAINFALL REPORTS LAST 3-HOURS FOR TIME ENDING AT 11:30IST OF TODAY **b)**CUMULATIVE SINCE RAIN EVENT STARTED AROUND 08:30IST OF TODAY)	SATATION NAME WITH TYPE(AWS/SYNOP IMD, ARG, SRG) AND RAINFALL AMOUNTS
Forecast or nowcast	As per latest observations, Satacruz and Adnheriareas have Very intense convective clouds which has the potential to cause heavy to very heavy rainfall during next ………hrs / during …………. To ……. Hours. and it is likely to last next 2-3 hours causing rainfall likely of 6-12cm in 3- hours.
Impact expected	
Action Suggested	

Next bulletin will be issued at 09:30UTC(15:00IST)

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Chapter 6

Thunderstorm Warning Services

6.1. Introduction

Thunderstorms (TS) occur over different parts of the globe with large spatial & temporal as well as diurnal, seasonal and annual variability. Over Indian region thunderstorms occur throughout the year during different seasons. Its frequency varies from region to region. Thunderstorm activities during monsoon, post-monsoon and winter seasons are mainly governed by the large scale synoptic weather systems with some alterations caused by local topographical effects. However, the highest frequency and the most severe thunderstorm events occur in general during the pre-monsoon season (March to May) throughout the length and breadth of the country. In India hundreds of people die due to phenomena associated with thunderstorms like lightning strikes, squalls and hails etc. The associated squally winds damage the property like Kachcha houses, thatched huts and asbestos houses, telephone and electric poles and other structures amounting to crores of rupees every year. Apart from standing crops which get severely damaged, it also affects transport sector like Highways, railways and aviation resulting in human and revenue losses.

Thunderstorm climatology in India is classified into six broad divisions:

(i) Northeast India (Assam & Meghalaya, Arunachal Pradesh and Nagaland, Manipur, Mizoram & Tripura)

(ii) East India (Sub-Himalayan West Bengal & Sikkim, Gangetic West Bengal, Bihar, Jharkhand, Orissa and Andaman & Nicobar Islands)

(iii) Northwest India (East Rajasthan, West Rajasthan, East-Uttar Pradesh, West Uttar Pradesh, Haryana, Chandigarh & Delhi, Punjab, Uttarakhand, Himachal Pradesh, Jammu & Kashmir)

(iv) West India (Gujarat Region, Saurashtra, Kutch & Diu, Konkan & Goa, Madhya Maharashtra and Marathwada)

(v) Central India (East Madhya Pradesh, West Madhya Pradesh, Chhattisgarh and Vidarbha)

(vi) Peninsular India (Costal Andhra Pradesh, Telangana, Rayalaseema, North Interior Karnataka, South Interior Karnataka, Costal Karnataka, Tamil Nadu, Kerala and Lakshadweep)

Intense and high frequency thunderstorm activities during the pre-monsoon season generally occur in East and Northeast India followed by southwest Peninsular India. The thunderstorm associated with dust storm mostly occurs over Northwest India. The climatological map of Thunderstorm is shown in Fig. 1. Thunderstorm and squall climatology of India based on data from 1981-2020 Figs. 2 (a&b).

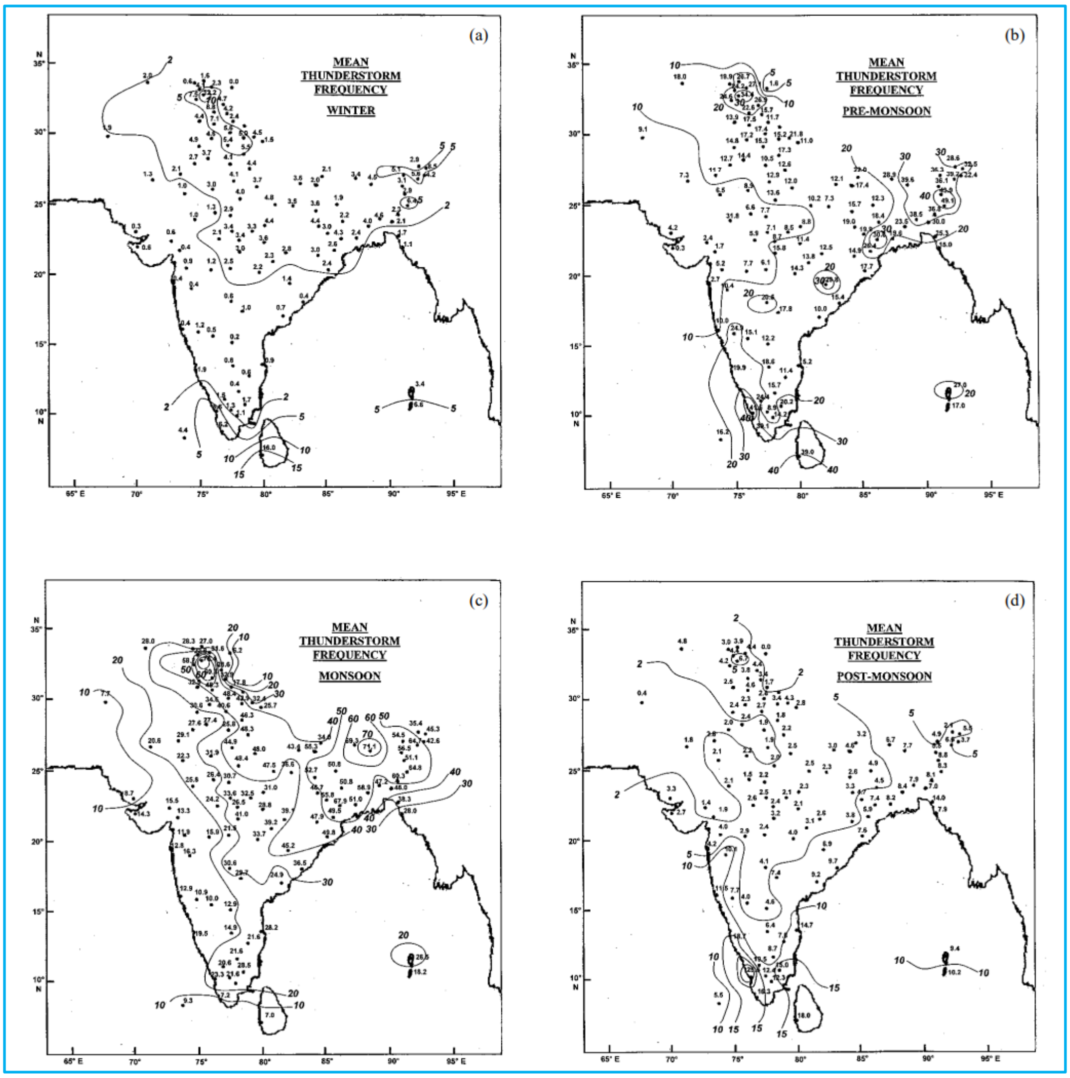


Figure 1. Seasonal thunderstorm climatology over India [AjitTyagi, MAUSAM, 58, 2 (April 2007), 189-212]

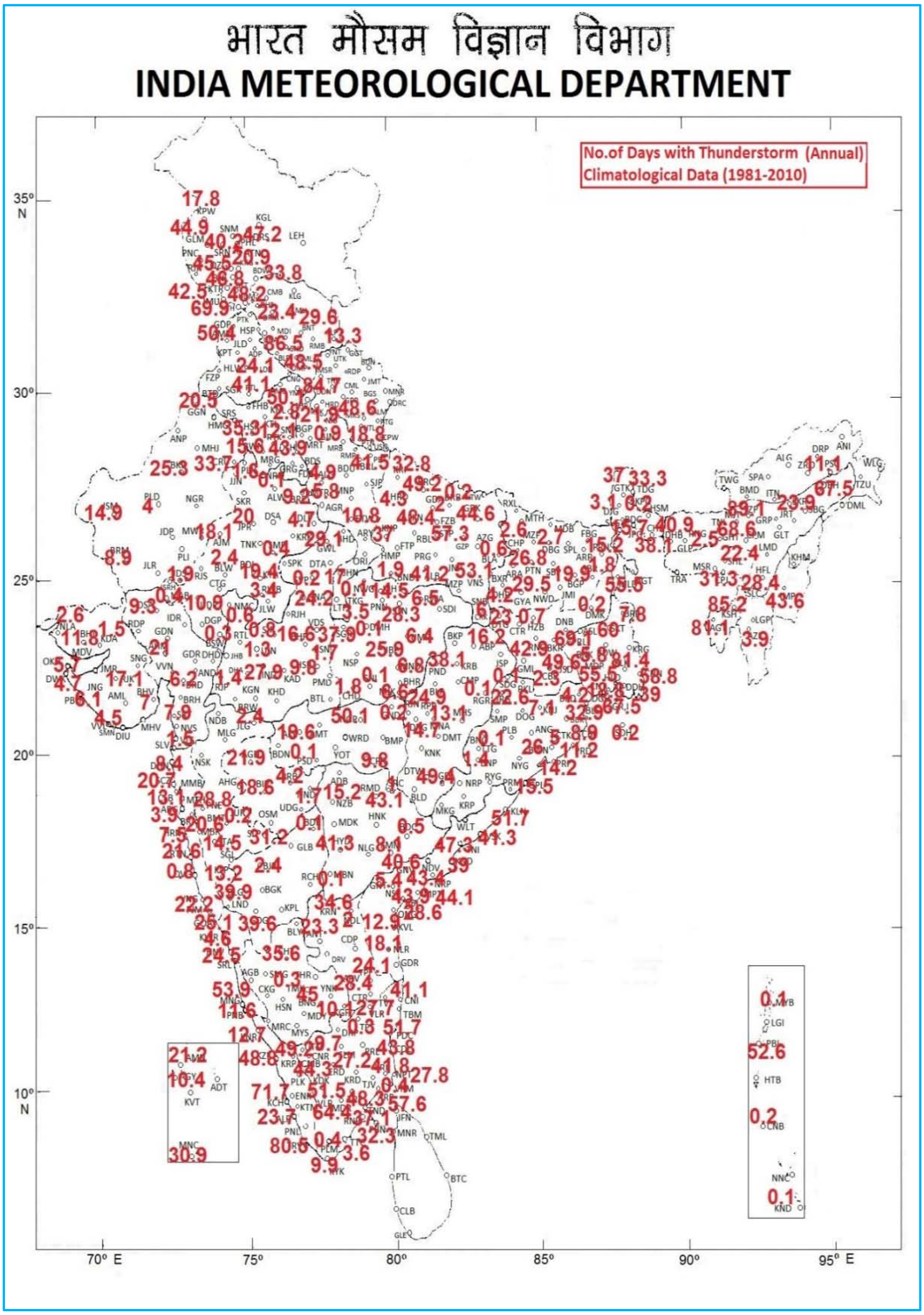


Figure 2(a). Annual thunderstorm climatology over India based of the period 1981-2010

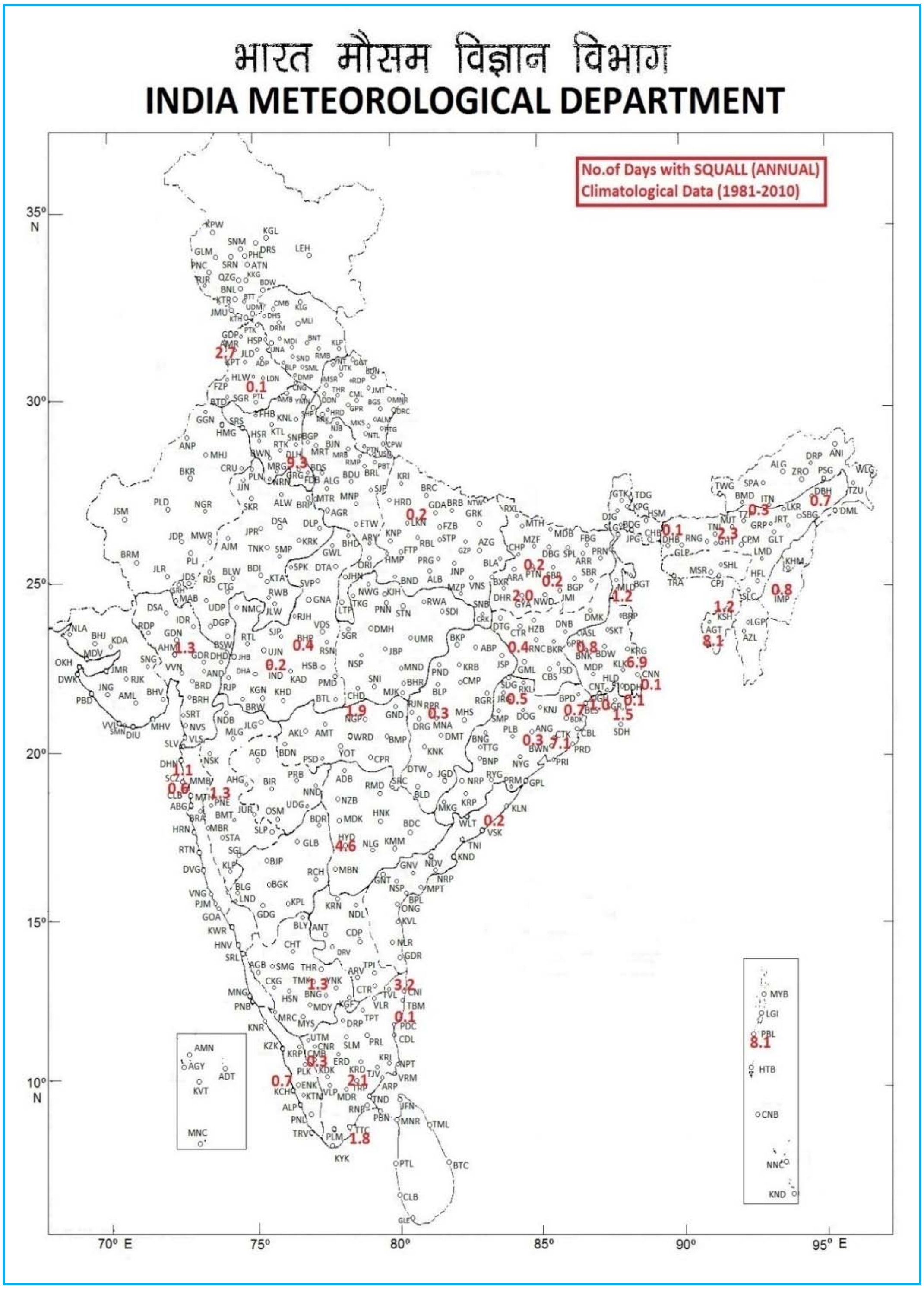


Figure 2(b). Annual Squall climatology over India based of the period 1981-2010

6.2. Objective

In view of the high impact of thunderstorms and its influence on social, cultural, commercial, health, defence and transport etc.monitoring, prediction and warning of thunderstorm is done by different offices of India Meteorological Department (IMD). A Standard Operating Procedure (SOP), to provide uniform monitoring and forecasting/warning services of abovementioned weather eventwas first published in 2012. During recent years due to augmentation in the monitoring and advancements in forecasting techniques, thunderstorm warnings and its dissemination has undergone rapid changes. Also the thunderstorm categories and criteria for issuing thunderstorm warnings have been revised. Hence a need is felt to update the existing SOP. This revised SOP document holistically describes the procedures for monitoring, forecasting and warning dissemination to be followed at different levels of forecasting offices at IMD.

6.3. Criteria of thunderstorm and associated warning

6.3.1. Thunderstorm warning sand colour codes for warnings

(a) No Thunderstorm (green colour)

(b) Light Thunderstorm: Thunderstorms with maximum surface wind speed less than 40 kmph (in gusts). (Yellow colour)

(c) Moderate Thunderstorm: Thunderstorms with maximum surface wind speed 41-61 kmph (in gusts/ squall). (Orange colour)

(d) Severe Thunderstorm: Thunderstorms with maximum surface wind speed 62-87 kmph (in gusts/ squall). (Red colour)

(e)Very Severe Thunderstorms: Thunderstorms with or without rain with maximum surface wind speed greater than 87 kmph (in gusts/ squall).(Red colour)

(f)Thunderstorms with Hail: Thunderstorm with hail (no gust criteria)(Red colour)

6.3.2. Duststorms warning

(a) Light duststorms: If the wind speed (in gusts) is up to 40 kmph and visibility is less than 1,000 metres but more than 500 meters. (Yellow colour)

(b) Moderate duststorms: If the wind speed (in gusts) is between 41- 61 kmph and visibility is between 200 and 500 metres. (Orange colour)

(c) Severe duststorms: If surface wind speed (in gusts) is between 62 -87 kmph (In gusts) and visibility is between 50-200 metres. (Red colour)

(d) Severe dust storms: If surface wind speed (in gusts) exceeds 87 kmph (In gusts) and visibility is less than 50 metres. (Red colour)

6.3.3. Lightning warning

(a) Low Lightning probability (<30% probability of lightning occurrence) (Yellow colour)

(b) Moderate Lightning probability (30 - 60% probability of lightning occurrence) (Orange colour)

(c) High Lightning probability (> 60% probability of lightning occurrence) (Red colour)

6.4. Favourable conditions for thunderstorm occurrence

The following are the basic criteria for thunderstorm:

- Intense surface heating
- Low level moisture
- Conditional Instability of the atmosphere and
- Triggering mechanism

6.4.1. Synoptic conditions

The triggering mechanism is obtained through synoptic systems like western disturbances.

- Western disturbances
- Low pressure systems like lows, depressions and troughs etc.
- Confluence of winds in lower levels generally below 700 hPa mainly at 850 and 925 hPa level.
- Wind discontinuity at 850 and 925 hPa.
- Interaction of dry and moist winds over particular region at 850 and 925 hPa
- Upper air Jet stream above 300 hPa level

6.4.2. Thermodynamic conditions

- Low level moisture
- Heating in lower levels
- Conditional instability (A layer of unsaturated air when its lapse rate of temperature is less than the dry-adiabatic lapse rate but greater than the moist-adiabatic lapse rate.)

6.4.3. Dynamic conditions

- High wind shear between 850 and 200 hPa.
- High lower level convergence
- High upper level divergence
- High vorticity below 700 hPa in general at 850 hPa

6.4.4. Thermo-dynamical indices

- Inversion in mid-upper level
- Inversion in mid tropospheric level
- Convective Available Potential Energy
- Convective Inhibition Energy
- Total totals index
- K Index
- Lifted index
- Showalter index
- Cloud condensation level
- Lifting condensation level
- High lapse rate (in general more than 7^0C/km)

- 0^0 C isotherm level height to be lower
- Richardson number to be low (in general less than 1).

6.4.5.1. Sample check list for thunderstorm forecasting Products

1. GEFS

a. 3 hourly 10 m wind
b. Genesis Potential
c. Gust wind probability at different thresholds
http://nwp.imd.gov.in/
http://srf.tropmet.res.in/srf/hires_gefs/gfs_based.php

2. GFS

a. 10 m wind
b. Gust wind
c. Meteogram
d. Instability indices
http://nwp.imd.gov.in/

3. WRF

a. 10 m wind
b. Meteogram
c. Instability indices
http://nwp.imd.gov.in/, http://srf.tropmet.res.in/srf/hires_gefs/wrf_based.php

4. NCUM regional/global

a. 10 m wind
b. Gust maxima
c. EPSgrams
d. Instability indices
http://www.ncmrwf.gov.in/All_times_ind_mihir_00.php
(*Thresholds values of indices & check list may be modified as per the local requirements at different locations*)

6.4.5.2. Dust-storm

Forecast Products in addition to 6.4.5.1

1. NCUM global

a. 3 hourly Dust concentration
b. Visibilityhttp://www.ncmrwf.gov.in/All_times_ind_mihir_00.php
c. Trajectoryhttp://www.ncmrwf.gov.in/product_grid_mihir.php

2. SILAM

a. PM 10 hourly forecast

3. WRF-HYSPLIT

a. Forward trajectory

b. Backward trajectoryhttp://nwp.imd.gov.in/

6.5. Needed Inputs (data products and their availability)

In order to provide accurate forecast, forecaster at the NWFC/RWFC/SWFC use following data as per Fig. 3.

(a) Observational data

i) Observational data from Surface observatories, RSRW & Pilot Balloon observation, Automatic Weather Station (AWS), Automatic Weather Observing System (AWOS), Global Positioning System (GPS), Automatic Rain Gauge (ARG), Wind Profiler, lightning detection network, Microwave Radiometers etc.

ii) Satellite digital data, satellite derived winds, precipitation estimates, sea surface temperature, vertical profiles of temperature and humidity, outgoing long wave radiation, sea surface winds, liquid water content, wind shear, vorticity, divergence,convergence of the atmosphere etc. and animation sequences of images and some of the derivedproducts.

iii) Radar data includes reflectivity, radial velocity and derived products, animation sequences of images and the derived products.

iv) Current weather observations from Airport met offices.

(b) Numerical Weather Prediction (NWP) (as given in point 6.4.5 and other products).

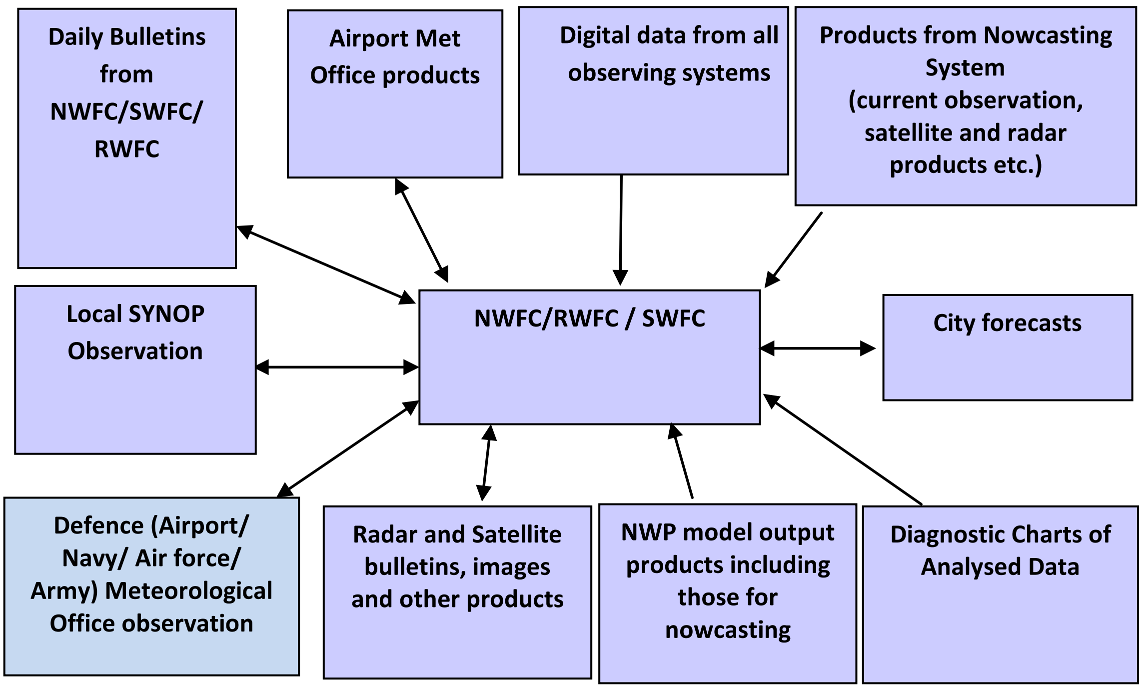


Figure 3. Data/ products to be considered by NWFC/RWFC/SWFC/AMOs for issue of forecast of thunderstorm and nowcasting

The forecaster will verify the receipt of products at scheduled time. In case of non-receipt, appropriate action will be initiated by the forecaster for timely receipt by sending email or through phone / WhatsApp message, to designated officials responsible in the concerned offices. The forecaster will inform corresponding SWFC/RWFC/ISSD and NWFC and make suitable effort to rectify the problem.

Forecasts for a particular region or sub-divisions issued at NWFC will be used by respective SWFC / RWFC as guidance to issue thunderstorm warning as and when warranted. As the ultimate responsibility lies with SWFC/RWFC, it can issue warning even when there is no guidance received from NWFC. However, NWFC and concerned RWFC should be informed with the copy of warning bulletin by the SWFC or in video conferencing.

(i) Suitable computer platform to visualize the data in real time, overlay various types of data, draw contours and derive useful information from the multiple database.

(ii) Finer resolution Meso-scale model outputs for state/district level as guidance.

The forecaster will be aware of technical systems, contingency plan in case of failure of the system and take appropriate action.

6.6. Organizations and their responsibilities

As TS is of mesoscale nature, the entire process of observation, prediction & dissemination to the end users should take place in a very rapid manner. The following divisions of IMD are responsible at various levels for appropriate thunderstorm and dust storm forecasts and warnings.

The ultimate responsibility of monitoring and issuing thunderstorm warning lies with State Weather Forecasting Centre (SWFC)/ Regional Weather Forecasting Centre (RWFC)/ Airport Meteorological Office (AMOs). RWFC will issue thunderstorm warning only for the state for which it issues forecasts as SWFC, e.g. RWFC Kolkata will be responsible for thunderstorm warning over the state of West Bengal. The SWFC/RWFC will be responsible for monitoring and disseminating the thunderstorm information and warning as shown in the block diagram Fig. 4.

In case of system failure at any SWFC, concerned RWFC will take over the duties and responsibilities till the restoration of the system.

- There will be two-way information exchanges between SWFC/ RWFC on one side and NWFC, AMO, RWFC, Mega City forecast centre (SWFCFC), Nowcast cell and Defence Meteorological Office on the other side.

- There will be no dilutions of charter of mandate in respect of AMO by exchange of information between SWFC/RWFC and AMO in relation to the thunderstorm warning issued by AMO.

- Thunderstorm warning system will be linked with Media Website (TV, Newspaper, etc.), private/ industries organizations, etc. through Public Weather Service (PWS) of IMD.

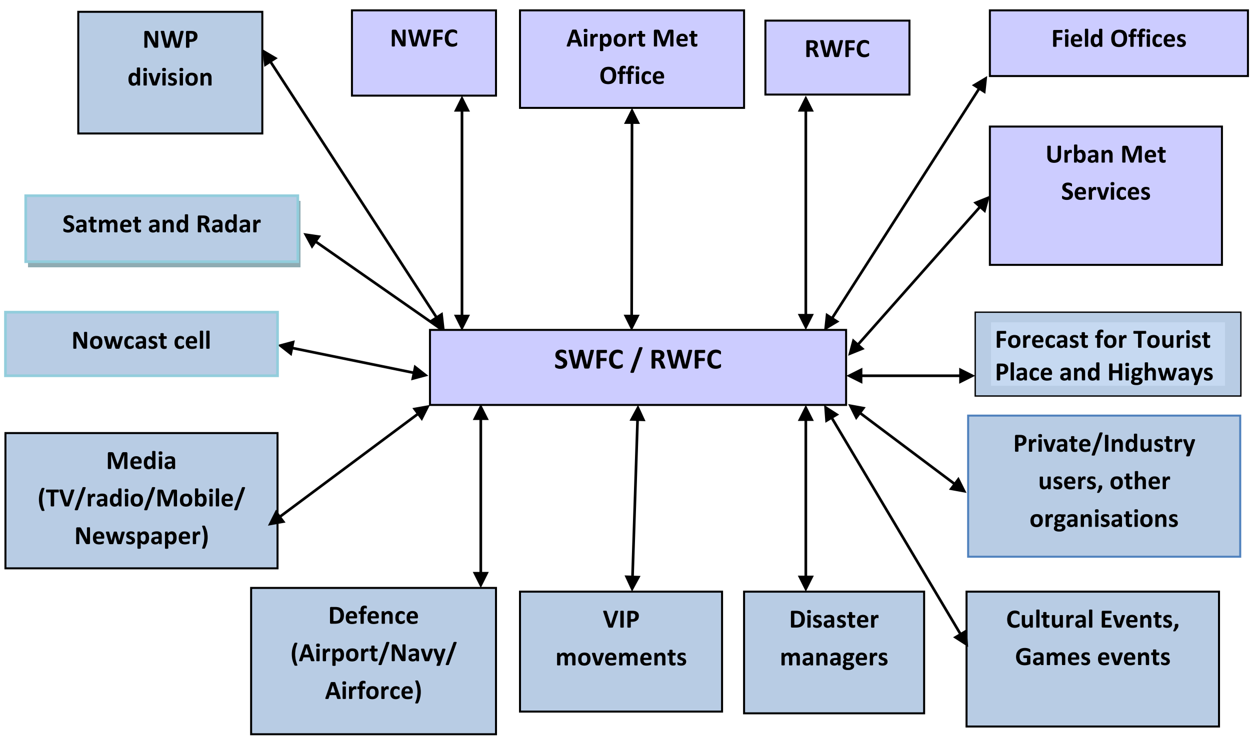


Figure 4. Thunderstorm warning structure at RWFC/SWFC

6.6.1. NWP Division

This group will provide necessary inputs in term of charts, dynamic/thermodynamic products charts, meteograms based on the model predictions in regional scale, 12km/3km/1Km over a particular region/area/division/city to forecasting centre. The NWP officer-in-charge/duty officer has to periodically update/review and inform the status NWFC, RWFC and SWFC at the interval of their model rerun outputs (6/12 hrs).

6.6.2. NWFC

The NWFC will provide details about potential for occurrence of Thunderstorms120, 96, 72, 48 and 24 hrs in advance for a specific area (meteorological subdivision or a part of it) to RWFC/SWFC and revise/update/review the report periodically every six hours. The report should also include the level of confidence about the forecasted event (such as most likely, very likely, likely and unlikely) and the colour codes indicating the possible impacts. The NWFC duty officer will maintain round the clock watch and coordinate with SWFC/RWFC for timely TS warning.

6.6.3. Sat Met Application Cell

It will carry out carry out interpretation and analysis of thunderstorm over a specific area. A proper round the clock watch is to be kept; It will communicate findings and thunderstorm developments and keep NWFC/RWFC/SWFC informed through structured bulletins over phone/e-mail/fax/SMS/WhatsApp etc.

6.6.4. Radar Application

The DWR stations will monitor the development and movement of the Mesoscale Convective Complexes and other important features relevant to the development of thunderstorms over their region. It will keep NWFC/RWFC/SWFC informed time to time through structured bulletins over phone/e-mail/fax/SMS/WhatsApp etc. It will issue every 10 minutes real time updates of DWR products.

6.6.5. RWFCs/SWFCs

The RWFCs/SWFCs play a major role in monitoring, forecasting and warning of Thunderstorm. It will decide on the scale and intensity of thunderstorm events its time of occurrence and the impact expected based on collective observations on real time and the past events. They shall all have local Thunderstorm climatology and local forecasting thumb rules for respective region/area prepared and kept available; (These documents are to be reviewed/ revised periodically. Pre-season exercise is to be carried out on the documents every year). RWFCs and SWFCs will perform the monitoring mechanism for disseminate of warning products, actual occurrence and feedback from the Field offices. The warnings will be verified on daily basis and consolidated report will be prepared on monthly basis. They will utilize all the data and products as mentioned in 6.5.

6.6.6. Field offices (Observatories and Met offices)

The field offices will have a good rapport with the other nearby government agencies and institutions through which they can collect truthful representation of the weather event for a post validation of the warning reports. They will provide real-time observations round the clock using existing telecommunication system to SWFC. They will also differentiate the thunderstorm warning for new region (districts) through WhatsApp group, phone, email to the district authorities and media on real time basis. They will also verify the warnings issued for their region and provide to NWFC.

6.7. Monitoring and forecasting

6.7.1. Monitoring

The essence of thunderstorm warning is timely and correct analysis of all the inputs in real time because of short lifespan of such weather events. The primary responsibility of detecting and monitoring lies with the SWFC / RWFC forecaster. However, the following offices will also provide their inputs to forecasting office:

- Observatories

- Radar field office
- Satellite Division
- Airport Met office
- FMO (During monsoon season)
- NWP Division

They will detect and inform the RWFC/SWFC about any impending weather activity over a particular area. It is also the responsibility of the RWFC/ SWFC forecaster to be pro-actively in touch with all agencies providing inputs.

The monitoring for nowcasting involves the following steps.

- Routine retrieval and review of scheduled bulletins and products issued by SWFC/RWFC/AMO/FMO/NWP/ NWFC etc.
- Routine retrieval and review of all remotely sensed data (Satellite, Radar and Lightning etc.)
- Maintenance of continuous watch.

6.7.2. Analysis and Forecasting

Thunderstorms and associated weather guidance, warnings and advisories are issued by different offices and with different lead times.

- Nowcast guidance for 48 and 24 hrs is issued by nowcasting division (NWFC at IMD, HQ).
- NWFC/RWFC/SWFC issues forecasts and warnings for thunderstorms for next 5 days.
- Forecasts and warnings by RADARS stations: Thunderstorm warning is issued whenever a convective cell is developed within the Radar range or approaches the radar range from outside. This warning is issued for entire life span of thunderstorm.
- Thunderstorm warnings are issued by AMOs whenever thunderstorm is likely to affect the particular airport.

If sufficient lead time is not available, the Thunderstorm outlook and Thunderstorm Forecast Bulletins shall be issued in succession by the respective offices and Thunderstorm warning bulletin will be issued accordingly by RWFC/SWFC/AMOs. As per Appenix-1.

6.7.3. Decision making process(Decision tree for forecasting of Thunderstorm)

STEP 1: Analysis of weather during past 24 hours
(Rainfall, Relative Humidity, Temperature, Wind) and Severe Weather phenomena such as Thunderstorm, Hailstorm, Squall etc

STEP 2: Analysis of weather observation (3 hourly Synoptic observations, half hourly/hourly current weather observations, Satellite and Radar and Lightning observation) to evaluate:
Location, intensity, evolution, structure and movement of weather Systems through analysis of the synoptic, dynamic and thermodynamic characteristics

STEP 3: Preparation of summary of synoptic, dynamic and thermodynamic characteristics in the form of checklist.

STEP 4: Evaluation of model guidance
(i) Evaluate each model by comparing their initial condition with the observation as derived in STEP 2 and STEP 3
(ii) Performance of their forecast during past 24 hours (by assessing skill and bias) especially with respect to synoptic scale system and severe weather.
(iii)Examine forecast of each model for next 24-48 hrs for different severe weather phenomena.

STEP 5: Development of objective consensus from NWP models
(i) Give more weightage to the model with best initial conditions.
(ii) Consider historically best model and make bias correction in forecast comparing with initial condition
(iii) Remove outliers (Models).
(iv) Develop consensus on weather system based on various model guidance on Synoptic, Dynamic and Thermodynamic Characteristics.
(v) Develop consensus on the predicted severe weather by different models using all the above and assign the probability of occurrence and intensity

STEP 6: Final Forecast
(i) Develop Subjective consensus based on experience, knowledge and expertise of the forecaster in interpretation of Synoptic, Dynamic, Thermodynamic pattern of the atmosphere and model guidance through a video conferencing system
(ii) Use Subjective consensus to modulate the Objective consensus developed above to prepare the final forecast of thunderstorm and associated weather along with the area of occurrence and intensity.
(iii) Assign probability in terms of likelihood of occurrence
(iv) Assign potential impact of the expected severe weather
(v) Based on (iii) and (iv) assign colour code (green, yellow, orange and red) to decide impact based forecast of thunderstorm

STEP 7: ISSUE SUBDIVISION LEVEL SEVERE WEATHER ADVISORY BY NWFC AND DISTRICT LEVEL SEVERE WEATHER ADVISORY MC/RMC AND MONITOR FOR 3 HOURLY NOWCASTING

Note : Similar decision tree, specific to the stations, for other severe weather phenomena such as dust storm and lightning has to be prepared by respective stations/MCs

6.7.4. Timeline for analysis, forecast and dissemination

Issue of thunderstorm warning involves mostly meso-scale weather events with short spatial and temporal scale. Thus, lead time and frequency of issuing the thunderstorm warning will play a vital role in its successful implementation. Various stages of meso-scale processes, i.e. monitoring, analysis, detection, decision making process of warnings will have to be synchronized, so that the objective of thunderstorm warning is achieved efficiently.

Sub-divisional level guidance will be issued by NWFC at time scale of 24, 48, 72, 96 and 120 hours with updates 4 times a day.All forecast/warnings will be issued at the time scale in short to medium range and upto 3 hours in nowcast of 12, 24, 48, 72, 96 and 120 hrs in short to medium range and upto 3 hours in nowcast range and spatial scale of districts for short to medium range forecast and district/stations in nowcast range from corresponding SWFC/RWFC. The time-line for this purpose is given below.

HH : Appreciation of the scenario through synoptic and NWP analysis and forecast
(Analysis of hourly data and products (satellite, AWS, ARG, METAR, Special Report etc)
HH+1: Preparation of Check list and decision making
HH+2: Generation of warning bulletin and product
HH+2.5: Uploading and dissemination

6.7.5. Forecast/ warning products

The thunderstorm warning product consists of:

(i) Text product
(ii) Visual Products
(iii) Impact based forecasts and suggested actions

Occurrence of impending weather event will be depicted in the district/station level map/bulletins with related weather symbols, animation etc.

- At each forecast hour, duty forecaster will issue a summary message on the basis of observations and messages received.
- In case severe weather occurrence is expected, from the various inputs, for the region of forecast of the SWFC/RWFC, the duty forecaster will issue brief characteristics of the severe system and necessary warnings.
- The forecast will be issued four times a day based on general weather forecast from NWFC, two times from RWFC/SWFC and whenever required from AMOs.

6.8. Forecast/Warning Dissemination

The NWFC will issue the Thunderstorm outlook twice daily valid for day 1 (24 hrs) and day 2 (24-48 hrs) and Thunderstorm forecast bulletins upto day 5 days four times daily. It should contain probable impact of the event at subdivision and part of subdivision level. It shall be disseminating the bulletin to all RWFCs/SWFCs/PWS through e-mail, fax, telephonic network, SMS etc. It will act to identify the potential area for possible occurrence of TS for a day and will trigger intensive watch by RWFC/SWFC for that period over that region.

High impact Thunderstorm Warning bulletin shall be disseminated to State Disaster Management Authority cells / relief commissioners, District Disaster Management Authority, AIR and DOORDARSHAN. The classifications of high impact Thunderstorm events are given in Appendix 1. At national level, as soon as NWFC receives information about the severe weather events likely to cause widespread damage to a particular region, NWFC will inform the concerned authority at national level.

In addition, dissemination of high impact thunderstorm (thunderstorm associated with severe squall) warning bulletin to the general public through SMS/WhatsApp based text messages as prescribed in Appendix 2-5 will be issued. The Thunderstorm Warning bulletin issued by RWFCs/SWFCs shall also be made available to NWFC. Higher officers of IMD shall be kept informed by NWFC on Thunderstorm warning, for further necessary action as required.

Table 1

Checklist for dissemination of thunderstorm warning bulletin

Bulletin issuing authority	End user	Mode of dissemination	Time of receipt by end user
NWFC	All met offices like RWFCs/SWFCs/AMOs and Disaster managers, Media and Public	Website, Email Facebook, Twitter, TV/Print Media, WhatsApp	(i)General Bulletins 0830,1330,1630&2130hrs IST (ii)Thunderstorm Guidance 1330 &1730 hrs IST
RWFCs and MCs	Railways, Transport Dept. Power sector, Irrigation Dept. Revenue Dept. Health Dept. DMs, SDMA & DDMA and other local Govt. agencies like Municipal Corporation etc. Median and public	Website, e-mail, Facebook, Twitter, TV/Print Media, WhatApp	i)General Bulletins1330&2130hrs IST (ii)Nowcast: Every 3 hours
Radar Stations	RWFC/SWFC /NWFC, Local Administration if entrusted by SWFC	SMS/WhatsApp/email/ Tweeter/TV/print media direct to the end users,	As and when required
AMOs	Airport Authority, Airport managers and operators	OLBS, telephone and personal briefing	As and when required

The forecast will follow the standard dissemination procedure. The forecaster will verify the dissemination of products to end user through a checklist as mentioned above.

The forecaster will provide appropriate oral briefing to disaster managers as and when required. The briefing should be timely, concise, relevant and consistent with the forecast; the feedback from the user should be solicited.

6.9. Post Event Review, feedback and documentation

Depending on the severity of the thunderstorm event, the RWFC would decide on conducting a post analysis. The high impact severe thunderstorm events (resulting in tornado generation, down bursts, hailstorms etc) causing much of the damage to the life and property shall be recorded to the fullest extent inclusive of field survey. A survey/inspection team constituted by RWFC in consultation with SWFC shall be deputed to the affected area within a short span of time to take the first hand assessment of the event. The guidelines for the surveying/inspection team are given in Appendix 6.

The brief report/documentation of the severe thunderstorm including weather system, occurrence of thunderstorm,forecast/warning issued and verification, to whom issued and time of issue is to be submitted to the NWFC within 24 hours of occurrence. Detailed report to be prepared within 7 days.

6.10. Pre-season exercise

All RWFC/SWFCs and NWFC should have

- season wise forecasting hints
- checklists for forecasting of major events both qualitatively (synoptically) as well as quantitatively (various dynamic/thermodynamic parameters) which must be kept ready on the forecaster's desk.
- suitable training (Refresher) programme for the forecasters for thunderstorm monitoring and forecasting in regular intervals, at least once in a year.
- Conduct lecture series for the benefit of forecasters in the beginning of each season
- Conduct meetings with stakeholders including disaster managers and media.

6.11. Conclusions

Successful implementation of thunderstorm SOP will depend on

(i) Availability of proper and adequate trained manpower at NWFC/RWFC/SWFC and AMOs,

(ii) IT infrastructure and effective communication between various agencies for reception/dissemination of data, information and warnings and

(iii) Continuous evaluation/verification and hence update of the procedure and warning products at forecasting centres.

Appendix-1

Classifications of Thunderstorm events

Category/Wind Speed	Structures	Communication & Power	Agriculture	Suggested Actions
Light Thunderstorm <40 kmph (21 knots)	Nil	Nil	Nil	Nil
Moderate Thunderstorms 41 —61 kmph (22-33 knots)	Minor damage to loose / unsecured structures	Nil	Minor damage to Banana trees. Damage to ripe paddy crops.	People are advised to keep a watch on the weather for worsening conditions and be ready to move to safer places accordingly.
Severe Thunderstorms 62-87 kmph (34-47 knots)	Damage to thatched huts.	Minor damage to power and communication lines due to breaking of branches.	Some damage to paddy crops, banana, papaya trees and orchards and Standing crops.	People are advised to take shelter in pukka structures and avoid taking shelter under trees. Farming operations to be temporarily suspended during occurrence of event. Also move away from electric poles and wires.
Very Severe Thunderstorms Greater than 87 kmph {(47Kt) in gusts/ squall}	Major damage to thatched houses/ huts. Roof tops may blow off. Unattached metal sheets may fly.	Minor damage to power and communication lines.	Breaking of tree branches, uprooting of large avenue trees. Moderate damage to banana and papaya trees. Large dead limbs blown from trees. Damage to Standing crops.	People are advised to stay away from weak walls and structures and take shelter in pukka structures. People in affected areas to remain indoors and avoid water bodies and flying projectiles. Farming operations to be temporarily suspended during occurrence of event.
Thunderstorm associated with Hailstorm	Major damage to Kutcha structures and tin and asbestos roofed houses, cars		The fruit, vegetable and field crops at maturity stages are more prone to damage. Damage to Standing crops.	People are advised to stay away from weak walls and structures and take shelter in pukka structures. People in affected areas to remain indoors.

Appendix-1

An example of MC level forecast of Thunderstorms

Doppler Weather Radar Bhopal (Nowcast bulletin 18th August 2020/12:30 IST)

District wise warnings

Warning	Districts	Weather features / Surface wind / Impacts		Period of occurrence
Light Thunderstorm	Singrauli, Anuppur, Shgajapur, Guna, Ashoknagar, Rajgarh, Neemuch, Mandsaur, Jhabua, Burhanpur, Khandwa, Dhar	Light to Moderate Rain हल्की से मध्यम वर्षा	Wind speed up to 35 kmph	3-4 hours
Moderate Thundershowers	Tikamgarh, Sidhi, Nivari, Dindori, Shahdol, Chhindwada, Harda, Dewas	***Moderate Rain & Lightning*** ***मध्यम वर्षा और वज्रपात***	Wind speed up to 35 kmph	4-6 hours
Light Rain	Bhopal, Sehore, Indore, Ujjain, Badwani, Khargone, Alirajpur, Ratlam, Sheopur, Shivpuri	Light Rain हल्की वर्षा	Wind speed up to 25 kmph	3-4 hours
Moderate to Heavy Thundershowers	Satna, Hoshangabad, Betul, Raisen, Vidisha, Balaghat, Umaria, Chhatarpur, Seoni	***Moderate to Heavy Rain & Lightning with wind speed up to 35 kmph*** ***मध्यम से भारी वर्षा और वज्रपात***	* Localized Flooding in roads & city underpasses *etc.* * Localized congestion in traffic *etc.* * Be safe from lightning.	5-6 hours
Heavy to Very Heavy Thundershowers	Sagar, Narsingpur, Jabalpur, Mandla, Katni, Panna, Damoh	***Intense Spells of Heavy Rain & Frequent Lightning with wind speed up to 45 kmph*** ***तेज हवाओं के साथ भारी वर्षा और बारंबार वज्रपात***	* Flooding in low-lying areas, roads, drainage & city underpasses *etc.* * Overflow in small bridges & congestion in traffic *etc.* * Be safe from lightning.	5-6 hours

Warnings for Tourist places/ Airports

Warning	Tourist places	Weather features		Period of occurrence
Light Thunderstorm	Pachmarhi, Chitrakoot, Khajuraho, Omkareshwar	Light Rain & ***Lightning*** हल्की वर्षा तथा ***वज्रपात***	Wind speed up to 35 kmph	3-4 hours
Moderate Thundershowers	Bandhavgarh, Pench, Maihar, Pachmarhi	***Moderate Rain & Lightning*** ***मध्यम वर्षा और वज्रपात***	Wind speed up to 35 kmph	4-6 hours
Light Rain	Udayagiri, Sanchi, Amarkantak, Mandu, Bawangaja, Maheshwar	Light Rain हल्की वर्षा	Wind speed up to 25 kmph	3-4 hours
Moderate to Heavy Thundershowers	Bhedaghat, Kanha	***Moderate to Heavy Rain & Lightning with wind speed up to 35 kmph*** ***मध्यम से भारी वर्षा और वज्रपात***	* Localized Flooding in roads & city underpasses *etc.* * Be safe from lightning.	5-6 hours

Appendix-2

SEVERE WEATHER ADVISORY BULLETIN FORMAT
(SEVERE WEATHER GUIDANCE FOR NOWCAST)
(for Day-1)

Date: **Time of issue:**

Chief Synoptic Features:

Under this heading there should be a point wise mentioning of Chief Synoptic features observed. For Eg.

♦ThemonsoontroughatmeansealevelnowpassesthroughBikaner,Alwar,Gwalior,Banda,Siddhi,Ranchi,Bankura,Canningandthencesoutheastwardsto NortheastBayofBengalandextendsupto1.5kmabovemeansealevel.

♦ThecycloniccirculationoversouthPunjab&neighbourhoodnowliesovernorthwestRajasthan&neighbourhoodandextendsupto1.5kmabovemeansealevel.

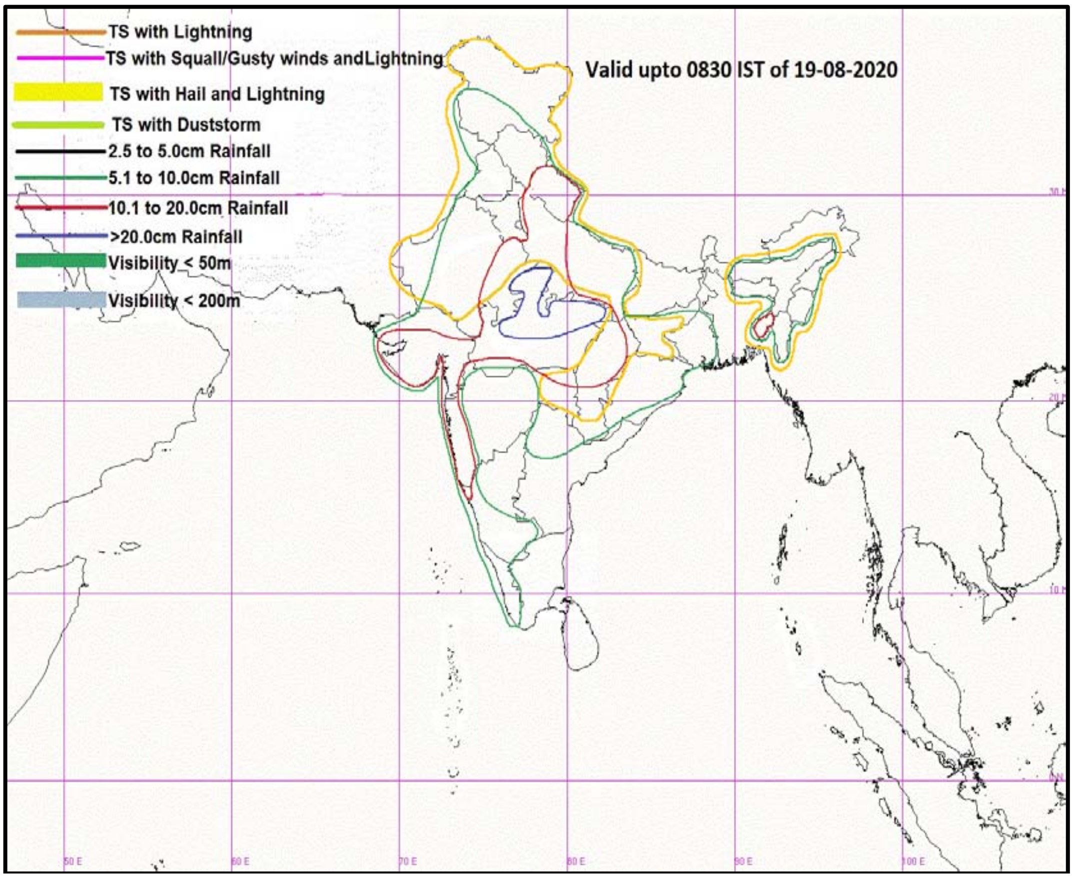
IOP Area for Day-1 (valid upto 0830 IST of next day)

IOP Advisory for 24 hours (Subdivisions wherever it is expected should be mentioned under the appropriate heading)
Significant Rainfall: Thunderstorm with Squally Winds (50-60 kmph and more) and lightning: Thunderstorm with Gusty Winds (upto 40-50 kmph) and lightning: Thunderstorm with Gusty Winds (upto 30-40 kmph) and lightning: Thunderstorm with Lightning: Thunderstorm with Hail and lightning: Thunderstorm with Dust storm and lightning: Dust raising winds: Visibility: <50m: <200m:

Graphical Presentation of Potential Areas for Severe Weather (IOP) for Day-1:

(Valid upto 0830 IST of next day)

The potential areas for Severe Weather should be graphically presented as the following example for 18th Aug, 2020.


TS with Lightning
TS with Squall/Gusty winds andLightning
TS with Hail and Lightning
TS with Duststorm
2.5 to 5.0cm Rainfall
5.1 to 10.0cm Rainfall
10.1 to 20.0cm Rainfall
>20.0cm Rainfall
Visibility < 50m
Visibility < 200m
Valid upto 0830 IST of 19-08-2020

Appendix-3

THUNDERSTORM OUTLOOK BULLETIN
(Based on 03 UTC / 12 UTC)

TOO:........hrs IST on date............. VALIDITY: 48hrs from 00 UTC of date...........

(1) Conditions are favourable for Scattered/fairly-widespread, moderate/ severe Thunderstorms/ Dust-storms/Hail storm over …………………………(meteorological subdivision), during next 24/48/72/96/120 hours. Strong surface wind associated with squall may reach or exceed ....kt.

(2) Conditions are favourable for Scattered/fairly-widespread, moderate/ severe Thunderstorms/ Dust-storms/Hail storm over …………………………(meteorological subdivision), during next 24/48/72/96/120 hours. Strong surface wind associated with squall may reach or exceed ....kt.

(3) So on as per requirement....

Appendix-4

FORMAT OF THUNDERSTORM FORECAST BULLETIN ISSUEDBY NWFC
(Based on 03 UTC / 12 UTC)

TOO:........hrs IST on date.............VALIDITY: 24hrs from 00 UTC of date...........

(1) Conditions remain favourable /becoming more favourable/ less favourableforScattered/fairly-widespread, moderate/severe Thunderstorm over ………………………………(meteorological subdivision & part of it), during the period ……………. To ……………. with wind approaching from ...... (16point scale) direction and speed reaching ………………… kt/kmph. The following events: squall/dust-storm/heavy-shower/hail are likely to cause scattered/wide-spread damage to life and property.

(2) Conditions remain favourable /becoming more favourable/ less favourableforScattered/fairly-widespread, moderate/severe Thunderstorm over ………………………………(meteorological subdivision & part of it), during the period ……………. To ……………. with wind approaching from.... (16 point scale) direction and speed reaching ………………… kt/kmph. The following events: squall/dust-storm/heavy-shower/hail are likely to cause scattered/wide-spread damage to life and property.

Appendix-5

FORMAT OF THUNDERSTORM WARNING BULLETTIN ISSUEDBY RWFC/SWFC
(Based on 18 UTC)

TOO:........hrs IST on date............. VALIDITY: 12 Hrsfrom .....00 UTC of date...........

Moderate/SevereThunderstorm/Dust-storm/Hail-Stormwould/will affect over …………………………(district/city), during the period from ……………. to …………. . It is likely to cause

a. Strong surface wind from......... (direction) and speed may reach/exceed ……kt/kmphand may cause damages to property/ life.....................................
....
(based on Beaufort scale estimate)

b. Heavy/very Heavy/extremely heavy rainfall over the area and may lead to flood.

c. Hail, leading damage to life and property

d. Suspended dust particles, affecting visibility.

Note:

a, b, c and/or d as applicable/relevant to be given by the issuing office

Appendix-5

FORMAT OF SMS/WhatsApp based nowcast bulletin

Thunderstorm warning
Through SMS for general public

HIGH IMPACT THUNDERSTORM ASSOCIATED WITH RAIN/LIGHTNING/HAIL/GUSTY-WINDLIKELY/WILL BY ....IST over the……..(area). ADVISED TO TAKE SHELTER INDOORS.

Appendix-6

GUIDELINES FOR THE SURVEYING/INSPECTION TEAM

1. Photographs of the affected areas, depicting loss/damages to property and life.
2. Interview with the public and analysis on,

i. Optical account of the event:
a. Shape of the clouds (Funnel/Trunk/..)
b. Sky conditions
c. Situation prevailing
d. Hail size and shape
e. Lightning frequency and location of hit

ii. Acoustic account of the event:
a. Vibrations felt
b. Sound type (hissing/roaring/rumbling/...)

iii. Impact account of the event:
a. Heavy objects twisted/turned upside-down/lifted/etc
b. Dent and pit marks in objects
c. Pattern of twist in stationary objects poles/trees etc
d. Orientation of fallen trees/poles/etc
e. Catastrophe of the event
f. Wind estimate based on Beaufort scale
g. Swath of impact
h. Areal cover of damage zone

General details on the causalities/ damages/ photographs/videos and situation prevailing and additional details as felt necessary by the surveyor/surveying team.

Chapter 7

Heat and Cold Wave Monitoring & Warning Services

7.1. Objective

The heat waves, periods of sustained high temperature and high humidity, have long been recognized as a significant weather hazard. The degree of discomfort that is felt during the hot weather period depends significantly on combined effect of the humidity of the air as well as the actual air temperature. An abnormal heat results from the increase of temperature can impose severe physiological stress and can adversely affect the life, health and well being of human society. The threshold ambient temperature at which, heat-related health complications varies greatly by location. However, in general, when summer temperatures increases to a value more than 40^0C, incidences of heat-related illness such as heatstroke, hyperthermia, and dehydration increase dramatically. High humidity compounds the effects of high heat by reducing evaporation, rendering perspiration a less-effective cooling mechanism.

Similar to the heat wave during summer the country India also suffers from severe winter and associated cold wave because of very low minimum temperature. Like the humidity in the heat wave case the wind speed in case of cold wave further compounded the effect of wind chill. Many parts of northern & central India generally experiences cold wave conditions during winter season.

Though the heat and cold waves are rarely given less sensational coverage as other natural disasters, it is one of the most severe disasters like heavy rainfall, thunderstorms, and cyclones. There are lot of casualties every year due to heat and cold wave conditions over India. Attempts have to be made to forecast these killer disaster on real time basis and the timely warning of the same will be very helpful not only for the general public but also for various users.

Objective is to examine the present criteria used in defining the heat wave & cold waves over India and also to define the procedure of delivering the warnings.

Sudden rise in temperature in summer can cause various health problems to the people who are exposed to direct sunlight. Similarly, the severe winter also can cause health problem for elderly people, children going to school and various operations. Thus, there is a need for the monitoring as well as forecasting of the same, which will be very beneficial for general public, children and also for other users. This has also got vast commercial applications to various sectors like Aviation, Power, Industries and Agriculture etc. Thus, there is a need:-

- To estimate climate - stress on:
  - human tolerance
  - crop tolerance
  - water resources

- To sensitize authorities and providing them with decision making options

- To satisfy specific sectorial requests for:
  - estimating power demand
  - transportation costs and safety
  - industrial productivity
  - agricultural productivity
  - individuals/ organizations requiring to take preventive actions

7.2. Observational aspects

The winter season from January to February (JF) is the winter time in almost all over India. However, the minimum temperatures (Tmin) drop below 8^0C over many parts of northern India during the month of November to February (Figs. 7.1a - 7.1d) as seen from the normal Tmin during the period 1981 to 2010. December and January are the coldest months over northern India with normal Tmin less than 8^0C over its many parts (Fig. 7.1b & 7.1c). This region also experiences cold wave during these months. Normally winters are dry in northern India, although it gets rainfall associated with western disturbances. After the passage of western disturbances, dry cold northwesterly winds penetrated into northern & central India. As a result, minimum temperatures drop over the regions and sometimes cause cold wave conditions. In southern parts, the temperature difference is not so marked due to moderating effect of Indian Ocean, Bay of Bengal and Arabian Sea (Fig. 7.1a to 7.1d).

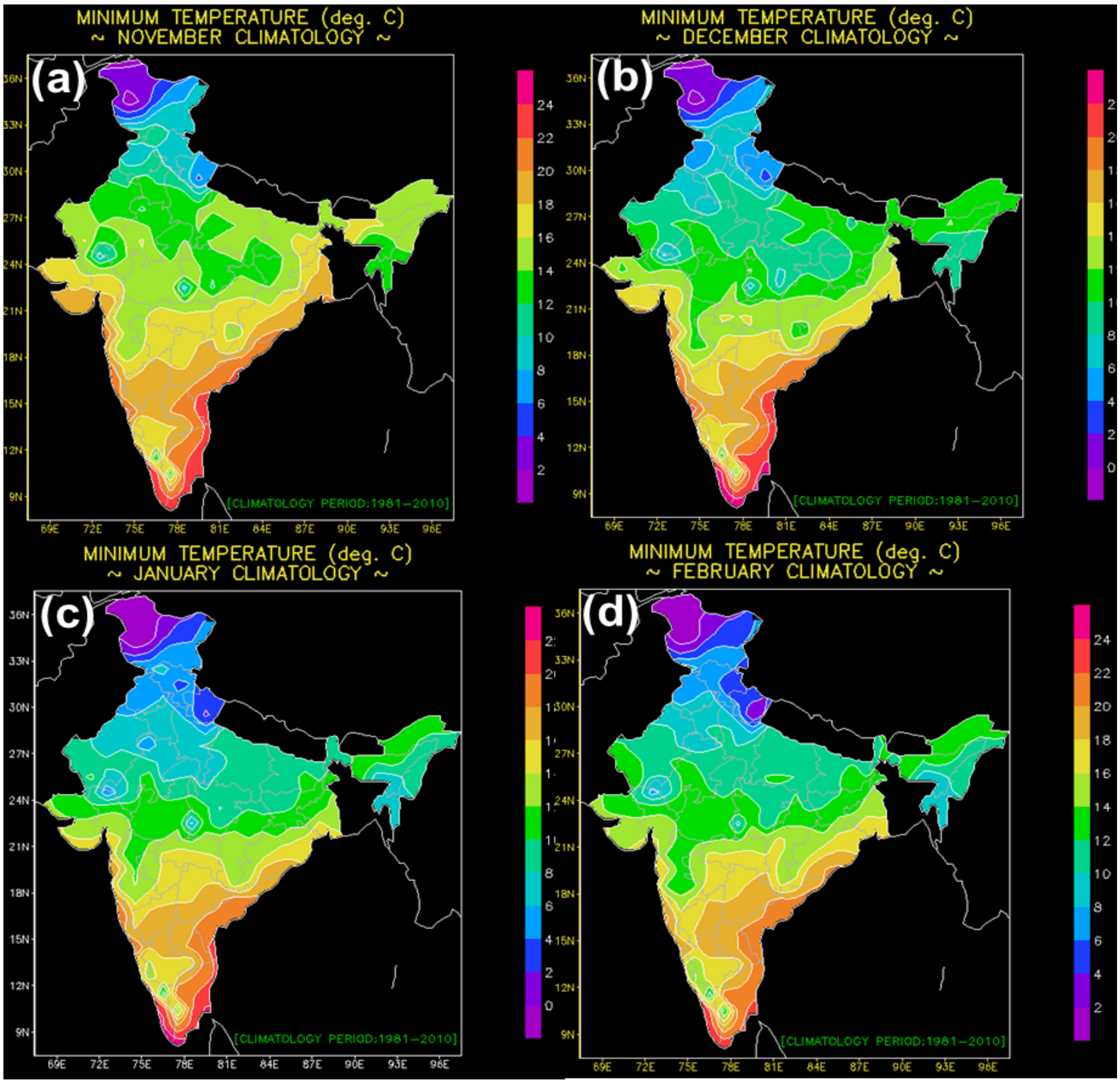


Figure 7.1. Normal Tmin duringNovember to February (1981-2010)

The average numbers of cold wave days are given in Table 7.1. These are highest over plains of northwest & adjoining central India with annual average numbers 6-8 days.

Table 7.1

Average Number of Cold Wave days

S. No.	State/UT	1971-80	1981-90	1991-00	2001-10	2011-19
1.	Punjab	6	6	6	7	3
2.	Haryana	9	4	3	5	9
3.	Delhi	4	3	4	5	4
4.	UP	8	3	2	4	6
5.	Rajasthan	11	8	4	5	4
6.	Sikkim	1	12	0	1	0
7.	Assam	3	2	0	0	1
8.	Madhya Pradesh	9	5	4	3	5
9.	West Bengal	3	1	1	1	2
10.	Bihar	5	4	3	4	6
11.	Gujarat	6	4	2	3	1
12.	Jharkhand	7	2	1	5	4
13.	Odissa	2	3	1	2	3
14.	Tripura	5	2	3	1	2
15.	Chattisgarh	3	5	3	3	6
16.	Maharashtra	7	2	5	3	5
17.	Telangana	6	2	6	4	6
18.	Andhra Pradesh	3	1	1	7	7
19.	Karnataka	1	0	0	0	0
20.	Tamil Nadu	2	2	2	2	0

The March, April and May are the summer months in India. The average temperature is around 32^{0}C but in northwest & central India, the maximum temperature (Tmax) can be far above the average. Hot wind known as 'Loo' is the marked feature of summers in northern India. The normal Tmax during the hot weather season from March to June is shown in Fig. 7.2a -7.2d. Fig. 7.2a shows that the Tmax are more than 36^{0}C over central parts of India during March, whereas during the month of April (Fig. 7.2b) the isotherm line more than 38^{0}C covers almost the large parts of India with a small pocket of central India with temperatures > 40^{0}C. During the month of May, the Tmax increases and exceeds more than 40^{0}C over the large parts of India covering northwestern parts of the country extending towards the Indo Gangetic plain (Fig. 7.2c).

During the month of June though the monsoon currents cools the southern parts of the country, the Tmax remains more than 40^{0}C over northwestern parts of the country (Fig. 7.2d). In general, heat wave occurs over plains of northwest India, Central, East & north Peninsular India during March to June. It covers Punjab, Haryana, Delhi, Uttar Pradesh, Bihar, Jharkhand, West Bengal, Odisha, Madhya Pradesh, Rajasthan, Gujarat, parts of Maharashtra & Karnataka, Andhra Pradesh and Telengana. Sometimes it occurs over Tamilnadu & Kerala also. Heat waves adversely affect human and animal lives. However, maximum temperatures more than 45°C observed mainly over Rajasthan and Vidarbha region in month of May. The average numbers of cold wave days are given in Table 7.2. These are highest over plains of northwest India with annual average numbers 6-8 days.

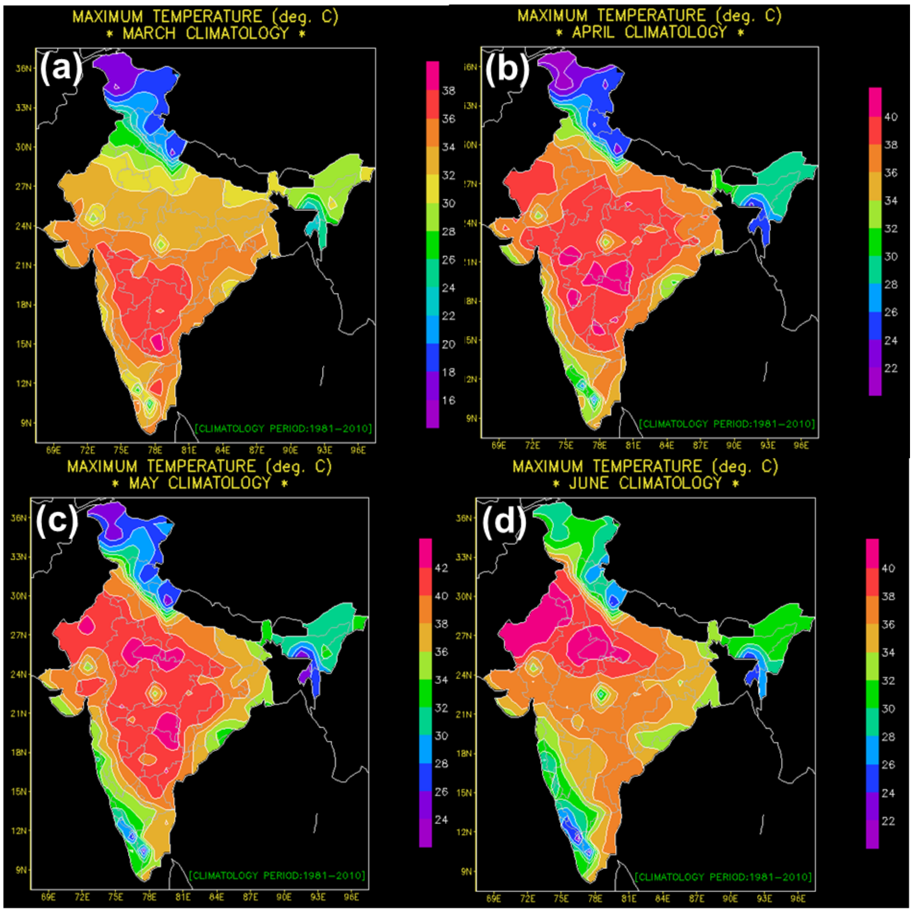


Fig. 7.2.Normal Tmax during March to June (1981-2010)

Table 7.2.

Average Number of Heat Wave days

S. No.	State / UT	1971-80	1981-90	1991-00	2001-10	2011-19
1.	Andhra Pradesh	10	9	9	9	11
2.	Bihar	7	5	4	6	8
3.	Chhattisgarh	2	3	3	5	3
4.	Delhi	4	3	6	7	6
5.	Gujarat	2	2	2	3	2
6.	Haryana	8	9	10	12	8
7.	Jharkhand	5	3	2	7	9
8.	Karnataka	1	1	2	1	1
9.	Kerala	0	0	0	0	0
10.	Madhya Pradesh	4	4	5	6	7
11.	Maharashtra	4	3	4	6	6
12.	Odisha	9	5	5	11	11
13.	Punjab	8	5	6	9	8
14.	Rajasthan	6	8	10	10	12
15.	Tamil Nadu	4	4	4	5	5
16.	Telangana	5	6	6	4	6
17.	Uttar Pradesh	9	7	8	6	8
18.	West Bengal	5	2	3	2	4

7.3. Analysis of the observations and declaration of Heat wave/cold wave

IMD has a big network of surface observatories covering entire country to measure various metrological parameters like Temperature, Relative humidity, pressure, wind speed & direction etc. Based on daily maximum/ minimum temperature station data, climatology of maximum/ minimum temperature is prepared for the period 1981-2010 to find out normal maximum/ minimum temperature of the day for particular station. Thereafter, IMD declared heat wave/ cold wave over the region as per the IMD Forecasting Circular No. 5/2015 (3.7).

7.3.1. Criterion for declaring heat wave

Heat wave is considered if maximum temperature of a station reaches at least 40^0C or more for Plains and at least 30^0C or more for Hilly regions.

- **Based on Departure from Normal**

Heat Wave: Departure from normal is 4.5^0C to 6.4^0C
Severe Heat Wave: Departure from normal is >6.4^0C

- **Based on Actual Maximum Temperature**

Heat Wave: When actual maximum temperature ≥ 45^0C
Severe Heat Wave: When actual maximum temperature ≥47^0C

If above criteria met at least in 2 stations in a Meteorological sub-division for at least two consecutive days and it declared on the second day.

- **Criterion for describing Heat Wave for coastal stations**

When maximum temperature departure is 4.5^0C or more from normal, *Heat Wave* may be described provided actual maximum temperature is 37^0C or more.

- **Criterion for warm night**

It is considered only when maximum temperature remains 40^0C or more. It is defined based on departures or actual minimum temperatures as follows:

Warm night: minimum temperature departure is 4.5^0C to 6.4^0C
Very warm night: minimum temperature departure is >6.4^0C

7.3.2. Criterion for declaring 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 10.0^0C or less for plains and 0°C or less for Hilly regions.

- **Based on Departure:**

Cold Wave: -ve departure from normal is 4.5°C to 6.4°C
Severe Cold Wave: -ve 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 Day

It should be considered when minimum temperature is 10.0°C 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

- **Cold Wave conditions for coastal stations**

When departure is -4.5°C or minimum temperature less over a station, “Cold Wave” may be described if the minimum temperature is 15.0C or less.

Cold day/cold wave or heat wave/warm night should be described, if conditions are satisfied simultaneously.

7.3.3. Meteorological favorable conditions for Heat wave

- **Transportation / Prevalence of hot dry air over a region** (There should be a region of warm dry air and appropriate flow pattern for transporting hot air over the region)**.**

- **Absence of moisture in the upper atmosphere** (As the presence of moisture restricts the temperature rise)***.***

- **The sky should be practically cloudless** (To allow maximum insulation over the region).

- **Large amplitude anti-cyclonic flow over the area*.***

Heat waves generally develop over Northwest India and spread gradually eastwards & southwards but not westwards (since the prevailing winds during the season are westerly to northwesterly). But on some occasions, heat wave may also develop over any region in situ under the favorable conditions.

7.3.4. Meteorological favourable conditions for Cold Wave

As cold wave conditions are associated with fall in minimum temperatures during the winter season. In this season, generally cold northwesterly winds prevail over the Indo- Gangetic Plains (IGPs). These winds come from colder regions of Central Asia/ Hindukush region and fall the temperatures over the IGP, as results, cold wave conditions prevail over the region. In general,

- Whenever a Western Disturbance (WD) approaches IGP, clouds develop over the region, maximum temperature fall and minimum temperature rise over the region. Thus, Cold Wave conditions over IGP get abated at the approach of a WD.

- When a WD moves away from the Indian region, clear skies start appearing over the IGP leading to rise in maximum and fall in minimum temperatures.

- Whenever a WD approaches north India, winds in lower levels over the region are either from Arabian Sea or from both Bay of Bengal & Arabian Sea. As both types of these winds are the moist, as a result, minimum temperatures rise over the region. At the same time, clouding over the region leads to lesser penetration of solar insolation into the earth and hence falls in maximum temperatures.

- Formation of an anticyclone in lower & mid tropospheric levels is also a driver of cold waves. Such an anti-cyclone gives rise to sinking motion over the IGP leading to fall in minimum temperatures.

- Left entrance and right exit of a Jet core belong to upper level convergence which in turn causes sinking motion over the surface hence causecold wave conditions.

7.4. Role and responsibility of different offices of IMD

At Meteorological Centre (MC) the heat/cold wave will be monitored for the state under the supervision of MC In-charge.

- At Regional Meteorological Centre (RMC)/ National Weather Forecasting Centre (NWFC), there should be round the clock duty headed by of Group-A officer if available, otherwise work may be managed by trained officials under the supervision of Group-A Officer.
- **NWFC to issue colour coded impact based heat/cold wave warning (Table 7.3 & 7.4) from Day 1 to Day 5 for all the 36 sub-divisions of the India.**

 MC/RMC to issue colour coded impact based heat/cold wave warning from Day 1 to Day 5 for all the districts of the respective state.

Table 7.3.

Impact based colour coded alert & warning for heat wave

Colour Code	Alert	Warning	Impact	Suggested Actions
Green (Noaction)	Normal Day	Maximum temperatures are near normal.	Comfortable temperature. No cautionary action required.	Nil
Yellow Alert (Be updated)	Heat Alert	Heat wave conditions at isolated pockets persists on 2 days	Moderate temperature. Heat is tolerable for general public but moderate health concern for vulnerable people e.g. infants, elderly, people with chronic diseases	Avoid heat exposure. Wear lightweight, light-coloured, loose, cotton clothes. Cover your head: Use a cloth, hat or umbrella
Orange Alert (Be prepared)	Severe Heat Alert for the day	(i) Severe heat wave conditions persists for 2 days (ii) Through not severe, but heat wave persists for 4 days or more	High temperature. Increased likelihood of heat illness symptoms in people who are either exposed to sun for a prolonged period or doing heavy work. High health concern for vulnerable people e.g. infants, elderly, peoplewith chronic diseases.	Avoid heat exposure– keep cool. Avoid dehydration. Drink sufficient water- even if not thirsty. Use ORS, homemade drinks like lassi, torani (rice water), lemon water, buttermilk, etc. to keep yourself hydrated
Red Alert (Take Action)	Extreme Heat Alert for the day	(i) Severe heat wave persists for more than 2 days. (ii) Total number of heat/severe heat wave days exceeding 6 days.	Very high likelihood of developing heat illness and heat stroke in all ages.	Extreme care needed for vulnerable people.

Table 7.4.

Impact based colour coded alert & warning for cold wave

Colour code	Alert	Warnings	Impact	Suggested Action
Green (No Action)	Normal day	Minimum temperatures are near normal.	Comfortable temperature.	No precautionary action required.
Yellow Alert (Be Updated)	Cold Wave Alert	Cold wave conditions in isolated areas persist for Two days.	Moderate temperature. Chilly winds may aggravate cold at time. Cold is tolerable but mild health concern for vulnerable people. (Infants, pregnant women, elderly, people with chronic diseases etc.)	Avoid prolonged exposure to cold. Wear several layers of loose fitting, light weight; warm woolen clothing rather than one layer of heavy cloth. Cover your head, neck, hands and toes adequately as majority of heat loss occurs through these body parts.
Orange Alert (Be Prepared)	Severe Cold Wave Alert	(I) Severe cold wave conditions persist for two days. (II) Though not severe, but cold wave conditions persist for Four days or more.	An increased likelihood of various illnesses like flu, running/ stuffy nose or nosebleed, which usually set in or get aggravated due to prolonged exposure to cold. Do not ignore shivering. It is the first sign that the body is losing heat. Get Indoors. Frostbite can occur due to prolonged exposure to cold. The skin turns pale, hard and numb and eventually black blisters appear on exposed body parts such as fingers, toes, nose and or earlobes. Severe frostbite needs immediate medical attention and treatment.	Listen to radio; watch TV, read newspaper for weather updates/ forecasts. Wear insulated/waterproof shoes. Moisturize your skin regularly with oil, petroleum jelly or body cream. Eat healthy fruits and vegetables rich vitamin-C and drink lots of fluids to maintain adequate immunity. Avoid or limit outdoor activities. Keep dry, if wet, change cloths immediately to prevent loss of body heat. Warm the affected area of the body slowly with lukewarm water; do not rub the skin vigorously. If the affected skin area turns black, immediately consult a doctor. Maintain ventilation while using Heaters to avoid inhaling toxic fumes. Take safety measures while using electrical and gas heating devices. Don't drink alcohol. It reduces your body temperature. Drink hot drinks regularly.

Red Alert (Take Action)	(I)Severe cold wave conditions persist for more than two days. (II)Total number of cold wave/severe cold wave/days exceeding Six days.	Severe exposure to cold wave can lead to Hypothermia; a decrease in body temperature which cause confusion, shivering, difficulty in speaking, sleepiness, stiff muscles, heavy breathing, weakness and/or loss of consciousness. Hypothermia is a medical emergency that needs immediate medical attention. Frost and cold wave affect pulse crops and livestock.	Along with suggested action for orange alert, extreme care needed for vulnerable people. Regularly check on elderly neighbours, especially those who live alone. Stay Indoors, if possible. Avoid unnecessary exertion. Locate designated public shelter nearby. In case of electricity or heating mechanism failure, take the affected person to such designated shelters. Seek medical attention as soon as possible for someone suffering from frostbite/ Hypothermia. Do not give the affected person any fluids unless fully alert. Store adequate water as pipes may freeze. Move pets indoors. Likewise, protect livestock or other big animals from cold weather by moving them to an enclosure.

7.5. Warning Product generation, presentation and dissemination

For issuing Heat/Cold Wave, following inputs are to be considered, such as surface and upper air charts, change chart, T-phi gram, Radar & Satellite products and guidance from various global & regional Numerical Weather Prediction (NWP) models used by IMD includes IMD Global Forecast System (GFS), NCEP GFS, NCMRWF Unified Model (NCUM), Global Ensemble Forecast System (GEFS) of MoES, NCMRWF Ensemble Prediction System (NEPS), European Centre for Medium Range Weather Forecast (ECMWF) model, Regional Weather Research & Forecasting (WRF) Model of IMD and NCMRWF regional (NCUAR) model (Fig. 7.3).

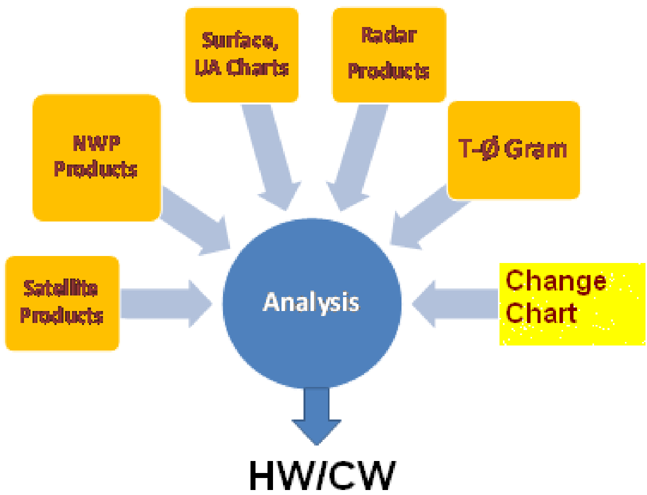


Fig. 7.3. Inputs for issuing HW/CW

At present, the heat /cold wave bulletins (colour coded and impact based) in text as well as graphic format for next 5 days and are updated four times in day (based on 0530, 0830, 1430 & 1730 hours IST) in All India Weather Forecast Bulletin (https://mausam.imd.gov.in/imd_latest/contents/all_india_forcast_bulletin.php) by NWFC, IMD, New Delhi.

In the Morning and Evening (at 0800 & 1600 hours IST) special heat wave guidance bulletins (http://internal.imd.gov.in/pages/heatwave_mausam.php) are also issued by NWFC.

The district wise heat/ cold wave warnings are issued by MCs/ RMCs of IMD. Thereafter, these warnings are shared with concerned State Government Authority, National Disaster Management Authority, Media and other stakeholders like Indian Railway, Health departments, Power Sector etc. In addition, RMCs/ MCs also provide temperature forecast for all the major cities of respective state as per the state disaster management requirement. In adding to above, warnings are also communicated **by all digital mode of communications like over phone (to senior disaster managers), whatsapp, SMS, e-mail, facebook, twitter, instagram and weekly weather in the form of audio-video model and uploaded inyoutube.**

7.6. Recent development

7.6.1. Heat/ cold wave Forecasting Demonstration Projects (FDPs)

In 2016, a multi-institutional initiative by involving IMD various divisions (NWFC, NWP, Satmet, RMC Delhi/ Kolkata/Guwahati, MWO Delhi/Kolkata, EMRC), NCMRWF, Noida, IITM Pune, SAC, Ahmadabad and IAF to understand & study the various characteristics of

- WDs & its associated weather i.e. heavy rain/snow, spatial distribution of precipitation
- Dense Fog
- Cold wave/day
- Ground frost etc.

mainly for the northern parts of the country (north of 20°N), so that a better weather forecast & warnings advisories at least five days in advance is to be issued during 1 December to 28 February from December 2016 onwards. Thereafter a detailed report is prepared during above period with following components:

1. Observation

   1.1. Past and current Observations:

   1.2. Satellite Observations:
   Satellite Division, IMD
   SAC Ahmadabad

   1.3. Atmospheric composition parameters:
   (i) Observations
   (ii) Forecast

2. Synoptic features:

3. Dynamical features:

4. Thermodynamical features:

5. Model analysis and Guidance

6. Forecast and Warning Guidance

This report is kept in IMD website and disseminate through emails to all concerned.

Similarly FDP heat wave was initiated from 2018 onwards for the period from 1 April to 30 June. During this period, two bulletins are issued daily, 1st bulletin is issued at 0800 hours IST with previous day maximum temperatures & its departure from the normal and heat wave warning for the same day. 2nd bulletin is issued at 1600 hours IST with previous day maximum temperatures & its departure, current maximum temperatures based on 1430 hours IST and its 24 hour tendency, Sub-divisionwise 5 days impact based heat wave warnings in text as well as graphic format. Warnings at meteorological sub-division levels issued to different users like, MHA, NDMA, SDMA, CS of states, DC/ DM of different districts of states, health department, Indian Railway, Road transport, Media etc. Seasonal and extended range (upto two weeks) outlook are also issued for maximum temperatures. Weekly extended range bulletin for temperatures and heat wave is also issued every Thursday.

7.6.2. Heat wave action plan

The Heat-Wave Action plan aims to provide a framework for implementation, coordination and evaluation of extreme heat response activities in cities/ town in India that reduces the negative impact of extreme heat. The Plan’s primary objective is to alert those populations at risk of heat-related illness in places where extreme heat conditions either exist or are imminent, and to take appropriate precautions, which are at high risk. **IMD is responsible for early warning for heat wave warnings.**

Presently, h**eat wave action plan has been implemented at more than 100 cities/towns of India.**

Source : Guidelines for Preparation of Action Plan – Prevention and Management of Heat-Wave-2016 https://ndma.gov.in/images/guidelines/guidelines-heat-wave.pdf

7.7. Preventive measures for Heat Wave

7.7.1. The measures one should do to minimize the impact during heat wave

- Listen to Radio, watch TV, read News paper for local weather forecast to know if a heat wave is on the way.
- Drink sufficient water and as often as possible, even if not thirsty.
- Wear lightweight, light-coloured, loose, and porous cotton clothes. Use protective goggles, umbrella/hat, shoes or chappals while going out in sun.
- While travelling, carry water with you.
- If you work outside, use a hat or an umbrella and also use a damp cloth on your head, neck, face and limbs.
- Use ORS, homemade drinks like lassi, torani (rice water), lemon water, buttermilk, etc. which help to re-hydrate the body.
- Recognize the signs of heat stroke, heat rash or heat cramps such as weakness, dizziness, headache, nausea, sweating and seizures. If you feel faint or ill, see a doctor immediately.
- Keep animals in shade and give them plenty of water to drink.
- Keep your home cool, use curtains, shutters or sunshade and open windows at night.
- Use fans, damp clothing and take bath in cold water frequently.
- Provide cool drinking water near work place.
- Caution workers to avoid direct sunlight.
- Schedule strenuous jobs to cooler times of the day.
- Increasing the frequency and length of rest breaks for outdoor activities.
- Pregnant workers and workers with a medical condition should be given additional attention.
  (*Source* : https://ndma.gov.in/images/guidelines/guidelines-heat-wave.pdf)

7.7.2. The measures one should do to minimize the impact during cold wave

- Stay indoors as much as possible.
- Check that you have adequate winter clothing.
- Monitor all media outlets for weather and emergency procedure information.
- Check on any neighbours who live alone, especially the elderly.
- Ensure emergency supplies are easily accessible-no power means-no electricity.
- Use only one room-an internal room or passage will be easier to heat. Regular hot drinks will maintain body heat to fight the cold.
- If electricity fails, freezers will preserve food for up to 48 hours if the door is kept shut.
- Ensure that adequate clothing is worn-many light layers are better than one thick layer.
- Hats and mufflers help to prevent heat loss.
- Maintain proper ventilation when using kerosene heater or coal oven to avoid toxic fumes.
- Eat healthy food to supply heat to the body and drink non alcoholic beverages.
- Visit doctor for signs of frostbite: loss of feeling and white or pale appearance on fingers, toes, ear lobes and the tip of the nose.
- Visit doctor for signs of hypothermia (subnormal body temperature); uncontrolled shivering, memory loss, disorientation, incoherence, slurred speech, drowsiness and apparent exhaustion.

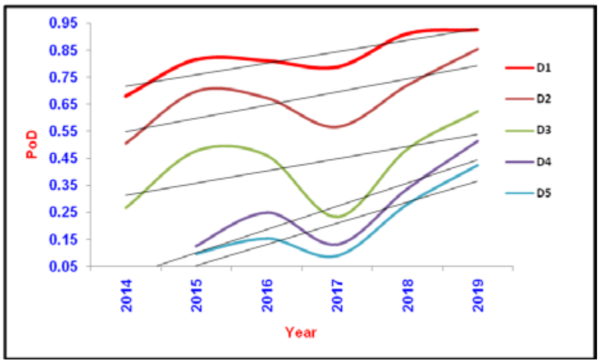
(*Source* : https://ndma.gov.in/en/national-plan/79-media-public-awareness/natural-disaster/cold-wave/1541-cold-wave-do-dont.html)

7.8. Documentation and Verification

- Must be based on absolute metrics and not normalized ones, except for differentiating high altitude areas from plains
- Must be sufficiently widespread and not pertaining to areas far too small to be identified unambiguously (District, State)
- Must not be ephemeral (lasting at least 2 days)
- Must be evaluated by objective observational methods as well accompanied by indices of human perception and spelt out specifically accordingly

The accuracy of the warning for heat wave and cold wave need to be verified in order to consider the effectiveness of the existing criteria (definition) used for defining the heat wave or cold wave episode. The heat wave and cold wave warning could be verified over Met. Sub-division level after the availability of all data.

Heat wave skill (Probability of Detection (PoD) and Missing Rate (MR)) for India as whole during 2014 to 2019 is given in Fig. 7.4.



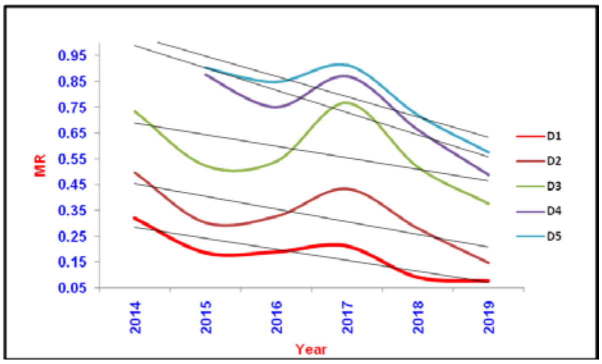


Fig. 7.4. PoD and MR of all India heat wave scores during 2014 to 2019

Chapter 8

Fog Warning Services

8.1. Introduction

The plains of north India is one of the most fog-prone areas in the world. During peak occurrences period of fog, one can see an extensive fog layer covering a vast areas across Indo-Gangetic plains(IGP), in day to day Satellite fog images, starting from Pakistan to Bangladesh across north Indian plains (Refer Fig. 1). Besides IGP, it also occurs over north-eastern states and East coast of India especially over Odisha and West Bengal coasts including Guwahati, Agartala, Bhubaneswar and Kolkata during few winter nights. Many hill stations of India also experience hill fog because of local topography and peculiar air pattern subject to the locations. Plains of Maharashtra, Gujarat, most parts of southern Peninsular India, and central parts of India rarely experience dense fog because of less humidity in the air. Even though the western parts of Rajasthan experiences rain due to western disturbances, it experiences lesser dense fog days mainly due to extreme low temperatures and lack of sustaining moisture sources and its availability because its western parts gets wind from dry deserts. Some urban locations e.g. Hyderabad, Chennai, Bhopal, Guwahati, Bangalore, etc. are also experiencing few dense fog days in winter season which may be due to rise in pollutions and urbanization.

Although it delivers beautiful scenery, Fog is dangerous and disturbing for all mode of transport especially aviation. Fog is defined as an obscurity in the surface layers of the atmosphere which is caused by a suspension of water droplets (with humidity > 75%), with or without smoke particles containing various types of pollutants, and associated with visibility less than 1000 m. Visibility (i.e. general visibility) is defined as the estimation of the minimum horizontal distance at the surface in all directions by an observer at which an object or light can be visible to the normal eye by referring to various pre-fixed landmarks around. Dense fog severely affects Aviation, Railway, Highway transport and other transport sector because of absence of desired visibility minima thus severely affecting their operation. In aviation sector, Fog has a significant impact on the conduct of flying operations particularly landing and take-off. Low ceiling and poor visibility are not just a safety issue. They can also severely reduce the capacity of an airport and lead to airborne or ground delays that result in diversions, cancellations, missed connections, and extra operational costs. It also affects river ferry Services across states like Bihar, Assam, UP etc., by affecting many inland water ways across Ganges and Brahmaputra where their intensity and frequencies are higher than rest part of India. Incidents of tripping of electrical power distribution wire lines have also been reported from several areas as of north India during prolonged dense fog period when associated with higher pollutants having electro-chemically charged particles. Human Health especially, of old and children gets severely affected in case dense fog layer persist over an area especially over parts of northwestern pains of India, for longer part of the day, disrupting the sun light and causing the day temp to remain very much lower than normal.

8.2. Basics of Fog events and Types in terms of physical process and local topography leading to their formation

Fog can form in a number of ways, depending on how the cooling that caused the condensation occurred : **Radiation fog** is formed by the cooling of land after sunset by thermal radiation in calm conditions with clear sky. The cool ground produces condensation in the nearby air by heat conduction. In perfect calm the fog layer can be less than a meter deep but turbulence can promote a thicker layer. Radiation fogs occur at night, and usually do not last long after sunrise. Radiation fog is common in autumn and early winter. Examples of this phenomenon include the dense fog event develops after rain spell followed by WD over north India in some winter date. **Ground fog** is fog that obscures less than 60% of the sky and does not extend to the base of any overhead clouds. However, the term is sometimes used to refer to radiation fog. **Advection fog** occurs when moist air passes over a cool surface by advection (wind) and is cooled. It is common during approach of a WD in peak winter period of 15 Dec-31 Jan over northwest Indian plains when easterly warmer and moist laden winds advected to these areas which already have come, under colder temperatures, just before changing westerly wind pattern to easterly winds at near surface level.

8.2.1. Fog formation and associated process

The occurrence, development and dissipation of fog over a region or place depends mainly on prevailing meteorological conditions and atmospheric particulate maters such as pollutants and aerosols. The complete processes passes through multiple processes (thermodynamical, radiative, dynamical, microphysical) that occur simultaneously, through a wide range of conditions, and that interact non-linearly with each other. The fog life cycle is determined by thermodynamic, dynamic, radiative and microphysical processes, and by surface conditions. Detailed understanding and modelling of the fine microphysical processes taking place inside a fog layer has been limited by the lack of suitable sets of dynamic, turbulent, radiative and microphysical measurements. **One of the particularities of Fog at surface level in BL in contrast to cloud at top of it is:**

a) its development within the surface boundary layer, in contact with the ground, where aerosol concentrations are the highest and surface heterogeneities imply complex heat, water, radiative and chemical fluxes.

b) CCN activation inside cloud associated with a significant cooling rate mainly forced by a vertical velocity where as being fog is a cloud in contact with the ground where aerosol concentrations are the highest where the cooling rate is mainly associated with radiative cooling and, consequently, is different from the cooling of other boundary layer clouds associated with vertical velocity and

c) Moreover, this cooling rate is maximum at the top of the fog layer, leading to maximum production of liquid water near the top of the fog where as in cloud cooling rate is highest at base. d) cloud forms under strong wind conditions where intermixing is fast, turbulent.

8.2.2. Mechanism of fog formation, intensification of layer, the maintenance phase and dissipation Process

Fog formation results from condensation of water vapor into liquid droplets near surface, as a result of air cooling, moistening, and/or through mixing of contrasting air parcels. The most common scenario considered when invoking fog formation over land involves nocturnal radiative cooling under light wind conditions (Roach 1995), while dissipation typically occurs a few hours after sunrise as a result of warming from sensible heat fluxes over a surface heated by solar radiation (the so-called fog burn-off). However, this statement hides a more complex reality, with regions experiencing fog events due to conditions such as advection fog or stratus lowering rather than the typical radiative fog event (Croft et al. 1997; Tardif and Rasmussen 2007). Furthermore, the nature and concentration of aerosols present in the surface layer are known to be critical parameters throughout the fog life cycle as their chemical and microphysical properties control the activation process (Rangognio et al. 2009), and their optical properties affect radiative cooling and heating (Elias et al. 2009). In addition, turbulent mixing is known to be a key but ambiguous factor in influencing fog formation. If turbulent mixing is too low, dew deposition at the surface will inhibit condensation in the atmosphere and hence inhibit fog formation. If turbulence is strong enough, it may promote condensation in a supersaturated surface layer of sufficient depth and hence lead to fog formation and development (Bergot et al. 2008).

During the maintenance phase, a significant fog layer maintains a relatively constant depth. This phase is characterized by a balance between opposing forces. These forces are fog-top radiative cooling, droplet settling, and fog-top mixing. Fog-top condensation balances evaporation and droplet settling processes to maintain the depth of the fog layer. Radiative cooling at fog top replenishes the supply of droplets as they settle downward, and even tries to strengthen the inversion and deepen the fog. At the same time, turbulent mixing attempts to weaken the inversion and erode the fog top. Since winds generally increase with height, a radiation fog layer typically deepens during its growth phase until it reaches a height where the winds are strong enough and induce enough fog-top mixing to halt the growth. Introduction of mid- and upper-level cloud layers, during the daytime, can help to maintain the radiation fog layer. These clouds reduce the solar radiation received at the ground surface, preventing warming at the surface and maintaining a higher relative humidity in the lower portions of the fog layer. However, the lower the level of an overlying cloud layer, the more it can reduce radiative cooling and condensate production at fog top, allowing dissipative processes such as settling to take over.

Fog Dissipation processes : The duration of the dissipation phase can vary due to several factors. Dissipation of droplets is generally caused by one or more of the following processes:

Solar Radiation : During the daytime, solar radiation is absorbed by the ground, even when there is an intervening layer of fog. As the ground warms, it heats a thin skin of air in contact with the surface through conduction. This heat initiates weak convective mixing, which begins to warm the lowest portion of the fog layer. The relative humidity in this layer begins to decrease, slowing the formation of fog droplets and eventually evaporating existing droplets. As the fog thins, the warming process accelerates, allowing more solar radiation to reach the ground. With moderately strong sunshine, the base of a fog or low cloud layer can lift at a rate of up to several hundred feet per hour.

Droplet Settling - Regardless of their size, all fog droplets continually settle. The depth of a fog layer decreases when the droplet formation rate cannot keep up with the settling rate. An average fog droplet, which is less than 20 micrometers in diameter, will settle at the rate of 1 cm/sec. So, fog initially 30 meters (or about 100 feet) deep should settle to the ground in about an hour if the maintenance processes are removed.

Wind Shear/Turbulent Mixing - A fog layer's capping inversion is often accompanied by a layer of significant vertical wind shear. Turbulent mixing of warmer and drier air into the top of the fog layer can reduce relative humidity in that layer and lower the inversion. The weaker the capping inversion is, the more susceptible it is to this ongoing mixing and erosion process.

Changes in the Wind : Introduction of moderate to strong low-level winds can cause fog to dissipate both at the fog top and near the surface. At the fog top, winds entrain warmer, drier air from aloft into the fog. Near the surface, winds cause mixing of the surface-warmed air with the fog above. Both promote evaporation of fog droplets and improved visibility.

Overlying Cloud Layers at Night : At night, loss of radiant heat is most rapid when there are no clouds above an established fog layer. If a broken or overcast layer of mid-level or a thick layer of upper-level clouds is introduced, fog-top cooling decreases because less radiation is able to escape the atmosphere. This effect can slow the rate of new droplet formation and contribute to fog dissipation.

8.2.3. Fog and Role of pollution

Many previous works have studied CCN activation inside stratocumulus or cumulus, i.e. associated with a significant cooling rate mainly forced by a vertical velocity. The specificity of this work is to study CCN activation in foggy conditions. Therefore, the framework is relatively different to past studies on activation. Firstly, the fog is a cloud in contact with the ground where aerosol concentrations are the highest. Secondly, the cooling rate is mainly associated with radiative cooling and, consequently, is different from the cooling of other boundary layer clouds associated with vertical velocity. Moreover, this cooling rate is maximum at the top of the fog layer, leading to maximum production of liquid water near the top of the fog. Aerosols influence the fog life cycle in a complex way. The number, size and chemical properties of aerosol particles are key properties in the activation processes. Consequently, the aerosol characteristics directly affect the microphysical properties of a fog layer (number and size of the fog droplets). But the microphysical properties of a fog layer indirectly influence the life cycle of the fog through the interactions between microphysical, dynamic and radiative processes.

8.2.4. Classification of Fog events

Fog events may be classified based on its scale, formation mechanism or from intensity prospective based upon horizontal visibility reduction, it causes. Hence, it may classify various types depending upon three following main factors (Refer Fig. 1)

- **Scale**

  - Meso-scale Fog
  - Synoptic scale fog
  - Large-scale fog

- **Physical Process**

  - Radiation fog
  - Advection Fog
  - Steam fog/evaporation fog
  - Lowering Cloud base
  - Valley fog/Upslope Fog

- **Intensity based**

  - Shallow fog
  - Dense fog/thick fog
  - Very dense/thick fog

8.3. Fog occurrences over India

The most favorable area of fog formation in India covers mainly western and central parts of parts of IGP covering Pakistan, Punjab, Haryana, Delhi and West Uttar Pradesh and northern parts of Uttar Pradesh because of availability of high moistures either from moving western disturbances or from local vast irrigated agricultural fields where abundance green vegetation are grown and moisture supply sustained during the season for supporting to agriculture day to day. Another area of maximum fog formation lies over Bihar and its north-eastern parts covering plains and valley of Assam and Meghalaya areas. Topography with wide plains and availability of abundance moisture secures in the region further due to presence of wide river networks in this region, from three major river basins those all feeding/distributing from/to Indus, Ganges and Brhmaputra-Meghna respectively also plays major role in such large-scale dense fog formation, stay for longer duration from early evening till late noon and then their persistence for weeks. While analysing fog coverage, one may note its distinct footprints distributed along these major river routes and accordingly often their major occurrences correspond to respective three river basins. Data shows Gorakhpur is the highest fog formation area in India. Nevertheless, the mostly suited low temperatures and calm wind conditions over the region helps dense fog for persisting to longer period which seriously affects daily life over the region. Such fog events sometimes observed to be developed simultaneously over the vast region of the IG plains and easily detected in recent days satellite morning visible pictures as a very large scale white patch persisting upto 1130 IST and extending twenty five hundred km from Lahore to Dhaka which may be rare in any other part of the world if one considers its unique larger spatial coverage for prolonged period (refer Fig. 2). Some urban locations e.g. Hyderabad, Chennai, Bhopal, Guwahati, Bangalore etc also experiencing few dense fog days in winter season which may be because of rise in pollutions and urbanization or very supporting synoptic circulation pattern over these places supporting moisture incursion followed by calm wind and fall in temperature.

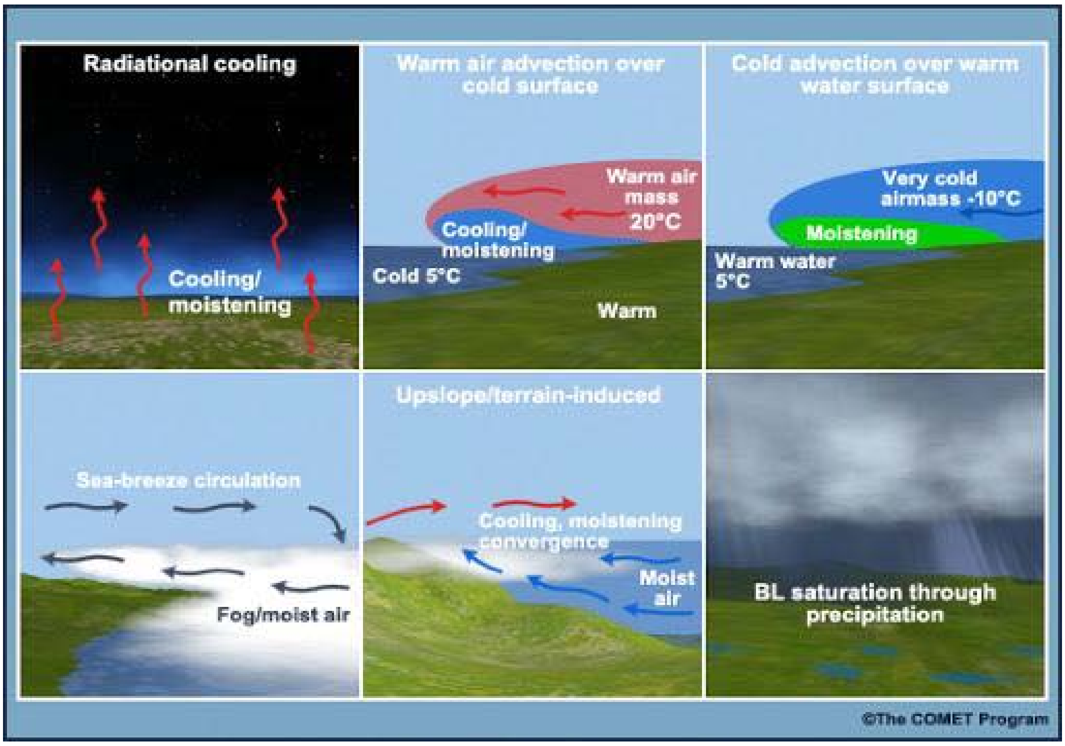


Fig. 1. Fog types as physical process and local topography and exposure conditions

8.3.1. Classification of Fog into different types for India region and their Climatological Characteristics

Considering the physical processes behind fog formation over India region, we can classify and distinguish between **radiation fog, radiation advection fog, advection fog, steam fog, cloud-base lowering fog and Precipitation Fog.** It can also be classified in terms of observed aerial extent it has covered in INSAT pictures routinely in peak winters, like restricted to a part of city or airport or to a RWY side leaving other RWY fog free called **local fog or meso-scale fog or cases when covered across a large areas of a country.** For common routine use, Fog can also be classified based upon how it impacts surface visibility reduction to any lowest value e.g. shallow, moderate, dense and very dense fog corresponding to Vis< 1000, <500m, <200m and <50m respectively (Table 1). IMD has also been using same classification for its day to day reporting and warning services.

Table 1

Classification of Fog into different Types based on general Vis reduction

Fog Types	General Visibility Range (in meters)
Shallow	Visibility fall upto 500m
Moderate	Upto 200m
Dense	Upto 50m
Very dense	< 50 m

Fog occurrences are very high for north-western Plains of India covering Punjab, Haryana, northern parts of Uttar Pradesh and Delhi which gradually decreases towards eastern Gangetic plains. Fog climatology for various airports in north India has been computed based upon visibility data as per data available from various sources at various temporal scale e.g. hourly visibility data as available from airports and from various met stations at 3-h interval in synop data. Table 2 to Table 5 shows climatological frequencies in number of days and durations for various types of fog at various visibility ranges as per types of data available from IAF and IMD for various periods. Wherever, good visibility data set for longer period, at 1-h interval say airport data for certain locations were made available, climatological occurrences for each types of fog (general fog, moderate fog, dense fog and very dense fog) in both duration and days for each months, have been prepared.

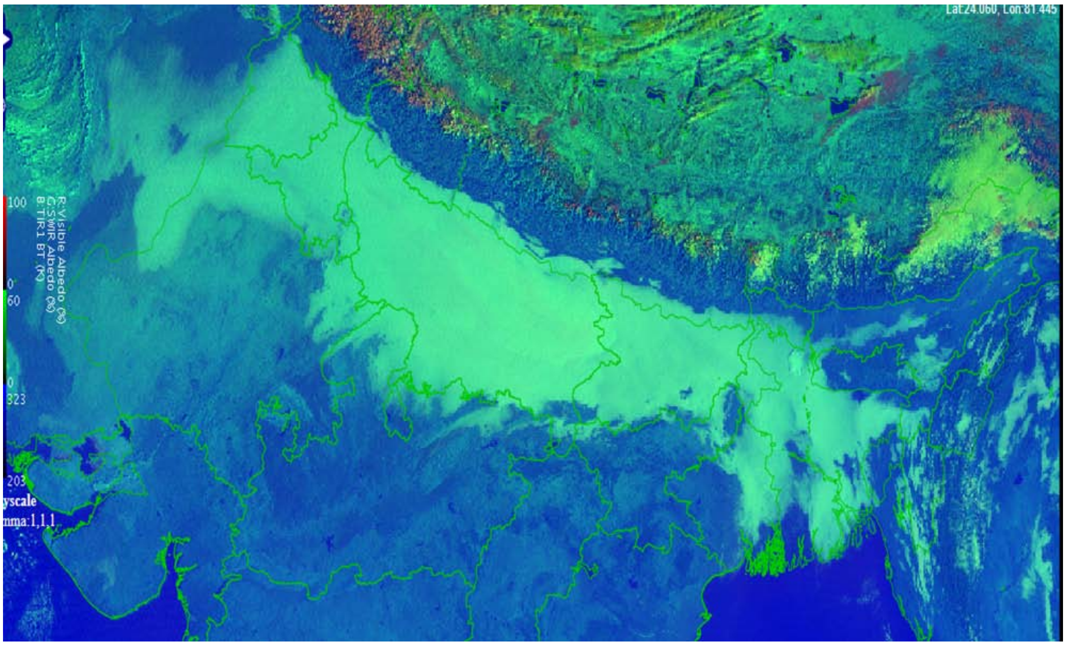


Fig. 2. Fog blanket as detected by INSAT 3D at 0830 Hours of IST of 5th Jan, 2018 which have been extensively covered vast areas of IGP region during a spell lasted for a week

Table 2 shows climatological frequencies in days and total duration for each month of Nov to Feb at IGI Airport for which continuous data for all months of winter covering fog period was available for 1991-2021 for Nov to Feb. As per Table 2, the capital Delhi based upon IGI Airport longer period data, one may finds, fog occurrences of vis< 1000m are as high as 823 hours and 88 days for whole Nov-Feb period while for Dense fog cases with Vis<200m, have total average of around 24 days and 126 hours. It may noted that dense fog occurrences severely affects day to day lives by impacting road transport, railway and flight operations. Table 2 further shows month-wise, among four months, Dec and Jan have almost 70-80% of occurrences on an average both in terms of durations and intensity-wise(Refer Table 2). Similarly, for other three major airports(Amritsar, Lucknow and Varanasi) of north India for which continuous 1-h gap IMD data are available but for Dec and Jan, have been compiled for these peak winter months and climatological occurrences in number of days and durations for each months have been given in Table 3 to Table 5. These shows in for each month of Dec/Jan, in total, fog occurs for 18-22 days on an average, which relatively less compared to Delhi which 26-27 days, in these months, while dense fog days are comparable of 8-11 days for all four airports in this belts per each month for Dec and Jan.

Table 6 shows climatological occurrences in total hours and days for Dec and Jan for IAF airports using data of another 7 airports (Kanpur, Ambala, Chandigarh, Allhabad, Agra, Gorakhpur and Hindon) shallow/ Moderate/dense fog along with duration and number of days, computed using data of 1999-2006. It shows general fog <1000m visibility occurs around 22-26 days as is seen for previous IMD data of four airports while dense fog are of 8-12 days, also comparable to IMD data of other four airports (Delhi, Amritsar, Lucknow and Varanasi given in table 2 to 5), all for the months of Dec and Jan, peak winter months when it affect the worst to flight operations and other transports. Average fog days data are also available from IAF for Dec and Jan 1971-2005 for another 7 airports - Bareilly, Gwalior, Pathankot, Jammu, Srinagar, Adampur and Bathinda which shows Bhatinda, Barilly and Adampur have very higher occurrences like other airport in this region with 18-20 days in each Dec and Jan months, peak winter months. But for other airports it is of 4-9 days. Table 8 shows average occurrences of different intensity of fog days at different ranges of Visibility another 18 major airports which includes airports over other parts of India with Nov and Feb average for Amritsar, Lucknow and Varanasi. One may note, Bangalore and Kolkota, Patna, Guwahati, etc are highly fog vulnerable.

Table 2

Average Fog hours duration and days 1991-2021 (31-years) IGI Airport, New Delhi

Months/ Types of fog	Duration				Days			
	<1000	**<500**	**<200**	**<50**	**<1000**	**<500**	**<200**	**<50**
Nov	151.3	29.3	4.5	1	17	4.8	1	0.5
Dec	277.8	102.3	41.3	25.3	26	15	7	5.2
Jan	289.6	127.2	66.3	38.3	26.1	17.9	11.4	8.2
Feb	104.9	36.2	13.8	5.9	18.5	9.5	4.0	2.1
Total	**823.6**	**295**	**125.9**	**70.5**	**87.6**	**47.2**	**23.4**	**16**

Table 3

Average Fog hours duration and days 1997-2021 (25-years) Amritsar Airport

Months/ Types of fog	Duration				Days			
	<1000	**<500**	**<200**	**<50**	**<1000**	**<500**	**<200**	**<50**
Dec	153.6	98.0	69.7	50.5	17.5	12.5	9.7	7.5
Jan	152.6	95.9	70.8	49.1	17.5	13.3	11.1	8.5

Table 4

Average Fog hours duration and days 2000-2021 (22-years) Lucknow Airport

Months/ Types of fog	Duration				Days			
	<1000	**<500**	**<200**	**<50**	**<1000**	**<500**	**<200**	**<50**
Dec	**169.1**	**93.6**	**64.4**	**8.0**	**19.7**	**11.5**	**8.9**	**1.5**
Jan	**193.0**	**112.4**	**75.6**	**14.1**	**20.3**	**13.9**	**10.9**	**2.8**

Table 5

Average Fog hours duration and days 2000-2021(22-years) Varanasi Airport

Months/ Types of fog	Duration				Days			
	<1000	**<500**	**<200**	**<50**	**<1000**	**<500**	**<200**	**<50**
Dec	157.8	70.0	43.1	24.3	22.2	10.5	6.4	4.4
Jan	182.8	99.5	70.4	40.4	22.1	13.7	10.5	7.1

Table 6

Climatological hours of occurrences for various intensity of fog in hours using IAF data for six airports of north India

Station Name	Month	Averaging Years	Average							
			<1000		<500		<200		<50	
			Hours	Days	Hours	Days	Hours	Days	Hours	Days
Allahabad	Dec	2000-2006	143.7	20.9	52.9	10.1	35.0	6.4	30.3	6.0
	Jan	2000-2006	201.7	22.4	101.9	14.3	76.3	10.4	70.9	9.9
Kanpur	Dec	1999-2006	165.6	24.8	67.9	14.0	40.5	8.5	34.6	7.0
	Jan	2000-2006	182.4	21.7	98.0	12.9	69.1	9.3	63.9	8.6
Agra	Dec	2000-2005	193.5	24.2	69.8	12.0	43.5	6.5	41.3	6.5
	Jan	2000-2006	212.3	24.1	111.3	12.8	88.9	10.3	82.3	9.8
Ambala	Dec	1999-2008	167.8	23.2	84.4	13.8	61.3	11.4	54.7	10.6
	Jan	2000-2008	204.1	19.2	98.1	13.7	69.7	11.0	64.1	10.7
Chandigarh	Dec	2000-2008	70.7	8.3	39.6	4.8	27.7	4.1	22.2	3.7
	Jan	2000-2008	135.5	17.7	68.6	9.3	48.3	7.2	44.1	7.1
Gorakhpur	Dec	1999-2008	313.7	27.6	124.4	18.4	80.6	12.8	71.4	11.4
	Jan	1999-2008	293.9	25.0	114.3	15.9	75.3	12.1	66.9	10.8
Hindon	Dec	1999-2007	241.1	27.3	81.6	15.3	40.1	8.3	31.3	6.7
	Jan	2000-2008	251.0	25.9	110.8	14.0	68.9	10.0	57.6	8.9

Table 7

General Fog occurrences in number of days using Air force data for additional 7 Airports

Station name	Month	Averaging Years	Average days
Bareilly	Dec	1971-2005	20.5
	Jan	1971-2005	18.5
Gwalior	Dec	1974-2005	7.8
	Jan	1974-2005	9.8
Pathankot	Dec	1971-2005	3.3
	Jan	1971-2005	5.4
Jammu	Dec	1971-2005	3.3
	Jan	1971-2005	5.9
Srinagar	Dec	1971-2005	3.9
	Jan	1971-2005	4.6
Adampur	Dec	1971-2005	18.2
	Jan	1971-2005	19.2
Bathinda	Dec	1977-2005	15.4
	Jan	1977-2005	18.6

Table 8

Average No of days of Fog Formation at 18 Airports during November, December, January & February months 2005-2020 using IMD data (with Amritsar, Lucknow, Varanasi only for Nov and Feb months. For latter airports for climatological occurrences of fog at various intensity in Dec and Jan, refer Table 3-5)

S. No	Airport	Visibility															
		January(Days)				February(Days)				November(Days				December(Days)			
		<50m	<200m	<500m	<1000m	<50m	<200m	<500m	<1000m	<50m	<200m	<500m	<1000m	<50m	<200m	<500m	<1000m
1	Amritsar					2	1.2	1.4	4.1	0.6	0.6	1.6	6.6				
2	Lucknow					0.6	1.3	1.3	3.7	0.1	1	0.7	5.7				
3	Varanasi					4.5	5.7	5.4	11.7	0	0	3.4	16.8				
4	Patna	5.7	10.3	11.4	24.5	0.1	0.1	0.1	0.4	0	0	0	1.2	6.8	6.9	12.9	19.9
5	Kolkata	0.3	0.4	0.7	0.5	0.1	0.1	0.1	0.4	0	0	0	0.2	0	0	0.2	0.5
6	Jaipur	1.1	0.9	1.4	4.5	0	0.1	0.2	1.2	0.1	0.1	0.1	1.3	0.1	0.2	0.3	2.5
7	Guwahati	0.1	1.4	1.8	5.4	0	0.1	0.3	0.9	0	0.1	0.4	1.4	0.1	1.7	2.6	5.1
8	Bangalore	0.1	0.6	0.6	1.1	0	0	0.1	0.2	0	0.1	0.1	0.4	0	0.2	0.3	0.6
9	Hyderabad	0	0	2	2	0	0	0	0	0	0	0	1	0	0	2	3
10	Chennai	0	0.1	0.2	0.4	0	0	0	0	0	0	0	0	0	0	0	1
11	Trivendrum	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
12	Coimbatore	0	0	0.1	0.2	0	0	0	0.2	0	0	0	0.5	0	0.1	0.1	0.3
13	Kochi	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
14	Calicut	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
15	Indore	0	2.1	3.1	5.2	0	0	0	0	0	0	0	0	0	0	0	1.5
16	Mumbai	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
17	Ahmedabad	0	0	0.1	2.6	0	0	0	0	0	0	0	0	0	0	1.3	2.1

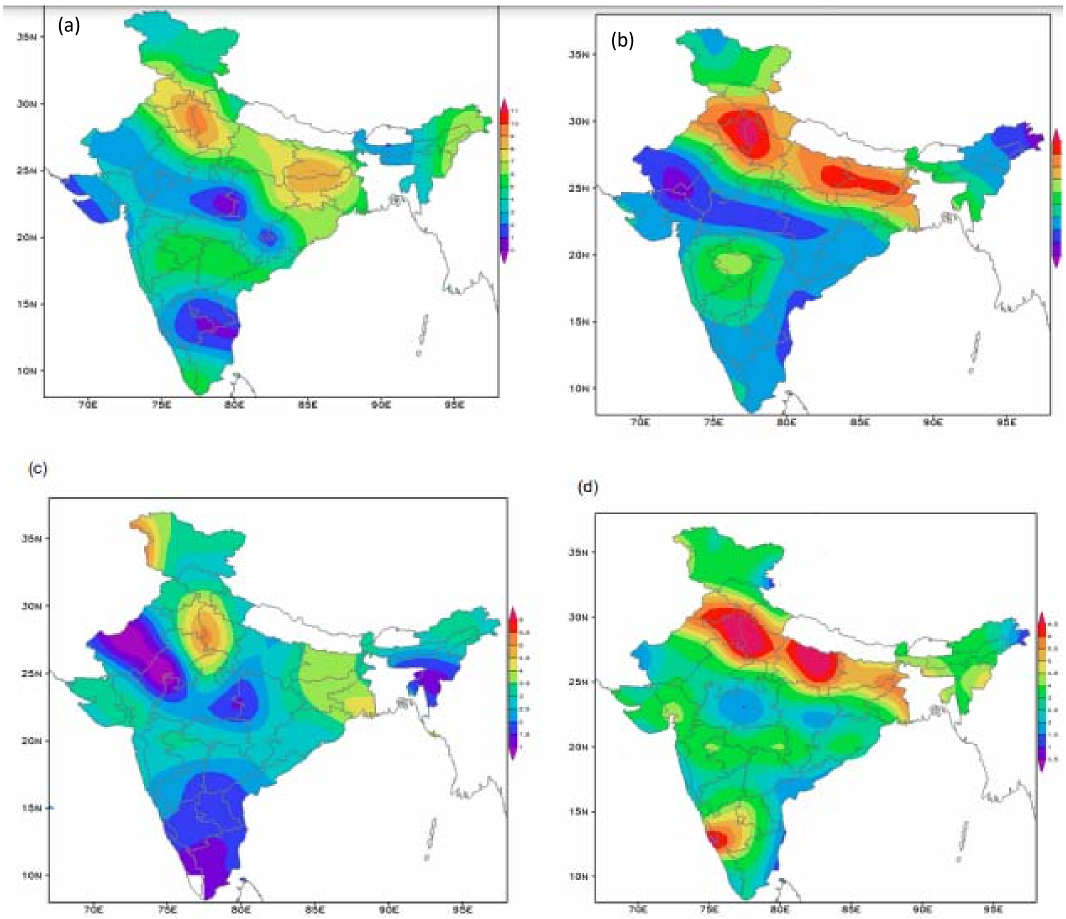


Figure 2b. Average number of days with fog having visibility < 1000 m for the period 1971-2000 (a) December, (b) January, (c) February and (d) Season from Sawaisarje, G. K., et al. 2014

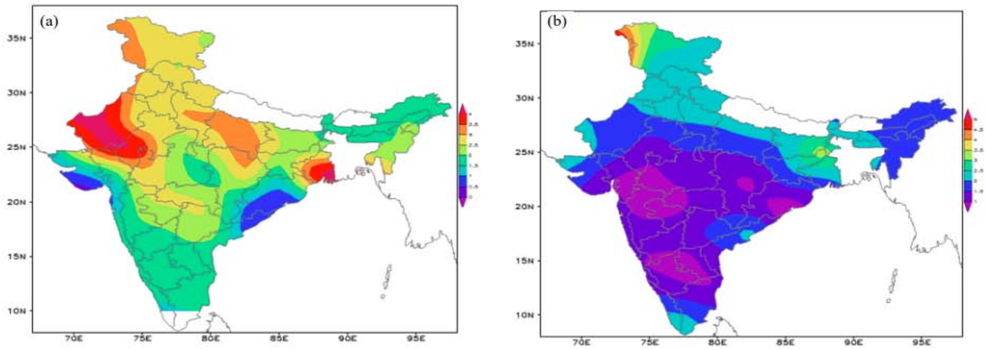


Figure 2c. Average number of days with (a) dense fog having visibility code 90 (During day observations, objects not visible at 50 m and at 100 m during night observations (b) thick fog having visibility code 91 (During day observations, objects visible at 50 m but not at 200 m and at 330 m during night observations) from Sawaisarje, G. K., et al. 2014

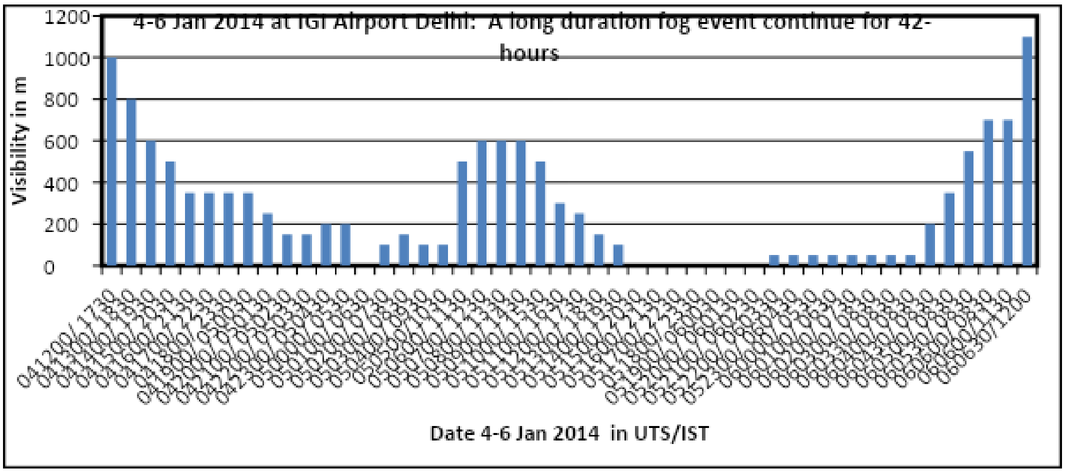
Fig. 2b and Fig. 2c shows spatial frequency of fog occurrences days at <1000m, < 200m and <50m for Dec to Feb month-wise cumulative days and season over all India using IMD data **from Sawaisarje, G. K., et al. 2014.** The areas of maximum fog areas also coincides with finding we noted from airport data and presented in tabular from in Table 2 to 8 with most vulnerable areas leis over Punjab Haryana and then over areas of northeast Uttar Pradesh and adjoining areas of Bihar.

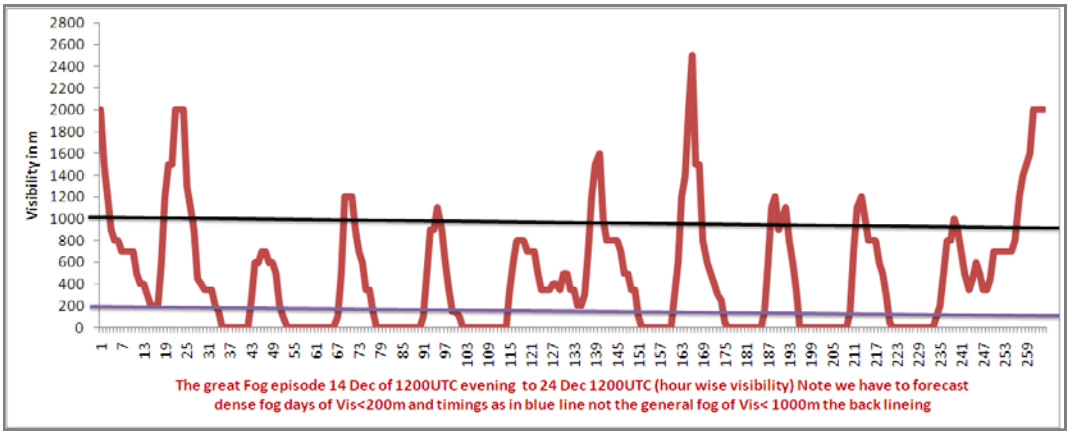
8.3.2. Longer duration dense fog spells over IGP and their Unique characteristic

One may look at Fig. 3a, Fig 3b and Fig 3c and find the daily variation of three fog cases from timing of fog formation and lifting process where their life cycle were noted to be of 76 hours (days lasted), 42 hours (2-days lasted) and 225 hours (9-days lasted) corresponding to tow major fog events at Delhi and one event at Amritsar. All these events sow, fog was occurred and then was remained persistently whole period with visibility almost less than <1000m all throughout with late evening to late morning, also dense fog have been report with longer night-morning period of v<200m. Hence, a system of fog forecast capability in case consider, must consider such extreme cases and capture such variation.

Study of fog events across IGP region for 2000-2021 using satellite fog coverage data and airport data show that fog events formed during the peak winter of mid Dec till end Jan are normally large-scale in terms of aerial coverage, longer spells and are combination of Radiation and advection types while cases in the months of Nov and Feb mostly occurred localized at meso-scale or synoptic scale, shorter in spell and hence are of radiation fog types. There are months and seasons when large-scale dense fog occurred across vast areas of IGP region was observed and persisted for very longer period of 10-30 days across IGP region e.g. Dec 1997 and 1998, Jan 2003, Jan 2010 and Dec-Jan of 2016-17, 2017-18 and 2020-21 when whole Indo-Gangetic plains (IGP) had frequent spells of occurrences of high duration dense fog layer covering most parts of it lasting for 12-15 hours with night-morning period with visibility below 200m. These longer spell dense fog events are called as episodic fog/smog as it severely impacts lives of people across this great IGP. It is also called as **high impact weather event** as data shows it impacted normal lives severely with 100s of flight and train delays/cancellations and also caused road accidents. Some additional unique **Characteristics** of large-scale Indo-Gangetic dense fog layer are:

- It mostly forms during peak winter of Mid Dec to 1st week Feb and of mixed type Radiation-advection.
- Once it forms, it continues to persist for weeks at night and morning over vast areas with only partial lifting at late noon with conversion to low stratus clouds.
- In fact, at both temporally and spatially, IGP fog events may be the fastest in formation, largest in areas and longest in duration, if compared to any other fog areas of the world and, also in terms of magnitude of its severe impact as it spreads over world's mostly densely populated region.
- Persistence of such thick fog layer further compounded lives of common people when dense fog layer prevents sunlight to reach to the surface during most parts of the day with day max temp falling to as low as 10-15degC with 8-12degC below normal for weeks.





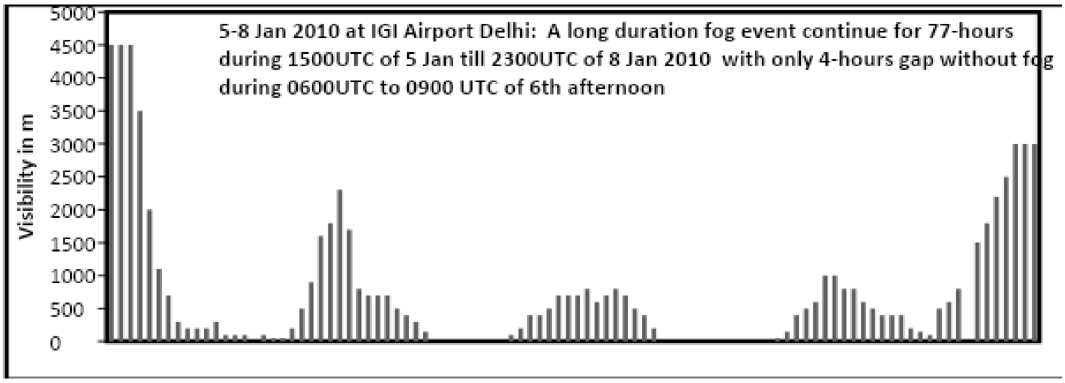


Figure 3(a,b,c). The daily variation of three of most longest duration fog cases at IGIA Delhi from timing of fog formation and lifting process where their life cycle were noted to be of 76 hours (4- days lasted) in Jan 2014 at IGI Airport Delhi, 225 hours(9-days lasted) during Dec 2018 at Amritsar Airport and 42hours(2-days lasted) occurred during Jan 2020 at IGI Airport Delhi

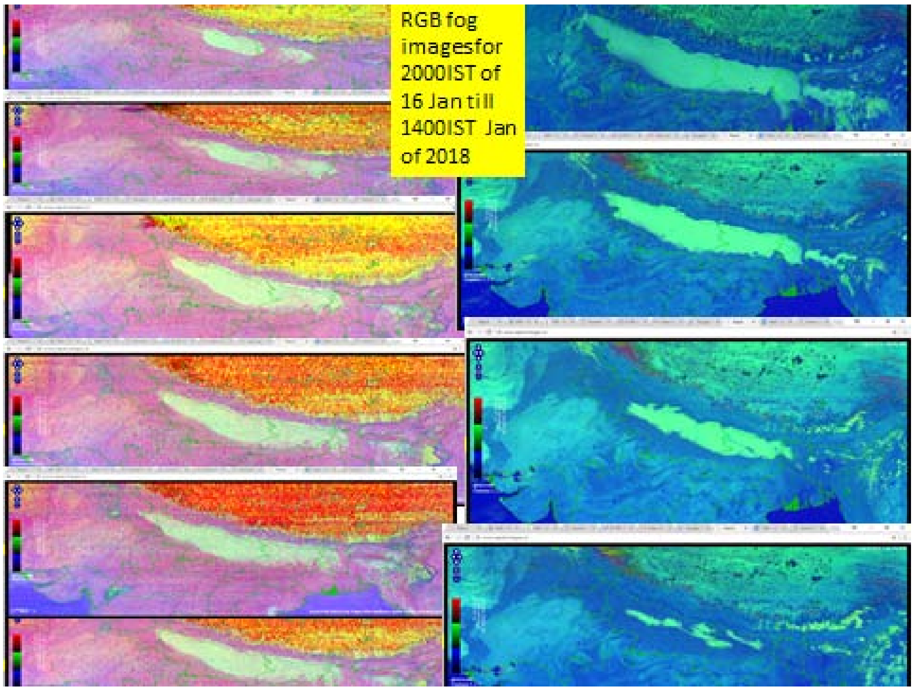


Figure 4. INSAT 3D RGB-Satellite based monitoring of fog formation/dissipation and Arial spread/receding across IGP during 2000IST night till 1400 IST afternoon of the next date

8.3.3. Variability and Extremes of fog occurrences across IGP and Impacts

8.3.3.1. Variability and Extremes of fog occurrences across IGP

The presence of heavy and extended period of fog in the northern regions of India across IGP in each Winter (Ref Fig 2), is one of the major weather hazards. **Followings are few salient features of variability of fog characteristics in IGP region when analyzed these events from satellite and surface fog data for month wise during 1997-2021:**

- Areas of IGP's northwestern parts and central parts, are more vulnerable for dense fog.
- On an average, longer period data of airports across this part of IGP except Delhi shows around 30-40(18-22 days) of General fog (Dense Fog) of Visibility<1000m(<200m) with average duration lasting 8-10-hours(6-7hours) per night-morning in the peak winter months of Dec-Jan.
- Delhi being more polluted, it records 54% more of fog days compared to others, with total of 54 days/618 hours i.e. 12 hours per day with almost all days reporting fog during whole period of Dec-Jan. But it is interesting to note that it has nearly similar 21 dense fog days with average of 6-7 hours per day as it records for other airports in IGP.
- Nov and Feb too reports fog in the region, but it is of marginal occurrences of 10-15 days/8-10 h per day for general fog and just of 1- 3 days with 3-4 hours per day dense fog. One of the most uniqueness of IGP fog events is that it has very high unusual variability with season of very high extreme fog coverage affecting severely life of people in the region while in some season, it is average or below average and few with, no dense fog reported at al.
- Data shows 1997-1998, 2002-03, 2009-10, 2014-15 and in 2017-18 and 2020-2021, are extreme fog years when 25-35 days/200-300 hours of dense were observed blinding most dates from mid-night till late morning. In these seasons, satellite fog also in some occasions shows almost all areas including eastern and northeastern parts of IGP including Delhi(Ref Fig 2) were under dense fog cover for 3-4 weeks.
- In contrast, 2007-08 and recent of 2018-19, were noted as prominent winters when hardly any significant dense fog was reported across IGP except few cases at its northwestern parts (It was total 2 days just at Delhi in 2007-2008 in all dates of Dec-Jan).
- Daily variability also shows fog cover remaining for 5-10 days uninterruptedly without any lifting covering 24-hours each date with dense fog with 0m Vis set in as early as 0630pm and continued till 11am next day morning including at Delhi, Lucknow, Amritsar and Varanasi in the belt (Ref Fig. 2, 3 and 4)

Other Important Characteristics

- Large-scale longer spell and longer duration dense fog coverage which occurred acorss IGP region mostly observed in 45-days window of peak winter season Mid- Dec to 1st week Feb and are of mixed type Radiation-advection
- Like other major fog regions of the world, transformation does occur from fog to low stratus clouds at late day and at night back as dense fog.
- It also severely affects air quality when it traps large amount of pollutions available in the region and hold them all at lower levels with not much dispersion. During lifting, it works as a scavenger and results low pollutions.
- It is interesting to note areas of such large-scale fog only restricts to those plain areas which is of very lower topographic part of this plain having the surface height upto 300m extending from Pakistan to Bangladesh across Punjab-Delhi-Utter Pradesh-Bihar-West Bengal and extends to further narrow north-eastern parts plains.
- Study finds, dense fog forms at most favorable Min temp of 3-10degC with lower levels wind often light/calm across IGP
- Colder surface light winds from north/nortnorthwest, blown from adjacent Ice covered Himalayan region also helps it, by intensifying surface colder layer temp and then inversion with upper layer warmer from subsidence of Anticyclone lay over the area in most date
- Large-scale pollution layer in this area has been major contributory factors
- Irrigation and Green revolution increased - role of change of Land scale processes through moisture increase and lowering surface air temp.

8.3.3.2. Analysis of fog Impact

Fog affects severely affects various sectors including human lives and it includes:

- Aviation, Railway and Highway transports
- River/Costal ferry services
- Stops Sunlight for weeks and cause severe cold day spell and hence affect Human Health
- Pollution and AQI
- High Power grid lines tripped from fog with higher pollutants
- Affect the crop at growth stage, Flowering stage and at seed formation stage
- Road accidents as major Impact of Fog: Very high in terms of lives lost at north India

a. Impact on Human lives

Dense fog affects road transport severely and not adopting fog safety rule during fog conditions causes road accidents. In fact for north India, it has been causing very high number of fatal accidents among all weather events. Fog of two winter for Dec-Jan shows, it has caused Very high cases of fatal accidents in terms of lives lost at north India. It shows during 2016-2018 winters, when their frequencies are very high, it caused around 120(159) human lives lost Dec-Jan 2016-17(2017-18). Following were major cases of impacts when accidents were reported in fog from media

2016-2017

- 24 Children who faced the accident on 19 Jan dense fog at Etah UP
- 9 people died in accident due to dense fog on 1 Feb in Barabanki district
- 12 school Teachers who lost their lives in fog related accidents at Punjab on 9 Dec Morning
- 11 people lost their lives in the Yamuna express high way in three different dates of accidents due to dense fog reducing visibility

2017-2018

- 11 lives lost on early morning of 3 Jan at Sikar and another 17 people lost in last 24-h at Raj alone (TNN 7AM 4 Jan)
- 5 power-lifters including world champion Saksham Yadav died in an accident that took place near Delhi-Panipat highway (NH-1) due to fog 6-7 Jan (4am 7 Jan).
- 11 people died on Kanpur-Agra road on 7 Jan Sunday evening, when a speeding truck rammed into a standing auto-rickshaw.

- 9 lives lost at WB on 20 Jan in dense fog
- 10 Lives lost at different cases as received in Patna on 28 Jan
- 15 lives lost in Fog at Raj(6), UP(7) and WB(2) on 28-29 Jan

b. Impact on aviation:

Fig. 4 shows total flights diverted and occurrence of total dense fog hours during 2000-2018 for Dec-Jan for peak fog months at IGI Airport Delhi (IGIAD). It shows diversion of 100s of flights during fog seasons at IGIAD when higher dense fog occurrences were observed.

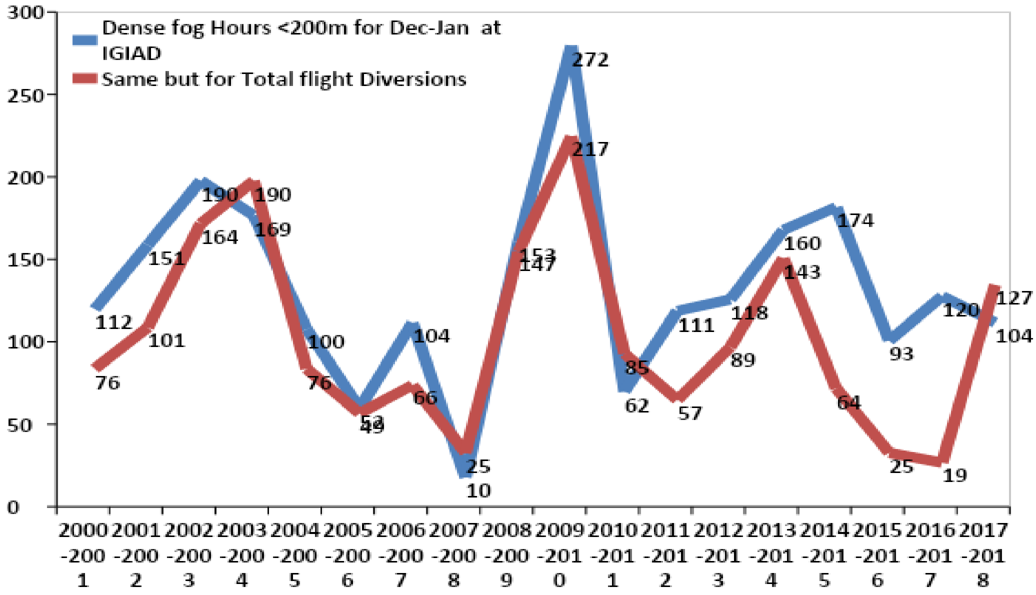


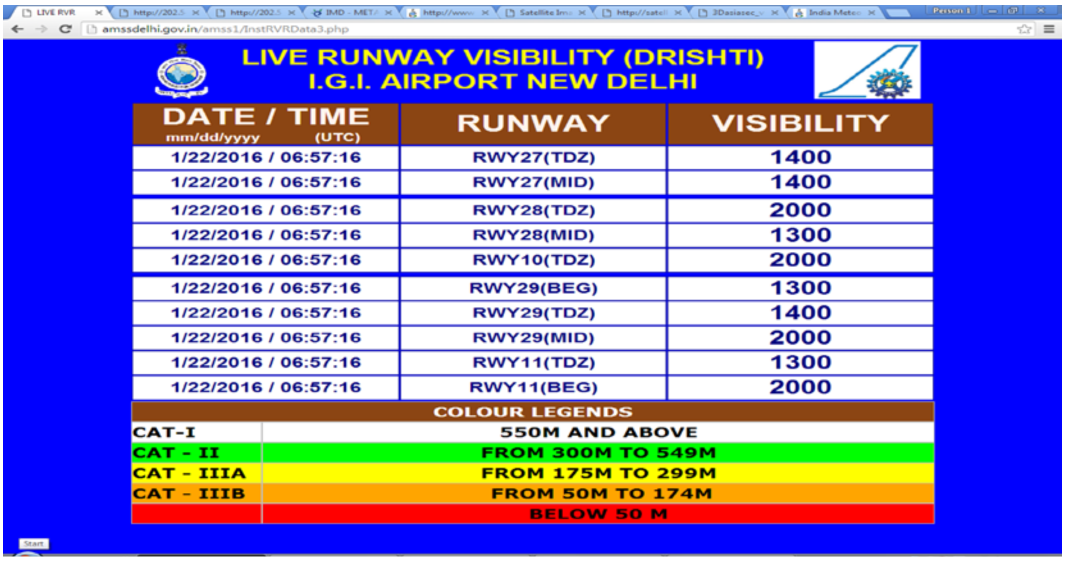
Fig. 4. Dense fog hours and flight diverted at IGI Airport Delhi 2000-2018

8.4. Fog detection and Monitoring System operational in IMD

IMD has been using an integrated fog monitoring and early warning system comparable to any best system in the world. This system uses both surface and space based observations round the clock at 24X7 for fog detection both at a location and over an area. With availability of INSAT 3-D based RGB fog products since Dec 2014, satellite based fog detection and monitoring for both day and night period using its RGB day/night fog detection algorithm have been in extensive use at real time to provide latest fog nowcast/warning for shorter period validity.

The satellite fog coverage when superimposed on surface visibility available at 30 min to 3- hours gap across 205 synop stations available through GTS and across 90 airports available in its Aviation met web based monitoring system of OLBS (Ref Fig 5 and 6), the fog coverage appearing in satellite can further be validated if it is a surface fog or low cloud events. By this both satellite and surface vis validation from time to time, no fog events goes undetected from IMD monitoring. In addition, IMD has also instant way of getting fog updates at each 10- second for major cities of north India where its airport based Visibility meters called RVR instruments installed at 8 major airports of north India having total 23 such equipment have been providing web based live data. In the fog season IMD got supports from all IAF airports by MoU, where, the latter also provides feeding of fog and vis of another 50 airports, to the same web based monitoring system which has been further enhanced its fog monitoring capability. For the national capital Delhi which is also a mega city and highly vulnerable for dense fog, IITM-IMD-NCMRWF in joint collaboration has its special fog warning system operational via WIFEX project. It has been operational at real time for each winter since the winter of Dec 2015. **In recent 2015-2021 winter, WIFEX successfully completed at IGIA Delhi 6th successively season-a 1st in Asia and 3rd in the world after France and USA which provide all new platforms for accurately capturing fog development along with fog forecast models** . The main objective of WIFEX to conduct successive winters at Delhi, has been to understand fog micro-Physics and role of various type of gaseous and other pollutants those trigger fog formation, intensification and its further life period including sampling of fog droplets to understand its chemistry. The other objective is to use those precious data at real time in development and validation of an effective fog forecast model that provide fog early warning 18-24 hours in advance for airport use. It provides fog micro-physics data **at boundary layer (BL) which includes moisture, lower levels wind and temp profile and fog droplet number-size-concentration and pollutants, etc. It also provides meso-scale modeling support for improving fog early warning system for north India.** IITM-IMD jointly have installed and made operational following equipment in WIFEX 2015-2021:

- RVR instruments
- Fog droplet microphysics
- Radiometer
- SODAR
- Flux tower – All in one sensors (10,20m) Temp/Rh/WS/WD/Pressure, Eddy Covariance (EC) 12m for TKE/KE/Sensible Heat Flux
- FM120-FOG DROPLET SPECTURM
- Aerosol, gases and fog water analysis
- Aethelometer for Aerosol scattering
- Nephelometer for Black carbon
- Soil Moisture/Temperature sensors
- Aerosol Microphysics for SM/ST
- Radiation
- MARGA (Chemical analysis of PM1, PM2.5 and gases) online first time in India on high temporal resolution(newly added and functional in 2017-18)
- Ceilometer -(newly added and functional in 2017-18)
- Fog dispersal set up (experimental mode Ion generator)- (newly added and functional in 2017-18)
- Tethered balloons data at Pusha upto 1000m collected during 10-23 January of 2016.



DATE / TIME mm/dd/yyyy (UTC)	RUNWAY	VISIBILITY
1/22/2016 / 06:57:16	RWY27(TDZ)	1400
1/22/2016 / 06:57:16	RWY27(MID)	1400
1/22/2016 / 06:57:16	RWY28(TDZ)	2000
1/22/2016 / 06:57:16	RWY28(MID)	1300
1/22/2016 / 06:57:16	RWY10(TDZ)	2000
1/22/2016 / 06:57:16	RWY29(BEG)	1300
1/22/2016 / 06:57:16	RWY29(TDZ)	1400
1/22/2016 / 06:57:16	RWY29(MID)	2000
1/22/2016 / 06:57:16	RWY11(TDZ)	1300
1/22/2016 / 06:57:16	RWY11(BEG)	2000

COLOUR LEGENDS	
CAT-I	550M AND ABOVE
CAT - II	FROM 300M TO 549M
CAT - IIIA	FROM 175M TO 299M
CAT - IIIB	FROM 50M TO 174M
	BELOW 50 M

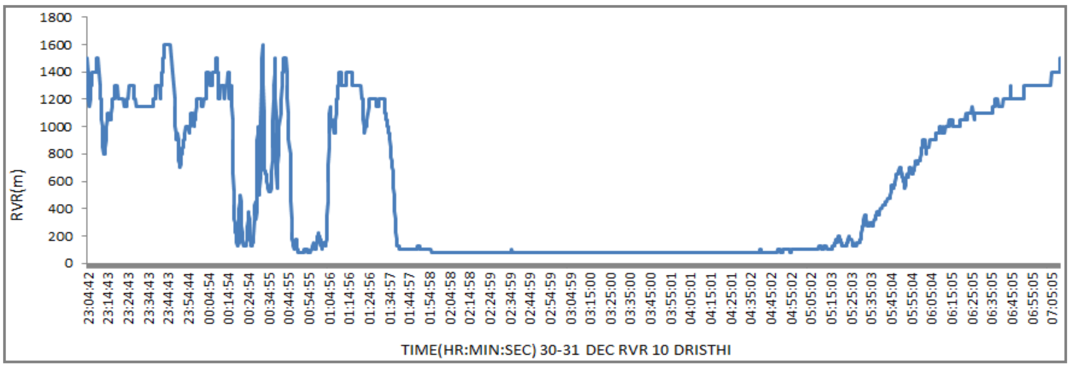
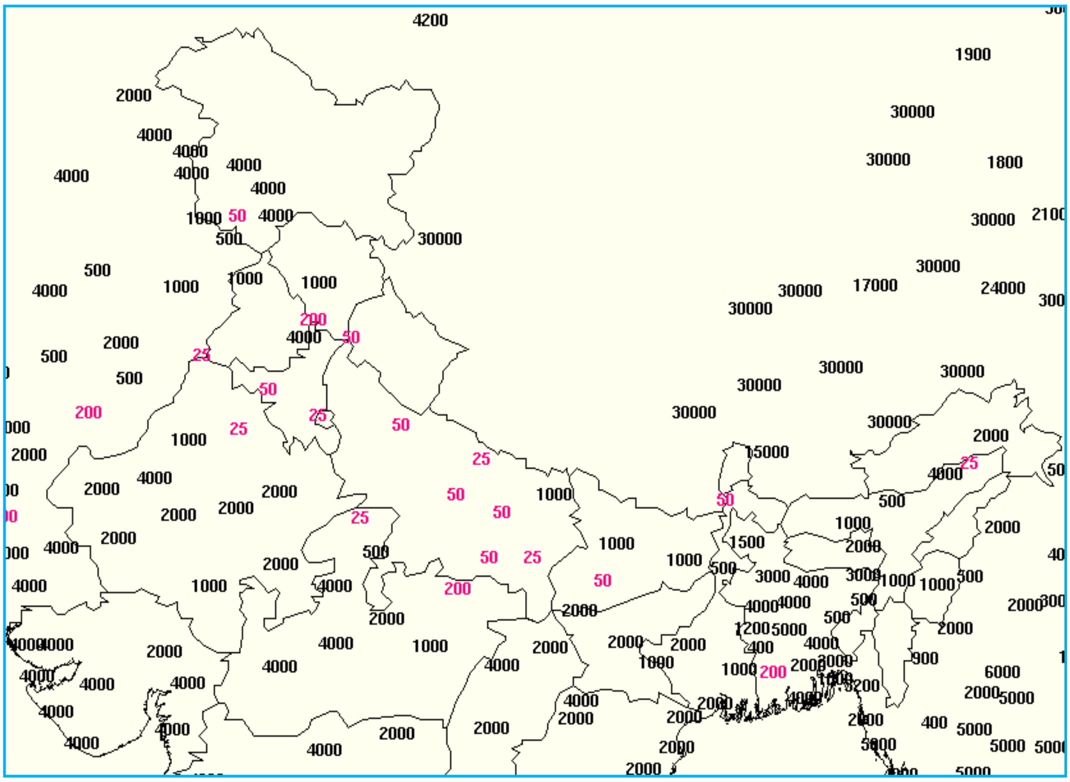


Figure 5. Integrated Rwy Vis display system of IGIA where Fog status is reported at each instant of time and updated at each 10 second(Top one). Instument Vis values–RVR for a dense fog date at IGIA



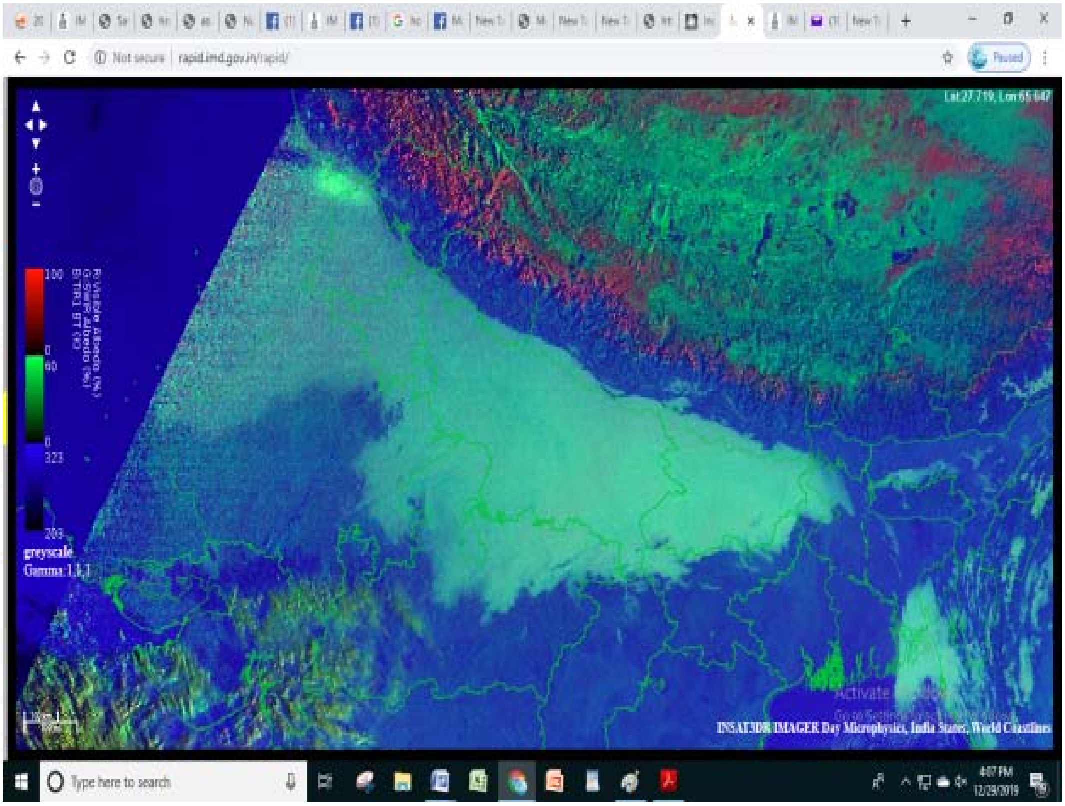


Figure 6. Surface vis map of winter date in Jan prepared at each 3-h using surface visibility data reported by Airport Met offices and Observatories (Top is for 0530 IST). Satellite day time RGB fog cover as detected on the same data by INSAT 3D taken at 0745 hours of IST

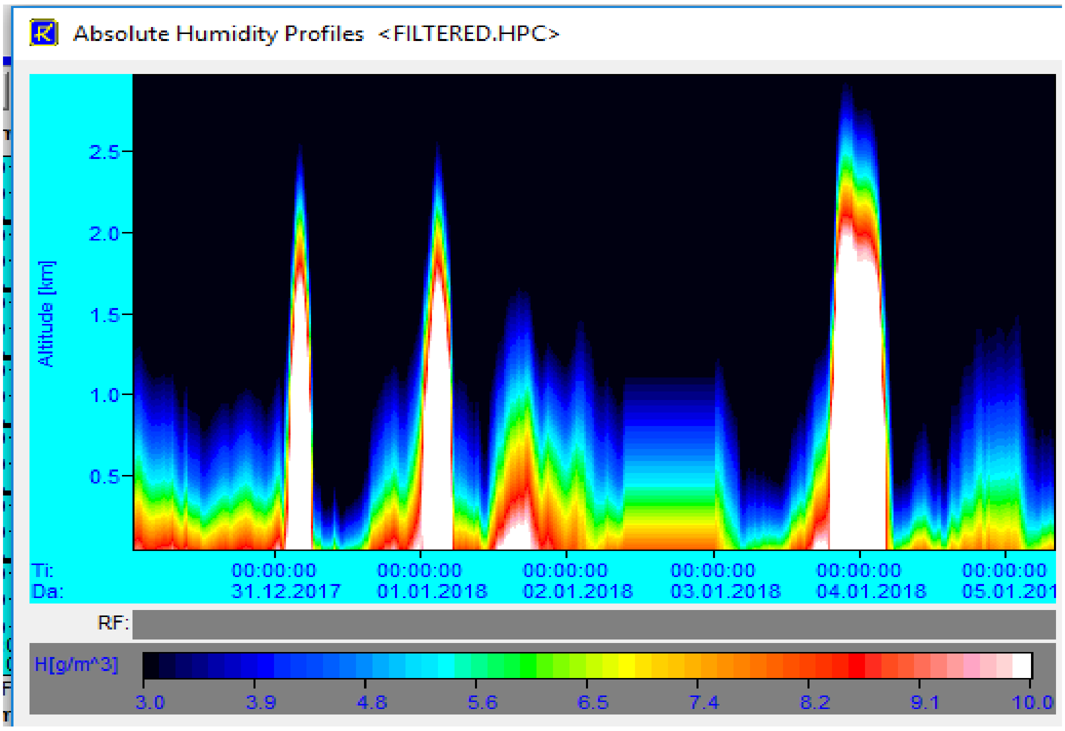


Figure 7. Micro- wave Radiometer captures fog layer in terms of moisture profiling at each instant. It captures the dense fog spell prevailed over IGI Airport Delhi during 30 De-5 Jan 2017-18 with day to day variation of time of onset, depth of fog layer and lifting

8.5. SOP on fog reporting in current weather and synoptic observations and issuing fog nowcasting (trend), forecasts and Warnings

IMD present status of fog monitoring using various observations already discussed in Sec 4. All these fog products are regularly made available in main IMD web page during winter round the clock. IMD present Fog information and warning system can be classified as Airport based fog information and warning system (including trend forecast) by AMS/AMO/MWO for use in a aviation sector and general fog information and warning system for all other purpose provided based on Met-sub-division, city, and district levels by NWFC/RWFC/MC. For readily reference, Table 9 has list of products to be referred by DO/Forecaster of all field stations and at NWFC, for reporting **timely fog conditions over a location/airport/areas** and to issue its further evolution covering fog nowcasting and forecasting and dense fog warnings. Fog products which to be regularly referred by Duty forecaster from time to time are, satellite RGB fog products at each 30 minute gap and synoptic observations and their trends, AWS/Airport data/live RVR, synoptic analysis, inversion layer, moisture advection, pattern and process based fog forecast tools and various statistical tools, all developed or to be developed at field level, along with latest state of art dynamical fog forecast systems already made operational both for met sub-division wise and airport wise for India region. SOP for finalization of forecast and warning at location, city, airport and district and met sub-division wise are given in Sec 5. 1, while SOP on satellite fog interpretation and its use in fog nowcasting is given in Sec 5.2 while Sec 5.3 shows **a demo on how to refer multi-sources Fog products for reporting timely fog development and issuing early warnings by considering two cases of unique dense fog occurrence at IGI Airport Delhi developed at very late morning after sun rise.** All these products are regularly updated on-line and hence all these products must be referred before making any decision on fog issuing fog forecast/warning. Various fog forecast products discussed in Table 9 are available at various website for which corresponding links are given in Sec 6 and hence it is duty of the forecasters to looks all these products and get updated fog information of his concern domain by noting in register all information available via on-line.

Fog model products available in IMD presently includes WRF chem high resolution at 2km(operational by IITM under WIFEX) giving forecast of visibility in hourly visibility form in histogram form for Airports of north India including IGI Airport as well as 1-h evolution of fog forecast products in form of spatial map for north India domain, Delhi fog model at 330m resolution for IGI Airport by NCMRWF provides both metgram form of Visibility at 1-h interval and spatial map form at Delhi domain, D-Fog model 1.5km covering all major airports of north India by NCMRWF, NCUM regional and global fog model products produces both deterministic and ensemble forecasts and capable to generate fog forecast map for single run and for ensemble forecast runs, with probability based fog forecast products. WRF, D-FOG, NCUM Fog forecast products available at location/airport based are hourly visibility based MET GRAMS and valid for 48-h and while WRF Chem, WRF, NCUM, NEPS and GFS fog products are spatial fog forecast maps with areas color coded at Vis below 1000m, <500m, <200m and <50m valid for 0000 UTC of day 1 and day 2. Fig 8a and Fig 8b are flowcharts which may be referred for reference to critically analysed from time to time all corresponding products, accurately and timely to successfully, monitor fog at RWY or over the airport, areas of fog development or likelihood over district or met sub-division and delivers a successful fog forecasts and warnings. One may refer Fig 9 to 12(a, b, c, d) which has sample copy of various fog forecast products available at airport basis and spatial basis from IITM, NCMRWF and IMD. Summery from all these products may be entered to register from time to time (at 30-minute to 3-h intervals depending upon the met conditions assessments) with each product udpates as available and inferences may be made using consensus approaches especially while anlayzed fog model products priority may be given in case dense fog events are forecasted by more number of models and for day 1 to day 2 synoptic diagnostic also may be given priority. One must get detail diagnostic to determine a fog event has been occurring or most likely to occur due to wind weakening and inversion layer building up, if it is ahead of WD or behind the WD for north Indian region.

8.5.1. SOP on issuing Fog forecast and warning (discussion and finalization through VC consultation daily)

IMD since late 2000s providing intensity based fog forecast and warning at both national level from NWFC IMD HQ at met sub-division wise in terms of spatial terminology (ISOL, SCTD, FWS and WS) for various fog intensity as in Table 1 with RWFC and MCs provide at district levels and city based for 5 days since 2015. Since 2016-17, with implementation Fog-FDP at national level, regular fog products and their forecasts based upon synoptic, satellite, NWP models, are discussed at national VC every day at 1030 am and then finalized areas likely under dense fog. FDP winter fog Guidance products are regularly shared with each other and 24X7 watch kept during winter. From winter of 2016-17, it has been further expanded and fog forecast upto 5 days with warning colour coded as multi-hazard map with outlook for 2-days (refer Fig 15).

IMD presently issuing airport wise fog warning at each 6-hourly intervals in winter period and these forecast are uploaded in IMD web page. It is presently operational at **12 airports at Delhi, Lucknow, Jaipur, Amritsar, Varanasi, Patna, Agartala, Bhubaneswar, Gaya, Kolkata, Guwahati,** and regularly updated at each 6-hours during fog season covering months of Nov, Dec, Jan and Feb. The history of fog forecasting at airport goes back to 1998, when Met Office Palam started issuing fog outlook once a day at 1500 UTC daily because of increasing dense fog occurrence over IGI Airport, which disrupted aviation services during those days. Due to a record highest occurrence of Cat III dense fog during Dec 1998 (179 hrs) and again in Jan 2003 (158 hours), the fog forecasting was increased to four times a day with 6 hourly updates and 12 hours outlook period. Such forecasts were made by traditional synoptic method till Dec 2006. With development of various objective based fog models and dynamical fog models, Met department has achieved its capacity to predict its density and timing with likely impact on air traffic since 2009-10, e.g. when the airport is likely to be Cat III or close with Cat IIIC conditions(refer tables 10 and 11). Simultaneously, fog when develops over more number of airports across north India, it makes difficult for flight operations if not planned properly as alternate will not be available and in case forecast available for more airports, it helps for effective decision. With current weather of all major airports and their fog forecast have been regularly updated and made available on-line, users may take advantage of these fog information for proper flight planning to minimized impact aviation operation.

Table 9

List fog Products to be referred by DO/Forecasters at NWFC/MC/AMO/AMS/MWO for reporting fog and issuing trend forecast/ fog nowcast and forecasting

- **Fog Monitoring System to report timely fog conditions over a location/airport/areas**

Time to time trends from Surface parameters and Upper Air Parameters of different stations/Airports
a) Trend in surface and lower level wind as reported from airport systems, Ta/Td from AWOS, RVR/MOR from RVR Network at 10 second to 1 minute intervals and synoptic stations at each 3-h gap
b) Trends from various fog formation parameters like LWC, Equivalence Potential Temp, Inversion and LL moisture from Radiometer (Fig 7)
c) Meteogram from NWP models (NEPS/ECMWF/GFS/WRF models)
d) Monitoring sky conditions by Ceilometer/ clouds from Current radar observation and Trend in Max Z at 10-minute updates or manual checking of sky conditions from time to time
e) Fog conditions from RGB if Current satellite observation at 30-minute gap

- **IMD Delhi Fog forecast/nowcast system**

- **<u>Process based using Analogues method (Formation types, scale and period) using past cases</u>**
- Radiation fog-basic predictors(Ta-Td, winds, clouds, inversion) for localized or synop-scale fog
- Advection and large-scale fog
- Different - analogue technique of localized, synop and large-scale types fog events.

- **<u>Synop based Fog forecast system</u>**
- STR/Subsidence and calm winds at lower levels and establishment of fog ridge line using *GFS winds Analysis and Forecast*
- *GFS Diagnostic of Fog and Pollution products*
- Sudden wind changes -advection fog
- WD-Ahead and Behind
- Certain synoptic systems –Easterly wave, Cyclone at south Bay etc.

- **<u>Climatological data based Threshold and checklist</u>**
- Threshold table using surface and UA at the location (TA, Td, RH and Wind) with Upper air Inversion depth and intensity
- Min temp vis-à-vis dense fog occurrences curve

f) <u>Objective based fog forecast using fog Models</u>

(refer Fig 9 to Fig 12 for sample fog model products from various dynamical fog medals currently operational in IMD)

- **IMD Empirical Fog model of intensity and duration based fog forecast System**
- **Dynamical Fog forecast systems based NWP models(samples are shown in Fig**
- **Experimental spatial and Airport based intensity based NCUM Global/Regional spatial Visibility based fog forecast map from NCMRWF for 24, 48, 72 hours and further validity**
- Probability NEPS Fog forecast valid for 2 days
- NCUM 12KM Global fog model from NCMRWF valid for 10 days
- NCUM 4KM Regional fog model from NCMRWF valid for 3 days
- NCMRWF 330m Delhi fog model -Valid for 2-days
- •NCMRWF all_times_DM_Chem-cities.php-1.5km NW India fog- -Valid for 2-days
- **IITM WRF chem Products spatial and Airport based Visibility based Fog Model at 4 Km resolution Delhi Region and at 2 km for Delhi Airport**

- **Fog information dissemination**

All fog information (fog as observed and all forecast/warnings of fog) are uploaded in IMD WEB page at IMD main website as well as each MC website
- **IMD main website**

SMS/WhatsApp and Live RVR

Table 10

CAT ILS RVR ranges as per ICAO and corresponding approx. general visibility ranges with fog types and impact, included in fog forecast for airport purpose

Visibility/Fog Types	Approx. General Visibility	Low Visibility and CAT-Types as per corresponding RVR ranges as per ICAO	Types of IGI service affected
Shallow to/Moderate Fog	1000m-200m	Low Visibility Procedures(850-1200)	Helicopters and small flights severely affected
		CAT-1(>=550m)	Bigger Flight which are not CAT Compliances severely affected
		CAT-II(>=275m)	
Dense fog (CAT-III)	<200m	CAT-IIIA(>=175m) CAT-IIIB- >=75m/50m CAT-IIIC- <50m}	All flights which are CAT-IIIB Compliances can operate upto RVR >=75m/50m and Airport is closed when RVR<50m

Table 11

Schedule of issue of Fog Forecast by Met office, IGI AP

Time of Issue of Fog F/c (UTC)	Validity of Fog Forecast (UTC)	Validity of Outlook (UTC)	Time of Upload in OLBS (UTC)
0000	0030-0630	0630-1830	Within 15 minute from the time of issue
0600	0630-1230	1230-0030	Within 15 minute from the time of issue
1200	1230-1830	1830-0630	Within 15 minute from the time of issue
1800	1830-0030	0030-1230	Within 15 minute from the time of issue

Following is the sample of a real time fog forecast issued operationally by MWO Delhi for Delhi for season 2016-17.

SAMAPLE OF FOG FORECAST FOR I G I AIRPORT

DATE 08/01/2017 TIME OF ISSUE 08/1200 UTC (08/1730 IST) VALID FROM 08/1230 UTC (08/1800 IST) TO 08/1830 UTC (08/2400 IST). VISIBILITY LIKELY TO REDUCE 0400M IN FOG FROM 08/1400 UTC (08/1930 IST). IT MAY FURTHER REDUCE BELOW 0200M IN DENSE FOG (CAT-II/CAT-III DENSE FOG) FROM 08/1800 UTC (082330 IST).

OUT LOOK FOR NEXT SUBSEQUENT 12 HOURS

FROM 08/1830 UTC (09/0000 IST) TO 09/0630 UTC (09/1200 IST) VISIBILITY MAY REDUCE BELOW 0050M IN VERY DENSE FOG (CAT-IIIB VERY DENSE FOG) FROM 08/2000 UTC (09/0130 IST). IT MAY IMPROVE UPTO 0200M IN DENSE FROM 09/0330 UTC (09/0900 IST) IT MAY FURTHER IMPROVE TO 0800M IN SHALLOW FOG FROM 09/0600 UTC (09/1130 IST).

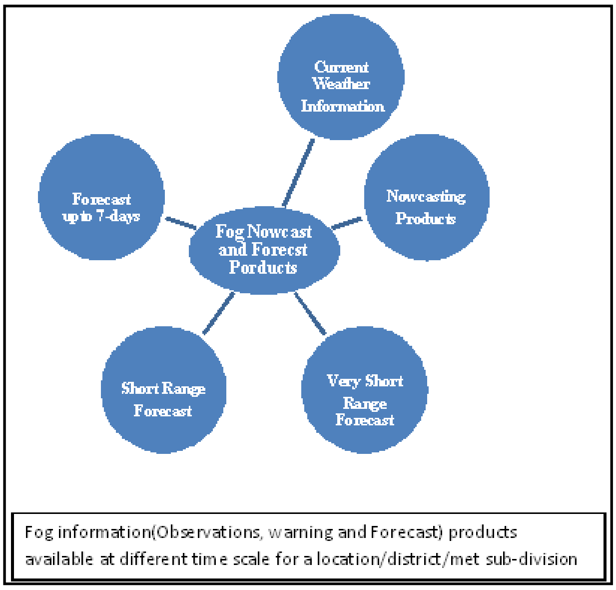


Figure 8a. Fog information system of IMD-Flow chart

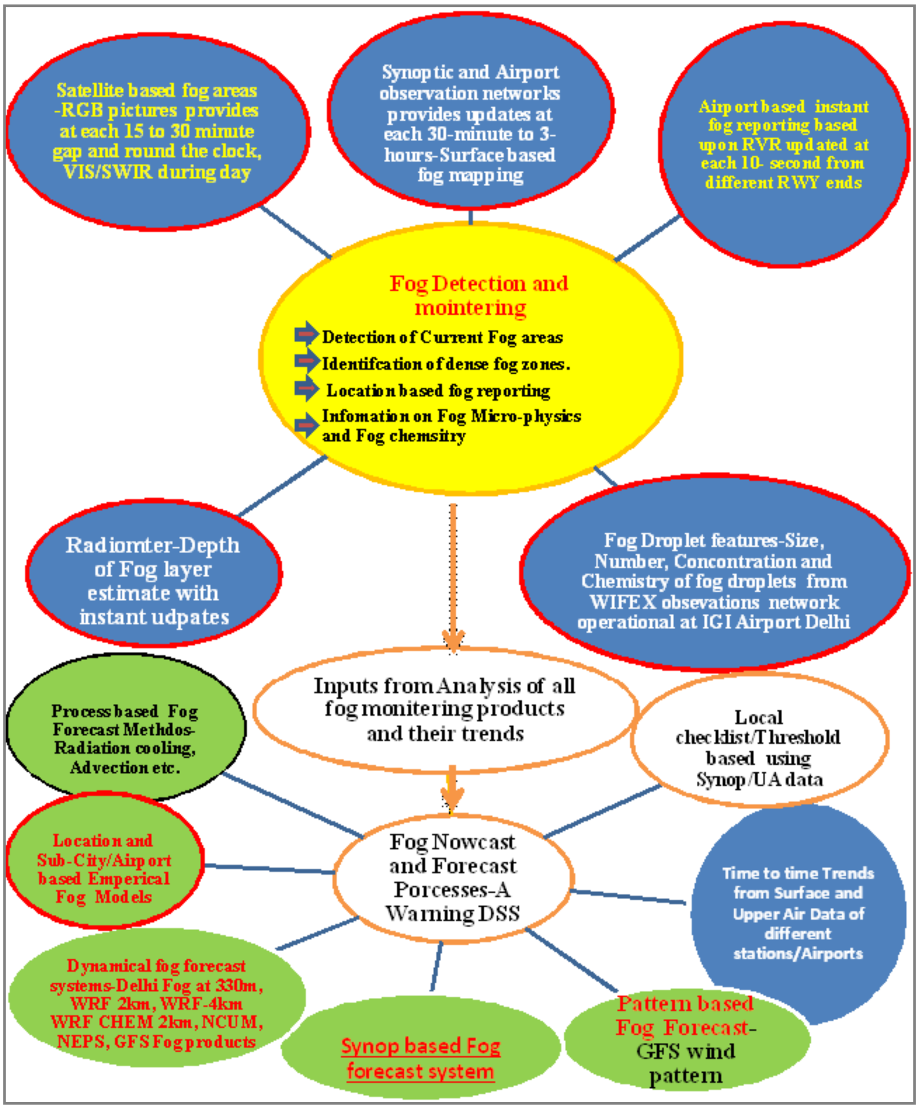


Figure 8b. Block diagram of present Fog Monitoring, Nowcasting, and Forecasting System functional in IMD

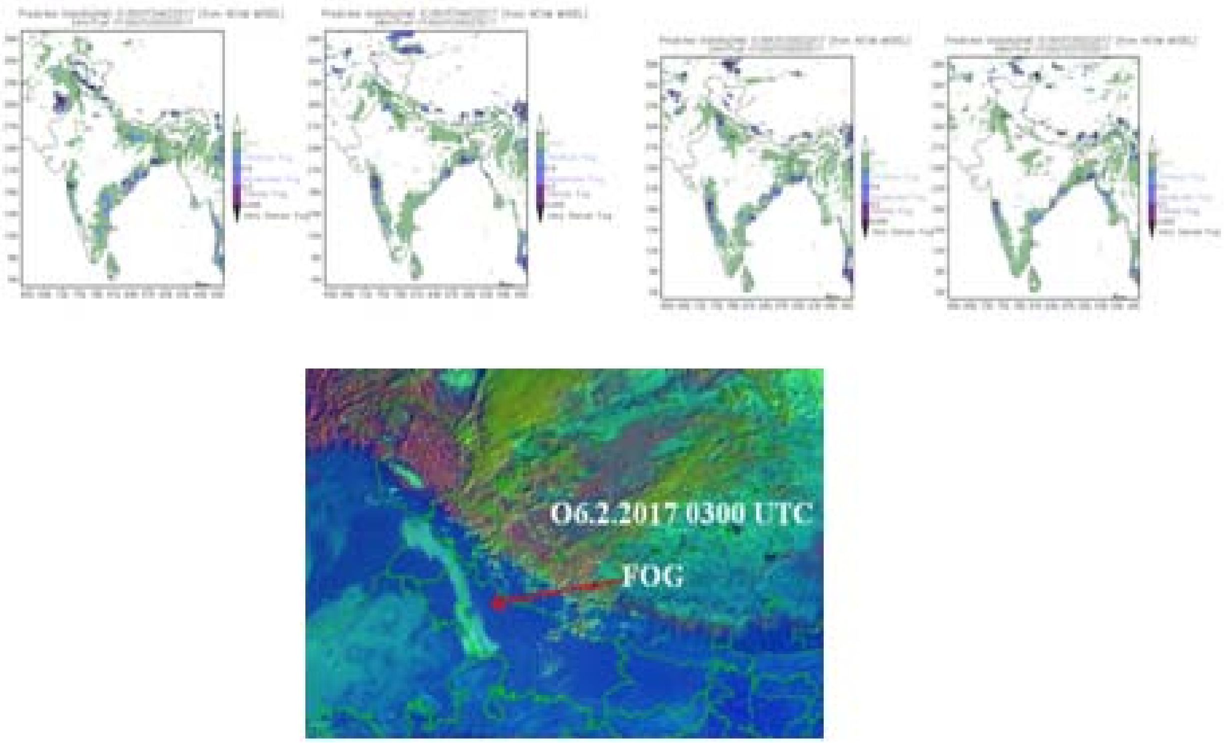


Figure 9. NCMRWF Fog forecast products from NCUM from 4 Feb and 5 Feb 2017 bodunery conditions for 24-h and 48-hours forecast for 6 Feb 2017 dense fog occurred across Punjab as seen from RAPID of 6 Feb 2017

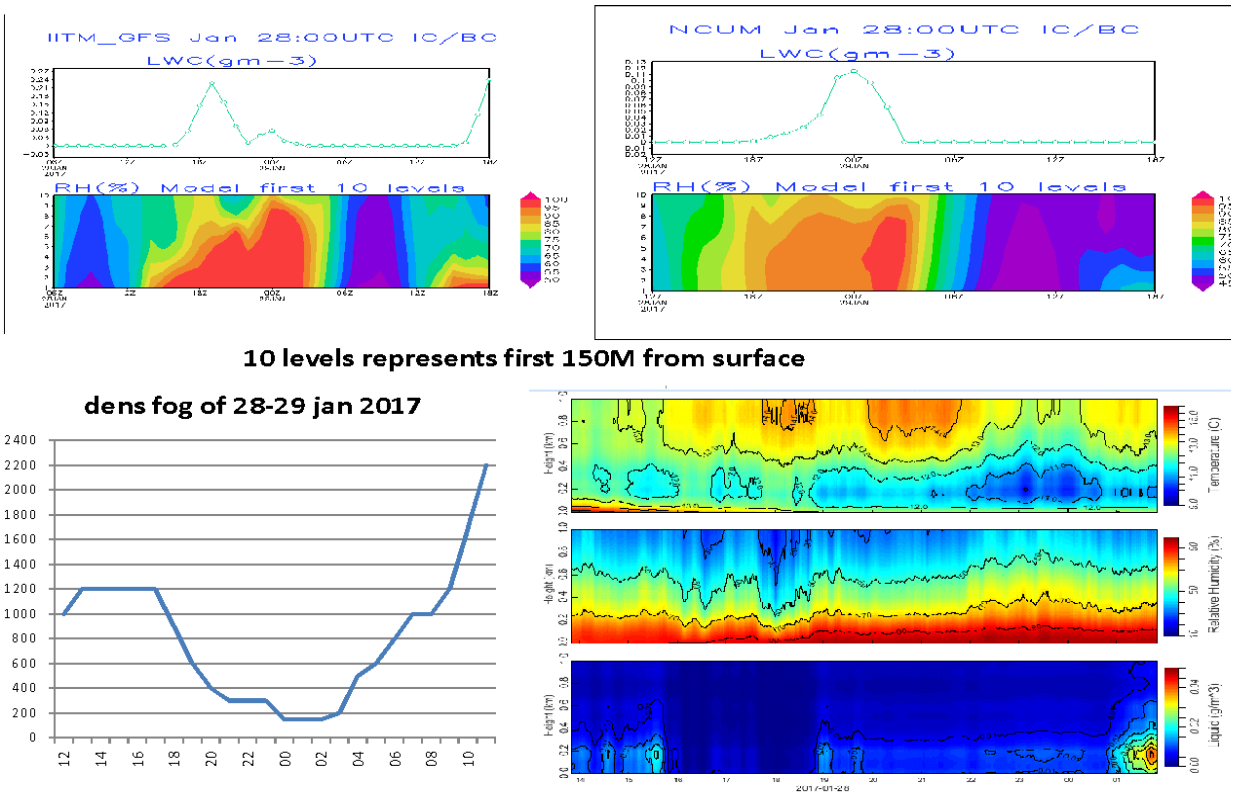
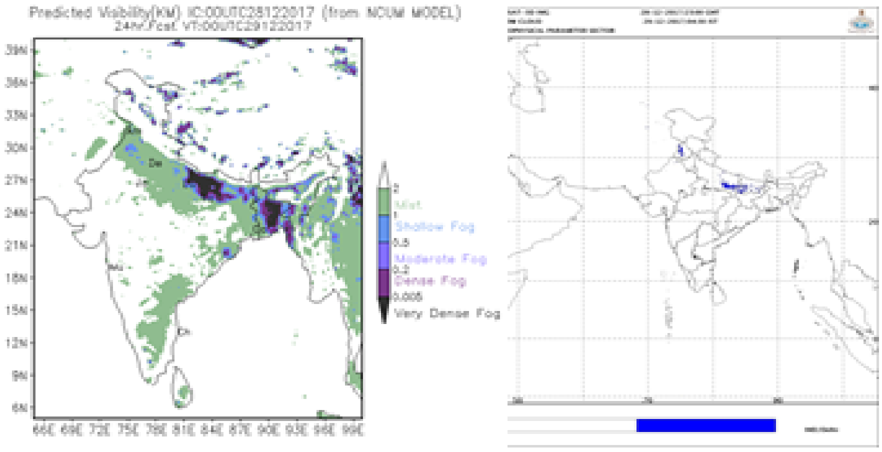


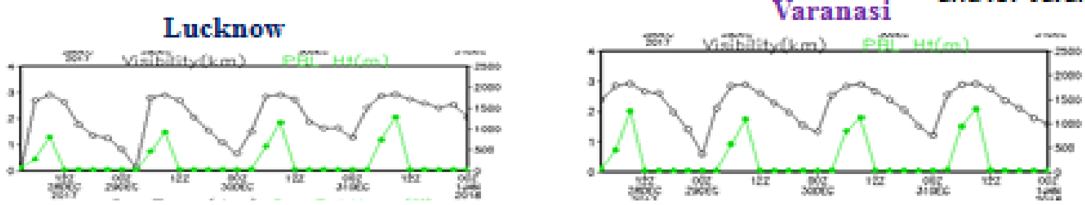
Figure 10. IITM Fog forecast products of 28-29 Jan 2017

NCUM predicts the fog over eastern parts of the country in Day-1 forecast valid for 29th Dec 2017 based on 00UTC 28th Dec initial conditions as observed in the INSAT-3D fog image.



❑Vis<50m for 1030pm till 11am of 28-29 Dec at AMT, LKN, VNS. NCUM has not captured very dense fog at any airport of LKN, AMR, VNS of any hours except only one 0300UTC OF VIS 0 AT LKN and 500m at VNS at 0000UTC. All visibility of all other hours were pre dicted above 1km for Lucknow and for Varanasi

Visibility Forecast Based on 00UTC 28th Dec Initial Conditions



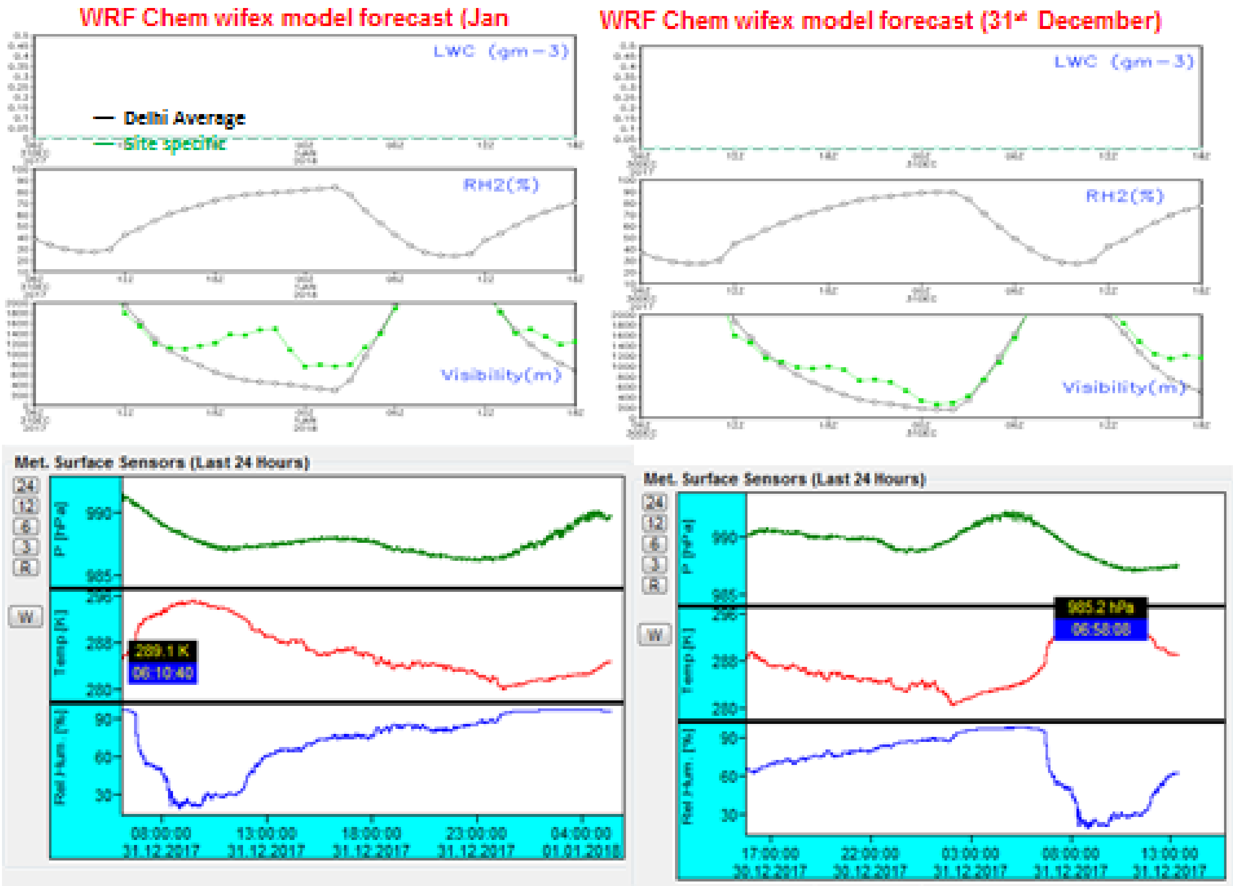


Figure 11. Samples of NCUM and WRF Chem fog forecast products from NCMRWF and IITM in Dec 2017

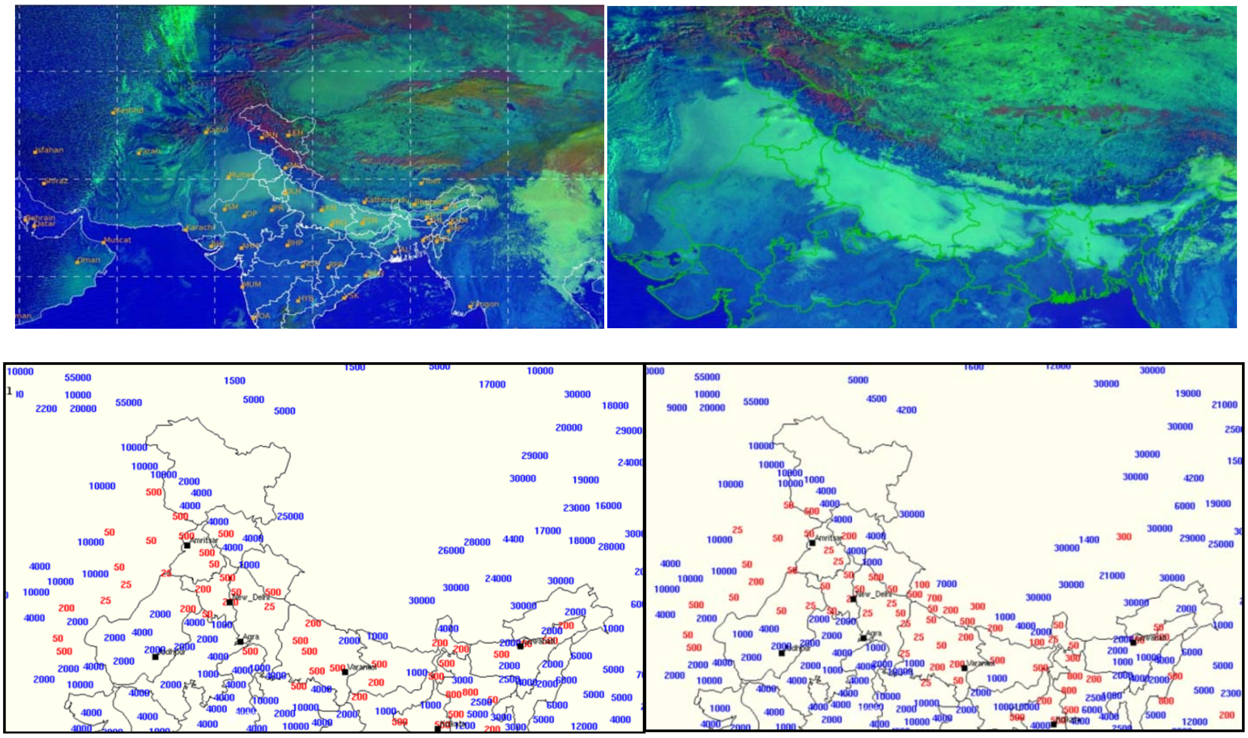


Figure 12a. Fog across IGP on 16 and 17 Jan 2021 as captured by INSAT 3D RGB Day period at 0830IST and by surface Visibility map plotted for the region for corresponding date and time(left panel is for 16 and right panel for 17th Jan 2021

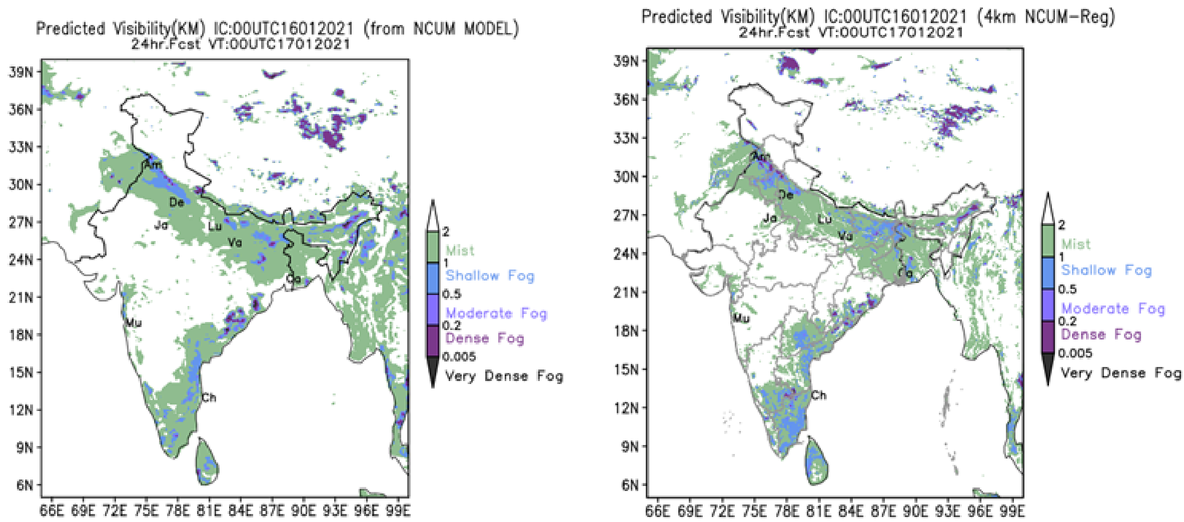


Figure 12b. Fog forecast of 17 Jan 2021 as by NCUM fog model (Global and Regional model for Day 1)

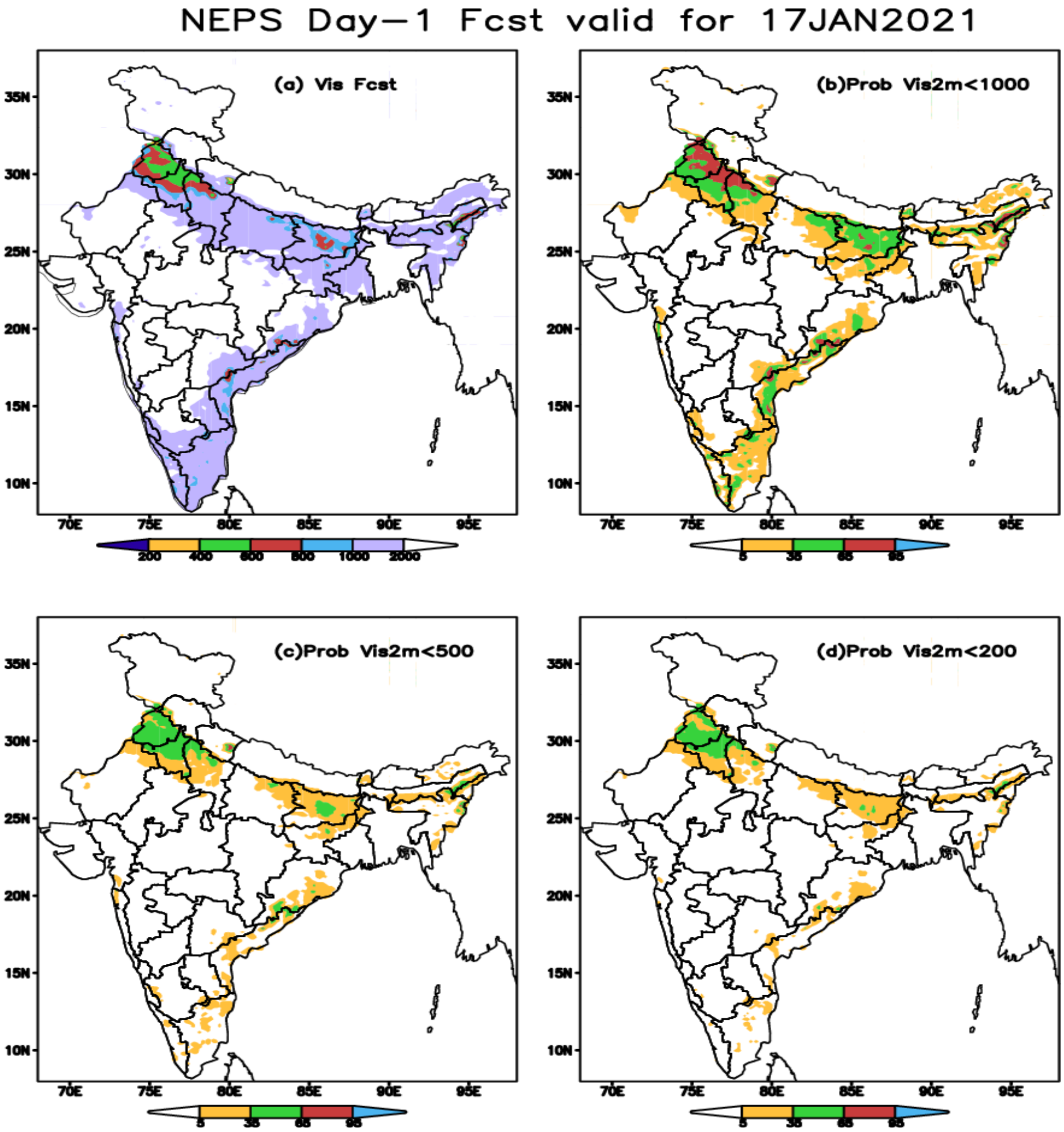


Figure 12c. Probabilistic *forecast of visibility from NEPS valid* for 00UTC 17 Jan 2021 and 18 Jan 2021

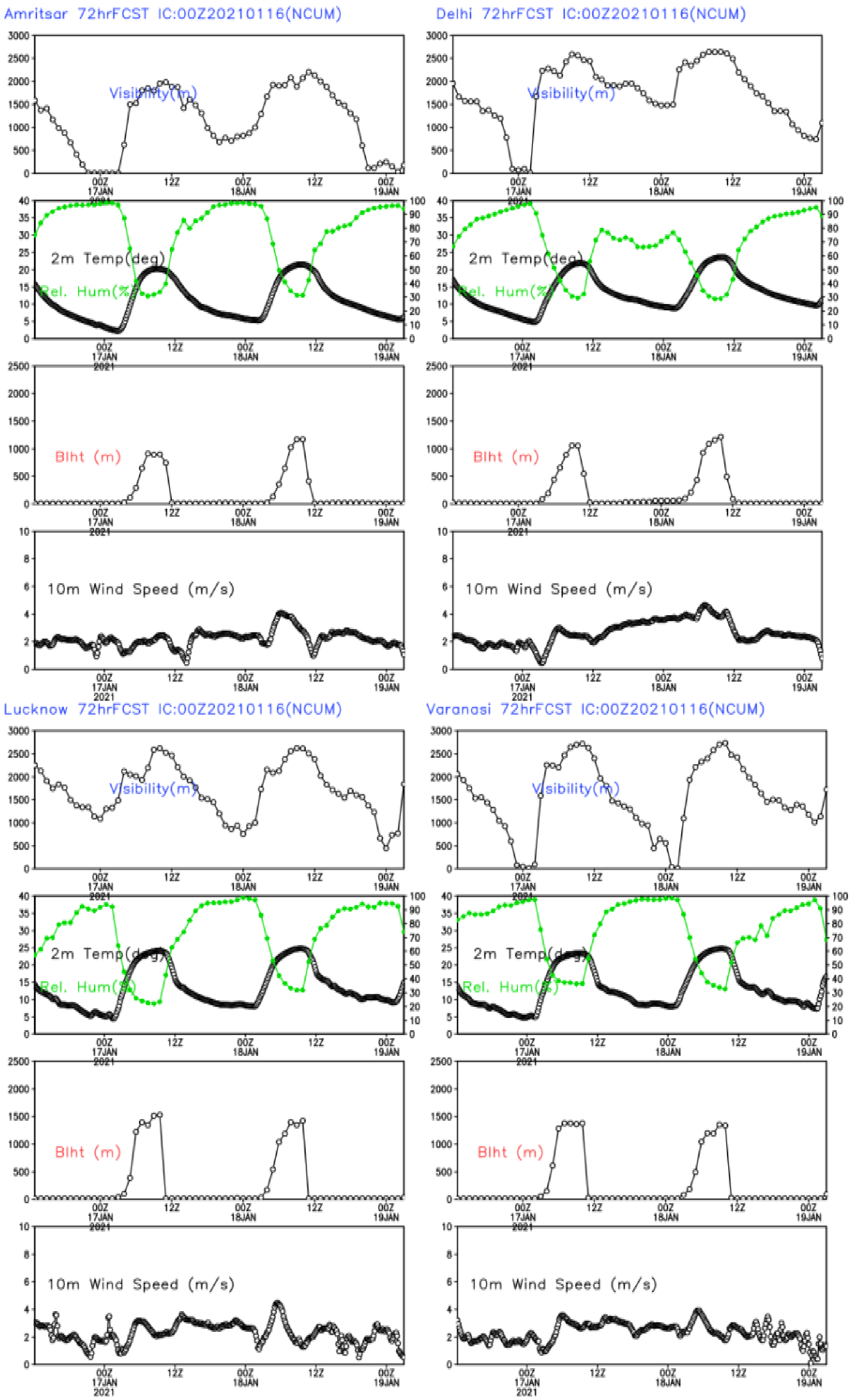


Figure 12d. NCUM Regional fog model airport vis forecast

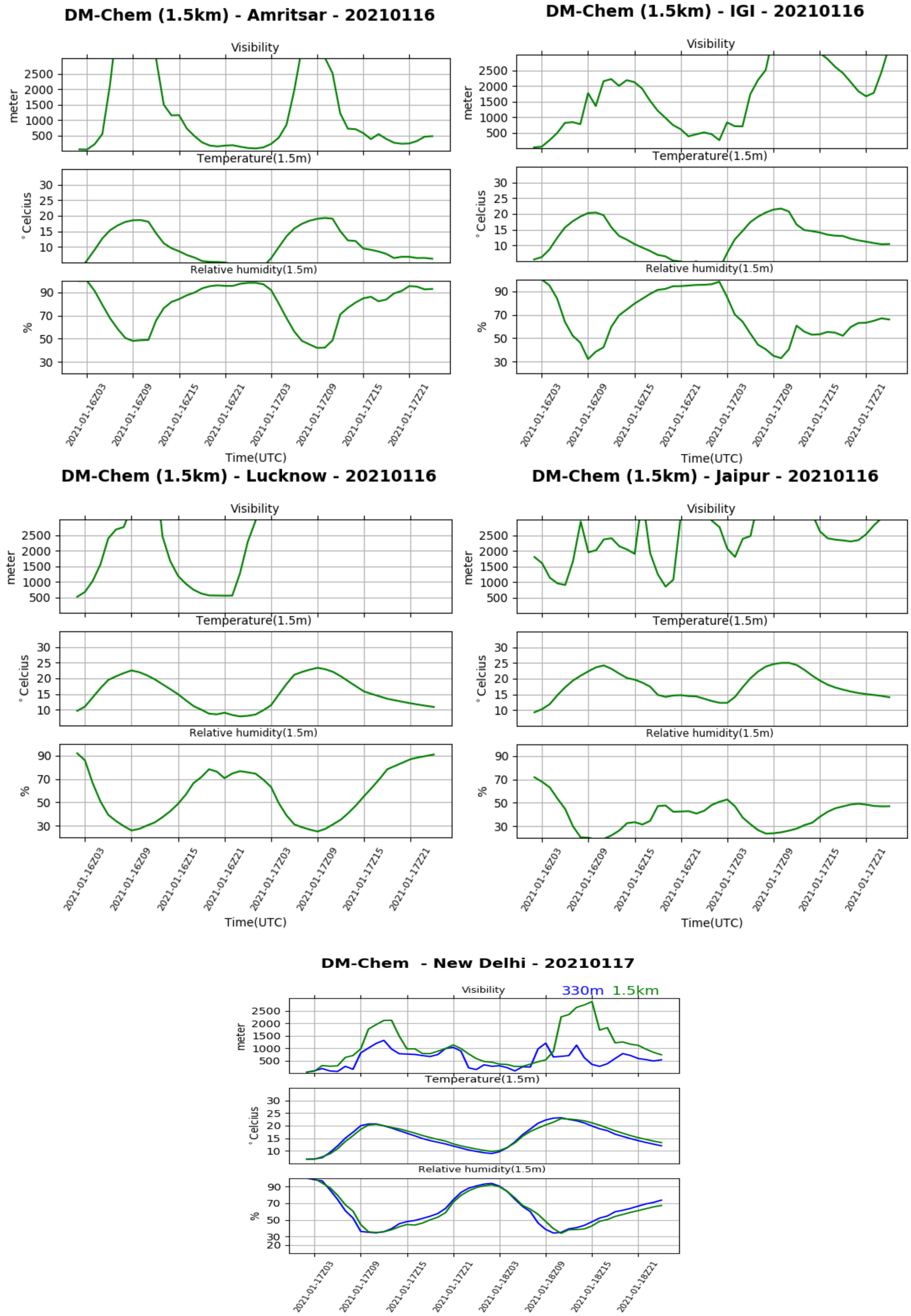


Figure 12e. Visibility from DM Chem Model for Amritsar, Delhi, Lucknow and Jaipur (Only Delhi has 330m in the last vis grams while all have 1.5 km resolution)

8.5.2. SOP on Satellite based guidance tools for Fog monitoring and forecasting

The thermal radiation, measured by the satellite, also referred to as “radiance” is converted to a brightness temperature or to an image grey shade. The methodology for representing computed physical parameters in terms of a composite images comprising Red, Green & Blue color is termed as RGB scheme. The physical parameters are solar reflectance in solar channels and brightness temperature in the thermal channels.

The main RGB compositions are:

i. “Day Natural Colors”, presenting vegetation in green, bare surface in brown, sea surface in black, water clouds as white, ice as magenta;
ii. “Day Microphysics”, presenting cloud microstructure using the solar reflectance component of the 3.9µm, visible and thermal IR channels;
iii. “Night Microphysics”, also presenting clouds microstructure using the brightness temperature differences between 10.8 and 3.9µm.

Based on above scheme, following the analysis and guidance tools like RAPID may be used to identify the fog and nowcast their onset, duration, extent and movement. The inference drawn from the guidance tools may help in issuance of TREND, TAF and Local forecast at the airport MET office and for nowcast by forecasting offices at station and district level.

8.5.3. Standard operating procedures for interpretation of RGB products for fog monitoring and forecasting

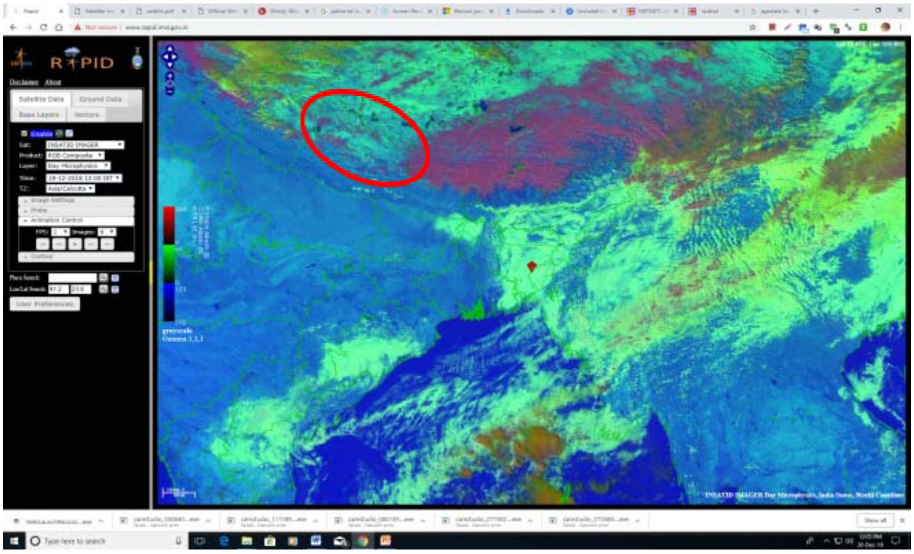
Station level Duty Forecasters may follow the following steps:
(1) Go to RAPID the online satellite image and product analysis systems on the main Satellite page.
(2) Select RGB composite under product menu.
(3) Select Day microphysics (after the local sun rise) or Night microphysics (after local sunset)
(4) If your station is already not marked in image map then enter Lat./Long. in (Example: Lat. 27.23 Long. 88.33).

8.5.3.1. Interpretation of Fog

a. Interpretation using Day Microphysics image

In day microphysics image, FOG can be identified with Green color.

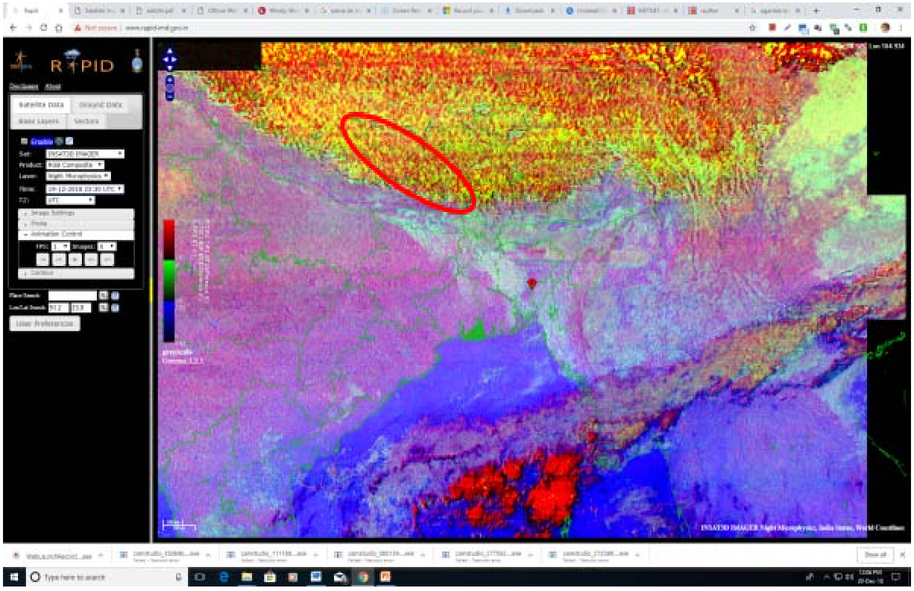
Example:



b. Interpretation using Night Microphysics image:

In night microphysics image, FOG can be identified Bluish green color.

Example:



c. Differentiating between low clouds and Fog

Fog can also be distinguished from low cloud by its sharp edge and smooth texture, compared to rough texture and slow movement of cloud. This can be visualized by running animation of respective images in RAPID.

d. Evolution of the FOG

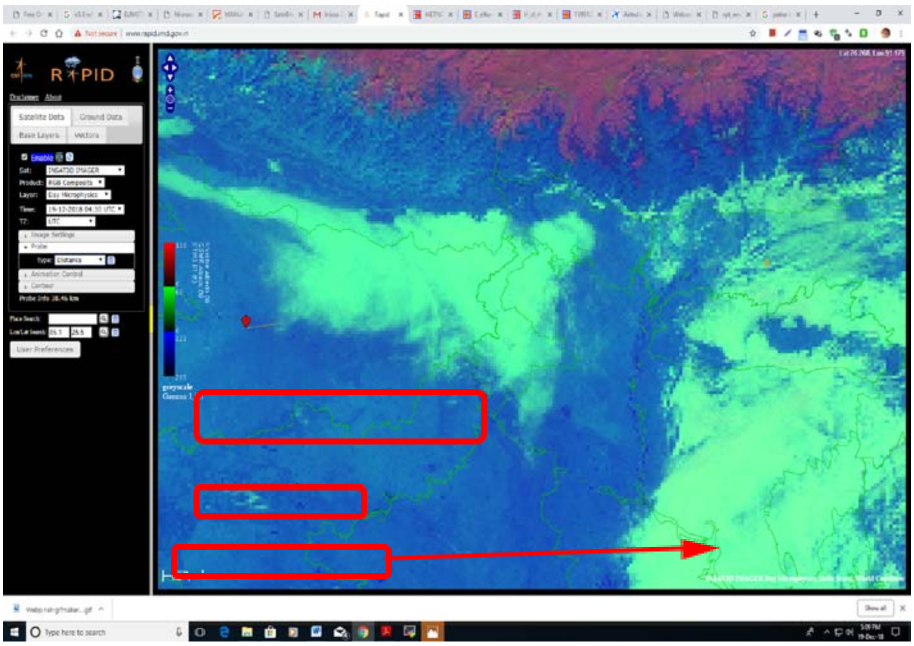
Genesis, development, spatial extent and movement of Fog can be probed by filling the field in RAPID.

Example: Please click the animation from RAPID

e. Time of onset of Fog

Expected time of onset of FOG at the station can also be assessed by measuring the distance between the station and edge of the fog patch in latest image. This can be utilized by selecting Distance under option Probe. The rate of movement can be estimated by running the animation loop in RAPID.

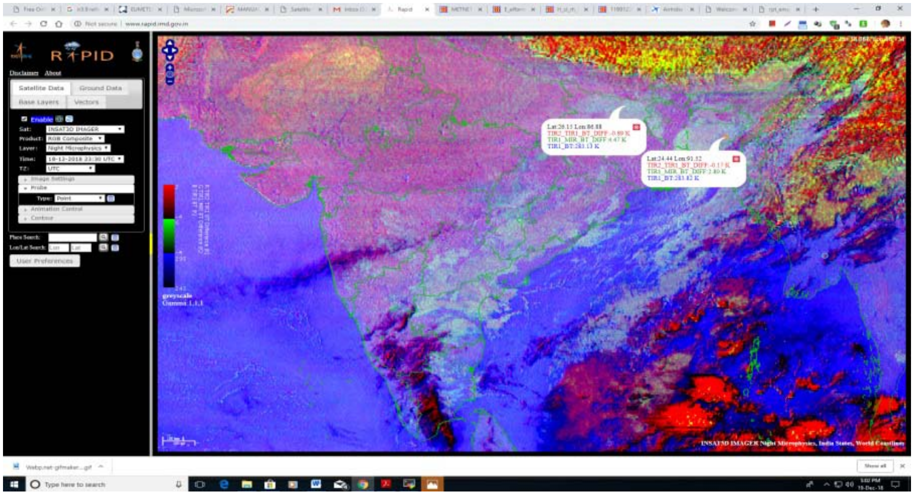
Example:

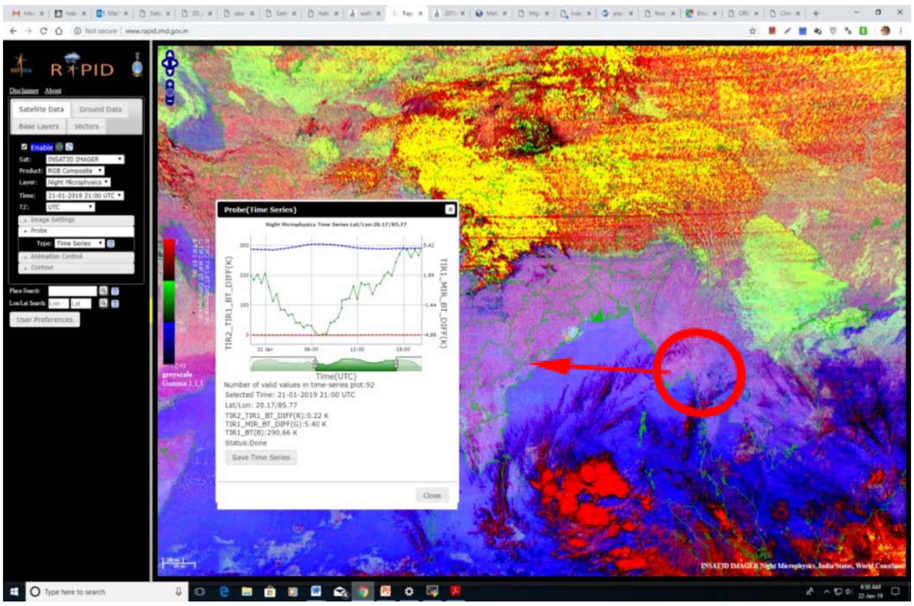


f. Intensity of Fog During night

The onset, intensification of FOG can also be assessed by reading the Temperature difference between TIR1 and MIR by putting probe at the area of interest. If the Temp difference has increased between time gap of 2 hours, then there is likelihood of onset and/or intensification of FOG over the particular area during night.

If ≥ 2.5 genesis of FOG
2.5 to 4.0 moderate FOG
4.0 to 6.0 dense FOG

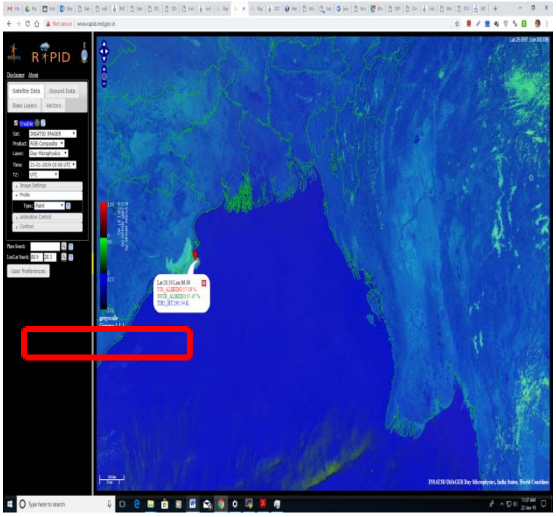




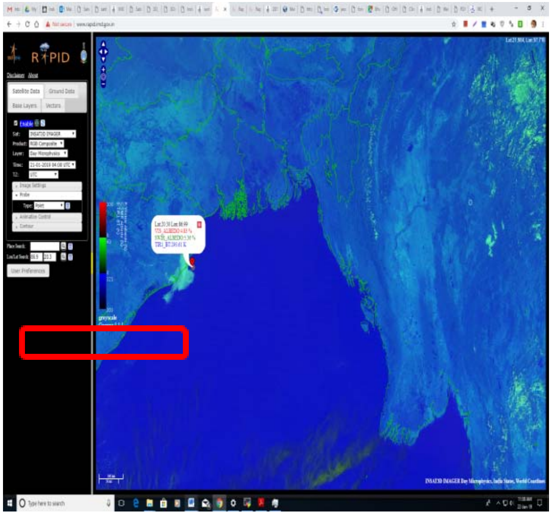
g. Intensity of Fog during Day Time

Making use of Day Microphysics image in RAPID the following criteria can be used to identify fog

Visible Albedo = 16-55%
SWIR Albedo = 31-60%
TIR 1 BT = 276-290K



Fog present over particular point

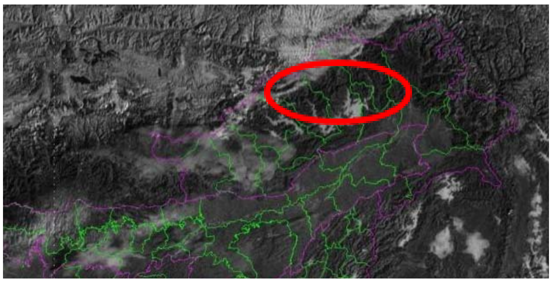


Dissipation of Fog on the same point after 1 hr

h. Valley Fog

Formation of Fog in the Mountain / river Valleys. Cold dense air settling into the lower parts of a valley causes it to condensethereby forming fog which is confined to local topography. SWIR channel imagery with 1km x 1km spatial resolution provides a better contrast to bring out small scale fog.

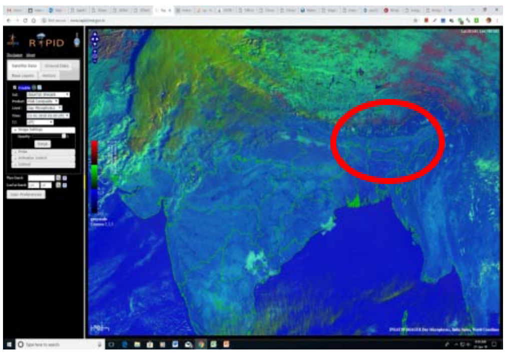
Example:



i. **Sea Fog**

Fog formation over Coastal Sea and adjoining sea area because of advection of moist air over a cooler surface.

Example:



8.5.4. How to refer multi-sources Fog products for reporting timely fog development and issuing early warnings

Two spells of unique fog formation and intensification of 25 Dec 2016 and 9 Jan 2017 at IGI Airport – There were two cases of unusual fog Intensification reported at late mornings at 0800am of **25 Dec 2016 and 9 Jan 2017** which were accurately monitor by Rapid, Radiometer and RVR (Shown in two figures at Fig 13 and 14 respectively)

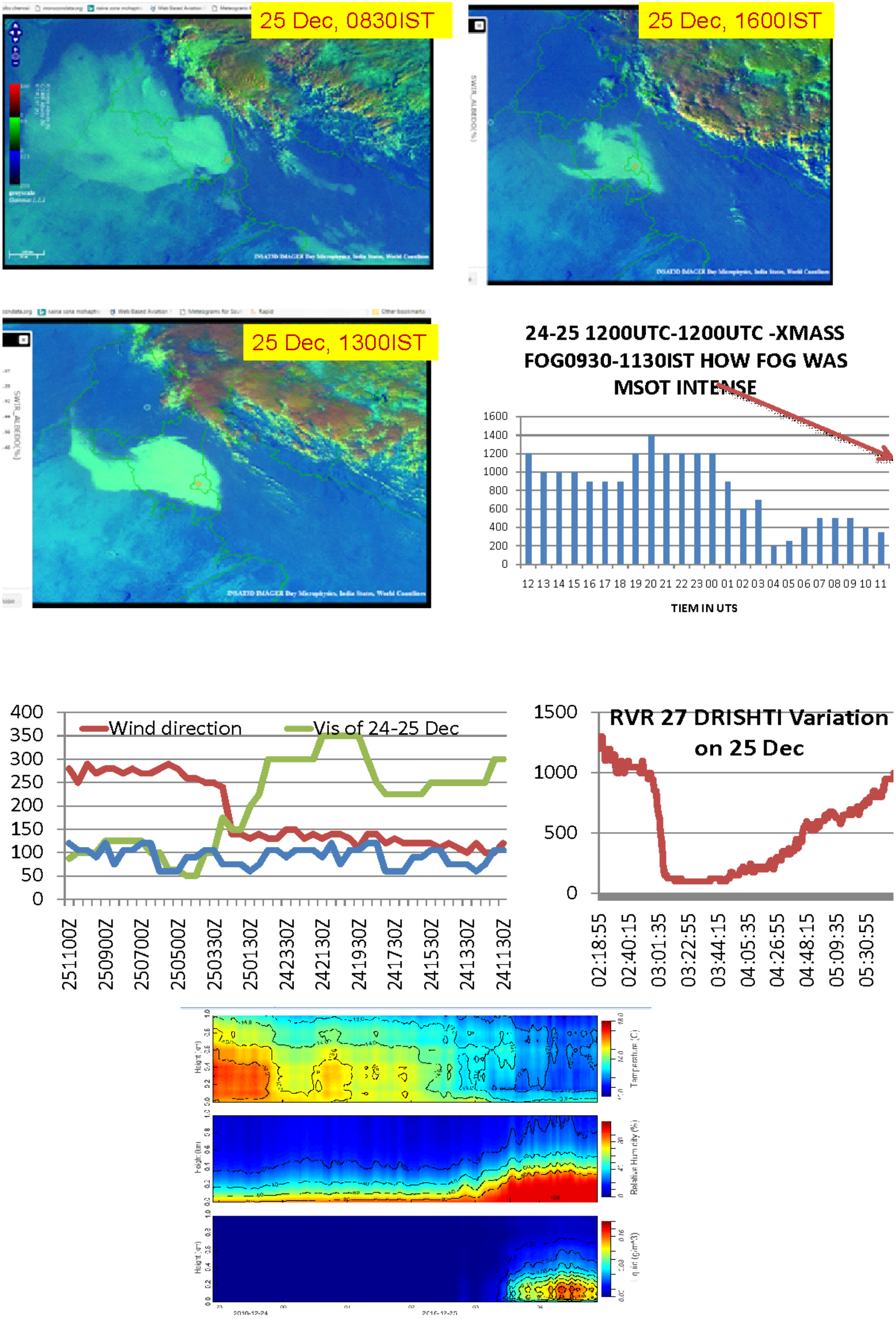


Figure 13. 25 Dec 2016 – Late morning Day period of fog Intensification during 0930-1030 IST on 25 Dec as captured by Drishti RVR, Rapid-Insat 3-D and Raidometer of WIFEXT 2016-17. One may see fall of vis from right to left in lest top of 2nd panel figure with change of wind direction from westerly to eaterly while at en right fig at same sudden fall of RVR from 030135 UTC to 032255UTC. The radiometer at lowest of panels shows late dense fog formation

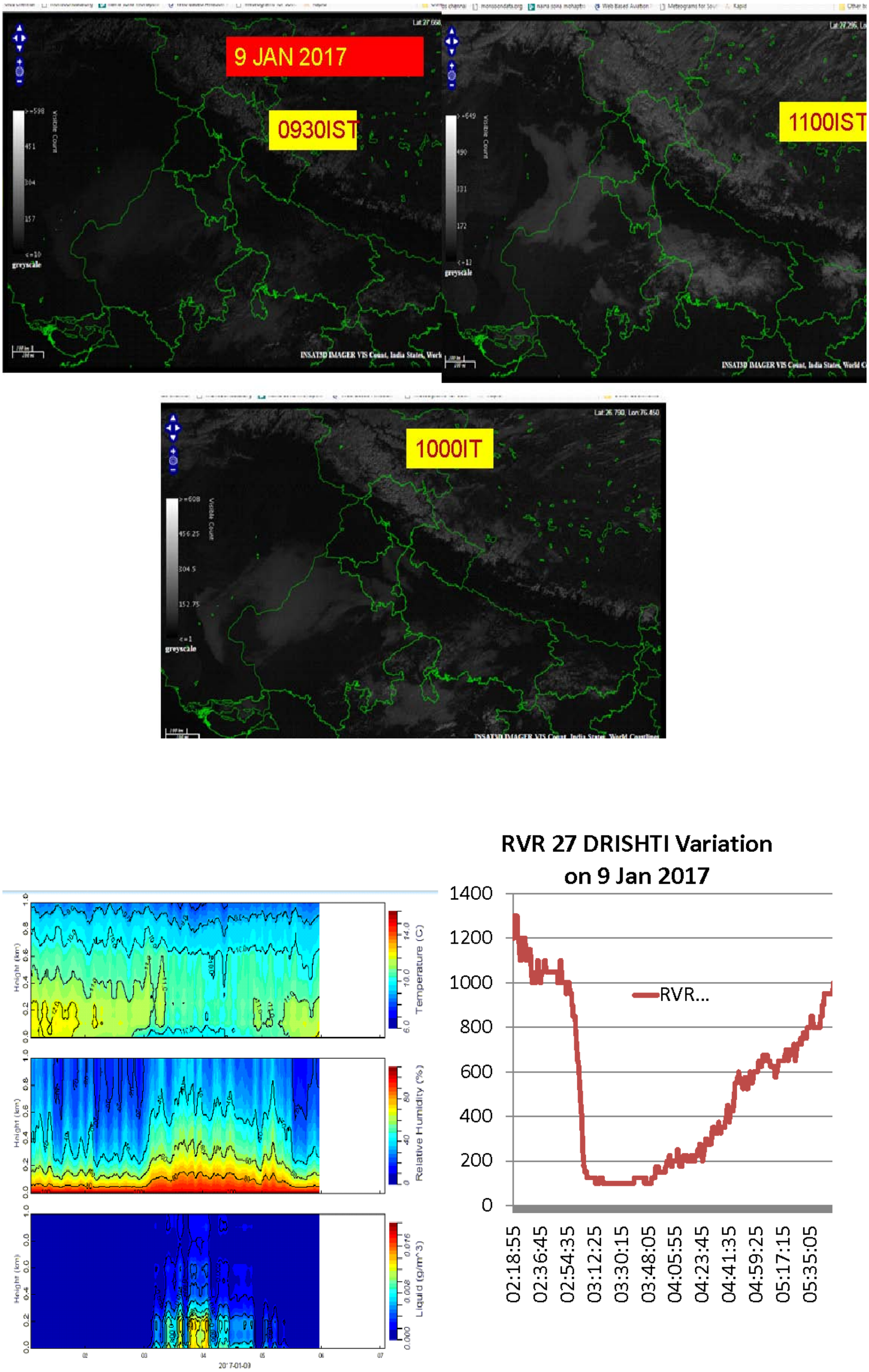


Figure 14. 9 Jan 2017 –Late morning Day period of fog Intensification during 0830-1030 IST on 9 Jan was captured by Drishti RVR, Rapid-Insat 3-D and Raidometer of WIFEXT 2016-17

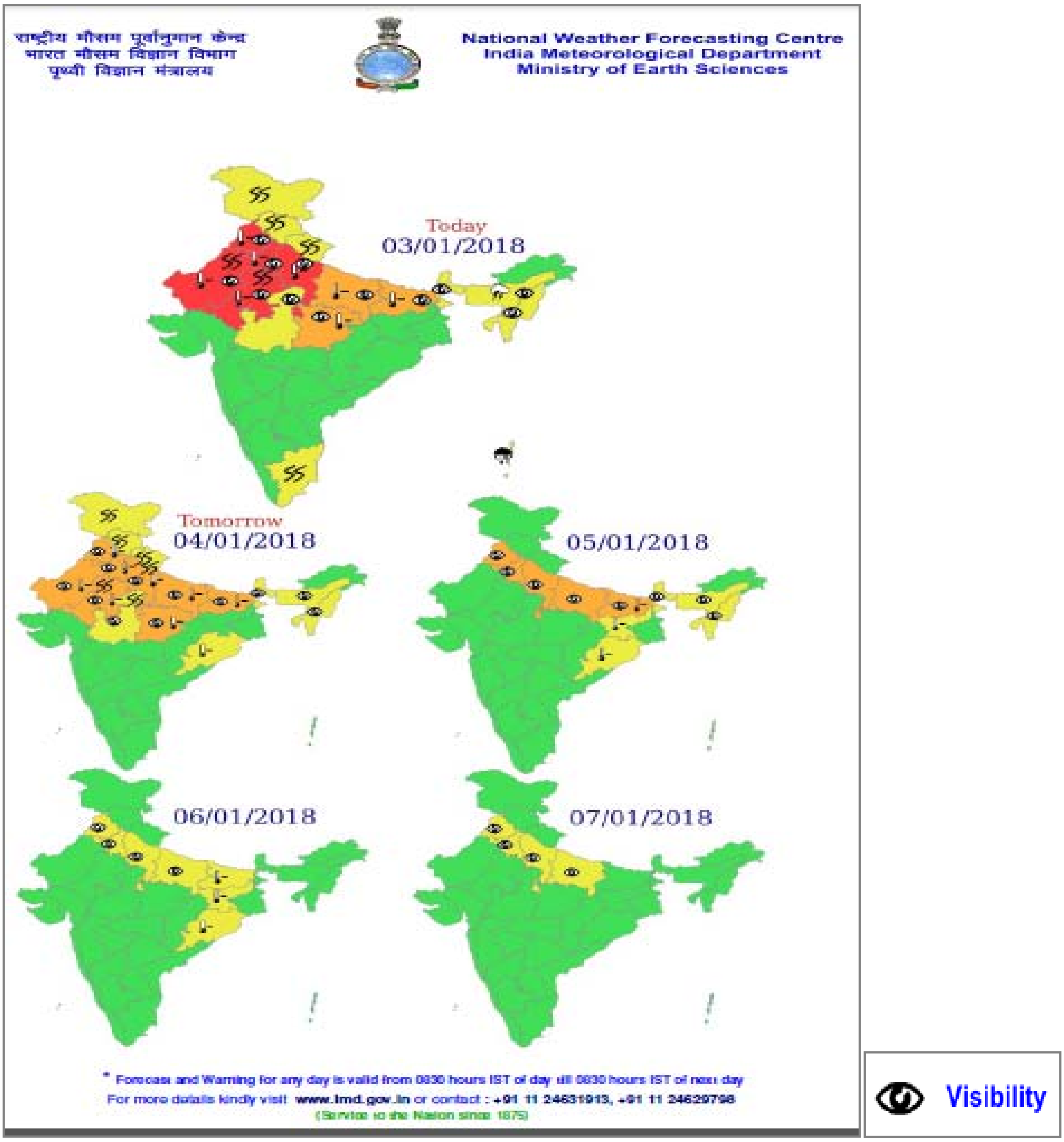


Figure 15. NWFC-national level met-sub-division based fog forecast and warning Products

8.6. Fog Products available in Web page and link URL

<u>a. IMD products available on-lin</u>
Live RVR for IGIA, JPR, LKN, AMT and BNG airports
Fog status of previous days -12 most vulnerable for major Airports
Fog forecast by 12 airport
NWFC Winter daily FDP inputs documents/ guidance
Satellite RGB Fog coverage
b. <u>Different Fog forecast products from NWP Models</u>
<u>NCMRWF FOG FORECAST PRODUCTS-</u>
•https://www.ncmrwf.gov.in/FOG_FCST/PROB_FCST.htm- Probability NEPS Fog forecast valid for 2 days

•https://www.ncmrwf.gov.in/FOG_REG_FCST/FOG_REG_FCST.htm -NCUM 12KM Global fog model from NCMRWF valid for 10 days
•https://www.ncmrwf.gov.in/FOG_REG_FCST/FOG_REG_FCST.htm NCUM 4KM Regional fog model from NCMRWF valid for 3 days
•https://www.ncmrwf.gov.in/All_times_Dm-Chem-visibility.php- 330mDelhi fog model -Valid for 2-days
•https://www.ncmrwf.gov.in/All_times_DM_Chem-cities.php-1.5km NW India fog- -Valid for 2-days
https://ews.tropmet.res.in/index.php -Spatial vis forecast maps at 2km for Delhi NCR and for NW India at 4km . Also has Vis met grams for all airports
•https://ews.tropmet.res.in/fog_forecast.php
•https://ews.tropmet.res.in/fog-airports.php
•https://ews.tropmet.res.in/fog-index-2.php
<u>IITM Rail line/Roadways fog forecsat-</u>
•https://ews.tropmet.res.in/fog-rail-lines.php
•https://ews.tropmet.res.in/fog-road-lines.php
 <u>IMD NWP GFS fog diagnostic products</u>
http://nwp.imd.gov.in/gfs_ventilation_index.php
http://weather.uwyo.edu/upperair/sounding.html

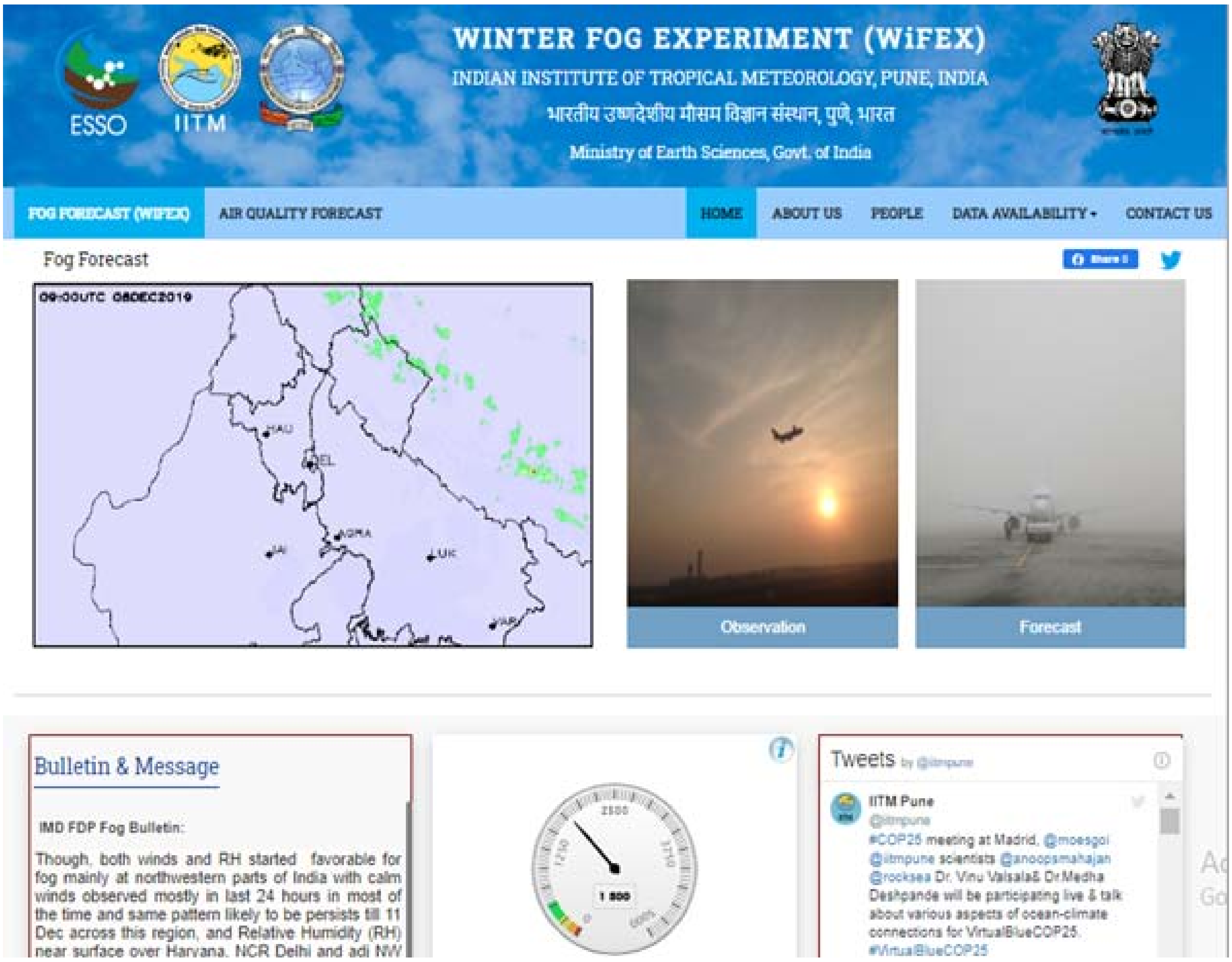


Figure 16. A state of art Fog web page jointly developed and made operational by IITM-IMD and it is WIFEX Page of IMD-IIMT where all integrated fog products (RVR, METAR based, satellite and RVR based data and forecast products from various fog mdeols) are available.

8.7. SOP to include Impact based fog forecast tables and suggested action for various fog intensity and occurrences at district/met sub-division depending upon exposure data

Colour Code	Alert	Warning	Impact	Suggested Actions
Green (No action)	No fog/Shallow fog	No warning	Nil.	Nil
Yellow Alert (Be updated)	**Moderate to Dense fog**	**Moderate fog at scattered places and Dense fog conditions at isolated pockets and forecasted to persist at least for day 1 or more**	**Transport and Aviation:** Difficult driving conditions with slower journey times. Some road traffic collisions **Below Visibility minima at airports in the areas may affect aircraft landing/take offs** **Inland River Ferry service operations partially affected**	**Transport and Aviation and Ferry services:** (a) Be touch with airlines and Railway and State transport for scheduled of your journey "Use fog lights" b)Careful while driving or outing through any transport. c)Be touch with River and coastal Ferry service Operators
Orange Alert (Be prepared)	**Dense fog to very dense fog**	**Dense fog to very dense at a few places already started/ forecasted to likely prevail/ persist at least for day 1 or more**	**Transport and Aviation:** May affect some airports, highways and railway routes in the areas of met-sub-division. also to be affected. Difficult driving conditions with slower journey times. Some road traffic collisions **Inland River Ferry service operation likely to be affected** **Power Sector:** **Tripping of Power lines** **Human Health:** **Lung related health impacts: Dense fog contains** particulate matter and other pollutants and in case exposed it gets lodged in the lungs, clogging them and decreasing their functional capacity which increases episodes of wheezing, coughing and shortness of breath **Impact on people having asthma bronchitis: Long time exposure to dense fog may cause respiratory problem for people having asthma bronchitis and other lung related health problems.** **Causes Eye Irritation: Dense fog contains pollutions of various types and these** Pollutants in the air if exposed may tend to irritate the membranes of the eye causing various infections leading to redness or swelling of the eye.	**Transport, Aviation and Ferry services:** Careful while driving or outing through any transport Use fog lights during driving Be touch with airlines, Railway and State transport for scheduled of your journey Be touch with River Ferry service Operators **Power Sector:** **To keep ready Maintenance Team** **Human Health:** **To avoid outing until unless emergency and to cover the face.**

Red Alert **(Take Action)**	**Dense to Very dense fog at most or many locations in the MET-Sub-Div**	**Wide spread/ FWS dense fog with SCTD and FWS Very dense fog reported in the met-Sub-div or forecasted to prevail in Day**	**Transport and Aviation:** **Closure of rail routes, train diversions/delays/cancellation of trains** **High way severely affected** **Airport which has CAT-IIIB becomes partially operational, but with highly reduced capacity and hence it has high chance of likely flight delays** **Cold day conditions over the areas** **River and coastal Ferry service operation to be fully suspended** **Power Sector:** **Tripping of Power lines** **Human Health:** **Lung related health impacts: Dense fog contains** particulate matter and other pollutants and in case exposed it gets lodged in the lungs, clogging them and decreasing their functional capacity which increases episodes of wheezing, coughing and shortness of breath **Impact on people having asthma bronchitis: Long time exposure to dense fog may cause respiratory problem for people having asthma bronchitis and other lung related health problems.** **Causes Eye Irritation: Dense fog contains pollutions of various types and these** Pollutants in the air if exposed may tend to irritate the membranes of the eye causing various infections leading to redness or swelling of the eye.	**Transport and Aviation:** **Do not drive unless very urgent. Drive very slowly.** **Use fog lights** **Carry all essential items in view of flights/trains/bus highway operating, likely to be delayed and/or stranded at airports and/or ferry at terminals.** **Be touch with airlines and Railway and State transport for scheduled of your journey.** Be touch with River Ferry service Operators **Power Sector:** **To keep ready Maintenance Team** **Human Health:** **To avoid outing until unless emergency and to cover the face.**

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Chapter 9

Nowcasting Services

9.1. Introduction

A highly populated tropical country like India is very much vulnerable to severe/ high impact Meso-scale weather events and requires an effective and efficient now-casting technique to mitigate the adverse effects of various weather events. In India Meteorological Department, Nowcasting comprises the detailed description of the current weather along with forecasts obtained by extrapolation for a period of 0 to 3 hours ahead. In this time frame, it is possible to forecast small features such as individual storms with reasonable accuracy. A forecaster using the latest radar, satellite and observational data is able to make analysis of the small-scale features present in a small area such as a city and make an accurate forecast for the following few hours. It is, therefore, a powerful tool in warning the public of hazardous, high-impact weather including tropical cyclones, thunderstorms and tornados which cause heavy rains, flash floods, hails, lightning strikes and destructive winds.

In addition to using Now-casting for warning the public of hazardous weather, it is also used for aviation weather forecasts in the terminal and en-route environment, marine safety, water and power management, off-shore oil drilling, construction industry and leisure industry. The strength of Now-casting lies in the fact that it provides location-specific forecasts of storm initiation, growth, movement and dissipation, which allows for specific preparation for a certain weather event by people in a specific location.

The elements to be included in the purview of the nowcasting in IMD will include:

(i) Thunderstorms and accompanying severe weather

(ii) Rainfall

9.2. Objective

In view of the increased public awareness of the high impact of severe weather events and its influence on social, cultural, commercial, health, defence, transport etc., it is felt that there is a requirement of a well laid out system/ methodology for monitoring and nowcasting of these weather events by India Meteorological Department (IMD). Hence there is a need to develop a Standard Operating Procedure (SOP), to provide uniform monitoring and nowcasting services of above mentioned weather events.

In addition to this, the nowcasting will help in Aviation, disaster management and Urban forecasting.

9.3. Standard Operating Procedure of Nowcast Services in IMD

The nowcast advisories for severe weather are issued by State Meteorological Centres at three hourly intervals for major cities as well as all districts of India round the clock. Nowcasts are currently being issued for 739 districts and about 894 stations throughout India in the beginning of 2020. (List of stations for which nowcasts are currently being issued is attached as Appendix 1). The list of stations for which nowcasts are issued includes most of the district headquarters all over India as well as towns and cities that are important for commercial or tourism purposes. These Nowcast warnings are updated on the IMD website at 3 hourly intervals at https://mausam.imd.gov.in/imd_latest/contents/stationwise-nowcast-warning.php. Additionally, district level nowcasts are also updated every three hours on the IMD website (https://mausam.imd.gov.in/imd latest/contents/districtwisewarnings.php). 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.

9.3.1. Categories for Nowcasting

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)

9.3.2. Impact colours of Nowcasting

The impact expected due to the severe weather has also been added to the nowcast warnings in terms of colour codes as follows:

i) **Green colour** (No weather)

ii) **Yellow colour** (Light rain: < 5 mm/ hr/ Light snow < 5cm/ hr / Light Thunderstorms with maximum surface wind speed upto 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)

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 metres due to dust/ High (> 60%) probability of cloud to ground lightning occurrence).

All these developments have greatly increased the quality, outreach and effectiveness of severe weather warnings issued by IMD.

Details of the Impact assessment and suggested action are included in Appendix 2 and also in the IBF SOP.

9.3.3. Organization of nowcast services in IMD

Meteorological centres located at each state perform the core role of operational now-casting in IMD. The MC is responsible for monitoring and dissemination of nowcast information to various stakeholders with guidance from the Nowcast division at New Delhi as shown in the Figure 1 below.

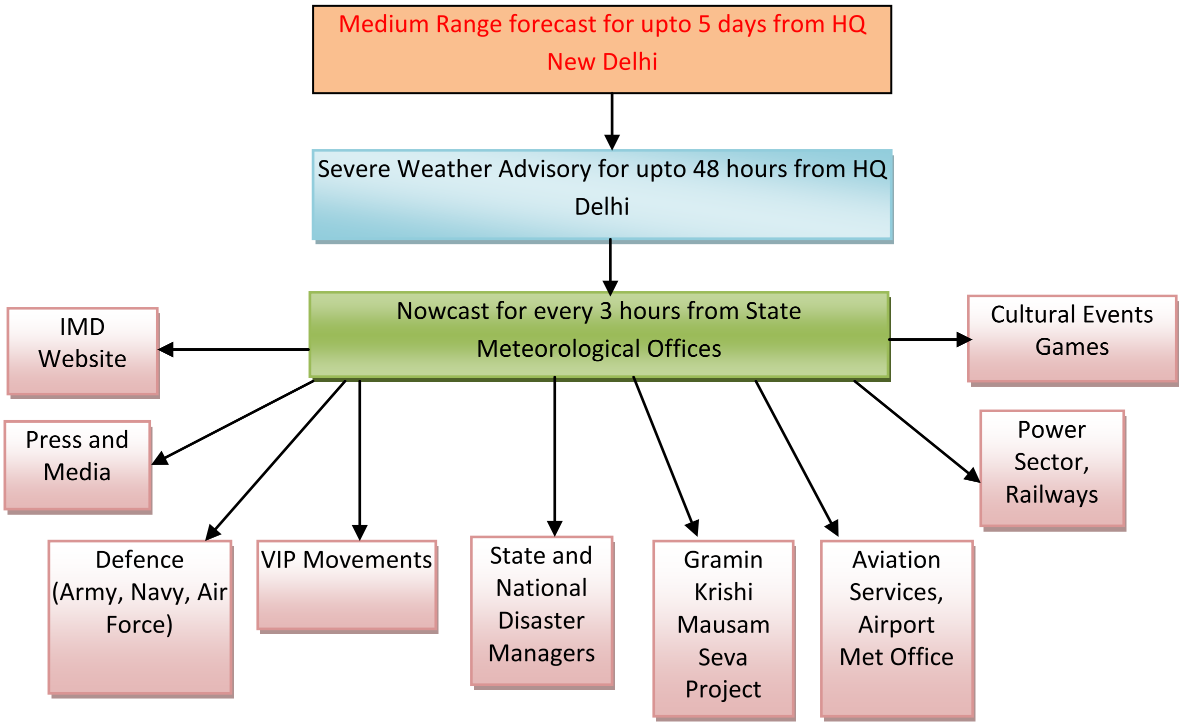


Figure 1. Salient features of organizational structure

9.3.4. Data Inputs (data products and their availability)

In order to give accurate nowcasts in real time, forecaster at the MC will require the following data as per figure 2 given below:

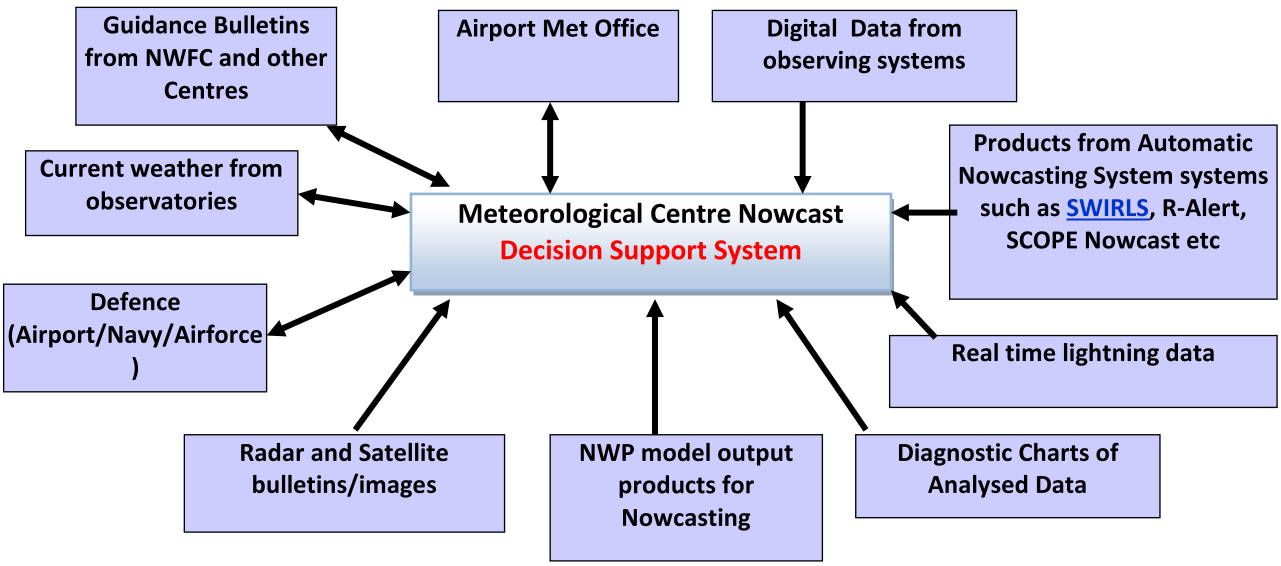


Figure 2. Data and Forecast support to Nowcast Unit at Meteorological centres

Digital Data from observing systems will include

- Data from AWS, AWOS, GPS, ARG, Wind Profiler data, lightning detection network data, RSRW data and synop observatory data
- Satellite digital data including radiance data from different channels, satellite derived winds, precipitation estimates, Sea Surface temperature, Vertical profile of temperature and humidity, sea surface winds, liquid water content, aerosol content of the atmosphere.
- Radar digital data includes reflectivity, radial velocity, spectrum width and derived products.

Derived Nowcast Guidance data will include

- NWP Model outputs from NWP Division, New Delhi and also other MoES organizations such as IITM, NCMRWF
- Automatic nowcast guidance products such as R-Alert, SWIRLS, SCOPE Nowcast etc

Analysed Data includes

- From weather charts uploaded by NWFC.

Forecast Bulletins including

- Extended range to Medium Range weather Bulletins of NWFC IMD
- Severe Weather Advisory of NWFC IMD
- Nowcast Guidance Bulletins of neighbouring Meteorological Centres
- Aviation forecasts of airports in the region

Real time availability of the raw data to the forecaster is essential for effective nowcasting. If data from any source is not available, forecaster will inform corresponding RMC and NWFC and make suitable effort to rectify the problem. Forecasts for a particular region issued at NWFC will be used by respective MC as guidance to issue nowcast as and when warranted.

A current list of some products that are to be used for Nowcasting purposes is given below as Appendix 3. Links to many of these products are also available at the Thunderstorm forecast webpage https://srf.tropmet.res.in/srf/ts_prediction_system/index.php.

9.3.5. Time line for analysis, forecast and dissemination of Nowcasts by a Nowcast Centre:

HH : Appreciation of the scenario through synoptic and NWP analysis and forecast,

Analysis of hourly data and products (satellite, AWS, ARG, Metar, Speci etc)

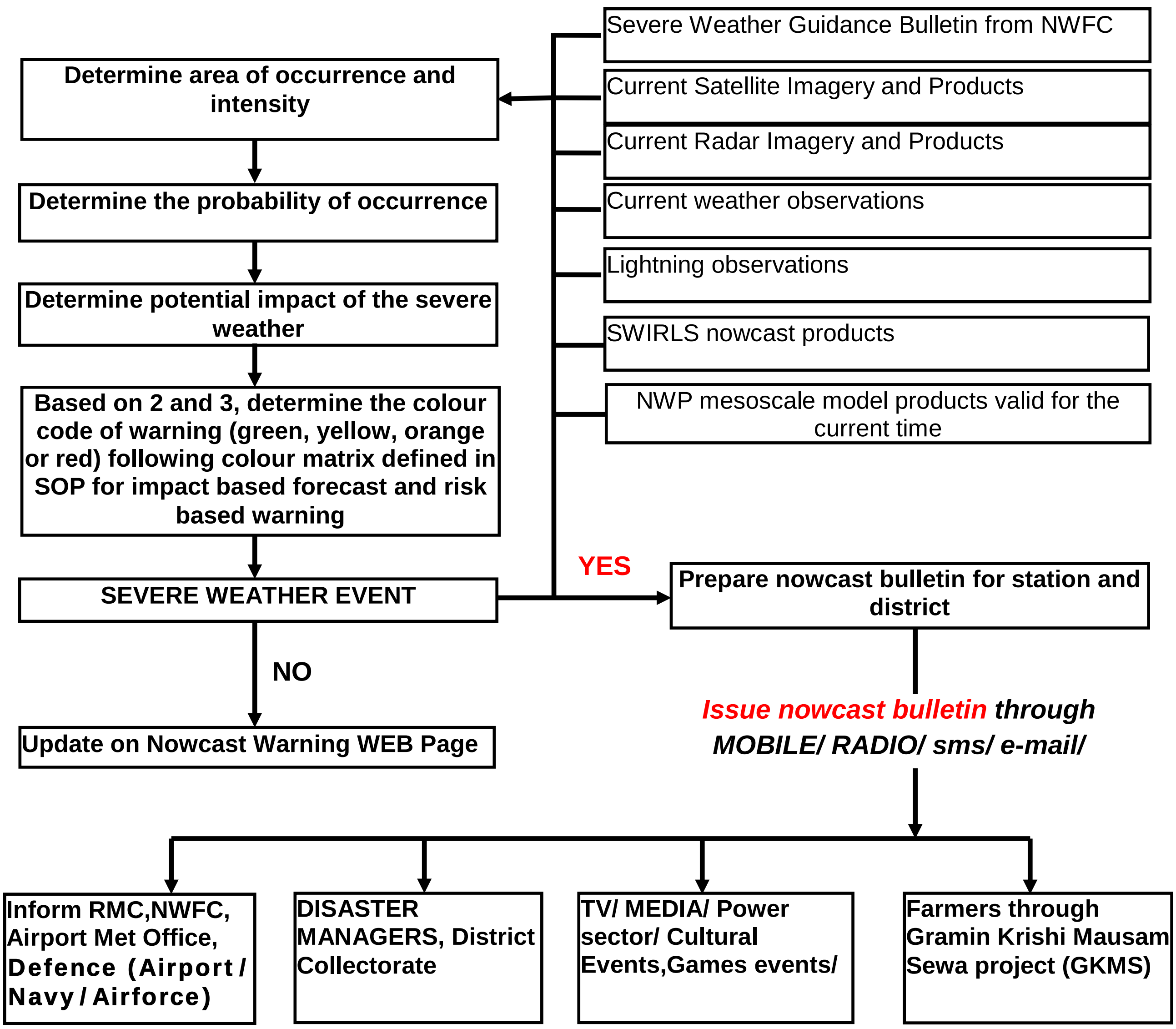
HH+15 : Monitoring radar products (every 10 minutes) and nowcast model products

HH+30 : Preparation of Check list and decision making

HH+45 : Generation of nowcast bulletin

HH+55 : Uploading and dissemination

9.3.6. Decision Tree of Nowcasting of Thunderstorm over a Station or District



9.3.7. Nowcasts to be issued by Nowcast Centre at State Meteorological Office

(a) **Station level Nowcast** : To be issued at three hourly intervals by Meteorological Centres for stations. This list includes: District Headquarters, Tourism important cities, cities along major pilgrimage routes, IMD observatories. These shall be updated on IMD website.

(b) **District level Nowcast** : To be issued at three hourly intervals by Meteorological Centres for stations. These shall be updated on IMD website.Warning will be issued by MCs and RMCs of IMD for districts within their domain only when severe weather is expected over a district along with start and end time in IST. There is a separate web page from the above.

(c) In case of Severe weather, **Nowcast Warning Bulletins** are to be issued at district level. These Nowcast Bulletins are to be issued through telephone/ SMS/ whatsapp/e-mail/ twitter/Instagram/Facebook/Social Media update/ media channels/FM radio for all districts to be warned.

Nowcast Warning Bulletin format

Nowcast warning consists of followings:

i) Text format-

All forecast/ warnings will be issued at the time scale of hours and spatial scale of districts from corresponding MC as per sample format given in Appendix 4.

ii)Visual Format-

Any supporting evidence in the form of satellite or radar pictures or any other relevant images.

Impacts and suggested actions associated with thunderstorms and associated phenomena are mentioned in Appendix 2.

MCs can slightly modify the format of Nowcast Bulletin as per Station Requirements. However, all the elements of the Sample format should appear in the bulletin.

Some sample bulletins are enclosed as Appendix 5.

9.3.8. Stakeholders (National/ regional and state level)

Natural calamities can occur due to many types of severe weather events. These severe weather events can cause wide spread loss to life and property. Therefore, it is but natural that Govt./authorities at national and state level should be informed well in time about the impending weather and situations likely to cause damage to public life and property.

Thus at MC level it is of paramount importance that information is passed promptly to district level disaster manager which in turn can inform the state authorities for taking necessary actions.

At national level as soon as NWFC receives information about the severe weather events likely to cause widespread damage to a particular region, NWFC will inform the concerned authority at national level.

In additional to the Government agencies as stakeholders in the nowcasting mechanism, interested private organizations, universities, and foreign users also need to be brought on board. Their inputs need to be incorporated to improve the quality of nowcasts, give a feedback regarding the products and helping in the overall efficiency of the nowcasting system.

9.3.9. Post event review, feedback, documentation

For validating nowcast products, it is important for post event review of the occurrence, location and intensity of the disturbed weather.

Review of severe weather nowcasts should be carried out continuously. For this, feedback from the stakeholders (especially the district administration) is necessary. Met centre should have liaison with the district administration in this regard.

In-house verification of all nowcasts should be carried out on a monthly basis and results thereof should be logged in the nowcast register. For this purpose Met centre has to maintain a nowcast register. These registers should be reviewed every month by Nowcast Station In charge.

After every major event in the state/ region of monitoring, a casebook may be created comprising the following

- Medium range forecast issued at state level for the event
- Nowcasts issued for the event by the state (along with list of persons to whom it has been issued)

- Supporting observations if any

- Press release and meetings and phone call logs to State Authorities about the event.

9.3.10. Pre-season exercise

Every season in the country has peculiar severe weather hazards which cause extensive damage to life and property. Hence all MCs should have

- Pre-season exercise with state government officials, media persons and NGOs raising awareness of major weather hazards of the season, IMDs services and bulletins and discuss the action to be taken at the ground levels based on different bulletins of IMD.
- Season wise forecasting hints, checklists etc for forecasting of major types of events both qualitatively (synoptically) as well as quantitatively (various dynamic/thermodynamic parameters) should be kept ready on forecaster's desk. This should include checklists for all types of thunderstorms, duststorms, hailstorm, heavy rain and any other type of event affecting the region. The checklists should be available at the forecaster's desk, and periodically revised to include new products as they become available.
- List of officers (with their phone numbers and e-mail ID) to whom Nowcasts are being communicated. This list should be revised at least once every six months on account of transfer of State Government officers. The list should be communicated to Nowcast Unit at Delhi every six months.

This will help greatly in successful implementation of the nowcasting system.

9.4. Points for consideration

Successful implementation of nowcast concept will depend on

- Proper an adequate trained manpower at MC / NWFC,

- IT infrastructure and effective communication between various agencies for reception /dissemination of data, information and warnings.

MCs can prepare their checklist as per their own requirements and the local condition under the broad framework of this SOP.

Appendix 1

List of Nowcast Stations

S. No.	Nowcast_Centre	Station
1.	cwc_visakhapatanam	Bapatla
2.	cwc_visakhapatanam	Eluru
3.	cwc_visakhapatanam	Gannavaram
4.	cwc_visakhapatanam	Guntur
5.	cwc_visakhapatanam	Kakinada
6.	cwc_visakhapatanam	Kalingapatnam
7.	cwc_visakhapatanam	Kavali
8.	cwc_visakhapatanam	Machilipatnam
9.	cwc_visakhapatanam	Nandigama
10.	cwc_visakhapatanam	Narsapur
11.	cwc_visakhapatanam	Nellore
12.	cwc_visakhapatanam	Nidadavolu
13.	cwc_visakhapatanam	Ongole
14.	cwc_visakhapatanam	Palakonda
15.	cwc_visakhapatanam	Jangamaheswarapuram
16.	cwc_visakhapatanam	Srikakulam
17.	cwc_visakhapatanam	Tuni
18.	cwc_visakhapatanam	Vijayawada
19.	cwc_visakhapatanam	Vishakhapatnam
20.	cwc_visakhapatanam	Vizianagaram
21.	cwc_visakhapatanam	Arogyavaram
22.	cwc_visakhapatanam	Chittoor
23.	cwc_visakhapatanam	Kadappa
24.	cwc_visakhapatanam	Kurnool
25.	cwc_visakhapatanam	Nandyal
26.	cwc_visakhapatanam	Tirupati
27.	cwc_visakhapatanam	Amravati
28.	mc_agartala	Agartala
29.	mc_agartala	Aizawal
30.	mc_agartala	Ambassa
31.	mc_agartala	Belonia
32.	mc_agartala	Champai
33.	mc_agartala	Churachandpur
34.	mc_agartala	Dharmanagar
35.	mc_agartala	Dimapur
36.	mc_agartala	Imphal
37.	mc_agartala	Kailasahar
38.	mc_agartala	Khowai
39.	mc_agartala	Kolasib
40.	mc_agartala	Lawngtlai

41.	mc_agartala	Lengpui
42.	mc_agartala	Lunglie
43.	mc_agartala	Mamit
44.	mc_agartala	Sabroom
45.	mc_agartala	Saiha
46.	mc_agartala	Sipahijala
47.	mc_agartala	Udaipur(Gomati)
48.	mc_agartala	Kohima
49.	mc_ahmedabad	Amreli
50.	mc_ahmedabad	Bhuj
51.	mc_ahmedabad	Botad
52.	mc_ahmedabad	Dholavira
53.	mc_ahmedabad	Dwarka
54.	mc_ahmedabad	Gandhidham
55.	mc_ahmedabad	Jamnagar
56.	mc_ahmedabad	Junagadh
57.	mc_ahmedabad	Mandvi
58.	mc_ahmedabad	Morbi
59.	mc_ahmedabad	Naliya
60.	mc_ahmedabad	New Kandla
61.	mc_ahmedabad	Okha
62.	mc_ahmedabad	Porbandar
63.	mc_ahmedabad	Rajkot
64.	mc_ahmedabad	Surendranagar
65.	mc_ahmedabad	Ahmedabad AP
66.	mc_ahmedabad	Navrangpura
67.	mc_ahmedabad	Rakhiyal
68.	mc_ahmedabad	Chandkheda
69.	mc_ahmedabad	Ahm Satellite
70.	mc_ahmedabad	ISRO Bopal
71.	mc_ahmedabad	Raikhad
72.	mc_ahmedabad	Pirana
73.	mc_ahmedabad	Gandhi Ng IIPH
74.	mc_ahmedabad	Gift City
75.	mc_ahmedabad	Diu
76.	mc_ahmedabad	VV Nagar
77.	mc_ahmedabad	Modasa
78.	mc_ahmedabad	Radhanpur
79.	mc_ahmedabad	Deesa
80.	mc_ahmedabad	Bharuch
81.	mc_ahmedabad	Bhavnagar
82.	mc_ahmedabad	Chhota Udaipur
83.	mc_ahmedabad	Dahod
84.	mc_ahmedabad	Ahwa

85.	mc_ahmedabad	Gandhinagar
86.	mc_ahmedabad	Veraval
87.	mc_ahmedabad	Nadiad
88.	mc_ahmedabad	Lunavada
89.	mc_ahmedabad	Mehsana
90.	mc_ahmedabad	Rajpipla
91.	mc_ahmedabad	Navsari
92.	mc_ahmedabad	Godhra
93.	mc_ahmedabad	Patan
94.	mc_ahmedabad	Idar
95.	mc_ahmedabad	Surat
96.	mc_ahmedabad	Vyara
97.	mc_ahmedabad	Vadodara
98.	mc_ahmedabad	Valsad
99.	mc_bengaluru	Agumbe
100.	mc_bengaluru	Bagalkot
101.	mc_bengaluru	Balehonnur
102.	mc_bengaluru	Ballari
103.	mc_bengaluru	Bandipur National Park
104.	mc_bengaluru	Belagavi
105.	mc_bengaluru	Bidar
106.	mc_bengaluru	Chamarajanagar
107.	mc_bengaluru	Chikballapur
108.	mc_bengaluru	Chikkamagaluru
109.	mc_bengaluru	Chikkanahalli
110.	mc_bengaluru	Chintamani
111.	mc_bengaluru	Chitradurga
112.	mc_bengaluru	Dandeli
113.	mc_bengaluru	Davanagere
114.	mc_bengaluru	Dharwad
115.	mc_bengaluru	Gadag
116.	mc_bengaluru	Gokarna
117.	mc_bengaluru	Hassan
118.	mc_bengaluru	Haveri
119.	mc_bengaluru	Honavar
120.	mc_bengaluru	Kadajji
121.	mc_bengaluru	Kalaburagi
122.	mc_bengaluru	Karwar
123.	mc_bengaluru	Kolar
124.	mc_bengaluru	Koppal
125.	mc_bengaluru	Kumta
126.	mc_bengaluru	Madikeri
127.	mc_bengaluru	Mandya
128.	mc_bengaluru	Mangaluru

129.	mc_bengaluru	Murdeshwar
130.	mc_bengaluru	Mysore
131.	mc_bengaluru	Raichur
132.	mc_bengaluru	Ramanagara
133.	mc_bengaluru	Sagara
134.	mc_bengaluru	Sambre
135.	mc_bengaluru	Shirali
136.	mc_bengaluru	Shivamogga
137.	mc_bengaluru	Sirsi
138.	mc_bengaluru	Tumakuru
139.	mc_bengaluru	Udupi
140.	mc_bengaluru	Vijayapur
141.	mc_bengaluru	Yadgir
142.	mc_bengaluru	Bengaluru HAL
143.	mc_bengaluru	Bengaluru BIAL
144.	mc_bengaluru	Bengaluru City
145.	mc_bengaluru	GKV Kendra
146.	mc_bhopal	Agar Malwa
147.	mc_bhopal	Alirajpur
148.	mc_bhopal	Amarkantak
149.	mc_bhopal	Anuppur
150.	mc_bhopal	Ashoknagar
151.	mc_bhopal	Balaghat
152.	mc_bhopal	Barwani
153.	mc_bhopal	Behedaghat
154.	mc_bhopal	Betul
155.	mc_bhopal	Bhandhavgarh
156.	mc_bhopal	Bhimbetka
157.	mc_bhopal	Bhind
158.	mc_bhopal	Burhanpur
159.	mc_bhopal	Chhatarpur
160.	mc_bhopal	Chhindwara
161.	mc_bhopal	Chitrakoot
162.	mc_bhopal	Damoh
163.	mc_bhopal	Datia
164.	mc_bhopal	Dewas
165.	mc_bhopal	Dhar
166.	mc_bhopal	Dindori
167.	mc_bhopal	Guna
168.	mc_bhopal	Gwalior
169.	mc_bhopal	Harda
170.	mc_bhopal	Hoshangabad
171.	mc_bhopal	Indore
172.	mc_bhopal	Jabalpur

173.	mc_bhopal	Jhabua
174.	mc_bhopal	Kanha
175.	mc_bhopal	Katni
176.	mc_bhopal	Khajuraho
177.	mc_bhopal	Khandwa
178.	mc_bhopal	Khargone
179.	mc_bhopal	Mahakaleshwar
180.	mc_bhopal	Maheshwar
181.	mc_bhopal	Maihar
182.	mc_bhopal	Mandla
183.	mc_bhopal	Mandsaur
184.	mc_bhopal	Mandu
185.	mc_bhopal	Morena
186.	mc_bhopal	Narsinghpur
187.	mc_bhopal	Neemuch
188.	mc_bhopal	Omkareshwar
189.	mc_bhopal	Orcha
190.	mc_bhopal	Pachmarhi
191.	mc_bhopal	Panna
192.	mc_bhopal	Pench
193.	mc_bhopal	Raisen
194.	mc_bhopal	Rajgarh
195.	mc_bhopal	Ratangarh
196.	mc_bhopal	Ratlam
197.	mc_bhopal	Rewa
198.	mc_bhopal	Sagar
199.	mc_bhopal	Sanchi
200.	mc_bhopal	Satna
201.	mc_bhopal	Sehore
202.	mc_bhopal	Seoni
203.	mc_bhopal	Shahdol
204.	mc_bhopal	Shajapur
205.	mc_bhopal	Sheopur
206.	mc_bhopal	Shivpuri
207.	mc_bhopal	Sidhi
208.	mc_bhopal	Singrauli
209.	mc_bhopal	Tikamgarh
210.	mc_bhopal	Udaygiri
211.	mc_bhopal	Ujjain
212.	mc_bhopal	Umaria
213.	mc_bhopal	Vidisha
214.	mc_bhopal	Bhopal AP
215.	mc_bhopal	Arera Hills
216.	mc_bhopal	Nabi Bagh

217.	mc_bhubneshwar	Angul
218.	mc_bhubneshwar	Balangir
219.	mc_bhubneshwar	Balasore
220.	mc_bhubneshwar	Bargarh
221.	mc_bhubneshwar	Baripada
222.	mc_bhubneshwar	Boudh
223.	mc_bhubneshwar	Bhadrak
224.	mc_bhubneshwar	Bhawanipatna
225.	mc_bhubneshwar	Bhubaneshwar AP
226.	mc_bhubneshwar	Berhampur
227.	mc_bhubneshwar	Chandbali
228.	mc_bhubneshwar	Chilika Lake
229.	mc_bhubneshwar	Cuttack
230.	mc_bhubneshwar	Deogarh
231.	mc_bhubneshwar	Dhenkanal
232.	mc_bhubneshwar	Gopalpur
233.	mc_bhubneshwar	Jagatsinghpur
234.	mc_bhubneshwar	Jajpur
235.	mc_bhubneshwar	Jharsuguda
236.	mc_bhubneshwar	Kendrapara
237.	mc_bhubneshwar	Keonjhargarh
238.	mc_bhubneshwar	Khordha
239.	mc_bhubneshwar	Konark
240.	mc_bhubneshwar	Koraput
241.	mc_bhubneshwar	Malkangiri
242.	mc_bhubneshwar	Nayagarh
243.	mc_bhubneshwar	Nowrangpur
244.	mc_bhubneshwar	Nuapada
245.	mc_bhubneshwar	Paradip Port
246.	mc_bhubneshwar	Paralakhemundi
247.	mc_bhubneshwar	Phulbani
248.	mc_bhubneshwar	Puri
249.	mc_bhubneshwar	Rayagada
250.	mc_bhubneshwar	Rourkela
251.	mc_bhubneshwar	Sambalpur
252.	mc_bhubneshwar	Sonepur
253.	mc_bhubneshwar	Sundergarh
254.	mc_bhubneshwar	Talcher
255.	mc_bhubneshwar	Bhubaneshwar OUAT
256.	mc_chandigarh	Ambala
257.	mc_chandigarh	Amritsar
258.	mc_chandigarh	Bhatinda
259.	mc_chandigarh	Bhiwani
260.	mc_chandigarh	Ferozepur

261.	mc_chandigarh	Jalandhar
262.	mc_chandigarh	Ludhiana
263.	mc_chandigarh	Patiala
264.	mc_chandigarh	Chandigarh AP
265.	mc_chandigarh	Chandigarh city
266.	mc_chandigarh	Mohali
267.	mc_chandigarh	Panchkula
268.	mc_chandigarh	Barnala
269.	mc_chandigarh	Faridkot
270.	mc_chandigarh	Fatehgarh Sahib
271.	mc_chandigarh	Fazilka
272.	mc_chandigarh	Gurdaspur
273.	mc_chandigarh	Hoshiarpur
274.	mc_chandigarh	Kapurthala
275.	mc_chandigarh	Mansa
276.	mc_chandigarh	Moga
277.	mc_chandigarh	Muktsar
278.	mc_chandigarh	Pathankot
279.	mc_chandigarh	Rupnagar
280.	mc_chandigarh	Sangrur
281.	mc_chandigarh	Nawanshahr
282.	mc_chandigarh	Tarn Taran Sahib
283.	mc_chandigarh	Kaithal
284.	mc_chandigarh	Kurukshetra
285.	mc_chandigarh	Sirsa
286.	mc_chandigarh	Yamunanagar
287.	mc_chandigarh	Fatehabad
288.	mc_dehradun	Almora
289.	mc_dehradun	Badrinath
290.	mc_dehradun	Bageshwar
291.	mc_dehradun	Mukteshwar
292.	mc_dehradun	Chamoli
293.	mc_dehradun	Champawat
294.	mc_dehradun	Dehradun
295.	mc_dehradun	Gangotri
296.	mc_dehradun	Haridwar
297.	mc_dehradun	Hemkund Sahib
298.	mc_dehradun	Joshimath
299.	mc_dehradun	Munsiyari
300.	mc_dehradun	Mussoorie
301.	mc_dehradun	Nanital
302.	mc_dehradun	Pantnagar
303.	mc_dehradun	Pithoragarh
304.	mc_dehradun	Rishikesh

305.	mc_dehradun	Roorkee
306.	mc_dehradun	Rudraprayag
307.	mc_dehradun	Srinagar Uttarakhand
308.	mc_dehradun	Ukhimath
309.	mc_dehradun	Uttarkashi
310.	mc_dehradun	Yamunotri
311.	mc_dehradun	Chakrata
312.	mc_dehradun	Gairsain
313.	mc_dehradun	Tehri
314.	mc_dehradun	Pauri
315.	mc_dehradun	Lakhamandal
316.	mc_dehradun	Kotdwar
317.	mc_dehradun	Kedarnath
318.	mc_dehradun	Mohkampur
319.	mc_dehradun	Karanpur
320.	mc_dehradun	Jhajhara
321.	mc_dehradun	Sahastradhara
322.	mc_dehradun	Asharori
323.	mc_dehradun	UCOST
324.	mc_gangtok	Gangtok
325.	mc_gangtok	Tadong
326.	mc_goa	Anjuna
327.	mc_goa	Arambol
328.	mc_goa	Canacona
329.	mc_goa	Mapusa
330.	mc_goa	Margao
331.	mc_goa	Morjim Beach
332.	mc_goa	Netravali Sanctury
333.	mc_goa	Panjim
334.	mc_goa	Ponda
335.	mc_goa	Querim
336.	mc_goa	Shiroda
337.	mc_goa	Vasco
338.	mc_goa	Pernem
339.	mc_goa	Old Goa
340.	mc_hyderabad	Adilabad
341.	mc_hyderabad	Asifabad
342.	mc_hyderabad	Bhongir
343.	mc_hyderabad	Bhupalpally
344.	mc_hyderabad	Gadwal
345.	mc_hyderabad	Hyderabad
346.	mc_hyderabad	Jagtial
347.	mc_hyderabad	Jangaon
348.	mc_hyderabad	Kamareddy

349.	mc_hyderabad	Karimnagar
350.	mc_hyderabad	Khammam
351.	mc_hyderabad	Kothagudem
352.	mc_hyderabad	Mahabubabad
353.	mc_hyderabad	Mahbubnagar
354.	mc_hyderabad	Mancherial
355.	mc_hyderabad	Medak
356.	mc_hyderabad	Nagarkurnool
357.	mc_hyderabad	Nalgonda
358.	mc_hyderabad	Narayanpet
359.	mc_hyderabad	Nirmal
360.	mc_hyderabad	Nizamabad
361.	mc_hyderabad	Peddapalli
362.	mc_hyderabad	Ramagundam
363.	mc_hyderabad	Sangareddy
364.	mc_hyderabad	Shamirpet
365.	mc_hyderabad	Shamshabad
366.	mc_hyderabad	Siddipet
367.	mc_hyderabad	Sircilla
368.	mc_hyderabad	Suryapet
369.	mc_hyderabad	Vikarabad
370.	mc_hyderabad	Wanaparthy
371.	mc_hyderabad	Warangal
372.	mc_hyderabad	Rajendra Nagar
373.	mc_hyderabad	Hayathnagar
374.	mc_hyderabad	Hakimpet
375.	mc_hyderabad	Patancheru
376.	mc_jaipur	Bundi
377.	mc_jaipur	Chittorgarh
378.	mc_jaipur	Ajmer
379.	mc_jaipur	Alwar
380.	mc_jaipur	Bharatpur
381.	mc_jaipur	Bhilwara
382.	mc_jaipur	Churu
383.	mc_jaipur	Bikaner
384.	mc_jaipur	Jhalawar
385.	mc_jaipur	Jhunjhunu
386.	mc_jaipur	Kota
387.	mc_jaipur	Nagaur
388.	mc_jaipur	Pilani
389.	mc_jaipur	Sawimadoipur
390.	mc_jaipur	Sikar
391.	mc_jaipur	Barmer
392.	mc_jaipur	Banswara

393.	mc_jaipur	Baran
394.	mc_jaipur	Jaipur AP
395.	mc_jaipur	Vaishali Ng
396.	mc_jaipur	Transport Ng
397.	mc_jaipur	Collector Circle
398.	mc_jaipur	Amer
399.	mc_jaipur	Dholpur
400.	mc_jaipur	Dausa
401.	mc_jaipur	Rawatbhata
402.	mc_jaipur	Dungarpur
403.	mc_jaipur	Hanumangarh
404.	mc_jaipur	Jaisalmer
405.	mc_jaipur	Jalore
406.	mc_jaipur	Jodhpur
407.	mc_jaipur	Phalodi
408.	mc_jaipur	Karauli
409.	mc_jaipur	Jawaibandh
410.	mc_jaipur	Pratapgarh
411.	mc_jaipur	Rajsamand
412.	mc_jaipur	Mount Abu
413.	mc_jaipur	Sri Ganganagar
414.	mc_jaipur	Anupgarh
415.	mc_jaipur	Banasthali VDP
416.	mc_jaipur	Udaipur AP
417.	mc_jaipur	VIP Colony
418.	mc_jaipur	Madar Jn.
419.	mc_jaipur	Mangliyawas
420.	mc_jaipur	Kharwa
421.	mc_jaipur	Beawar
422.	mc_jaipur	New bar
423.	mc_jaipur	Chandawal
424.	mc_jaipur	Sojat Road
425.	mc_jaipur	Marwar Jn.
426.	mc_jaipur	Bhinwaliya
427.	mc_jaipur	Rani
428.	mc_jaipur	Falna
429.	mc_jaipur	nana
430.	mc_jaipur	Banas
431.	mc_jaipur	Kivarli
432.	mc_jaipur	Sarotra road
433.	mc_jaipur	Karjoda
434.	mc_lucknow	Allahabad
435.	mc_lucknow	Bahraich
436.	mc_lucknow	Ballia

437.	mc_lucknow	Banda
438.	mc_lucknow	Bareilly
439.	mc_lucknow	Fatehpur
440.	mc_lucknow	Ghazipur
441.	mc_lucknow	Gorakhpur
442.	mc_lucknow	Hamirpur_UP
443.	mc_lucknow	Hardoi
444.	mc_lucknow	Jaunpur
445.	mc_lucknow	Kanpur
446.	mc_lucknow	Orai
447.	mc_lucknow	Raebareli
448.	mc_lucknow	Shahjahanpur
449.	mc_lucknow	Sultanpur
450.	mc_lucknow	Varanasi
451.	mc_lucknow	Ambedkar Nagar
452.	mc_lucknow	Amethi
453.	mc_lucknow	Amroha
454.	mc_lucknow	Auraiya
455.	mc_lucknow	Azamgarh
456.	mc_lucknow	Badaun
457.	mc_lucknow	Baghpat
458.	mc_lucknow	Balrampur
459.	mc_lucknow	Barabanki
460.	mc_lucknow	Basti
461.	mc_lucknow	Bijnor
462.	mc_lucknow	Chandauli
463.	mc_lucknow	Chitrakoot
464.	mc_lucknow	Deoria
465.	mc_lucknow	Etah
466.	mc_lucknow	Etawah
467.	mc_lucknow	Faizabad
468.	mc_lucknow	Farrukhabad
469.	mc_lucknow	Firozabad
470.	mc_lucknow	Gonda
471.	mc_lucknow	Jhansi
472.	mc_lucknow	Kannauj
473.	mc_lucknow	Kanpur Dehat
474.	mc_lucknow	Kasganj
475.	mc_lucknow	Kaushambi
476.	mc_lucknow	Kushinagar
477.	mc_lucknow	Lakhimpur Kheri
478.	mc_lucknow	Lalitpur
479.	mc_lucknow	Maharajganj
480.	mc_lucknow	Mahoba

481.	mc_lucknow	Mainpuri
482.	mc_lucknow	Mau
483.	mc_lucknow	Mirzapur
484.	mc_lucknow	Pilibhit
485.	mc_lucknow	Pratapgarh
486.	mc_lucknow	Rampur
487.	mc_lucknow	Saharanpur
488.	mc_lucknow	Sant Kabir Nagar
489.	mc_lucknow	Bhadohi (Sant Ravidas
490.	mc_lucknow	Sambhal
491.	mc_lucknow	Shravasti
492.	mc_lucknow	Siddharthnagar
493.	mc_lucknow	Sitapur
494.	mc_lucknow	Sonbhadra
495.	mc_lucknow	Unnao
496.	mc_lucknow	Lucknow AP
497.	mc_lucknow	Hanuman Setu
498.	mc_lucknow	Flood Control
499.	mc_lucknow	Malihabad
500.	mc_lucknow	Mohanlalganj
501.	mc_patna	Jehanabad
502.	mc_patna	Hajipur
503.	mc_patna	Gopalganj
504.	mc_patna	Buxar
505.	mc_patna	Bihar Sharif
506.	mc_patna	Bhagalpur
507.	mc_patna	Bhabhua
508.	mc_patna	Bettiah
509.	mc_patna	Chappra
510.	mc_patna	Dehri
511.	mc_patna	Dharbanga
512.	mc_patna	Gaya
513.	mc_patna	Muzaffarpur
514.	mc_patna	Jamui
515.	mc_patna	Banka
516.	mc_patna	Begusarai
517.	mc_patna	Arrah
518.	mc_patna	Araria
519.	mc_patna	Arwal
520.	mc_patna	Aurangabad
521.	mc_patna	Katihar
522.	mc_patna	Khagaria
523.	mc_patna	Kishanganj
524.	mc_patna	Lakhisarai

525.	mc_patna	Madhepura
526.	mc_patna	Madhubani
527.	mc_patna	Motihari
528.	mc_patna	Munger
529.	mc_patna	Nalanda
530.	mc_patna	Nawada
531.	mc_patna	Purnea
532.	mc_patna	Rajgir
533.	mc_patna	Saharsa
534.	mc_patna	Samastipur
535.	mc_patna	Sasaram
536.	mc_patna	Sheikhpura
537.	mc_patna	Sheohar
538.	mc_patna	Sitamarhi
539.	mc_patna	Siwan
540.	mc_patna	Supaul
541.	mc_patna	Valmiki Nagar
542.	mc_patna	Patna AP
543.	mc_patna	Patna City
544.	mc_raipur	Ambikapur
545.	mc_raipur	Baikunthpur
546.	mc_raipur	Balod
547.	mc_raipur	Baloda Bazar
548.	mc_raipur	Balrampur
549.	mc_raipur	Bemetara
550.	mc_raipur	Bijapur
551.	mc_raipur	Bilaspur
552.	mc_raipur	Dantewada
553.	mc_raipur	Dhamtari
554.	mc_raipur	Durg
555.	mc_raipur	Gariaband
556.	mc_raipur	Jagdalpur
557.	mc_raipur	Janjgir
558.	mc_raipur	Jashpur
559.	mc_raipur	Kanker
560.	mc_raipur	Kawardha
561.	mc_raipur	Kondagaon
562.	mc_raipur	Korba
563.	mc_raipur	Mahasamund
564.	mc_raipur	Mungeli
565.	mc_raipur	Narayanpur
566.	mc_raipur	Raigarh
567.	mc_raipur	Rajnandgaon
568.	mc_raipur	Sukma

569.	mc_raipur	Surajpur
570.	mc_raipur	Lalpur
571.	mc_raipur	Raipur Mana
572.	mc_raipur	Labhandi
573.	mc_ranchi	Bokaro
574.	mc_ranchi	Chatra
575.	mc_ranchi	Deoghar
576.	mc_ranchi	Dhanbad
577.	mc_ranchi	Dumka
578.	mc_ranchi	Garhwa
579.	mc_ranchi	Giridih
580.	mc_ranchi	Godda
581.	mc_ranchi	Gumla
582.	mc_ranchi	Hazaribag
583.	mc_ranchi	Jamshedpur
584.	mc_ranchi	Jamtara
585.	mc_ranchi	Khunti
586.	mc_ranchi	Koderma
587.	mc_ranchi	Latehar
588.	mc_ranchi	Lohardaga
589.	mc_ranchi	Pakur
590.	mc_ranchi	Palamu
591.	mc_ranchi	West Singhbhum
592.	mc_ranchi	East Singhbhum
593.	mc_ranchi	Ramgarh
594.	mc_ranchi	Ranchi
595.	mc_ranchi	Sahibganj
596.	mc_ranchi	Saraikela Kharsawan
597.	mc_ranchi	Simdega
598.	mc_ranchi	Kanke
599.	mc_shimla	Bilaspur(HP)
600.	mc_shimla	Chamba
601.	mc_shimla	Hamirpur_HP
602.	mc_shimla	Dharamsala
603.	mc_shimla	Keylong
604.	mc_shimla	Mandi
605.	mc_shimla	Shimla City
606.	mc_shimla	Nahan
607.	mc_shimla	Solan
608.	mc_shimla	Una
609.	mc_shimla	Manali
610.	mc_shimla	Dalhousie
611.	mc_shimla	Kalpa
612.	mc_shimla	kangra

613.	mc_shimla	Bhuntar
614.	mc_shimla	Sundernagar
615.	mc_shimla	Baddi
616.	mc_shimla	Dehra Gopipur
617.	mc_shimla	Jogindernagar
618.	mc_shimla	Kaza
619.	mc_shimla	Paonta Sahib
620.	mc_shimla	Pooh
621.	mc_shimla	Sarahan
622.	mc_shimla	Shimla AP
623.	mc_srinagar	Anantnag
624.	mc_srinagar	Baltal
625.	mc_srinagar	Bandipora
626.	mc_srinagar	Banihal
627.	mc_srinagar	Baramulla
628.	mc_srinagar	Batote
629.	mc_srinagar	Budgam
630.	mc_srinagar	Chandanwari
631.	mc_srinagar	Ganderbal
632.	mc_srinagar	Gulmarg
633.	mc_srinagar	Gund
634.	mc_srinagar	Handwara
635.	mc_srinagar	Holy Cave
636.	mc_srinagar	Jammu City
637.	mc_srinagar	Kukernag
638.	mc_srinagar	Kupwara
639.	mc_srinagar	Phalgam
640.	mc_srinagar	Panchtarni
641.	mc_srinagar	Qazigund
642.	mc_srinagar	Sheshnag
643.	mc_srinagar	Shopian
644.	mc_srinagar	Sopore
645.	mc_srinagar	Srinagar City
646.	mc_srinagar	Udhampur
647.	mc_srinagar	Vaishno Devi
648.	mc_srinagar	Jammu AP
649.	mc_srinagar	Leh
650.	mc_srinagar	Srinagar AP
651.	mc_srinagar	Dal Lake
652.	mc_srinagar	Gilgit
653.	mc_srinagar	Skardu
654.	mc_srinagar	Chilas
655.	mc_srinagar	Kharmang
656.	mc_srinagar	Khaplu

657.	mc_srinagar	Hunza
658.	mc_srinagar	Muzaffarabad
659.	mc_srinagar	Shigar
660.	mc_srinagar	Ghizer(Ghakuch)
661.	mc_srinagar	Astore
662.	mc_srinagar	Nagar
663.	mc_srinagar	Mirpur
664.	mc_srinagar	Kotli
665.	mc_srinagar	Hattian(Jhelum Valley)
666.	mc_srinagar	Bagh
667.	mc_srinagar	Bhimbar
668.	mc_srinagar	Nilam
669.	mc_thiruvananthapuram	Alappuzha
670.	mc_thiruvananthapuram	Aryankavu
671.	mc_thiruvananthapuram	Ernakulam
672.	mc_thiruvananthapuram	Kakkanad
673.	mc_thiruvananthapuram	Kochi
674.	mc_thiruvananthapuram	Kollam
675.	mc_thiruvananthapuram	Kottayam
676.	mc_thiruvananthapuram	Kovalam
677.	mc_thiruvananthapuram	Kumarakom
678.	mc_thiruvananthapuram	Kumily
679.	mc_thiruvananthapuram	Munnar
680.	mc_thiruvananthapuram	Painavu
681.	mc_thiruvananthapuram	Pathanamthitta
682.	mc_thiruvananthapuram	Periyar NP
683.	mc_thiruvananthapuram	Ponmudi
684.	mc_thiruvananthapuram	Punalur
685.	mc_thiruvananthapuram	Sabarimala
686.	mc_thiruvananthapuram	Thekkady
687.	mc_thiruvananthapuram	Thiruvananthapuram AP
688.	mc_thiruvananthapuram	Thrissur
689.	mc_thiruvananthapuram	Varkala
690.	mc_thiruvananthapuram	Thiruvananthapuram City
691.	mc_thiruvananthapuram	Palakkad
692.	mc_thiruvananthapuram	Manjeri
693.	mc_thiruvananthapuram	Vythiri
694.	mc_thiruvananthapuram	Kozhikode
695.	mc_thiruvananthapuram	Kannur
696.	mc_thiruvananthapuram	Kudulu
697.	mc_thiruvananthapuram	Agati
698.	mc_thiruvananthapuram	Aminidivi
699.	mc_thiruvananthapuram	Kavarati
700.	mc_thiruvananthapuram	Minicoy

701.	rmc_chennai	Adiramapatinam
702.	rmc_chennai	Ariyalur
703.	rmc_chennai	Meenambakkam AP
704.	rmc_chennai	Coimbatore
705.	rmc_chennai	Coonoor
706.	rmc_chennai	Cuddalore
707.	rmc_chennai	Dharmapuri
708.	rmc_chennai	Dindigul
709.	rmc_chennai	Erode
710.	rmc_chennai	Kanchipuram
711.	rmc_chennai	Kanyakumari
712.	rmc_chennai	Karaikal
713.	rmc_chennai	Karur
714.	rmc_chennai	Karur Paramathi
715.	rmc_chennai	Kodaikanal
716.	rmc_chennai	Kovilangulam
717.	rmc_chennai	Krishnagiri
718.	rmc_chennai	Kudimiamalai
719.	rmc_chennai	Madurai
720.	rmc_chennai	Mahabalipuram
721.	rmc_chennai	Manamelkudi
722.	rmc_chennai	Nagapattinam
723.	rmc_chennai	Namakkal
724.	rmc_chennai	Pamban
725.	rmc_chennai	Perambalur
726.	rmc_chennai	Periakulum
727.	rmc_chennai	Puduchheri
728.	rmc_chennai	Pudukkottai
729.	rmc_chennai	Ramanathapuram
730.	rmc_chennai	Salem
731.	rmc_chennai	Sivaganga
732.	rmc_chennai	Sivakasi
733.	rmc_chennai	Thanjavur
734.	rmc_chennai	The Nilgiris
735.	rmc_chennai	Theni
736.	rmc_chennai	Thiruvarur
737.	rmc_chennai	Thondi
738.	rmc_chennai	Thoothukudi
739.	rmc_chennai	Tiruchirapalli
740.	rmc_chennai	Tirunelveli
741.	rmc_chennai	Tiruppattur
742.	rmc_chennai	Tiruppur
743.	rmc_chennai	Tiruttani
744.	rmc_chennai	Tiruvallur

745.	rmc_chennai	Tiruvannamalai
746.	rmc_chennai	Valparai
747.	rmc_chennai	Vedaranyam
748.	rmc_chennai	Vellore
749.	rmc_chennai	Villupuram
750.	rmc_chennai	Villupuram
751.	rmc_chennai	Virudhunagar
752.	rmc_chennai	Yercaud
753.	rmc_chennai	Nungambakkam
754.	rmc_chennai	Madhavaram
755.	rmc_chennai	Ennore
756.	rmc_guwahati	Cherrapunji
757.	rmc_guwahati	Dhubri
758.	rmc_guwahati	Dibrugarh
759.	rmc_guwahati	Guwahati AP
760.	rmc_guwahati	Jorhat
761.	rmc_guwahati	North Lakhimpur
762.	rmc_guwahati	Shillong
763.	rmc_guwahati	Silchar
764.	rmc_guwahati	Dispur
765.	rmc_guwahati	IIT Guwahati
766.	rmc_guwahati	Itanagar
767.	rmc_kolkata	Alipurduar
768.	rmc_kolkata	Asansol
769.	rmc_kolkata	Bankura
770.	rmc_kolkata	Canning
771.	rmc_kolkata	Chinsura
772.	rmc_kolkata	Contai
773.	rmc_kolkata	Cooch Behar
774.	rmc_kolkata	Darjeeling
775.	rmc_kolkata	Diamond Harbour
776.	rmc_kolkata	Digha
777.	rmc_kolkata	Durgapur
778.	rmc_kolkata	Haldia
779.	rmc_kolkata	Jalpaiguri
780.	rmc_kolkata	Jhargram
781.	rmc_kolkata	Kalimpong
782.	rmc_kolkata	Kolkata AP
783.	rmc_kolkata	Alipore
784.	rmc_kolkata	Krishnanagar
785.	rmc_kolkata	Maldah
786.	rmc_kolkata	Midnapore
787.	rmc_kolkata	Purulia
788.	rmc_kolkata	Raiganj

789.	rmc_kolkata	Sagar Island
790.	rmc_kolkata	Siuri
791.	rmc_kolkata	Sriniketan
792.	rmc_kolkata	Tamluk
793.	rmc_kolkata	Uluberia
794.	rmc_kolkata	Balurghat
795.	rmc_kolkata	Bardhaman
796	rmc_kolkata	Berhampore
797.	rmc_kolkata	Basirhat
798.	rmc_kolkata	Saltlake
799.	rmc_kolkata	Port Blair
800.	rmc_kolkata	Nancowry
801.	rmc_kolkata	Car Nicobar
802.	rmc_kolkata	Maya Bandar
803.	rmc_mumbai	Ahmednagar
804.	rmc_mumbai	Alibag
805.	rmc_mumbai	Baramati
806.	rmc_mumbai	Bhimashankar Reserve
807.	rmc_mumbai	Dahanu
808.	rmc_mumbai	Dapoli
809.	rmc_mumbai	Devgad
810.	rmc_mumbai	Harnai
811.	rmc_mumbai	Jeur
812.	rmc_mumbai	Kalyan
813.	rmc_mumbai	Karad
814.	rmc_mumbai	Khandala
815.	rmc_mumbai	Kolhapur
816.	rmc_mumbai	Mahableshwar
817.	rmc_mumbai	Malegaon
818.	rmc_mumbai	Malvan
819.	rmc_mumbai	Mitbhav Beach
820.	rmc_mumbai	Colaba
821.	rmc_mumbai	Santacruz
822.	rmc_mumbai	Nashik
823.	rmc_mumbai	Raigad Reserve
824.	rmc_mumbai	Ratnagiri
825.	rmc_mumbai	Sangli
826.	rmc_mumbai	Satara
827.	rmc_mumbai	Sawantwadi
828.	rmc_mumbai	Shirdi
829.	rmc_mumbai	Shrirampur
830.	rmc_mumbai	Shriramwadi
831.	rmc_mumbai	Shrivardhan
832.	rmc_mumbai	Sindhudurg

833.	rmc_mumbai	Thane
834.	rmc_mumbai	Vengurla
835.	rmc_mumbai	Vijaydurg
836.	rmc_mumbai	Vikramgad
837.	rmc_mumbai	Borivali
838.	rmc_mumbai	Worli
839.	rmc_mumbai	Powai
840.	rmc_mumbai	Dadra Nagar
841.	rmc_mumbai	Chembur
842.	rmc_mumbai	Mulund
843.	rmc_mumbai	Shivajinagar
844.	rmc_mumbai	Pune Pashan
845.	rmc_mumbai	Lohegaon AP
846.	rmc_nagpur	Buldhana
847.	rmc_nagpur	Akola
848.	rmc_nagpur	Amravati
849.	rmc_nagpur	Bhandara
850.	rmc_nagpur	Brahmapuri
851.	rmc_nagpur	Chandrapur
852.	rmc_nagpur	Gadchiroli
853.	rmc_nagpur	Gondia
854.	rmc_nagpur	Wardha
855.	rmc_nagpur	Washim
856.	rmc_nagpur	Yeotmal
857.	rmc_nagpur	Sonegaon AP
858.	rmc_nagpur	CoA Nagpur
859.	rmc_nagpur	Pusad
860.	rmc_nagpur	Hinganghat
861.	rmc_nagpur	Katol
862.	rmc_nagpur	Ramtek
863.	rmc_newdelhi	Agra
864.	rmc_newdelhi	Aligarh
865.	rmc_newdelhi	Delhi PLM AP
866.	rmc_newdelhi	Delhi SFD
867.	rmc_newdelhi	Gurgaon
868.	rmc_newdelhi	Hissar
869.	rmc_newdelhi	Karnal
870.	rmc_newdelhi	Mathura
871.	rmc_newdelhi	Meerut
872.	rmc_newdelhi	Noida
873.	rmc_newdelhi	Rohtak
874.	rmc_newdelhi	Bulandshahr
875.	rmc_newdelhi	Ghaziabad
876.	rmc_newdelhi	Hapur

877.	rmc_newdelhi	Hathras
878.	rmc_newdelhi	Moradabad
879.	rmc_newdelhi	Muzaffarnagar
880.	rmc_newdelhi	Shamli
881.	rmc_newdelhi	Ayanagar
882.	rmc_newdelhi	Narela
883.	rmc_newdelhi	Ridge
884.	rmc_newdelhi	DU North Campus
885.	rmc_newdelhi	Jind
886.	rmc_newdelhi	CharkhiDadri
887.	rmc_newdelhi	Faridabad
888.	rmc_newdelhi	Jhajjar
889.	rmc_newdelhi	Narnaul
890.	rmc_newdelhi	Nuh
891.	rmc_newdelhi	Palwal
892.	rmc_newdelhi	Panipat
893.	rmc_newdelhi	Rewari
894.	rmc_newdelhi	Sonipat

Appendix 2

Impact, Hazard and Response Matrix for Heavy Rainfall

Very Low Impact	Low Impact	Medium Impact	High Impact
Business as Usual	Localized = Single District Municipality affected Business as usual	Localized = Single District Municipality affected Short term strain on emergency personnel	Widespread = Multiple Districts affected Prolonged strain on emergency personnel
Some pooling of water on roads or in rural settlements Day to day activities not disturbed Wet roads Minimal traffic congestion Isolated mudslides and rock falls	Localized flooding of susceptible informal settlements or roads, low lying areas and bridges Localized and short term disruption to municipal services (water, electricity, etc.) Major roads affected but can be used, increased travel times Minor motor vehicle accidents due to slippery roads Closure of roads crossing low water bridges Localized mudslides and rock falls	Flooding of roads and settlements (formal and informal) Disruption to municipal services (water, electricity, etc.) Major disruption of traffic flow due to major roads being flooded or closed Possible damage to roads and bridges Danger to life (fast flowing streams I deep water) Some communities temporarily not accessible/ cut-off Displacement of affected communities Damage to property, infrastructure and loss of livelihood Mudslides and rock falls	Widespread flooding of roads and settlements Widespread, prolonged disruption to municipal services (water, electricity, etc.) Widespread transport routes and travel services severely affected Major roads and bridges damaged or washed away Danger to life (fast flowing streams I deep water) Large communities not accessible/cut-off for a prolonged period Widespread displacement of affected communities Widespread damage to property, buildings and loss of livelihoods Widespread mudslides and rock falls

Damages associated with thunderstorms and associated phenomena

Category/ Wind Speed	Structures	Communica tion & Power	Agriculture	Suggested Actions
Light Thunderst orm <41 kmph (21 knots)	Nil	Nil	Nil	Nil
Moderate Thunderst orms 41 – 61 kmph (22-33 knots)	Minor damage to loose / unsecured structures	Nil	Minor damage to Banana trees. Damage to ripe paddy crops.	People are advised to keep a watch on the weather for worsening conditions and be ready to move to safer places accordingly.

Severe Thunderstorms 62 -87 kmph (34 -47 knots)	Damage to thatched huts.	Minor damage to power and communication lines due to breaking of branches.	Some damage to paddy crops, banana, papaya trees and orchards and Standing crops.	People are advised to take shelter in pukka structures and avoid taking shelter under trees. Farming operations to be temporarily suspended during occurrence of event. Also move away from electric poles and wires.
Very Severe Thunderstorms Greater than 87 kmph {(47Kt) in gusts/ squall}	Major damage to thatched houses/ huts. Roof tops may blow off. Unattached metal sheets may fly.	Minor damage to power and communication lines.	Breaking of tree branches, uprooting of large avenue trees. Moderate damage to banana and papaya trees. Large dead limbs blown from trees. Damage to Standing crops.	People are advised to stay away from weak walls and structures and take shelter in pukka structures. People in affected areas to remain indoors and avoid water bodies and flying projectiles. Farming operations to be temporarily suspended during occurrence of event.
Thunderstorm associated with Hailstorm	Major damage to Kutcha structures and tin and asbestos roofed houses, cars		The fruit, vegetable and field crops at maturity stages are more prone to damage. Damage to Standing crops.	People are advised to stay away from weak walls and structures and take shelter in pukka structures. People in affected areas to remain indoors.

Actions to be taken for Lightning

- Postpone outdoor activities.
- Remember the 30/30 Lightning Safety Rule: Go indoors if, after seeing lightning, you cannot count to 30 before hearing thunder. Stay indoors for 30 minutes after hearing the last clap of thunder.
- If out in the open, DO NOT take shelter under a tree.
- Get out of water. This includes getting all small boats out of water and get out of pools, lakes, water bodies.
- If working in an outdoor watery area (e.g. paddy transplantation etc), immediately move out of the field to a dry area (at least to the field border).
- Get inside a pukka home, pukka building, or hard top automobile (not a convertible or open truck) with doors and windows closed.
- Stay away from windows and doors and stay off verandas. Close windows and secure outside doors.
- Avoid contact with electrical equipment and landline telephone. Unplug any electronic equipment well before the storm arrives.
- Avoid contact with plumbing and metal pipes. Do not wash hands, do not take a shower, do not wash utensils and do not wash clothes.
- If you have insulation like a foam pad or a sack, put it underneath you.
- If no shelter is available, immediately get into **the lightning crouch** : (Squat or sit in a tight ball, arms wrapped around your legs. Keep your feet together (touching), head lowered, ears covered, and eyes closed. This makes you as small a target as possible. <u>Do NOT lie down.)</u>

Appendix 3

1. **Nowcast Model SWIRLS**

Link : http://srf.tropmet.res.in/srf/ts_prediction_system/index.php

Description:Through analyzing radar echoes in two successive radar scans, SWIRLS computes the direction and speed of movement of rain areas to obtain information for the distribution of high-resolution radar echo motion distribution.

2. Mosaic of Radar Reflectivity and winds, superposed by Satellite, Lightning and other data on GIS platform

Link : http://ddgmui.imd.gov.in/radar/leaflet-map-csv-master/mosaic.php

Description:Interactive GIS with user select able overlay of products from Radar, Satellite and Lightning in real time for combined analysis

3. INSAT 3D Satellite data superposed by Lightning and Radar Reflectivity of individual radars superposed by Lightning

Link : http://www.imd.gov.in/section/satmet/lightning/

Description:Superposition of INSAT 3D brightness temperature (latest available image) with Lightning data (from IAF, IITM and LMI network) and Superposition of individual Radar CAPPI image (animated for the last one hour) with lightning data

4. Meteosat Satellite data superposed by Lightning

Link : http://foreignsat.imd.gov.in/

Description:Superposition of Meteosat satellite brightness temperature (latest available image) with Lightning data (from IAF and LMI network) provides snapshot information of movement of major lightning areas across the Indian region

5. IMD hosting EUMETCAST images

Link : http://foreignsat.imd.gov.in/

Description:EUMETCAST products are made available in the website with detailed guide on the interpretation of the products.

6. SCOPE nowcasting

Link : http://sigma.cptec.inpe.br/scope/

Description: SCOPE Nowcast system provides extrapolation based on rainfall areas upto next three hours based on HydroTrack , which is similar to ForTrACC technique

7. INSAT-3D based nowcasting

Link : http://www.rapid.imd.gov.in/

Description: INSAT-3D based nowcasting provides extrapolation based on Brightness temperature upto next three hours based on HydroTrack , which is similar to ForTrACC technique

8. GNSS Integrated Precipitable Water Vapour

Link : http://gnss.imd.gov.in/TrimblePivotWeb/MemberPages/AtmosphericConditions/IpwvMap.aspx

Description: The GNSS-Met system provides four meteorological variables such as Pressure, temperature, humidity and integrated precipitable water vapour (IPWV) in real time. The IPWV data is updated every 15 min interval and met data are updated every min

9. NCMRWF-NCUM model Severe weather products

Link : https://www.ncmrwf.gov.in/product_main_ind_mihir.php https://www.ncmrwf.gov.in/latest_charts.php#

Description: NCUM 4km regional model products upto 72 hours ahead are aimed to aid the prediction of severe weather associated with thunderstorms over the Indian region.

10. ITM GFS model based Severe weather products

Link : http://srf.tropmet.res.in/srf/hires_gefs/gfs_based.php

Description: IITM GEFS model products upto 72 hrs ahead are aimed to aid the prediction of severe weather associated with thunderstorms over the Indian region

11. ITM WRF model based LPI Lightning products.

Link : http://srf.tropmet.res.in/srf/lpi/index.php
Description: Threat of Lightning occurrence (as given by Lightning Potential Index) for upto 48 hours ahead at three hour intervals is provided based on WRF Model

12. ITM WRF model with DLP scheme based Lightning products
Link : http://srf.tropmet.res.in/srf/lightening_flash/index.php
Description: Frequency of Lightning occurrence for upto 48 hours ahead at three hour intervals is provided based on WRF Model

13. IMD GFS model products
Link : http://nwp.imd.gov.in/diagpro_new.php
Description: In addition to GFS basic products on the IMD website, additional diagnostic parameters which are derived are also made available

14. IMD WRF model products
Link : http://nwp.imd.gov.in/wrfhrl_products.php
Description: In addition to WRF basic products on the IMD website, additional Hourly Reflectivity Values and Storm Relative Helicity over the Indian region

15. Tropical tidbits
Link : https://www.tropicaltidbits.com/analysis/models/model=gfs&region=io&pkg=mslp_pcpn_frzn&run
Description: Provides model forecasts from various global models including NCEP GFS group, ECMWF, JMA which allows observers an alternate access to various model forecasts to reach a decision about likely weather

16. Windytv
Link : https://www.windy.com/
Description: It provides easy comparison of various model forecast fields from two very important models: GFS and ECMWF. Forecaster can easily compare the location of rainfall and other parameters in the two models and reach an objective decision

17. ECMWF products
Link : https://www.ecmwf.int/en/forecasts/charts
Description: This provides many model products that are very useful to forecasters, including precipitation for the Indian region

18. Model Forecasts:EFI
Link : http://gpvjma.ccs.hpcc.jp/TIGGE/tigge_warning.html
Description: The Extreme Forecast Index is computed for many weather parameters, for different forecast ranges and accumulation periods.

19. Model Forecasts: EFI from NCMRWF
Link : https://www.ncmrwf.gov.in/product_grid_cvr_mihir.php
Description: The Extreme Forecast Index is computed for many weather parameters, for different forecast ranges and accumulation periods from NCUM Unified model and generated by NCMRWF

20. R-Alert
Link : Available internally at Radar stations
Description: Fully automatic Radar based location specific short term severe weather Alerting system

Appendix 4

Format for issue of Severe weather Nowcast in TEXT format

Time of issue.....
Validity time:.....................
Thunderstorms accompanied by .... are currently occurring in .... districts.
............(e.g. Thunderstorm/Dust storm etc.) ....likely to affect .... Districts ....within next ..... hours. It may be accompanied with ....and strong winds reaching ....kmph or more.
Visibility may reduce to below ....metres during the period.

Rainfall amount ......occurred in .... in last ....hours.
.... (light/ moderate/ heavy) rainfall likely to affect ...... District/ ....within next ..... hours.
During the period of weather, (***IMPACT Dos and Donts***)
Warning in local language if possible

Signature

To: User1,
User2

Appendix 5

Sample Nowcast Bulletins

Met Center……..

India Meteorological Department
Ministry of Earth Sciences
3 HOURLY UPDATE OF ONGOING MUMBAI HEAVY RAINFALL EVENT
WARNING NO. 1
DATE: 20-07-2020 TIME OF ISSUE: *12:00 HRS IST*

DATE/TIME (IST) OF OBSERVATION	**11:30 HRS IST OF 20-07-2020 / 06:00 UTC OF 20.07.2020**
Rainfall realized **a)**RAINFALL REPORTS LAST 3-HOURS FOR TIME ENDING AT 11:30 IST OF TODAY **b)**CUMULATIVE SINCE RAIN EVENT STARTED AROUND 08:30 IST OF TODAY)	STATION NAME WITH TYPE(AWS/SYNOP IMD, ARG, SRG) AND RAINFALL AMOUNTS
Forecast or nowcast	As per latest observations, Satacruz and Andheri areas have Very intense convective clouds which has the potential to cause heavy to very heavy rainfall during next ………hrs / during ………… To ……. Hours. and it is likely to last next 2-3 hours causing rainfall likely of 6-12cm in 3- hours.
Impact expected	The impact expected has to be issued with respect to the occurring severe weather event.
Action Suggested	

Next bulletin will be issued at 09:30 UTC(15:00 IST)
Figure 1 Figure of current observations over map (if available)
Figure 2 RADAR products over map with location details of the city
Figure 3 Satellite Images zoomed over a region for the city

[02/07, 4:11 AM] +91 6386 988 208:

Sir/Madam,
Rain/Thundershowers and Lightning are very likely to occur today during next three hours (valid up to 07:10 hrs. IST) at few places over Saharanpur, Muzaffarnagar, Bijnor, Balrampur, Bahraich, Lakhimpur Kheri, Prayagraj, Lalitpur district and adjoining areas.

Meteorological Centre
Lucknow-226009
Date: 02/07/2020

##
[11/07, 2:21 PM] +91 81350 06792: Nowcast Bulletin
Date: 11/07/2020
Time of issue: 14:10 IST
Thunderstorms & Lightning accompanied with moderate to heavy spell of rainfall is very likely to affect parts of GOALPARA districts during next 1/2 to 3 hours.
PROBABLE IMPACT: Water logging in low lying areas..

Regional Weather Forecasting Centre,
Regional Meteorological Centre, Guwahati
[11/07, 2:26 PM] +91 94354 90381:

অহা তিনি ঘণ্টাৰ বতৰৰ আগজাননী /সতৰ্কবাণী সূচনা
তাৰিখ: ১১/০৭/২০২০। সময়: ১৪:১০ ভাৰতীয় সময় --। অহা আধা ঘণ্টাৰ পৰা তিনি ঘণ্টাৰ ভিতৰত ধুবুৰী, দক্ষিণ শালমাৰা, কোকৰাঝাৰ আৰু বাক্সা জিলাত বিজুলী ঢেৰেকনিৰ লগতে মজলীয়া পৰা দবপটীয়া বৰষুণ হোৱাৰ সম্ভাৱনা ।
সাম্ভাব্য প্ৰভাৱ: চাপৰ ঠাইবোৰত পানী জমা হ'ব পাৰে।

আঞ্চলিক বতৰ বিজ্ঞান কেন্দ্ৰ, গুৱাহাটী
##

Weather Section Hyderabad (+917901090675) sent: In view of the thunderstorm and hail storm occurrences over Telangana State. District levels officers/SDMA are requested to intimate the above information if it comes to your notice (place, date and approximate time) through weather group whatsapp.

తెలంగాణ రాష్ట్రంలో ఉరుములు మరియు వడగండ్ల వర్షం వంటి వాతావరణ పరిస్థితులు ఏర్పడినప్పుడు అవి ఏర్పడిన ప్రదేశం , తేదీ, సమయం (సుమారుగా) వంటి సమాచారం మీ దృష్టికి వచ్చినచో వాతావరణానికి సంబంధించిన ఈ గ్రూపులో . పోస్ట్ చేయగలరని మనవి.
for Director I/C & Head,
Meteorological Centre, Hyderabad(IMD).

भारत सरकार
भारतमौसमविज्ञानविभाग
मौसम विज्ञान केंद्र अनिशाबाद पटना
बिहार पिन कोड- 800002

GOVERNMENT OF INDIA
INDIA METEOROLOGICAL DEPARTMENT
METEOROLOGICAL CENTRE, ANISHABAD,
PATNA, BIHAR PIN CODE:-800002

दूरभाष/Telephone:0612-2252356/2251867/2222071;फैक्स/Fax: 0612-2252356/2222071
ई-मेल (e-mail) : patnamc@gmail.com,wspatna@gmail.com

DATE: 02.07.2020 TIME OF ISSUE: 02:32 IST

तात्कालिक मौसम चेतावनी/NOWCAST WEATHER WARNING

वर्तमान रेडार/उपग्रह एवं अन्य प्रेक्षण के अनुसार **पश्चिम चम्पारण,गोपालगंज** जिले के कुछ भागों में अगले दो से तीन घंटों में (दिनांक 02.07.2020 को भा.मा.स **03:00** बजे से) मेघ-गर्जन/वज्रपात,बिजली के साथ हल्की से मध्यम वर्षा होने की संभावना है।

Latest Radar/Satellite observations indicate that Thunderstorm, Lightning accompanied with Light to Moderate rain is very likely to affect some parts of the districts of **WEST CHAMPARAN,GOPALGANJ** during next 2-3 hours from **03:00** Hrs IST of today dated **02.07.2020**.

Doppler Weather Radar
Anisabad, Patna 800002.
Phone +91 612 2252356
Fax +91 612 2222071

Chapter 10

Multi-Hazard Early Warning System

10.1. Introduction

India is vulnerable, in varying degrees, to many disasters. More than 58.6 per cent of the landmass is prone to earthquakes of moderate to very high intensity; over 40 million hectares (12%) of its land is prone to floods and river erosion; close to 5,700 kms, out of the 7,516 kms long coastline is prone to Cyclones and Tsunamis; 68% of its cultivable area is vulnerable to droughts; and its hilly areas are at risk from landslides and avalanches. Apart from these natural hazards, we need to know about the other manmade hazards which are frequent and cause huge damage to life and property. It is therefore important that we are aware of how to cope with their effects.

India Meteorological Department (IMD) issue weather warnings when hazardous weather is expected. Often, one type of weather event would lead to multiple hazards, sometimes once weather associated hazard would trigger another one or even two or more types of hazards co-exist. Also we are now incorporating the possible impacts, which a potential weather hazard can cause over an area. Hence prior to discussing the SOP on Multi-Hazard weather warnings, we need to understand the meanings of certain important terms like ‘Disaster, Hazard, Vulnerability & Risk’.

10.1.1. Disaster

A disaster can be defined as a “A serious disruption in the functioning of the community or a society causing wide spread material, economic, social or environmental losses which exceed the ability of the affected society to cope using its own resources”.

A disaster is a result from the combination of hazard, vulnerability and insufficient capacity or measures to reduce the potential chances of risk.

A disaster happens when a hazard impact on the vulnerable population and causes damage, casualties and disruption of their properties and activities. Thus, disaster occurs only when hazards and vulnerability meet. But it is also to be noted that with greater capacity of the individual/community and environment to face these disasters, the impact of a hazard reduces. The interrelation between the three major components namely hazard, vulnerability and capacity are given in the Fig. 10.1. below.

10.1.2. Hazard

Hazard may be defined as “a dangerous condition or even, that threat or have the potential for causing injury to life or damage to property or the environment.” Hazards can be grouped into two broad categories namely natural and manmade.

1. Natural hazards are hazards which are caused because of natural phenomena (hazards with meteorological, geological or even biological origin).

2. Manmade hazards are hazards which are due to human negligence.

The list of hazards is very long. Many occur frequently while others take place occasionally. However, on the basis of their genesis, they can be categorized as discussed in Table 10.1

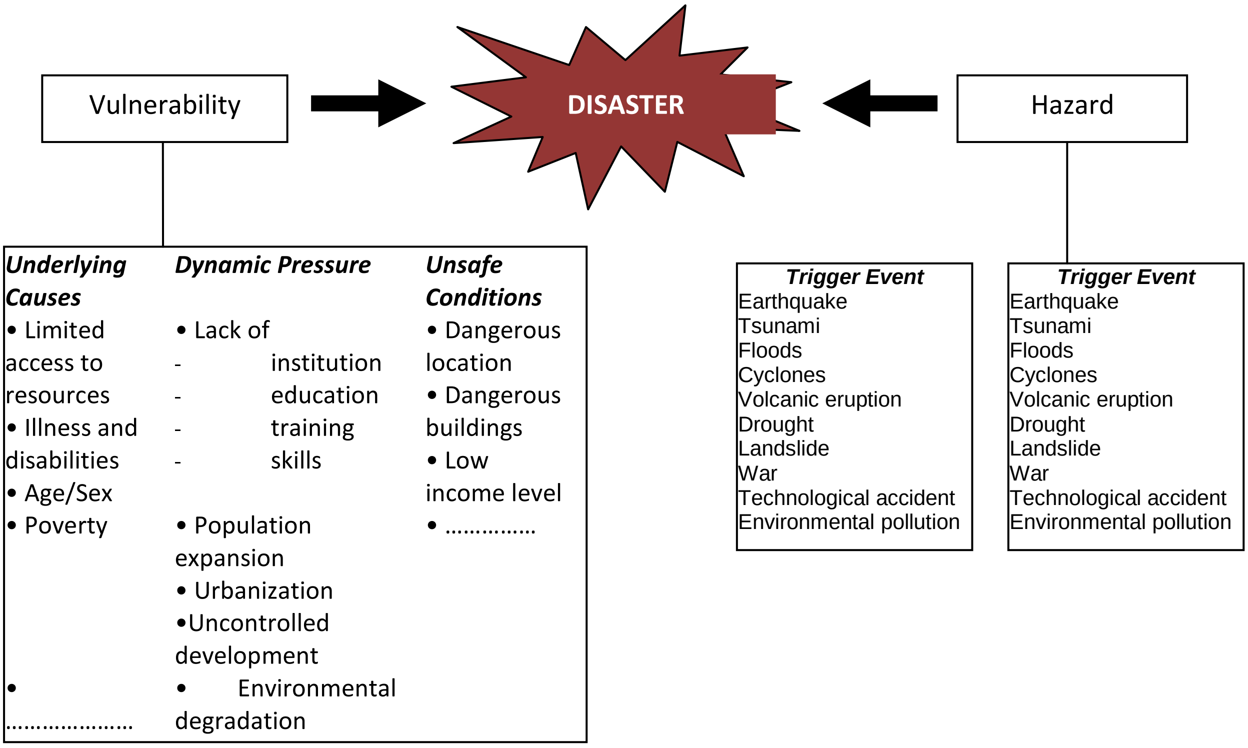


Figure 10.1. Interrelation between vulnerability, disaster and hazard

10.1.3. Vulnerability

Vulnerability may be defined as "The extent to which a community, structure, services or geographic area is likely to be damaged or disrupted by the impact of particular hazard, on account of their nature, construction and proximity to hazardous terrains or a disaster prone area.

Vulnerability can be categorized into physical and socio-economic vulnerability.

10.1.4. Risk

Risk is a "measure of the expected losses due to a hazard event occurring in a given area over a specific time period. Risk is a function of the probability of a particular hazardous event and the losses each would cause." The level of risk depends upon:

❖ Nature of the hazard

❖ Vulnerability of the elements which are affected

❖ Economic value of those elements

Table 10.1

Various types of hazards

Types	Hazards	
Geological Hazards	1. Earthquake 2. Tsunami 3. Volcanic eruption	4. Landslide 5. Dam burst 6. Mine Fire
Weather, Water & Climatic Hazards	1. Tropical Cyclone 2. Tornado and Hurricane 3. Floods 4. Drought 5. Hailstorm	6. Cloudburst 7. Landslide 8. Heat & Cold wave 9. Snow Avalanche 10. Sea erosion
Environmental Hazards	1. Environmental pollution 2. Deforestation	3. Desertification 4. Pest Infection
Biological	1. Human/Animal Epidemics 2. Pest attacks	3. Floods poisoning 4. Weapons of Mass Destruction
Chemical, Industrial and Nuclear Accidents	1. Chemical disasters 2. Industrial disasters	3. Oil spills/Fires 4. Nuclear
Accident related	1. Boat/Road/Train accidents/air crash Rural/ Urban fires Bomb/serial bomb blasts 2. Forest fires	3. Building collapse 4. Electric Accidents 5. Festival related disasters 6. Mine flooding

A community/locality is said to be at 'risk' when it is exposed to hazards and is likely to be adversely affected by its impact. Disaster risk management includes all measures which reduce disaster related losses of life, property or assets by either reducing the hazard or vulnerability of the elements at risk.

10.1.5. Multi-Hazard Forewarning and Impact Assessment

Disaster risk management consists of three broad activities- mitigation, preparedness and early warning. Early warning consists of hazard forecasts, communication and dissemination.

IMD contributes to risk management in three ways. Firstly, we provide early warning of weather, water and climate hazards for operational decisions; secondly we support risk and impact assessments to determine who and what is at risk and why; and thirdly, we work hard to improve forecasts and analyses to help reduce or prevent risks on continuous basis.

10.1.6. Multi-hazard Warning System to Strengthen disaster preparedness

At times of disaster, impacts and losses can be substantially reduced if authorities, individuals and communities in hazard-prone areas are well warned with a user friendly and easily understandable 'Multi-hazard warning System'.

IMD has been providing a variety of meteorological warnings through its general forecasting system presently in existence. The forecasting centres at RMC/ MC s are providing necessary forecasts to all the users. But owing to the improvements in the forecasting & dissemination system, there is a need to revise the existing Standard Operating Procedure (SOP) on various types of hazards like thunderstorms, squall lines, gale winds, snow storms, hail storms etc that cause severe and wide spread damages to men and material. Hence the SOP document on Multi-Hazard system has been revised for a comprehensive monitoring, displaying and reporting system on all possible meteorological hazards, including cyclones, so that no hazard goes un-reported.

The following are the major weather hazards dealt with in this Chapter.

1.	**Heavy Rain / Heavy Snow**
2.	**Thunderstorm / squall / hail / Lightning** (combination of)
3.	**Coastal risks (port warnings)**
4.	**Dangerous Sea (Fishermen warnings)**
5.	**Heat wave**
6.	**Cold wave**
7.	**Fog**
8.	**Tropical Cyclone**

10.2. Warning Thresholds

Various thresholds are already in use for various types of hazards in the department. In reality the thresholds need a revision in view of the hazard realization/ damage potential in a particular region, due to the terrain and environment of a given region, population density, urbanization, infra-structure, industries and expensive investments, standing crops at the time of occurrence etc. Prioritization of phenomena is not possible for the country as whole as each hazard has its own importance for an individual region. Places where mitigation actions are possible and need urgent action are generally given higher priority.

10.2.1. Heavy Rainfall

Existing criteria for the country as a whole are as follows.

Table 10.2.

Criteria for heavy rainfall

Heavy rain	64.5-115.5 mm/ 24 hrs
Very heavy rain	115.6 -204.4 mm/ 24 hrs
Extremely heavy rain	Greater than or equal to 204.5 mm/ 24 hrs
Exceptionally Heavy Rainfall	When the amount is a value near about the highest recorded rainfall at or near the station for the month or season. However, this term will be used only when the actual rainfall amount exceeds 12 cm.

Places in north-east are on various hilly slopes and smaller cities on east and west coast are in close proximity to the eastern and western ghats that serve as rapid draining mechanisms into the open seas. But plain areas like Gangetic plains and mega cities without proper drain arrangements like Chennai suffer severely even for smaller amount of rains.

10.2.2. Thunder storm/ squall

Thunderstorm/ squall are phenomena associated with summer season, low pressure systems, cyclones, and sometimes local weather systems.

There is a separate SOP for issue of warnings regardingthe hazards of Thunderstorm/Squall. To add to other inputs like NWP, known TS genesis and track climatology has to be generated season wise based on Radar observations to assist the Hazard analysis of Thunderstorms.

10.2.3. Heat Wave

Existing Criteria for heat wave are as follows.

Table 10.3.

Criteria for Heat wave

1)Heat wave is considered if maximum temperature of a station reaches at least 40^0C Or more for Plains and at least 30^0C or more for Hilly regions.	
a) Based on Departure from Normal Heat Wave Severe Heat Wave	 Departure from normal is 4.5^0C to 6.4^0C Departure from normal is >6.4^0C
b)Based on Actual Maximum Temperature Heat Wave Severe Heat Wave	 When actual maximum temperature ≥ 45^0C When actual maximum temperature ≥47^0C
2)Heat Wave for coastal stations:	When maximum temperature departure is 4.5 ^{0}C or more from normal, Heat Wave may be described provided actual maximum temperature is 37^0C or more.
3)Warm night :It should be considered only when maximum temperature remains 40^0C or more. It may be defined based on departures or actual minimum temperatures as follows:	
Warm night :	minimum temperature departure is 4.5^0C to 6.4^0C
Very warm night :	minimum temperature departure is >6.4^0C

10.2.4. Cold Wave

Existing Criteria for cold wave is as follows.

Table 10.4.

Criteria for Cold wave

1) 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.	
a) Based on Departure from Normal Cold Wave Severe Cold Wave	 Negative departure from normal is 4.5^0C to 6.4^0C Negative departure from normal is >6.4^0C
b) Based on Actual Maximum Temperature Cold wave Severe Cold Wave	 When actual minimum temperature ≥ 04^0C When actual minimum temperature is ≤ 02°C
“Cold Wave” 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.
2) Cold Day *In the plains of north India, foggy conditions prevail during winter for several days or weeks. The minimum temperature on these days remains above normal, while maximum temperature remains much below normal. This creates cold conditions for prolonged period. To cover such situations the concept of “cold day” is introduced.*It should be considered when minimum temperature is 10^0C or less for plains and 0°C or less for Hilly regions	
Cold day: Severe Cold day:	Maximum Temperature Departure is -4.5°C to -6.4°C Maximum Temperature Departure is < -6.4°C

10.2.5. Cyclone

The categorization of cyclone warning is given below in Table 8.5

Table 10.5.

Categorization of Cyclone Warning Bulletins

Category	Description	Stage
Cyclone Alert	Issued at least 48 hours before the commencement of bad weather when a system is located about 500 Km or more away from the coast. The forecast may not contain information about landfall and hence it is still of informatory type but at the same time meant to trigger preparatory actions. During this stage, Disaster Managers plan on the course on action required to be initiated once the system moves closer to the coast.	Yellow
Cyclone Warning	These messages are issued 24 hours before commencement of bad weather and are of a "serious nature". During this stage the system is monitored closely and the expected place and time of landfall and the districts along the coastal areas likely to be affected are clearly indicated in the warning messages. The location of the system at this stage may still be 300 km – 500 Km away from the coast. Disaster Management Machinery is expected to be geared up fully during this phase.	Orange
Post landfall outlook:	During this phase warning messages are issued about 12 hours before actual landfall and are of a "very serious nature". At this stage, it is expected that the Disaster Management Machinery is in full operational mode to face the impending disaster. All preparedness action should have been completed by this time. MHA would be closely monitoring steps taken by the concerned State Governments regarding evacuation and relief activities like food, sanitation etc. This phase is fit to be classified as "Great Danger" and all warning messages issued to MHA Control Room are required to be forwarded to senior officials of the PMO.	Red

10.2.6. Port Warnings

Port warnings are issued by ACWCs and CWCs at different locations along Indian coast. By definition and order of priority the port warnings gives risk level in an increasing order. It is easy to decode and to use them in an effective way.

DC1 and DW2 – Indicative of a depression or cyclone at a distance in sea without any immediate weather over the indicated port

LC3 and LW4 -- Indicative of a depression or cyclone at a distance in sea with likely squally weather over the indicated port

D5, D6, D7 -- Presence of a cyclone that is likely to affect the port in the increasing order of number

GD8, GD9, GD10 -- Presence of a severe cyclone and above that is likely to affect the port in the increasing order of number

NUMBER XI – Communication with the forecasting office is lost for any reason but bad weather is expected. (Irrelevant in the present communication scenario)

It can surely be decided that DC1 and DW2 indicate no bad weathersituation, LC3 and LW4 indicate an alert situation, D5, D6, D7 indicate an alarm situationand GD8, GD9, GD10 indicate a higher alarm situation.

10.2.7. Fishermen warning

Fishermen warnings are issued by Cyclone Warning Centres based on two criteria.

a) In the presence of low pressure systems below the intensity of depression on in the case of strong Monsoon conditions or when squally weather is expected with the wind speed more than 45 kmph is expected fishermen are advised not to venture into the sea.

b) High Wave /Swell criterion: If the high waves/ swell waves (wave /swell wave / with significant wave height of 4.0m or more corresponding to very rough sea conditions) are forecast by INCOIS, then fishermen are advised not to venture into the sea.

Fishermen warnings are issued with a validity period of five days.

10.3. Multi hazard Warning System

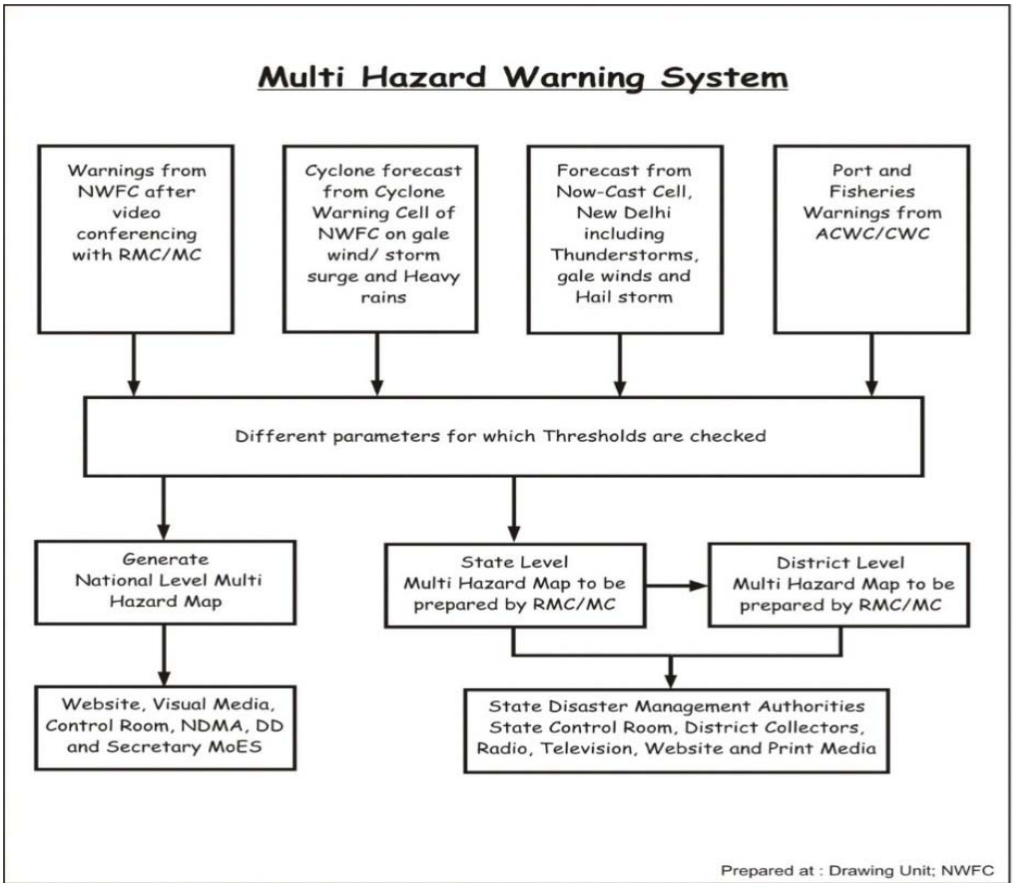


Figure 10.2. Multi hazard Warning System flow chart

The flow chart showing different action of various offices/agencies is shown in Fig. 8.2

10.3.1. Activity chart of Multi-hazard Warning Centre.

After the Video-conferencing with different forecasting offices of NWFC and SWFCs the Chart is prepared in the following format based on finalised warning bulletins by various offices.

Four colour codes of various hazardous conditions are generated as shown below

Table 10.6.

Colour coding for hazardous conditions

Level 1	Green	No particular awareness required
Level 2	Yellow	Potentially dangerous, but not unusual
Level 3	Orange	Potentially dangerous and unusual phenomena
Level 4	Red	Particularly dangerous and intense meteorological phenomena (extreme event)

The colour codes for various types of warnings are given in Table 10.6.

Table 10.7.

Actual Hazard Data flow

HAZARD	COLOUR CODE WITH EQUIVALENT MESSAGE	CONDITIONS TO FULFILL
Heavy Rainfall/ snowfall	No heavy rainfall	Less than 70 mm/hr
	heavy	64.5-115.5 mm/ 24 hrs
	Very heavy	115.6 -204.4 mm/ 24 hrs
	Exceptionally heavy	Greater than or equal to 204.5 mm/ 24 hrs
Thunder storm/squall/ hailstorm	No TS	No Thunderstorm
	Light TS	Thunderstorms with maximum surface wind speed less than 40 kmph (In gusts)
	Moderate TS	Thunderstorms with maximum surface wind speed 41 – 61 kmph (In gusts / squall).
	Severe TS	Thunderstorms with maximum surface wind speed 62 -87 kmph (In gusts/ squall).
	Very Severe TS	Thunderstorms with or without rain with maximum surface wind speed greater than 88 kmph (in gusts/ squall).
	Hailstorm	Severe thunderstorm with hail
Duststorm	No dust storm	No dust storm
	Light dust storm	If the wind speed is up to 40 kmph and visibility is less than 1,000 metres but more than 500 meters
	Moderate dust storm:	If the wind speed is up to 40 kmph and visibility is less than 1,000 metres but more than 500 meters
	Severe dust storm	If surface wind speed (in gusts) is between 62 - 87 kmph (In gusts) and visibility is less than 200 metres
	Very Severe dust storm	If surface wind speed (in gusts) exceeds 88 kmph (In gusts) and visibility is less than 200 metres

Heat Wave		Normal Temperatures	No Heat wave conditions
Heat Wave		Hot day conditions	Hot day conditions and no Heat wave
Heat Wave		Heat wave	Heat wave conditions
Heat Wave		Severe Heat Wave	Severe Heat Wave conditions
Cold Wave		Normal Temperatures	No Cold wave conditions
Cold Wave		Cold day conditions	Cold day conditions and no Cold wave
Cold Wave		Cold wave	Cold wave conditions
Cold Wave		Severe Cold Wave	Severe Cold Wave conditions
Port Warning		DC1 and DW2	Alert type message
Port Warning		LC3 and LW4	Warning Message No danger
Port Warning		D5, D6, D7	Danger message – danger expected
Port Warning		GD8, GD9, GD10	Great Danger Message – Severe damages expected
Fishermen Warning		No warning	Wind speed below45 kmph
Fishermen Warning		Alert	Wind speed 45 to 50 kmph
Fishermen Warning		Warning	Wind speed 50 kmph sea rough
Fishermen Warning		Warning	Wind speed 63 kmph sea rough to very rough
Fog (Visibility)		No Fog	Visibility greater than 1000 metres
Fog (Visibility)		Shallow Fog	Visibility 500 -- 1000 metres
Fog (Visibility)		Moderate Fog	Visibility 200 -- 500 metres
Fog (Visibility)		Dense Fog	Visibility less than 200 metres
CYCLONE	Heavy Rains	No heavy rainfall	Less than 60 mm/ 24 hrs
CYCLONE	Heavy Rains	Heavy	64.5-115.5 mm/ 24 hrs
CYCLONE	Heavy Rains	Very heavy	115.6 -204.4 mm/ 24 hrs
CYCLONE	Heavy Rains	Extremely heavy	Greater than or equal to 204.5 mm/ 24 hrs
CYCLONE	Storm Surge	No Warning	Less than 0.5 metres
CYCLONE	Storm Surge	Low level	Upto 1 meter
CYCLONE	Storm Surge	Moderate level	1 to 2.5 metres
CYCLONE	Storm Surge	High level	More than 2.5 metres
CYCLONE	Gale Winds	Squally winds	Less than 62 kmph
CYCLONE	Gale Winds	Gale Winds	62-89 kmph
CYCLONE	Gale Winds	Moderate Gales	90-119 kmph
CYCLONE	Gale Winds	Very high Gales	120 kmph and more

The national level and state level pictorial presentation of multi-hazard warnings are shown in Fig. 10.3 and 10.4 respectively.

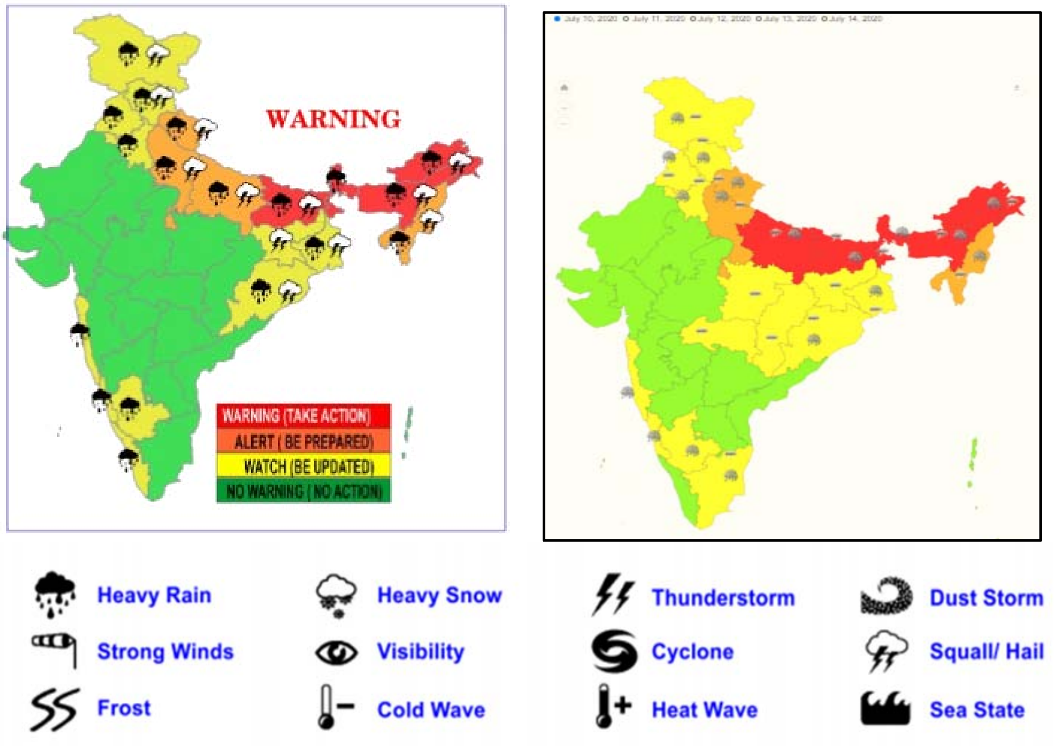


Figure 10.3. National Level Pictorial presentation of Multi-Hazard System

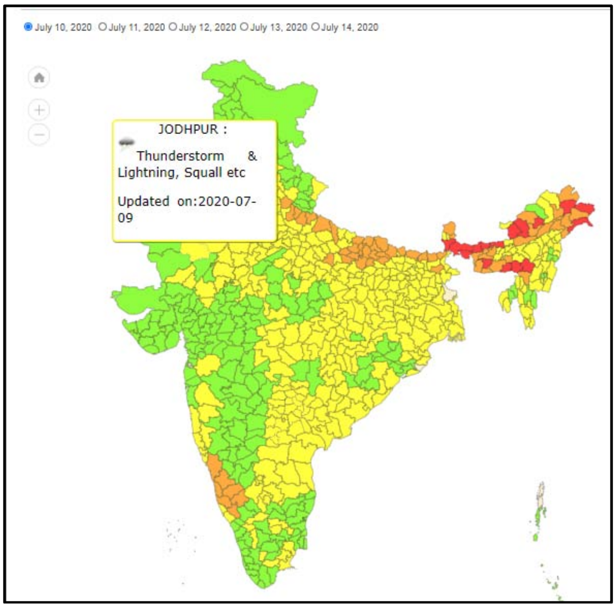


Figure 10.4. District level Pictorial presentation of Multi-Hazard System

10.3.2. Text Message of Multi- Hazard Warnings

From the warnings received from different forecasting centres a small text message will also generated and sent with the visual map so that it will help in decoding the map quickly. The automated programme will be designed in such a way that the text message will also be generated automatically. Individual State maps with districts will be prepared and supplied to State MCs as required.

10.3.3. Timeliness of Map generation and transmission

Though the Multi-hazard warning system needs continuous updating as and when a new warning situation arises, this should be automated completely. Thus no manual intervention is required in generation, display and transmission of the end product.

However in view of the experimental run of the system one Hazard map may be manually generated at any convenient time after the forecasts conferences and inputs from different hazard groups are received. From that time onwards the PWS group will monitor for new inputs and update the Multi-hazard map continuously without any set time frame.

10.3.4. Dissemination System

Forecast and warnings are disseminated to various users through telephone, fax, email SMS, Global Telecom System (GTS), WMO Information System (WIS), All India Radio, FM & community radio, Television, Social media (facebook, whatsapp, twitter) and other print & electronic media, press conference & press release. These warnings/advisories are also put on the various websites of IMD such as (www.rsmcnewdelhi.imd.gov.in and www.mausam.imd.gov.in). Another means to transmit warning is IVRS (Interactive Voice Response system). It is functioning with effect from July 2000.The requests for weather information and forecasts from the general public are automatically answered by this system. One can access current weather and forecast for major Indian cities by dialling Toll-free number 1800 220 161. Presently a centralized IVRS is catering the weather information of major cities.

IMD has taken various initiatives in recent years for improvement in the dissemination of weather forecast and warning services based on latest tools and technologies. Since 2009, IMD has started SMS based weather and alert dissemination system through AMSS (Transmet) at RTH New Delhi. To further enhance this initiative, India Meteorological Department has taken the leverage of Digital India Programme to utilize “Mobile Seva” of Department of Electronics and Information Technology (DeitY), Ministry of Communication and Information Technology; Govt. of India and Quick SMS of NIC for SMS based Warnings /Weather information dissemination for a wide range of users. The SMS based cyclone alert to the registered users including public was inaugurated on 25th December 2014. Global Maritime Distress and Safety System (GMDSS) message is also put in RSMC, New Delhi website (URL: www.rsmcnewdelhi.imd.gov.in) as well as transmitted through GTS. The WIS Portal–GISC New Delhi is another system for cyclone warning dissemination. The user can access the warning messages through the -URL: http://www.wis.imd.gov.in. IMD has also started issuing of NAVTEX bulletins for the coastal region along east as well as the west coast of India for the operation of lightships and fishermen from 30th March 2016.

Nine IMD offices viz, the Regional Meteorological Centres at Chennai, Guwahati, Kolkata, Mumbai and Nagpur, CRS Pune, MTI Pune and M.C. Bhubaneswar have been linked with National Weather Forecasting Centre (NWFC) at IMD Head quarters, Delhi through dedicated video conferencing systems for daily forecast discussion.

In addition, the SMS-based alert/warnings are issued to registered farmers through Kisan portal of Govt. of India (Ministry of Agriculture) and to registered fishermen through Indian National Centre for Ocean Information Sciences (INCOIS), Hyderabad also.

IMD is working in collaboration with ISRO for disseminating the SMS to fishermen in deep seas through GAMES and NAVIC systems. IMD has collaborated with NEGD, Department Of Electronics And Information Technology for disseminating warning via UMANG mobile app. IMD has also established new cyclone warning centre at Thiruvananthapuram w.e.f. October, 2018 to improve dissemination of warnings and advisories for the states of Kerala, Karnataka and Lakshadweep Islands.

IMD is also working with WMO and NDMA for disseminating the warning through CAP (Common Alerting Protocol).

10.3.4.1. Dissemination and Information Flow of CAP Message using NDMA tool

C-DOT under an MoU with NDMA has been mandated to develop and field a pilot project for Early warning system for natural disasters based on Common Alerting Platform (ITU-T standard x.1303) for the state of Tamil Nadu). In the Pilot Project, C-DOT will integrate concerned stakeholders (IMD, CWC, TN-SDMA and TSPs) on a web-based platform in order to disseminate location specific early warning messages in Tamil Nadu Diagrammatic flow of information has been depicted in Figure below.

A sample CAP message is given in Annexure.

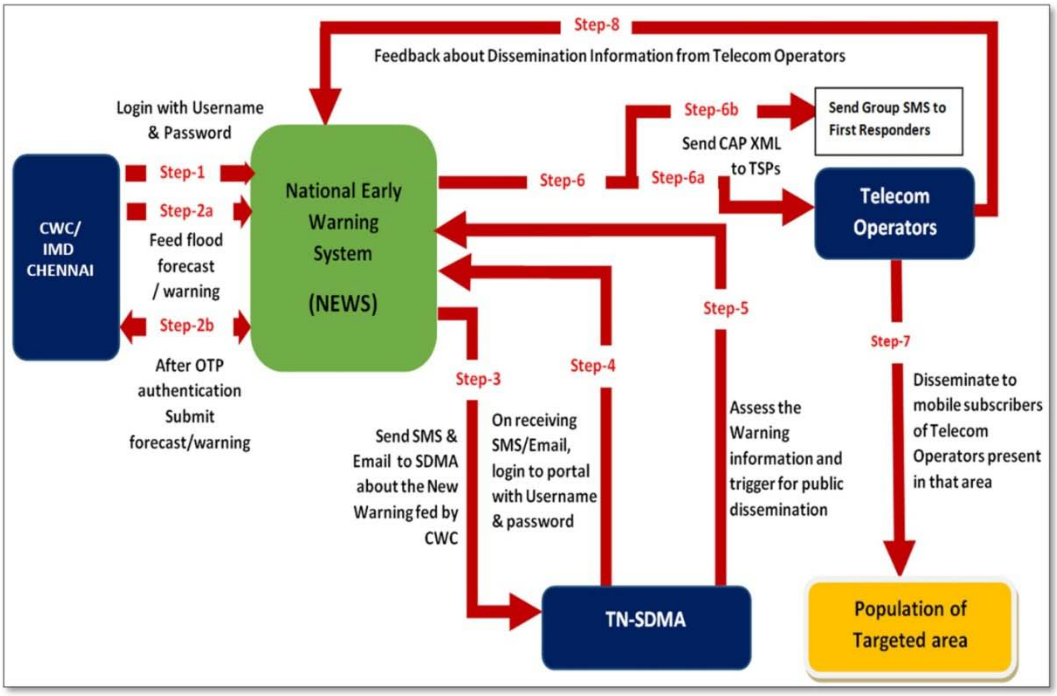


Figure 10.5. Schematic diagram of Flow of information in the CAP tool developed for Tamil Nadu

10.4. Cyclone warning Dissemination

IMD has taken various initiatives in recent years for improvement in the dissemination of weather forecast and warning services based on latest tools and technologies.

- Cyclone warnings are disseminated to various users through telephone, fax, email, SMS, Global Telecom System (GTS), WMO Information System (WIS), All India Radio, FM & community radio, Television and other print & electronic media, press conference, press release and Social media like Facebook, Twitter etc, FM radio & Community radio. These warnings/advisories are also put on the website (www.rsmcnewdelhi.imd.gov.in and www.mausam.imd.gov.in) of IMD.

- Another means to transmit warning is IVRS (Interactive Voice Response system). It is functioning with effect from July 2000. The requests for weather information and forecasts from the general public are automatically answered by this system. One can access current weather and forecast for major Indian cities by dialling Toll-free number 1800 180 1717. Presently, a centralized IVRS is catering the weather information of major cities.

- Since 2009, IMD has started SMS based weather and alert dissemination system through AMSS (Transmet) at RTH New Delhi.

- To further enhance this initiative, IMD has taken the leverage of Digital India Programme to utilize “Mobile Seva” of Department of Electronics and Information Technology (DeitY), Ministry of Communication and Information Technology; Govt. of India for SMS based Warnings /Weather information dissemination for a wide range of users. The SMS based cyclone alert to the registered users including public was inaugurated on 25th December, 2014.
- General Public can register in RSMC website free of cost for getting SMS on cyclone warnings. The SMS-based alert/warnings are issued to registered farmers through Kisan Portal of Govt. of India (Ministry of Agriculture) and to registered fishermen through Indian National Centre for Ocean Information Sciences (INCOIS), Hyderabad also.

- Global Maritime Distress and Safety System (GMDSS) message is also put in RSMC, New Delhi website (URL: www.rsmcnewdelhi.imd.gov.in) as well as transmitted through GTS. The WIS Portal –GISC New Delhi is another system for cyclone warning dissemination. The user can access the warning messages through the URL: http://www.wis.imd.gov.in. IMD has also started issuing of NAVTEX bulletins for the coastal region along east as well as the west coast of India for the operation of lightships and fishermen from 30th March 2015.

- The cyclone warnings are also disseminated through Tsunami warning dissemination system of INCOIS and Potential Fisheries Zone (PFZ) Bulletins of INCOIS to registered Fishermen.

- The Cyclone warnings are also communicated registered farmers along the coastal regions through the Kisan portal of Ministry of Agriculture, Govt. Of India.

There is separate SOP for Cyclone related warnings and their dissemination.

Annexure-I

Sample CAP Message-

<?xml version="1.0" encoding="UTF-8" ?>
<?xml-stylesheet type="text/xsl" href="https://cap-sources.s3.amazonaws.com/in-imd-en/alert-style.xsl" ?>
<cap:alertxmlns:cap="urn:oasis:names:tc:emergency:cap:1.2" >
<cap:identifier>urn:oid:2.49.0.1.356.0.2019.12.27.8.19.38</cap:identifier>
<cap:sender>nowcastnwfc@gmail.com</cap:sender>
<cap:sent>2019-12-27T08:19:38-00:00</cap:sent>
<cap:status>Test</cap:status>
<cap:msgType>Alert</cap:msgType>
<cap:scope>Public</cap:scope>
<cap:info>
<cap:language>en</cap:language>
<cap:category>Met</cap:category>
<cap:event>Moderate Thunderstorm</cap:event>
<cap:responseType>Prepare</cap:responseType>
<cap:urgency>Expected</cap:urgency>
<cap:severity>Moderate</cap:severity>
<cap:certainty>Likely</cap:certainty>
<cap:onset>2019-10-31T18:00:00+05:30</cap:onset>
<cap:expires>2019-10-31T18:30:00+05:30</cap:expires>
<cap:senderName>NOWCAST DIVISION</cap:senderName>
<cap:headline>Moderate Thunderstorm warning</cap:headline>
<cap:description>LIGHTNING DETECTION AND IDENTIFICATION REPORT FOR Thu Oct 31 17:17:53 IST 2019 ,Akola District 7,Amravati District 3, Aurangabad District 37,Buldhana District 19,Chandrapur District 117,Jalgaon District 11,Sindhudurg District 3,Wardha District 1,Yavatmal District 61,Thunderstorm with Gusty winds with wind speed of 40-50 kmph are likely over Akola, Amravati districts during the next three hours.</cap:description>
<cap:instruction>People are advised to keep a watch on the weather for worsening conditions and be ready to move to safer places accordingly.</cap:instruction>
<cap:web>http://srf.tropmet.res.in/srf/ts_prediction_system/index.php</cap:web>
<cap:contact>nowcastnwfc@gmail.com,011-43824241</cap:contact>
<cap:area>
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Chapter 11

Urban Meteorological Services

11.1. Introduction

An exponential growth of urban populations has become a driving force for human development, particularly in developing countries. Although, crowded cities are centres of creativity and economic progress, but face serious challenges on account of polluted air, extreme weather conditions, flooding and other hazards. Increasingly dense, complex and interdependent urban fabrics are rendering cities vulnerable: a single extreme event can lead to a widespread breakdown of a city's infrastructure often through cascading downstream or "domino" effects and even loss of human life in large numbers.

The World Meteorological Organization (WMO) recognizes that rapid urbanization necessitates on new types of services which make the best use of science and technology and considers the challenge of delivering these as one of the main priorities for the meteorological community. Urban Services, in the traditional sense are related to transportation, housing, water management, waste management, public health, electricity, snow clearance, etc. In rapidly changing urban complexion, there is need of Urban Integrated Services consisting observational data and prediction for weather, climate, hydrology and air quality infrastructure to support traditional (and new) urban services in art of state manner.

Urban Integrated Services typically shouldinclude:

(i) Observation and Monitoring;
(ii) Data, databases and data sharing;
(iii) Modelling and prediction capability;
(iv) Tailored urban service applications;
(v) Decision Support Systems to support decision-making that includes human behaviour/response considerations
(vi) Products, service delivery, communications and outreach;
(vii) Evaluation, assessment, societal impacts;
(viii) Research and Development.

The main elements and subsystems should integrate:

- Weather (especially high impact weather for now cast and short range forecast at the urban and suburban scales, in all conditions, and taking into account the urban influences)
- Climate (urban climate, climate extremes, sector specific climate indices, climate projections, climate risk management and adaptation).
- Hydrology and water related hazards (flash river floods, heavy precipitation, river water stage, inundation areas, storm tides, sea level rise, urban hydrology)
- Air Quality (urban air quality and other larger scale hazards: dust storms, wildfires, smog etc.)

Urban Integrated Services systems need to consider fine-scale urban observations for assimilation and model initialization, urban canopy models, urban vegetation, land use and land cover (to assess both exposure, vulnerability but also soil permeability, which might affect the hazard in terms of lag time) ensemble prediction, quantification of uncertainties and processes requiring multi-disciplinary approach.

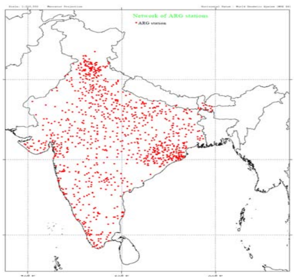
With increasing demand, IMD has already taken Urban Meteorological Services as one of its priority projects to provide location-specific severe weather warnings for 10 major cities in the country and 110 capital cities (listed in Annexure 1) with the advent of dense observational networks, high-resolution forecasts, multi-hazard early warning systems and climate services promoting the Sustainable Development Goals.However, there are other urban centres with large populations which are tending to become megacities. In view of the expansion of Indian cities, there is an imperative need for strengthening of infrastructure for megacity oriented weather services.

11.2. Current status of observational network

IMD recently introduced a system of urban city forecast in mega, capital and other smart cities facilitated with the synoptic observational network, Automatic weather stations (AWS), Automatic Rain Gauge (ARG), C&S-band Doppler Weather Radar, vertical wind profilers, radiosonde etc. The list of 110 stations for location specific forecast in Capital cities selected under the urban meteorology. Quantification and specific timing of the weather events are generally not provided. The forecasts for imminent severe weather events (eg. Thunderstorms/squalls) are also issued by certain offices with existing DWR observing facility. Current weather information for representative observatories in the cities are also updated hourly/three hourly basis in the web-site.

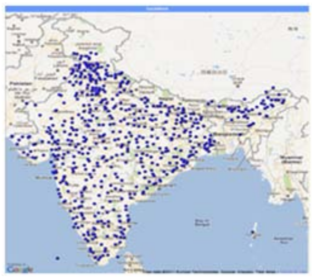
1. **Update cycle** : Twice a day in IMD website and once in print media.
2. **Validity period** : Three days
3. **Forecast Parameters** : Maximum temperature, Minimum temperature, state of the sky and weather phenomena.
4. **Users** : Mostly civic authorities.

The details of the IMD observational network are as follows :



1400

27 Doppler Weather RADAR



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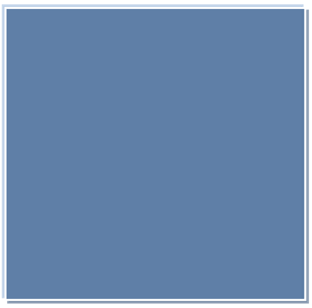


264 Agro met Observatory

4500 DRMS

558 Surface observatories

S. No.	City	DWR	ARG	Synoptic stations	AWS
1.	Mumbai	1 (S – Band)	NA	2	2
2.	Delhi	1 (C – Band)	1	5	10
3.	Bangalore	NA	3	3	1
4.	Kolkata	1 (S – Band)	1	3	1
5.	Chennai	1 (S – Band)	2	2	4
6.	Hyderabad	1 (S – Band)	5	1	2
7.	Ahmedabad	NA	6	1	NA
8.	Pune	NA	13	4	5
9.	Nagpur	1 (S – Band)	2	2	**1**
10.	Guwahati	1 (S – Band)	1	1	**1**

11.3. Weather information deliverables for urban cities

Current weather and forecast weather at different spatial and spatio-temporal scales respectively are the deliverables for urban cities as depicted in Fig. 1.

Figure 1. Deliverables for urban cities

11.3.1. Current weather information

Information required at important locations in the city (preferably every 5-10 km) to be updated in 15 minutes to1 hour, while rainfall forecast is updated every 15 minutes, the parameter line temperature updated every one hour with sufficient requirement of monitoring.

11.3.2. Weather forecasts

11.3.2.1. Now cast (for next 6 hours and updated every 15 minutes as and when triggered by observing system)

(i) Information about weather phenomena–rainfall/snowfall,dust storm, thunderstorm, hailstorm/sleet, lightning, squalls, wind gust, fog, extreme temperatures, gale force winds, cyclones and tsunami / storm surge.

(ii) Forecasts will be issued for specific events (e.g. sports events, national functions, festivals etc.) and locations in the cityfor 24 hour forecast from high resolution model and 48 hour outlook from high resolution global model.

(iii) IMD issues thunderstorm now cast for around 875 stations and 48 hour ahead thunderstorm forecast guidance for the country as a whole.

11.3.2.2. Very short range (for next 12 hours and updated every 3 hours)

(i) Three hourly temperature, relative humidity, wind speed and direction, heat indices, wind.

(ii) Chill and rainfall in quantitative terms, cloudiness, fog and occurrence of any weather events with probable time period.

(iii) Forecasts will be issued for specific events (e.g. sports events, national functions, festivals etc.) and locations in the city.

11.3.2.3. Short range (for next 72 hours starting from 12 hours and updated twice a day)

(i) Maximum and minimum temperatures and relative humidity, heat indices, wind chill and rainfall in quantitative terms, cloudiness, severe weather phenomenon like cyclones, heavy rains, thundershower, cold and heat waves and occurrence of any weather events with probable time period.

(ii) Forecasts will cover different sub-regions/ district in the city.

11.3.2.4. Medium range (4th day – 7th day updated twice a day)

(i) Global Ensemble Forecasting System (GEFS-SL) for ensemble forecasts in the medium range time scale. The GEFS-SL at semi-Lagrangian resolution T-1534 in horizontal resolution (~12.5 km) with 64 hybrid sigma-pressure layers was made operational in June, 2018.

(ii) Maximum and minimum temperatures and relative humidity, heat/cold wave and rainfall, cloudiness and occurrence of weather events.

(iii) Forecast will be issued for the city as a whole.

11.3.2.5. Extended Range forecastformonthly outlook updated weekly

(i) Four week forecasts (~50 km) from CFS and GFS based multi-model ensemble forecast system is issued weekly once over Indian region.

(ii) The Maximum and minimum temperatures (bias corrected), heat/cold wave, wind rainfall and cyclogenesis over the region.

11.3.2.6. Long Range weather forecastfor a season

Long Range Forecasting may range from a month to a seasonal forecast which is elaborately described in Chapter…..

11.4. Inputs needed for urban weather forecast

The inputs needed for urbanweatherforecasting services are shown in Fig. 2.

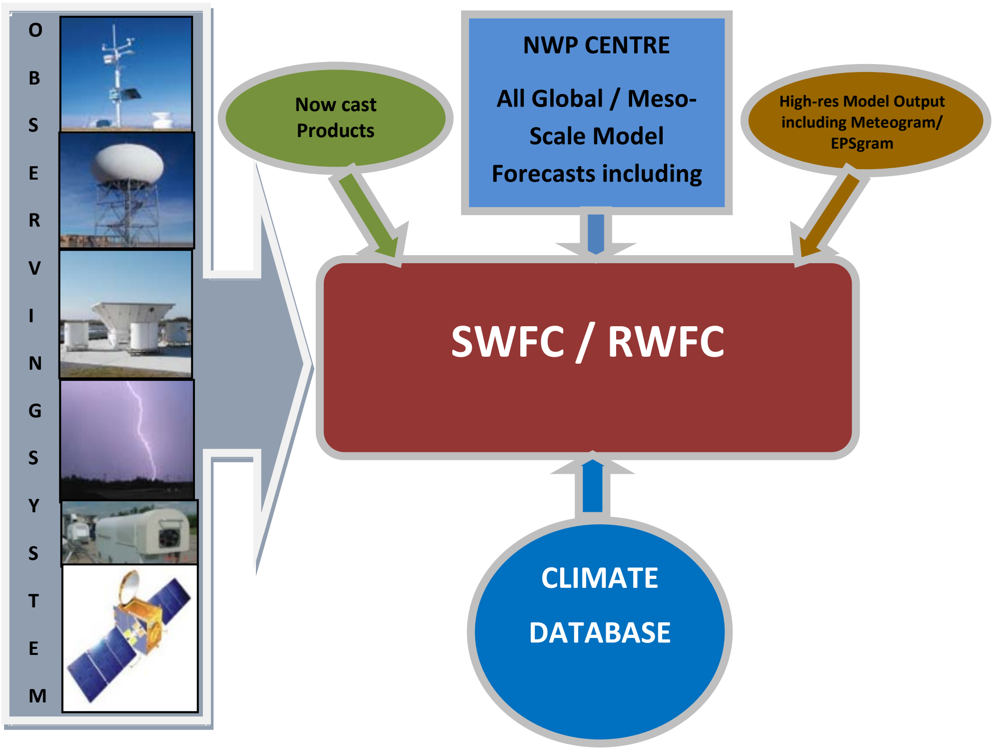


Figure 2. Inputs needed for urban weather forecast

11.4.1. Observing system

The observing system available for issuing urban weather forecast is given below:

i) A network of AWS/ARG at every 4 km capable of providing observations.
ii) Surface observation /Metar–1 to 3 hour interval
iii) Upper-air observation

a. Vertical Wind Profiler- 2-3 depending upon main approach path of weather phenomena (continuous observations)
b. Radiometer – 1-2 (continuous observations)
c. GPS sonde – twice a day

iv) X, C&S-band Doppler Weather Radar –10 minutes volume scan image and prognosis
v) Satellite Observation from INSAT-3D &INSAT-3DR–sector image at 30 minutes interval
vi) Other international satellites of NOAA, EUMETSAT, HIMAWARI and FY- series.
vii) Lightning detection network
viii) At some locations AWS stations should be attached with video camera
ix) Thermodynamic indices

11.4.2. NWP Products

11.4.2.1. Global Model analysis and forecasts – updated 4 times daily for next 7 days at 1 hour for day 1 and 3 hour intervalthereafter (from HQs)

Forecast products of following parameters will be provided by the model

i. Rainfall
ii. Wind flow pattern at surface (10 m) and different upper-air levels
iii. Temperature and geopotential height at different upper-air levels

iv. Surface temperature and relative humidity (2 m)
v. Mean sea level pressure
vi. Different indices and diagnostic parameters (stability indices, CAPE, CIN, equivalent potential temperature, relative vorticity, divergence, potential vorticity, moisture convergence and shear etc.)
vii. Derived parameters including dynamic and thermodynamic indices

11.4.2.2. Meso-scale Model analysis and forecasts – updated four times daily for next 3 days at 1 hour interval (from HQs)

Forecast products of following parameters will be provided by the model

i. Rainfall
ii. Wind flow pattern at surface (10 m) and different upper-air levels
iii. Temperature and geo-potential height at different upper-air levels
iv. Surface temperature and relative humidity (2 m)
v. Mean sea level pressure
vi. Different indices and diagnostic parameters (stability indices, CAPE, CIN, equivalent potential temperature, relative vorticity, divergence, potential vorticity, moisture convergence and shear etc.)
vii. Forecast radar reflectivity
viii. Cloud Top Temperature

11.4.2.3. High Resolution Rapid Refresh (HRRR) products - updated hourly basis for next 24 hours at 1 hour interval (from HQs)

Hourly forecast animated products over selected regions of India will be issued for next 24 hours.

i. Rainfall
ii. Wind flow pattern at surface (10 m) and different upper-air levels
iii. Surface temperature and relative humidity (2 m)
iv. Forecast radar reflectivity
v. Storm relative helicity

11.4.2.4. Now cast Products

i. Location specific temperatures (hourly for next 6 hours)
ii. Location specific humidity (hourly for next 6 hours)
iii. Location specific wind speed/direction (hourly for next 6 hours)
iv. Location specific heat index (hourly for next 6 hours)
v. Location specific visibility (hourly for next 6 hours)
vi. Location specific rainfall quantity (hourly for next 3 hours)
vii. Location specific severe weather phenomena (thunderstorm, dust storm, hail, gusts, squall, lightning etc. hourly for next 3 hours)

Detailed list of NWP products along with their availability and updating frequency are given in SOP of NWP model.

11.4.3. Climate Database

Generated locally and through CLYSIS will be made available to forecasting centre.

i) Normal temperature, rainfall, wind, humidity
ii) Extreme temperature, rainfall, wind (thunderstorm/squall)
iii) Anomaly of the day
iv) Wind rose diagram

11.5. SOP of Urban weather forecast

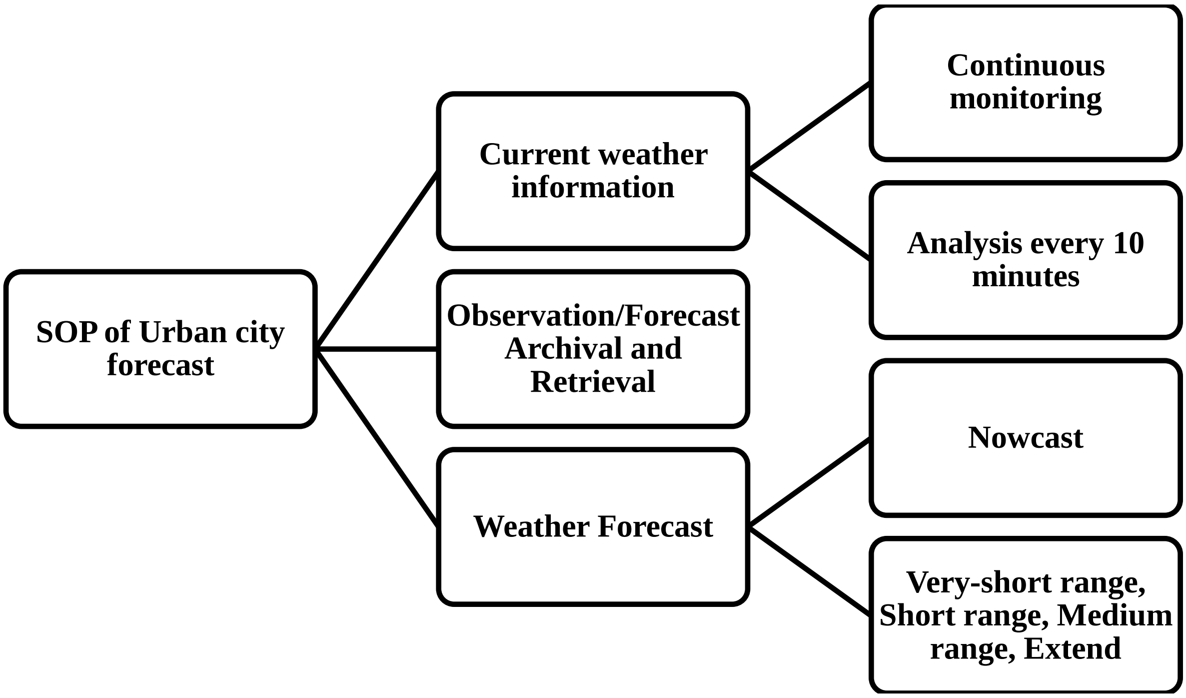


Figure 3. Flowchart of the SOP of City Forecast

11.5.1. Impact Based Forecast

Refer SOP of Impact Based Forecasting.

11.6. Event wise urban meteorology services

11.6.1. Heavy rainfall

An urban Meteorological service includes **impact based warnings for local heavy rainfall events** which causes flash flood. The present Urbanmet services of IMD functional at most cities in India can be classified as:

i) 6-h local forecast updates issued routinely at sub-City level that includes temp and rainfall observations.
ii) Sub-city level now cast at least at each 3-h gap during potential severe weather development
iii) Impact Based Forecast for City heavy rainfall forecast.

However, NWP models are capable to provide indications and likelihood over a city at 2-5 Days in advance especially in case it is associated with some well-defined monsoon systems**.**For detailed SOP, please refer section no.……

(iv) City basedthresholds and topography will be considered for determining heavy rainfall impact for different parts of city.

11.6.2. Heat wave and cold wave

The heat waves, periods of sustained high temperature and high humidity, have long been recognized as a significant weather hazard. There is lot of casualties every year due to heat and cold wave conditions over India. Though, IMD issuing heat wave and cold wave warning during their respective seasons. For detailed SOP, please refer section no.……

Due to urban heat island effect, the temperature at the middle of the city will be different from the sub-urban area.Therefore, while issuing heat wave warning for urban areas heat island effect will be taken into consideration and area specific warning will be provided. It will be integrated with city specific heat action plan.

11.6.3. Thunderstorm and lightening

In view of the increased public awareness of the high impact of thunderstorms and its influence on social, cultural, commercial, health, defence, transport etc., it is felt that there is a requirement of a well laid out system/methodology for monitoring, prediction and warning of thunderstorm. India Meteorological Department (IMD) provides a uniform monitoring and forecasting/warning services of above mentioned weather event. In addition to this, the thunderstorm warning will help in aviation, disaster management and new concept of mega-city forecasting and now casting.The occurrence of lightning in India is being monitored with the help of lightning detectorsestablished by Ministry of Earth Sciences and Indian Air Force. Currently, there are 203 No.of lightning detectors in the country (46 Indian Institute of Tropical Meteorology and 157Indian Air Force). The area of lightning during preceding 10 min., 20 min. and 30 min. aresuperimposed with satellite and radar imageries. It helps in proper monitoring of thunderstormand lightning activities and now casting of such events. The lightening detectors as warning will be visualized in a GIS platform for the urban areas. For detailed SOP, please refer section no.…….

The lightning detection and warning will be visualized on GIS platform for the urban region.

11.6.4. Fog

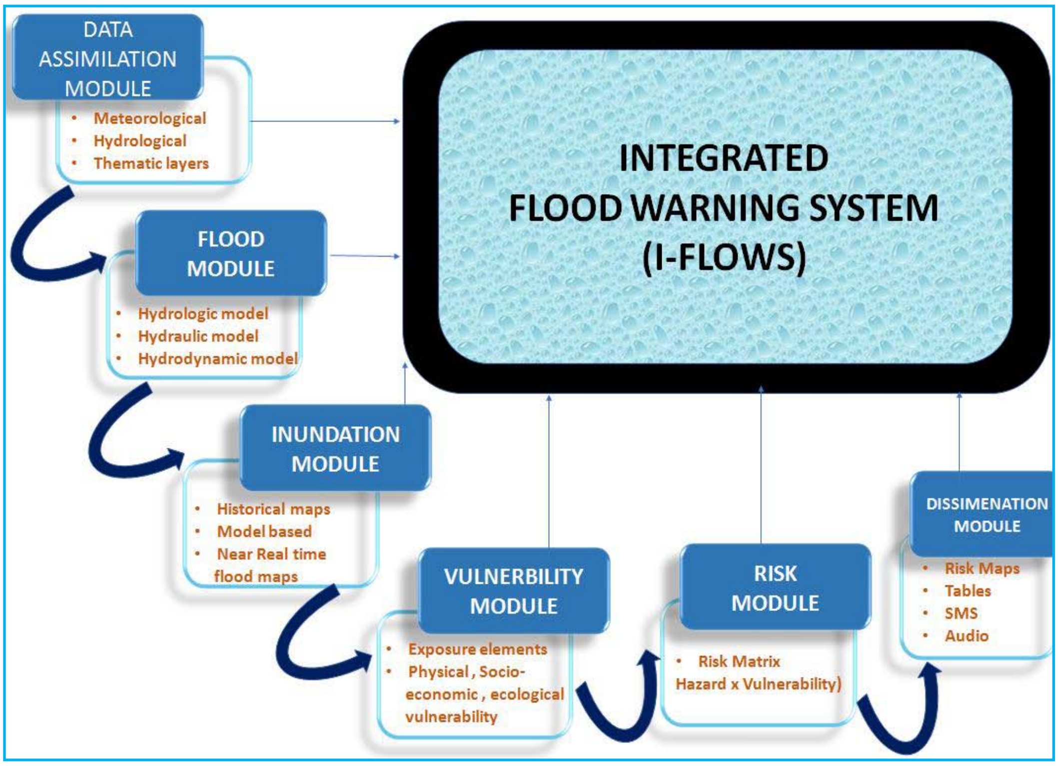
The presence of dense and extended period fog in the northern regions of India is one of the major weather hazards, impacting aviation, road transportation, economy and public life in the world's most densely populated region. Maximum fog occurrence over Northwest India is about 48 days (visibility < 1000m) per year and occurs mostly during the December-February time period. Recent studies on fog in India during the past 10-15 years have prompted significant socio-economic concern due to an increase in frequency, persistence, and intensity of fog occurrence over the northern parts of the country. Winter Fog Experiment (WIFEX) are to develop better now-casting (next 6 hours) and forecasting of winter fog on various time and spatial scales and help reduce its adverse impact on aviation, transportation and economy, and loss of human life due to accidents. Local conditions will be considered while issuing the fog forecast for different parts of the city.For detailed SOP, please refer section no.……

11.6.5. Cyclone

For detailed SOP, please refer section no.……

11.6.6. Integrated Flood Warning System (I-FLOWS)

I-FLOWS is an innovative approach to flood risk mapping in a disaster risk reduction framework, leveraging weather models, field data using numerical flood modeling and Web GIS technologies. It is a framework to map spatially explicit flood hazard, exposure and vulnerability, and to merge the data into a flood risk index (FRI). The major objectives of this system are to develop operational decision support system for flood risk assessment and management for the State Government. Conceptual Framework of I-FLOWS is as follows:



I-FLOWS incorporates forecast data from the following models from IMD, NCMRF

- NCMRWF : 10 days forecast, 19*13 km spatial resolution
- GFS : 11 days forecast, 14 km spatial resolution
- WRF : 3 days forecast, 9 km spatial resolution

IMD issues advisories using the following colour codes, and the colour are assigned to a given weather forecast situation under the 5-day forecast scheme, following matrix, giving thrust on the probability of occurrence of the event as well as its impact assessment. The probability of occurrence for D1 to D5 may be arrived based on the ensemble probabilistic forecasts provided by NCMRWF/IMD/IITM and various Global Centers, which are as follows:

S. No.	Terminology	Warning Advisories by IMD
1.	No Warning	No Warning (No Action)
2.	Heavy Rainfall	Watch (Be Updated)
3.	Very Heavy Rainfall	Alert (Be Prepared)
4.	Extremely Heavy Rainfall	Warning (Take Action)

IMD has a SOP for Weather Forecasting and Heavy Rainfall Warnings as a part of their Megacity Forecasting System. This includes :

- Forecast for spatial distribution of rainfall
- Intensity of Rainfall (in 24 hours)
- Probability Forecasts of Rainfall or Weather
- Temporal distribution of rainfall

Heavy Rainfall Warnings are issued based on colour codes by IMD. HRW bulletins are passed on to Central Govt., State Govt. authorities, Doordarshan/AIR/press and other users by SWFC/RWFC.

I-FLOWS will supplement the qualitative forecast given by IMD and generated quantitative forecast on likely inundation and water levels and the work flow will be as given below:

i. HRF from the weather models (NCMRWF, IMD) will be picked up and along with discharge.
ii. from upstream (if any) flood inundation models will be run (72 hours in advance).
iii. The models will continue to run based on the probability of occurrence for D1 to D5 as arrived at, based on the ensemble probabilistic forecasts provided by NCMRWF/IMD/IITM and various Global Centres.
iv. The inundation/vulnerability and risk maps will be generated 24 hours in advance based on model predictions.
v. Nowcast inundation maps will be generated 3-6 hours in advance and this will continue in near real-time using field data.
vi. All maps/data will be made available at IMD as a part of the megacities forecasting programme.

The system is operational in Chennai and Mumbai and needs to be augmented in other Megacities and other cities.

11.7. Stakeholders

The users of forecasts in mega cities are different from those of the general area forecasts. Some of the potential users are listed below:

i. Civic authorities responsible for maintaining roads, drainage systems and dewatering the stagnation of water.
ii. Disaster managers including fire offices.
iii. Power generation and distribution companies.
iv. Organisers of mega events including sports events, exhibitions, meals, national days' celebration authorities.
v. Government organisation having large outdoor functions.
vi. Electronic and print media.
vii. General public.
viii. Drinking water and sanitation, labour and welfare, education, transport, communication and tourism, industrial installation, shopping malls.

11.8. Post-event Review

i) It is also proposed to carry out thorough survey of certain severe weather events in the city within next 24 hours.
ii) This job requires transport, audio-visual recording aids.
iii) Regular and standard practice to pull together events specific feedbacks from different stake holders.
iv) Collection of detail impact data aftermath of an event.
v) Time-bound borrowed manpower with specified training from RMCs/MCs.
vi) Urban forecasting is proposed to be a part of the RWFC/SWFCs dealing with nowcast, short/medium range forecast.

11.9. Conclusion

Successful implementation of weather and climate services in Mega cities is dependent upon the observational network, weather forecast, availability of proper and adequate trained manpower at regional stations, IT infrastructure and effective communication between various agencies for reception /dissemination of data, information and warnings.

i) Verification and feedback
ii) Documentation
iii) Forecast and warning dissemination
iv) Liaison with civic authorities

Annexure I

List of Location Specific Stations for Capital Cities – State and UT

S. No.	Capital Cities	No. of Stations	Station	Abbreviated Name proposed by UMCC	Final Name for Nowcast Warning
1.	**AGARTALA (AGT)**	01	Agartala	Agartala	Agartala
2.	**AHMEDABAD (AHM)**	10	Ahmedabad Airport	AHM-Airport	Ahmedabad AP
			Navrangpura	AHM-Navrangpura	Navrangpura
			Rakhiyal	AHM-Rakhiyal	Rakhiyal
			Chandkheda	AHM-Chandkhela	Chandkhela
			Satellite Area	AHM-Satellite	Ahm Satellite
			AmbliBopal *	AHM-ISRO Bopal	ISRO Bopal
			Raikhad *	AHM-Raikhad	Raikhad
			Pirana *	AHM-Pirana	Pirana
			IIPH, Gandhi nagar *	GDN-IIPH	Gandhi Ng IIPH
			Gift City, Gandhinagar *	GDN-Gift City	Gift City
3.	**AIZAWL**	02	Aizawl	Aizawl	Aizawl
			Lengpui	Lengpui	Lengpui
4.	**AMRAVATI**	03	Amravati	Amravati	Amravati
			Vijayawada	VJW	Vijayawada
			Gannavaram	Gannavaram	Gannavaram
5.	**BENGALURU (BNG)**	04	Bengaluru city	BNG-City	Bengaluru City
			Bengaluru International Airport	BNG-Int. Airport	Bengaluru BIAL
			Bengaluru HAL Airport	BNG-HAL Airport	Bengaluru HAL
			GKVK	BNG-GKVK	GKV Kendra
6.	**BHOPAL (BHP)**	03	Airport	BHP-Airport	Bhopal AP
			Arera Hills	BHP-Arera Hills	Arera Hills
			NabiBagh	BHP-NabiBagh	NabiBagh
7.	**BHUBANESHWAR (BBS)**	03	Bhubaneshwar Airport	BBS-Airport	Bhubaneshwar AP
			OUAT	BBS-OUAT	Bhubaneshwar OUAT
			Cuttack	BBS-CTK	Cuttack
8.	**CHANDIGARH (CHD)**	04	Chandigarh Airport	CHD-Airport	Chandigarh AP
			Chandigarh city	CHD-City	Chandigarh city
			Mohali	Mohali	Mohali
			Panchkula	Panchkula	Panchkula
9.	**CHENNAI (MDS) *(CHN)**	04	Meenambakkam	CHN-Meenambakam	Meenambakam AP
			Nungambakkam	CHN-Nunambakkam	Nungambakkam
			Madhavaram	CHN-MDVM	Madhavaram
			Ennore	CHN-Ennore	Ennore
10.	**DADRA & NAGAR HAVELI**	01	Dadra Nagar Haveli	D&N Haveli	Dadra Nagar

11.	**DIU**	01	Diu	Diu	Diu
12.	**DEHRADUN (DDN)**	06	Mokhampur	DDN-Mokhampur	Mokhampur
			Karanpur	DDN-Karanpur	Karanpur
			Jhajhara	DDN- Jhajhara	Jhajhara
			Sahashtradhara	DDN- Sahashtradhara	Sahashtradhara
			Asharori	DDN-Asharori	Asharori
			UCOST	DDN-UCOST	UCOST
13.	**GANGTOK (GTK)**	02	Gangtok	Gangtok	Gangtok
			Tadong	Tadong	Tadong
14.	**GUWAHATI (GHY)**	03	Guwahati Airport	GHY-Airport	Guwahati AP
			Dispur	Dispur	Dispur
			Guwahati	IIT-GHY	IIT Guwahati
15.	**HYDERABAD (HYD)**	05	Rajendra Nagar	HYD-Rajendra Nagar	Rajendra Nagar
			Hayathnagar	HYD-HayathNagar	HayathNagar
			Hakimpet	HYD-Hakimpet	Hakimpet
			ICRISAT-Patancheru	HYD- Patancheru	Patancheru
			Hyderabad	HYD	Hyderabad*
16.	**IMPHAL (IMP)**	01	Imphal	Imphal	Imphal
17.	**ITANAGAR**	01	Itanagar	Itanagar	Itanagar
18.	**JAIPUR (JPR)**	05	AMO Jaipur	AMO-JPR	Jaipur AP
			Vaishali Nagar	JPR-Vaishali	Vaishali Ng
			Transport Nagar	JPR-Tpt Nagar	Transport Ng
			Collectorate Circle	JPR-Collectorate	Collector Circle
			Amer	JPR-Amer	Amer
19.	**JAMMU (JMU)**	03	Mata Vaishno Devi ji	Vaishno Devi	Vaishno Devi
			Jammu City	JMU- City	Jammu City
			Jammu Airport	JMU- Airport	Jammu AP
20.	**KOHIMA (KHM)**	02	Kohima	Kohima	Kohima
			Dimapur	Dimapur	Dimapur
21.	**KOLKATA (KOL)**	04	Alipur	KOL-ALP	Alipore
			Dumdum	KOL-DDM	Kolkata AP
			Salt Lake	KOL-Salt Lake	Saltlake
			Howrah (Uluberia)	KOL-Howrah	Howrah
22.	**LADAKH**	01	Leh	Leh	Leh
23.	**LUCKNOW (LKN)**	05	Lucknow Airport	LKN-Airport	Lucknow AP
			Lucknow Hanuman Setu	LKN-Hanuman Setu	Hanuman Setu
			Lucknow Control Room	LKN-Control Room	Flood Control
			Malihabad	LKN-Malihabad	Malihabad
			Mohalnlalganj	LKN-MohanLalGanj	MohanLalGanj
24.	**MUMBAI (BNB)**	07	Colaba	BNB-Colaba	Colaba

			Santacruz	BNB-Santacruz	Santacruz
			Worli	BNB-Worli	Worli
			Powai	BNB-Powai	Powai
			Borivali	PNB-Borivali	Borivali
			Chembur	BNB-Chembur	Chembur
			Mulund	BNB-Mulund	Mulund
25.	**NAGPUR (NGP)**	02	Sonegaon Airport	NGP-Airport	Nagpur AP
			College of Agriculture	NGP-CoA	CoA Nagpur
26.	**NEW DELHI (DEL)**	06	Safdarjung	SFD	Delhi SFD
			Palam	PLM	Delhi PLM AP
			Ayanagar	Ayanagar	Ayanagar
			Narela	Narela	Narela
			Ridge	Ridge	Ridge
			Delhi University	D.U	DU North Campus
27.	**PANAJI (PJM)**	04	Pernem	Pernem	Pernem
			Mapusa	Mapusa	Mapusa
			Old Goa	Old Goa	Old Goa
			Panjim	Panjim	Panjim
28.	**PATNA (PTN)**	02	Patna Airport	PTN-Airport	Patna AP
			Patna City	PTN-City	Patna City
29.	**PORT BLAIR (PBL)**	01	Port Blair	Port Blair	Port Blair
30.	**PUDUCHERRY (PDC)**	01	Puducherry	Puducherry	Puducherry
31.	**RAIPUR(RPR)**	03	Raipur (Lalpur)	RPR	Lalpur
			Mana (AMS Raipur)	RPR-Mana	Raipur Mana
			Labhandi (IGKV)	RPR-IGKV	Labhandi
32.	**RANCHI (RNC)**	02	Ranchi	Ranchi	Ranchi
			Kanke	RNC-Kanke	Kanke
33.	**SHILLONG (SHL)**	01	Shillong	Shillong	Shillong
34.	**SHIMLA (SML)**	02	Shimla City	SML- City	Shimla City
			Shimla Airport	SML- Airport	Shimla AP
35.	**SRINAGAR (SRN)**	03	Srinagar City	SRN-City	Srinagar City
			Srinagar Airport	SRN-Airport	Srinagar AP
			Dal Lake	Dal Lake	Dal Lake
36.	**THIRUVANANTHPURAM (TRV)**	02	Thiruvananthpuram City	TRV-City	Thiruvananthapuram City
			Thiruvananthpuram Airport	TRV-Airport	Thiruvananthapuram AP
	Total	**110**			

Chapter 12

Marine Weather Forecasting Services

12.1. Introduction

Weather services for marinesectoris coordinated by the Marine Services Division (MSD) of NWFC, New Delhi. The products are generated by MSD as well as Area Cyclone Warning Centres (ACWCs) and Cyclone Warning Centres (CWCs).The various warning & forecast products and the offices generating them are listed below:

12.2. Global Maritime Distress Safety System (GMDSS)

12.2.1. Under Global Maritime Distress Safety System (GMDSS) scheme, India has been designated as one of the 16 services in the world for issuing Sea area bulletins for broadcast through GMDSS for MET AREA VIII (N), which covers a large portion of north Indian Ocean. The METAREA VIII N is the area of the Indian Ocean enclosed by lines from the Indo-Pakistan frontier in 23°45'N 68°E to 12°N 63°E, thence to Cape Gardafui; the east African coast south to the equator, thence to 95°E, to 6°N, thence north eastwards to the Myanmar/ Thailand frontier in 10°N 98°30'E. As a routine, two GMDSS bulletins are issued at 0900 and 1800 UTC. During cyclone situations, additional bulletins (up to 4) are issued for GMDSS broadcast. The area of responsibility and designated National Meteorological Services for issue of weather and sea area bulletins is shown in Fig.11.1.List of **s**tations issuing cyclone warnings for ships on the high seas is given in table 11.1.

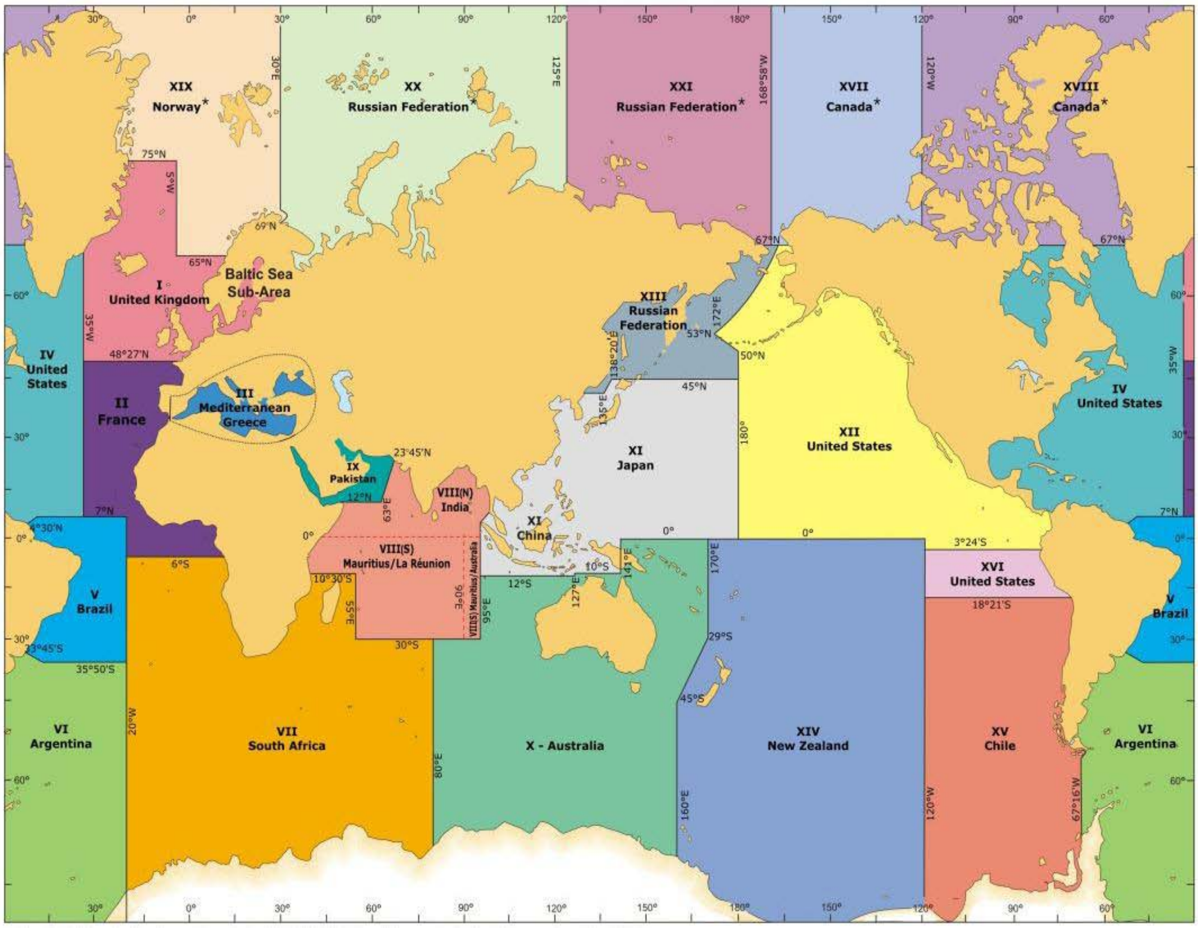
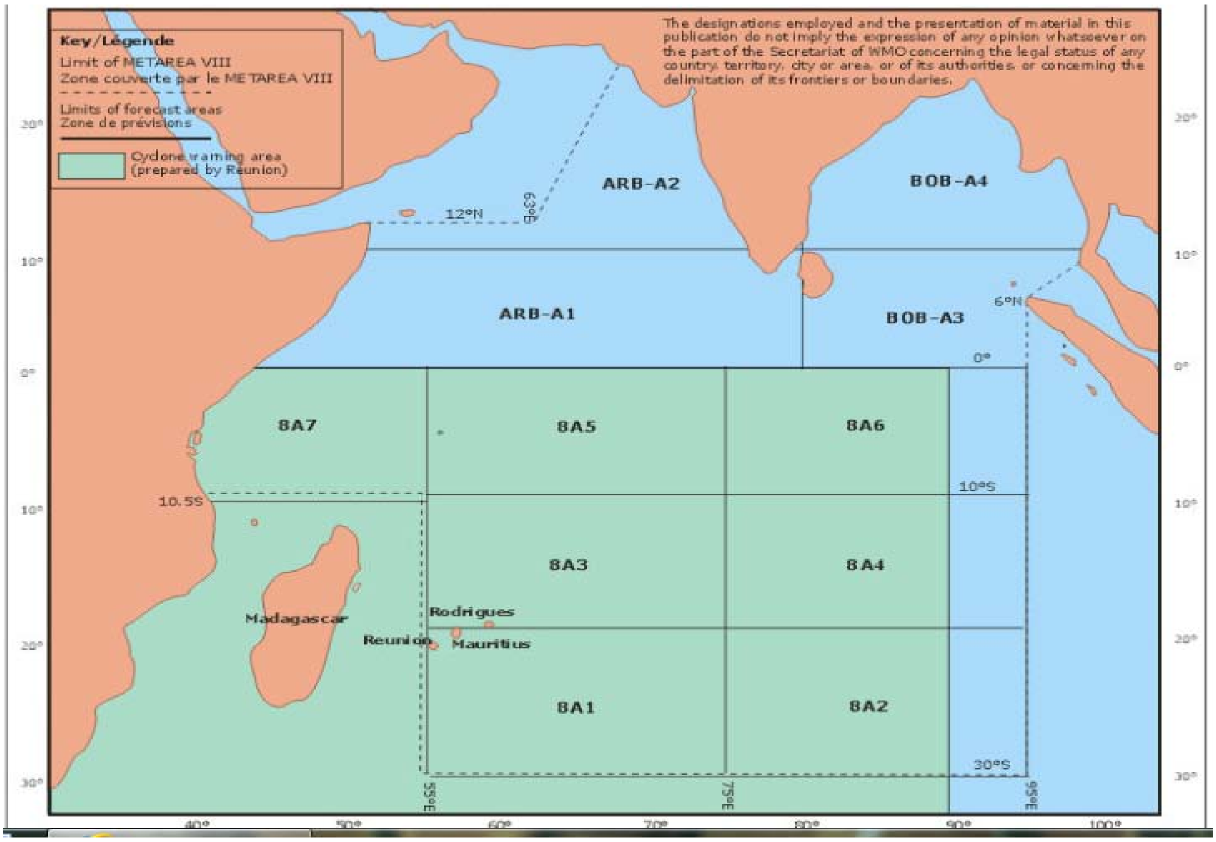


Figure 12.1. Area of responsibility and designated national meteorological services for the issue of warnings and weather and sea bulletins for the GMDSS



Limits of GMDSS METAREA VIII (N)

Table 12.1.

Stations issuing cyclone warnings for ships on the high seas

Station	Call sign of Coastal Area covered Radio Station	Area covered
Bangladesh, Chittagong	ASC	Bay of Bengal north of 18°N Lat.
India, Mumbai		Arabian Sea north of Lat. 5°N and east of Long. 60°E excluding the area north of Lat. 20°N and west of Long. 68°E. The eastern boundary of the Arabian Sea for which these bulletins are issued by Mumbai is Long. 80°E meridian excluding the Gulf of Mannar.
India, Kolkata		Bay of Bengal north of Lat. 5°N except the area between the coastline on the east and the line drawn through the points 18°N 94.5°E, 18°N 92°E, 13.5°N 92°E, 13.5°N 94°E, 10°N 94°E, 10°N 95°E and 5°N 95°E. The western boundary of the sea area for which bulletins are issued by Kolkata is up to and inclusive of the Gulf of Mannar (i.e., 77.5°E meridian).
***India,** Chennai		Bay of Bengal bulletins issued by ACWC Kolkata are being broadcast through Navtex, Chennai by Narrow Band Direct Printing (NBDP)
Myanmar, Yangon	XYR	Bay of Bengal except area west of Long. 92°E and South of 10°N Lat.
Oman (Sultanate of)	A4M	Muscat Coastal Radio Station

****Pakistan,** Karachi	ASK	Arabian Sea north of 20oN, Gulf of Oman and Persian Gulf.
Sri Lanka, Colombo	4PB	Indian Ocean, Arabian Sea and Bay of Bengal from the equator to 100N between 600E and 950E. The area 50N to 100N between 600E and 950E is an overlap with India.
Thailand, Bangkok	HSA HSS	Gulf of Thailand, west of southern Thailand. Strait of Malacca and South China Sea.

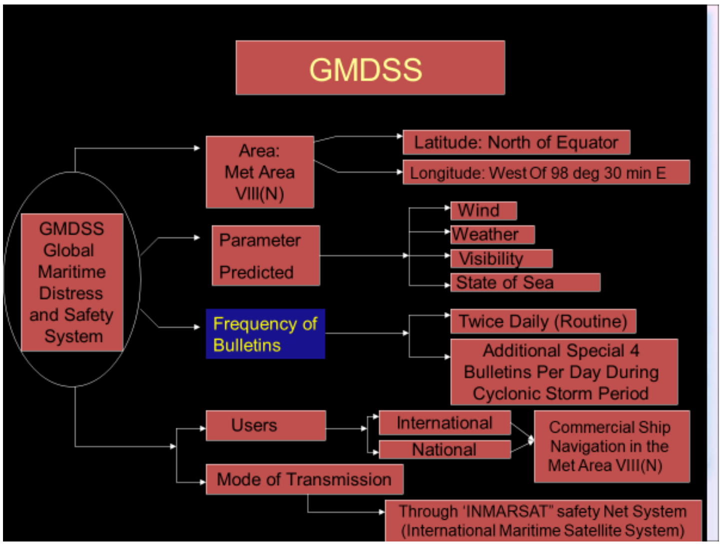
Under the new Marine Meteorological Broadcast system, GMDSS (Global Marine Distress Safety System) of IMO/WMO, India issues two bulletins at 0900 and 1800 UTC every day for broadcast through INMARSAT SAFETY SYSTEM. Additional bulletins are broadcast during Cyclone period.

To comply IMO/WMO GMDSS and marine Meteorological Broadcast System Pakistan issues the high seas forecast / Marine bulletins for met area-IX daily at 0700 UTC for broadcast through INMARSAT SAFEYNET SYSTEM. These bulletins are issued at 1900 UTC if so required.

12.2.2. Transmission of GMDSS bulletin

In India, the weather forecast and warning bulletin is prepared by Marine Services Division of NWFC, New Delhi and transmits to Tele-communication Division (Regional Telecommunication Hub (RTH), New Delhi) for further transmission by e-mail to theLocal Earth Station (LES) of VSNLin Noida. They in turn transmit the message to INMARSAT.

12.2.3. Contents of GMDSS Bulletin



12.2.4. Frequency of Broadcasts

To start with as a routine only one GMDSS bulletin for METAREA VIII (N) was broadcast at 0900 UTC. From October 1998, a second bulletin is also broadcast at 1800 UTC. During Cyclone situations, additional bulletins (up to 4) are also being issued for GMDSS broadcast depending on the requirement.

In addition, India is also issuing weather and warning bulletins to the NAVTEX transmitting stations located at Mumbai and Chennai.

12.2.5. Sample of GMDSS bulletin

GLOBAL MARITIME 222330

DATE 22-07-2020 GMDSS BULLETIN-II 221800
FROM:-MARINE FORECAST DIVISION, DGM, NEW DELHI

TO: DGM (ISSD), NEW DELHI
------------------------------------ --------------------------

GMDSS BULLETIN FOR MET AREA VIII (N), NORTH OF EQUATOR

VALID FOR 24/48 HOURS FROM 1800 UTC 22 JULY 2020.

PART-ISTORM WARNING NIL (.)

PART-II WEATHER SEASONAL(.)

ARB A1 ARABIAN SEA: EQUATOR TO 10 DEG. N AND W OF 80 DEG.E (.)

A1-FORECAST FOR 24 HOURS

I) WINDSPEED AND DIRECTION :

1) W OF 60 DEG E: SW-LY 15/30 KTS (.)

2) E OF 60 DEG E: NW/W-LY 10/20 KTS BEC W/SW-LY 10/15 KTS TO THE E OF 75 DEG E (.)

II) WEATHER:

1) E OF 62 DEG E : WIDESPREAD RA/TS (.)

2) REST AREA: FAIR (.)

III) VISIBILITY:

1) E OF 62 DEG E : 3-2 NM (.)

2) REST AREA: 10-8 NM (.)

IV) WAVE HEIGHT:2.5-4.0 MTR (.)

A1-FORECAST FOR 48 HOURS

I) WINDSPEED AND DIRECTION :

1) W OF 60 DEG E: SW-LY 15/30 KTS (.)

2) E OF 60 DEG E: NW/W-LY 10/20 KTS BEC SW/W-LY 10/20 KTS TO THE E OF 70 DEG E(.)

II) WEATHER:

1) E OF 60 DEG E : WIDESPREAD RA/TS (.)

2) REST AREA: FAIR (.)

III) VISIBILITY:

1) E OF 60 DEG E : 3-2 NM (.)

2) REST AREA: 10-8 NM (.)

IV) WAVE HEIGHT: 2.5-4.0 MTR (.)

ARB A2-ARABIAN SEA:-23 DEG 45 MIN N 68 DEG E TO 12 DEG N 63 DEG E

TO CAPE GARDAFUI TO N OF 10 DEG N (.)

A2-FORECAST FOR 24 HOURS

I) WINDSPEED AND DIRECTION:

1) N OF 20 DEG N : SW-LY 10/20 KTS (.)

2) S OF 20 DEG N TO THE W OF 60 DEG E: SW-LY 15/30 KTS(.)

3) S OF 20 DEG N TO THE E OF 60 DEG E: SW/W-LY 15/25 KTS BEC W/NW-LY 05/15 KTS TO THE E OF 68 DEG E (.)

II) WEATHER:

1) S OF 17 DEG N TO THE E OF 62 DEG E: WIDESPREAD RA/TS (.)

2) N OF 17 DEG N TO E OF 65 DEG E: ISOLATED RA/TS (.)

3) REST AREA: FAIR (.)

III) VISIBILITY:

1) S OF 17 DEG N TO THE E OF 62 DEG E: 4-3 NM (.)

2) N OF 17 DEG N TO E OF 65 DEG E: 8-6 NM (.)

3) REST AREA: 10-8 NM (.)

IV) WAVE HEIGHT: 2.5-4.0 MTR (.)

A2-FORCAST FOR 48 HOURS

I) WINDSPEED AND DIRECTION:

1) N OF 20 DEG N: SW/W-LY 10/20 KTS(.)

2) S OF 20 DEG N TO THE W OF 60 DEG E: SW/W-LY 15/25 KTS(.)

3) S OF 20 DEG N TO THE E OF 60 DEG E: SW/W-LY 15/20 KTS BEC W/NW-LY 10/15 KTS TO THE E OF 66 DEG E (.)

II) WEATHER:

1) S OF 22 DEG N TO THE E OF 64 DEG E: WIDESPREAD RA/TS (.)

2) REST AREA: FAIR (.)

III) VISIBILITY:

1) S OF 22 DEG N TO THE E OF 64 DEG E: 3-2 NM (.)

2) REST AREA: 10-8 NM (.)

IV) WAVE HEIGHT: 2.5-4.0 MTR (.)

BOB A3-BAY OF BENGAL: EQUATOR TO 10 DEG N BETWEEN E OF 80
DEG E AND WEST OF 10 DEG N/98 DEG 30 MIN E TO 6 DEG N/95 DEG

E AND THENCE S-WARDS TO EQUATOR (.)

A3-FORECAST FOR 24 HOURS

I) WINDSPEED AND DIRECTION:

1) W OF 87 DEG E: SW-LY 10/20 KTS (.)

2) REST AREA: ANTICYCLONIC 05/10 KTS (.)

II) WEATHER: WIDESPREAD RA/TS(.)

III) VISIBILITY: 3-2 NM

IV) WAVE HEIGHT: 1.5-3.5 MTR (.)

A3-FORECAST FOR 48 HOURS

I) WINDSPEED AND DIRECTION:

1) S OF 6 DEG N TO THE E OF 83 DEG E: CYCLONIC 05/10 KTS (.)

2) REST AREA: SW/W-LY 10/20 KTS BEC W/NW-LY 10/15 TO THE E OF 90 DEG E(.)

II) WEATHER: FAIRLY WIDESPREAD RA/TS (.)

III) VISIBILITY: 4-3 NM (.)

IV) WAVE HEIGHT: 2.5-3.5 MTR (.)

BOB: A4: BAY OF BENGAL N OF 10 DEG N AND E OF 80 DEG E (.)

A4-FORECAST FOR 24 HOURS

I) WINDSPEED AND DIRECTION: SW/W-LY 10/20 KTS (.)

II) WEATHER: WIDESPREAD RA/TS(.)

III) VISIBILITY: 3-2 NM (.)

IV) WAVE HEIGHT: 1.5-2.5 MTR

A4-FORECAST FOR 48 HOURS

I) WINDSPEED AND DIRECTION: SW/W-LY 10/20 KTS (.)

II) WEATHER:

1) W OF 87 DEG E: FAIRLY WIDESPREAD RA/TS (.)

2) REST AREA: ISOLATED RA/TS (.)

III) VISIBILITY:

1) W OF 87 DEG E: 4-3 NM (.)

2) REST AREA: 8-6 NM (.)

IV) WAVE HEIGHT: 1.5-2.5 MTR (.)

TOO:-22/2330

RA : Rain, TS : Thundershower, KT : Knot, DEG N : Degree North, BEC: Becoming, W/SW : West/southwest,

12.3. Sea Area Bulletin

12.3.1. Sea area bulletins for Bay of Bengal are issued by ACWC Kolkata and are broadcast by the coastal radio stations at Kolkata (VWC) and Chennai (VWM) and those for Arabian Sea are issued by ACWC Mumbai and are broadcast by the coastal radio station at Mumbai (VWB). The area covered by these bulletins which is the area of responsibility assigned to India by the World Meteorological Organization (WMO), is shown in Fig. 11.1.

During undisturbed weather, only two bulletins are issued per day, known as **Daily** bulletins. In the event of disturbed weather, a third bulletin known as **extra** is broadcast, if considered necessary. However, when a depression has actually formed, the Extra bulletin must be issued. When a cyclonic storm has developed, every attempt should be made to broadcast three additional bulletins a day. The three additional bulletins are known as **Storm bulletins** which together with the three bulletins mentioned earlier, make up a total of six bulletins a day. Storm three, i.e., GASBAG bulletin (1500 UTC) should be issued on routine basis during cyclone situation. These bulletins are broadcast at fixed hours according to a schedule. In addition, if any unexpected development of weather warrants urgent communication to ships, in between scheduled broadcasts, it is broadcast in the form of a special bulletin, called Hexagon which should be issued immediately after the development is noticed. A code word (which is not for broadcast) is prefixed to each of the bulletins as a preamble for easy identification by the coastal radio stations on receipt. These are given in the table 11.2.

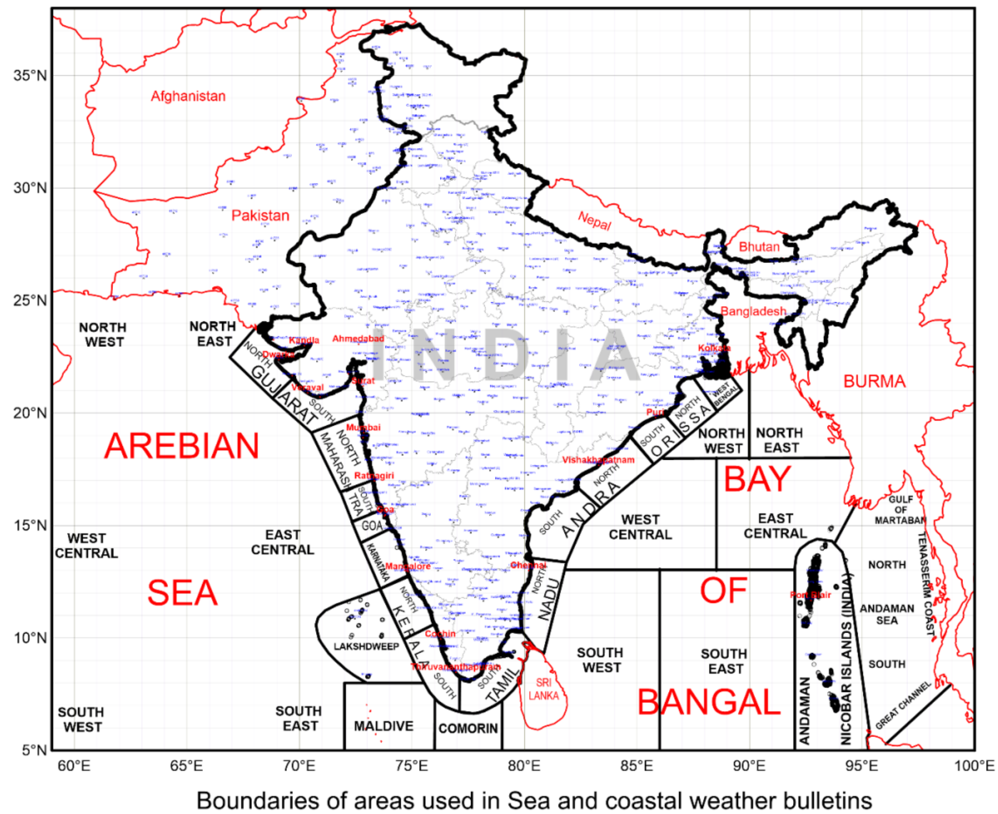


Figure 12.3. Area of coverage for issue of coastal weather bulletin and sea area bulletin

Table 12.2.

Prefix of Code Word to Sea Area Bulletin for coastal Radio Stations

Code word	Type of bulletin	Chart on which based (UTC)
ELECTRON	Storm-One	0000
AURORA	Daily-One	0300
FORMULA	Storm-Two	0900
BALLOON	Daily-Two	1200
GASBAG	Storm-Three	1500
DEW DROP	Extra	1800
HEXAGON	Special	

12.3.2. Format of 'daily' bulletin

The formats for the three messages are as follows:
i) Aurora/ Balloon OBS Date……………. Part One etc……………… Part Two etc. …………..
ii) OBS Date…… Part Three Area Forecast etc. ………..Part Four Analysis etc. ……………
iii) OBS Date …Part Five Ships' Broadcast etc. …..Part Six 0300 Z synop etc. …
In case of 'extra', 'storm' and 'special' type, bulletin consists of only Part I

Format of Part- I:

When a depression or a cyclonic storm has formed or is expected to form or when gales are expected, Part I of the bulletin will contain the following items in the order mentioned below:

(1) International Safety Call sign (TTT).
(2) Statement of type of warning (Warning, gale warning, cyclone warning etc.)
(3) Date and time of reference in UTC in the international six figure date-time group.
(4) Type of disturbance (low, when it is expected to intensify into a depression before broadcast of the next bulletin, depression, monsoon gale, cyclonic storm etc.) with central pressure in hPa in the case of disturbances of cyclonic storm intensity and above.
(5) Location of disturbance in terms of latitude and longitude.
(6) Direction and speed of movement of disturbance. (The direction may be given in 16 points of compass or in degrees to the nearest ten; the speed is given in knots.) The departmental practice is to give the direction in sixteen points of the compass.
(7) Extent of area affected.
(8) Speed and direction of wind in various sections of the affected area. (Wind speeds are given, if possible, for different distances from the centre, in different sectors of the storm area. Wind speeds are given in knots and distances in nautical miles.
(9) Further indications, if any

Contents of Part-II:

When there is no warning in the area, Part I in the Daily bulletin contains the words *No storm warning*. In Part II, Weather is characterized as *Seasonal* when there is no synoptic system in the area. However, during the monsoon season, the strength of the monsoon is described according to corresponding wind speed over the area.

Contents of Part III:

Part III contains a forecast of
(i) weather,
(ii) wind and
(iii) visibility.

The period of validity of the forecast should be till the broadcast time of the next routine DailyOne or Two bulletins. The message should begin with a preamble on the period of validity of the forecast, which will be indicated by the phrase forecast valid till …… UTC of ………. (date). Forecast of weather (such as rain, rainsqualls, thunderstorms etc.) is given only for areas over which it is expected to occur. No forecast is included for areas where no weather is expected. Wind direction is given in eight points of the compass and the wind speed in knots.

Contents of Part-IV

Part IV of the bulletin contains surface analysis encoded in the abridged form of the International Analysis Code for marine use (IAC FLEET) and includes essential isobars. ACWC Mumbai issues analysis for the area from Lat. 5^0 – 25 ^{0} N and Long 60 ^{0} – 80^0 E and ACWC Kolkata for the area from Lat. 5^0 – 30^0 N and Long. 75^0 – 100^0 E.

Part V: Data of observations from ships in WMO codes.

Part VI: Data of observations from selected land stations and upper air reports in WMO codes.

12.3.3. Sample Sea Area Bulletinfor Bay of Bengal

Government of India
India Meteorological Department

Regional Meteorological Centre, Alipore, Kolkata - 700027

AURORA OBSERVATION:: Dated - Friday 24/07/2020
From: Area Cyclone Warning
Centre Kolkata (AliporeWeather office) To :: Port Blair Radio , Kolkata Port
Wireless

No storm warning.

Part Two

A trough lies over Northwest Bay of Bengal. Southwest monsoon moderate over Northeast Bay, Westcentral

North Bay	Wind	Mainly South westerly; 15 to 20 knots.
	Visibility	Good becoming moderate in rain.
West Central Bay	Wind	Mainly south westerly; 15 to 20 knots.
	Visibility	Good becoming moderate in rain.
East Central Bay(WEST OF LONG. 92° EAST)	Wind	Mainly south westerly; 10 to 15 Knots.
	Visibility	Good becoming moderate in rain.
South East Bay & Andaman Sea(WEST OF LONG. 95° EAST)	Wind	Southwest to Westerly; 05 to 10 knots.
	Visibility	Good becoming moderate in rain.
South West Bay	Wind	South to south westerly; 10 to 15 knots.
	Visibility	Good becoming moderate in rain.

TOO:12.30 IST 24/07/2020

Duty Officer ACWC Kolkata 24/07/2020

12.4. Coastal Weather Bulletins

These bulletins are meant for ships plying in coastal waters (within 75 kilometresfrom the shoreline). These are for the benefit of vessels sailing close to the coast and are issued by the ACWCs Kolkata, Chennai, Mumbai and CWCs Visakhapatnam, Bhubaneshwar, Thiruvananthapuram and Ahmedabad for the different coastal areas (Fig.11.3) under their responsibility. These bulletins are broadcast by NAVTEX stations in plain language from the 11 coastal DOT radio stations – 6 on the west coast, 4 on the east coast and 1 in Andaman and Nicobar Islands. From CWC Ahmedabad, coastal bulletins are issued twice daily to ACWC Mumbai and Mumbai Radio for both South Gujarat and North Gujarat coasts. Similarly, CWC Bhubaneswar and Visakhapatnam send the bulletins to ACWC, Kolkata/ Kolkata Radio and ACWC, Chennai/ Chennai Radio respectively.

12.4.1. Format of Coastal Weather Bulletin

As in the case of sea area bulletins, the coastal weather bulletin is issued twice daily based on 03 & 12 UTC in normal weather, thrice a day based on 03, 12 & 18 UTC in case of depression/deep depression stage and 5/6 times a day at 00, 03, 06, 09, 12 & 21 UTC in cyclone stage. In undisturbed weather, the two bulletins issued are based on 0300 and 1200 UTC charts and they are called Daily One and Daily Two, corresponding to Aurora and Balloon sea area bulletins. However, during periods of disturbed weather, when Extra, Storm or Special sea area bulletins are issued, corresponding coastal bulletins are also to be issued for the particular coast which is likely to be affected, necessitating the hoisting of signals of LC-III and above at the ports. If local weather along a coast is not affected by the disturbance, additional coastal bulletins for the coast need not be issued. Each bulletin (*Daily*, *Extra*, *Storm* and *Special*) contains the following information in the order given below:

(1) Name of coastal Strip
(2) Synoptic system, if any, affecting the weather over the coastal strip and its movement in the case of depressions and cyclonic storms.
(3) Period of validity of forecast.
(4) Forecast of wind, weather, visibility and state of sea for the coastal strip.
(5) Information about storm warning signals, if any, hoisted at ports on the coastal strip concerned.
(6) Information on storm surges/tidal waves (whenever necessary).

Government of India
India Meteorological Department

Regional Meteorological Centre,Alipore, Kolkata - 700027

DAILY ONE BULLETIN FOR ANDAMAN AND NICOBER COAST: Dated - Friday 24/07/2020

South West monsoon weak over Andaman sea.

Forecast valid from 10:00 UTC to 22:00 UTC of 24/07/2020

WIND:	Southwest to Westerly; 05 to 10 knots.
WEATHER:	Rain or thundershower very likely to occur at many places.
VISIBILITY:	08 to 06 reducing to 04 km in rain.
SEA CONDITION:	Smooth.
PORT WARNING:	Nil.

TOO :12:30 IST 24/07/2020

Duty Officer

Area Cyclone
Warning Centre,
Kolkata
24/07/2020

DAILY ONE BULLETIN FOR WEST BENGAL COAST:: Dated - Friday 24/07/2020

A trough lies over Northwest Bay of Bengal.

Forecast valid from 10:00 UTC to 22:00 UTC of 24/07/2020

WIND:	Mainly south westerly; 15 to 20 knots.
WEATHER:	Rain or thundershowers very likely to occur at most places with heavy rain at one or two places.
VISIBILITY:	08 to 06 reducing to 04 km in rain.
SEA CONDITION:	Slight to Moderate .
PORT WARNING:	Nil.

TOO:12:30 IST 24/07/2020
Duty Officer
Area Cyclone Warning Centre, Kolkata 24/07/2020

12.5. Fleet forecast for Indian Navy

Since Naval ships normally do not keep watch on commercial W/T wavelengths andhence do not listen to the broadcasts from the coastal radio stations, separate weatherbulletins for broadcast to the ships of the Indian Navy are issued to the Naval W/T stations.The bulletins that are issued exclusively for broadcast to Indian Naval ships are called the Fleet Forecasts.They are issued twice daily, corresponding to Aurora and Balloonsea area bulletins. The offices which issue the Fleet forecasts and their areas of responsibility are shown in Fig. 12.4 and Table 12.3.

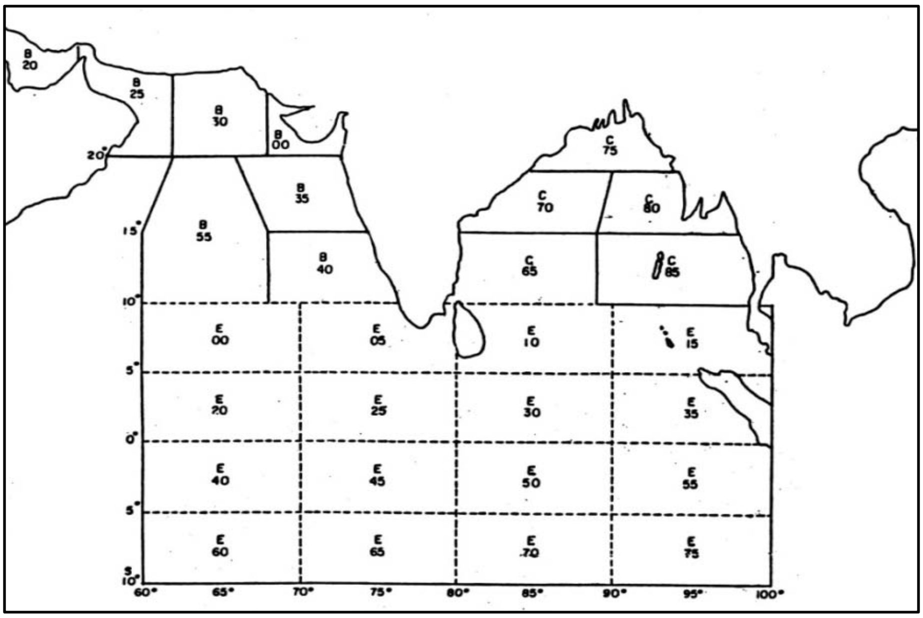


Figure 12.4. Map showing areas for fleet forecast issued by IMD

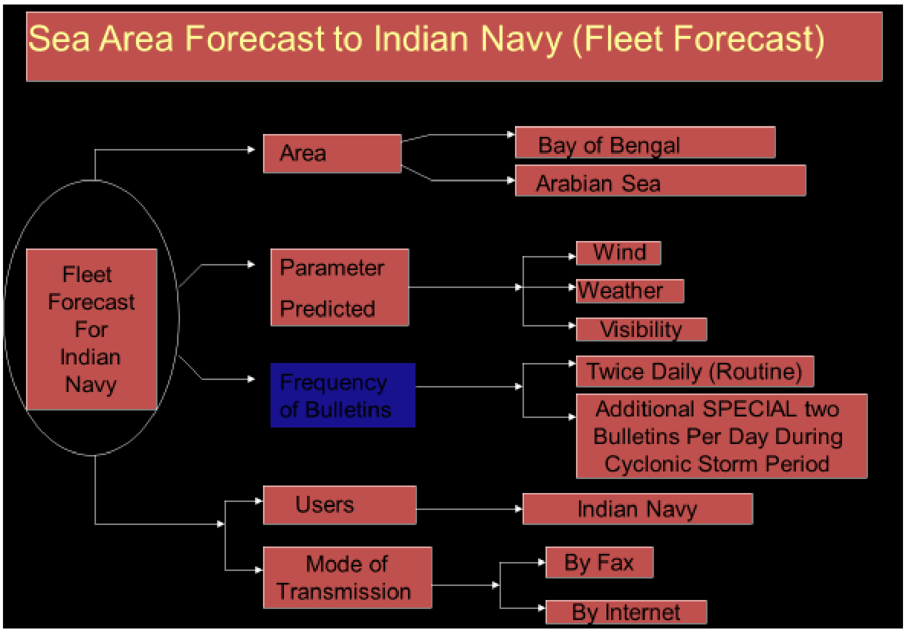
Table 12.3.

Area of responsibility for fleet forecast

S. No.	Office of issue	Area of responsibility	Sub-areas
1.	ACWC Mumbai	Arabian Sea to the north of Lat. 5°N and East of Long.60°E, Gulf of Oman and Persian Gulf	B 00, 20, 25, 30, 35, 40, 55 & E 00, 05
2.	ACWC Kolkata	Bay of Bengal and Andaman Sea to the north of Lat. 5°N	C 65, 70, 75, 80, 85 E10 and West half of E 15.
3.	Marine Division (NWFC) New Delhi	Indian Ocean between Lat.5°N and 10°S and Long.60°E and 100°E	E 20, 25, 30, 35, 40,45, 50, 55, 60, 65, 70,75.

12.5.1. Contents of Fleet Forecast

The Fleet Forecast is in plain language and contains a brief general inference for the area including warnings. In the case of Bay of Bengal and Arabian Sea, the inference will confirm to the *Aurora* and *Balloon* bulletins issued by ACWCs Mumbai and Kolkata. The forecast covers surface wind, visibility and state of sea and an *outlook* for the next 12 hours. Fixed times of origin are given to the Fleet Forecast messages – 0800 UTC in the case of day bulletin and 1700 UTC in the case of the night bulletin. These Fleet forecasts are broadcast by Naval W/T station, Mumbai, during weather broadcast periods commencing from 0930 UTC and 1830 UTC respectively. Fleet Forecast messages should be brief with the view that the requirements of ships at sea are principally wind (direction and speed) and visibility and hence the area forecasts must contain only these two elements and their variations. The central pressure is given from Storm stage upwards. The two daily forecasts are valid for 12 hours from 1000 UTC and 2200 UTC respectively. Outlook for next 12 hours in clear terms from the termination of the forecast period should be appended to both day and night bulletins as a routine. When weather conditions are reasonably stable, the evening forecast may be abbreviated with reference to the previous morning forecast.



12.5.2. Mode of Transmission of Fleet Forecast to Naval W/T Mumbai

ACWC Kolkata and MSD, New Delhisend their Fleet Forecasts to ACWCMumbai through Departmental telecommunication channels and also through e-mails. These Fleet Forecasts together with the one issued by ACWC Mumbai are transmitted to Naval W/T Station, Mumbai, through the Naval Met.Office, Mumbai.

12.6. *Warnings to Ports*

12.6.1. Port warnings are issued by Cyclone Warning Division in New Delhi in association with ACWCs and CWCs at different locations along Indian coast.

12.6.2. The office of responsibility is given below:

(1) ACWC Kolkata: West Bengal Coast, Andaman and Nicobar Islands
(2) ACWC Chennai: Tamil Nadu coast
(3) ACWC Mumbai: Maharashtra coast and Goa coast
(4) CWC Bhubaneswar: Odisha Coast
(5) CWC Visakhapatnam: Andhra Pradesh Coast
(6) CWC Thiruvananthapuram: Kerala coast, Karnataka Coast and Lakshadweep Islands
(7) CWC Ahmedabad: Gujarat Coast

12.6.3. Hoisting of signals

A uniform system of storm warning signals was introduced at all the ports in India from 1st April 1898 and it is still in vogue with very little changes. The salient features of the system are described below:

(i) General System

A General System with eleven signals (Table 12.4); the first two of which (signals No. I and II) indicate the existence of distant disturbed weather, the next eight (signals III to X) indicate that the port itself is threatened by bad weather and the last one (signal No. XI) Indicates that the communication with the ACWC/CWC had broken down and that in the opinion of the local Port Officer, there is danger of bad weather. Signals No. I and II are called Distant Signals and the rest Local signals. The ports where this system of signals is in use are called General Ports.

(ii) Extended System

An Extended System which in addition to the eleven signals of the General System, has six Section signals (Details are given in Cyclone Manual) to indicate the location of the disturbance. These additional signals are hoisted along with Distant Signals. This system is a special case of the General System and is in use only at a few ports on the east coast (Bay of Bengal). These ports are: Sagar Island, Kakinada, Chennai, Cuddalore and Nagapattinam. These ports are called Extended Ports. There is no port under the Extended System on the west coast.

(iii) Brief System

A Brief System of portwarning consisting of only five of the signals of the General Systems (viz. Signal Nos. III, IV, VII, X and XI) is also in practice in ports frequented mainly by smaller vessels engaged in local traffic and these ports are called Brief Ports. These are hoisted in association with prospects of bad weather at the port itself caused by disturbances out at sea.

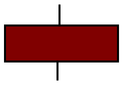
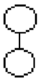
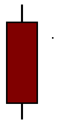
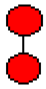
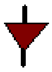
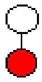
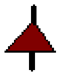
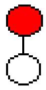
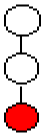
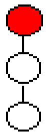
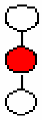
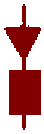
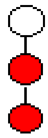
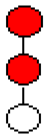
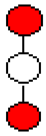
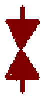
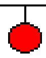
(iv) Ports without Signals

In addition, there are some minor ports where no signals are hoisted but which get a special type of warning message; they are called Ports without signals. For purposes of warning, these ports are treated as Brief ports and corresponding port warnings are issued when adverse weather threatens them although no signals are advised to be hoisted. These warning messages will contain information on the location, intensity and direction of movement of the disturbance and the expected weather over the port.

The India Meteorological Department (through the ACWCs/CWCs) maintains a port warning service by which the port officers are warned by telefax about disturbed weather likely to affect their ports. On receipt of the warning bulletin from the ACWC/CWC, the port officers hoist appropriate visual signals prominently on signal masts so that they are visible from a distance. Mariners and other sea-faring people, including fishermen who may not be literate, are generally aware of the meaning of these signals and the port authorities are always ready to explain them whenever necessary. At some ports, the meanings of the signals are displayed in English as well as in the local languages prominently on a notice board. While the India Meteorological Department is responsible for issuing the warnings, the port authorities arrange the display of signals. In addition to hoisting the signals, the port officers in most cases, make arrangements for disseminating the warnings received by them, to country craft and sailing vessels in the harbours. The port warning signals (general system) used in India are shown in Table 12.4

Table 12.4.

Port Warning Signals (General System) used in India

Signal/Flag No.		NAME	Symbols		Description
			Day	Night	
1	DISTANT BAD WEATHER	DC1			Depression far at sea. Port NOT affected.
2		DW2			Cyclone far at sea. Warning for vessels leaving port.
3	LOCAL BAD WEATHER	LC3			Port Threatened by local bad weather like squally winds.
4		LW4			Cyclone at sea. Likely to affect the port later.
5		D5			Cyclone likely to cross coast keeping port to its left.
6.	DANGER	D6			Cyclone likely to cross coast keeping port to its right.
7.		D7			Cyclone likely to cross coast over/near to the port.
8.		GD8			Severe cyclone to cross coast keeping port to its left.
9.		GD9			Severe cyclone to cross coast keeping port to its right.
10.	GREAT DANGER	GD10			Severe cyclone to cross coast over or very near to the port.
11.		XI			Communication failed with cyclone warning office.

12.6.4. Frequency of Issue and contents of Port Warning Bulletin

Ports in the maritime States are warned 5 to 6 times a day during periods of cyclonic storm by telefax. The warnings contain information about the location, intensity and expected direction of movement of the storm or depression, the part of the coast where it is expected to strike and the type of signal which the port should hoist. As landline communication between the port and the CWC may break down during a cyclone, provision exists for using state and inter-state police W/T channels wherever available for passing on the warnings.

12.6.5. Format for Port Warning

Port Warning No.

Date and Time for Issue

(i) Information on cyclone: The cyclonic storm lay over Bay of Bengal/Arabian Sea near Lat.__/Long. ____ at a distance _______ km. from __________ at ______ IST _____ Estimated Central Pressure _______ hPa.
(ii)Forecast:

Further intensification:
Direction of Movement:
Expected Landfall Area :
Expected Time of Landfall :
Advice for hoisting Storm Warning Signals:
Likely impacts and actions : Depending on intensity of the storm as per IMD Monograph on "Damage Potential of Tropical cyclones.

12.6.6. Explanation of the port warnings

By definition and order of priority the port warnings give risk level in an increasing order. It is easy to decode and to use them in an effective way.

DC1 and DW2	–	Indicative of a depression or cyclone at a distance in sea without any immediate weather over the indicated port.
LC3 and LW4	--	Indicative of depression or cyclone at a distance in sea (within 500 km from the respective coasts) with likely squally weather over the indicated port. LC3 is also an indicative of low pressure at sea with likely squally weather over the indicative port.
D5, D6, D7	--	Presence of a cyclone that is likely to affect the port in the increasing order of number
GD8, GD9, GD10	--	Presence of a severe cyclone and above that is likely to affect the port in the increasing order of number
NUMBER XI	–	Communication with the forecasting office is lost for any reason but bad weather is expected. (Irrelevant in the present communication scenario)

It can surely be decided that DC1 and DW2 indicate no bad weather situation, LC3 and LW4 indicate an alert situation, D5, D6, D7 indicate a lower alarm situation and GD8, GD9, GD10 indicate a higher alarm situation.

12.6.7. Meanings of Signals

The meanings of the various signals are given in the above table. Details of the specifications of the visual signals used during day time and lamp signals used during night are given in the departmental publication Code of Storm Warning Signals for use at Indian maritime Ports – Sixth edition, 1984.

(i) Distant Signals : Distant signals are hoisted only at ports under General and Extended Systems and not at Brief ports.

There are two Distant Signals: Distant cautionary signals No. I (DC I) and Distant Warning signal No. II (DW II). DC I is hoisted at a port when the system out at sea is a depression or a deep depression and while the local weather at the port itself is not likely to be affected immediately, ships leaving the port may run into danger during their voyage.

Discretion has, therefore, to be exercised while assessing such a probability, taking into account the location of the weather system out at sea with reference to the port and the estimated direction and speed of movement of the system. When the system has intensified into a storm and still out at sea. Distant Warning signal No. II (DW II) is to be hoisted. If there is a risk of the port itself experiencing bad weather, the appropriate local signal is to be hoisted in preference to the Distant signals. Thus, when a port having a Distant signal is also likely to have squally weather although the depression/storm is still away, the obvious action will be to change the Distant signal to LC-III. Nothing precludes hoisting of LC-III at a port where Distant signal is to be hoisted if the port is expected to have squally weather. In general, when a weather situation warrants more than one signal, the highest numbered signal is hoisted. Unless one of the Local signals is more appropriate and hoisted, the Distant signal is also hoisted at Arabian Sea Ports when a disturbance from the Bay is crossing the peninsula and may develop into a depression/cyclone after entering the Arabian Sea.

(ii) Sections Signals : When a Distant signal (DC I or DW II) is hoisted at an Extended port, an appropriate Section (or Locality) signal must also be hoisted. For the purpose of Locality signals, Bay of Bengal has been divided into six sections as given below :

Section I	:	North Bay area to the north of Lat. 18½^{o}N
Section II	:	West Central Bay – lies south of I and is bounded on the south by Lat. 13^o N and on the east by Long. 88½^{o}E.
Section III	:	East Central Bay – lies south of I and east of II. It is bounded on the south by Lat. 13^{o}N and on the east by a line from the point, Lat. 13^{o}N, Long. 93^{o}E to Diamond Island, the Arakan Coast and thence upto Lat. 18½^{o}N.
Section IV	:	Southwest Bay – lies south of II, and west of Long. 86^{o}E
Section V	:	Southeast Bay – lies east of IV, south of II, III and west of Long. 93^{o}E.
Section VI	:	Andaman Sea – lies east of III and V. The southern boundary for Sections IV, V and VI is lat. 5^{o}N.

(iii) Change In Section Signals : The section signal will be changed when the center of the system moves from one section into another, even if there is no material change in other respects. Similarly, if DC I is changed to DW II or vice versa, Section signals are also to be repeated in the message, even if there is no change in the Section signal(s).

(iv). Number of Section Signals : Generally the Locality signal Number is of that section in which the center of the depression/storm is situated. If, however, the center is near the boundary of a division, two Locality signals are asked to be hoisted, the first indicating the division in which the center is actually situated and the second the division nearest to the first. In the event of a center being near the corner where three divisions meet, three Locality signals are asked to be hoisted, the first indicating the division in which the storm is estimated to be centred, the second the nearest adjoining division and the third, the remaining division. Examples : Storm Centre Locality Signals Lat. 16^{o}N – Long. 86^{o}E II Lat. 16^{o}N – Long. 88^{o}E II and III Lat. 16^{o}N – Long. 89^{o}E III and II Lat. 18^{o}N – Long. 87½^{o}E II, I & III Lat. 19^{o}N – Long. 89½^{o}E I, III & II

(v). Local Cautionary Signal Number Three (LC – III) : LC – III is a signal very frequently hoisted at the ports. It is hoisted at a port which is likely to experience squally weather. Squally weather is meant to cover occasional or frequent squalls with rain or persistent type of strong gusty winds (mean wind speed not less than 20 kt.) accompanied by rain. Such conditions are associated with low pressure systems or onset and strengthening of monsoon. Mean wind speed exceeding 33 kt. associated with cyclonic storms are generally covered by signals higher than LC-III. The significance of the word generally in the previous sentence is to permit the hoisting of LC-III at ports outside the inner storm area where wind speed may exceed 33 kt.

(vi). LC-III In Association with the Monsoon : The general convention not to keep LC-III hoisted too long requires an amplification in the case of squally weather associated with the monsoon. LC-III should be hoisted

(a) when squally weather is expected in the port due to the first advance of the monsoon or

(b) whenever after the monsoon has been established, it is expected to strengthen markedly following a period of weak or moderate monsoon and cause associated markedly squally weather at the port. If the occasions of hoisting this signal are regulated by these considerations, then it will follow that the signal should also remain hoisted for such time as the associated threat of squally weather at the port remains. The criterion followed for hoisting LC-III under condition

(c) above is that the expected wind speed should be 30 kt. or more. This minimum limit of 30 kt has been adopted with a view to restrict the number of occasions on which LC-III will have to be hoisted. The term markedly squally weather will always be used in all such messages. When advice to hoist LC III or to keep LC III hoisted is given to a port, there should be a reference in the message to the likelihood (or continuance) of squally weather at the port, like squally weather likely (or likely continue) at your port next …….. hours. However, in messages to hoist higher signals, no such elaboration is made and the associated weather in such cases is to be inferred by the Port Officer.

(vii). Local Warning Signal Number Four (LW IV) : When a cyclonic storm has actually formed, LW IV is hoisted at ports which could possibly be struck later by the storm, since the existence of a storm can often be determined before its direction of motion can be fixed. It is a preliminary stage when the direction of motion of the system is yet to be fixed with certainty and serves as a prelude to the possibility of Danger or Great Danger signals at a later time. From the specification of the signal, it is evident that LW IV by itself is not associated with any particular severity of weather. When the direction of movement becomes definite (i.e. when the coast and the ports where the storm will strike is indicated in the sea area bulletin), LW IV will be replaced by Danger or Great Danger signals as appropriate at the ports expected to be affected directly by the storm and LC-III at ports where squally weather associated with the storm is expected to prevail.

(viii). Danger and Great Danger Signals : Danger signals are hoisted when the storm is of slight or moderate intensity and Great Danger Signals when the storm is severe. The intensity refers to the intensity of the storm at and about its center and not to the intensity or severity of the weather in different parts of the cyclone. In the circumstances, hoisting of Great Danger signals at some ports and Danger signals at other ports at the same time to convey the varying severity of the effect of the cyclone at the different ports is inconsistent with the existing specifications of the signals. While Danger or Great Danger signals should be hoisted at such ports which will be affected by the inner storm area (where wind speed may exceed 33 kt.), LC – III may be hoisted at the same time at such of the ports outside the inner storm area as may be considered necessary

12.6.8. Some General Rules regarding Signals

12.6.8.1. Signals Confirm to Intensity of Systems : As a general rule, signals have to conform strictly to the existing intensity of the system. If some rapid development is expected, the office should keep a careful and continuous watch on the basis of the special observations and issue suitable modifications as and when necessary. They (the signals) are stepped up or down, as and when necessary, depending upon the intensity of the system.

12.6.8.2. Typical Progression of Signals : A typical progression of signals is the Distant Cautionary (DC I), Distant Warning (DW II), Local Warning (LW IV) and Danger or Great Danger. During such a succession of signals, it is essential that the change from Cautionary to Warning be accompanied by a verbal description of the change of the system from a depression or area of squally weather or disturbed weather to a storm. This progression does not however over-rule the practice of having LC III with the declaration of storm at ports towards which the storm is not heading but which may still experience squally weather. This progression does not also over-rule if occasion demands, the changing of signals by two stages like replacing of DW II by Danger or LC III by Great Danger. Similarly there is nothing to preclude replacing an existing Danger/Great Danger signal by LC-III, when the threat to the port is removed by the system moving away but squally weather is still likely over the port for some more time.

12.6.8.3. Signals not to be Kept Hoisted Longer than Necessary : Signals should not be kept hoisted longer than necessary, so as not to adversely affect the operations at a port. When a storm is crossing or crossed the coast, in general, discretion is allowed in stepping down from Danger signal to LC-III or no signal at all depending upon whether the return of the weather to normal is foreseen to take place through successive stages or quickly. When the system is over land and the port is likely to continue to experience bad weather with same severity, appropriate signals can be kept hoisted at that port.

12.6.8.4. Informatory messages due to Steep Pressure Gradient : Informatory messages are sent to ports about strong winds in association with steep pressure gradients but no signals are hoisted. However, as per local practice at ACWC Kolkata, CWC Bhubaneswar and ACWC Mumbai and CWC Ahmedabad, LC-III is hoisted under such condition also.

12.6.8.5. Informatory Messages for Brief Ports : Informatory messages are also sent to Brief ports without any advice to hoist any signal when disturbances currently out at sea, are likely to affect the ports during the next 48 hours.

12.6.9. Text of Warnings to Ports : Ports under General, Extended and Brief systems should receive warning messages consisting of relevant portions of sea area bulletins along with instructions to hoist the appropriate signals. The port warning messages are expected generally to conform to the radio weather messages issued to shipping. The bulletins issued by ACWCs at Kolkata, Chennai and Mumbai are to be the basis on which port warnings and other action will be initiated by the CWCs at Bhubaneswar, Visakhapatnam and Ahmedabad respectively till the system is picked up by the radars at Paradip, Machilipatnam, Visakhapatnam and Bhuj. For the benefit of ships lying at ports which may not receive sea area bulletins, the central pressure of the system is also included in the port warning messages from the stage of cyclonic storm onwards. The number of the signal to be hoisted is given in plain language to avoid errors in transmission. Similar procedure should also be followed for other items such as latitude and longitude of center of the storm etc. In all messages to ports subsequent to the one advising the hoisting of a signal, the words keep signal number -----hoisted should be mentioned till the signal is lowered or replaced by another signal. The ports without signals also receive messages whenever adverse weather threatens them due to a disturbance. These messages may be similar to the one to the adjoining ports with signals and will contain information on the location and direction of movement of the system and the expected weather over the ports in brief. Only the advice to hoist any signal is omitted in the messages.

12.6.10. Transmission of messages to ports : Port warning messages are normally sent by fax. Immediate telephone calls also are made to Port Officers regarding the disturbed weather at their ports. Police W/T facilities can also be utilized for passing on the port warning messages to such of the ports where Police W/T stations are existing, in the following cases: (i) when the meteorological telecommunication channels have either failed or (ii) when there is a likelihood of the messages getting unduly delayed.

12.7. Frequency of messages to ports for hoisting the signals

12.7.1. For Distant Signals : It is sufficient if ports with Distant signals (DC I or DW II) get a message once a day, usually based on 0300 UTC chart. However, in between, if there is a necessity to change the section to another, fresh messages are to be sent to the concerned Extended ports. Or, if the system changes in intensity from depression to storm (or vice versa), even without change of position necessitating change of signal from DC I to DW II (or vice versa), fresh messages are to be sent to the General and Extended ports concerned.

12.7.2. For LC III Or Higher Signals : When LC III or higher signals are hoisted, the concerned ports should get a message each time a sea area bulletin is issued i.e. thrice a day in the depression stage and at least six times a day when the system is a cyclonic storm.

12.7.3. For Ports without signals : Ports without signals should be informed at least once in 24 hours or whenever there is a change in signals in the nearby Brief port. There seems to be differences in the practice followed at ACWCs Chennai and Mumbai.

12.8. Warnings for Fisheries

12.8.1. Issuing office and area of responsibility

The following offices have the responsibility of issuing warning for fishermen for the respective coast and sea areas indicated against them:

(i) ACWC Kolkata : West Bengal Coast, Northwest Bay of Bengal, Northeast BoB, North &South Andaman Sea

(ii) CWC Bhubaneswar : North& South Odisha coast.

(iii) CWC Visakhapatnam : North& South Andhra Pradesh coast

(iv) ACWC Chennai : North& South Tamil Nadu coast, Comorin Area, Maldives Area, Southeast BoB, Southwest BoB, West Central BoB, and East Central BoB.

(v) CWC Thiruvananthapuram : Kerala Coast, Karnataka Coast, Lakshadweep area, Southwest Arabian Sea and southeast Arabian Sea.

(vi) ACWC Mumbai : North & South Maharashtra Coast, Goa coast, West Central Arabian Sea, East central Arabian Sea

(vii) CWC Ahmedabad : North Gujarat Coast, South Gujarat Coast, northwest Arabian Sea, northeast Arabian Sea.

12.8.2. Criteria for issuing fisherman warning

Fishermen warning should be issued for next five days for the respective coasts of CWC/ACWC with warnings for other coasts and for open sea areas in text format as well as in graphics (Figure 12.7)

1. **Categories of warning** : Hereafter, there will be only one category of Fishermen Warning and should be issued for “not to venture into sea”. Messages with “alert” or “to be cautious” may not be used henceforth.

2. **Wind criterion** : In the presence of low pressure systems below the intensity of depression or in the case of strong Monsoon conditions or when squally weather is expected with **mean wind speed more than 45 kmph** fishermen are to be advised “not to venture into the sea”.

The actual surface wind should be estimated based on the observations from ships, buoys, coastal & island synoptic/ AWS observations and satellite based wind products , like, SCATSAT, ASCAT, WINDSAT, CIMSS etc. The forecast wind will be based on the consensus derived from various numerical models guidance for 10M wind modulated by the consensus arrived through Video Conference among forecasters.

Example: Squally wind speed reaching (i) 40-50 kmph gusting to 60 kmph/ (ii) 45-55 kmph gusting to 65 kmph likely along and off ………coasts and/or over …….sea areas. Sea condition will be very rough. Fishermen are advised not to venture into sea along and off ………coasts and/or into …….sea areas.

3. **High Wave/ Swell criterion** : If high waves/ swell waves (wave/ swell wave/ with significant wave height of 4.0 meter or more corresponding to very rough sea conditions) are forecast by INCOIS, then warning should be issued with text “not to venture into the sea”.

Example: Rough to very rough sea conditions are very likely due to high waves in the range of 3.5 - 5.0 metersduring 17:30 hours on 25-06-2018 to 23:30 hours of 27-06-2018 along the coast of Gujarat from Jakhau to Diu Head. Fishermen are advised not to venture into sea along and off south Gujarat coast during the same period.

4. **Guidance by INCOIS** : Website of INCOIS gets updated once a day around 1730 IST. Whenever there is a high wave/ swell wave alert on their website, the same shall be incorporated in all relevant warning and bulletins originated by all the forecasting offices even in the absence of strong wind conditions.

5. **Presence of Intense low pressure systems** : In case of intense low pressure systems (depression and above), various bulletins should invariably follow the numbered national bulletins issued by RSMC, New Delhi.

6. **Area under warning** : In addition to the coastal areas under the jurisdiction of the forecast issuing office, the relevant sea areas are also to be indicated in the warning text in the interest of the safety of the marine community who travels to open sea or to other coastal areas.Thus, ACWCs, CWCs and coastal MCs shall also incorporate the warnings for the neighbouring coast, or the sector of the sea or open sea in their bulletins in order to warn those fishermen who plan for fishing in distant locations.

7. **Uniformity in Bulletins** : Sea weather conditions should be discussed routinely in the daily Video Conferencing (VC) along with other weather warnings for the mainland. The decisions taken in the morning Video Conference should be invariably followed by all concerned offices. In case, an issuing office feels a change is necessary from the decisions taken in the VC or from the national Bulletin, the same should be done only in consultation with NWFC and concerned CWC/ACWC in order to maintain uniformity in the bulletins nationwide.

8. **Validity period of warnings** : Fishermen warningsare issued with a validity period of five days.

12.8.3. Time and Frequency of issue : Fishermen warning should be issued four times in a day around 0530, 1330, 1730, 2130 hrs IST.

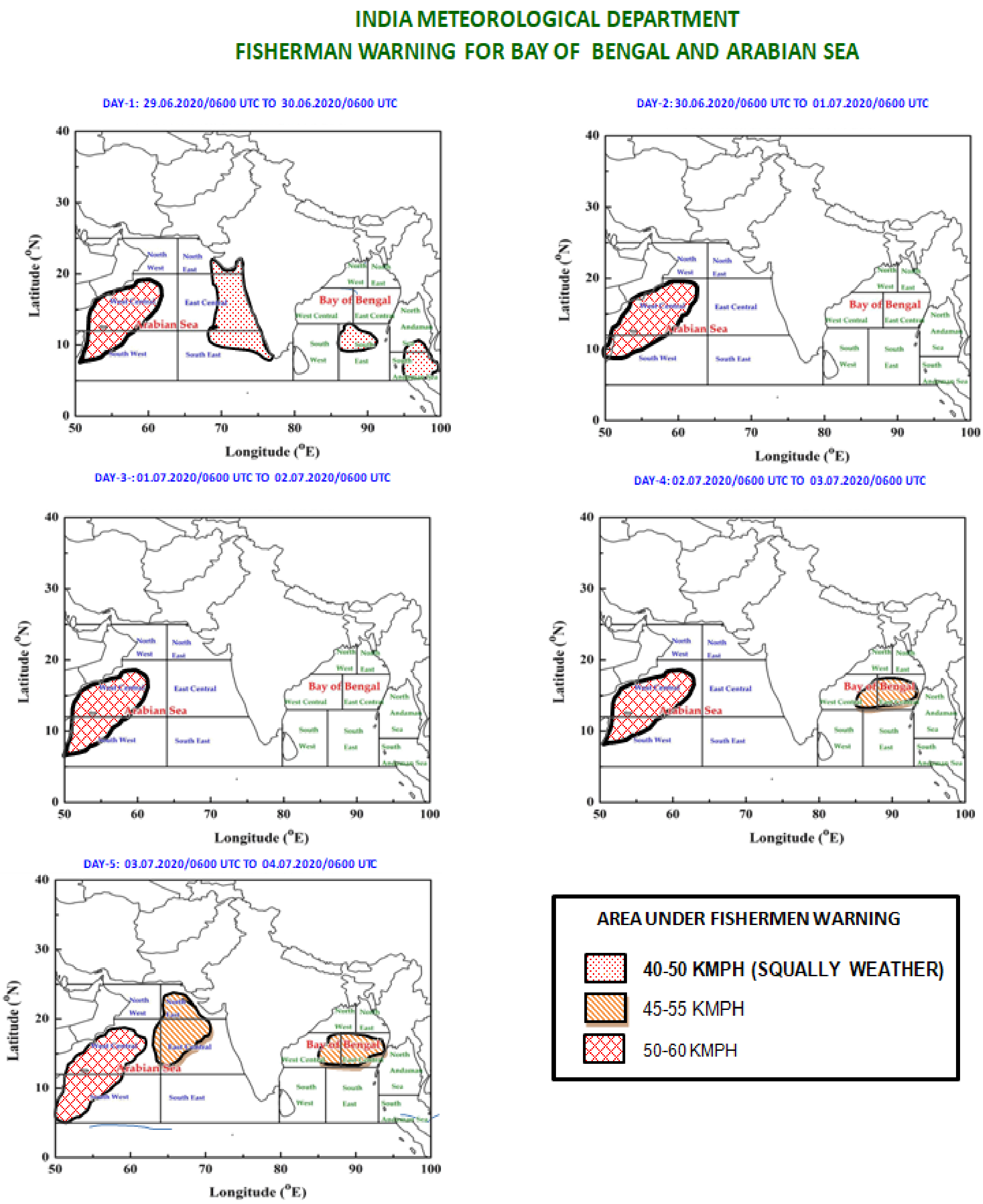


Figure. Shaded areas represents warning for fishermen

12.8.4. Mode of transmission of Fishermen warnings

Warnings for fishing interests are transmitted by landline telegram or over telephone to the AIR stations (about 30 in number) in the maritime states. These warnings are broadcast as a routine four times a day (morning, mid-day, evening and night) from the AIR stations in the local language. During a cyclonic storm, such warnings are covered in the cyclone bulletins sent to the AIR stations at hourly or 3 hourly intervals for frequent broadcast. The fishermen can listen to these broadcasts through portable radio receiving sets.

Warnings through FAX

In addition to warnings broadcast by AIR stations, direct warning messages are also sent by telefax to a large number of officials belonging to the fisheries departments in maritime states.

12.8.5. Format for fisheries Warning

Fisheries warning No. ________________

Date and Time of Issue ______________

Information on Cyclone:
Cyclonic Storm lay over ________________ Bay of Bengal / Arabian Sea at a distance
_______________ kms. _______________ from _________ at ______________ IST on _________________ (date)
Forecast:

Further intensification
Direction of Movement
Expected landfall area
Expected time of landfall
Warnings: Wind, Sea Condition and Tidal Waves
Storm Warning Signals at ports

Advice and Action : i) Fishermen not to venture into open seas
ii) Fishermen at Sea not to come to the ports (names)_____ in coast.
iii) Fishermen to be cautious while going out in the sea
iv) Fishermen are advised to return to coast

12.9. The source of information and products

Following are the products to be consulted/ utilised for the preparation of marine bulletins and warnings:

1.Synergie surface analysis with ship and bouy data plotted
2. IMD GFS site for isobaric analysis, 10 meter wind and also for 10 day forecast
https://nwp.imd.gov.in/diag_all_new.php
3. INCOIS website for Wave, swell information
https://incois.gov.in/portal/osf/osf.jsp
4. ECMWF for 1000 hPa wind, Isobaric analysis, wave and swell forecast (probability forecast also) for significant levels for warnings
https://www.ecmwf.int/en/forecasts/charts/catalogue/swfdp-bengal-bay-swh-mwd?facets=undefined&time=2020073000,6,2020073006 (password protected)
5.In addition, JMA through SWFDP website (https://nwp.imd.gov.in/mme/fdp-bob/login.php) gives forecast of swells for the southern oceans which gives a good indication about the forthcoming episodes in NIO eventhough full areal coverage is not available at present.
6. WINDY website https://www.windy.com/ gives animation of various ocean state forecast products of ECMWF model as well as that of GFS model, in addition to the atmospheric parameters.

12.10. Other products generated by Cyclone Warning Division/ RSMCNew Delhi

Few graphical products which are of relevance to the provision of marine services are developed every six hours based on 00, 06,12 & 18 UTC by the CWD and sent to users when there is a cyclonic storm in NIO. These products are also uploaded on the cyclone page of IMD website.

12.10.1. Ship avoidance guidance

Radius of circle to construct the area of ship avoidance guidance is given in Table 6.6. The radius of this circle is the combination of radius of cone of uncertainty and the radius of gale wind (34 kts or more). Details on all products are available in Cyclone warning SOP.

Table 12.6.

Radius of circle to construct the cone of ship avoidance guidance

F/C Period	Radius (km/nm) of circle to construct cone of ship avoidance
12 hr	Radius of 34 kts wind + 75/40
24 hr	Radius of 34 kts wind + 150/80
36 hr	Radius of 34 kts wind + 200/105
48 hr	Radius of 34 kts wind + 250/135
60 hr	Radius of 34 kts wind + 300/165
72 hr	Radius of 34 kts wind + 350/190

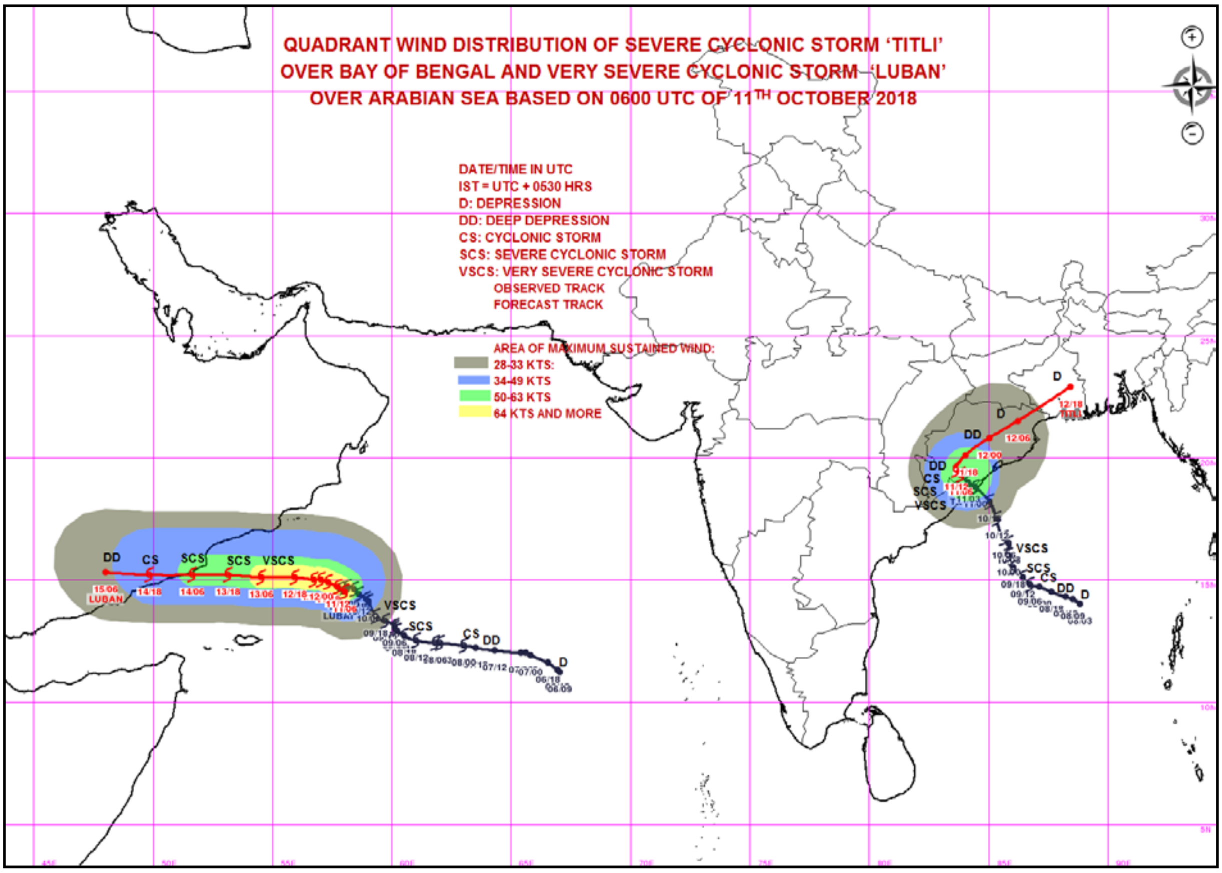


Figure 12.6. Typical example of radii of quadrant wind forecast issued by IMD

12.11. Damage potential and action suggested in the bulletin

The bulletin for India coast during cyclonic storms gives the expected damage and action suggested as given in Table. This contains suggested action for the fishermen community also.

Table 12.7.

Damage potential and action suggested in Bulletin for India coast

Intensity	Damage expected	Action Suggested
Deep Depression 50 – 61 kmph (28-33 knots)	Minor damage to loose and unsecured structures	Fishermen advised not to venture into the open seas.
Cyclonic Storm 62 – 87 kmph (34-47 knots)	Damage to thatched huts. Breaking of tree branches causing minor damage to power and communication lines	Total suspension of fishing operations
Severe Cyclonic Storm 88-117 kmph (48-63 knots)	Extensive damage to thatched roofs and huts. Minor damage to power and communication lines due to uprooting of large avenue trees. Flooding of escape routes.	Total suspension of fishing operations. Coastal hutment dwellers to be moved to safer places. People in affected areas to remain indoors.
Very Severe Cyclonic Storm 118-167 kmph (64-90 knots)	Extensive damage to kutcha houses. Partial disruption of power and communication line. Minor disruption of rail and road traffic. Potential threat from flying debris. Flooding of escape routes.	Total suspension of fishing operations. Mobilise evacuation from coastal areas. Judicious regulation of rail and road traffic. People in affected areas to remain indoors.
Extremely Severe Cyclonic Storm 168-221 kmph (91-119 knots)	Extensive damage to kutcha houses. Some damage to old buildings. Large-scale disruption of power and communication lines. Disruption of rail and road traffic due to extensive flooding. Potential threat from flying debris.	Total suspension of fishing operations. Extensive evacuation from coastal areas. Diversion or suspension of rail and road traffic. People in affected areas to remain indoors.
Super Cyclone 222 kmph and more (120 knots and more)	Extensive structural damage to residential and industrial buildings. Total disruption of communication and power supply. Extensive damage to bridges causing large-scale disruption of rail and road traffic. Large-scale flooding and inundation of sea water. Air full of flying debris.	Total suspension of fishing operations. Large-scale evacuation of coastal population. Total suspension of rail and road traffic in vulnerable areas. People in affected areas to remain indoors.

12.12. Terminologies in the bulletins

Some of the important terminologies used in the bulletins pertain to description of sea condition, amount/ intensity of heavy rainfall, distribution of rainfall etc. are presented in following Tables.

Table 12.10.

State of Sea

Descriptive Term	Height Metres	Wind Speed Knots (Kmph)	In Beaufort Scale
CALM (GLASSY)	0	0	0
CALM (RIPPLED)	0 - 0.1	1 - 3 (2 - 6)	1
SMOOTH (WAVELESS)	0.1 - 0.5	4 - 10 (7 - 19)	2 - 3
SLIGHT	0.5 - 1.25	11 - 16 (20 - 30)	4
MODERATE	1.25 - 2.5	17 - 21 (31 - 39)	5
ROUGH	2.5 - 4.0	22 - 27 (41 - 50)	6
VERY ROUGH	4.0 - 6.0	28 - 33 (52 - 61)	7
HIGH	6.0 - 9.0	34 - 40 (63 - 74)	8
VERY HIGH	9.0 - 14.0	41 - 63 (76 - 117)	9 - 11
PHENOMENAL	OVER 14	64 or above (119 or above)	12

Table 12.11.

Distribution of Rainfall

Distribution	No. of Places	Description
Isolated	Isolated/One or two places	<25% of area gets rainfall
Scattered	A few places	(26 –50)% of area gets rainfall
Fairly Widespread	Many places	(51 – 75)% of area gets rainfall
Wide Spread	Most places	(76 – 100)% of area gets rainfall

Table 12.12.

Intensity of Rainfall

Descriptive term used	Rainfall amount in mm
No rain	0.0
Very light rain	0.1- 2.4
Light rain	2.5 – 15.5
Moderate rain	15.6 – 64.4
Heavy rain	64.5 – 115.5
Very heavy rain	115.6 – 204.4
Extremely heavy rain	≥204.5
Exceptionally heavy rain	When the amount is a value near about highest recorded rainfall at or near the station for the month or season. However, this term will be used only when the actual rainfall amount exceeds 12 cm.

12.13. Marine impact of cyclonicstorms

S. No.	Intensity	Strength of wind (kmph/knots)	Satellite 'T' No.	Condition of Sea	Wave height (m)
1.	Depression	(i)(31- 40)/(17-21) (ii)(41- 49)/(22-27)	1.5	Moderate Rough	1.25-2.5 2.5-4.0
2.	Deep Depression	(50–61)/(28-33)	2.0	Very Rough	4.0-6.0
3.	Cyclonic Storm	(62–87)/(34-47)	2.5-3.0	High	6.0-9.0
4.	Severe Cyclonic Storm	(88-117)/(48-63)	3.5	Very High	9.0-14.0
5.	Very Severe Cyclonic Storm	(118-167)/(64-90)	4.0-4.5	Phenomenal	Over 14.0
6	Extremely Severe Cyclonic Storm	(168-221)/(91-119)	5.0–6.0	Phenomenal	Over 14.0
7.	Super Cyclonic Storm	222/120 and more)	6.5 and more	Phenomenal	Over 14.0

12.14. Nomograms : Following nomograms are to be used in case of non-availability of model outputs:

12.14.1. For wave height estimation:

Wind speed in (knots)	Corresponding estimated significant wave height (meter)
5-10 kt	0.5-1 m
10-15 kt	1-2 m
15-20 kt	2-3 m
20-25 kt	3-4 m
25-30 kt	4-5 m
30-35 kt	5-6 m

12.14.2. Nomogram for visibility estimation in rain

Visibility products are not very common. Hence for estimating visibility in areas of rain the following table is used:

Spatial distribution of rainfall	Estimated visibility
Wide spread	3-2 nautical miles (NM)
Fairly wide spread	4-3 NM
Scattered	6-4 NM
Isolated	8-6 NM
Fair	10-8 Nm

12.15. Product generation

During the morning Video conferencing with the regional forecasting offices (ACWCs), Marine Division will propose the sea areas and coasts for issuing warnings and type of warning based on the actual observations and analyses and also based on the model forecast. The regional offices/ ACWCs/ CWCs will put forward their points and a consensus would form on the expected development of major weather systems and related warnings for the forthcoming 5 days. In case of a possible development of a low pressure system, the marine products should be the same as that of the national bulletins issued by the Cyclone warning Division.

Chapter 13

Meteorological Communication & Early Dissemination

13.1. Introduction

All disaster emergencies and crisis events are by nature chaotic and highly dynamic, creating physical, emotional and social disorder. In such crisis events and emergencies, timely communication of information to all stakeholders is critical at all phases of disaster management. Communications during disaster weather events incorporates a wide range of measures to manage risks to communities and the environment. Communicating information from various data sources that include observations like surface, upper air, satellites, radar and remote sensing etc., early warning is made possible. Before disasters strike, telecommunications can be used as a conduit for disseminating information about the impending danger thus, making it possible for government agencies and people to take the necessary precautions and measures to mitigate the impact of the hazards.

Major weather events such as Tropical Cyclones, Earthquakes, Heavy rainfall, Floods, Drought, Heat / Cold wave warnings are disseminated to various users through telephone, fax, e-mail, SMS, Global Telecom System (GTS), WMO Information System (WIS), All India Radio, FM & community radio, Television, Social media (facebook, whatsapp, twitter, Youtube, Instagram) and other print & electronic media, press conference & press release. These warnings/advisories are also put on the website **(www.rsmcnewdelhi.imd.gov.in and www.mausam.imd.gov.in)** of IMD HQs and concerned MCs/CWCs. Another means to transmit warning is IVRS (Interactive Voice Response system). It is functioning with effect from July 2000. The requests for weather information and forecasts from the general public are automatically answered by this system. One can access current weather and forecast for major Indian cities by dialing Toll-free number 1800 220 161. Presently a centralized IVRS is catering the weather information of major cities. India Meteorological Department has taken various initiatives in recent years for improvement in the dissemination of weather forecast and warning services based on latest tools and technologies. Since 2009, IMD has started SMS based weather and alert dissemination system through AMSS (Transmet) at RTH New Delhi. To further enhance this initiative, India Meteorological Department has taken the leverage of Digital India Programme to utilize “Mobile Seva” of Department of Electronics and Information Technology (DeitY), Ministry of Communication and Information Technology; Govt. of India for SMS based Warnings /Weather information dissemination for a wide range of users. The SMS based cyclone alert to the registered users including public was inaugurated on 25thDecember 2014. Global Maritime Distress and Safety System (GMDSS) message is also put in RSMC, New Delhi website (URL: www.rsmcnewdelhi.imd.gov.in) as well as transmitted through GTS. The WIS Portal –GISC New Delhi is another system for cyclone warning dissemination. The user can access the warning messages through the -URL: http://www.wis.imd.gov.in. IMD has also started issuing of NAVTEX bulletins for the coastal region along east as well as the west coast of India for the operation of lightships and fishermen from 30th March 2016.

In addition, the SMS-based alert/warnings are issued to registered farmers through Kisan portal of Govt. of India (Ministry of Agriculture) and to registered fishermen through Indian National Centre for Ocean Information Sciences (INCOIS), Hyderabad also.

IMD is also working in collaboration with ISRO for disseminating the SMSs to fishermen in deep seas through GAMES and NAVIK systems.IMD also working with WMO and NDMA for disseminating the warning through CAP (Common Alerting Protocol).IMD is also working in collaboration with NEGD, Department Of Electronics And Information Technology for disseminating warning via UMANG mobile app. IMD has also established new cyclone warning centre at Thiruvananthapuram w.e.f. October, 2018 to improve dissemination of warnings and advisories for the states of Kerala, Karnataka and Lakshadweep Islands.

Figure 1. Overview of Information System

13.2. Automatic Messaging Switching System (AMSS)

India Meteorological Department has a very extensive Telecommunication network with a Regional Telecom Hub (RTH) in MausamBhavan, New Delhi and Four Regional Automatic Message Switching Systems (AMSS) at Palam, Kolkata, Mumbai, Chennai, airports.

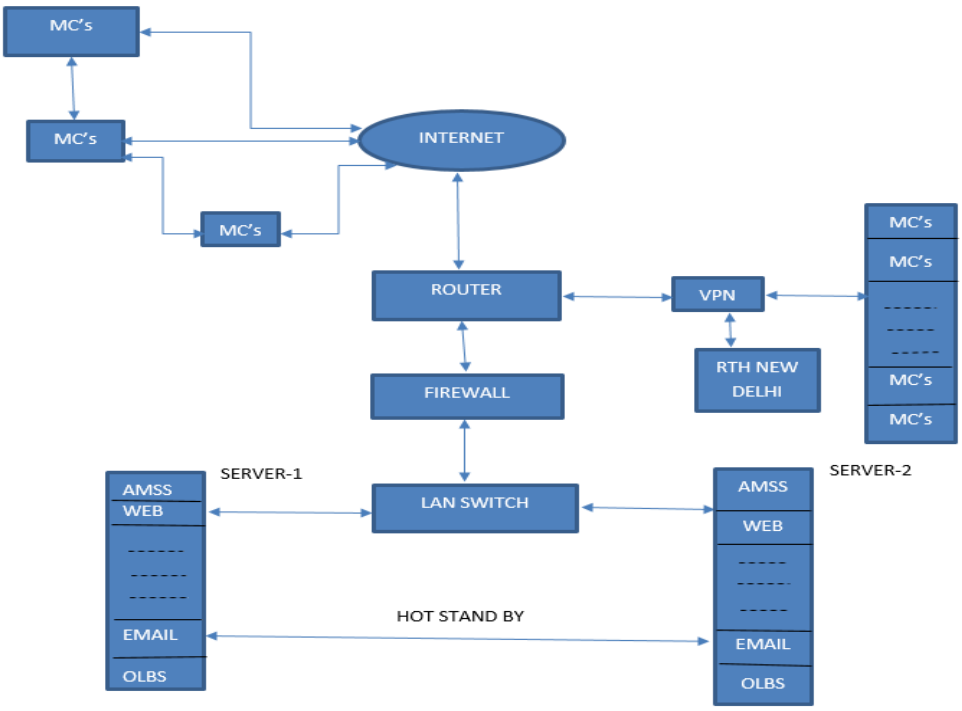


Figure 2. Data Flow of AMSS

These Four AMSS are connected to the GTS (Global Telecommunication System), the central hub of WMO through RTH New Delhi. RTH New Delhi is one of the 15 designated RTHs and three World Meteorological Centre (WMCs) on the Main Telecommunication Network (MTN) of the GTS for exchange of meteorological data and products globally. These six AMSSs are also connected to the AFTN (Aeronautical Fixed Telecommunication Network) for the exchange of operational meteorological messages (OPMET). The responsibility of these AMSS, therefore, is to collect and exchange the meteorological data and products from the various observatories, meteorological centres (MCs), Meteorological offices(Airports), Radar Stations(i.e. DWR) and other institutions under their control among themselves and to WMO/ICAO member countries through RTH New Delhi / AFTN network.

IMD being the national meteorological service provider provides the meteorological services to all the aviation operators at all the major airports. IMD is also providing aviation meteorological services to the aviation operators through dedicated automated pre-flight information systems for briefing, consultation, flight planning and flight documentation **(OLBS)** from AMO Palam (Delhi) & AMO Chennai since 2012-2013.

Table 1

Types of Data received in AMSS

S. No.	Data Type	Data Volume per day (MB)	Volume per month (GB)	Format of Data
1.	Satellite	82172	2407.4	**HDF/BUFR**
2.	Satellite	350	10.3	**GIF/JPEG**
3.	Radar	23552	690	**NETCDF/BUFR**
5.	NWP	17264640	505800	**GRIB**
6.	Cyclone	200	5.9	**TEXT**
7.	Marine	1	0.03	**TEXT**
8.	NWFC	140	4.1	**TEXT**
9.	Observation • Surface • Upper Air • Aviation Data • Buoy Data	500	14.6	**TEXT/BUFR**

Table 2

Types of Bulletins transmitted through GTS

S. No.	Bulletins	Frequency	Received from
1.	Tropical Cyclone RSMC Bulletin	(i)Depression – When felt necessary (ii)Deep Depression and Cyclone formation – Every 3 hourly	Cyclone Warning Division (CWD)
2.	Tropical Cyclone Advisory TCAC Bulletin	Every 6 hourly	Cyclone Warning Division (CWD)
3.	National Cyclone Bulletin	During Cylcone Every 3 hours	National Weather Forecasting Centre (NWFC)
4.	Quadrant Wind	During Cylcone Every 3 hours	National Weather Forecasting Centre (NWFC)
5.	Tropical Weather Outlook	Once in a day	National Weather Forecasting Centre (NWFC)
6.	India Weather Bulletin (IWB)	Twice a day	National Weather Forecasting Centre (NWFC)
7.	GMDSS Bulletin	(i)During Normal times - Twice a day (ii) During Cyclone – Special GMDSS bulletin issued in addition to twice a day.	Marine Meteorology Division
8.	Morning Air News	Once a day	National Weather Forecasting Centre (NWFC)
9.	Satellite Bulletin	Every 3 hourly	Satellite Application Unit

- **Main components of Communication System –**
    - **Central Information Processing System (CIPS):** High end database management system having task centre to develop, test and operationalize meteorological tasks for real time generation of meteorological products.

- **Transmet:** Automatic Message Switching System (AMSS) to receive, check and route the meteorological data and products according to WMO standards/requirements.
- **Public Weather System (PWS):** To deliver High quality weather products and alerts to end users like print media and Television.
- **Clisys:** Climatological data storage system with scalable management tool for effective utilization of these data.
- **Synergie:** Decision support system for forecasters to gather, visuslize, interacts and value adds meteorological forecasts and products.

The Mirror RTH at Pune is functional to act as Disaster Recovery Centre (DRC) which would be able to take over all the responsibilities of RTH New Delhi in case of any catastrophe at RTH New Delhi. This will also function as WMO WIS GISC for South East Asia and cater to all data needs for Indian users and all other WMO GISC centres in real time with 24 hours cache for all data.

Procedure for submission of data to RTH New Delhi

Step 1: open the IP address in your web browser 125.21.185.16

Step 2: 1st login: user XXXXX
password: XXXXX

2nd login: user ID: XXXXX
password: XXXXX

Step 3:

After login go to the created message

Step 4: Go to blank to the right .The following screen will open.

Step 5: You can enter the data to send directly to RTH New Delhi.

Contact Details for RTH/AMSS

Mr. Y. S. Tandale, MET-A	91-9421679421	yashwant.tandale@imd.gov.in	RTH, CRS, IMD, Shivajinagar, Pune - 411005
D. S. PAI, Sc-'F'	91 9422313758	sivapai@hotmail.com ds67.pai@imd.gov.in	
Fax	91 20 25535435	sivapai@hotmail.com	
Phone	91 20 25535877		
AMSS, RMC Kolkata			
Shri Sourav Adhikary, Sc.-'F'	9433126234	s.adhikary@imd.gov.in	Office Address: MWO Kolkata, NSCB International Airport, Dum Dum, Kolkata, West Bengal 700052
	033-2511 9434		
AMSS Mumbai			
Mr. V. RathinaSamy, Met."B"	9890801693 022-26829415 / 022-26819671	rathinas61@yahoo.co.in	Meteorological Office Mumbai, New ATS Complex, Sutarpakhadi Road, Near Cargo Complex, Andheri (East), Mumbai : 400 099.
AMSS DELHI	9643419638	kushvir.singh@imd.gov.in	
Mr. Khushvir Singh, Sc-'E'	1143824255		
AMSS CHENNAI			
Mr. L. K. Rangarajan, Met."A"	9840686693	aviationreturns@gmail.com	Airport Meteorological

	04422560790		office, ATS Complex, Meenambakkam, Chennai-27
The i/c of AMO Chennai			
N. M. Nathan, Sc-'E'	9444645020044 -22345388(O)	email: nathan.imd@gmail.com	
AMSS GUWAHATI			
Ashish Kumar, Sc-'C'	8474062988	ashish.kumar85@imd.gov.in	RMC, L.G.B.I Airport, Guwahati - 781015
off No.	0361-2840243		
AMSS Nagpur			
Brajesh Kumar Kanaujjya, Sc-'C'	9643963212 7122288544	brajesh.kanaujiya@imd.gov.in	

13.3. Availability of data

As per WMO guidelines past 24 hours data is available in RTH/AMSS. Data is not supplied to any user directly from RTH/AMSS. Real time Data is shared with all NHMS of WMO member countries.

13.3.1. VPN Circuits

Fifty Seven, IMD stations are connected with IPVPN connectivity speeds ranging from 512kbps to 10mbps. These VPN circuits are connected with Synergie Systems at various out stations, Doppler Weather Radar Stations, AMSS Centres and Regional Centres.

13.3.2. IVRS

India Meteorological Department has been rendering its services to the public in many sphere of their life by providing weather related information/ forecast/ alert/ warnings including earthquake reports. In order to serve general public in a better way, IVRS facility of IMD has been providing the weather services on telephone catering the weather information of major cities in India successfully for the last fifteen years . Presently a centralized IVRS is catering the weather information as well as air quality information of major cities. One can access current weather and forecast for major Indian cities and air quality of some selected cities by dialing Toll free number 1800 220 161.

13.3.3. Internet Services

At present IMD HQ has two independent Internet leased links of 150 Mbps from different Internet service providers. IMD is also connected to 1 Gbps NKN (National Knowledge Network) link of NIC for internet, data exchange within Close User Group (CUG), Video conferencing &Telepresence services. The new upgraded LAN with latest state-of-the-art technology has more than 1500 nodes to accommodate increased voluminous data/product flow interruptedly at IMD HQ. In the new set up, DGM Building (MausamBhawan),Sat.Met. Building, Workshop, DDGM (UI) building, RMC New Delhi Building, Trainee‟s Hostel and EREC Building connected under ring using new technology switches with 10 Gbps optical fibre backbone support to provide high availability of LAN as well as high volume of data flow.

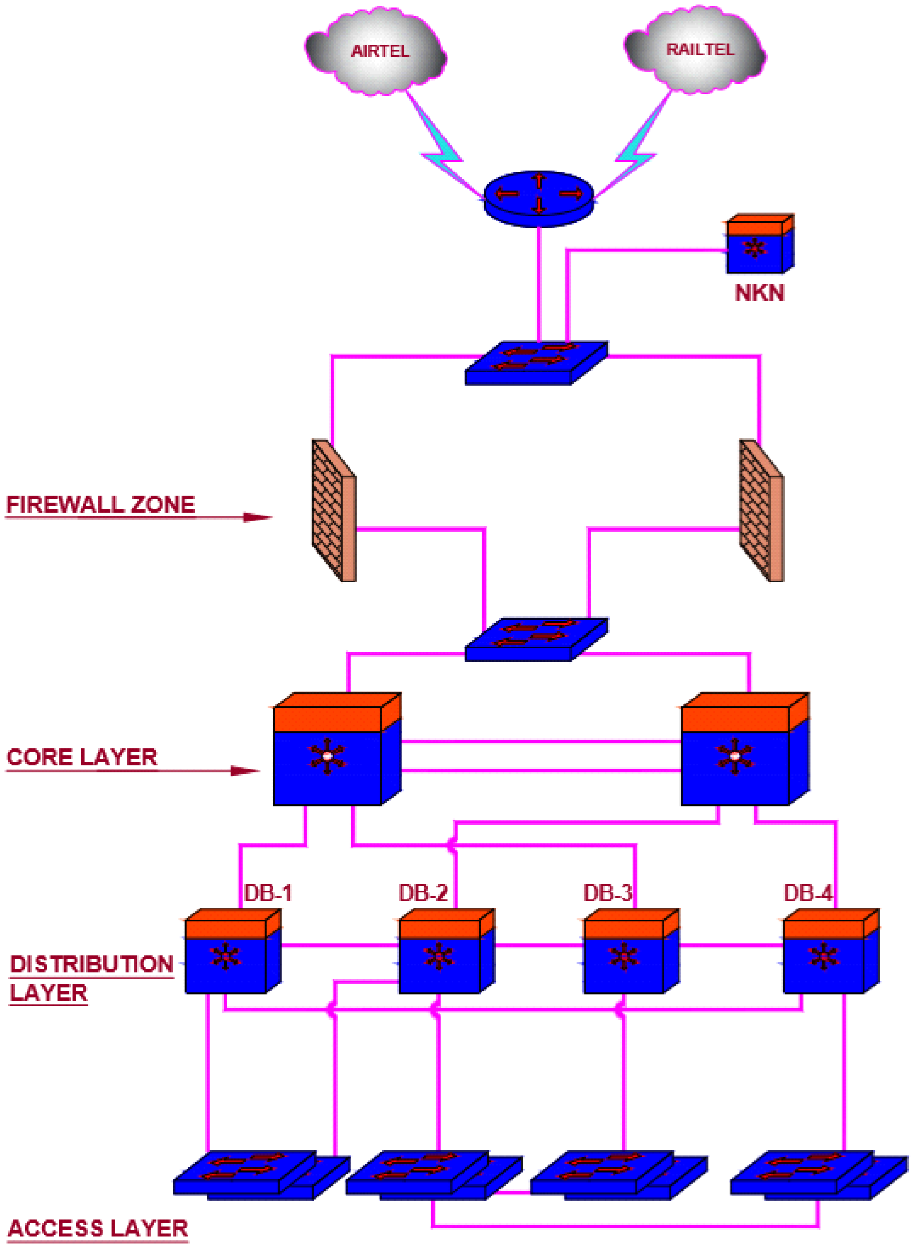


Figure 3. Network Diagram of IMD, New Delhi

13.4. Global Maritime Distress and Safety System (GMDSS)

India has been designated as an issuing authority under the GMDSS program for Meteorological Area VIII (N). This covers the area of the Indian Ocean enclosed by the lines from Indo-Pakistan frontier in 23°45'N 68°E; 12°N 63°E, thence to Cape Gardafui; the east African coast south to equator, thence to 95°E to 6°N, thence to the Myanmar / Thailand frontier in 10° N 98° 30' E.

India Meteorological Department is transmitting daily two GMDSS bulletins for Met. Area VIII(N), one at 0900 UTC and other at 1800 UTC. During Cyclone Season additional bulletins (4) are also being issued for GMDSS broadcast depending on the requirement. GMDSS: INMARSAT (International Maritime Satellite Organisation) operates a constellation of geo-stationary satellites designed to extend phone, fax and data communications all over the world. Land Earth Station (LES) at Gaziabad.

13.5. World Information System (WIS)

The WMO Information system (WIS) is the single coordinated global infrastructure responsible for the telecommunications and data management functions. It is the pillar of the WMO strategy for managing and moving weather, climate and water information in the 21st century. WIS provides an integrated approach suitable for all WMO Programmes to meet the requirements for routine collection and automated dissemination of observed data and products, as well as data discovery, access and retrieval services for all weather, climate, water and related data produced by centers and Member countries in the framework of any WMO Programme.
WIS is an enhanced information system capable of exchanging large data volumes, such as new ground- and satellite-based systems, finer resolutions in numerical weather prediction and hydrological models and their applications. These data and products must be available to National Hydrological and Meteorological Services, but also national disaster authorities for more timely alerts where and when needed. WIS will be the vital data communications backbone integrating the diverse real-time and non-real-time high priority data sets, regardless of location.

Existing centres within WMO Member States that comply with the required WIS functions and technical specifications will be designated as one of the three types of centres forming the core infrastructure of WIS:
Global Information System Centres (GISCs):

https://www.wmo.int/pages/prog/www/WIS/centres_en.html
Data Collection or Production Centres (DCPCs): https://www.wmo.int/pages/prog/www/WIS/centres_en.html

National Centres (NCs):
https://www.wmo.int/pages/prog/www/WIS/centres_en.html

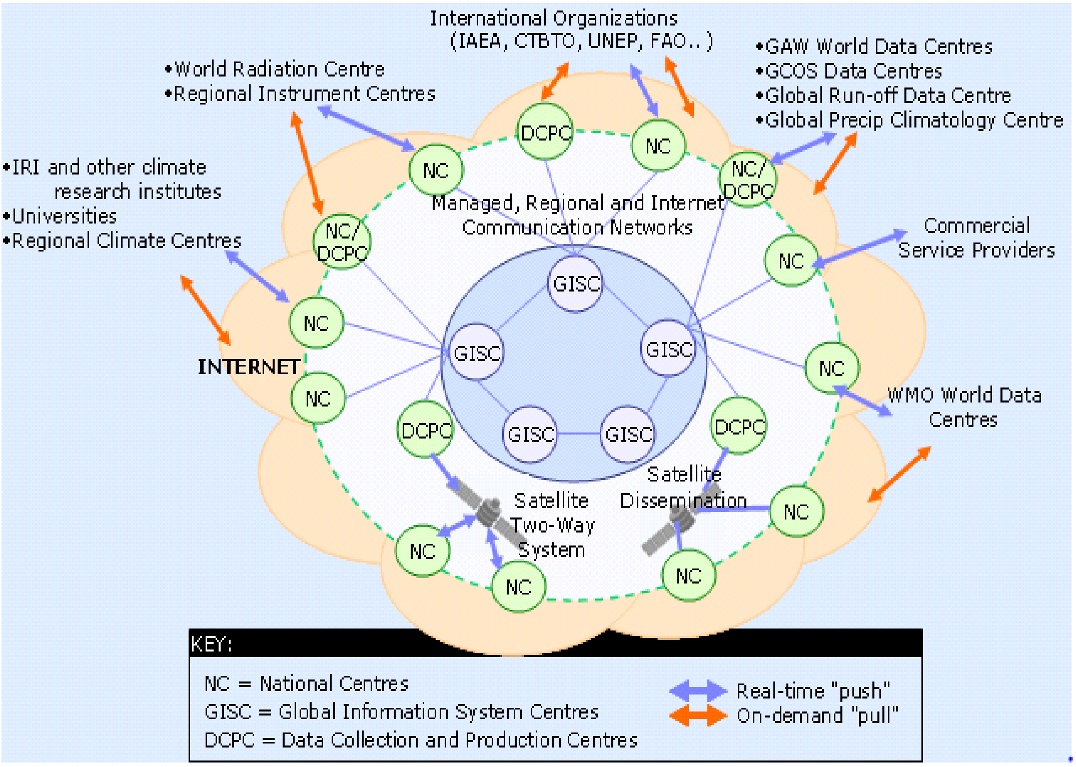


Figure 4. Diagram showing WIS core components and Information Exchange

- **Procedure to Access WIS and fetch Data**

WIS is configured to allow Self-Registration; the Register menu appears on the header of the main page of url:http://www.wis.imd.gov.in

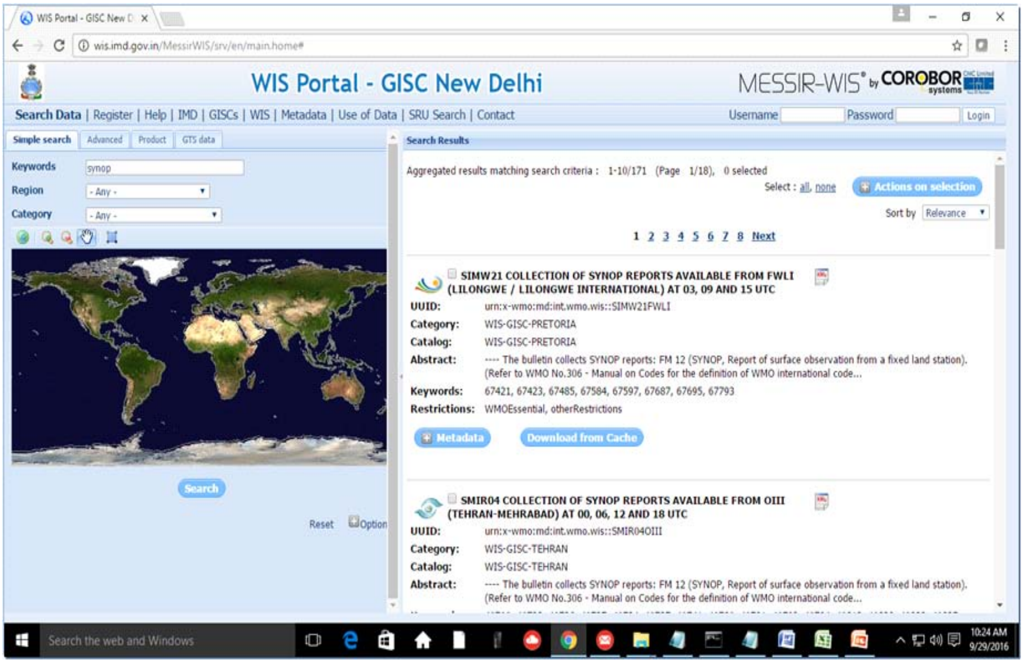


Figure 5. Data Portal of WIS/GISC New Delhi

13.6. On line Briefing System (OLBS) at Chennai & Delhi (Palam)

IMD being only authorized meteorological service provider provides the meteorological services to all the aviation operators at all the major airports. Earlier the service was provided manually and switched to online services w.e.f. 2008 on test basis. As the service got well appreciation from Aviation operators, IMD started Online Meteorological services through dedicated OLBS from AMO Palam and AMO Chennai since 2012-2013.
The URL to access the Aviation data and products are as follows
OLBS delhi: https://olbs.amssdelhi.gov.in/
OLBS Chennai: https://olbs.amsschennai.gov.in/

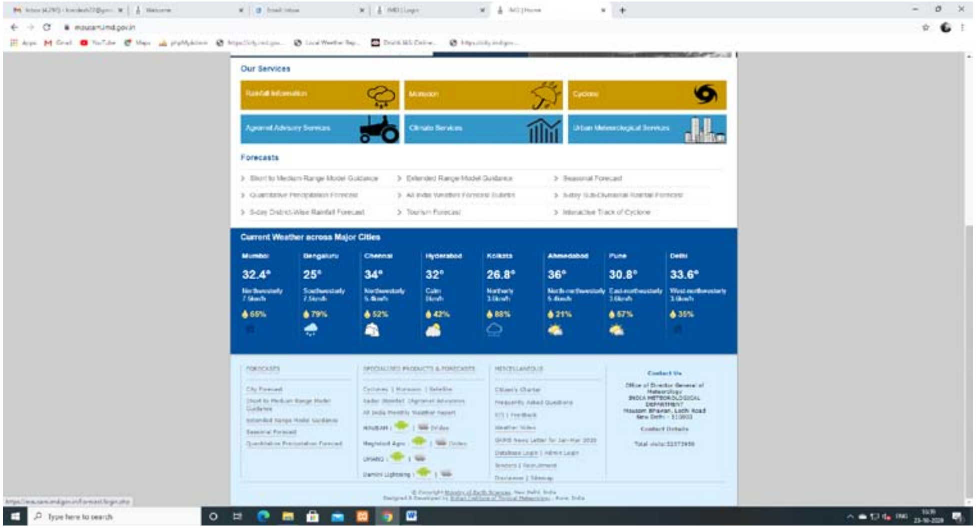
The user can register to access the system and IMD will approve the same after following formalities.

13.7. Warning System In India Meteorological Department

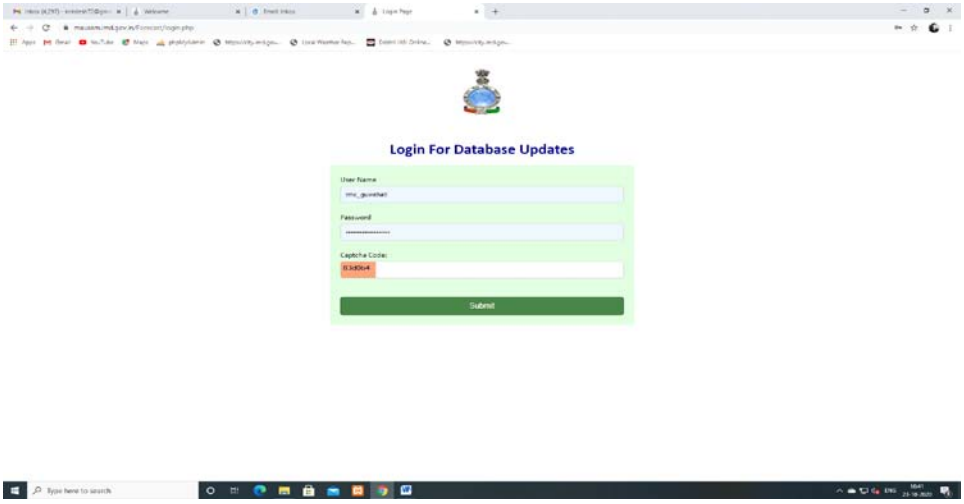
India Meteorological Department (IMD) issues warnings and alerts on high impact weather events such as Tropical Cyclones, Thunderstorms and Heavy Rainfall etc. The warning procedure comprises of a 3-tier system, viz., warnings and forecasts issued at the National, Regional and State levels by the National / Regional / State Weather Forecasting Centres (NWFC/RWFC/SWFCs), Cyclone Warning Division at New Delhi, Area Cyclone Warning Centres (ACWCs) and local Cyclone Warning Centres (CWCs), Flood Meteorological Offices (FMOs), Seismological Division at New Delhi etc. Different warnings pertain to different stakeholders such as National and State level Disaster Management Authorities, Civil Administrators, NGOs involved in disaster management, Ports, Hydrologists, Mariners and Fishermen. The modes of dissemination of warnings vary from time to time depending on advances in the IT industry and at present warnings are disseminated through email, fax, website etc. In addition to IMD websites, public warnings are disseminated through the press, SMS, radio and television media. It also varies depending upon the type of hazard and the stakeholder.

- <u>**Procedure for updating cityweather, nowcast and warning data**</u>

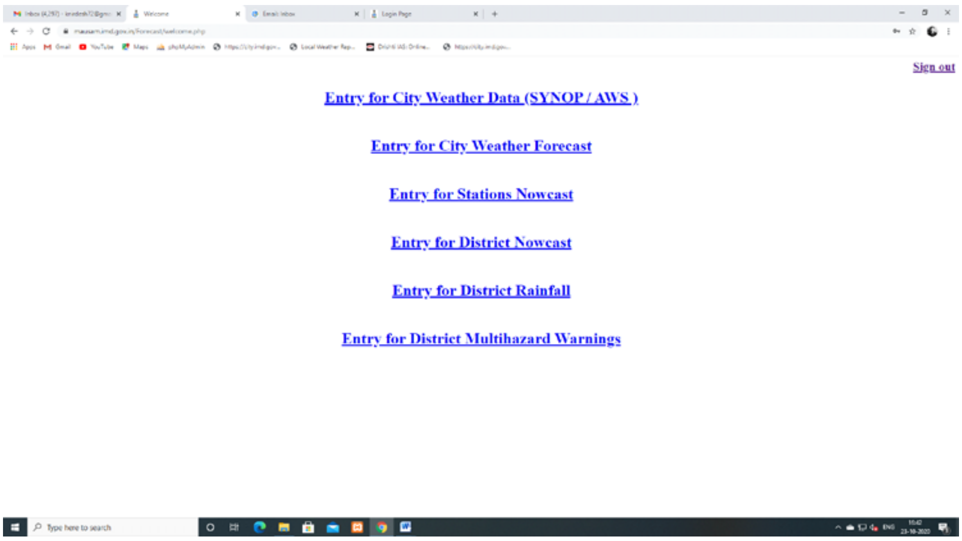
- Open the **mausam.imd.gov.in** website in your browser and click the **database login** tab in the footer section.



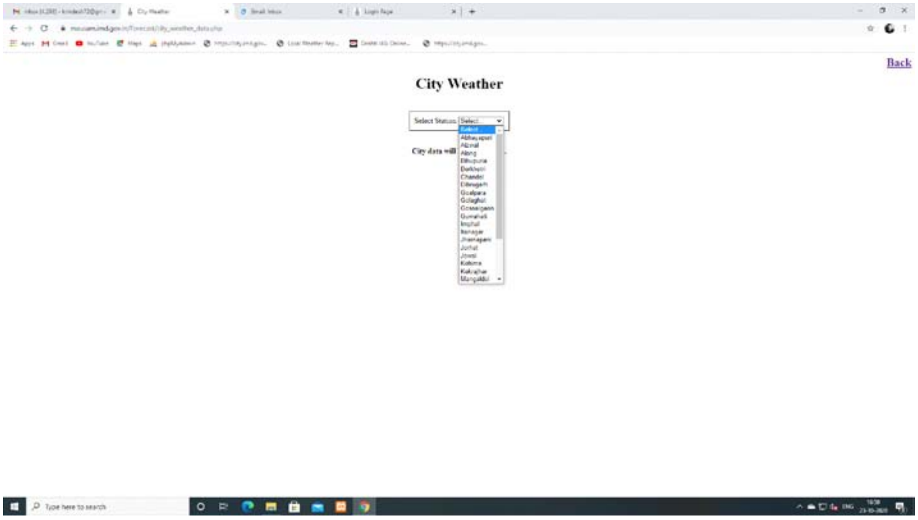
- Fill the login details for the particular RMC or MC.



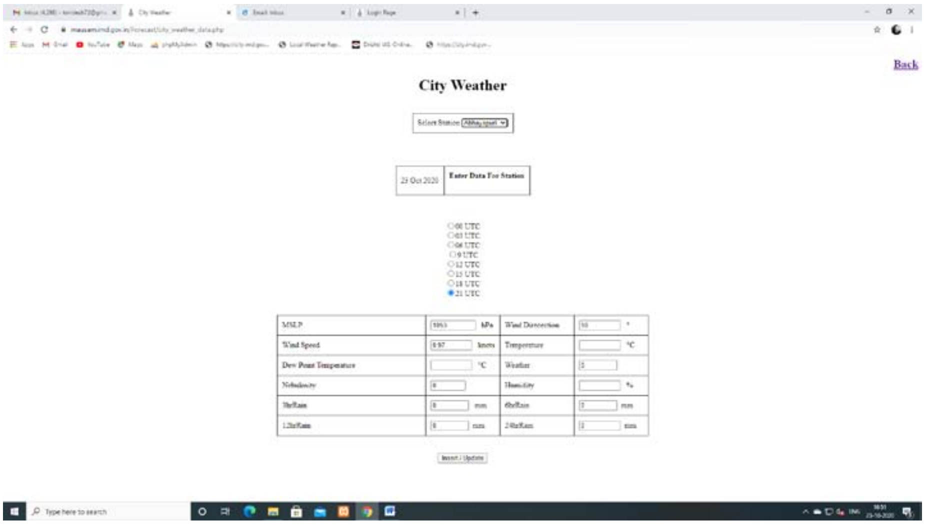
- After login the data for cityweather, nowcast and warning can be updated through the available options.



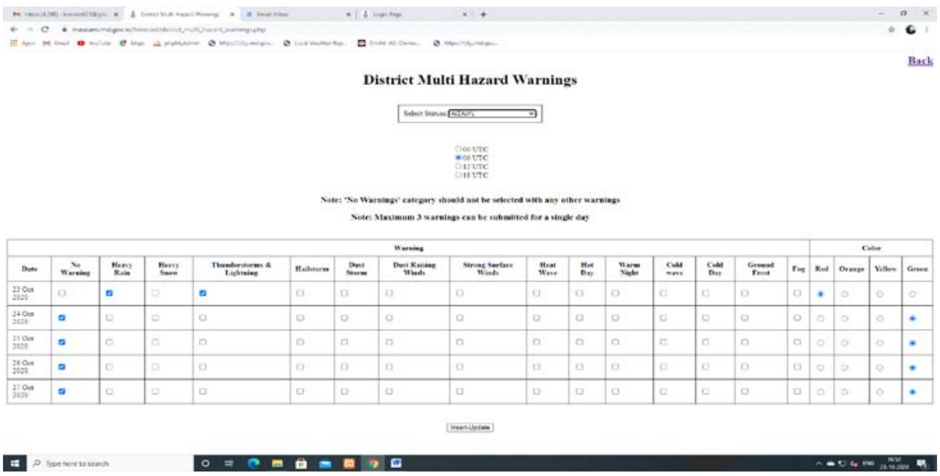
- For updating cityweather data: click the cityweather tab and select any city from the list.



- Insert the data in the table for the selected city and update it.



- For updating warnings data: click the warnings tab and select any city from the list. Insert the data in the table for the selected city and update it.



13.8. Telecommunication Infrastructure

GTS links with Regional Telecommunication Hub (RTH) New Delhi consists of 18 international circuits. It manages 6Mbps IPVPN link with Tokyo, Moscow, Beijing, Toulouse, Exter and Offenbach; whereas Yangon, Oman, Colombo, Male, Bhutan, Kathmandu, Cairo, Jeddah and Melbourne through 150 Mbps internet (at New Delhi end). Other international links Bangkok, Dhaka and Karachi are operating at 64 Kbps leased line. Communication links established at RTH New Delhi are shown in Fig.5.

Functioning as National Meteorological telecommunication centre (NMTC), India Meteorological Department maintains its dedicated networks for exchange of meteorological data/ information with other centres. At present, nationwide main communication link is IPVPN with 10Mbps at NMTC New Delhi and 512Kbps/1Mbps at various other centres, Radar stations. 8Mbps leased link with Indian Air Force (IAF) and 2 Mbps link with Indian Navy (IN) has been established to continuously exchange data. Also, 1Gbps NKN CUG link has been established with NCMRWF, IITM, INCOIS and other institutes of MoES for information exchange.

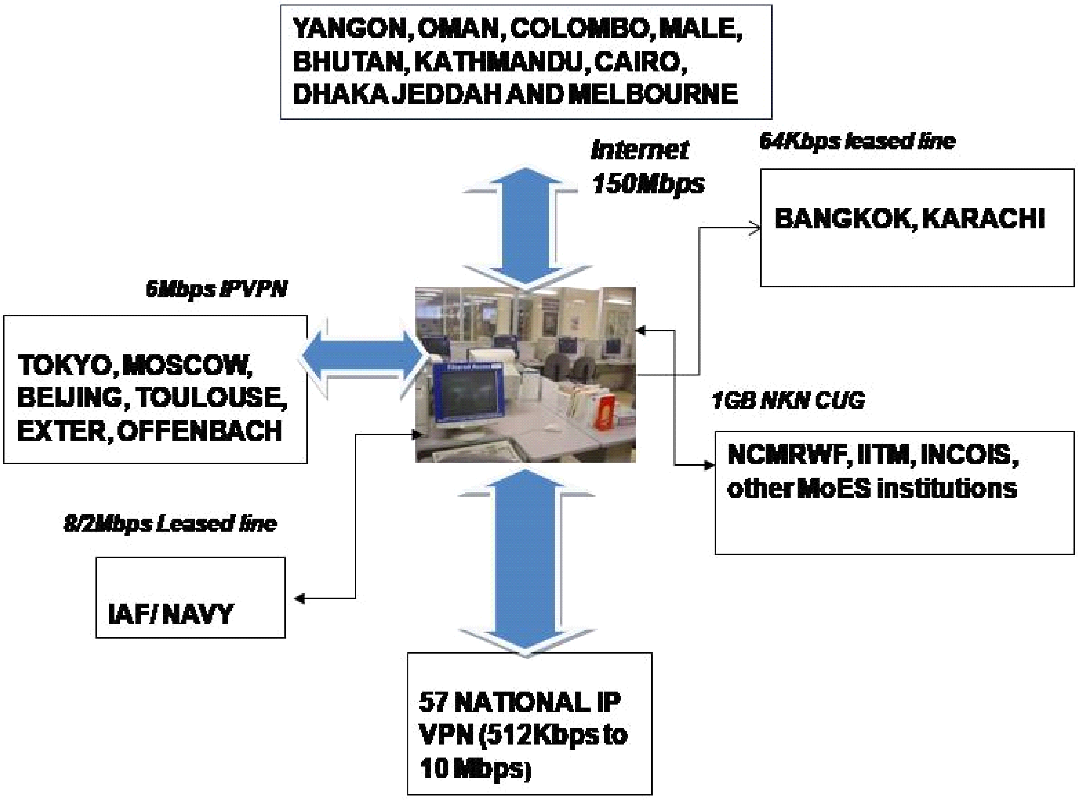


Figure 6. Telecommunication Infrastructure of IMD

Meteorological data and processed products containing half hourly INSAT images, surface and upper air data, aerodrome forecast, weather charts and model outputs etc. exchanged over GTS. A receive only Satellite Data Dissemination System (SADIS) is in operation at New Delhi to receive aeronautical meteorological information from International Civil Aviation Organization (ICAO) Centres which are routed to four International Airports of India for National and International flight briefing and for providing data in GRIB/BUFR format for wind/temperature and Significant weather charts.

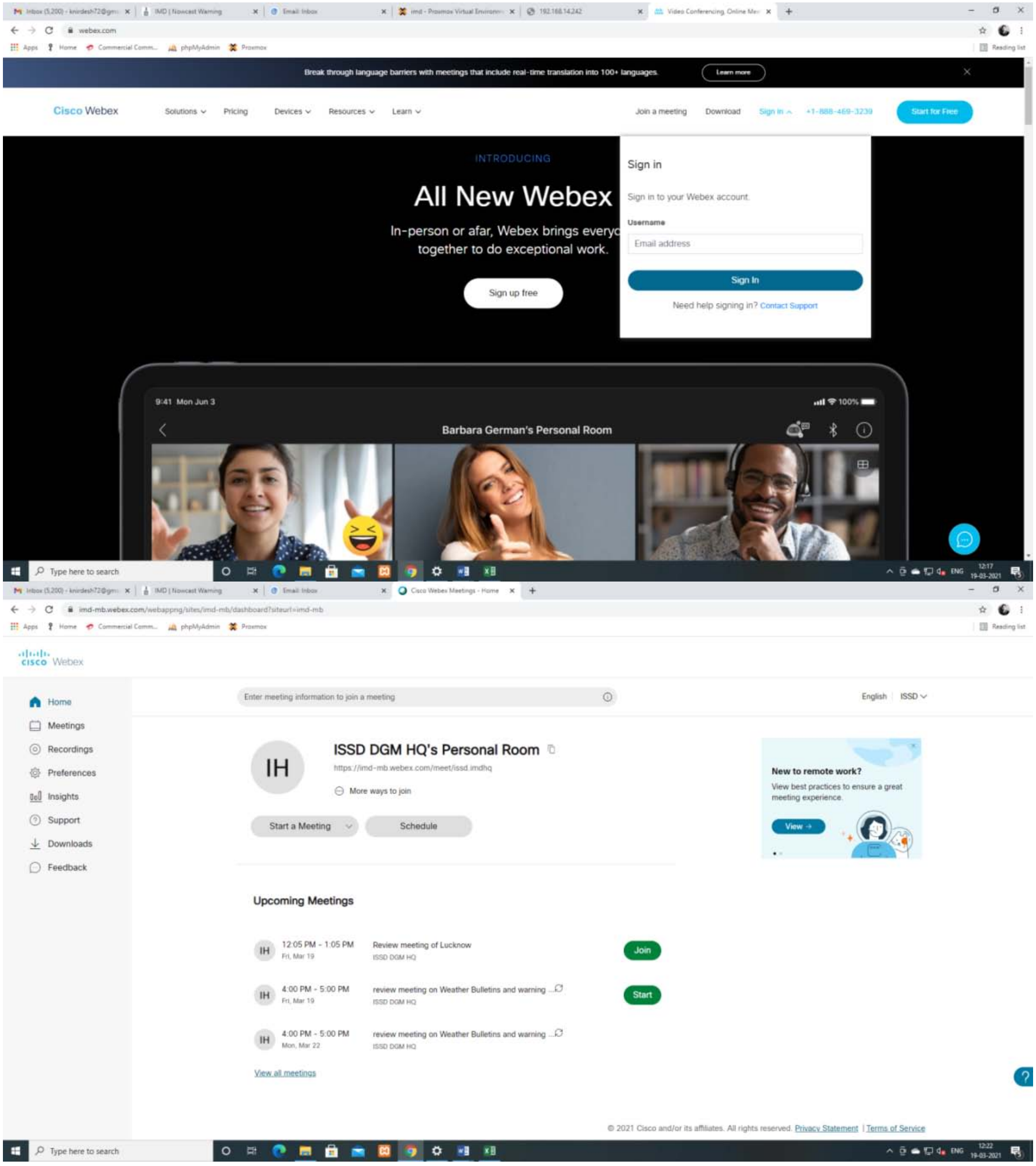
13.9. Video-Conferencing Network

The HQs/RMCs/MCs have provided with Cloud based Desktop Videoconferencing licences from CISCO WebEx. Each licence provides for creating two parallel VC rooms, each room having a limitation of 1000 participants. The administrator of each licence can configure the VC schedules at their choice. List of licences is shown below:

	First Name	Last Name	Display Name	Email	Status
	CRS	Pune	CRS Pune	crs-pune@imd.gov.in	Active
	ISSD	DGM HQ	ISSD DGM HQ	issd.imdhq@imd.gov.in	Active
	MTI Pune	Agromet Pune	MTI Pune Agromet Pune	mtipune@imd.gov.in	Active
	RMC	Mumbai	RMC Mumbai	nitha.ts@imd.gov.in	Active
	RMC	Nagpur	RMC Nagpur	ml64.sahu@imd.gov.in	Active
	RMC	Chennai	RMC Chennai	acwc.rmcchennai@imd.gov.in	Active
	RMC	Kolkata	RMC Kolkata	ddgm.rmckolkata@imd.gov.in	Active
	rmc.delhi	rmc.delhi	rmc.delhi@imd.gov.in	rmc.delhi@imd.gov.in	Active
			sanjay.shaw@imd.gov.in	sanjay.shaw@imd.gov.in	Active
			icitrg.centre@imd.gov.in	icitrg.centre@imd.gov.in	Active

Figure 7. Web interface software accounts used for Video Conferencing

- **Procedure for scheduling the VC:**VC scheduling is done through the following url: https://www.webex.com/ by logging in with required credentials.



13.10. Website of IMD

The India meteorological department has mainly two Websites with URL **http://www.mausam.imd.gov.in and http://www.rsmc.imd.gov.in** containing all the forecast and warning related static & dynamically updated information.

All warnings related to cyclone, heat wave, cold wave are displayed in front page with detailed analysis of warnings. IMD websites contain huge information for public awareness. All satellite imagery, Radar images, NWP products, Nowcast imagery, Cyclone Warning etc. updated regularly in IMD webpage for pubic to give updated information at regular intervals.

Table 3

Website Update Report

	Types of Bulletin/Reports/Warnings	**Frequency of updation**
Weather Information	All India Weather Inference	Thrice in a day
	All India Weather Forecast	Thrice in a day
	All India Weather Warnings	Once in a day
	Weekly Weather Report	weekly
	Extended Range Outlook	fortnightly
	Marine Weather Bulletins	Once in a day
	Now cast Warnings	3 Hourly
	T-Phi Grams	Hourly
	City Weather	3 Hourly
Specialized Forecasts	Tourism Forecast	Hourly
	Highway Forecast	Hourly
	Mountain Weather Bulletin	Once in a day
	ChardhamYatra	Twice in a day
	ShriKailashMansarovarYatra	Once in a day
	ShriAmarnathJiYatra	Twice in a day
	Mata Vaishno Devi Yatra	Twice in a day
Satellites Products	Infrared/Visible/Water Vapor	Half Hourly
Radar Products	25 Radars	Every 10 Minutes
Cyclone	(i)Depression – When felt necessary (ii)Deep Depression and Cyclone formation (iii) During Cyclone Landfall	3 Hourly 3 Hourly Hourly
Miscellaneous	Press Release	as and when required
	Conference/Workshop/Seminar	
	Tenders/RFI/EOI	
	Advertisements/Notices	
	Crowd sourcing	

- **Crowd-sourcing**

India Meteorological Department (IMD) has launched its crowdsourcing web interface and the link is available @ (https://city.imd.gov.in/citywx/crowd/enter_th_datag.php).The same is available mausam.imd.gov.in as a heading 'Public Observation".

13.11. EPBAX

IMD has an AIRTEL CENTREX system installed at MausamBhawan in different office/ sections in six main buildings, a workshop and guest houses with in its campus and some limited telephone connections in IMD residential campus. The system has 400 working extensions including direct dialing lines. The telephone numbers and email ids of senior officers of IMD are given in Annexure-I.

13.12. FTP Server

The Information System and Services Division has ftp server to exchange the realtime meteorological data to the users. The user can upload/download the data using the approved credentials.

The user can request access the data to the following email address rthnewdelhi4@gmail.com mentioning the details requirements along with organization name ect. to get the credential for accessing the data.

13.13. ICITC

ICITC caters to the needs of training in IT, Meteorological Instruments and Telecommunications for HR develpment of IMD officials.

A formal training course started in 1977 to train IMD personnel. In mid seventies, training at New Delhi for Upper Air Instrumentation and Meteorological Telecommunication started. The WMO Executive Council at its thirty-eighth session approved the designation of the training facilities of India Meteorological Department at New Delhi and Pune as WMO Regional Meteorological Training Centre (RMTC) for the Regional Association II (Asia) & V in the year 1986.

Commitments

- **Departmental commitment** : To impart training at different levels to the IMD personnel including ab-initio training to newly recruited departmental officers and staffs.
- **Extra departmental/national commitment** : To impart advanced instrumentation training to the officials of other Govt of India Organizations.
- **International commitment** : To impart training at different levels to the operational Meteorologists of the neighboring countries in RA-II & V region under WMO regional co-operation programme.
- Continuing Education and training programme (CET): Imparting summer/winter training to the Engineering students time to time
- **Faculty development** : RTC New Delhi conducts different faculty development training programmes to update their Knowledge, Skill and Attitude.

To fulfill the commitments, RTC organise following training courses:

- **Regular Courses**

- Level-I Course in IT & Meteorological Telecommunication (3 months duration)
- Intermediate Training Course in Meteorological Instrumentation and Information Systems (4 months duration : one month self study & three month class room study)
- Advance Training Course in Meteorological Instrumentation and Information Systems (6 months duration : one and half month self study & four month class room study)
- Semester – II of Meteorologist Grade – II (Sc. B) Instrument Training Course

- **Short Term Courses**

1. Familiarization Course in IT & Meteorological Telecommunication Techniques (1 Month Duration)

2. Short Term Course For Mechanics / Radio Mechanics (3 Weeks Duration)

3. Short Term Course in Fundamentals of IT & PC Applications (1 Month Duration)

(i) RTC also organize outreach programme to communicate knowledge on various instruments used for meteorological observation and communication cum-information purpose among different stake holders like school/college and university students/trainees.

(ii) The e-Learning material for National as well as Foreign Trainees is easily accessible over IMD website in the following link: https://mausam.imd.gov.in/imd_latest/contents/departmentalweb.php

13.14. Conclusion

The communication systems of IMD have given a thrust to achieve quick and reliable exchange of large volume of almost all data types and related products. This is quite useful for forecaster, disaster manager and others. However, responses/feedback on various dissemination systems need to be monitored continuously to provide better services by adopting new technology, upgrading bandwidth as well as systems etc. It is clear from the above discussion that the Meteorological communication system plays a vital role for forecasting and information dissemination to public/ authorities engaged in disaster mitigation to minimize the losses of lives and property.

Chapter 14

Post-Event Survey

14.1. Introduction

When a high impact severe weather event like cyclone, thunder squall and heavy rain causing flood affects a region, it is essential to make a technical survey immediately after the event. The objective of this survey is to find out on the spot technical details about the high impact weather event for better understanding of its characteristics, assessment of its intensity and location and associated physical processes. Though there exists a well laid down procedure for post-cyclone survey, there is no such procedure for post-thunderstorm, post thunder squall, post-tornado, post-flash flood survey by India Meteorological Department. Here, the standard operation procedure (SOP) to be adopted by IMD for the post-event survey of different significant weather phenomena is presented.

14.2. Identification of high impact weather event (HIWE) needing post-event survey

The post-event survey will be conducted for the following significant weather events in case they cause high impact.

(i) Land falling Cyclone
(ii) Severe thunderstorm / lightning leading to loss of life and property
(iii) Tornado leading to loss of life and property
(iv) Flash flood following cloud burst

14.3. Purpose of survey

The main purpose of a survey of the damage caused by the HIWE is to assess in greater detail than is possible with the available synoptic observations and press reports. It is also aimed to find out actual track, intensity and other characteristics of the HIWE and to evaluate the effectiveness of the warnings issued.

14.4. Standard Operation Procedure (SOP) for Post-Event survey

14.4.1. Assessment of damage

Whenever a high impact weather event (HIWE) as mentioned above causes considerable damage to life and property, an officer from the concerned region should be sent on tour to visit the affected areas to assess the nature and extent of the damage caused, both from the economic and scientific points of view. Tour programme of the officer proceeding on tour should be initiated and approved immediately during the event or within 24 hrs of the occurrence of the event telephonically/ by email/ through WhatsApp by the competent authority. The competent authority is the concerned Head, Regional Meteorological Centre. The office of CRS Pune and NWFC New Delhi should be informed by E-mail/WhatsApp about the tour. The touring officer should visit the crucial locations in the affected area, contact the various State and Central Government officers and interview people to examine the characteristic of the event and how effectively the warning system worked during the event. The officer has to submit the report to the concerned Head, MC/RMC, Head NWFC and Head CRS Pune immediately after his return from tour.

14.4.1.1. Use of departmental transport/hiring of transport for damage survey

On occasions, when a HIWE caused considerable damage, public transport services may not be available immediately to the touring officer to visit the affected areas or the public transport facilities are not extended in the intended areas of visit. In such cases departmental transport will be used for damage survey. Whenever departmental transport is not available, suitable hired transport will be used.

14.4.2. Contents of survey report

The touring officer should consider the following points while preparing the report:

14.4.2.1. For Cyclone

(i) The track followed by the HIWE.
(ii) The 'eye' or calm centre and its characteristics.
(iii) Duration of the lull period.
(iv) Areas affected by gales/ squally winds and relative strength of winds in the different quadrants.
(v) Estimate of the maximum wind speed.
(vi) Time of commencement/cessation of severe local storm/ multiple local storms.
(vii) Recession of the sea.
(viii) Storm surges, based on tide gauge, landmarks etc.
(ix) Rainfall associated with the storm

14.4.2.2. For severe thunderstorm / lightning

(i) The track followed by the HIWE.
(ii) Areas affected by gales/ squally winds/ lightning and relative strength of winds.
(iii) Estimate of the maximum wind speed/ lightning strikes (if available).
(iv) Time of commencement/cessation of the HIWE.
(v) Rainfall associated with the HIWE.

14.4.2.3. For tornado

(i) The track followed by the HIWE.
(ii) Areas affected by the HIWE, and the relative strength of winds.
(iii) Estimate of the maximum wind speed.
(iv) Time of commencement/cessation of the HIWE.
(v) Rainfall associated with the HIWE.

14.4.2.4. For cloud burst

(i) Areas affected by the HIWE, and the relative strength of winds.
(ii) Time of commencement/cessation of the HIWE.
(iii) Rainfall associated with the HIWE.
(iv) Height of the maximum water level.

In addition to the above-mentioned points, the officer should consider the following points which are common for all the HIWE:

(i) Comments from the recipients of the warnings about accuracy and timeliness of the warnings.
(ii) Suggestions and recommendations for the improvement of the warning system/ observational network, etc.
(iii) Recorded observations, if any from other organisations.
(iv) Photographs of HIWE, if any collected by any office/ individual.

Keeping the above in view, the touring officer should try to obtain and keep a record of such information which will enable him to estimate, as quantitatively and objectively as possible, the above features associated with the HIWE.

14.5. Guidelines and instructions for Officers going on surveys of damage caused by HIWE

14.5.1. Knowledge of SOP

14.5.1.1. The officers nominated for survey should go through the SOP for post-event survey and reports of such past surveys made earlier, to familiarise themselves with the work. The offices should also keep these touring officer's reports bound as permanent records as they contain valuable scientific data on events, collected with great effort, which may be required in the future.

14.5.1.2. A pre-season workshop should be organised by NWFC for field officers on different events (annual). This would help refreshing the procedure. A mechanism for experience sharing between RMCs on the post event surveys could be included for learning experience.

14.5.1.3. Each RMC may identify the officials who are to work as the members of such Post-Event survey team with alternates/ substitutes in case of unforeseen emergencies and training will be imparted to them for their actions, for documentation etc.

14.5.2. Equipment

There are a few basic minimum items of equipment, an officer who goes on such survey tours should carry with him. These are:

(i) A digital camera/mobile phone with charger to record pictures and videos.
(ii) A measuring tape, at least 20 m in length.
(iii) A magnetic compass
(iv) A GPS unit.
(v) Small plastic bottles to collect samples of water in the coastal belt to test for saline inundation in case of cyclone.
(vi) A survey theodolite and pole (may be obtained from local PWD); and
(vii) A detailed map of area affected in the scale 1" = 16 miles (to be obtained from the State Government or survey of India map available with IMD.) (As the maps for each district in the scale 1" = 16 miles are available with the State Governments, it would be advantageous if the MOs/MCs/RMCs obtain the maps of all the coastal districts pertaining to their centres and keep them ready so that the touring officers can take these maps with them when they proceed on tour to the affected area.)
(viii) First-aid Kit

14.5.3. Guidelines for survey

14.5.3.1. Itinerary of tour

Concerned Head and the touring officer should first contact the State Government officials to find out the areas affected and prepare the itinerary for the survey accordingly.

A formal letter/ email should be written by the concerned Head MC/RMC to State Relief Commissioner (SRC)/ DM authorities to felicitate the post event survey. It would facilitate the involvement and participation of these agencies in the most important activity of post-event survey. Also, the data and information collected by these agencies are to be collected by the concerned MC/RMC.

14.5.3.2. Damage to be assessed in great detail

The touring officer must assess the damage in as great a detail as possible, as indicated below:

(a) **Directions of bent poles** : In the case of electric or telephone poles, the direction in which the pole was bent (with the help of the magnetic compass), the total height of the pole and the height at which it was bent, the diameter of the pole and whether it was solid or hollow and old or new. If it is feasible, he/she can obtain some data relating to the material of which the pole is made, its weight, age etc. from the local DoT or PWD or other such offices concerned.

(b) **Direction of fallen tree** : In the case of trees, such details as whether just branches were broken; whether the whole tree was uprooted and in which direction the tree had fallen; a rough estimate of the diameter, height, etc. and the name of the tree.

(c) **Building** : In the case of damage to property like buildings, the details relating to the type of building, whether it is a hut with mud walls etc. or pucca concrete building, the type of ceiling (thatched/ tin/ asbestos/ tiled/ concrete) and type and dimensions of the wall etc.

(d) **Direction of wind** : The direction of the wind over the area where a large number of trees have fallen or poles bent, has to be determined from the general direction in which most of the trees have fallen or poles bent in that area, making use of the magnetic compass.

(e) **Height of water level** : The height of the maximum water level from the ground, up to which inundation due to the flash flood happened to be determined by making use of the tape. The height can be estimated from the marks left by the water on trees and walls of buildings. Also, it can be estimated through interview with the local people like knee deep water, water up to belly/neck etc.

(f) **Casualties** : The total number of casualties occurred and the exact cause should be documented through interview with the local people. The nature of the place (i.e. topography, population density and vegetation) also should be noted.

14.5.3.3. Height and extension of storm surge (in case of cyclone only)

In the areas in which there was inundation due to storm surge, detailed estimates of the height up to which the sea water had come in different localities of a village or a group of villages should be obtained. The height can be estimated from the marks left by the sea water on trees and walls of buildings. It should be remembered that the purpose of this survey is also to get a profile of the water level as the surge advanced inland. For this purpose, the distance up to which the water entered inland and the stretch along the coastal belt over which this phenomenon had occurred should be ascertained. These data will enable in arriving at a clear picture of the storm surge profile.

Storm Surge = Total Water Level - Astronomical Tides - Waves - Freshwater Input

One has to use information of time of occurrence, place of occurrence, datum point of sea land and astronomical tide at that point of time. Based on all these one has to calculate the storm surge height in a systematic procedure.

14.5.3.4. Photographs/video to aid such survey

All items of damage which are vital for an assessment of the track and intensity of the HIWE should be photographed and videographed clearly to bring out the particular effect which is proposed to be illustrated, e.g. bending of telephone, telegraph or electric pole, uprooting of trees, tiles blown off and their distribution in the neighbourhood, watermarks on trees, buildings etc.

14.5.3.5. Spare Camera/Smart Phone

Whenever possible a spare camera/smart phone with charger and power bank should be carried in order not to miss this unique opportunity of getting vital data. Photographs/videos of damage and other details taken by local photographers or newspaper agencies should also be obtained to supplement those taken by the touring officer.

14.5.3.6. Interviewing local people who had experienced the severe weather phenomenon

Cross section of people should be interviewed. The local people who had experienced the ravages of the HIWE are the best judges of the happenings and the severity of the phenomenon and no opportunity should be missed to interview them. The touring officer should select a cross-section of the people who will be in a position to give reliable and useful information and are normally geared up to the routine activities in the locality, e.g. Teachers, Village Development Officers, Panchayat Officials, Port Officers, Fishermen, Govt. officers etc. Questions should be framed in such a manner that the answers will lead us to make an estimate of the time of commencement of the weather phenomenon such as heavy rainfall, tidal wave, gales/squall, calm centre etc., an estimate of the intensity of the phenomenon and any special effects noticed or felt by the persons concerned (e.g. change in humidity & wind, acoustics, colour of sky, shape of cloud, movement of cloud, frequency of thunder, lightning, type and size of hail, if any and time of occurrence etc in case of tornado/ thunderstorm, commencement of rain and type of rain, duration and cessation of rain in case of cloud burst).

14.5.3.7. Sample Questions

A sample questionnaire has to be prepared in English, Hindi and in the local language before visiting the place. The sample questionnaires for cyclone, thunderstorm, cloud burst and tornado are given in Annexure (I-IV).

14.5.3.8. Track of the Event

One of the most important things that has to result from such a survey of areas affected by a cyclonic storm is a detailed track of the storm. Therefore, we have to assess where the eye of the storm passed. For this purpose, assessment of the direction of the fall of trees on either side of the track will be very vital and photographic evidence of this must be carefully registered. People in the area over which the eye of the storm might have passed should be asked whether they experienced any clear weather or relatively calm wind for a short period followed by gales and severe weather. If so, the time of commencement and cessation of the calm period may be ascertained.

In case of severe thunderstorm/ lightning/ thunder squall/ cloudburst, the track should be prepared based on the assessment of wind direction and interview with cross section of people.

14.5.3.9. Ring of maximum winds and relative strength in different quadrants (in case of cyclone only)

The second important parameter to be assessed is the ring of maximum winds, 28 knots or more, 34 knots or more, 50 knots or more and 64 knots or more around the centre in different quadrants. For this purpose, it is important to notice the severity of the damage in order to assess the wind strength over a broad belt on either side of the track of the storm utilizing Beaufort scale.

14.5.3.10. Rainfall

Another important information to be collected by the touring officer is the rainfall recorded at the rain gauges which are available in the localities surveyed, in case it is not available in real-time.

14.5.3.11. Copies of photographic records etc.

The touring officer should also obtain copies of important autographic records like barogram, anemogram or hyetogram available from the nearest observatory. He/she may also scrutinise the observational records with reference to the local damage observed to see whether the observations recorded and reported during the event period were reliable and consistent.

14.5.3.12. Detailed sketch of damage and derived parameters

It is essential that on the basis of the survey carried out, the following maps / sketches should be prepared:

(a) A map or diagram showing the places visited by the touring officer and the route followed by him.

(b) A map showing the best track of the cyclone/thunder storm/tornado/cloud burst over land area based on the information collected. In the same map, the maximum wind speed estimated at the different places visited should be plotted (with the direction of the wind and time of occurrence wherever possible).

(c) A map showing the areas affected by storm surge and the height of the surge at different places along the coastal belt in case of cyclone.

The N-S line should be clearly marked on the above sketches / maps. The above maps may be prepared on the scale of highest available resolution.

14.5.3.13. Contacting Warnees: Working of the warning system

(a) Receipt of warnings by warnees

The warnees (Collectors and other Govt officials in the affected area (BDO, Tehsildar, Police station), Officials of PWD, Railways, DoT, Ports, Fisheries etc.) to whom warnings were issued in connection with the storm have to be contacted by the touring officer to find out whether the warnings were received by them in time and whether they were useful. He should also ascertain how they were utilised. In the case of serially numbered warnings, he should see whether the warnings were received serially. The remarks of the officials concerned on the reception of Four Stage Warnings, in case of cyclone, heavy Rainfall through the broadcasts of AIR and short to medium range forecast and nowcast in case of thunderstorm have to be obtained. In the case of Port Officers and designated/registered warnees the forms in which they have to fill the details regarding receipt and action taken on warnings may be collected for taking suitable action with the DoT officials in cases of non-receipt / late receipt of warnings by the warnees.

The sample questionnaire is given in Annexure-V for DM officers and VI for port-authorities.

(b) Suggestions for improvements

He/she should also elicit suggestions from the warnees for the improvement of the warning system and make suitable recommendations in his/her report. Similarly any deficiencies in the observational organisation noticed should also be pointed out by him/her with suggestions for remedial measures.

(c) Meeting the AIR/Door Darshan authorities and other Media personnel

If there is an AIR station/Door Darshan station in the area covered by the tour, he/she should also visit the AIR station/Door Darshan station and ascertain from the authorities whether the bulletins for broadcast were received by them in time and according to the sequence of the serial numbers and whether they were broadcast immediately. He/she should also ascertain whether the AIR station/Door Darshan station extended the transmission hours to broadcast the bulletins received outside the scheduled transmission hours and if not the reason for not extending the transmission hours.

If possible, the touring party will contact the local media reporters/personnel who have covered the event, during their tour and try to find out the severity of the event. The touring party should also obtain evidence in the form of footage of recordings by the electronic media and videos. These should form a part of report of the touring officer/party.

(d) Working knowledge of local language

As the touring officer has to gather information from the local people in addition to the public officials, it is preferable that he/she has a working knowledge of the local language of the HIWE affected area. In the case of a HIWE which affects more than one meteorological region, an officer from each region must be deputed on tour and each visiting officer will restrict his/her study, survey etc. to his/her region only. Based on the inputs of these officials, a final consolidated report shall be prepared by the officer from the region which was the most affected by the HIWE.

Annexure-I

(The sample questions for Cyclone)

i) When did you come to know about this cyclone?
ii) When did wind started to increase?
iii) When did rainfall started?
iv) What was the estimated wind speed you have noticed?
v) How long did gale wind continued?
vi) When did you get IMD forecast and warning for this cyclone?
vii) Have you ever noticed the sudden marked changes of weather phenomenon?
viii) How did direction of wind changed?
ix) When (date and time) did you first notice the water entering your village?
x) Could you tell us when water reached its maximum height?
xi) What is your estimate of the maximum height?
xii) How much damage has occurred in your area?
xiii) Is there any death of human/animal reported?
xiv) What was the main reason for the casualties occurred?

Annexure-II

(The sample questions for Severe Thunderstorm)

i) What was the colour of the sky before the incident and how did it change with gradual appearance of the cloud?
ii) What was the shape and size of the cloud in different period?
iii) What was the location and movement of the thunder cloud?
iv) When did the rain start? How does the intensity of rain increased or decreased?
v) Was there any incident of hail?
vi) Have you heard any thunder?
vii) Have you seen any cloud to ground lightning strike?
viii) How was the wind before the incident? How did it change over the period of time (in direction and speed)? It will help to assess the wind speed based on BF scale.
ix) What was the time of occurrence and duration of the event? What was its direction of movement?
x) How much damage has occurred in your area?
xi) Was there any casualty?
xii) What was the main reason for casualties (storm/ lightning/heavy rain)?
xiii) Whether you received warning? If so, whether it was timely (early/ delayed receipt) and accurate (correct/ partially correct, wrong). What was the source of warning?
xiv) Do you have any suggestion to improve warning?
xv)

Annexure-III

(The sample questions for Tornado)

i) What was the colour of the sky before the incident and how did it change with gradual appearance of the cloud?
ii) What was the shape and size of the cloud in different period?
iii) What was the location and movement of the thunder cloud?
iv) How was the wind before the incident? How did it change over the period of time (in direction and speed)? (It will help to assess the wind speed based on BF scale.)
v) What was the time of occurrence and duration of the event? What was its direction of movement?
vi) Have you seen any waterspout?
vii) Have you noticed any lifting of animate/inanimate objects?
viii) How much damage has occurred in your area?
ix) Was there any casualty?

Annexure-IV

(The sample questions for Cloud Burst)

i) What was the colour of the sky before the incident?
ii) Whether it was all of a sudden or you had apprehended beforehand?
iii) What was the duration of rain?
iv) Can you estimate the intensity of rain?
v) Is there any report of land slide/mud slide/flash flood?
vi) What is the area of inundation and extent of damage?
vii) Was there any casualty?
viii) Have you seen/heard such incident like this earlier? If so, what is the tentative time period?
ix) Do you received any warning of heavy rainfall/extreme weather condition?

Annexure-V

The touring officer should collect the following information from DM authoritieson the working of the warning system.

i) Were the communication links maintained till the receipt of the last warnings?
ii) Was any alternate channel used?
iii) Did the warnee make any further dissemination of warnings to his lower formations and if so when, to what areas and how?
iv) What was the general response to these warnings from the public?
v) What were the preventive action taken such as,
   - evacuation of people from low-lying areas to places of safety (in case of cyclone),
   - closing down of schools, colleges and public offices; and
   - preventing fishermen from going out into the sea, etc (in case of cyclone)

Annexure-VI

In the event of the storm affecting a port itself, the touring officer should meet the port Officer and ascertain how the warning system had functioned during the storm. He/she should particularly enquire.

i) whether the communication links with the storm warning centre were maintained till the issue of the last warning (i.e. to lower the signal)
ii) if not, what action was taken by him.
iii) Whether, the warnings received by the port were put to other use than hoisting or replacing the signals.
iv) Any other feedback

Information available with the Port Officer relating to the damage to the port installations and to ships, country crafts, ferry boats etc. in the port areas or in coastal waters near the port should be collected and included in the report.

Chapter 15

FORECAST VERIFICATION

15.1. Introduction

Weather plays an important role in almost all aspects of life on earth. Hence, its accurate and timely forecasting has got wide implications ranging from increasing the agricultural production to reducing the damage to life and property. Currently, forecasting services are rendered to farmers, fishermen, shipping, air navigation etc., apart from the general public. The main objective is to forewarn people so as to reduce death and damage from impending natural disasters like floods, droughts, cyclonic storms and other extreme weather.

Forecast verification is the process of assessing the quality of a forecast. The forecast is compared, or *verified*, against a corresponding observation of what actually occurred, or some good estimate of the true state of atmosphere, (so that it can believed to a reasonable accuracy).

The three most important reasons to verify forecasts are:

i) To *monitor* forecast quality - how accurate ~~are~~ the forecasts are to ascertain users that to which extent these can be believed & how are these improving over time.

ii) To *improve* forecast quality - the first step towards getting better knowledge on the precise reasons of wrong forecast.

iii) To *compare* the quality of different forecast systems - to what extent does one forecast system give better forecasts than another, and in what ways that system is better?

Allan Murphy, a pioneer in the field of forecast verification, wrote an essay on what makes a forecast "good" (Murphy, 1993). He distinguished three types of "goodness":

(i) **Consistency** - The degree to which the forecast corresponds to the forecaster's best judgement about the situation, based upon his/her knowledge base

(ii) ***Quality*** - the degree to which the forecast corresponds to what actually happened

(iii) ***Value*** - the degree to which the forecast helps the decision makers to realize its importance.

Since we're interested in forecast verification, let's look a bit closer at the forecast ***quality***. Murphy described nine aspects (called "attributes") that contribute to the quality of a forecast. These include:

(i) **Bias** - The correspondence between the mean forecast and mean observation.

(ii) **Skill** - The relative accuracy of the forecast over some reference forecast. The reference forecast is generally an unskilled forecast such as random chance, persistence (defined as the most recent set of observations, "persistence" implies no change in condition), or climatology. Skill refers to the increase in accuracy due purely to the improvement of the forecast system. A typical weather forecast may be more accurate simply because that weather is easier to forecast. Hence, skill gives a better judgement of the quality of forecast.

Considering the importance of forecast verification, the subject of verification of forecasts was discussed by the Director's Conference – **October 1955** where it was agreed that the initial checking of all forecasts should be done at the issuing centres. Since then, the forecast verification method has undergone many changes. Here the standard operation procedure for forecast verification by various forecasting offices is presented.

15.2. Types of forecast and forecast verification methods

Various types of forecast and their verification methods are given in Table 15.1 and 15.2.

Table 15.1.

Nature of Forecast and Verification Methods

Specificity of Forecast	Example (s)	Verification Methods
Dichotomous (Yes/No)	Occurrence of Fog	Visual, dichotomous, probabilistic, spatial, ensemble
Multi-category	Cold, Normal or warm conditions	Visual, probabilistic, spatial, ensemble, multi category
Continuous	Maximum temperature	Visual, continuous, probabilistic, spatial, ensemble,
Object or event-oriented	Tropical cyclone motion and intensity	Visual, dichotomous multi category, continuous, probabilistic, spatial

Table 15.2.

Specificity of Forecast and Verification Methods

Nature of forecast	Example (s)	Verification Methods
Deterministic (non-probabilistic)	Quantitative precipitation forecast	Visual, dichotomous, multi-category, continuous spatial
Probabilistic	Probability of precipitation, ensemble forecast	Visual, probabilistic, ensemble
Qualitative (worded)	5-day outlook	Visual, dichotomous, multi category
Time series	Daily maximum temperature forecasts for a city	Visual, dichotomous , multi category, continous, probabilistic
Spatial distribution	Map of geopotential height, rainfall chart	Visual, dichotomous, multicategory, continuous, probabilistic, spatial, ensemble
Pooled space and time	Monthly average global temperature anomaly	Dichotomous, multicategory, continuous, probabilistic, ensemble

15.2.1. Methods for dichotomous (yes/no) forecasts

A dichotomous forecast says, *"yes, an event will happen"*, or *"no, the event will not happen".* Rain and fog prediction are common examples of yes/no forecasts. For some applications a threshold may be specified to separate *"yes"* and *"no"*, for example, winds greater than 50 knots.

(i) To verify this type of forecast we start with a *contingency table* that shows the frequency of *"yes"* and *"no"* forecasts and occurrences. The four combinations of forecasts (yes or no) and observations (yes or no), called the *joint distribution*, are:

a) *hit* - event forecast to occur, and did occur
b) *miss* - event forecast not to occur, but did occur
c) *false alarm* - event forecast to occur, but did not occur
d) *correct negative* - event forecast not to occur, and did not occur

(ii) The total numbers of observed and forecast occurrences and non-occurences are given on the lower and right sides of the forecast contingency table, and are called the *marginal distribution*.

15.2.2. Forecasts issued by IMD

Depending on the spatial and temporal scales of atmospheric systems and the details of the accuracy desired, the weather forecasts are divided into the following categories.

(i) ***Nowcasting*** - in which the details about the current weather and forecasts upto a few hours ahead are given.

(ii) ***Short range forecasts (1 to 3 days)*** - in which the weather (mainly rainfall) in each successive 24 hr intervals may be predicted upto 3 days. This forecast range is mainly concerned with the weather systems observed in the latest weather charts, although generation of new systems is also considered.

(iii) ***Medium range forecasts (4 to 10 days)*** – Average weather conditions and the weather on each day may be prescribed with progressively lesser details and accuracy than that for short range forecasts. The forecaster has to be more dependent on NWP products for issuing medium range forecasts.

(iv) ***Long range /Extended Range forecasts (more than 10 days to a season).***

There is no rigid definition for Long Range Forecasting, which may range from a monthly to a seasonal forecast.

The responsibility of issuing forecasts, bulletins and warnings by various met. Offices differ widely. The ACWCs and CWCs involved in the cyclone warning work have an additional set of bulletins and forecasts to be issued by them, which are elaborately described in Chapter 9 of the document, 'Cyclone Warning in India' of Regional Specialised Meteorological Centre (RSMC), New Delhi, viz., *'Bulletins and Warnings'*. Similarly, those met. offices attached to the aerodromes are to follow an entirely different routine of Bulletins and Warnings to ensure the safety, regularity and efficiency of air navigation, the details of which are readily available in the SOP on 'Cyclone Warning in India' Pls see link: http://www.rsmcnewdelhi.imd.gov.in/images/pdf/sop.pdf) which is being updated every year.

The forecasting responsibilities of all other forecasting offices viz. Meteorological Centre (MC), Regional Weather Forecasting Centre (RWFC) and NWFC, New Delhi, are also well defined and differ from one another.

15.3. General Forecasting Organisation

The Organization for providing different types of non-aviation forecasts and warnings is given in the Table 15.3.

Table 15.3

General forecasting organisation

S. No.	Category/Meteorological offices issuing weather forecasting	Details of service	User interest
1. Marine	RSMC New Delhi	Tropical Weather outlooks and tropical cyclone advisories	Countries in the WMO/ESCAP panel region bordering the Bay of Bengal and the Arabian Sea
	Cyclone Warning Division, New Delhi, Cyclone Warning centres at Kolkata (Alipore), Mumbai (Colaba), Chennai (Nungambakam), Ahmedabad, Bhubaneshwar, Vishakapatnam and Thiruvanthapuram (7)	1. Forecasts for Bay of Bengal and Arabian Sea, Disaster managers at national level. General public, press and electronic media 2.Coastal forecast 3.Cyclone Warnings 4.Port Warnings	Ships, Disaster Management, fishermen, General public Ships, Govt. Depts., Maritime State and Public ports
	Cyclone Warning Centre at Mumbai, Kolkata, Marine forecast division, DGM Office, New Delhi	Fleet forecast twice a day, frequency of bulletins increases to four during tropical storm period over north Indian Ocean	Indian Navy
	Global maritime Distress and safety system (GMDSS), ACWCs Mumbai, Kolkata and, Marine forecast division, DGM Office, New Delhi. ~~INOSHAC, Pune~~	Bulletins twice a day are issued for Met. Area VIII N for Arabian sea, Bay of Bengal and Indian Ocean. To north of Equator, the frequency increases to six during tropical storm period	All ships
2. Fisheries	Cyclone Warning centres at Kolkata (Alipore), Mumbai (Colaba), Chennai (Nungambakam), Ahmedabad, Bhubaneshwar, Vishakapatnam and Thiruvanthapuram (7) ~~(6)~~	(i) Adverse weather along coast, four times daily (including nil warnings). (ii) Cyclone warnings	(i) Fishing craft through A.I.R (ii) Fisheries
3. Agriculture	(a)Regional Met Centres / Met.centres at Ahmedabad, Bangalore, Mumbai, Bhubaneshwar, Kolkata, Guwahati, Hyderabad, Jaipur, Lucknow, Chennai, Nagpur, Bhopal, New Delhi. Patna, Srinagar, Thiruvanthapuram and Chandigarh (17)	(i) Farmer's weather bulletins (two bulletins are issued daily during all seasons) (ii) Agricultural advisory message	Message for farmer's broadcast from A.I.R. stations in local languages
	(b)Meteorological offices at Ahmedabad, Amravathi, Bangalore, Bhopal, Goa, Bhubaneshwar, Kolkata, Guwahati, Hyderabad, Jaipur, Lucknow, Chennai, Pune, Deharadun New Delhi. Patna, Ranchi, Srinagar, Thiruvanthapuram and Chandigarh, Simla, Agartala, Gangtok and Raipur.	Agromet Advisory service bulletins(weekly/biweekly)	Advisories for farmers broadcast/telecast in local languages through A.I.R/ Doordarshan
4. Floods	Agra, Ahmedabad, Asansol, Bangalore, Bhubaneaswar, Chennai, Guwahati, Hyderabad, Jalpaiguri, Lucknow, New Delhi, Patna and Srinagar (13)	(i) Quantitative Precipitation forecasts (ii) Prevailing synoptic situations (iii) Heavy rainfall warnings (iv) Realised average precipitation	Water resources flood forecasting Division of CWC (Total No. 19)

		for each sub-basin during past 12/24 hours. (i) Point rainfall data of selected stations	
5. General Forecasting	Ahmedabad, Agartala, Amaravati, Shilong, Bangalore, Bhopal, Goa, Chandigarh, Bhubaneshwar, Kolkata, Guwahati, Hyderabad, Bhopal, Jaipur, Lucknow, Chennai, Deharadun, New Delhi, Patna, Srinagar, Thiruvanthapuram and Chandigarh, Nagpur, Raipur, Shimla, Chennai. Mumbai, Itanagar	(i) District and subdivision wise forecasts for one or more states for next five days. (ii) Local forecasts for capital cities. (iii) Multihazard Warning against adverse weather. (iv) City Forecast (v) Tourist Forecast (vi) Ferry Forecast (Wherever issued) (vii) ERF	Public, Newspapers, AIR and Govt. officials about 1500 officials registered with different offices
6. Special events	RMC New Delhi RMC Guwahati	(i)Weather forecast is provided 3 times daily to state Govt. authorities to regulate Amar Nathji Yatra during 40 days period. (ii)Weather forecast is provided to govt.to regulate kailash Mansarovar Yatra during the three-month period. (i) Weather forecast information is provided on IVRS by dialling Toll free NO. 1600-180-1717 from Met. Office, Safdarjung for 200 important cities	
7. Planning		(a) Forecasts for seasonal (June to September) rainfall over four broad rainfall homogeneous regions of india viz. Northwest india, Northeast India and Central India and South Peninsula issued by the end of June/first week of July (b) Forecast for July rainfall over the country as a whole issued by the end of June/first week of July. (c) Forecast for northeast monsoon season (Oct to Dec) rainfall over southern peninsula issued in the first week of Oct. (d) Forecast for rabi season (October to March) rainfall over Northwest India issued in the first week of October. (e) Forecast for winter season (January-March) precipitation issued in the first week of January	Govt. officials Public and Media. Govt. officials

Table 15.4. Lists the Forecasting Centres responsible for issuing of forecast for different region

Table 15.4.

List of Forecasting Offices of IMD

Forecasting Office	Forecast Region
RWFC, Guwahati	1. Arunachal Pradesh
	2. Assam
	3. Nagaland
	4. Manipur
	5. Mizoram
MC, Agartala	6. Tripura
MC, Shilong	7. Meghalaya
MC, Gangtok	8. Sikkim
	9. Andaman & Nicobar Islands
	10. West Bengal
MC/CWC Bhubaneswar	11. Orissa
MC Ranchi	12. Jharkhand
MC Patna	13. Bihar
RWFC, New Delhi	14. Delhi
MC Lucknow	15. Uttar Pradesh
MC Dehradun	16. Uttarakhand
MC Chandigarh	17. Haryana
	18. Punjab
	19. Chandigarh
MC Simla	20. Himachal Pradesh
MC Srinagar	21. Jammu & Kashmir
MC Jaipur	22. Rajasthan
MC Bhopal	23. Madhya Pradesh
MC/CWC Ahmedabad	24.Gujarat
	25.Daman & Diu
RWFC Mumbai	26. Maharashtra excluding Vidarbha
MC, Goa	27. Goa
RWFC Nagpur	28.Vidharba
MC Raipur	29.Chattisgargh
MC Amravathi	30.Coastal Andhra Pradesh
MC Hyderabad	31.Telengana
	32.Rayalseema
RWFC Chennai	33.Tamil Nadu
	34. Puducherry
MC Bangalore	35. Karnataka
MC/CWC Thiruvananthapuram	36.Kerala
	37. Lakshadweep

15.4. Current status of verification

A need had been felt for quite sometime to make the forecast verification be made more quantitative, incorporating various skill scores. To meet this requirement, a sub-committee was constituted by AMR-2007. The sub-committee formulated a set of procedures for assessing the forecast performance in terms of various skill scores along with schedule of issuance of local forecast which has been accepted by the Annual Monsoon Review meeting-2008. The present verification is being done according to the procedures given in forecasting circular 01/2008.

15.5. SOP

(i) The general forecasts / local forecasts are issued by all MC / RWFCs.

(ii) These forecasts / local forecasts will be verified at their respective centres and the results will be sent to NWFC, New Delhi on weekly basis.

(iii) NWFC, New Delhi will monitor the receipt/non-receipt of results of general forecasts / forecasts from all centres and prepare the weather forecast verification report.

15.6. Verification of Local Forecast

An area of 50 km radius around a city will be used for verification of local forecast. Maximum/Minimum temperatures and other elements are forecast in the local forecast. Local forecast issued, based on 0300 UTC charts is verified with the observed maximum/minimum temperature and other parameters of the next day. For example, local forecast issued on 10th for maximum and minimum temperature and other elements is verified with the minimum temperature attained on 11th morning and maximum temperature attained on 11th afternoon and other elements realised on 11th. Local forecast issued in the night for maximum/minimum temperature and other elements is verified with the maximum temperature and other elements realised on the next day and the minimum temperature for the next to next day. For example: verification of local forecast for maximum/minimum temperature and other elements issued on 10th is verified with maximum temperature and other elements realised on 11th and minimum temperature realised on 12th forenoon. All the forecasting offices (RWFCs and MCs through RWFCs) will send the verification the forecasts based on 0300 UTC and 1200 UTC charts to the office of the Climate Research and Services (CR & S), IMD, Pune on weekly basis.

In local forecast, whenever any weather phenomenon is expected, its intensity, frequency and time of occurrence is indicated. In the absence of a weather phenomenon, the local forecast describes anticipated sky conditions. The other parameters for which the local forecast issued include, maximum temperature and / or minimum temperature, rainfall, wind and special phenomenon. Detailed instructions for issuing local forecast for different parameters are given below.

Temperature

Information on maximum temperature will be indicated during April to June (till onset of monsoon) or minimum temperature during the period November to February and both maximum and minimum during March and October (after withdrawal of monsoon). Temperature description need not normally be given during monsoons (southwest and northeast), but on occasions when due to subdued monsoon, the maximum and minimum temperatures deviate much from normal, temperature description may be given. However, local forecast for maximum temperature during winter can also be indicated in addition to minimum temperature if forecasters feel that such a forecast will help the users. For example, in Delhi there are some days during December when minimum temperature over Delhi is 8 ^{o}C and maximum temperature is between 12 and 15 ^{o}C. In such situations forecast for maximum temperature is equally important. Similarly, during summer if forecasters feel that minimum temperature is important, local forecast for minimum temperature during summer may be issued in addition to local forecasts for maximum temperature. As the public is interested to know about the fluctuations in temperature in summer or winter, the temperature trends, viz., slight fall / rise, significant fall / rise etc may be indicated in local forecast. The terms day (night) temperature and maximum (minimum) temperature are to be used in the context described below.

At present the change in maximum temperature is forecast in five categories; namely, No large change (-1.5^{o}C to +1.5^{o}C) appreciable rise or fall (±2.1 to 4^{o}C), marked rise or fall (±4.1^{o}C and above). Keeping the forecast procedure same, the forecast for these categories may be described as given below.

Table 15.5 (a).

Terminology used in maximum and minimum temperature forecast

Forecast for maximum temperature following earlier procedure	**Forecast to be issued**
No Large Change (-2^{o} to +2^{o}C)	Maximum temperature will be around T ± 2 ^{0}C. (where T indicates the today's maximum temperature in degrees Celsius).
Appreciable rise/ fall (2.1 ^{o} to 4^{o}C)	Significant Rise/ Fall in day temperature and maximum temperature will be around (T ±2.1 to 4^{o}C).
Marked rise/ fall (4.1^{o} C and above)	Marked Rise/ Fall in day temperature and maximum temperature will be around T± 4.1^{o}C or more.

Reference : Forecasting Circular No. 5/2015 (3.7)

Table-15.5 (b)

Sample Temperature verification table for the reference

Minimum Temperature July -2020 Station: x						
Parameter		**Day-1**	**Day-2**	**Day-3**	**Day-4**	**Day-5**
Absolute Error		1.022	1.112	1.345	1.248	1.7
RMSE		1.290	1.412	1.585	1.482	2.030
Frequency of error within range	**<=1.0**	19	18	12	12	10
	>1.0 &<=2.0	9	8	13	16	11
	>2.0 &<=3.0	3	5	6	3	7
	>3.0	0	0	0	0	3
Percentage	**<=1.0**	61	58	39	39	32
	>1.0 &<=2.0	29	26	42	52	35
	>2.0 &<=3.0	10	16	19	10	23
	>3.0	0	0	0	0	10

Rainfall

The terminology used for indicating rainfall intensity will be as given in Table 15.6.

Table 15.6.

Rainfall terminologies

Rainfall amount in mms	**Plotted on charts as (in equivalent cm)**	**Descriptive term used**
0.0		No rain
Trace-2.4	…	Very light rain
2.5-7.5	-	Light rain
7.6-15.5	1	
15.6-24.4	2	
24.5-35.5	3	

35.6-44.4	4	Moderate Rain
44.5-55.5	5	
55.6-64.4	6	
64.5-75.5	7	Heavy Rain
75.6-84.4	8	
84.5-95.5	9	
95.6-104.4	10	
104.5-115.5	11	
115.6-124.4	12	Very heavy rain
124.5-135.5	13	
135.6-144.4	14	
144.5-155.5	15	
155.6-164.4	16	
164.5-175.5	17	
175.6-184.4	18	
184.5-195.5	19	
195.6-204.4	20	
>204.5	21 or more	Extremely Heavy rain
When the amount is a value near about the highest recorded rainfall at or near the station for the month or season. However, this term will be used only when the actual rainfall amount exceeds 12 cm.		Exceptionally Heavy rain

Reference : Forecasting Circular No. 5/2015 (3.7)

15.6.1. Issue of local forecast

In 24 hours, the local forecast is issued 4 times. The first local forecast is issued in the early morning at about 0700 hrs IST based on 2100 and 0000 hrs UTC charts. The second local forecast is issued at about noontime everyday based on 0300 UTC charts. This is published in the Daily Weather Summaries, Regional Weather Summaries. This is given to the Public, Press and all the users. The third local forecast is issued at about 1730 hrs IST based on 0900 hrs UTC charts. The fourth Local forecast is issued at about 2100 hrs IST based on 1200 UTC charts. This is again issued to the users, All India Radio and the press.

15.6.2. Format for issuing local forecast

In local forecast, Maximum/Minimum temperature (depending upon the month) and other parameters like clouds, rainfall etc may be indicated as given above. The forecasters can use his / her discretion and ingenuity to frame the language of the forecast but should ensure that all features of the local forecast are properly represented. However, in respect of maximum/minimum temperature the following format should be used. For example

*i)*Local forecast issued at noontime on Sunday, the 26th March, 2000 based on 0300 hrs UTC charts “Mainly clear skies, Maximum and Minimum temperatures will be around 39^{o}C and 20^{o}C respectively on Monday” or “Mainly clear skies; maximum and minimum temperatures will be around 39^{o}C and 20^{o}C respectively” (This means that minimum temperature likely to be realized on Monday early morning will be 20^{o}C and Maximum temperature likely to be realized on Monday afternoon will be 39^{o}C).

*ii)*Local forecast issued at 1730 hrs IST on Sunday, the 26th March 2000 based on 0900 hrs UTC charts. Same as given above in (I).

*iii)*Local forecast issued at 2100 hrs IST on Sunday, the 26th March 2000 based on 1200 hrs UTC charts.

“Mainly clear skies; Maximum temperature will be around 39^{o}C on Monday, and Minimum temperature will be around 20^{o}C on Tuesday” or “Mainly clear skies; Maximum temperature on Monday and minimum temperature on Tuesday will be around 39^{o}C and 20^{o}C respectively”.

iv) Local forecast issued at 0700 hrs IST on Monday the 27th March based on 2100 and 0000 hrs UTC charts.

"Mainly clear skies; Maximum temperature will be around 39^{o}C on Monday and minimum will be around 20^{o}C on Tuesday" or "Mainly clear skies; maximum and minimum temperatures will be around 39^{o}C and 20^{o}C respectively".

The local forecast should be verified in terms of the following three parameters:

(i) Temperature

The forecasts for maximum and minimum temperature will be verified by calculating absolute error, Root Mean Square Error (RMSE) frequency and percentage of error within the range (Pls refer, Table 15.5 b). The temperature forecast issued based on 0300 UTC charts, for communication to Headquarters for the display in the IMD, New Delhi website and forecast based on 1200 UTC charts, which is to be communicated to the press, be considered for verification. The verification may be carried out separately for 24 hrs. and 48 hrs. forecasts.

(ii) Rainfall

Rainfall verification will be made in terms of its occurrence/non-occurrence (yes/no) using 2 × 2 Contingency table and computing various skill scores as given in Table 15.7)

(iii) Significant/ Special weather events

Forecasts of Fog, thunderstorm, dust storm, hail storm, haze, mist, smog, heat wave, cold wave, hot day, cold day, squall, heavy rain and sky conditions will be verified based on the 2 × 2 Contingency table and computing various skill scores as given in Table 15.7). Fog forecast verification for different categories viz, light, moderate, dense and very dense will be verified. Nowcast of the weather event based on its intensity will be verified using dichotomous verification shown in Table 15.7.

Also, in this connection, in order to bring about uniformity, the forecasts for IMD website, WMO website and that for IVRS need to be disseminated by 1130 hrs IST.

The warning for heavy, very heavy and extremely heavy rainfall, cold wave, heat wave etc. also be verified using the above 2 × 2 Contingency table (Wilks, 1995):

Table 15.7.

Deterministic forecast

Forecast	**Observed**		
	Yes	**No**	**Total**
Yes	Hits	False alarms	**Forecast yes**
No	misses	Correct negatives	**Forecast no**
Total	**Observed yes**	**Observed no**	**Total**

Forecast	**Observed**		
	Yes	**No**	**Total**
Yes	a	b	a+b
No	c	d	c+d
Total	a+c	b+d	n=a+b+c+d

Using above 2x2 contingency table and following skill scores may be calculated:

a) Probability of Detection, $PoD = \frac{a}{(a+c)}$, Range: 0 to 1, Perfect score = 1

Characteristics: It is sensitive to hits and ignores false alarms. This score is good for rare events and can be artificially improved by issuing more "yes" forecasts. It should be used combining with the false alarm ratio.

b) Frequency Bias Index, $FBI = \frac{(a+b)}{(a+c)}$, Range: 0 to ∞, Perfect score = 1

Characteristics: Values higher than one indicate over forecasting (too frequently) and values less than 1 indicate under forecasting (not frequent enough). When used in connection with the PoD or the False Alarm Ratio (FAR), the bias can be used to explain the forecasting strategy with respect to the frequencies of false alarms or misses. The bias also can be computed for the non-events, as (*c + d*)/(*b + d*). If the frequency bias is computed for all the categories of the variable, then it gives an indication of the differences between the forecast and observed distributions of the variable.

c) False Alarm Ratio, $FAR = \frac{b}{(a+b)}$, Range: 0 to 1, Perfect score = 0

Characteristics: The false alarm ratio (FAR) is the ratio of the total false alarms (*b*) to the total events forecast (*a + b*). Its range is 0 to 1 and a perfect score is 0. It does not include c and therefore is not sensitive to missed events. It also is an incomplete score and should be used in connection with the POD.

d) Miss Rate, $MR = \frac{c}{(a+c)}$, Range: 0 to 1, Perfect score = 0

Characteristics: It is useful in understanding the missed cases. It is also used in connection with the POD.

e) Percentage Correct, $PC = \frac{(a+d)}{n}$, Range: 0 to 1, Perfect score = 1

Characteristics: It is not useful for low frequency events such as severe weather warnings. In these cases, there is a high frequency of "not forecast/not occurred" events. This gives high PC values that are misleading with regard to the forecasting of the low frequency event.

f) False Alarm Rate, $F = \frac{b}{(b+d)}$, Range: 0 to 1, Perfect score = 0

Characteristics: The false alarm rate is not often used by itself but rather is used in connection with the POD in a comparative sense. The POD is also referenced to the observations, specifically, the total number of observed events.

g) Critical Success Index, $CSI = \frac{a}{(a+b+c)}$, Range: 0 to 1, Perfect score = 1

Characteristics: The CSI is more complete than the FoD and FAR because it is sensitive to both missed events and false alarms. It does, however, share one drawback with many other scores: it tends to go to 0 as the event becomes rarer.

h) Equitable Threat Score (ETS), $ETS = \frac{a-a_r}{a+b+c-a_r}$, $a_r = \frac{(a+b)(a+c)}{T}$

Where *T* is the sample size. The quantity a_r is the number of forecasts expected to be correct by chance, by just guessing the category to forecast.

Characteristics: It adjusts for the effects of differences in the climatological frequencies of the event between samples. For evaluation of a forecast or for comparison of the accuracy of forecasts based on the same dataset, the CSI is a good general score.

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

Perfect score = 1

Characteristics: The HSS measures the fractional improvement of the forecast over the standard forecast. Like most skill scores, it is normalized by the total range of possible improvement over the standard, which means Heidke Skill scores can safely be compared on different datasets. The range of the HSS is -∞ to 1. Negative values indicate that the chance forecast is better, 0 means no skill, and a perfect forecast obtains a HSS of 1.

j) True Skill Score, $TSS = \frac{a}{(a+c)} + \frac{d}{(b+d)} - 1$, Range: 0 to 1, Perfect score = 1

Characteristics: This score measures the ability of the forecast to distinguish between occurrences and non-occurrences of the event. This score is used to indicate whether the forecast is able to discriminate situations that lead to the occurrence of the event from those that do not.

15.7. Verification of district level agro-meteorological forecast

District level agrometeorological forecasts are issued twice a day for five parameters as mentioned in Table 15.8. These forecasts are issued after the value addition by the forecasters to the NWP guidance available to them from the multi-model ensemble (MME) technique.

Table 15.8.

Parameters of district level forecast

S. No.	Parameter
1	Rainfall
2.	Temperature
3	Relative Humidity
4	Wind direction
5.	Wind Speed
6.	Cloud cover

These forecasts will be verified by calculating the RMS error, Absolute error, frequency of absolute error and percentage error respectively (pl refer Table 15.5b). The monthly time series of the forecast error for these parameters for city, district and subdivision wise forecast will be prepared. Similarly, monthly and seasonal average forecast errors will be calculated.

15.8. Verification of quantitative precipitation forecast (QPF) issued by FMOs

The QPF issued for different river catchments be verified by computing Percentage Correct (PC), Heidke Skill Score (HSS) and Critical Success Index (CSI), from 6 × 6 Contingency table. The detailed procedure of this forecast verification technique is given in Table 15.9.

Table 15.9.

Contigency Table for verification of QPF

Observed range (mm)	**Forecast range (mm)**						
	0	**1-10**	**11-25**	**26-50**	**51-100**	**>100**	**Total**
0	*A*	*b*	*C*	*d*	*e*	*f*	*A*
1-10	*G*	*h*	*I*	*j*	*k*	*l*	*B*
11-25	*m*	*n*	*O*	*p*	*q*	*r*	*C*
26-50	*S*	*t*	*U*	*v*	*w*	*x*	*D*
51-100	*Y*	*z*	*Aa*	*ab*	*ac*	*ad*	*E*
>100	*ae*	*af*	*Ag*	*ah*	*ai*	*aj*	*F*
Total	***G***	***H***	***I***	***J***	***K***	***L***	***T***

*PC = [(a+h+o+v+ac+aj)/T]*100*
CSI = a/(A+G-a), h/(B+H-h), o/(C+I-o), v/(D+J-v), ac/(E+K-ac), aj/(F+L-aj)
HSS=(a+h+o+v+ac+aj)-[AG+BH+CI+DJ+EK+FL)/T]/[T-(AG+BH+CI+DJ+EK+FL)/T]

The POD, FAR, MR, CSI, BIAS, PC, TSS and HSS, etc, for each category be calculated by reducing the above 6×6 Contingency Table into 2×2 Contingency table for Yes / No forecast.

15.9. Verification of sub-division level forecasts

(i) The present verification method will be continued in case of spatial distribution and intensity forecast.
(ii) The consolidated report will be prepared by the o/o DDGM (WF), Pune.

The contingency table and methodology for verification of spatial distribution and intensity of rainfall at district level issued daily based on 0300 UTC observation are shown in Table 15.10 and 15.11 respectively.

Table 15.10.

Verification of Spatial distribution forecast

Observed Range	Forecast Range					
	Dry	Isol	Scatt	Fairly widespread	Widespread	Total
Dry	*a*	*b*	*c*	*d*	*e*	*J*
Isol	*f*	*g*	*h*	*i*	*j*	*K*
Scatt	*k*	*l*	*m*	*n*	*o*	*L*
Fairly widespread	*p*	*q*	*r*	*s*	*t*	*M*
Widespread	*u*	*v*	*w*	*x*	*y*	*N*
Total	***O***	***P***	***Q***	***R***	***S***	***T***

*PC = [(a+g+m+s+y)/T]*100*
CSI = a/(J+O-a), g/(K+P-g), m/(L+Q-m), s/(M+R-s), y/(N+S-y)
HSS= a+g+m+s+y – [JO+KP+LQ+MR+NS)/T]/ [T-(JO+KP+LQ+MR+NS)/T]
Conversion of categorical forecast into deterministic forecast. The POD, FAR, MR, CSI, BIAS, PC, TSS and HSS etc for each category be calculated by reducing the above 6x6 Contingency Table into 2×2 Contingency Table for yes/no forecast.

OBSERVED	FORECAST						
	Dry	Light Rain	Moderate Rain	Heavy Rain	Very Heavy Rain	Extreme Heavy rain	Total
Dry	*a*	*b*	*c*	*d*	*e*	*F*	*A*
Light Rain	*g*	*h*	*i*	*j*	*k*	*l*	*B*
Moderate Rain	*m*	*n*	*o*	*p*	*q*	*r*	*C*
Heavy Rain	*s*	*t*	*u*	*v*	*w*	*x*	*D*
Very Heavy rain	*y*	*z*	*aa*	*ab*	*ac*	*ad*	*E*
Extreme Heavy rain	*ae*	*af*	*ag*	*ah*	*ai*	*aj*	*F*
Total	*G*	*H*	*I*	*J*	*K*	*L*	*T*

*PC = [(a+h+o+v+ac+aj)/T]*100*
CSI = a/(A+G-a), h/(B+H-h), o/(C+I-o), v/(D+J-v), ac/(E+K-ac), aj/(F+L-aj)
HSS=[a+h+o+v+ac+aj -(AG+BH+CI+DJ+EK+FL)/T]/[T- (AG+BH+CI+DJ+EK+FL)/T)]

The POD, FAR, MR, CSI, BIAS, PC, TSS and HSS, etc, for each category be calculated by reducing the above 6×6 Contingency Table into 2×2 Contingency Table for yes/no forecast.

15.10. Future scope

By the new method of forecast verification, the verification is being made more quantitative, incorporating various skill scores like Probability of Detection (POD), False alarm rate (FAR) Missing rate (MR) = b/(b+a) Correct Non-occurrence (C-Non), Critical Success Index (CSI) Bias for Occurrence (Bias) Percentage Correct (Pc) True skill score (Tss) Heidke skill score (HSS). It is desired that:

(i) A separate/independent forecast verification cell as well as verification by respective forecasting unit.
(ii) Verification against climatology and persistency.
(iii) To write a report every week to check the consistency of forecast in order to improve the forecast accuracy & hence its reliability.
(iv) To write a report on monthly and seasonal forecast verification.
(v) Display of all forecast's performance on IMD website.

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