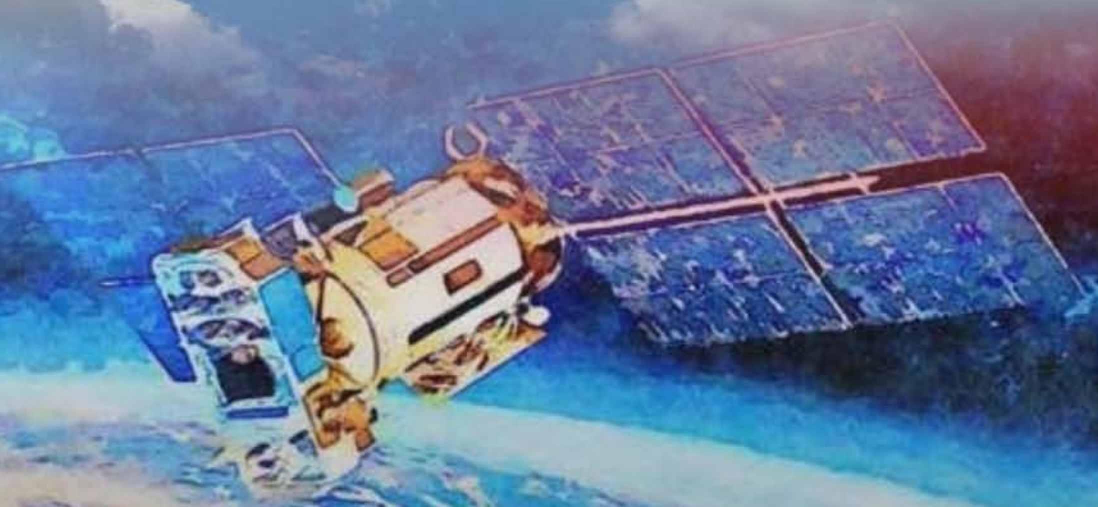
भारत मौसम विज्ञान विभाग
INDIA METEOROLOGICAL DEPARTMENT
आदित्यात् जायते वृष्टिः



वार्षिक प्रतिवेदन
ANNUAL REPORT
2021

भारत मौसम विज्ञान विभाग
INDIA METEOROLOGICAL DEPARTMENT
पृथ्वी विज्ञान मंत्रालय, भारत सरकार
Ministry of Earth Sciences, Govt. of India

वार्षिक प्रतिवेदन

ANNUAL REPORT

2021

INDIA METEOROLOGICAL DEPARTMENT

(MINISTRY OF EARTH SCIENCES)

(GOVT. OF INDIA)

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INDIA METEOROLOGICAL DEPARTMENT
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Minister of State (Independent Charge) Ministry of Earth Science,
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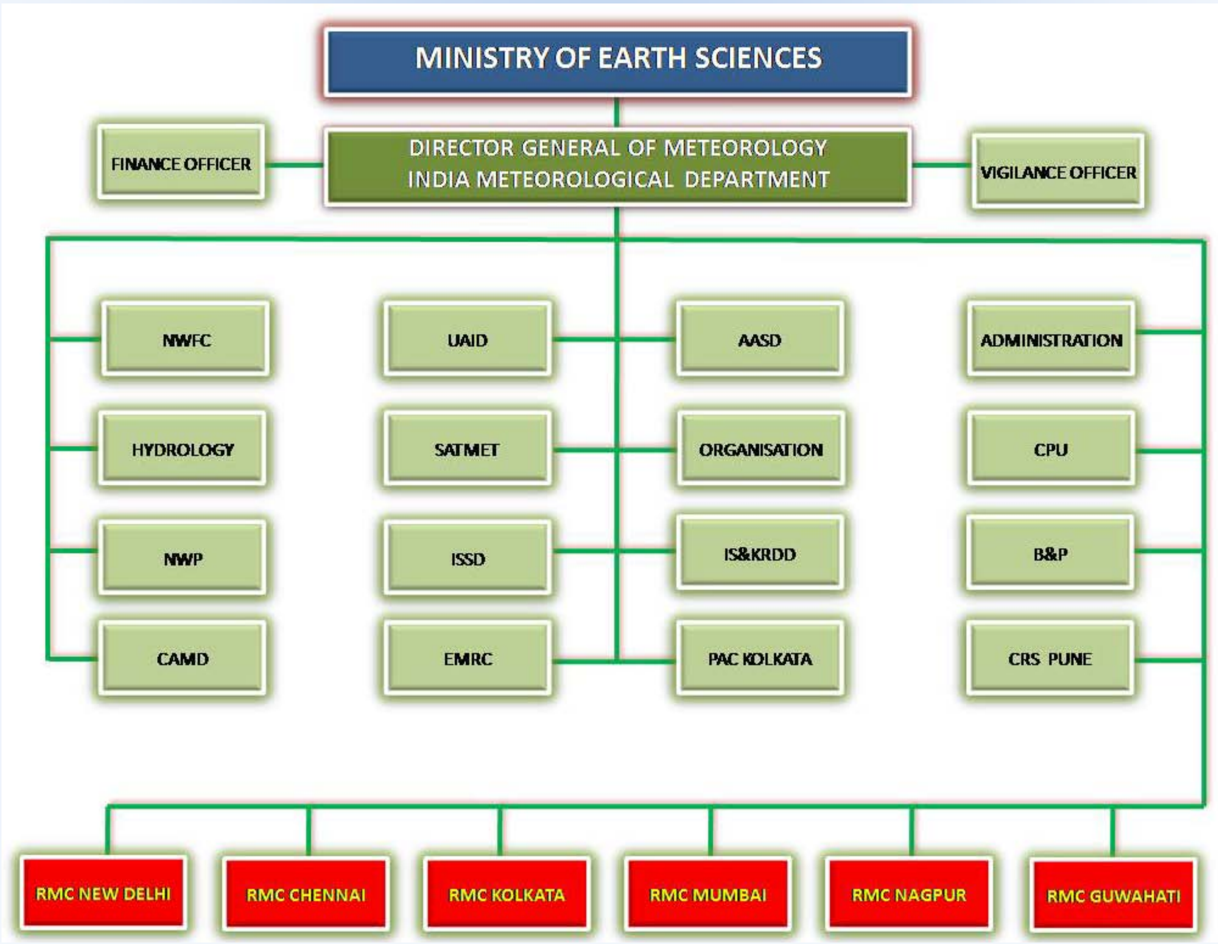

FOREWORD

It gives me immense pleasure to bring out the Annual Report of India Meteorological Department (IMD) for the year 2021. The report highlights significant activities of the department during the year. The department has been playing a leading role in the field of Earth and Atmospheric Sciences by providing eminent services in meteorology and contributing to safety of life and property and socioeconomic development since its establishment in 1875. By all means this contribution is major towards the cause of national development.

During 2021, the Department’s progressive strides towards modernization of scientific infrastructure in the fields of meteorological observations and information systems has helped to render better services in areas of agriculture, aviation, shipping, fisheries, energy and transport. IMD’s services of very short (up to 6 hrs), short (up to 3-days in advance), medium (up to 7-10 days in advance), extended (up to 15 to 20 days in advance), long range (monthly and seasonal) and severe weather (cyclones, thunderstorms, extreme rainfall, heat wave, cold wave, fog) forecasts have continuously improved to meet the demands of the user agencies, disaster managers, emergency response groups and other stakeholders.

The celebration of 146th IMD’s Foundation Day on 15th January, 2021 has provided ample opportunity to commemorate past glory and a reflection of the future vision. The then Hon’ble Union Minister Dr. Harsh Vardhan, dedicated two Doppler Weather Radars installed at Mukteshwar, Uttarakhand and Kufri, Shimla, Himachal Pradesh to the nation. Dr. Jitendra Singh, Hon’ble Minister of State has also inaugurated tower based dual polarized X-band Doppler weather radar (DWR) and Indigenous GPS based Pilot Sonde at Meteorological Office Jammu at on 5thSeptember, 2021.

The International Research Journal of IMD, MAUSAM (Formerly Indian Journal of Meteorology, Hydrology & Geophysics) has entered into 72nd year of its publications. The Online Web Portal of IMD Journal MAUSAM has also been launched by the then Union Minister on 15th January, 2021. The research articles are constantly being published on website of MAUSAM immediately after its launch which can be accessed by visiting https://mausamjournal.imd.gov.in/index.php/MAUSAM. We are also glad to inform that DOI numbers have been issued for research papers of MAUSAM Journal. Further, the growth towards publishing research finding in national and International journals has embarked a new high by publishing around one hundred seventeen (117) research papers/publications during the year.

IMD also launched its Crowd Sourcing mechanism through web interface to collect all observed weather phenomena like rain, thunderstorm, squall etc. from public on 12th January, 2021. The link (https://city.imd.gov.in/citywx/crowd/enter_th_data.php) is available in IMD main website (https://mausam.imd.gov.in/) under the heading ‘Public Observation’ with an objective to gather and archive all observed weather phenomena including rain, thunder, snow, hail, squall, strong winds, hail storm etc. to carry out forecast verification and further improve forecast. IMD has also implemented e-office w. e. f. 1st January, 2021 in IMD.

The annual mean temperature for the country was +0.44 °C above the 1981-2010 average, thus making the year 2021 as the fifth warmest year on record since 1901. The other 4 warmest years on record in order were: 2016 (anomaly +0.71 °C), 2009 (0.55 °C), 2017 (0.54 °C), 2010 (+0.539 °C). It may be mentioned that 11 out of the 15 warmest years were from the recent past fifteen years (2007-2021). In addition, the past decade (2011-2020/2012-2021) was the warmest decade on record with anomalies of 0.34 °C / 0.37 °C above average. During 1901-2021, the annual mean temperature showed an increasing trend of 0.63 °C/100 years with significant increasing trend in the maximum temperature (0.99 °C /100 years), and relatively lower increasing trend (0.26 °C/100 years) in the minimum temperature.

The rainfall activity over the country as a whole was above normal (105% of LPA) during the year. Out of 36 meteorological subdivisions, 18 received excess rainfall, 13 received normal rainfall and remaining 5 subdivisions received deficient rainfall. At the end of year, of the four homogeneous regions, South Peninsular India received 129% of its LPA, central India received 110% of its LPA, and Northwest India received 97 % of its LPA while East & Northeast India received 89% of its LPA rainfall.

During 2021, 10 cyclonic disturbances (CDs) over the north Indian Ocean (NIO) including 7 over the Bay of Bengal (BoB) and 3 over the Arabian Sea (AS) against the normal of 11-12 CDs per year over the NIO based on the data of 1961-2020. Out of these, 5 intensified into cyclonic storms (CS) against the normal of 4.8 CS per year over the NIO based on the data of 1961-2020. Out of these 5 CS, 3 intensified into severe category storms. Over all there was 1 extremely severe cyclonic storm (ESCS) (Tauktae), 1 very severe cyclonic storm (VSCS) (YAAS), 1 severe cyclonic storm (SCS) (Shaheen) and 2 cyclonic storms (CS) (Gulab & Jawad). IMD has provided frequent and accurate updates on cyclonic storms.

Dissemination of agromet advisories to the farmers through different multi-channel system of All India Radio (AIR) and Doordarshan, private TV and radio channels, newspaper and internet, SMS and IVR (Interactive Voice Response Technology) etc. is being made on wider scale. Agromet Advisories Services (AAS) are disseminated under PPP mode and through Kisan Portal to 43.0 million farmers. In addition to above Crop Specific Weather based Agromet Advisories for the country on daily basis are being telecasted through DD Kisan Channel, on real time in programs like ‘Kisan Samachar’ and ‘Mausam Khabar’ in Hindi and in regional languages of Gujarati, Marathi, Malayalam and Tamil. . A total of present 700 Agromet Advisory Service (AAS) districts and 3100 block level bulletins are being prepared and issued to cater to the needs of farmers in the country. Moreover, 1923 Farmer awareness Programs were carried out under Gramin Krishi Mausam sewa, which were attended by Around 81827 farmers across the country.

IMD has also provided Climate Services for the water sector for monitoring & prediction of average rainfall over 101 sub basins of India and for health bulletins to give the outlook for suitability for Vector- borne diseases based on extended range weather forecast had been started and are continuously in practice.

During the covid scenario, the department organized several users’ e-conferences, e-workshops, e-seminars and e-symposia to create awareness about the weather among the people. The implementation of officials languages policy in popularizing use of Hindi in day-to-day officials works pursued and encouraged.

Finally, I take this opportunity to thank all the members of IMD for their dedication and landmark to further enhance the reputation and credibility of the department at national and international level. My special thanks to Dr. S. D. Attri, Sc ‘G’, Head [Information Science & Knowledge Resource Development Division (IS&KRDD) (Formerly Publication Section)] and his team of publication unit for their sincere efforts in compilation, editing and publication of this Annual Report 2021 & various divisions and offices of IMD for providing requisite inputs.

(Dr. Mrutyunjay Mohapatra)

Director General of Meteorology

Document Control Sheet

India Meteorological Department

Ministry of Earth Sciences (MoES)

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12.	Reviewing and Approving Authority	Director General of Meteorology
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14.	Abstract	This report highlights the progress made by the department during the year 2021. The Department has continuously augmenting its observational, forecasting and information systems to render improved services in areas of agriculture, aviation, shipping, fisheries, environment, water, health, energy, transport etc. Some significant achievements during 2021 include 190 new Agro-AWS have been established at District Agromet Units (DAMUs), Launched “pune live weather app”, 12 no. of new High Wind Speed Recorder (HWSR) installed, 10 no. of Digital Current Weather Instrument System (DCWIS) installed, Commissioning of 3 Doppler Weather Radars at Mukteshwar (Uttarakhand); Kufri, Shimla (Himachal Pradesh); and Jammu (J&K) in 2021, 200 no. agro-aws installed at Krishi Vigyan Kendras (KVKs), IMD with MeitY for development and dissemination of weather information in Umang Mobile App, web-GIS based interactive map for cyclone, X-Band Doppler Weather Radar mounted on mobile platform installed at Leh, Countrywide network of 25 nos. Global Navigation Satellite System (GNSS) stations, Integration of Agromet advisories with the mobile apps and websites of various State Department.The Online Web Portal of IMD Journal MAUSAM launched and Iconic week during 18-24 October, 2021 as a part of ‘Azadi Ka Amrit Mahotsav’.
15.	Key words	IMD Annual Report 2021, MoES, Publication, Mausam, Weather.

Contents

CHAPTER 1

INDIA METEOROLOGICAL DEPARTMENT - OVERVIEW

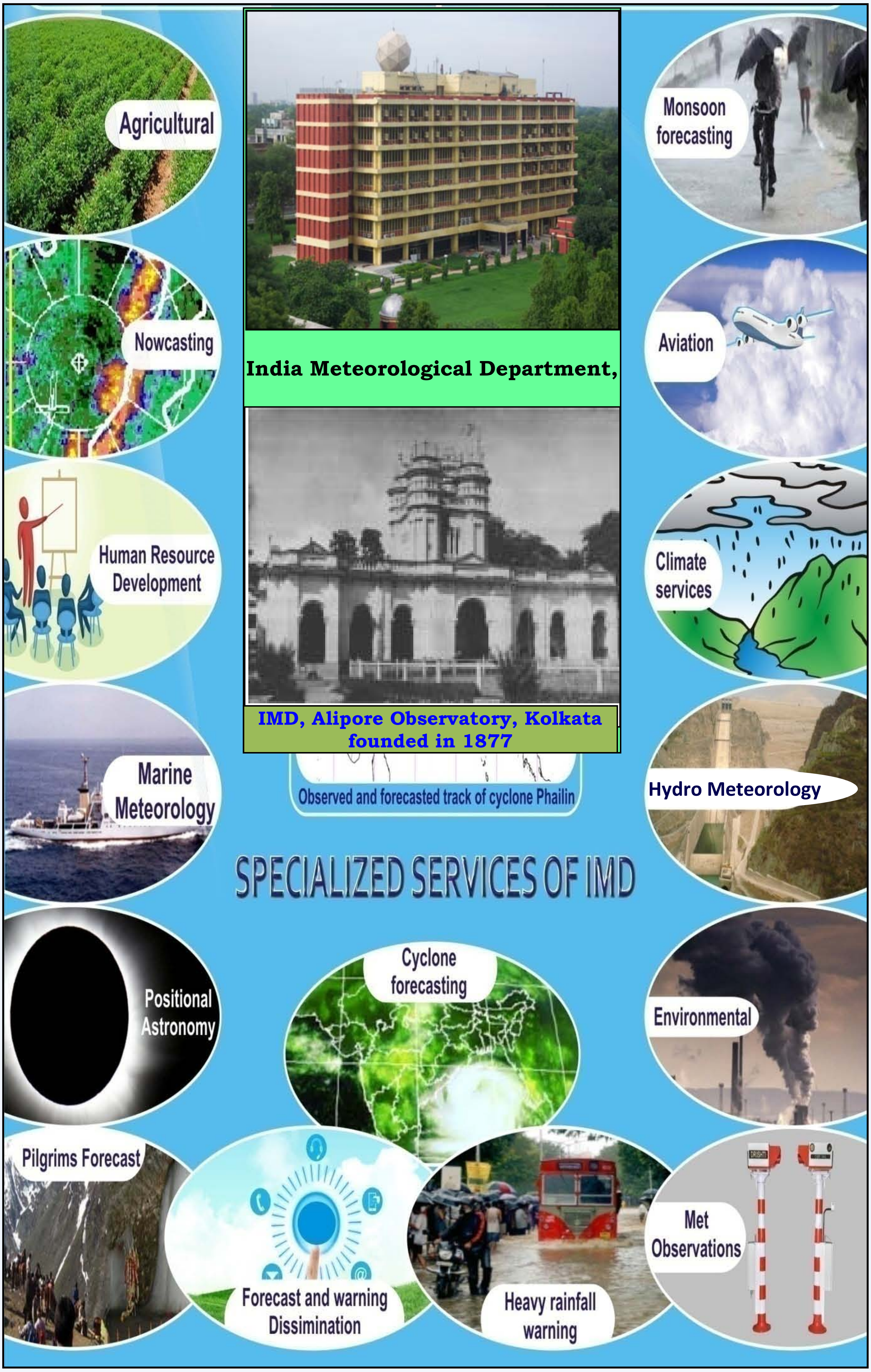
India Meteorological Department, Ministry of Earth Sciences is the National Meteorological Service of the country and the principal Government agency in all matters relating to Meteorology, Seismology and allied discipline and provides weather and climate services to the public and specialized sectors.

It's mandate is:

- To take meteorological observations and to provide current and forecast meteorological information for optimum operation of weather-sensitive activities like agriculture, irrigation, shipping, aviation, offshore oil explorations, etc.
- To warn against severe weather phenomena like tropical cyclones, norwesters, duststorms, heavy rains and snow, cold and heat waves, etc., which cause destruction of life and property.
- To provide meteorological statistics required for agriculture, water resource management, industries, oil exploration and other nation-building activities.
- To conduct and promote research in meteorology and allied disciplines.
- To detect and locate earthquakes and to evaluate seismicity in different parts of the country for development projects.

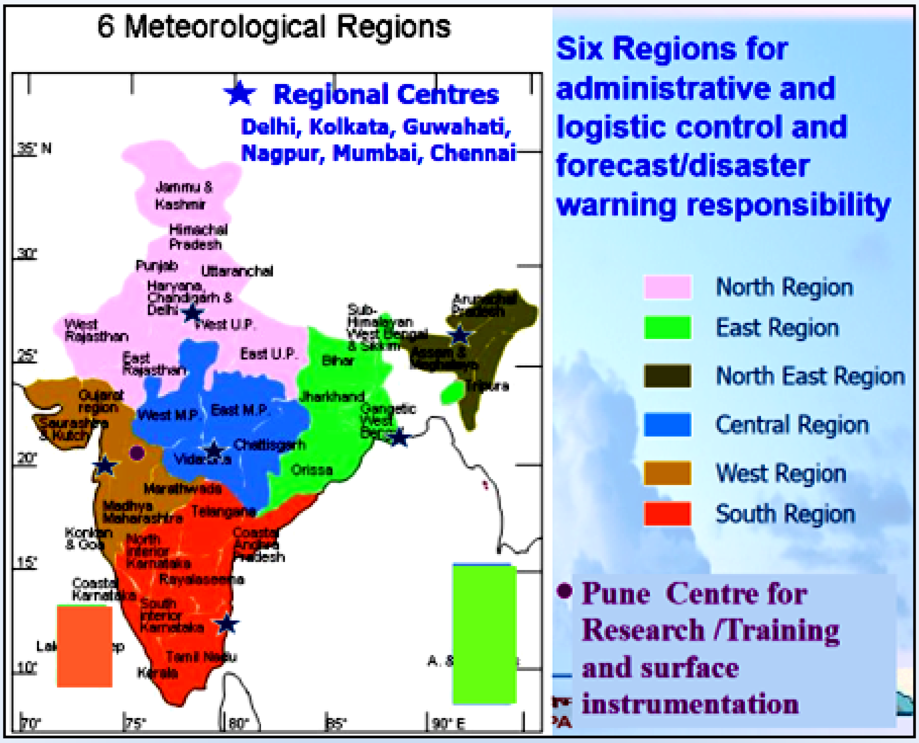
A disastrous tropical cyclone struck Calcutta in 1864 and this was followed by failures of the monsoon rains in 1866 and 1871. In the year 1875, the Government of India established the India Meteorological Department, bringing all meteorological work in the country under a central authority. Mr. H. F. Blanford was appointed Meteorological Reporter to the Government of India.

From a modest beginning in 1875, IMD has progressively expanded its infrastructure for meteorological observations, communications, forecasting and weather services and it has achieved a parallel scientific growth. IMD has always used contemporary technology. In the telegraph age, it made extensive use of weather telegrams for collecting observational data and sending warnings. Later IMD became the first organization in India to have a message switching computer for supporting its global data exchange. One of the first few electronic computers introduced in the country was provided to IMD for scientific applications in meteorology. India was the first developing country in the world to have its own geostationary satellite, INSAT, for continuous weather monitoring of this part of the globe and particularly for cyclone warning. IMD has continuously ventured into new areas of application and service, and steadily built upon its infra-structure in its history of 145 years. It has simultaneously nurtured the growth of meteorology and atmospheric science in India. Today, meteorology in India is poised at the threshold of an exciting future.


India Meteorological Department,
IMD, Alipore Observatory, Kolkata founded in 1877
Agricultural
Nowcasting
Human Resource Development
Marine Meteorology
Positional Astronomy
Pilgrims Forecast
Forecast and warning Dissimination
Heavy rainfall warning
Cyclone forecasting
Observed and forecasted track of cyclone Phailin
SPECIALIZED SERVICES OF IMD
Monsoon forecasting
Aviation
Climate services
Hydro Meteorology
Environmental
Met Observations

India had some of the oldest meteorological observatories of the world and the first astronomical and meteorological unit started at Madras in 1793. Thus, meteorological observation in India was taken even prior to the establishment of the department in 1875. Since then IMD has achieved many milestones during the period from 1793 to 2021.

The Director General of Meteorology is the Head of the India Meteorological Department, with headquarters at New Delhi. For the convenience of administrative and technical control, there are 6 Regional Meteorological Centres, each under a Deputy Director General with headquarters at Mumbai, Chennai, New Delhi, Kolkata, Nagpur and Guwahati. Under the administrative control of Deputy Director General, there are different types of operational units such as Meteorological Centres, Forecasting Offices, Agromet. Advisory Centres, Flood Meteorological Offices and Cyclone Detection Radar Stations.



India Meteorological Department has continued its efforts for the improvement of observing, warning and dissemination mechanism/systems all through 2021. Its improved services rendered in respect of very short (up to 6 hrs), short (up to 3-days in advance), medium (up to 7-10 days in advance), extended (up to 15 to 20 days in advance), long (monthly and seasonal) range and severe weather (cyclones, thunderstorms, extreme rainfall) forecasts have been built to meet the demands of the user agencies, disaster managers, emergency response groups and other stakeholders in an organized manner in 2021. Its short, medium, extended & long range and cyclone forecasts were appreciated all over the world.

Climate over India during 2021 was above normal. The annual mean temperature for the country was +0.44°C above the 1981-2010 average, thus making the year 2021 as the fifth warmest year on record since 1901. It may be mentioned that 11 out of the 15 warmest years were from the recent past fifteen years (2007-2021). In addition, the past decade (2011-2020/2012-2021) was the warmest decade on record with anomalies of 0.34°C / 0.37°C above average. During 1901-2021, the annual mean temperature showed an increasing trend of 0.63°C/100 years with significant increasing trend in the maximum temperature (0.99°C / 100 years), and relatively lower increasing trend (0.26°C/100 years) in the minimum temperature.

The annual rainfall over the country was above normal (105% of LPA) during the year. Rainfall over homogeneous region of south peninsula (444.6 mm) was highest since 1901.Rainfall over core region (northeast monsoon region) of south peninsula (579.1 mm) was highest since 1901.

In 2021, five cyclonic storms formed over the north Indian Ocean. These are: (1) Extremely Severe Cyclonic Storm TAUKTAE, (2) Very Severe Cyclonic Storm YAAS, (3) Severe Cyclonic Storm SHAHEEN (remnant of GULAB), (4) Cyclonic Storm GULAB & (5) Cyclonic Storm JAWAD. Of these, three cyclones (YAAS, GULAB and JAWAD) formed over the Bay of Bengal. & the remaining two cyclones (viz. TAUKTAE & SHAHEEN) formed over the Arabian Sea.

Among these 5 cyclones, the most devastating was Extremely Severe Cyclonic Storm TAUKTAE (14 May to 19 May) which formed in the pre-monsoon season over the Arabian Sea, crossed Saurashtra coast on 17^{th} May, claiming 144 lives from across the states in western India stretching from Kerala in the far southern part of the country to Gujarat in the northwest.

The Very Severe Cyclonic Storm YAAS, (23 May to 28 May) formed during the pre-monsoon season over the Bay of Bengal, crossed the north Odisha coast on 26th May, 2021 and claimed 9 lives from Odisha, Jharkhand, West Bengal & Bihar.

The Cyclonic Storm GULAB (24 September to 28 September), formed during the southwest monsoon season & crossed north Andhra Pradesh - south Odisha coasts on 26th September, claiming 19 lives from Andhra Pradesh, Telangana, Odisha, Maharashtra.

The Severe Cyclonic Storm SHAHEEN (29 September to 4 October) formed over Arabian Sea and moved away from Indian region towards Oman coast.The Cyclonic Storm JAWAD (2-6 December) formed over Bay of Bengal and weakened close to Odisha coast. However, these two systems do not have extreme impacts in India.

Heavy rain & flood related incidents reportedly claimed over 750 lives from different parts of the country during the pre-monsoon, monsoon & post-monsoon seasons. Of these, 215 lives were reported from Maharashtra, 143 from Uttarkhand, 55 from Himachal Pradesh, 53 from Kerala and 46 from Andhra Pradesh.

Thunderstorm & Lightning reportedly claimed over 780 lives from central, northeastern, northwestern and peninsular parts of the country throughout the year. Of these, 213 lives were reported from Odisha, 156 from Madhya Pradesh, 89 from Bihar, 76 from Maharashtra, 58 from West Bengal, 54 from Jharkhand, 49 from Uttar Pradesh and 48 from Rajasthan.

SUMMARY OF MAJOR ACHIEVEMENTS IN 2021

Observations

Agrometeorological Observatories & Data Management

- Agromet Division maintains a network of conventional agrometeorological observatories. Around 191 such agrometeorological observatories have uploaded Agrometeorological observations in the website of Agromet Division, out of which 166 observatories are updating regularly and remaining 25 observatories upload the same on a near real-time basis.

- Around 190 new Agro-AWS have been established till December 2021 at newly established District Agromet Units (DAMUs) in the premises of Krishi Vigyan Kendras (KVKs) under the network of the Indian Council of Agriculture Research (ICAR). The Agro-AWSs also have soil moisture and soil temperature sensors up to one-meter depth apart from the other sensors of a standard AWS.

- Agromet data received from various stations have been scrutinized and are being archived at National Data Centre Pune.

Enhancement in Modelling & Weather and Climate Services

Under the flagship programme of Government of India, Integrated Agromet Advisory Services, Gramin Krishi Mausam Sewa (GKMS) is being implemented in the country successfully in collaboration with a number of Central Government Ministries and organizations, state level institutions, private agencies, NGOs, progressive farmers and media. More than 43 million farmers have subscribed for the information through mobile for planning their agricultural activities.

- Climate of capital cities and smart cities has been prepared along with the trend analysis

- Climatological Summaries have been published for 22 airports during the year 2020

- The online Climate Data Portal has been developed for supply of data to various users
- Long range forecast of temperature and rainfall was issued for all the seasons under South Asia Climate Outlook Forum (SASCOF)
- Health guidance product based on Extended Range (up to Two Weeks) forecast for all meteorological subdivisions and districts
- Meteorological Centres/Regional Meteorological Centres issued Extended Range Forecasts for their area of responsibility on weekly basis every Thursday
- Commissioning of 3 Doppler Weather Radars at Mukteshwar (Uttarakhand); Kufri, Shimla (Himachal Pradesh); and Jammu (J&K) in 2021 and another 4 radars are being commissioned in January 2022 at New Delhi, Leh, Mumbai and Chennai
- Online web portal of imd international journal mausam
- multi mission meteorological data receiving & processing system at IMD New Delhi
- Implementation of climate data service portal (CDSP) at CRS, IMD Pune
- Standard operation procedure (SOP) manuals on various forecasting services of IMD
- Launched ‘Public observation’ under crowd-sourcing mechanism to gather and archive observed weather phenomena
- Launched “Pune live weather app”
- Urban metrological services for Delhi NCR region through dedicated web portal
- Development of web GIS portal for real time monitoring and forecasting of severe weather hazards
- Development of 12 no. of new apis for delivery of weather services to state governments stakeholders and disaster managers
- Nowcast stations increased to 1085 with addition of 194 new stations
- City forecast stations increased to 1129 from 526
- 12 no. of new High Wind Speed Recorder (HWSR) installed
- 10 no. of Digital Current Weather Instrument System (DCWIS) installed
- 200 no. agro-aws have been instated at Krishi Vigyan Kendras (KVKs)
- For real-time dissemination of agromet advisories, 10,448 whatsapp groups have been formed covering 90,865 villages of 3,301 blocks
- Multi hazard weather warning issued for next 5 days
- Impact Based multi hazard Forecast (IBF) and warnings extended to whole country for all types of severe weather at city, district & meteorological sub-division levels

- The High Resolution Rapid Refresh (HRRR) model implemented for three domains (north-west, east & north-east & south peninsular) with radar data assimilation & forecast products update at every two hours valid upto next 12 hrs
- Significant improvement in forecast accuracy of severe weather events by 15 to 35% in last 5 years
- Nine (9) no of cyclones/depressions formed in 2021 were accurately predicted with reasonable lead period of 5 days or more
- Introduction of multi-model ensemble forecast scheme for monthly/seasonal rainfall & temperature commencing from April 2021 along with probabilistic prediction of spatial distribution of rainfall & temperature
- Weather information provide to national agriculture market for 500 districts (markets yards/ mandies) (eNAM)
- 80 research papers were published by IMD scientist in national and international journals
- IMD launched its new mobile App, Mausam. IMD also worked jointly with MeitY for development and dissemination of weather information in Umang Mobile App
- IMD introduced web-GIS based interactive map for cyclone, heat wave and cold wave warning
- Social media interaction has been enhanced significantly with the presence in Facebook, twitter, instagram, telegram, You Tube and Whats App groups established at IMD HQ and MC/RMC etc.
- Application Programming Interface (API) for weather observed and forecast products of IMD has been developed and provided to different states, different central Government organizations including NITI Aayog, Tourism, DD News etc. About 10 states have implemented this API for their services
- Common Alert Protocol (CAP) has been implemented as per WMO standard for severe weather warning. It is being utilized for Global Multi-Hazard Alert System (GMAS) of WMO. Google International is also using CAP for Google Alert
- Crowd Source Platform has been launched through website and mobile app for collecting the weather observations from people
- The Journal MAUSAM is being made on line like any other international Journals
- Appreciation of IMD services by WMO and others

CHAPTER 2

Weather Summary during 2021

1. Winter Season (January & February)

Highlights

Mean temperature over All India (21.43 °C) was third highest after the years 2016 (21.8 °C), 2009 (21.59 °C) since 1901. Minimum temperature over All India (15.39 °C) was second highest since 1901 after the year 2016 (15.54 °C). Rainfall over the homogeneous region of south peninsular India was fourth highest since 1901.

Cold Wave conditions

During January cold wave conditions were subdued over central, western and parts of eastern India while over northern parts of India these events were mainly observed in the 2nd half of January. During February cold wave conditions prevailed during the first fortnight of the month on one or two days.

Rainfall Features

Rainfall realized during the season was 68% of its LPA. It was 117% of its LPA during January and was 32% of its LPA during February. Generally, sub divisions of peninsular India, western part of central India and both the islands received large excess/excess rainfall remaining sub divisions received deficient/ large deficient rainfall.

During the season, out of 36 meteorological subdivisions, 10 received large excess rainfall, rainfall, 13 received large deficient rainfall and 3 received excess rainfall, one subdivision received normal rainfall, 8 received deficientone subdivision didn't receive any rain (Fig. 1). Rainfall over east Rajasthan, Gujarat Region, Konkan & Goa, Madhya Maharashtra, Marathwada, Rayalaseema, Tamilnadu, Puducherry & Karaikal, Karnataka state, Kerala & Mahe and Lakshadweep was more than one and half times of its normal value.

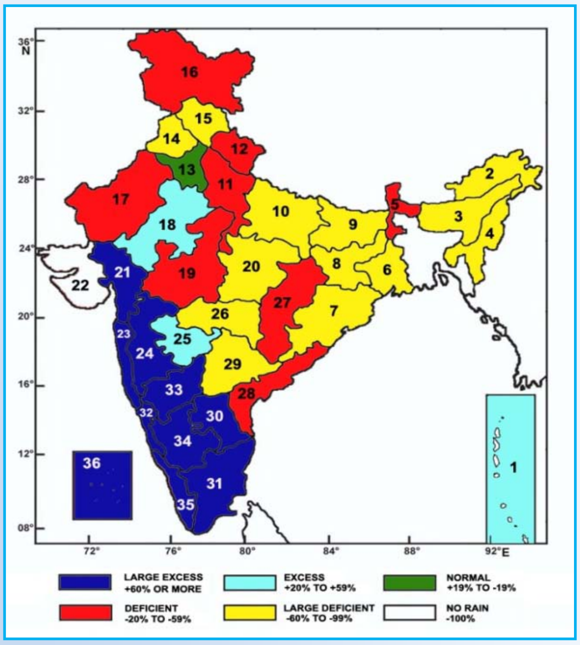
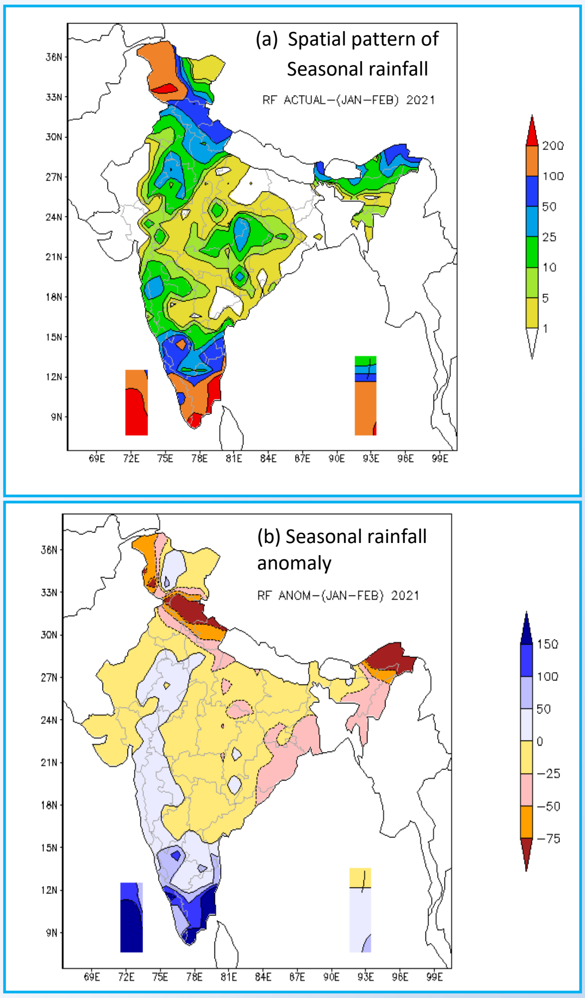


Fig. 1. Sub-divisionwise rainfall percentage departures

Fig. 2(a) shows the spatial pattern of rainfall (mm) received during the season. Rainfall activity was observed over parts of northwest, east and northeast, central, peninsular India and both the islands except some west central and northeast parts. Parts of Jammu & Kashmir and Ladakh, Tamilnadu, Puducherry & Karaikal, Kerala & Mahe and both the islands received more than 100 mm rainfall. Parts of Jammu & Kashmir, Tamilnadu, Puducherry & Karaikal and Lakshadweep received more than 200 mm rainfall.

Fig. 2(b) shows the spatial pattern of rainfall anomaly (mm) during the season. Rainfall anomaly was more than 100 mm over parts of Tamilnadu, Puducherry & Karaikal, Kerala & Mahe and Lakshadweep. Magnitude of negative rainfall anomaly was more than 50 mm over parts of Arunachal Pradesh, Assam & Meghalaya, Uttarakhand, Punjab, Himachal Pradesh and western parts of Jammu & Kashmir and Ladakh. Magnitude of negative rainfall anomaly was more than 75 mm over parts of Arunachal Pradesh, Uttarakhand, Punjab, Himachal Pradesh and Jammu & Kashmir.



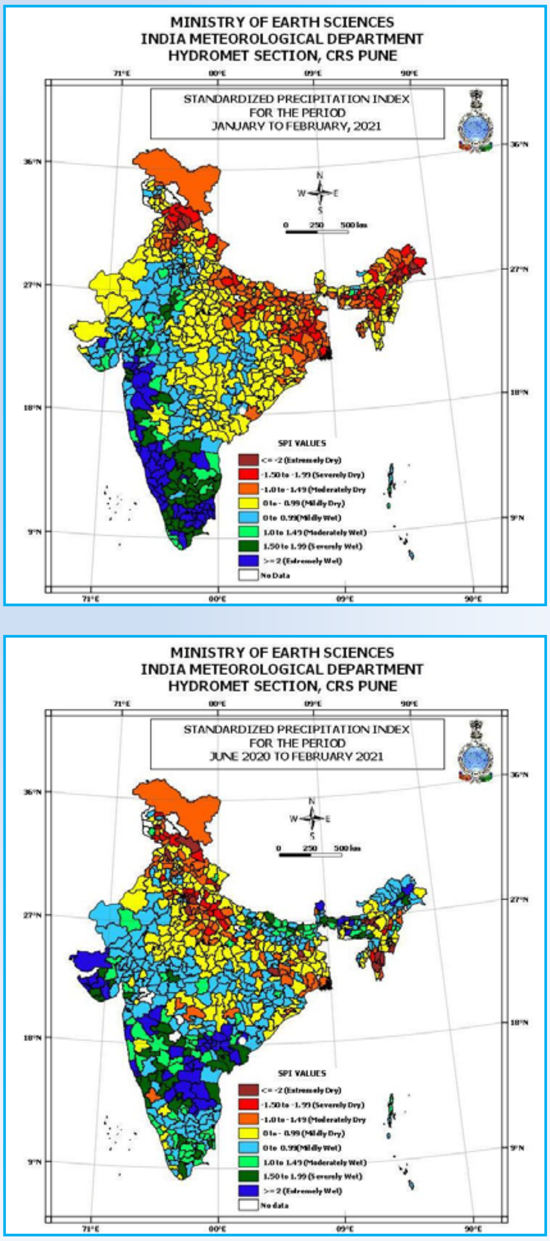
Figs. 2(a&b). Spatial pattern of (a) Seasonal Rainfall Winter (January-February)
(b) Seasonal rainfall anomaly (mm)(*Based on 1961-2010 NOR*)

Standardized Precipitation Index (SPI)

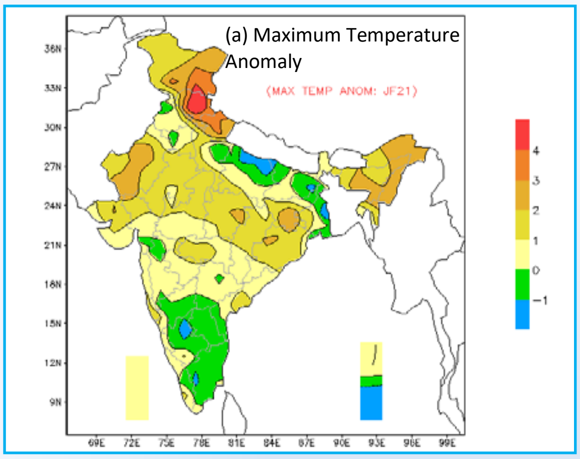
The Standardized Precipitation Index (SPI) is an index used for measuring drought and is based on only precipitation. This index is negative for drought, and positive for wet conditions. As the dry or wet conditions become more severe, the index becomes more negative or positive respectively. Figs. 3(a&b) show the SPI values for the winter season 2021 (January-February, 2 months cumulative) and period from June 2020-February 2021 (nine months cumulative) respectively.

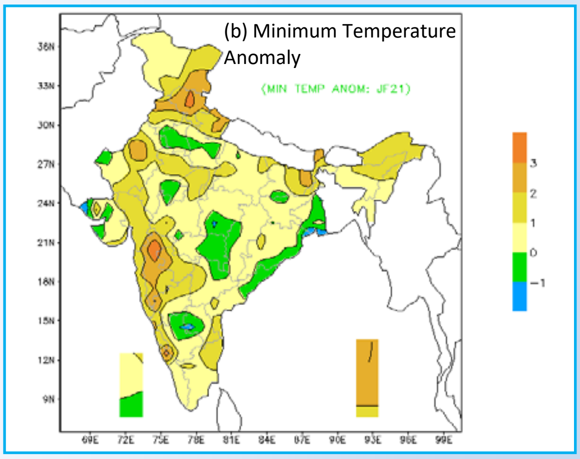
Cumulative SPI values of the past two months (January and February) indicate that extremely wet/severely wet conditions were observed over parts of East Rajasthan, West MadhyaPradesh, Gujarat state, Konkan & Goa, Madhya Maharashtra, Marathawada, Rayalaseema, Tamilnadu, Puducherry & Karaikal, Karnataka state, Kerala and Lakshadweep, while extremely dry/severely dry conditions were observed over parts of Arunachal Pradesh, Assam & Meghalaya, Nagaland, Manipur, Mizoram & Tripura, Sub Himalayan West Bengal & Sikkim, Gangetic West Bengal, Bihar, East Uttar Pradesh, Uttarakhand, Punjab, Himachal Pradesh, Jammu & Kashmir& Ladakh.

Cumulative past nine months SPI values indicate extremely wet/severely wet conditions over parts of Arunachal Pradesh, Assam & Meghalaya, Sub Himalayan West Bengal & Sikkim, Odisha, Bihar, East Uttar Pradesh, West Madhya Pradesh, Gujarat state, Konkan & Goa, Madhya Maharashtra, Marathawada, Chhattisgarh, Andhra Pradesh state,Telangana, Tamilnadu, Puducherry &Karaikal,



Figs. 3 (a&b). Standardized Precipitation Index (SPI) Cumulative for (a) two months (b) nine months





Figs. 4(a&b). Mean seasonal temperature anomalies (°C) for winter (January-February) 2021 (a) Maximum (b) Minimum (*Based on 1981-2010 Normals*)

Karnataka state and Lakshadweep, while extremely dry/severely dry conditions were observed over parts of Assam & Meghalaya, Nagaland, Manipur, Mizoram & Tripura, Jharkhand, Uttar Pradesh state, Uttarakhand, Haryana, Chandigarh & Delhi, Punjab, Himachal Pradesh and Jammu & Kashmir & Ladakh.

Temperatures

Mean seasonal maximum and minimum temperature anomalies are shown in Figs. 4(a&b) respectively.

Maximum temperature was above normal over most parts of the country except some parts of east India, central India, south peninsular India and Andaman & Nicobar Islands. Maximum temperature anomaly was more than 4 °C over parts of Jammu, Kashmir & Ladakh and Himachal Pradesh. Maximum temperature anomaly was less than -1 °C over parts of East Uttar Pradesh, Bihar, Gangetic West Bengal, South Interior Karnataka, Tamilnadu, Puducherry & Karaikal and Andaman & Nicobar Islands.

Minimum temperature was above normal over most parts of the country except some parts of northwest India, central India, south peninsular India and Lakshadweep. Minimum temperature anomaly was more than 3 °C over parts of Himachal Pradesh, Madhya Maharashtra and Kerala and Mahe. Minimum temperature anomaly was less than -1 °C over parts of extreme western Saurashtra & Kutch and southern Gangetic West Bengal, East Madhya Pradesh and Rayalaseema.

Outgoing Longwave Radiation (OLR)

OLR anomaly (W/m^2) over the Indian region and neighbourhood is shown in Fig. 5. OLR was normal over central India, northern parts of peninsula and adjoining Arabian Sea and Bay of Bengal. OLR anomaly was less than -10 W/m^2 over southwest part of peninsula and adjoining Arabian Sea and Bay of Bengal.

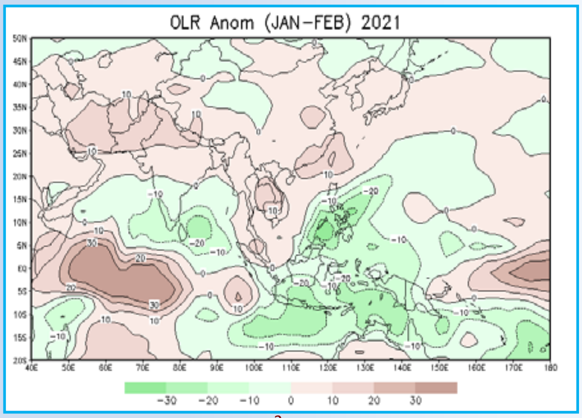


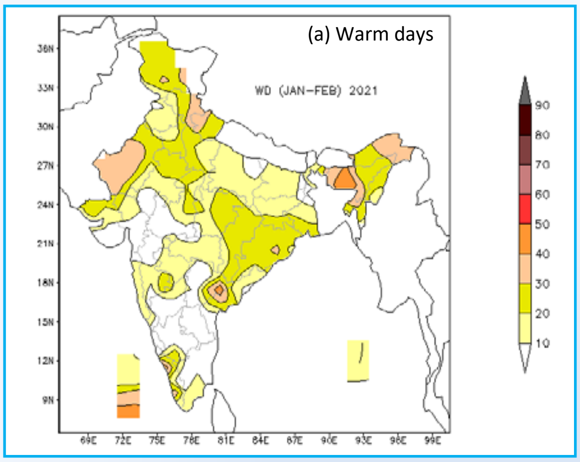
Fig. 5. OLR anomaly (w/m^2) for the winter season 2021 (*Source*: CDC / NOAA, USA) (*Based on 1981 - 2010 climatology*)

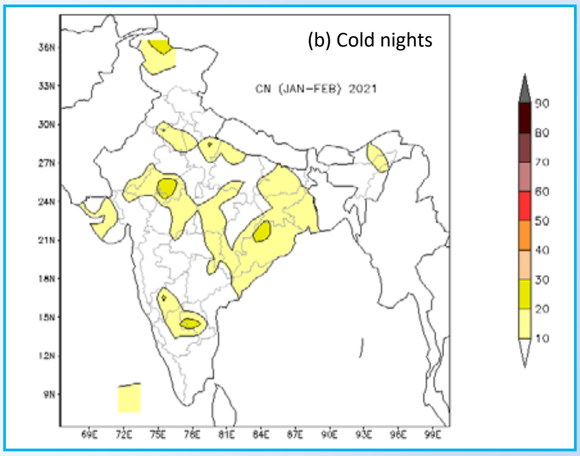
Positive OLR anomaly exceeding 10 W/m^2 was observed over northwestern parts of country.

Warm days/cold nights

Figs. 6(a&b) show the percentage of days when maximum (minimum) temperature was more (less) than 90th (10th) percentile.

Over parts of Assam & Meghalaya, Telangana and Lakshadweep maximum temperature was greater than 90th percentile for more than 40% of the days of the season. For minimum temperature, no significant distribution was observed.





Figs. 6(a&b). Percentage of days when (a) maximum temperature > 90th percentile (b) minimum temperature < 10th percentile

Both maximum and minimum temperatures were above normal over all the homogeneous regions. Maximum temperature over All India (27.47 °C) was seventh highest, central India (29.69 °C) was eighth highest and northwest India (21.17 °C) was ninth highest since 1901. Minimum temperature over all India (15.39 °C) was second highest, south peninsular India (22.01 °C) was sixth highest and central India (15.43 °C) was seventh highest since 1901.

Low Pressure Systems

No intense low pressure systems formed during the season.

Significant Weather Events

Floods & Heavy Rain: 70 persons reportedly claimed dead & 205 persons still missing due to Nandadevi Glacier breaks at Joshimath in Chamoli district of Uttarakhand on 7th February which triggered flash flood in Dhauli Ganga area.

Snowfall : Total 6 persons reportedly claimed dead in the first fortnight of January.

Cold Wave : Due to cold wave, total 5 persons reportedly claimed dead in the month of January.

Lightning : Total 7 persons reportedly claimed dead during the season. Of which, 2 from Morena district of Madhya Pradesh and 5 persons from Buldhana, Jalna & Nanded districts of Maharashtra.

Hailstorm : Due to hailstorm on 18th & 19th February in Jalna, Kolhapur, Nashik, Pune, Raigad, Ratnagiri, Satara, Sindhudurg districts of Maharashtra.

2. Pre-monsoon Season (March-May)

Highlights

Rainfall over homogeneous region of central India (85.2 mm) was third highest since 1901 after the years 1933 (105.9 mm) and 1990 (102.3 mm).

During the season, one low pressure area formed in the month of March over Arabian Sea. One depression (2-3 April) formed in the month of April. In the month of May Extremely Severe Cyclonic Storm **"TAUKTAE"** (14-19 May) formed over Arabian sea and Very Severe Cyclonic Storm **"YASS"** (23-27 May) formed over Bay of Bengal.

During the season 273 persons reportedly claimed dead, more than 120 persons injured, 53 persons missing & more than 190 livestock excluding thousands of birds perished.

Heat Wave Conditions

During the season, heat wave/severe heat wave conditions were observed in March and April. In the month of May, no significant heat wave conditions were observed. During March the heat wave conditions were observed at most places with Severe Heat wave conditions at isolated places occurred over West Rajasthan during 29-31 March, Heat wave conditions were also observed at a few places over east Rajasthan during 30-31 March, over Odisha and adjoining parts of Gangetic West Bengal, Coastal Andhra Pradesh and Tamil Nadu on 31 March. During April Heat wave conditions were occasional and also for shorter periods over very smaller pockets. They were observed over Tamil Nadu, Puducherry & Karaikal, Coastal Andhra Pradesh & Yanam, Rajasthan, Haryana, Chandigarh & Delhi, Saurashtra & Kutch, Gangetic West Bengal and Odisha.

Rainfall Features

Rainfall activity during the season was above normal. Rainfall realized during the season was

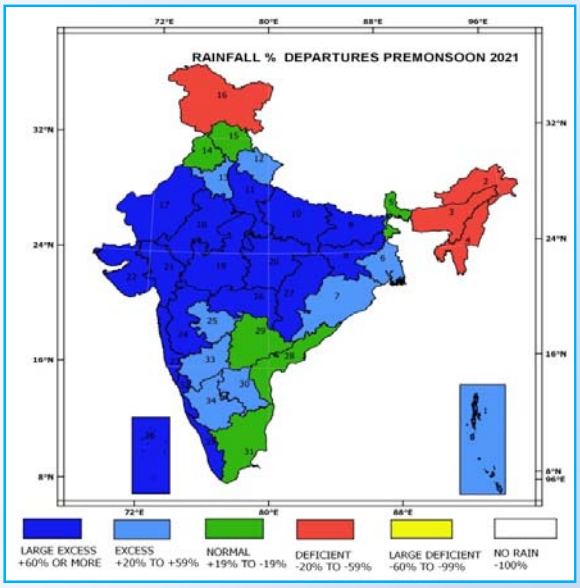
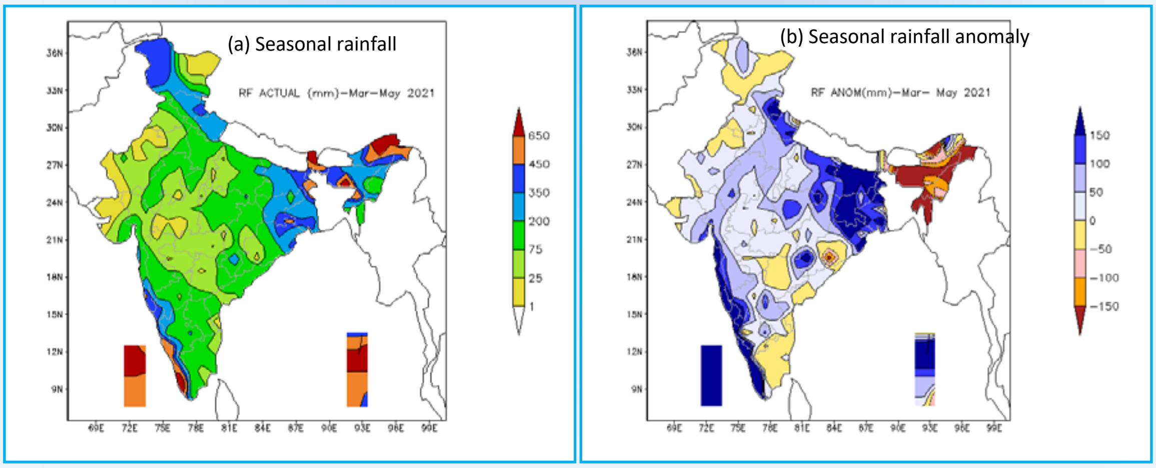


Fig. 7. Sub-divisionwise rainfall percentage departures

118% of its LPA. During the season, out of 36 meteorological subdivisions, 17 received large excess rainfall, 9 received excess rainfall, 6 received normal rainfall, 4 received deficient rainfall (Fig. 7).

Fig. 8(a) shows the spatial pattern of rainfall (mm) received during the season. Parts of Assam & Meghalaya, Arunachal Pradesh, Sub-Himalayan West Bengal & Sikkim, Jharkhand, Bihar, Gangetic West Bengal, Odisha, Jammu & Kashmir and Ladakh, Uttarakhand, Konkan & Goa, Coastal Karnataka, Kerala & Mahe and both the islands received more than 350 mm rainfall. Parts of Arunachal Pradesh, Assam & Meghalaya Sub-Himalayan West Bengal & Sikkim, Odisha, Gangetic West Bengal, Jharkhand, Bihar, Kerala & Mahe and both the islands received more than 450 mm rainfall. Parts of Arunachal Pradesh, Assam & Meghalaya, Sub-Himalayan West Bengal & Sikkim, Kerala & Mahe and both the islands received more than 650 mm rainfall.

Fig. 8(b) shows the spatial pattern of rainfall anomaly (mm) during the season. Rainfall anomaly was positive over entire country except extreme northeast region, Jammu & Kashmir andand Ladakh, Odisha, Tamil Nadu, Puducherry & Karaikal and some pockets. Positive rainfall anomaly more than 100 mm was observed over Arunachal Pradesh, Gangetic West Bengal, Odisha, Jharkhand, Bihar, East Uttar Pradesh, Uttarakhand, East MadhyaPradesh, Chhattisgarh, entire west coast and both the islands. Positive rainfall



Figs. 8(a&b). (a) Seasonal rainfall (mm) (b) Seasonal rainfall anomaly (mm) (*Based* on 1961-2010 *Normals*)

anomaly more than 150 mm was observed over Gangetic West Bengal, Odisha, Jharkhand, Bihar, East and west Uttar Pradesh, Uttarakhand, Chhattisgarh, entire west coast and both the islands. Magnitude of negative rainfall anomaly was more than 150 mm over parts of Arunachal Pradesh, Nagaland, Manipur, Mizoram & Tripura, Assam & Meghalaya.

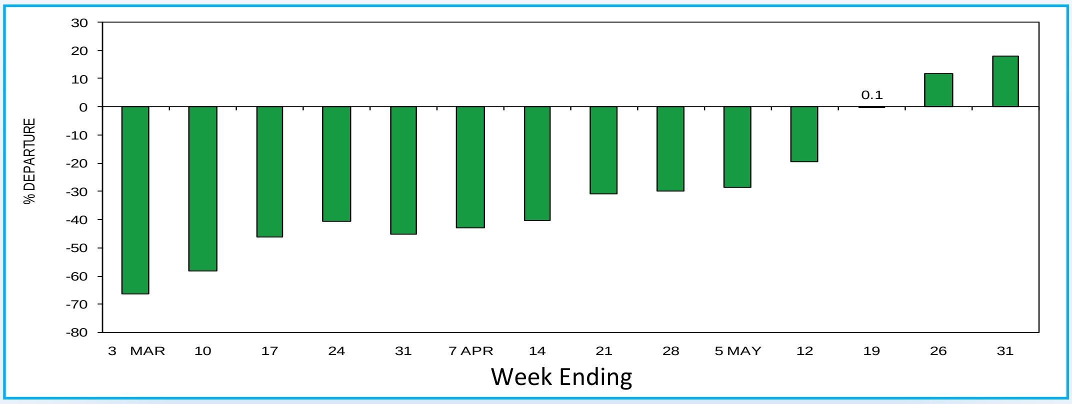


Fig. 9. Accumulated percentage departure of area weighted weekly rainfall over the country as a whole

Fig. 9 shows the area weighted cumulative weekly rainfall percentage departure during the season for the country as a whole.

Fig. 10(a) shows the area weighted seasonal rainfall over the country as a whole for the period 1951-2021.

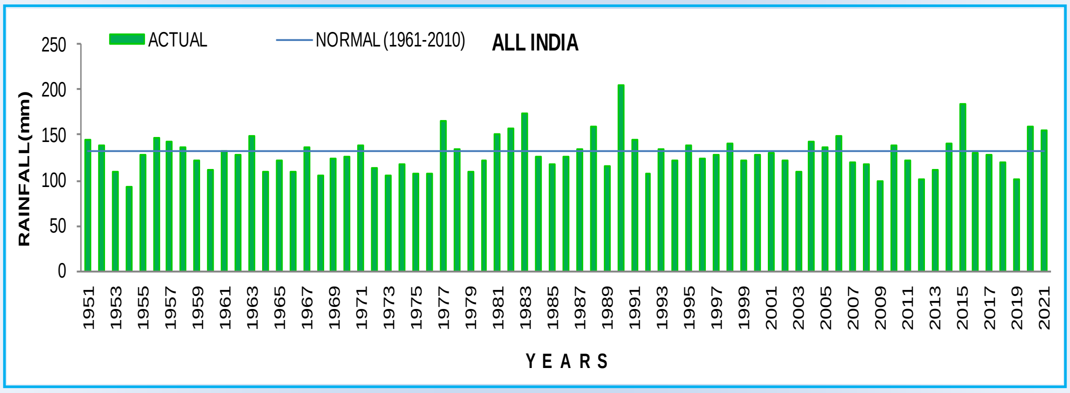


Fig. 10(a). Time series of area weighted rainfall over the country as a whole (1951 - 2021)

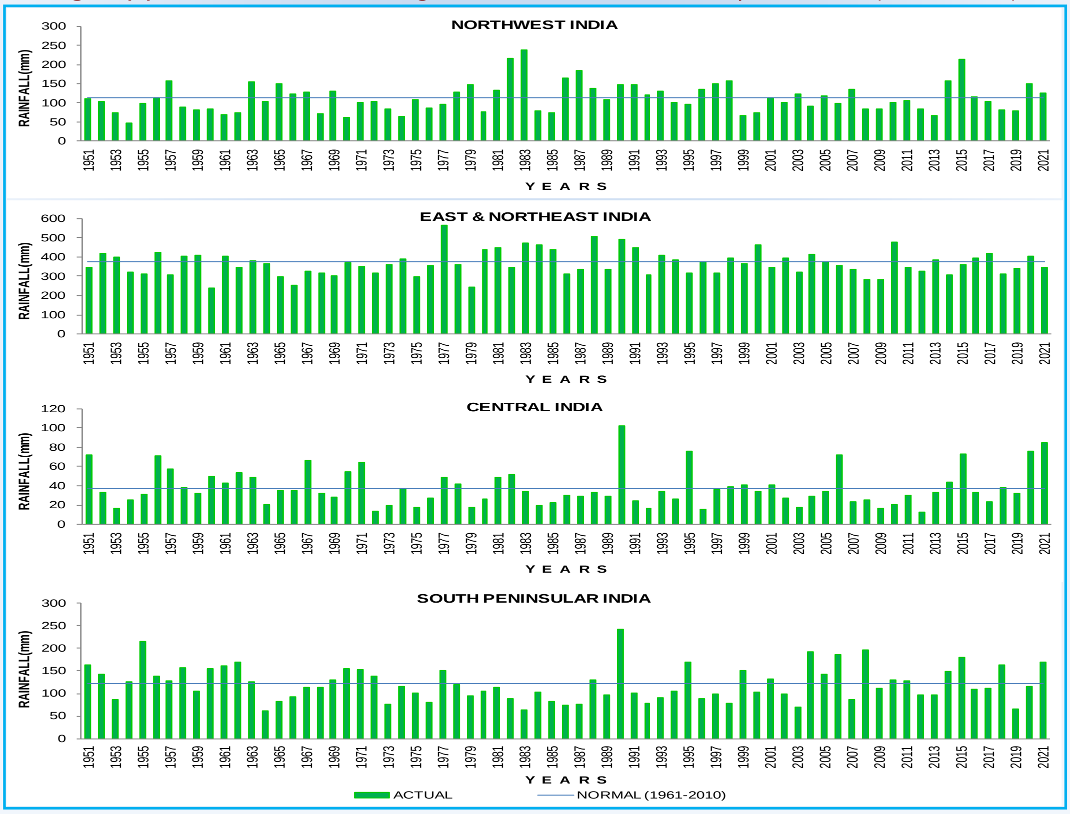


Fig. 10 (b). Time series of area weighted rainfall over the four homogeneous regions (1951 - 2021)

Fig. 10(b) shows the time series of area weighted seasonal rainfall over the four homogeneous regions for the period 1951-2021.

Standardized Precipitation Index

The Standardized Precipitation Index (SPI) is an index used for monitoring drought and is based on only precipitation. This index is negative for dry, and positive for wet conditions. As the dry or wet conditions become more severe, the index becomes more negative or positive. Fig. 11 gives the SPI values for the Pre-monsoon season this year.

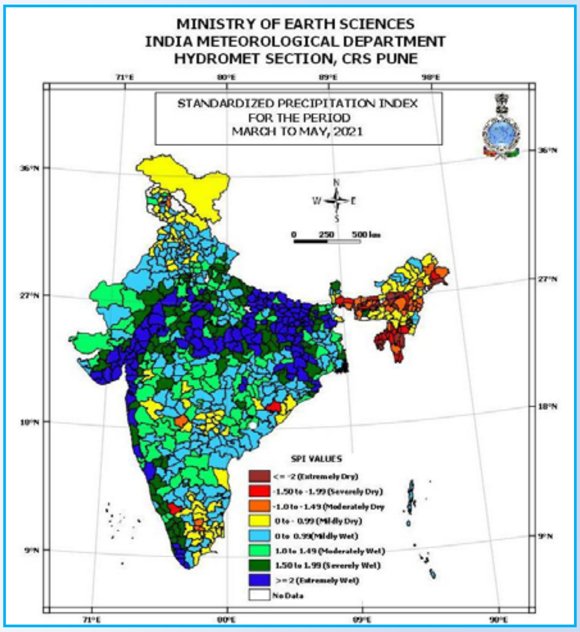


Fig. 11. Standardized precipitation index (SPI) cumulative for pre monsoon season (Mar-May, 2021)

Cumulative SPI values of the past three months show extremely wet/severely wet conditions over parts of Assam & Meghalaya, Sub Himalayan West Bengal & Sikkim, Gangetic West Bengal, Odisha, Jharkhand, Bihar, Uttar Pradesh state, Uttarakhand, Haryana, Chandigarh & Delhi, Rajasthan state, Madhya Pradesh state, Gujarat state, Konkan & Goa, Madhya Maharashtra, Chhattisgarh, Tamil Nadu, Puducherry & Karaikal, Karnataka state, Kerala & Mahe and Lakshadweep while extremely dry/severely dry conditions were observed over Arunachal Pradesh, Assam & Meghalaya, Nagaland, Manipur, Mizoram & Tripura, Sub Himalayan West Bengal & Sikkim, Odisha, Haryana, Chandigarh & Delhi, Jammu & Kashmir and South Interior Karnataka.

Outgoing Longwave Radiation (OLR)

OLR anomaly (W/m^2) over the Indian region and neighbourhood is shown in Fig. 12.

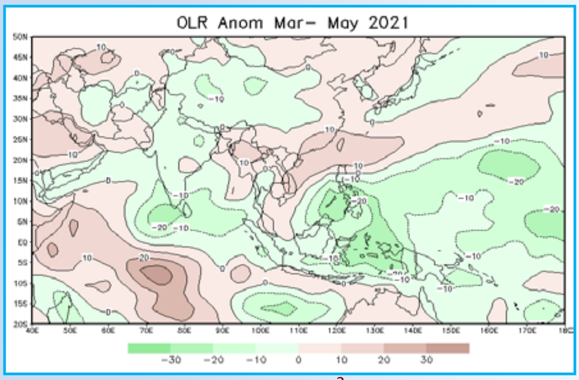
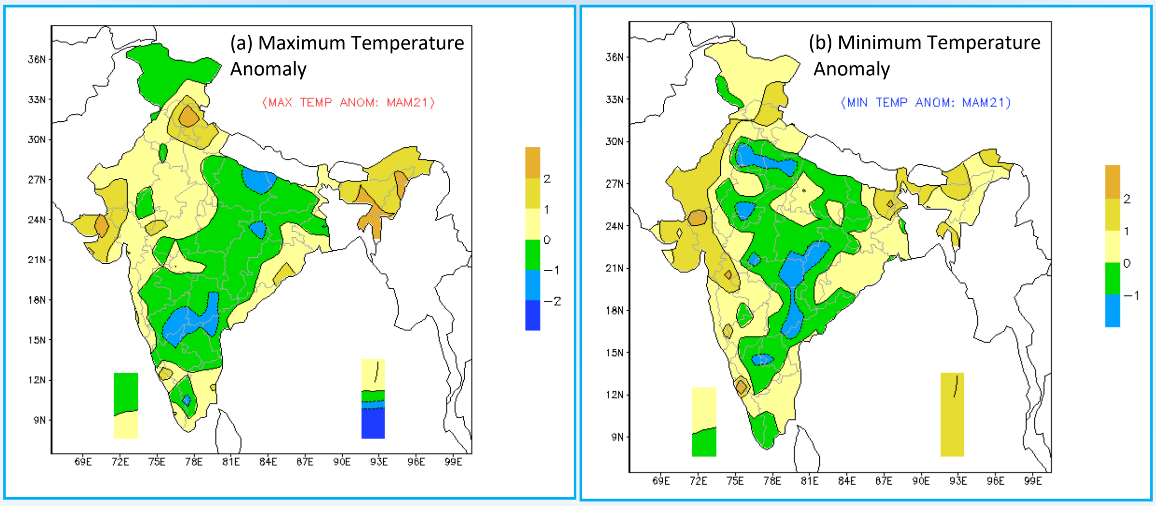


Fig. 12. OLR Anomaly (W/m^2) for Pre-monsoon Season (Mar-May) 2021



Figs. 13(a&b). Mean seasonal temperature anomalies (°C) (a) maximum (b) minimum (*Based on 1981-2010 normals*)

OLR anomaly was negative over most parts of the country except northeastern parts and adjoining Bay. OLR anomaly was less than -10 W/m^2 over southern parts of south peninsula and adjoining Arabian sea and Bay of Bengal. OLR anomaly was less than -20 W/m^2 over east central Arabian Sea. Positive OLR anomaly exceeding 10 W/m^2 was observed over northern Bay of Bengal.

Temperature

Mean seasonal maximum and minimum temperature anomalies during the season are shown in Figs. 13(a&b) respectively.

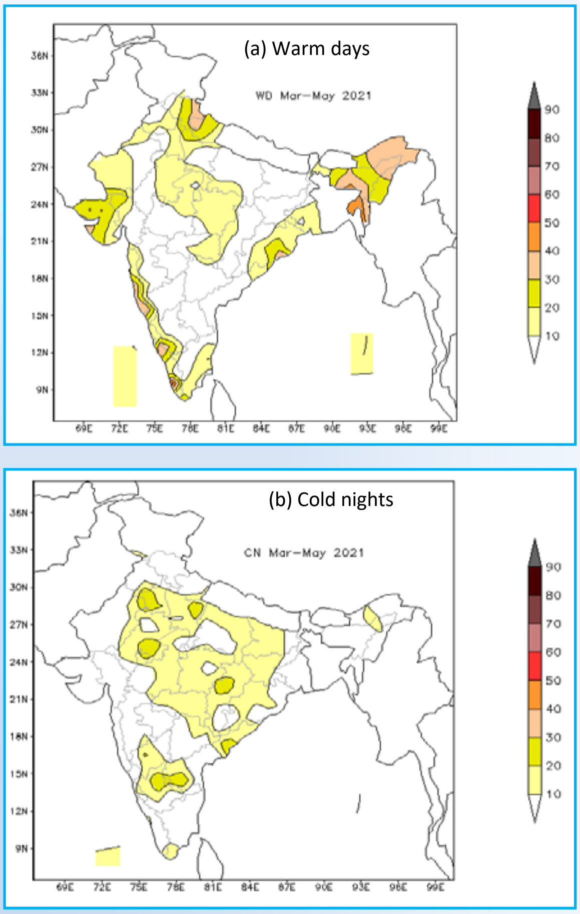
Maximum temperature was above normal over most parts of the country except some parts of northwest India, east & northeast India, central India, south peninsular India and both the islands. Maximum temperature anomaly was more than 2 °C over parts of Himachal Pradesh, Assam & Meghalaya, Nagaland, Manipur, Mizoram, Tripura and Saurashtra & Kutch.

Minimum temperature was above normal over most parts of the country except some parts of northwest India, central India, south Peninsular India and Lakshadweep. Minimum temperature anomaly was more than 2 °C over parts of northern Saurashtra & Kutch, Madhya Maharashtra, Bihar, North Interior Karnataka, and southern Kerala & Mahe. Minimum temperature anomaly was less than -1 °C over parts of Haryana, Chandigarh & Delhi, West Uttar Pradesh, East Rajasthan, southern Madhya Pradesh state, Chhattisgarh, Vidarbha, Andhra Pradesh state, Telangana and South Interior Karnataka.

Percentage of Warm days/Cold nights

Figs. 14(a&b) show the percentage of days when maximum (minimum) temperature was more (less) than 90th (10th) percentile.

Over parts of Kerala, Assam & Meghalaya and Mizoram & Tripura, maximum temperature was greater than 90th percentile for more than 40% of the days of the season. For minimum temperature, no significant distribution was observed.



Figs. 14(a&b). Percentage of days when (a) maximum temperature > 90th Percentile (b) Minimum

Low Pressure Systems

During the season, one low pressure area formed in the month of March over Arabian sea. One depression (2-3 April) formed in the month of April. In the month of May Extremely Severe Cyclonic Storm **"TAUKTAE"** (14-19 May) formed over Arabian sea and Very Severe Cyclonic Storm **"YASS"** (23-27 May) formed over Bay of Bengal.

Significant Weather events during the season

During the season 273 persons reportedly claimed dead, more than 120 persons injured, 53 persons missing & more than 190 livestock excluding thousands of birds perished. Of which, more than 200 persons reportedly claimed dead, also more than 100 persons injured, 53 persons missing, more than 170 livestock perished in the worst hit month of the pre-monsoon season "MAY 2021" due to the different weather events, as given below:

Cyclonic Storms: Both the coast of India affected during the month of May 2021 due to the cyclonic storms, viz., Extremely Severe Cyclonic Storm "**TAUKTAE**" (14-19 May) - west coast & Very Severe Cyclonic Storm "YAAS" (23-28 May) - east coast. Total 153 persons reportedly claimed dead, 94 injured & more than 50 missing because of both the cyclones. Of these, 144 persons reportedly claimed dead due to "**TAUKTAE**" across the states in western India stretching from Kerala in the far southern part of the country to Gujarat in the northwest which includes 79 persons reportedly claimed dead from Gujarat, 45 from Maharashtra including 26 persons on board of the barge P-305 & another tugboat 'Varaprada' in vicinity of district Mumbai City, 9 from Kerala, 8 from Karnataka, 3 from Goa. While, total 9 persons reportedly claimed dead due to "**YAAS**", of which 3 each from Odisha & Jharkhand, 2 from West Bengal & one from Begusarai district of Bihar. Extensive damage to crops & public, private property also reported.

Hailstorm : One person reportedly claimed dead from Kathua district of Jammu & Kashmir (18th April). Also, extensive damage to crops, vegetables, different types of fruits & houses reported from Kota district of Rajasthan (7th & 8th March); Ashoknagar, Bhind, Dhar, Guna, Khandwa, Morena, Shajapur, Ujjain districts of Madhya Pradesh (8th, 19th, 23rd March); Aurangabad, Beed, Jalna, Hingoli, Parbhani, Pune districts of Maharashtra (20th, 21st March; 9th May); East Sikkim (9th April); Anantnag, Baramulla, Kulgam, Kupwara, Pulwama, Shopian districts of Jammu & Kashmir (7th , 15th , 21st, 31st May); Maldah district of West Bengal (11th May).

Thunderstorm : Total 22 persons reportedly claimed dead and more than 70 livestock perished during the month of April and May of the season. Of which, 15 persons reportedly claimed dead from Banka, Bhagalpur, Bhojpur, Jamui, Katihar, Munger, Nalanda, Rohtas, Samastipur districts of Bihar (12th May), 5 from Parts of Uttar Pradesh (21st April), 2 persons from Nashik and Nanded districts of Maharashtra on (29th and 30th May). Also, damage to crops, public & private property including houses, shops, electricity lines & poles reported from Bathinda, Patiala districts of Punjab (6th April), Union Territory 'Chandigarh' (6th April), East Sikkim (9th April), Jhabua district of Madhya Pradesh (14th April), Aurangabad, Beed, Hingoli, Jalna, Jalgaon, Nanded, Osmanabad, Parbhani, Pune, Sindhudurg, Solapur districts of Maharashtra (11th, 13th, 28th April; 9th, 24th and 27th May).

Lightning : Total 77 persons reportedly claimed dead during the season. Of which, 28 persons reportedly claimed dead from Maharashtra (20th March; 10th, 11th April; 2nd, 3rd, 6th, 7th, 9th& 26th May), 3 from Telangana (11th May), 2 each from Kerala (11th April and 9th May) & Jammu & Kashmir (14th April and 7th May), One each from Haryana (12th March) and Tamil Nadu (9th May).

Duststorm : Due to Duststorm, 5 persons reportedly claimed dead from Hardoi district of Uttar Pradesh on 12th May. Thousands of birds perished from Jaisalmer district of Rajasthan (22nd March). Also, damage to crops, houses, transformers, etc. reported from Ajmer, Alwar, Barmer, Bikaner, Churu, Jaipur, Jaisalmer, Jhunjhunu districts of Rajasthan (22nd & 23rd March).

Gale : Damage to the Government School & residential house reported from Anantnag & Baramulla districts of Jammu & Kashmir (22-23 March).

Floods & Heavy Rain : Total 15 persons reportedly claimed dead due to floods & heavy rains during the season. Of these, 11 persons reportedly claimed dead in an avalanche in the Chamoli district of Uttarakhand on 23rd April, 2 from Anantnag, Udhampur districts of Jammu & Kashmir (26th March, 6th May), while, one each from Davangere district of Karnataka (during 11th-12th April) & other from Kolkata, West Bengal on 11th May. Also, due to heavy rains & flash flood, damage to crops, public & private property including bridge reported from Kupwara district of Jammu & Kashmir (29th March), Ahmednagar, Akola, Aurangabad, Beed, Buldhana, Hingoli, Jalna, Kolhapur, Latur, Nanded, Nashik, Osmanabad, Parbhani, Pune, Sangli, Satara, Sindhudurg, Solapur, Washim districts of Maharashtra (19th, 20th Mar.; 14th Apr.; 7th, 9th May), Dakshina Kannada, Yadgir district of Karnataka (6th, 11th, 12th April), East Sikkim (9th Apr.), Uttarkashi district of Uttarkhand (29th May), Ganderbal district of Jammu & Kashmir (7th May).

Dust Storm : 5 persons reportedly claimed dead from Hardoi district of Uttar Pradesh on 12th May. Thousands of birds perished from Jaisalmer district of Rajasthan (22nd March).

Hailstorm : One person reportedly claimed dead from Kathua district of Jammu & Kashmir (18th

April). Also, extensive damage to crops, vegetables, different types of fruits & houses reported from Kota district of Rajasthan (7th & 8th March); Ashoknagar, Bhind, Dhar, Guna, Khandwa, Morena, Shajapur, Ujjain districts of Madhya Pradesh (8th 19th, 23rd March); Aurangabad, Beed, Jalna, Hingoli, Parbhani, Pune districts of Maharashtra (20th, 21st March; 9th May); East Sikkim (9th April); Anantnag, Baramulla, Kulgam, Kupwara, Pulwama, Shopian districts of Jammu & Kashmir (7th , 15th , 21st, 31st May); Maldah district of West Bengal (11th May).

Gale : Damage to the Government School & residential house reported from Anantnag & Baramulla districts of Jammu & Kashmir (22nd & 23rd March).

3. Southwest (SW) Monsoon (June-July-August-September)

Chief Features

Rainfall during the monsoon season was normal.The area weighted rainfall for the monsoon season for All India this year was 99% of its LPA value. Minimum temperature over all India (24.53°C) was 3rd highest after the years 2019 (24.66°C), 2020 (24.60 °C) since 1901. The minimum temperature over Northwest India during Monsoon season 2021 was second highest (23.41 °C), while mean temperature over East & northeast India was fifth highest (28.55 °C) since 1901. All India rainfall in the month of August was sixth lowest since 1901.

Onset and advance of SW Monsoon

Onset of the southwest monsoon had taken place over Andaman Sea on 21st May. It covered some more parts of Bay of Bengal upto 2nd June. Southwest Monsoon advanced into some parts of south Arabian Sea, Lakshadweep area, south Kerala, south Tamil Nadu, remaining parts of Comorin–Maldives area and some more parts of southwest Bay of Bengal on 3rd June 2021. Thus southwest monsoon set in over Kerala on 3rd June. The Northern Limit of Monsoon (NLM) passed through Lat. 10°N/Long. 60° E, Lat. 10° N/Long. 70° E, Kochi, Palayamkottai, Lat. 9° N/Long. 80° E, Lat. 12° N/Long. 85° E Lat. 14° N/Long. 90° E, Lat. 17° N/Long. 94° E. Southwest monsoon advanced into Karnataka, remaining parts of Kerala and some parts of Andhra pradesh and more parts of Tamilnadu On 4th June. It covered northeastern states and Sub-Himalayan West Bengal & Sikkim between 6th to 8thJune. The Northern Limit of Monsoon (NLM) passed through Lat. 18° N/Long. 65° E, Lat. 18.5° N/Long. 70° E, Alibag, Pune, Medak, Nalgonda, Rentachintala, Sriharikota, Lat. 14° N/Long. 85° E, Lat. 16° N/Long. 88° E, Lat. 20° N/Long. 90.5° E, Lat. 24° N/Long. 89.5° E and Baghdogra. Till 11th June it covered entire Arabian sea, south Gujarat, south Madhya Pradesh and Chhattisgarh and most parts of North Bay of Bengal and more parts of West Bengal. Upto 13th June it covered many parts of northern and central India. The Northern Limit of Monsoon (NLM) passed through Lat. 20.5° N/Long. 60° E, Diu, Surat, Nandurbar, Bhopal, Nowgong, Hamirpur, Barabanki, Bareilly, Sahranpur, Ambala and Amritsar (14-17 same position). By 18th June Southwest Monsoon advanced into some more parts of north Arabian sea, most parts of Gujarat region, some parts Saurashtra, southeast Rajasthan and some more parts of Madhya Pradesh and Uttar Pradesh. On 19th June it covered remaining parts of north Arabian sea, Saurashtra, Gujarat Region, Madhya Pradesh, entire Kutch, some more parts of Rajasthan and west Uttar Pradesh. The Northern Limit of Monsoon (NLM) passed through Lat. 26° N/Long. 70° E, Barmer, Bhilwara, Dholpur, Aligarh, Meerut, Ambala and Amritsar.

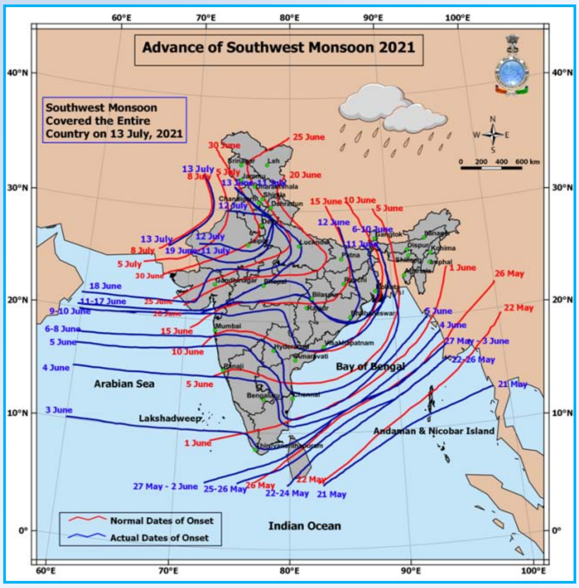


Fig. 15. Advance of southwest monsoon 2021

The southwest monsoon which covered most parts of the country in stages outside north/northwest India till 19th June remained at the same position till 11th July. Then after hiatus of about three weeks it advanced into remaining parts of Rajasthan and Punjab and some more parts of Haryana and West Uttar Pradesh on 12th July 2021. On 12th July the northern Limit of southwest monsoon passed through Jaisalmer, Nagaur, Bharatpur, Aligarh, Karnal and Ganganagar. Advancing further over Delhi southwest monsoon covered entire country on 13th July, 2021. Fig. 15 depicts the isochrones of advance of southwest monsoon.

Rainfall Features

Most sub-divisions of the country received excess/normal rainfall except a few from extreme northeastern region, West Uttar Pradesh, Jammu & Kashmir, Ladakh and Lakshadweep.

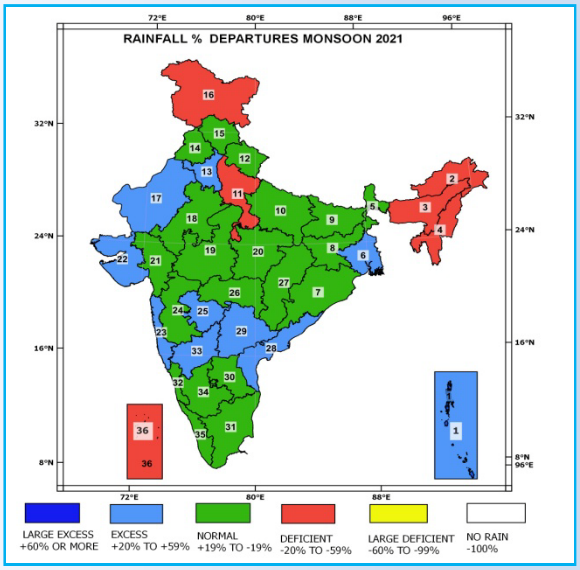
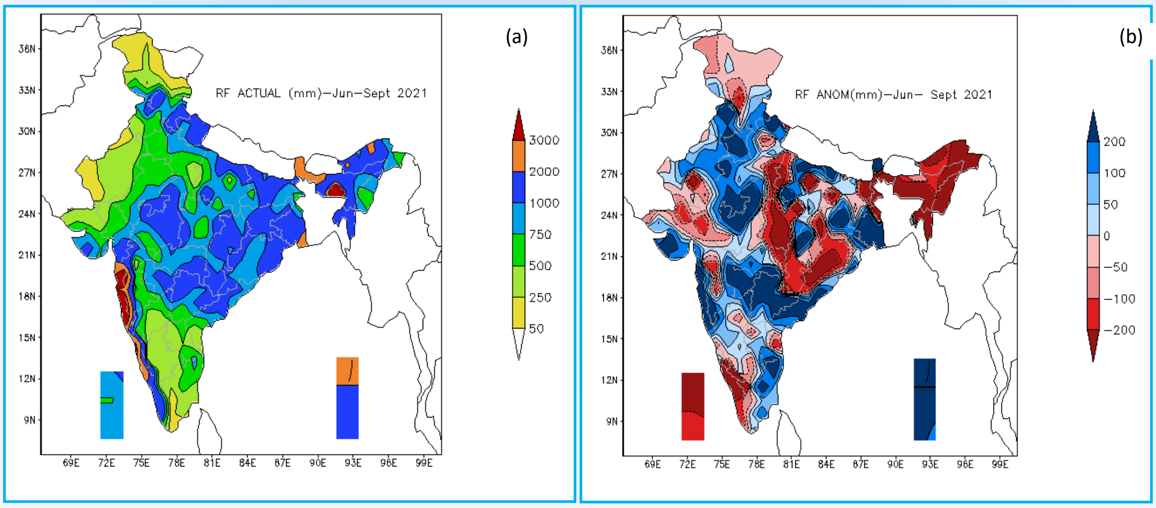


Fig.16. Sub-divisionwise rainfall percentage departures for the Monsoon 2021

During the season, out of 36 meteorological subdivisions, 20 subdivisions received excess rainfall, 10 received normal rainfall and the remaining 6 sub-divisions received deficientrainfall Fig. 16. Figs. 17(a&b) show the spatial pattern of rainfall received during the season and its anomaly (mm) respectively.

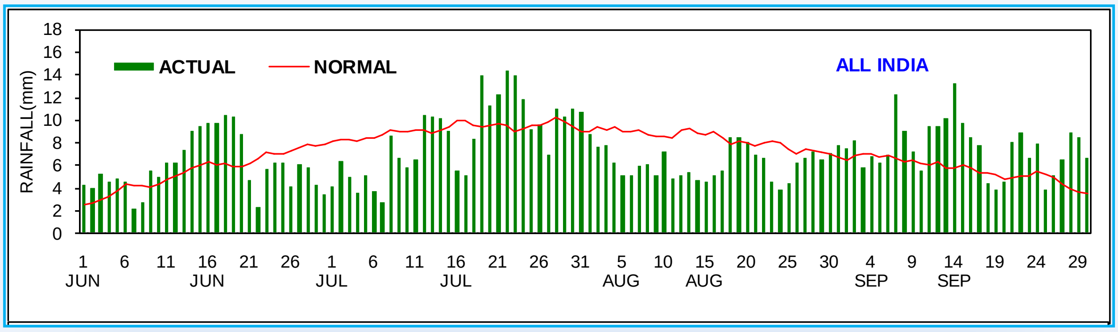
Parts of Arunachal Pradesh, Assam & Sikkim, Meghalaya, Sub-Himalayan West Bengal & Gangetic West Bengal, Jharkhand, Bihar, Odisha, West Uttar Pradesh, Uttarakhand, Himachal Pradesh, East and west Madhya Pradesh, Chhattisgarh, Saurashtra & Kutch, Marathwada, Vidarbha, Coastal Andhra Pradesh & Yanam, Telangana, entire west coast and Andaman & Nicobar Islands received more than 1000 mm rainfall. Parts of Arunachal Pradesh, Assam & Meghalaya, Sub-Himalayan West Bengal & Sikkim, Gangetic West Bengal, Konkan & Goa, Coastal Karnataka and Andaman & Nicobar Islands received more than 2000 mm rainfall. Parts of Assam & Meghalaya, Konkan & Goa received more than 3000 mm rainfall.

Positive Rainfall anomaly more than 200 mm was observed over parts of Sub-Himalayan West Bengal & Sikkim, Gangetic West Bengal, Jharkhand, East Uttar Pradesh, Uttarakhand, Punjab, Haryana, Chandigarh & Delhi, west and east Rajasthan, Saurashtra & Kutch, West Madhya Pradesh, Chhattisgarh, Coastal Andhra Pradesh & Yanam, Telangana, Tamilnadu, Puducherry & Karaikal, Konkan & Goa, Marathwada, Vidarbha and Andaman & Nicobar Islands. Magnitude of negative rainfall

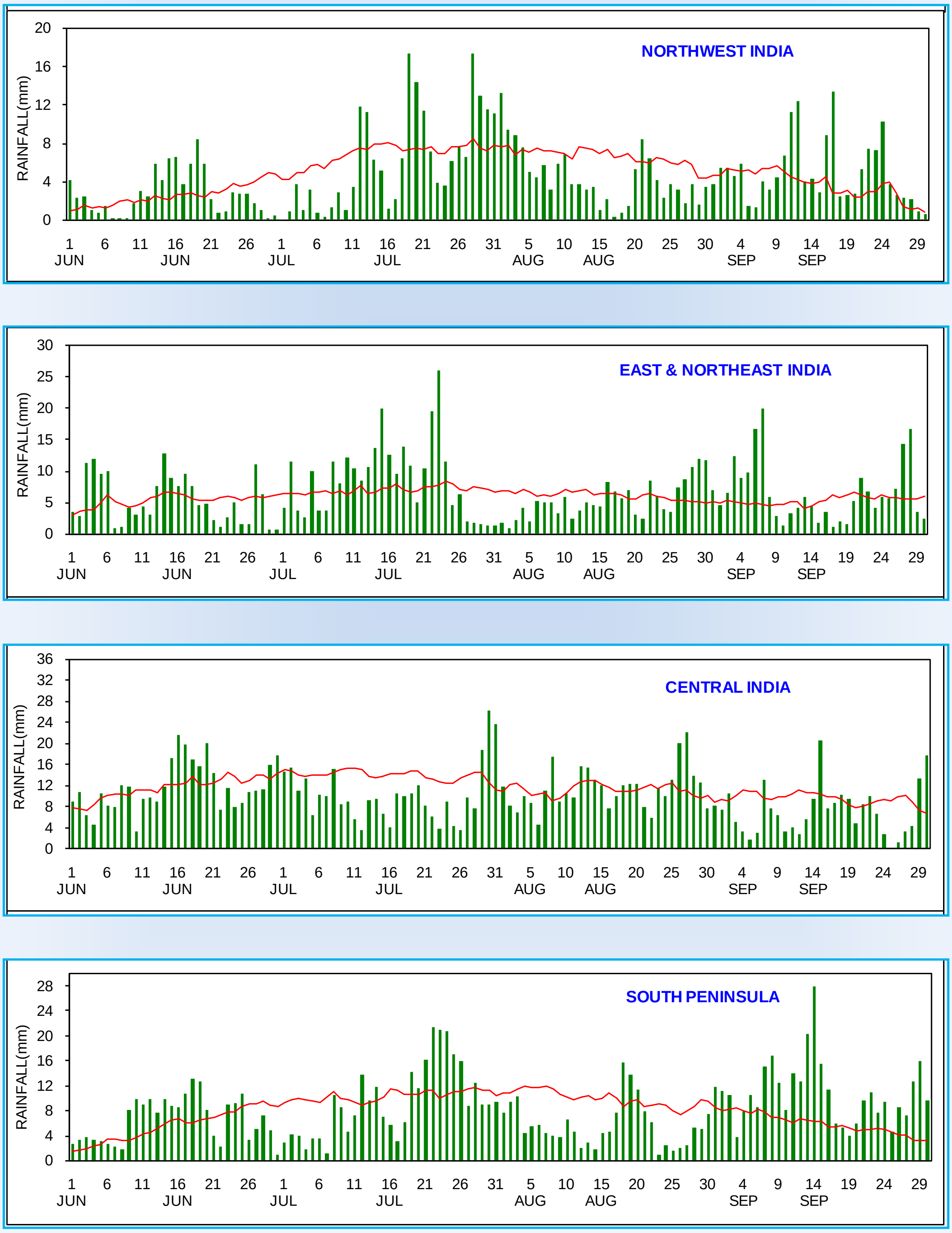


Figs. 17(a&b). (a) Seasonal rainfall (mm) (b) Seasonal rainfall anomaly (mm) (*Based on 1961-2010 Normals*)

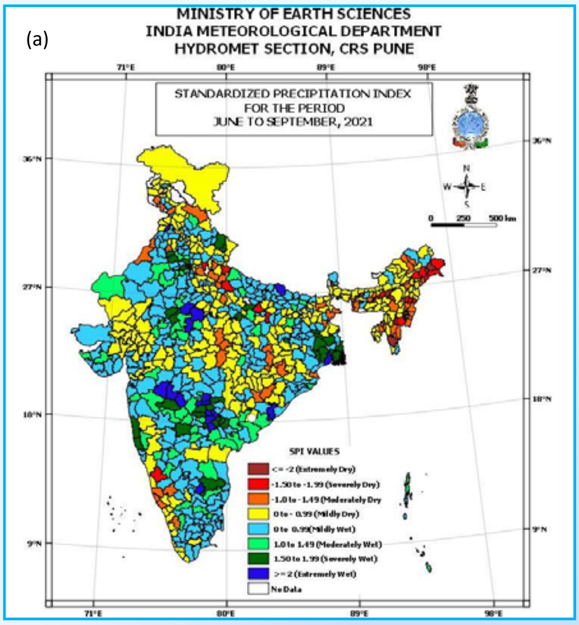
(a)

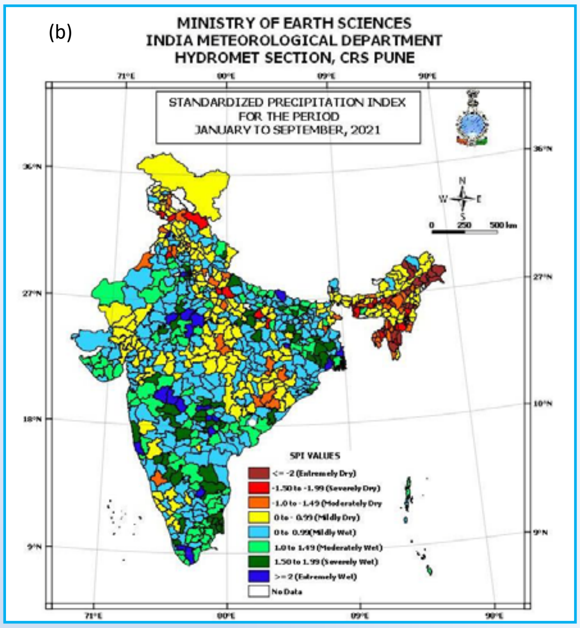


(b)



Figs. 18(a&b). (a) Daily Area Weighted Rainfall (mm) and its Long Term Normal for The country as a whole and (b) the Four Homogeneous Regions for Southwest Monsoon (1 June - 30 September) Season, 2021





Figs. 19 (a&b). Standardized Precipitation Index (SPI) for (a) Four months (b) Nine months

Anomaly was more than 200 mm over parts of Arunachal Pradesh, Assam & Meghalaya, Nagaland, Manipur, Mizoram & Tripura, Sub-Himalayan West Bengal & Sikkim, Bihar, WestMP, East MP, Odisha, Kerala & Mahe and Lakshadweep. Figs. 18(a&b) show the daily area weighted rainfall (in mm) and its long term normal over the country as a whole and the four homogeneous regions during the season. Rainfall over all India during the season was 874.6 mm against the normal value of 880.6 mm.

The rainfall realized over south peninsular India was 111% of LPA, over Central India 104 % of LPA, over northwest India 96% of LPA and over east & northeast India 88 % of LPA. Rainfall over the homogeneous region of south peninsular India (804.2 mm) was sixth highest since 2001 after the years 2020 (937.4 mm), 2007 (906 mm), 2019 (838.2 mm), 2013 (834.1 mm) and 2010 (832.7 mm).

Standardized Precipitation Index

The Standardized Precipitation Index (SPI) is an index used for monitoring drought and is based only on precipitation. This index is negative for dry and positive for wet conditions. As the dry or wet conditions become more severe, the index becomes more negative or positive. Figs. 19(a&b) give the SPI values for the monsoon season (four months) and the year since January 2021 (nine months) respectively.

Cumulative SPI values of the past four months indicate, extremely wet/severely wet conditions over parts of Gangetic West Bengal, Jharkhand, Bihar, East Uttar Pradesh, Uttarakhand, Haryana, Chandigarh & Delhi, Punjab, East Rajasthan, West Madhya Pradesh, Konkan & Goa, Marathwada, Andhra Pradesh state, Telangana, North Interior Karnataka and South Interior Karnataka while, extremely dry/severely dry conditions were observed over parts of Arunachal Pradesh, Assam & Meghalaya, Nagaland, Manipur, Mizoram & Tripura, Sub Himalayan West Bengal & Sikkim, Uttar Pradesh state, Jammu & Kashmir & Ladakh and South Interior Karnataka.

Cumulative past nine months SPI values indicate, extremely wet/severely wet conditions over parts of Gangetic West Bengal, Odisha, Jharkhand, Bihar, East Uttar Pradesh, Uttarakhand, Haryana, Chandigarh & Delhi, Punjab, East Rajasthan, Madhya Pradesh state, Gujarat Region, Konkan & Goa, Madhya Maharashtra, Marathwada, Andhra Pradesh state, Telangana, Tamil Nadu & Karaikal, North Interior Karnataka, South Interior Karnataka and Kerala & Mahe while, extremely dry/severely dry conditions were observed over parts of Arunachal Pradesh, Assam & Meghalaya, Nagaland, Manipur, Mizoram & Tripura, Sub Himalayan West Bengal & Sikkim, East Uttar Pradesh, Punjab, Himachal Pradesh and Jammu & Kashmir & Ladakh.

Outgoing Longwave Radiation (OLR)

OLR anomaly (W/m^2) over the Indian region and neighborhood is shown in Fig. 20. OLR anomaly was negative throughout the country except over west central and northern region. OLR anomaly was positive over most western parts of bay and over most eastern parts of Arabian Sea. Magnitude of negative OLR anomaly exceeded 10 W/m^2 over parts of coastal Andhra Pradesh and adjoining Bay of Bengal.

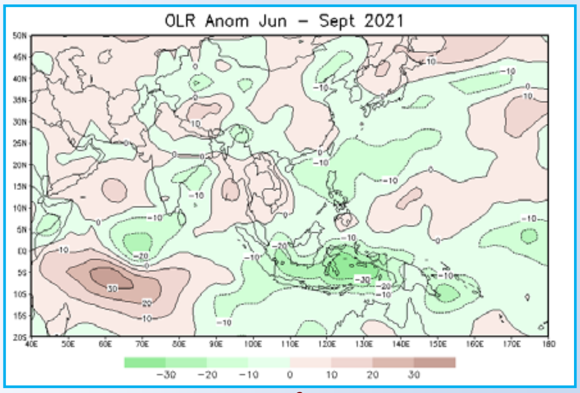


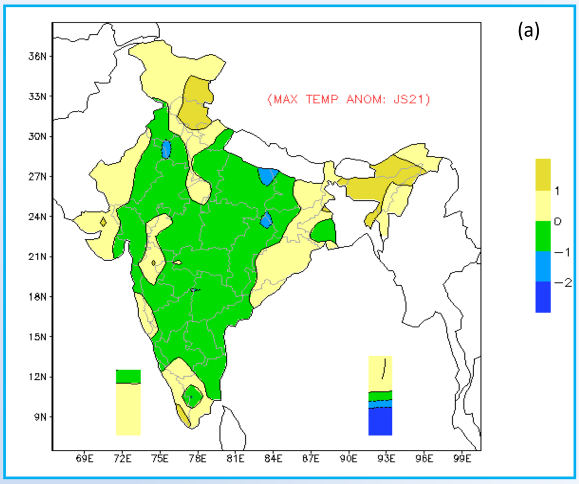
Fig. 20. OLR anomaly (W/m^2) for the monsoon season 2021 (*Source*: Cdc / Noaa, Usa) (*Based On 1981 - 2010 Climatology*)

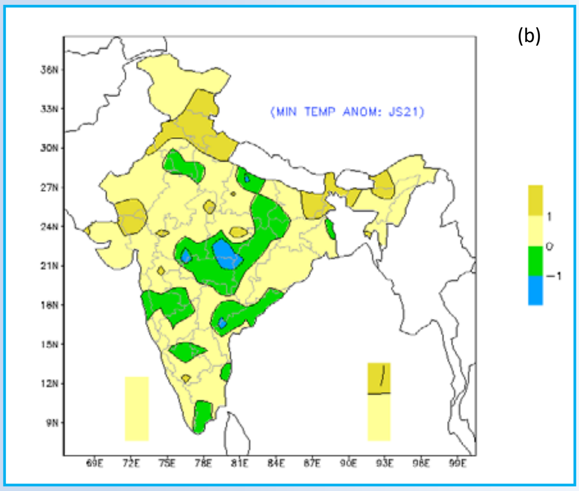
Temperature

Mean seasonal maximum and minimum temperature anomaly is shown in Figs. 21(a&b).

Maximum temperature was below normal over most parts of the country except some parts of east & northeast India, northwest India, central India, south Peninsular India and both the islands. Maximum temperature anomaly was more than 1°C over parts of Arunachal Pradesh, Assam & Meghalaya, Nagaland, Manipur, Mizoram, Tripura, Ladakh, Himachal Pradesh, Uttarakhand, Gangatic West Bengal and Kerala & Mahe. Maximum temperature anomaly was less than -2°C over parts of Andaman & Nicobar Islands.

Minimum temperature was above normal over most parts of the country except some parts of central India, south Peninsular India and northwest India. Minimum temperature anomaly was more than 1°C over parts of Ladakh, Himachal Pradesh, Uttarakhand, Punjab, Rajasthan state, Gujarat region, Madhya Maharashtra, Madhya Pradesh state, Bihar, Jharkhand, Sub Himalayan West Bengal & Sikkim, Arunachal Pradesh, Assam & Meghalaya, Tripura and South Interior Karnataka. Minimum temperature anomaly was less than -1°C over parts of Madhya Pradesh state, Vidarbha, Chhattisgarh, Telangana and Coastal Andhra Pradesh & Yanam.





Figs. 21(a&b). Mean seasonal temperature anomalies (°C) (a) Maximum (b) Minimum (*Based on 1981-2010 Normals*)

Low Pressure Systems

During the season, fifteen low pressure systems (1 cyclonic storm, 1 Deep Depression, 4 well marked low pressure areas, 7 low pressure areas and 2 land low pressure areas) were formed.

The frequency and place of origin of these low pressure systems formed over the Indian region during the monsoon season is shown in the table below:

Month/ Systems	CS	DD	D	WML	LPA	LAND LPA
June	0	0	0	0	1(BOB)	1
July	0	0	0	2 (BOB)	1(BOB),1(AS)	1
August	0	0	0	0	2(BOB)	0
September	1(BOB)	1(BOB)	0	2(BOB)	1(BOB),1(AS)	0
	(AS : Arabian Sea)		(BOB : Bay of Bengal)			

The first intense low pressure system in form of Deep depression formed in the month of September over Bay of Bengal during the period 12-15 September. The first cyclonic storm of the season (CS "GULAB") formed during 24-28 September over Bay of Bengal. Remaining thirteen systems were well marked low pressure areas/low pressure areas/land low pressure areas. Fig. 22 shows the track of intense low pressure system formed during the season.

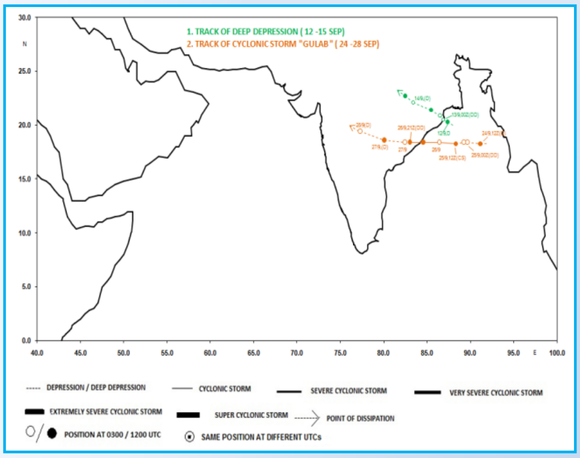


Fig. 22. Tracks of intense low pressure systems formed during the Monsoon season

Significant Weather events

During the season, total 801 persons reportedly claimed dead, more than 250 persons injured, more than 70 persons missing & more than 3100 livestock perished. The details of causalities given below, which are based on real time media reports.

Floods & Heavy Rain: Total 444 persons reportedly claimed dead, 96 persons injured, 72 persons missing & more than 2700 livestock perished only from Maharshtra because of heavy rains, floods & landslide during the season. 210 deaths were reported from Maharashtra, 55 from Himachal Pradesh, 38 from Uttar Pradesh, 32 from Madhya Pradesh and many from other states. In addition to this damage to crops, public & private property reported.

Lightning: Total 353 persons reportedly claimed dead, 165 injured & 383 livestock perished during the season because of Lightning. Of these, 58 persons reportedly claimed dead from Agar Malwa, Alirajpur, Betul, Burhanpur, Balaghat, Dewas, Dhar, Datia, Chhatarpur, Gwalior, Hoshangabad, Khandwa, Mandla, Morena, Panna, Rewa, Shahdol, Shivpuri, Sheopur, Umaria of Madhya Pradesh, 58 from from Araria, Aurangabad, Begusarai, Banka, Bhagalpur, Darbhanga, East Champaran, Gaya, Jamui, Katihar, Khagaria, Lakhisarai, Madhepura of Bihar, 52 from Angul, Bargarh, Balasore, Bhadrak, Boudh, Cuttack, Dhenkanal, Gajapati, Ganjam, Jagatsinghpur, Jharsuguda of Odisha, 49 from Bankura, Birbhum, Bankura, East Burdwan, Hooghly, Howrah, Murshidabad, Nadia of West Bengal, 43 from Allahabad (Prayagraj), Bareilly, Banda, Chitrakoot, Fatehpur, Firozabad, Hamirpur, Hardoi, Kanpur Dehat of Uttar Pradesh and 35 from Baran, Barmer, Chittorgarh, Dhaulpur, Dholpur, Jaipur, Jhalawar, Jodhpur, Kota, Sawai Madhopur, Nagaur, Pali, Sawai Madhopur, Tonk, Udaipur of Rajasthan.

Thunderstorm: Due to thunderstorm,One person reportedly claimed dead and 3 others injured due to thunderstorm. One each from Bareily of Uttar Pradesh and Khandwa of Madhya Pradesh.

Cyclonic Storms: Total 3 persons (2 from Srikakulam, Andhra Pradesh and 1 from Ganjam, Odisha) reportedly claimed dead & one missing during the season because of Cyclonic Storm GULAB.

4. Post Monsoon Season (October-November-December)

Northeast Monsoon Activity

The southwest monsoon withdrew from the entire country on 25th October and northeast monsoon rains subsequently commenced on the same day. Rainfall activity over core region of the South Peninsular India (comprising of 5 subdivisions, *viz.*, Coastal Andhra Pradesh, Rayalaseema, Tamil Nadu & Puducherry, South Interior Karnataka and Kerala) during the season as a whole was above normal [171% of Long Period Average (LPA)]. It was above normal during October and November (129 %of its LPA, 269%of its LPA respectively) and below normal during December (78% of is LPA). Rainfall over this core region (579.1 mm) was highest since 1901.

Rainfall Features

Rainfall realized over the country as a whole during the season was 143% of LPA. It was 133%, 186% and 117% of its LPA during October, November and December months respectively. All the subdivisions received large excess/ excess/ normal rainfall except Arunachal Pradesh, Assam & Meghalaya, Nagaland, Manipur, Mizoram & Tripura, East Madhya Pradesh and Telangana.

During the season, out of 36 meteorological subdivisions, 16 received large excess rainfall, 9 received excess rainfall, 6 received normal rainfall, 5 received deficient rainfalls (Fig. 23).

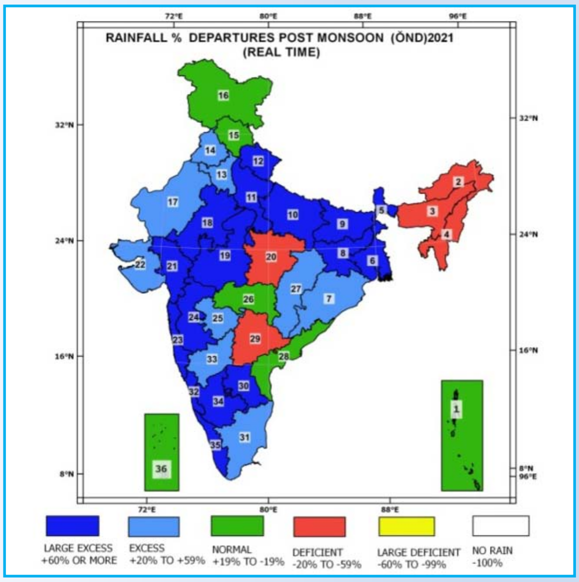
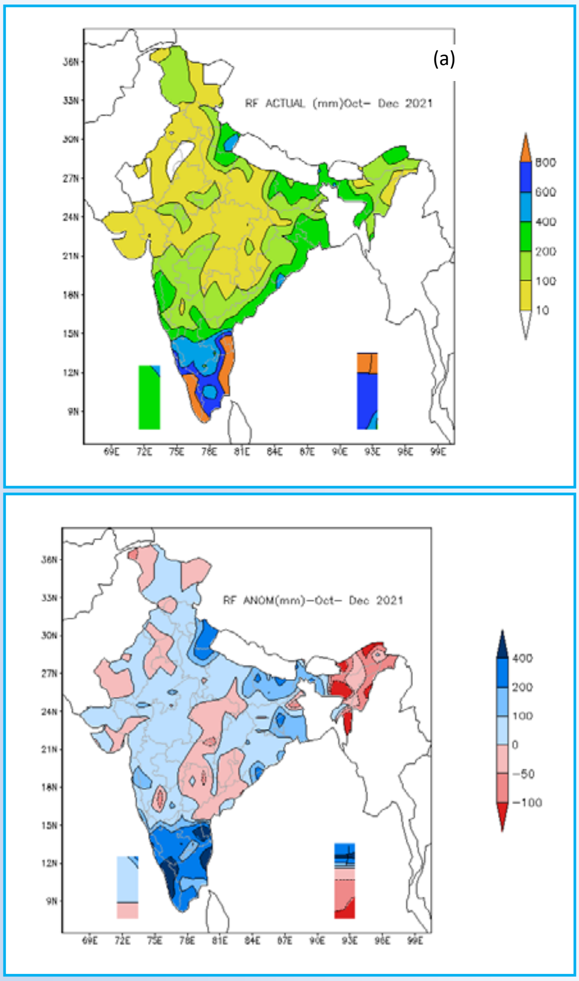


Fig. 23. Sub-divisionwise rainfall percentage departures

Figs. 24(a&b) show the spatial pattern of rainfall (mm) received during the season and its anomaly respectively. Parts of Coastal Andhra Pradesh & Yanam, Rayalaseema, Odisha, Uttarakhand, Tamilnadu, Puducherry & Karaikal, Kerala & Mahe, South Interior Karnataka and Andaman & Nicobar Islands received more than 400 mm rainfall. Parts of Coastal Andhra Pradesh & Yanam, Rayalaseema, of Coastal Andhra Pradesh & Yanam, Rayalaseema, and Andaman & Nicobar Islands received more than 800 mm rainfall.



Figs. 24(a&b). (a) Seasonal rainfall (mm) (b) seasonal rainfall anomaly (mm) (*Based on 1951-2000 Normals*)

Tamilnadu, Puducherry & Karaikal, Kerala & Mahe Tamilnadu, Puducherry & Karaikal, Kerala & Mahe, Islands received more than 600 mm rainfall. Parts South Interior Karnataka and Andaman & Nicobar Rainfall anomaly was positive over most parts of the country except northeastern parts, some parts of eastcentral India and Andaman & Nicobar Islands. It was generally more than 100 mm over most parts of the country.

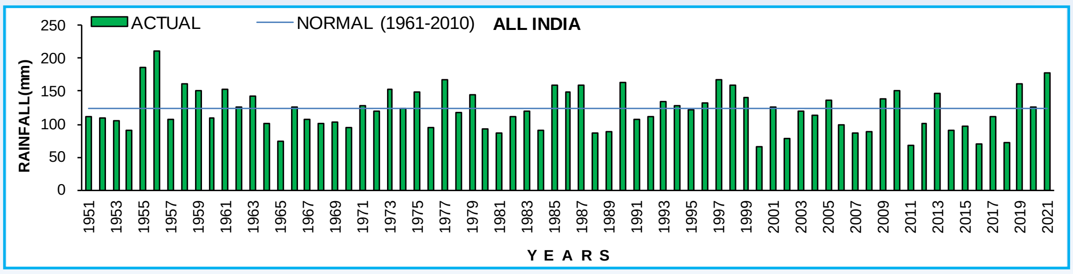


Fig. 25(a). Time series of area weighted rainfall over the country as a whole (1951-2018)

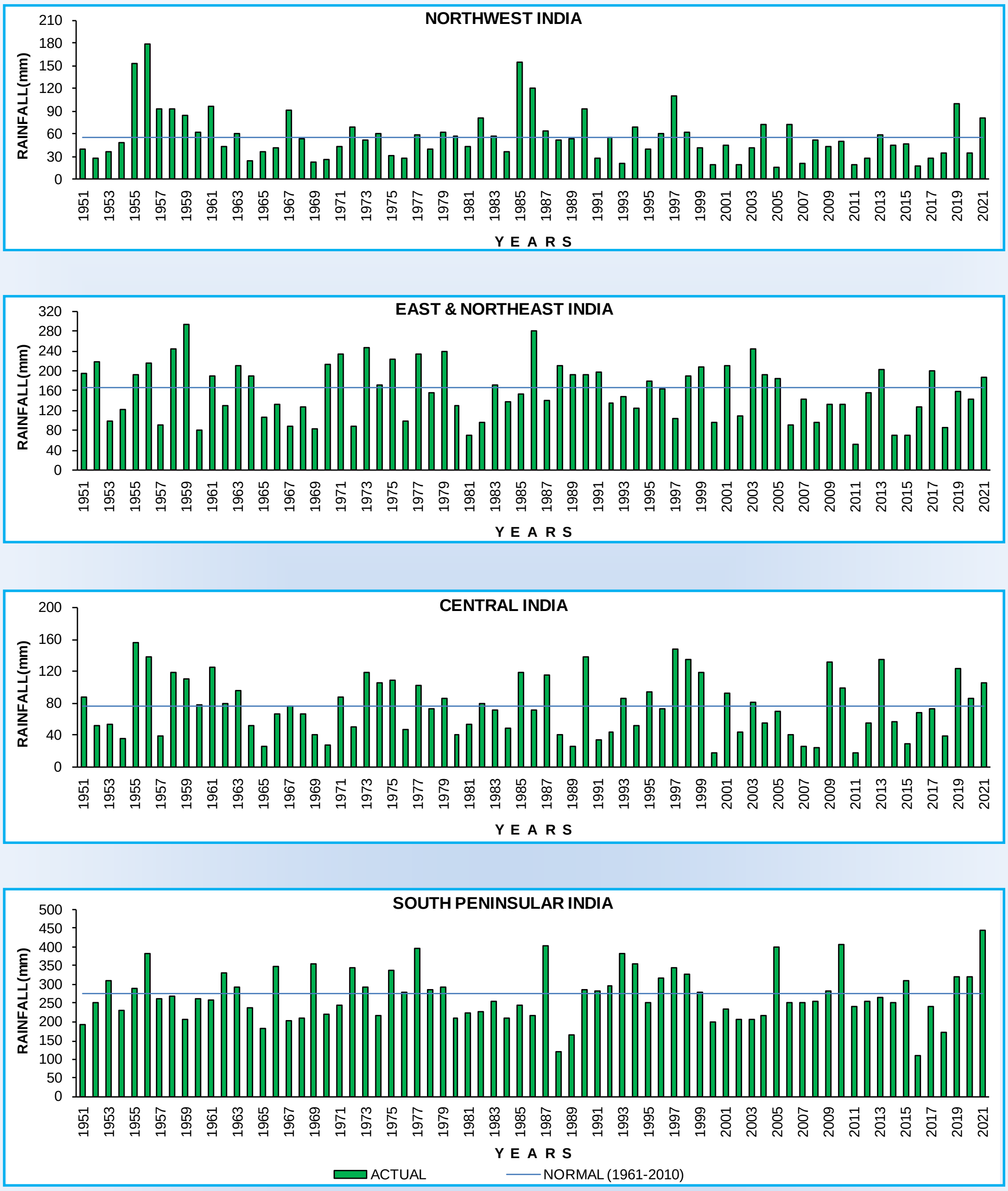
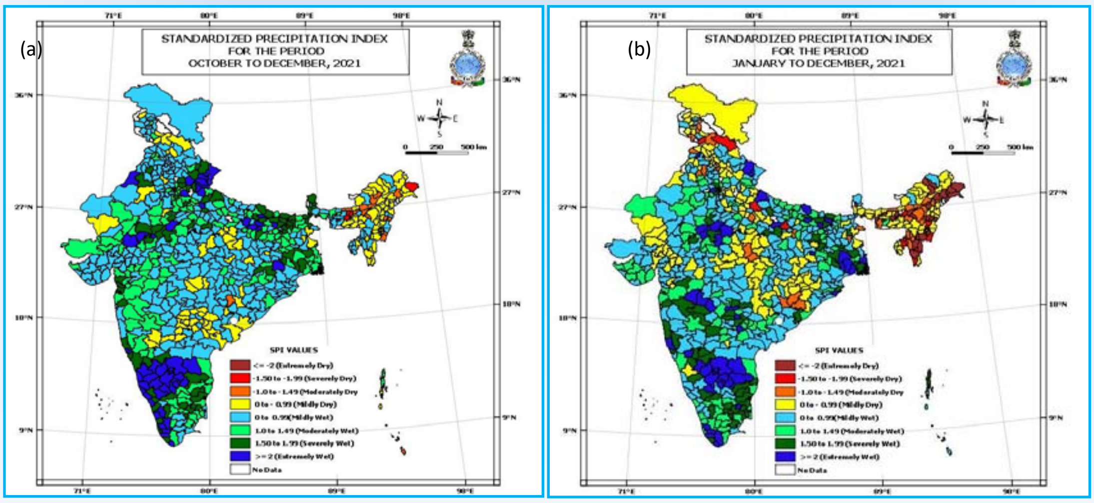


Fig. 25(b). Time series of area weighted rainfall over the four homogeneous regions (1951 - 2021)



Figs. 26(a&b). Standardized Precipitation Index (SPI) cumulative for (a) Three months (b) Twelve months

Rainfall anomaly was more than 200 mm over parts of Uttarakhand, West Uttar Pradesh, Coastal Andhra Pradesh & Yanam, Rayalaseema, Odisha, Tamilnadu, Puducherry & Karaikal, Kerala & Mahe, South Interior Karnataka and Andaman & Nicobar Islands. Rainfall anomaly was more than 400 mm over parts of Coastal Andhra Pradesh & Yanam, Rayalaseema, Tamilnadu, Puducherry & Karaikal, Kerala & Mahe, South Interior Karnataka and Andaman & Nicobar Islands. Magnitude of negative rainfall anomaly was more than 100 mm over parts of Arunachal Pradesh, Assam & Meghalaya, Nagaland, Manipur, Mizoram & Tripura and Andaman & Nicobar Islands. Fig. 25(a) shows the all India area weighted rainfall series for the season since 1951.

Fig. 25(b) shows the area weighted rainfall series for the season over the four homogeneous regions since 1951.

The rainfall for the season was above normal over all the homogeneous regions. It was 160% of its LPA over south peninsula, 145% of its LPA over northwest India, 140 % of its LPA over central India and 112 % if it's LPA over east & northeast India. Rainfall over homogeneous region of south peninsula (444.6 mm) was highest since 1901.

Standardized Precipitation Index

The Standardized Precipitation Index (SPI) is an index used for measuring drought and is based only on precipitation. This index is negative for dry and positive for wet conditions. As the dry or wet conditions become more severe, the index becomes more negative or positive. Figs. 26(a&b) give the SPI values for the northeast monsoon season (October to December 2021, *i.e.*, 3 months cumulative) and the year (January-December 2021, i.e., 12 months cumulative) respectively.

Cumulative SPI values of the past three months indicate extremely wet-severely wet conditions over parts of Sub Himalayan WestBengal & Sikkim, Gangetic West Bengal, Odisha, Jharkhand, Bihar, Uttar Pradesh state, Uttarakhand, Haryana, Chandigarh & Delhi, Punjab, Rajasthan state, West Madhya Pradesh, Gujarat Region, Konkan & Goa, Rayalaseema, Tamil Nadu, Karnataka state and Kerala while extremely dry-severely dry conditions were observed over parts of Arunachal Pradesh, Assam & Meghalaya.

Cumulative SPI values of the past twelve months indicate extremely wet-severely wet conditions over parts of A & N Islands, Gangetic West Bengal, Odisha, Jharkhand, Bihar, East Uttar Pradesh, Uttarakhand, Haryana, Chandigarh & Delhi, Punjab, East Rajasthan, West Madhya Pradesh, Gujarat Region, Konkan & Goa, Madhya Maharashtra, Marathawada, Andhra Pradesh state, Telangana, Tamil Nadu, North Interior Karnataka, South Interior Karnataka and Kerala, while extremely dry-severely dry conditions were observed over parts of Arunachal Pradesh, Assam & Meghalaya,Nagaland, Manipur, Mizoram & Tripura, Sub Himalayan West Bengal & Sikkim, East Uttar Pradesh, Himachal Pradesh and Jammu & Kashmir.

Pressure & Wind

Wind anomaly at 850 hPa shows an anomalous cyclonic circulation over south peninsula and adjoining south Arabian Sea. At 500 hPa level, an anomalous anticyclonic circulation was seen over central parts of the country. An anomalous anticyclonic circulation over central parts of the country persisted at 250 hPa level also.

Outgoing Longwave Radiation (OLR)

OLR anomaly (W/m^2) over the Indian region and neighbourhood is shown in Fig. 27. OLR anomaly was negative over entire country except some northwestern parts. Negative OLR anomaly exceeding 20 W/m^2 was observed over central parts of Bay of Bengal.

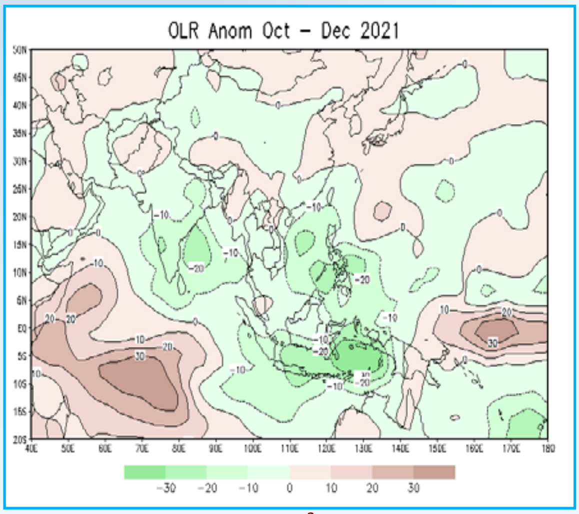
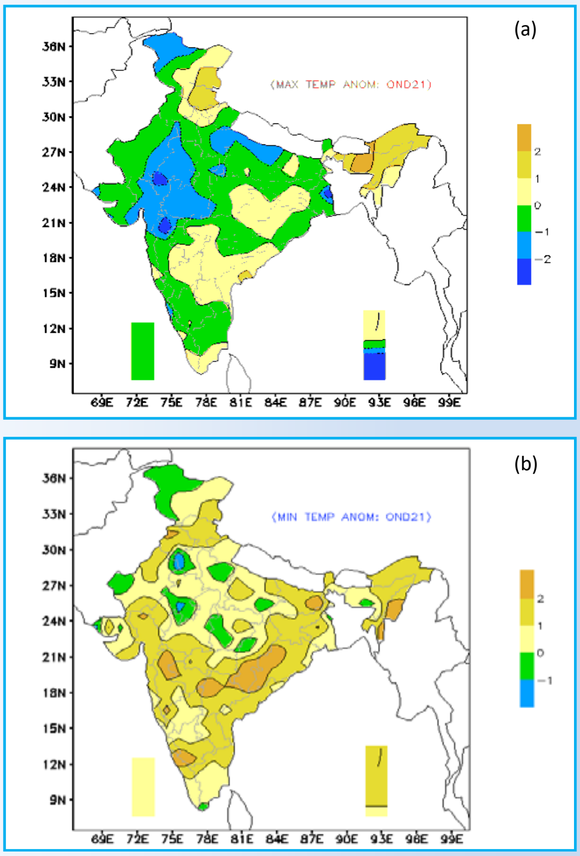


Fig. 27. OLR Anomaly (w/m^2) for the post-monsoon season 2018 (*Source* : CDC / NOAA, USA)
(*Based on 1981 - 2010 Climatology*)

Temperature

Mean seasonal maximum and minimum temperature anomaly is shown in Figs. 28 (a&b) respectively.



Figs. 28(a&b). Mean seasonal temperature anomalies (°C) (a) Maximum (b) Minimum (*Based on 1981-2010 Normals*)

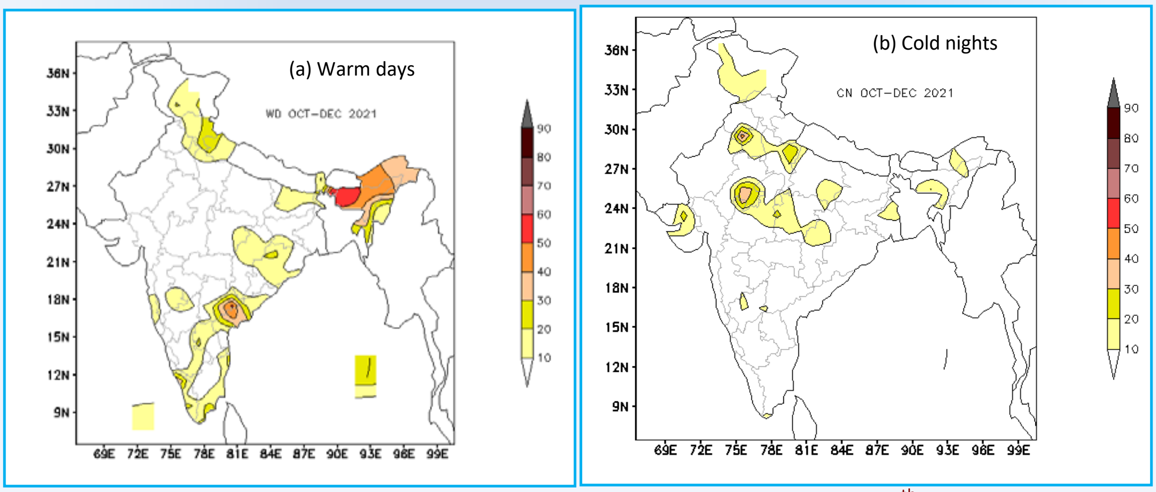
Maximum temperature was below normal over most parts of the country except some parts of east & northeast India, south peninsular India, central India, northern northwest India and Andaman & Nicobar Islands. Maximum temperature anomaly was more than 2 °C over parts of Assam & Meghalaya and Arunachal Pradesh. Maximum temperature anomaly was less than -2 °C over parts of northern Madhya Maharashtra, East Rajasthan, Gangetic West Bengal and Andaman & Nicobar Islands.

Minimum temperature was above normal over most parts of the country except some parts of northwest India and central India. Minimum temperature anomaly was more than 2°C over parts of Madhya Maharashtra, Marathwada, Bihar, Manipur, Mizoram, Odisha, Chhattisgarh, Telangana, North Interior Karnataka, South Interior Karnataka and Kerala and Mahe. Minimum temperature anomaly was less than -1 °C over parts of Haryana, Chandigarh & Delhi and East Rajasthan.

Percentage of Warm days/Cold nights

Figs. 29(a&b) show the percentage of days when maximum (minimum) temperature was more (less) than 90th (10th) percentile.

Over parts of Assam & Meghalaya and Sub-Himalayan West Bengal & Sikkim maximum temperature was greater than 90th percentile for more than 50% of the days of the season. For minimum temperature no such significant distribution was observed.



Figs. 29(a&b). Percentage of days when (a) maximum temperature > 90th percentile (b) minimum temperature < 10th percentile

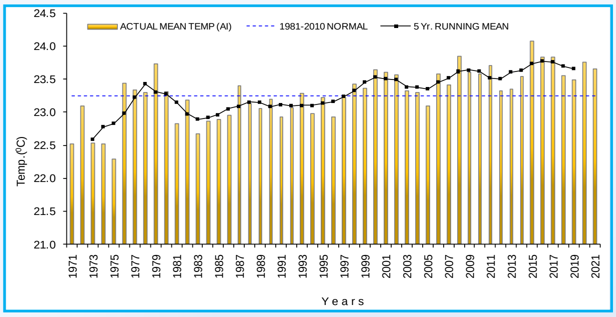
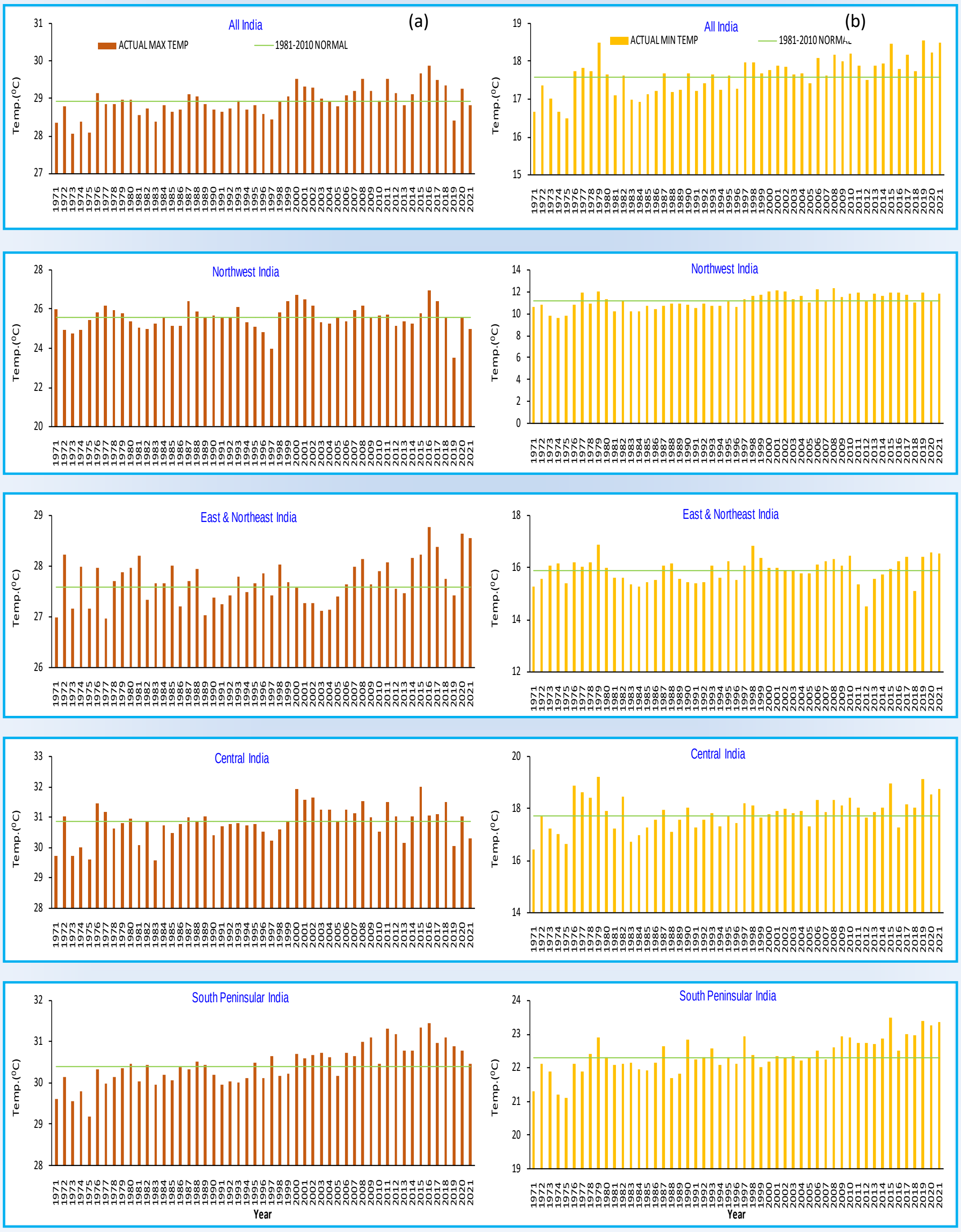


Fig. 30. Time series of mean temperature averaged over India (vertical bars) and five year running mean (continuous line) for the post monsoon season (1971-2021)

Fig. 30 shows the mean temperature for the country as a whole for the season since 1971. Five year moving average values are also shown. The mean temperature for the season this year was 23.66 ^{0}C with anomaly 0.42 °C and 8th highest since 1901. Mean temperature over east and northeast India (22.56 °C) was 2nd highest, south peninsular India was (26.91 °C) 10th highest since 1901.



Figs. 31(a&b). Time series of temperature for the country as a whole and the four homogeneous regions (1971-2021) (a) Maximum (b) Minimum

Figs. 31(a&b) show, the maximum and minimum temperature series respectively for the country as a whole and the four homogeneous regions during the season since 1971. Maximum temperature over East & Northeast India (28.57 °C) was 3rd highest after the years 2016 (28.77 °C), 2020 (28.65 °C) since 1901. Over all India minimum temperature (18.49 °C) was 3rd highest after the years 1979 (18.51 °C), 2019 (18.58 °C) since 1901. Over SouthPeninsular India minimum temperature (23.36 °C) was also 3rd highest after the years 2015 (23.47 °C), 2019 (23.40 °C) since 1901. Minimum temperature over Central India (18.78 °C) was 5th highest and over East & Northeast India (16.56 °C) was 8th highest since 1901.

Low Pressure Systems

During the season, ten low pressure systems [2 cyclonic storms (CS), 3 depressions (D), 2 well marked low (WML) & 3 low pressure area (LPA)] were formed.

In the month of October one Severe Cyclonic storm "Shaheen "(30th September- 4th October) formed over Arabian Sea and three low pressure areas (oneover Bay of Bengal, one over Arabian Sea and one over land) formed. In the month of November three depressions (two over Bay of Bengal and one over Arabian Sea) and one wellmarked low over Arabian Sea formed. In the month of December cyclonic storm "Jawad" (2-6 December) and one well marked lowformed over Bay of Bengal. Fig. 32 shows track of intense low pressure of intense low pressure systems formed during the season.

Fig. 33 shows the number of depressions and storms formed over Bay of Bengal during the post monsoon season (1951-2021).

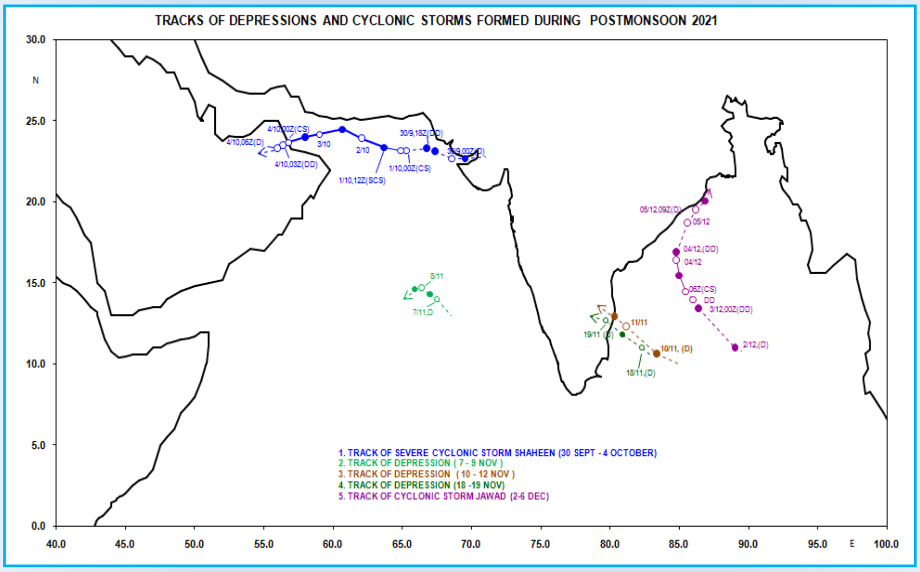


Fig. 32. Tracks of intense low pressure systems formed during the post-monsoon season

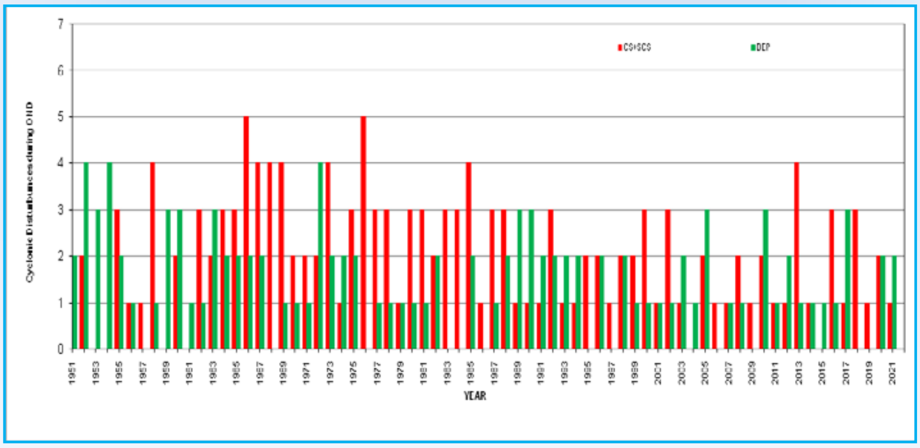


Fig. 33. Frequency of depressions / cyclonic storms formed over the Bay of Bengalduring the post-monsoon season (1951-2021)

Significant Weather events

From 1st October to 31st December, total 272 persons reportedly claimed dead, 56 persons injured, 30 persons missing & 2567 livestock perished from different parts of the country.

Floods & Heavy Rains : Total 200 persons reportedly claimed dead, 30 persons injured, 28 persons missing & 2558 livestock perished because of heavy rains, floods & landslides during 1st October to 31st December, in addition to this damage to crops, public & private property reported.

52 persons reportedly claimed dead from Almora, Bageshwar, Chamoli, Champawat, Nainital, Pauri Garhwal, Pithoragarh, Ranikhet, Udham Singh Nagar of Uttarkhand during 16th to 19th October.

From 11th to 19th October and 10th to 15th November, 49 persons were claimed dead fromAlappuzha, Idukki, Ernakulam, Kannur, Kottayam, Kollam, Kozhikode, Malappuram, Palakkad, Pathanamthitta, Thrissur, Thiruvananthapuram districts of Kerala. Andhra Pradesh is the worst affected where 44 persons reportedly clainmed dead and 2400 livestock got perished during 8th to 21st November. While, Chennai, Kallakurichi, Krishnagiri, Madurai, Thanjavur, Teni, Tiruvannamalai, Tiruchirappalli, Tiruvannamalai, Thiruvarur, Vellore, Villupuram of Tamil Nadu were also affected during 6th to 21st November.

During 3rd to 6th October and 15th to 20th November, Belgaum, Chikkaballapura, Chitradurga, Tumkur & parts of Karnataka were affected as 23 persons ere found dead.

Lightning : Total 61 persons reportedly claimed dead, 24 injured & 9 livestock perished 1st October to 31st December, because of Lightning. Of these, 15 persons reportedly claimed dead from Darbhanga, Gaya, Gopalganj, Kaimur, Nalanda, Nawada, Saharsa, Rohtas, Samastipur, Saran, Siwan, Vaishali districts of Bihar on 1st, 2nd, 17th and 19th October. 14 persons reportedly claimed dead & 6 livestock perished from Amravati, Beed, Jalna, Latur, Nanded, Nashik, Parbhani, Pune, Raigad districts of Maharashtra on 1st, 5th, 6th, 7th, 9th October and 28th December. 10 persons each from Betul, Dewas, Guna, Khandwa, Rajgarh, Neemuch, Ujjain and Vidisha Districts of Madhya Pradesh and Bargarh, Deogarh, Dhenkanal, Jagatsinghpur, Kandhamal, Kalahandi, Keonjhar, Koraput districts of Odisha reportedly claimed dead on 1st, 2nd, 3rd, 17th, 18th October and 3rd, 4th, 5th, 7th, 19th, 21st October & 1st, 14th November respectively.

Snowfall : 6 persons (4 from Chamoli district of Uttarakhand and 2 from Anantnag of Jammu & Kashmir) reportedly claimed dead & 2 others missing during 1st October to 31st December, because of snowfall.

Cold Wave : Total 5 persons reportedly claimed dead, during 1st October to 31st December, because of Cold wave.

Thunderstorm : 2 persons from Agra of uttar Paradesh got injured during 1st October to 31st December because of Thunderstorm.

CHAPTER 3

NUMERICAL WEATHER PREDICTION

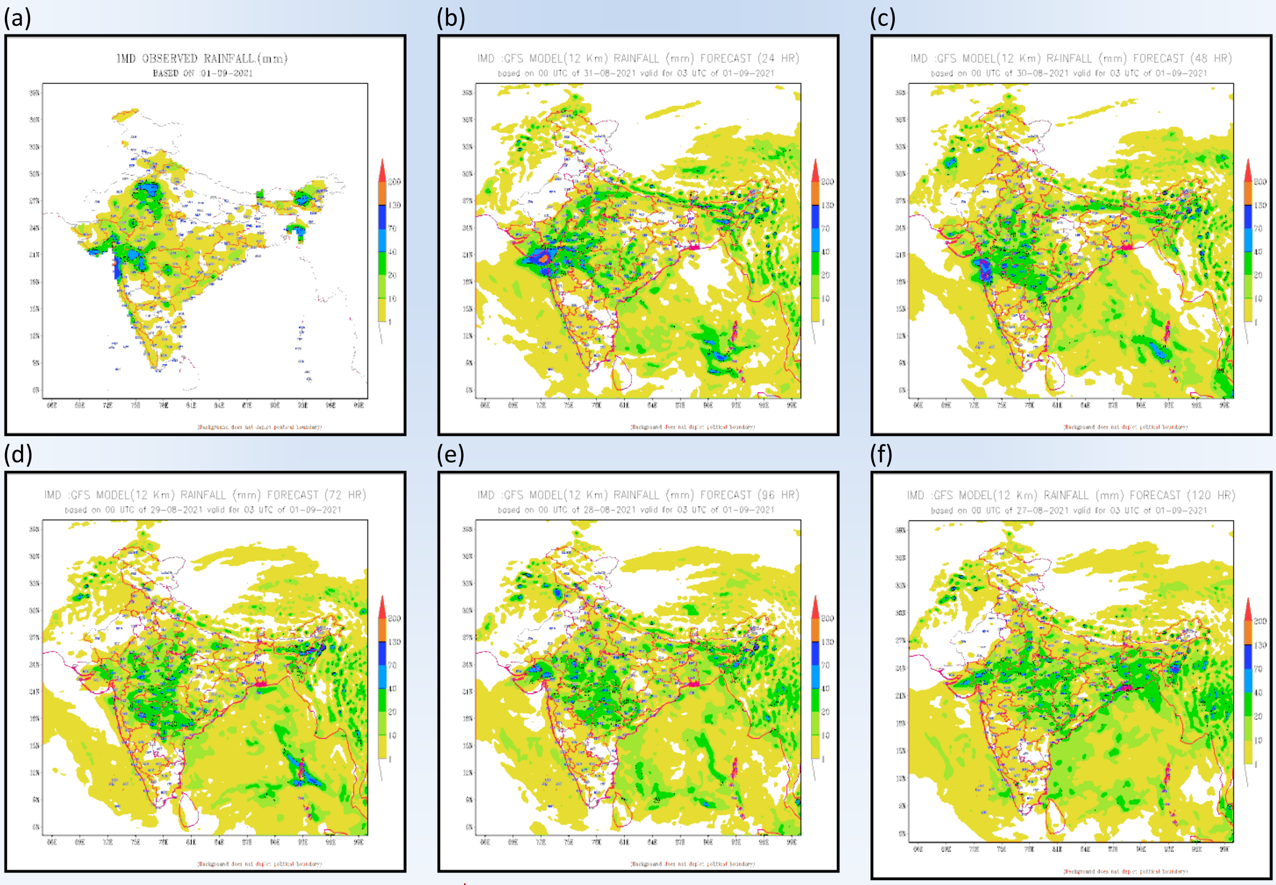
Global and Regional Modelling (NWP)

GFS Model

Global Forecasting System (GFS T1534L64) model is run operationally at India Meteorological Department (IMD) four times in a day (0000, 0600, 1200 & 1800 UTC) to give deterministic forecast in the short to medium range upto 10 days. The forecast model has a resolution of approximately 12 km in horizontal and has 64 levels in the vertical. The initial conditions for this GFS model is generated from the four-dimensional (4D) ensemble-variational data assimilation (DA) system (4DEnsVar) building upon the grid point statistical interpolation (GSI)-based hybrid Global Data Assimilation System (GDAS) run on High Performance Computing Systems (HPCS) at National Center for Medium Range Weather Forecasting (NCMRWF). The real-time GFS T1534L64 model outputs are generated daily at IMD. This 4DEnsVar data assimilation system has capabilities to assimilate various conventional as well as satellite observations including radiances from different polar orbiting and geostationary satellites. The real-time outputs are made available to operational weather forecasters and various users through the national web site of IMD. Figs. 1(a-f) given below show the forecast and observed heavy rainfall event of 1st September, 2021 during southwest monsoon 2021:

GEFS Model

Global Ensemble Forecast System (GEFS) GEFS is an operational weather model at IMD to address underlying uncertainties in the input data such limited coverage, instruments or observing systems biases, and the limitations of the model itself. GEFS quantifies these uncertainties by

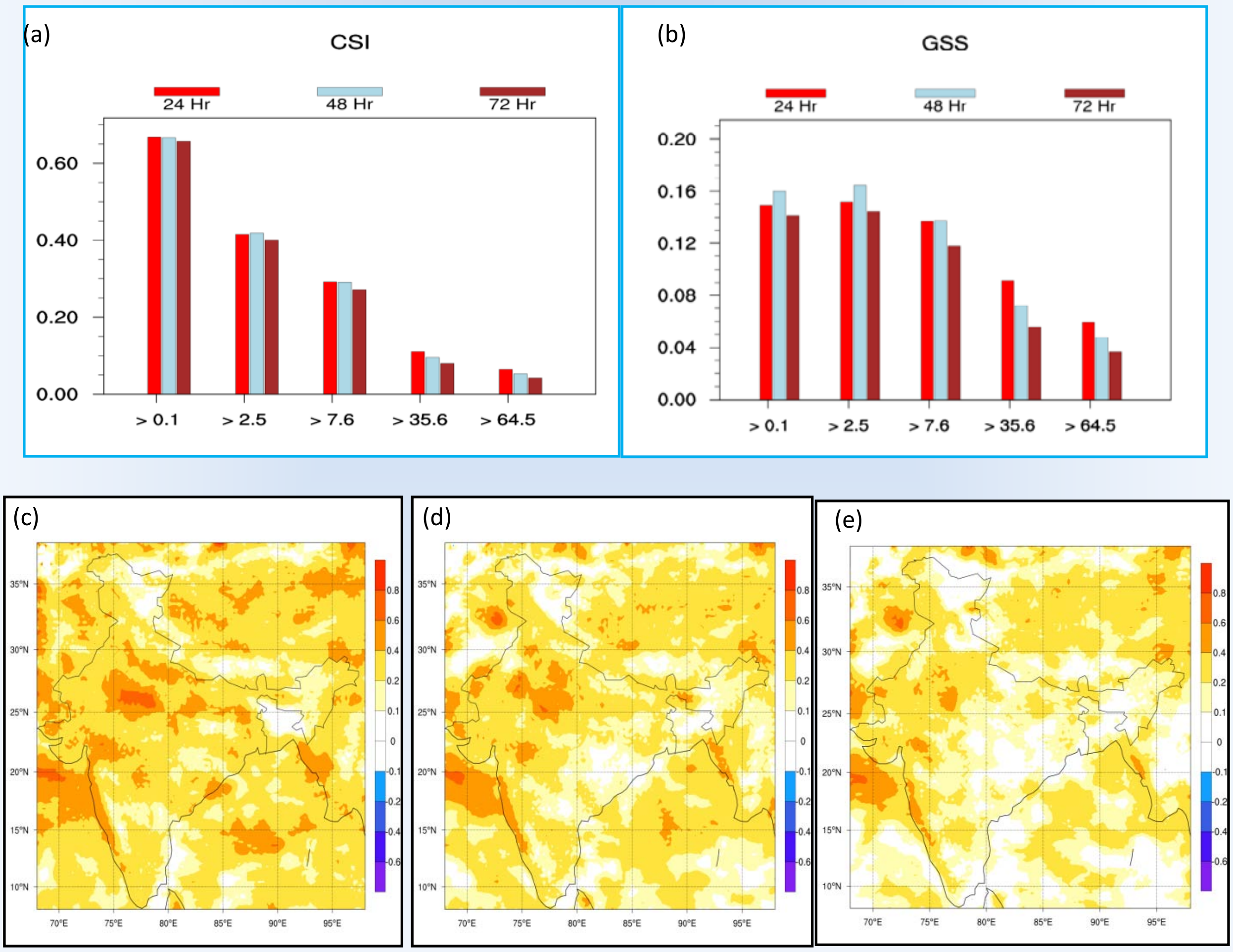


Figs. 1.(a) IMD Observed rainfall for 1st September, 2021 and IMD-GFS forecast for (b) 24 hours, (c) 48 hours, (d) 72 hours, (e) 96 hours and (f) 120 hours valid for 1st September, 2021

generating multiple forecasts, which in turn produce a range of potential outcomes based on differences or perturbations applied to the data after it has been incorporated into the model. Global Ensemble Forecast System (GEFS) at IMD is adopted from NCEP and it runs in ~12 km (T1534) resolution. The total number of 21 Ensembles (20 perturbed forecasts + 1 control forecast) constitutes the ensemble system. These 20-ensemble members are generated by Ensemble Kalman Filter (EnKF) method from the forecast perturbation of the previous cycles four times a day (00, 06, 12 and 18 UTC) at all 64 model vertical levels. These analysis perturbations are added to the reconfigured analysis obtained from the hybrid four-dimensional Ensemble variational data assimilation system (GDASHybrid4DEnsVar) as part of the suite. The 243 hours forecast of GEFS is routinely generated based on 0000UTC and 1200 UTC initial conditions which include a control forecast starting from GDAS assimilation and 20 (20 perturbations) ensemble members with each perturbed initial condition (Deshpande et al., 2020).

WRF model

During southwest monsoon season 2021, the WRF model (ARW) delivered three days forecasts at 3 km horizontal resolution four times daily at 0000, 0600, 1200 and 1800 UTC with hourly interval. The data assimilation component, regional GSI (Global Statistical Interpolation) takes global GFS analysis and all other conventional quality-controlled observations as its input and generates mesoscale analysis at 3 km resolution. The model produced forecasts over a domain spanning about 5^{o} S to 41^{o} N in north-south and 49^{o} E to 102^{o} E in east-west directions respectively. The upper row of Figs. 2(a-e) portrays skill scores (a) critical success index and (b) gilbert skill scores for different rainfall thresholds whereas lower row exhibits seasonal averaged spatial correlation coefficient for (c) 24 hours, (d) 48 hours and (e) 72 hours rainfall forecasts with observation.



Figs. 2. (a) Critical Success Index, (b) Gilbert Skill Score & spatial correlation coefficient averaged over whole monsoon season for (c) 24 hours forecast, (d) 48 hours forecast and (e) 72 hours forecast of rainfall

HWRF-Ocean (HYCOM/POM-TC) coupled model

During pre-monsoon and post-monsoon cyclone seasons of 2021, the movable triple nested HWRF-Ocean (HWRF/POM-TC) coupled model with horizontal resolutions of 18 km, 6 km and 2 km delivered five days forecasts four times a day at 0000 UTC, 0600 UTC, 1200 UTC and 1800 UTC for tropical cyclones formed over north Indian Ocean (NIO). The data assimilation component of HWRF, regional GSI Data Assimilation, generated mesoscale analysis for intermediate and innermost nests which are then merged to generate analysis for all three domains. The model parent domain (18 km horizontal resolution) remained stationary whereas the intermediate domain (6 km horizontal resolution) and the inner most domains (2 km horizontal resolution) moved to track the storm centre.

The annual average statistics of all errors is summarized in below Table 1.

Table 1

IMD-HWRF Annual Track and intensity forecasts Error Statistics for all cyclones over North Indian Ocean during the year 2021

ERROR STATISTICS FOR HWRF-HYCOM COUPLED MODEL										
Lead Time / **Errors**	12 Hr (15)	24 Hr (15)	36 Hr (15)	48 Hr (13)	60 Hr (11)	72 Hr (9)	84 Hr (7)	96 Hr (5)	108 Hr (3)	120 Hr (1)
Direct Position Errors (DPE) (km)	49	64	90	115	118	121	152	155	153	287
Along Track Errors (AT) (km)	42	44	49	64	74	82	93	128	122	78
Cross track Errors (CT) (km)	74	92	111	140	133	121	90	104	85	94
Landfall PointErrors (km)	59	99	88	49	24	88	90	N/A	N/A	N/A
Landfall TimeErrors (hr)	+3	+3	+9	+6	+6	0	+3	N/A	N/A	N/A
Average Absolute Intensity Errors (AAE) (kts)	11.8	13.1	15.8	17.8	10.4	10.5	12.0	9.9	13.4	7.7
Root Mean SquareIntensity Errors(RMSE) (kts)	14.3	16.7	20.2	21.5	13.5	13.1	15.2	10.8	19.2	10.4

(*Number of forecasts verified is given in the parentheses)

Table 2

Average track forecast errors (Direct Position Error (DPE)) in km (Number of forecasts verified is given in the parentheses)

Lead time →	12h	24h	36h	48h	60h	72h	84h	96h	108h
IMD-MME	35 (23)	49 (23)	59 (22)	78 (20)	106 (15)	138 (12)	164 (7)	258 (5)	258 (2)

Performance of MME and SCIP for forecasting tropical cyclones over the North Indian Ocean during the year 2021

(a) Mean track forecast error (km) of MME - 2021

The annual average track forecast errors [Direct position error (DPE)] of multi-model ensemble (MME) during the year 2021 are shown in Table 2. The annual average is computed for the four cyclonic storms TAUKTAE, YAAS, GULAB and SHAHEEN formed over the North Indian Ocean (NIO) in 2021. The track forecast errors were 49 km, 78 km, 138 km, and 258 km for MME for the forecast hours 24h, 48h, 72h, and 96h respectively.

(b) Mean Intensity forecast error (kt) of SCIP – 2021

The annual average intensity forecast errors of SCIP model are shown in Table 3. The absolute average error (AAE) was 4.5 kts at 24h, 10.6 kts at 48h, 12.3 kts at 72h, and 16.8 kts at 96 h for all the four cyclonic storms (TAUKTAE, YAAS, GULAB and SHAHEEN) over the NIO during the year 2021. The Root Mean Square (RMSE) errors were 5.5 kts at 24h, 14.8 kts at 48h, 16.7 kts at 72h, and 23.2 kts at 96 h.

Table 3

Average absolute errors (AAE) and Root Mean Square (RMSE) errors in knots of SCIP model (Number of forecasts verified is given in the parentheses)

Lead time →	12H	24H	36H	48H	60H	72H	84H	96H	108 H
IMD-SCIP (AAE)	4.8 (23)	4.5 (21)	7.7 (20)	10.6 (17)	9.9 (12)	12.3 (9)	14.4 (7)	16.8 (5)	22.0 (2)
IMD-SCIP (RMSE)	5.9	5.5	8.9	14.8	14.8	16.7	21.4	23.2	28.4

High Resolution Rapid Refresh (HRRR) MODEL

The 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. Utilising the WRF Data Assimilation system (WRF-DA), the RADAR data is assimilated in HRRR model every 10-15 min over a 1-h period. The HRRR is hourly updated, cloud-resolving, convection-allowing atmospheric model, with horizontal resolution of 2km and provides reflectivity and rainfall forecast for next 12 hours. The HRRR model is run in cyclic mode every hour for three domains covering entire mainland of India viz. North-West Domain, East & North-East Domain and South Peninsular India domain and forecast products are updated on the NWP website after every two hours.

Extended Range Forecasts

A coupled model with a suite of models from CFSv2 coupled model has been developed, implemented, and operationalized in IMD in 2017 for generating operational Extended Range Forecast products for different users. This suite of models are (i) CFSv2 at T382 (≈ 38 km) (ii) CFSv2 at T126 (≈100 km) (iii) GFSbc (bias corrected SSTfrom CFSv2) at T382 and (iv) GFSbc at T126. The Multi-model ensemble (MME) of the above suite is run operationally for 32 days based on every Wednesday initial condition with 4 ensemble members to give forecast for 4 weeks for days 2-8 (week1; Friday to Thursday), days 09-15 (week2; Friday to Thursday), days 16-22 (week3; Friday to Thursday) and days 23-29 (week4; Friday to Thursday). The observed weekly rainfall over India during monsoon 2021 indicating the active phase in June, 2nd half of July and the entire September are shown in Fig. The corresponding forecast weekly rainfall anomalies are also shown in Fig. 3 As it is seen from Fig. 3 the model could capture these active phases of monsoon along with the normal monsoon periods. However, the weak phase of monsoon during 1st week of July 3rd and 4th week of August were not very well captured as the model slightly over predicted the actual departure of rainfall. On smaller spatial scales (homogeneous regions and met subdivision levels) the forecast shows useful skill up to two weeks. On met subdivision level the category forecasts upto two weeks are being used for agro-advisory purpose. The active phases of monsoon for the target weeks of 10-16 September and 24-30 September 2021 with three weeks lead time is shown in Figures.

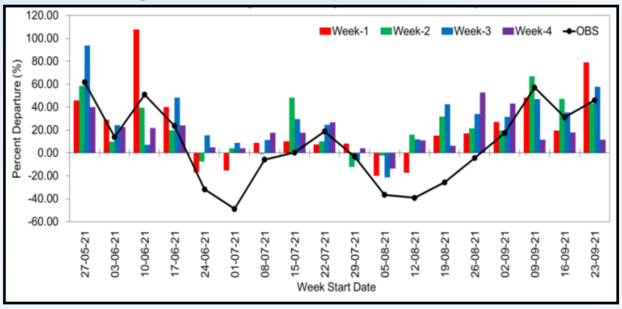
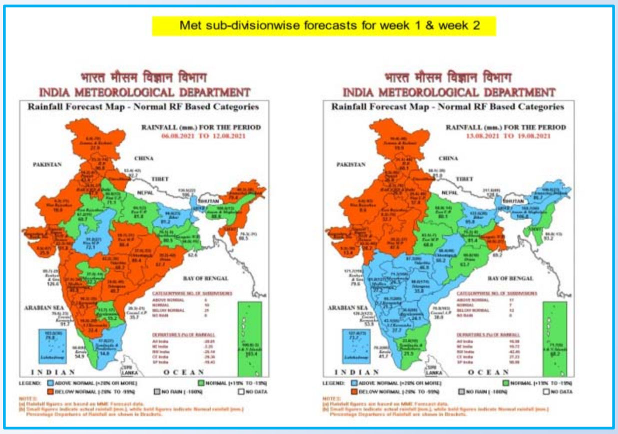


Fig. 3. Weekly observed and forecast rainfall departure during the monsoon season 2021 with 4 weeks lead time

Agromet applications forecast for 36 met subdivisions of India is prepared for two weeks with categorising the subdivisions as below normal, normal, or above normal category depending on the rainfall departure during the week. The two weeks forecast on met-subdivision level is widely used for application in Agriculture for farmers' advisory. The observed active to break transition of monsoon during 6-19 August 2021 as shown in Fig. 4(a) and Fig. 4(b). The transition of monsoon from above normal to below normal is well captured in the extended range forecast, which is being used widely for Agromet advisory purpose.



Figs. 4(a&b). Met-subdivision wise forecast for two weeks based on 4 August 2021 IC and forecast for (a) 6-12 August 2021 and (b) 13-19 August, 2021

Districts level extended range forecast

Experimental ERF products are also being prepared for application in other sectors :-

- Agriculture and veterinary sector (The winter frost forecast and extreme low temperature will be used for crop advisory; high temperature for veterinary sector like poultry firm will be used)

- Water sector/Disaster management (The ERF forecast of active and break phases of monsoon, heavy rainfall, severe weather like cyclone etc will be generated for application in hydrological models and reservoirs operations).

- Health sector (indices like heat index, transmission windows for vector borne diseases, cold wave etc will be generated for services in health sector).

- Energy sector (The extreme high and low temperature forecasts products are being generated for potential use in power/energy sector) as shown in the Fig. 5.

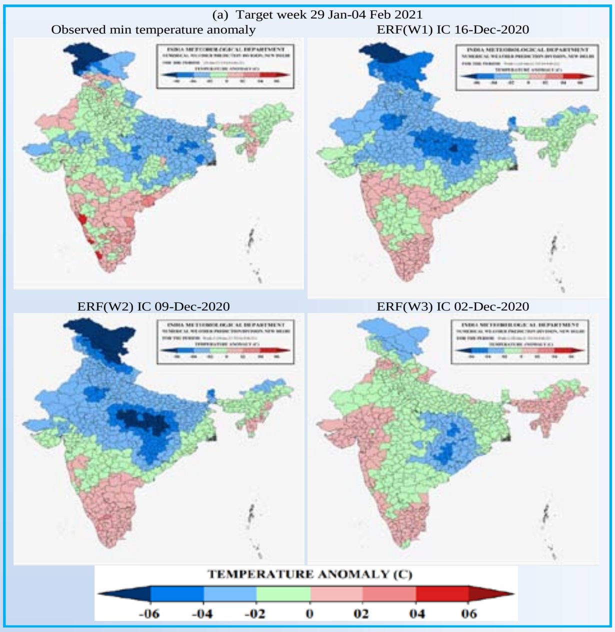


Fig. 5. Indicated the observed weekly minimum temperature anomaly and three weeks ERF minimum temperature anomaly for the same target week 29 Jan-4 Feb 2021

Generation of Multimodel Ensemble (MME) forecast for Indian districts

IMD generates location based as well as area averaged forecast from five models also its MME in real time for decision support. The NWP model forecasts available with IMD is of different spatial resolution (Table 4).

Table 4

Operational Global models

	Operation Models	Agency	Resolution (km)
1.	GFS	IMD	12
2.	GEFS	IMD	12
3.	GFS	NCEP	25
4.	UM	NCMRWF	12
5.	GSM	JMA	25

Five days of the area-averaged forecast of rainfall, maximum temperature, minimum temperature, wind speed, wind direction, relative humidity (at

0300 UTC and 1200 UTC), and cloud cover from each model is generated for Indian districts, followed by MME-mean forecasts have been generated. Currently, forecast over 732 districts are generating in real time. Over these spatial domains, forecast of rainfall distribution also calculated by estimating the percentage of grids reporting a rainfall amount greater than 2.5 mm/day. These forecasts are disseminating to the operational forecasters at RMCs and MCs as a decision support while issuing forecast. These forecasts (as digital values) and figures are also available at NWP division's website. The district rainfall forecast from different NWP model and MME are compared against IMD 0.250 gridded data during July to October 2021. A case study is presented in this report to evaluate the performance of MME forecast qualitatively over Indian districts. The extremely heavy rainfall reported at Uttarakhand state on 19thOctober, 2021 is compared qualitatively with the MME forecast as shown in Fig. 6. The extremely heavy rainfall observed at Uttarakhand [Fig. 6(a)], is well predicted in MME day 1, day 2 and day 3 forecast. Similar to MME district rainfall forecast met-subdivision and location specific city forecasts based on MME are also generated in real-time and available at IMD-NWP website.

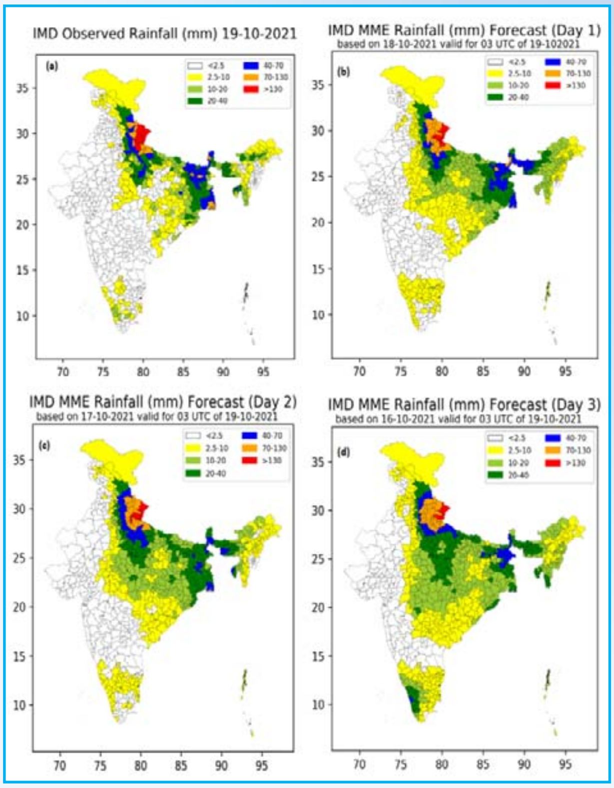


Fig. 6. IMD observed rainfall and MME day 1, day 2 and day 3 rainfall forecast for 19th October, 2021

Development of MME based operational forecast product for 153 River sub-basin

The summer monsoon rainfall is the major water source for most parts of India and people depend on this water source for their livelihood. The rainfall during this season is highly variable over space and time. The rainfall during the southwest monsoon period is the main source of flow discharge in most of the rivers in India.

The MME forecast product for the 153 river sub-basin is developed and operationalized for the five days forecast. Each day forecast is based on the simple MME of five global models as shown in the Table above. The area average values over each subbasin is computed form the five models and average over the models is represented as MME for that day. Fig. 7 show the two sample plots for day 1 and day 5 operation forecast. These forecasts (as digital values) and figures are also available at NWP division's website.

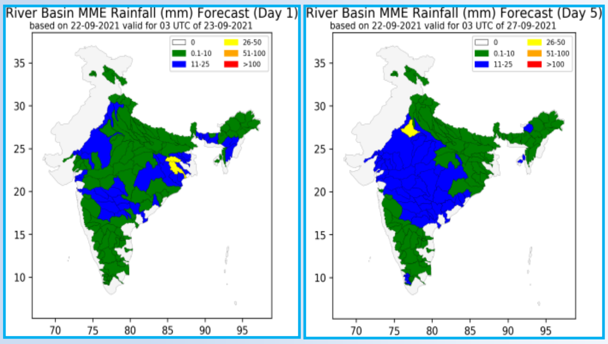


Fig. 7. 153 River sub-basin day-1 and day- 5 forecast

Development of MARINE Forecast basd on MME for GMDSS, SeaArea, Fleet and Coastal forecast

The development of the products for the Marine required computation surface wind, visibility, weather, state of sea information. We utilized data from five global operational model's forecasts (IMD-GFS, GEFS, NCUM, NCEP-GFS and NCUM) daily up to five days. Individual models and their MME based graphical products are generated two time a day based on 0000UTC abd 1200 UTC data and updated on the IMD website for the Marine forecast and bulletin preparations.

Some example products based on Single models (GFS) and MME are prepared and included below for the Fig. 8 (a) GMDSS, (b) Sea Area, (c) Fleet, and (d) coastal forecast.

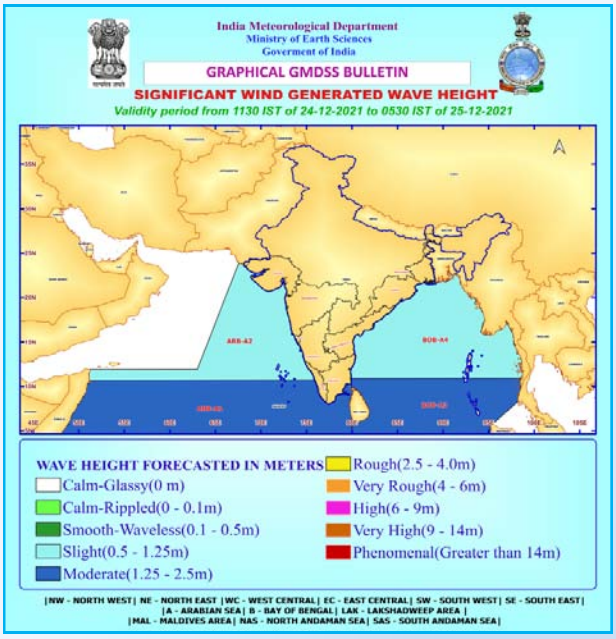


Fig. 8(a). Graphical GMDSS Guidance

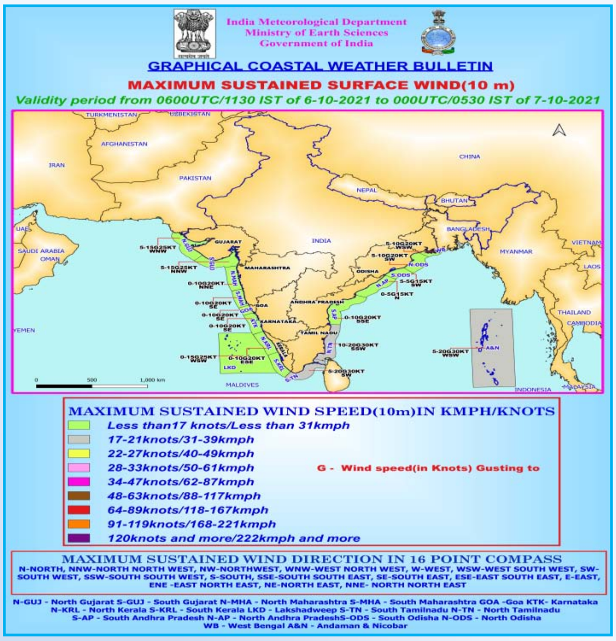


Fig. 8(d). Graphical Fleet Forecast Guidance

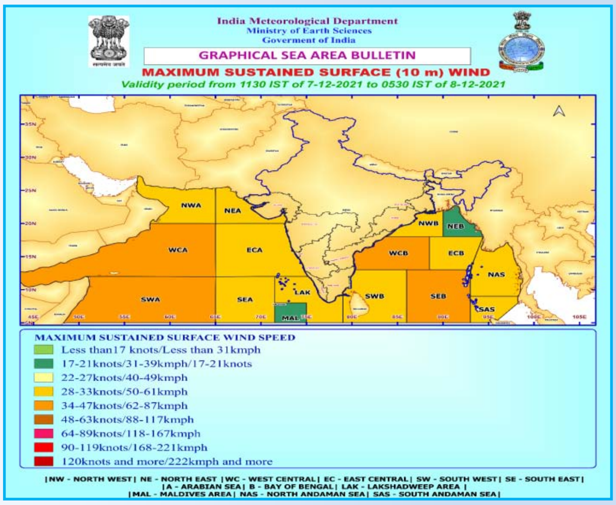


Fig. 8(b). Graphical Sea Area Guidance

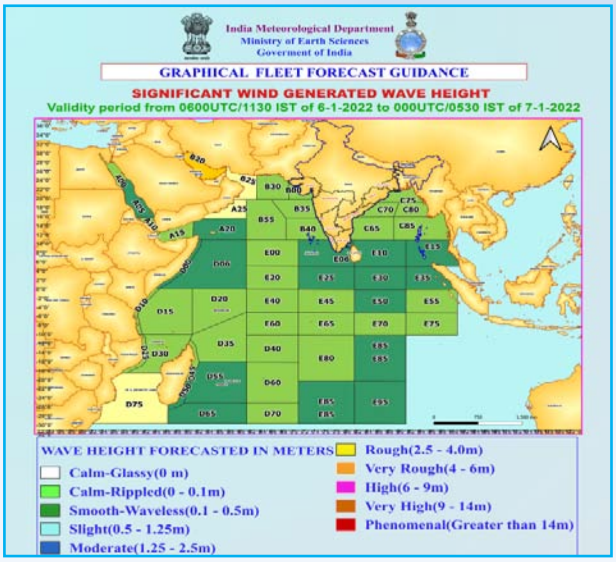


Fig. 8(c). Graphical Fleet Forecast Guidance

E-WRF Operationalization

Recently during March 2022, IMD NWP division has operationally implemented the model EWRF. Presently three different products (Lightning Flash Density, Max Reflectivity and Hourly rainfall) from the Electric-WRF model have been updated in the IMD NWP internal website on the experimental basis for the kind feedback of forecasters. In case of E-WRF model run, ground-based lightning flash rate is assimilated in the model.The details of these products available in the NWP website (https://nwp.imd.gov.in/) are depicted below. Presently due to the limitation of the computational resources, we are running the model at three different times in a day to cover the entire 24 hours of the day.

Early Run is based on the 0000 UTC IMD-GFS initial condition with the validity of the forecast being for 12 hours at hourly intervals (0100 UTC to 1200 UTC). The Early run products will be available on the website around 0600 UTC (1130 IST).

Update Run is also based on the 0000 UTC IMD-GFS initial conditions, with the validity of the forecast being for 18 hours at hourly intervals (0700 UTC to 0000 UTC of next day). The Update run's products will be available on the website around 1130 UTC (1700 IST).

Third run is based on the IMD-GFS 1200 UTC initial condition with the validity of the forecast being for

21 hours at hourly intervals (1300 UTC to 0900 UTC of next day). The Third run products will be available on the website around 1830 UTC (0000 Night).

This Electric WRF model is based on the proper and explicit cloud electrification physics mechanism through which the model generates the electric field over the different grid points of the domain. This electrification mechanism has separate charging and discharging schemes based on different laboratory experiments. In the charging mechanism, Inductive and no-inductive processes have been introduced.

Few plots of the products are given below for the understanding of the forecasters (Fig. 9).

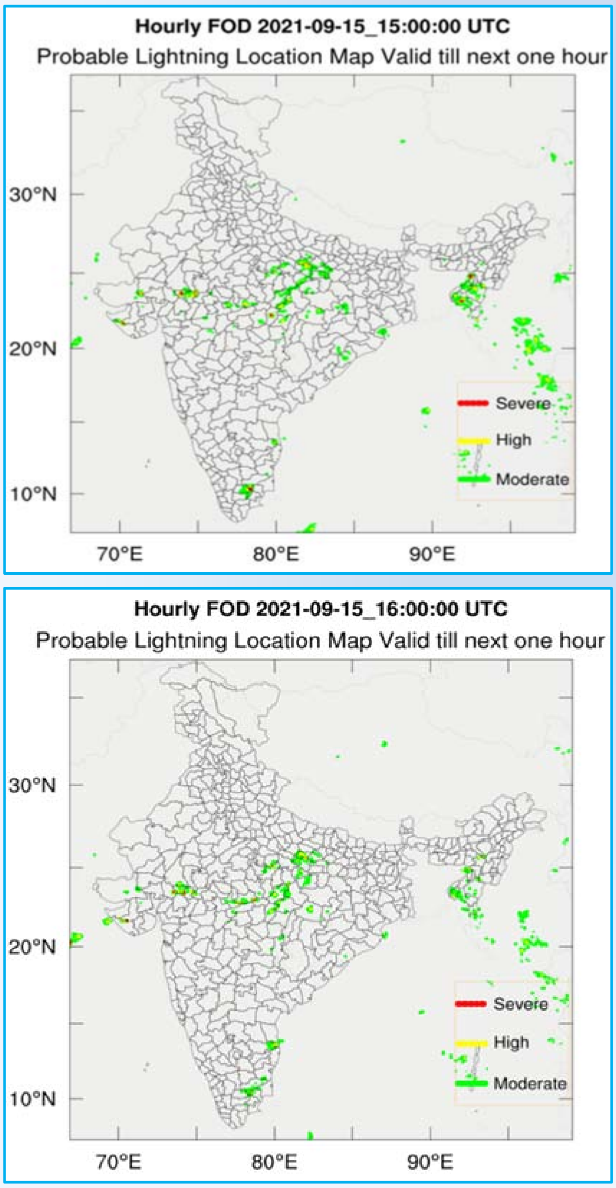


Fig.9. Simulated Flash Origin Density with ground based litghning data assimilation for 15 Sep., 2021

Wind Speed Probabilities

The Wind speed is one of the major parameters to identify the intensity of the cyclonic circulation. The IMD-NWP division developed and implemented to monitor the surface (10-meter height) wind speed probabilities exceeding 4 different thresholds which can explain the intensity of the cyclonic circulations using IMDGEFS (21 members) and NEPS (23 members) ensemble models. The four operational wind speed thresholds are≥ 28 knots (14.4 m/s), ≥ 34 knots (17.5 m/s), ≥ 50 knots (25.7 m/s), ≥ 64 knots (32.9 m/s) and its associated categories are such as Deep Depression, Cyclonic Storm, Severe Cyclonic Storm, and Very Severe Cyclonic Storm, respectively. This wind speed forecast probabilities monitor Fig. 10 are produced at every 6 hourly intervals up to 240 hours. The screenshots of operationalized wind speed probabilities plots using IMDGEFS and NEPS of the IMD-NWP.

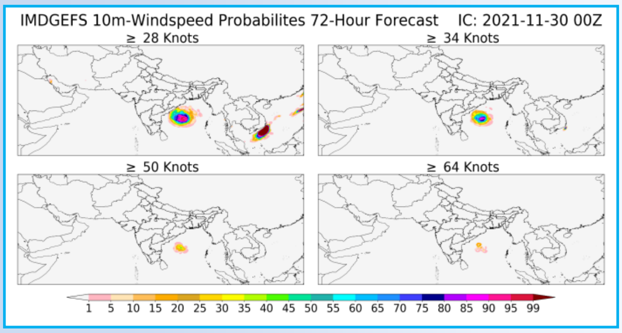


Fig. 10. 10-meter wind speed probability at threshold ≥ 28 Knots, ≥ 34 Knots, ≥ 50 Knots, and ≥ 64 Knots using IMDGEFS (20 ensemble members + 1 Control run) based on initial condition as on 2021-11-30-0000 UTC valid for 72nd hour forecast

Multi Model Ensemble Tropical Cyclone Tracker

ECMWF IFS TC Tracker : The European Centre for Medium-Range Weather Forecasts (ECMWF) developed the Integrated Forecasting System (IFS) model for the global numerical weather prediction at medium range timescale and developed Tropical Cyclone tracker (IFS-TC-Tracker).

The ECMWF IFS-TC-Tracker source code has been modified by the NWP division of IMD, to feedin multi-model global forecasts outputs and made the individual model TC-tracker lines plot along with multi-model-mean, and the verifications of Tc-Tracker both the visual, and statistical outputs are discussed.

By using these 5 global model outputs including IMDGFS, the IFS-TC-Tracker outputs have been made over north Indian Ocean, operationally at NWP, IMD. All model outputs are being interpolated to T159 Gaussian Grid horizontal resolution before running the IFS-TC-Tracker. For the case study, the recent cyclonic storm named as 'JAWAD' during 2021-12-02-0000 UTC to 2021-12-04-0000 UTC over the Bay of Bengal (BoB) has been explored (Fig. 11) & verified (Fig. 12).

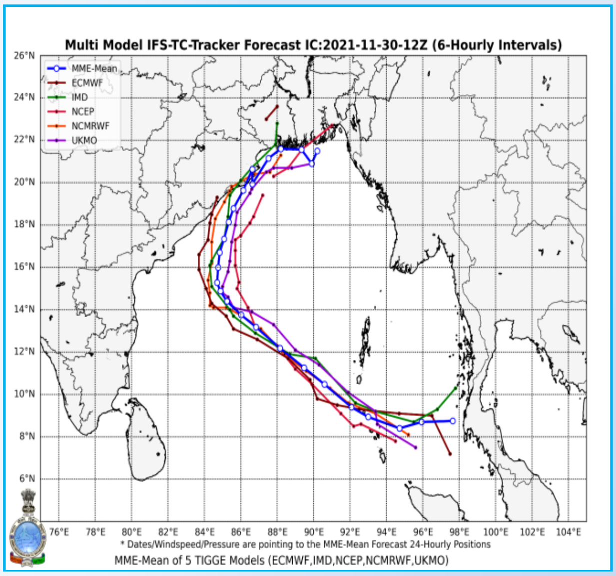


Fig. 11. Real-time production of tropical cyclone tracker outputs ('JAWAD' cyclone storm) using ECMWF's IFS-TC-Tracker. The Multi Model Mean is shown in dark blue line. The TC tracker outputs are at 6-hourly intervals which are marked in black color dots over individual model-colored lines and white color hollow circles over the MMMean blue line. The number of different models used to compute the Multi Model Mean cyclone track details are mentioned in the bottom of figure

The verification of cyclonic storm 'JAWAD' using 9 TIGGE global models and multi-model mean outputs fed into the IFS-TC-Tracker at different forecast lead times (upto 72 hours by 6 hourly intervals). In Fig. 12 shows the distance position error (DPE) of the IFS-TC-Tracker outputs of the nine TIGGE models and MMMean, during different initial conditions from 2021-12-02-1200 UTC and 2021-12-04-1200 UTC at both 0000 and 1200 UTC, and upto 240 hours forecast lead time. The 9 models track errors are within 150 km (200 km) for lead time upto 30 hours (42 hours), and 8 models track errors are within 150 km for lead time upto 72 hours. The Multi Model Mean Track error is consistently below 100 km, 150 km upto 66-, 72-hours forecast lead time, respectively.

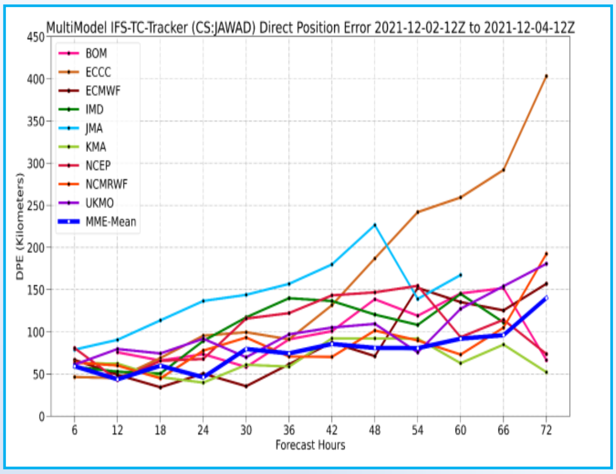


Fig. 12. Verification of JAWAD cyclone storm predicted by the ECMWF IFS-TC-Tracker using 9 TIGGE multi model outputs (shown in multiple colored lines) and MMMean (shown in thick blue line) during 2021-12-02-1200 UTC to 2021-12-04-1200 UTC. X-axis shows forecast lead hours and Y-axis shows Distance Position Error (DPE) in Kilometers

Madden-Julian Oscillation (MJO) Monitoring and Real-time Verification

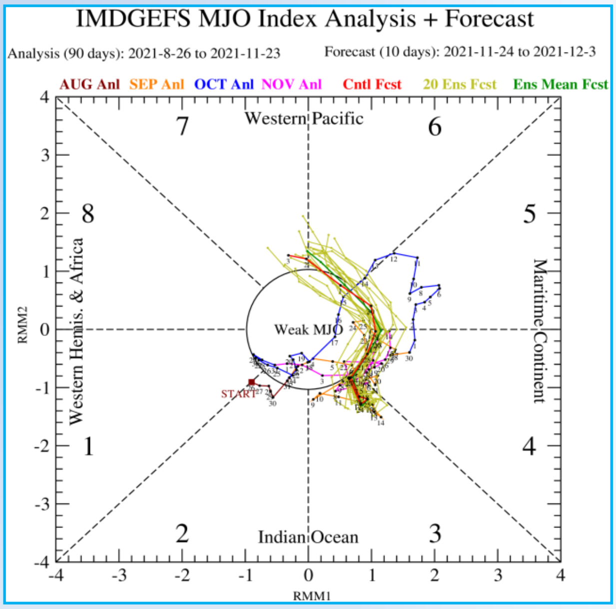


Fig. 13. MJO monitor for the last 90 days (2021-08-26 to 2021-11-23)

The Madden-Julian Oscillation (MJO) is the largest element of the intraseasonal (30 to 90 day) variability in the tropical atmosphere. Fig. 13 shows the last 90 days observed+ analysis MJO Index monitoring along with next 10 days forecasts based on initial condition as on 2021-11-23-0000 UTC. The MJO forecast ensemble (IMDGEFS) indices are at phase 3, 4, 5 and 6, and its consequences as expected for the much activity

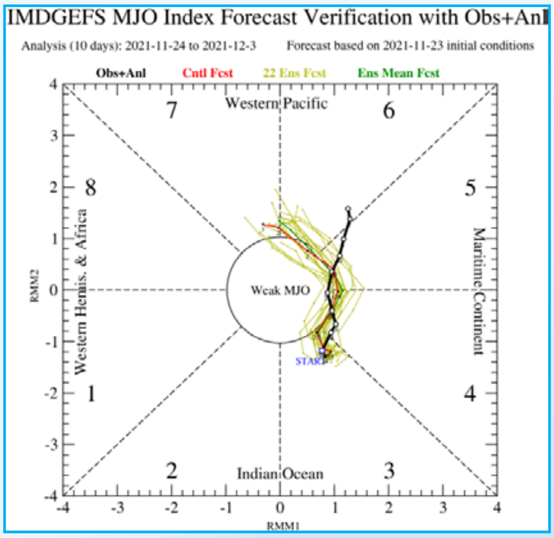


Fig. 14. Verification of IMDGEFS MJO index ensemble 10 days forecast based on initial condition as on 2021-11-23-00Z. Forecast index is verified against the IMDGFS analysis u-winds (850, 200 hPa) and observed OLR (NOAA) which is shown in black thick line. The forecast lines are the same as shown in Fig. 1

over Bay of Bengal, and it happened as a Cyclonic Storm (JAWAD) during 2021-12-02-0000 UTC to 2021-12-04-0000 UTC. Also, the NWP developed a real-time verification of MJO Index with observed (OLR) + IMD GFS analysis (u-winds) by 11 days lag time, which is shown in Fig. 14 (forecasts based on initial condition as on 2021-11-23-0000 UTC), predictions are well match upto 7 days fcst.

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CHAPTER 4

OBSERVATIONAL NETWORK

One of the mandates of IMD is to take meteorological observations for use by different users. Strengthening of atmospheric observational network and its regular maintenance is absolutely required to sustain and improve skill of weather forecasts. IMD has been augmenting its observing system networks over the past years.

4.1. Upper Air Observational Network

Radiosounding Radiowind (RS/RW) network

India Meteorological Department (IMD) has 56 operational Radiosonde radiowind stations in their upper air network, as a part of global observing system (GOS) network of WMO**.** These stations take observations for measuring the vertical profile of the Atmosphere, viz., Temperature, Pressure, humidity, Wind Speed and Direction, the upper air observations are taken by using balloon borne soundings. These stations are engaged in taking the radiosounding observations twice a day at 0000 UTC and 1200 UTC hours.

As a subset of Global Observing System (GOS) network, World Meteorological Organization (WMO) in collaboration with the Intergovernmental Oceanographic Commission (IOC) of the United Nations Educational, Scientific and Cultural Organization (UNESCO), the United Nations Environment Programme (UNEP) and the International Council for Science (ICSU) established Global Climate Observing system (GCOS) network in 1992, as an outcome of 2^{nd} World Climate Conference. In the upper air domain of GCOS, aiming on further improvement of upper air data quality, IMD established GUAN standard radiosounding observations at its six (6) Regional Meteorological Centres (New Delhi, Mumbai, Kolkata, Chennai, Guwahati and Nagpur). The performance of these stations was presented at WMO Technical Conference on Instruments and Methods of Observations (TECO-2016) and a formal claim was made to Secretary General WMO for inclusion of these stations into the GCOS Upper Air Network (GUAN) (Fig. 1).

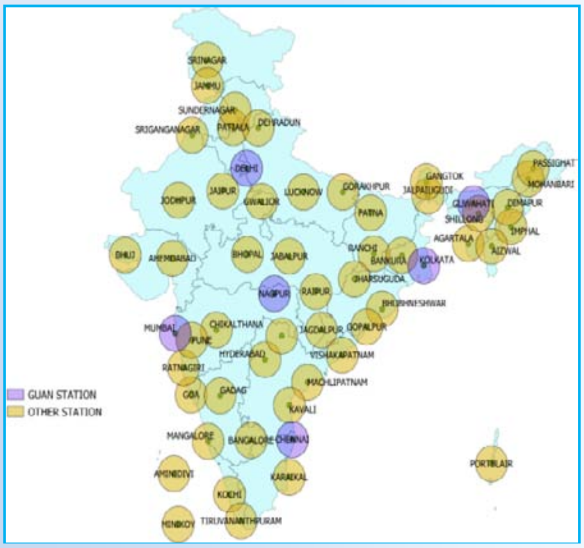


Fig. 1. Existing RS/RW Network of India Meteorological Department

Based on the sustained performance, these stations have been included in the WMO - GUAN standard network by GCOS Secretariat, and their performance indicators figures in the summary of NOAA's monthly report with effect from June 2017 on regular basis.

Pilot Balloon (PB) Network

IMD is operating 62 PB observatories taking 2 to 4 observations for upper air wind profiles at 0000, 0600, 1200 and 1800 UTC hrs of observations. PB stations are using optical theodolites for balloon tracking manually. Efforts have been made to switch over to GPS based fully automatic PB systems from conventional optical theodolite based observations. For this, GPS based pilot-sonde has been developed and being manufactured in-house in IMD Workshop. The same has been implemented in the PB network at PB stations of New Delhi, Mumbai and Lucknow (Fig. 2).

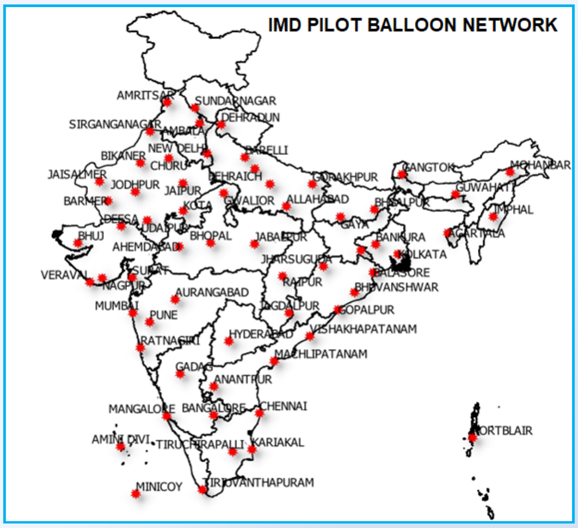


Fig. 2. Upper Air Pilot Balloon (PB) Network of IMD

Major achievements during the year 2019

(i) Continuation of 06 Nos. of WMO GCOS Upper Air Network (GUAN) standard RS/RW stations at New Delhi, Mumbai, Kolkata, Chennai, Guwhati and Nagpur equipped with GPS based high quality radiosounding systems.

(ii) Sustenance of total network of upper air radiosounding (RS/RW) of 56 stations with GPS based radiosounding systems.

(iii) Fabricated PCBs procured from Indian manufacturers for the production of indigenous Pilot-sonde in IMD Workshop at New Delhi, under make in India programme.

(iv) Procurement of GPS based radiosondes being done from Indian sources, as per make in India / Atma Nirbhar Bharat initiatives. Testing arranged as per WMO standards and guidelines.

Testing of GPS based radiosondes being procured from Indian sources at RMO Ayanagar utilizing the method of inter-comparison (Fig. 3).

Fig. 3. Testing of GPS based radiosondes being procured from Indian sources at RMO Ayanagar

Testing of GPS based Pilot-sonde manufactured in IMD Workshop New Delhi (Fig. 4).

Fig. 4. Testing of GPS based Pilot-sonde manufactured in IMD Workshop New Delhi

4.2. Surface Observational Networks

New Installation and Up-gradation of Airport Instruments

- GPRS based AWS and ARG have introduced IMD Surface Observations. Data transmission is possible at an interval of every 15 minutes. Maximum wind is also generated in it.

- **15 GPRS based AWS** have been installed in Kerala State during 2020 and have used **10 m Tiltable mast**.

- Two AWS have been installed in Ladakh UT - MC Leh and Kargil

- **Installation of 19 AWS for wind measurement for Indian Railway (Ajmer Division area).**

Central Radiation Laboratory, Pune designated as Regional Radiation Centre (RA-II) in WMO is maintaining group of standards including self-calibrating cavity radiometers which are taken to International Pyrheliometer Comparison held by WMO. The new Cavity Radiometers with Solar Trackersand Upgradation of Calibration Hut have been installed at Central Radiation Laboratory, Pashan, Pune.

New Scientific data loggers were installed at Delhi, Jodhpur, Goa, Kolkata, Nagpur, Visakhapatnum, Coimbatore, CAgMO Pune, Chennai, Mumbai, Shillong, Ahmedabad, Kodaikanal, Thiruvananthapuram for measurement of Solar Radiation (Fig. 5).

Fig. 5. Scientific Data Logger

New Pyranometers were installed at Delhi, Jodhpur, Goa, Kolkata, Nagpur, Visakhapatnum, Coimbatore, CAgMO Pune, Chennai, Mumbai, Shillong, Ahmedabad, Kodaikanal and Thiruvananthapuram for measurement of Global and Diffuse Solar Radiation [Figs. 6&7].

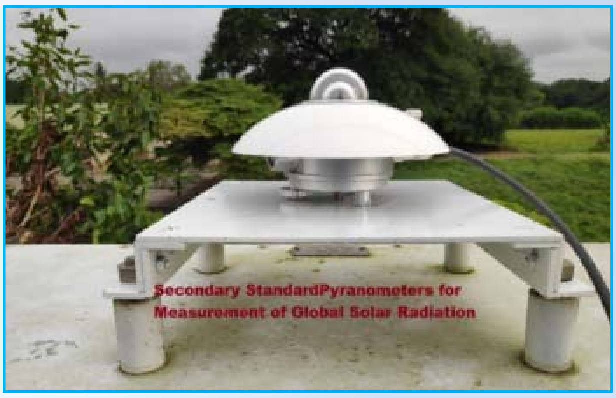


Fig. 6. Secondary Standard Pyranometers for Measurement of Global Solar Radiation

Fig. 7. Pyranometer for measurement of diffuse radiation

New Radiation station has been installed at MO Jammu by the team from Radiation Lab. The new installation and up-gradation of airport instruments (Fig. 8).

Fig. 8. Cavity radiometers with solar trackers and upgardation of calibration

Launching of Pune Live Weather App by **Dr.M. Rajeevan**, Secretary MOES on 27th July, 2021 in the presence of **Dr. M. Mohapatra**, DG IMD and other senior delegates on the occasion of MOES Foundation Day Celebration. The App is developed by Surface Instrument Division under CRS Pune.

DCWIS systems were installed at the following station during the months :-

(a) January 2021 - RWY14 at Nagpur, Sindhudurg, Mundra, Thiruchirapally (Figs. 9&10),
(b) March 2021 - Salem,
(c) July 2021 - Sindhudurg,
(d) August 2021 - Bairagarh,
(e) September 2021 - Shamshabad,

DCWIS systems with PWD (Present Weather Detector) were installed at the following station during the months :-

(a) October 2021 - Dehradun,

(b) November 2021 - Indira Gandhi International Airport (IGI), New Delhi RWY11, Devgarh Airport

(c) December 2021 - Rupsi Airport, Diu.

Nagpur

Fig. 9. RWY14 at Nagpur

Sindhudurg

Fig. 10. DCWIS system installed at Sindhudurg

HWSR was installed [Figs. 11-14] at the following stations:

May-July, 2021 - Ratnagiri, Naliya, Balasore, Chandbali, Colaba, Kavali, Nellore, Nagapattinam; also at Chennai, Cuddalore, Thanjavur, Kanyakumari, Ramnathapuram and Nagapattinam of Tamilnadu and Karaikal and Puducherry of Puducherry.

Chandbali

Fig. 11. HWSR installed atChandbali

Chennai

Fig. 12. HWSR installed at Chennai

Kanyakumari

Fig. 13. HWSR installed atKanyakumari

Karaikal

Fig. 14. HWSR installed at Karaikal

DIWE system was installed at Jagadalpur in July 2021.

Laser Ceilometer was installed during September 2021 at Santa Cruz, Mumbai.

Installation of Present Weather and visibility sensor at RGI airport, Hyderabad (Fig. 15).

Vaisala make Present weather sensor PWD 22 – 2 Nos. along with background luminance sensors was installed at Runway#27R and 09L of RGI airport, Hyderabad in the month of August, 2021. This is a first sensor based on forward scatter meter sensor deployed at the airport in India for measurement of visibility and estimation of runway visual range and present weather information.

Fig. 15. Installation of Present Weather and visibility sensor at RGI airport, Hyderabad

Installation of DCWIS system on 10 metre frangible mast at different 21 airports (26 runway sites) is in progress. Installation of mast is completed at following airports Raipur, Gannavaram, Hyderabad, Jamshedpur and Madurai during June, 2021.

A network of 181 Agro Automatic Weather Station has been established at Krishi Vigyan Kendra all over India under the project of 200 Agro AWS.

A network in Pune district enhanced by installing new 10 Automatic Raingauage Station (ARG) and new 3 Automatic Weather Station (AWS).

Installation of New ARG Girivan on 4th May, 2021.

Installation of New ARG Walhe, Pune on 11th May, 2021.

Installation of New ARG Khadakwasla 19th May, 2021 (Fig. 16).

Fig. 16. Installation of New ARG Khadakwasla

Installation of New ARG Kutbav-Daund 22nd May, 2021.

Installation of New ARG Lonikalbhor 24th May, 2021.

Installation of New ARG Bhor 10th June, 2021 (Fig. 17).

Fig. 17. Installation of New ARG Bhor

Installation of New ARG Rajmata Jijau college Alandi Road.

Installation of New ARG Lakadi-Indapur 23rd June 2021.

A Rainfall monitoring Network across Mumbai Railway enhanced by installing new 6 ARGs Stations across Central Railways stations.

A Rainfall monitoring Network across enhanced by adding new 10 ARGs in Guwahati City, 6 ARGs in Chennai City and 4 ARGs in Kolkata city.

5 No's New Automatic Rain Gauge Station in Chennai Urban metro under the Meso-net Project in Chengalpattu, Chennai and Kanchipuram districts of Tamilnadu (Figs. 18&19).

Chengalpattu

Fig. 18. ARG Installed at Chengalpattu

Chennai

Fig. 19. ARG Installed at Chennai

4.3. Atmospheric Sciences

Summary of the activities Air Pollution:

W. M. O BAPMoN programme of 1972 was consolidated under Global Atmosphere Watch (GAW) in 1989. India Meteorological Department, O/o Head Climate Research and Services, Air Pollution Section maintains a network of eleven GAW stations across India covering different geographical regions. Wet only precipitation samples collected at GAW stations are analyzed at Central Chemical laboratory, Pune for pH, conductivity, major cations (Ca, Mg, Na, K, NH4) and major anions (SO4, NO3, Cl) with the objective of interpreting geo-chemical processes and understanding the acid rain issue. At four stations including two of 11 GAW stations, size segregated aerosols are sampled through TSP, PM10 and PM2.5 high volume air samplers with aim of studying mass and chemical characterization of aerosols.

Precipitation Chemistry Program: Wet only precipitation samples collected at GAW stations are analyzed at Central Chemical laboratory, Pune for pH, conductivity, major cations (Ca, Mg, Na, K, NH4) and major anions (SO4, NO3, Cl)

Air Sampling Program: Air sampling for mass and chemical characterization of size segregated aerosols (TSP, PM10 & PM2.5) through High Volume Air Samplers has been carried out at Pune, Varanasi, Ranichauri and New Delhi.

Air Pollution Laboratory, IMD, Pune is equipped with following equipments:

- Ion Chromatograph (Metrohm, 940 Professional IC Vario Two/Chs/PP)
- Atomic Absorption Spectrophotometer with furnace (Analytic Jena)
- Microwave Digestor
- UV VIS Spectrophotometer
- High Volume Air Samplers
- Semi Microbalance
- pH and Conductivity Meters
- Ultra -pure water purification System
- Sun Sky Radiometer
- Nephelometer
- Aethalometer

Activity during 2021:

- **Precipitation chemistry -**

(i) completed chemical analysis of all precipitation samples received from 11 GAW stations for the year 2020.

(ii) Air Pollution Section Laboratory, O/o Head Climate Research and Services, participated in 63rd and 64th Laboratory Inter-comparison programme conducted by WMO. Simulated Acid rain samples received from WMO in May and November 2021 were analyzed for ten parameters (pH, Conductivity, major anions and cations) and sent the results to QASAC, Americas.

- **Air Sampling -** Air sampling for mass and chemical characterization of size segregated aerosols (TSP, PM10 & PM2.5) through High Volume Air Samplers has been carried out at Pune, Varanasi, Ranichauri and New Delhi. Acid base and water base samples are prepared using microwave digestor and ultra sonicator water bath from the samples received from Delhi and Ranichauri stations. Chemical analysis for major cations (Na, K, Mg, Ca and Nh4) and other metals, i.e., Cu, Fe, Cr and Pb of Delhi samples completed for two years 2017 and 2018 and Ranichauri samples for year 2017.

New projects/schemes/programmes

Under Atmospheric Observations Network scheme, the following activities were carried out.

After installation of newly procured Atomic absorption spectrophotometer and Microwave digestor, chemical analysis of Aerosol samples for major cations and other metals such as Cu, Fe, Cr and Pb has been carried out.

Environment Monitoring and Research Center (EMRC)

Environment Monitoring and Research Center, a division of IMD conducts monitoring and research related to atmospheric constituents that are capable of forcing change in the climate of the Earth, and may cause depletion of the global ozone layer, and play key roles in air quality from local to global scales. EMRC also provides specific services to Ministry of Environment and Forest & Climate Change and other Government Agencies in the assessment of air pollution impacts. IMD contributes in the field of atmospheric environment to the World Meteorological Organization (WMO) Global Atmosphere Watch (GAW) programme. The main objective of GAW is to provide data and other information on the chemical composition & related physical characteristics of the atmosphere and their trends, required to improve understanding of the behaviour of the atmosphere and its interactions with the oceans and the biosphere.

Ozone Monitoring Network

National Ozone Centre of IMD is designated as secondary regional ozone centre for Regional Association II (Asia) of World Meteorological Organization. The centre maintains a network of ozone monitoring stations including Maitri and Bharati in Antarctica (Fig. 20):

- Total Columnar ozone measurement using Dobson spectrophotometer.
- Surface Ozone monitoring network.
- Measurement of Vertical Distribution of Ozone.

Fig. 20. IMD Ozone monitoring network

Dobson Spectrophotometer D36 was calibrated and refurbished at Regional Dobson Calibration Center (RDCC) at the Meteorological Observatory Hohenpeissenberg, Germany in 2020. Another Dobson Spectrophotometer D112 was calibrated during WMO International Comparison of Dobson Spectrophotometers (DIC) held at Irene Technical Centre, Pretoria, Gauteng Province, South Africa, 7-18 October 2019.

Precipitation and Particulate Matter Chemistry Monitoring

IMD is monitoring Precipitation Chemistry through a network of eleven stations since 1970s (Fig. 21). The rainwater and particulate matter samples collected from these stations are analyzed in Air Pollution Chemistry Laboratory at IMD, Pune which is equipped with Ion-chromatograph, UV-VIS Spectrophotometer, Semi-micro Balance, pH & Conductivity Meter, Ultra-pure Deionized Water Purification System. A new Atomic Absorption Spectrophotometer has been installed in the laboratory. The IMD laboratory participated in WMO Laboratory Intercomparison Study 61 and 62 held in the year 2020.

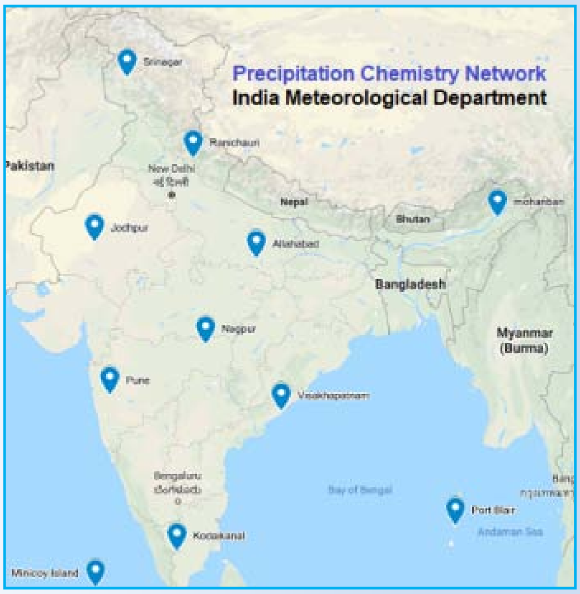


Fig. 21. IMD Precipitation chemistry network

Fig. 22. Aerosol monitoring network of IMD

Aerosol Monitoring Network

IMD has established Aerosol Monitoring Network covering different geographic regions of India (Fig. 22). The Aerosol Monitoring Network consists of following sub-networks:

Sun-Sky radiometer Network

Environment Monitoring and Research Center, India Meteorological Department has established Aerosol Monitoring Network by installing skyradiometer at twenty locations. The network is used to measure optical properties of aerosols such as Aerosol Optical Depth, Single Scattering Albedo, Size Distribution, Phase Function etc.

Black Carbon Aerosol Monitoring Network

Black Carbon Monitoring Network of 25 stations for measurement of Spectral Aerosol Absorption Coefficient, Equivalent Black Carbon Concentration and bio-mass burning component is operational.

Multi-wavelength Integrating Nephelometer Network

IMD has established a network for measurement of aerosol scattering coefficient at twelve locations is operational at New Delhi, Ranichauri, Varanasi, Nagpur, Pune, Port Blair, Visakhapatnam, Guwahati, Kolkata, Jodhpur, Bhuj, Thiruvananthpuram.

Chemical Characterization of Aerosols

High Volume Samplers for collecting PM10, PM2.5 and Total Suspended Particulate Matter have been installed at Delhi, Ranichauri, Pune and Varanasi. The filter papers are being analyzed for chemical characterization of aerosols at Air Pollution Section, O/o CRS, IMD, Pune.

Air Quality Forecasting and Research

Under the FMI-IMD cooperation agreement, the latest version of Air Quality forecast model “System for Integrated modeLling of Atmospheric coMposition (SILAM v5.7)” has been operationalized for Indian region. Hourly air quality forecast for 72 hours of all criteria pollutants

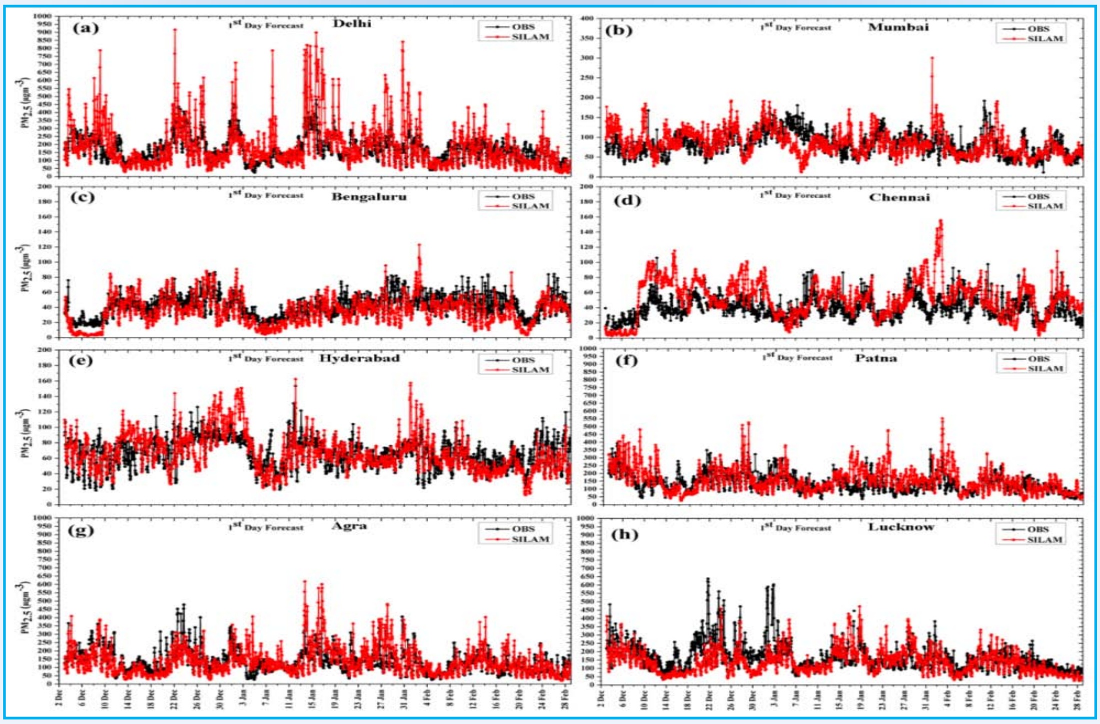
(PM10, PM2.5, O3, CO, NO2, SO2 and other species) is generated for the domain 60-100°E, 0-40°N. SILAM is coupled with hourly 3-km IMD-WRF meteorological forecasts model. The latest emission inventories CAMS-GLOB v2.1, 0.1-deg supplemented with EDGAR v4.3.2 for coarse and mineral-fine anthropogenic particulate matter, GEIA v1 lightning climatology and MEGAN-MACC biogenic climatology for isoprene and mono-terpene are used in SILAM model. The model is validated with air quality observations available from CPCB. A very high resolution city scale air quality model "ENvironmental information FUsion SERvice (ENFUSER)" has been also operationalized for Delhi. Hourly air quality forecast for 72 hours of all criteria pollutants (PM10, PM2.5, O3, CO, NO2, SO2) is generated for the domain (28.362N-28.86N, 76.901E-77.56E) at 30 m spatial resolution. The model uses and assimilates a large amount of Geographic Information System (GIS) data to describe the modelling area on a high resolution. This includes a detailed description of the road network, buildings, land-use information, high-resolution satellite images, ground elevation, population data, traffic density etc. SILAM and ENFUSER are developed under a collaborative project with Finnish Meteorological Institute.

IMD issues AQ Early Warning bulletins based on SILAM and WRF-Chem (IITM) models.

The System for Air quality Forecasting and Research (SAFAR) is operational to monitor and forecast air quality in Delhi. This is a joint project of IITM and IMD. The system is also operational at Pune, Mumbai and Ahmedabad. All major air pollutants (PM2.5, PM10, Ozone, CO, NOx (NO, NO2), SO2, BC, Methane (CH4), Non-methane hydrocarbons, VOC's, Benzene, Mercury), solar radiation and meteorological parameters are measured at ten air quality station installed in each city.

Performance Verification of Air Quality Model

Fig. 23 shows the comparison for temporal variation between observed surface PM2.5 mass (black) and the modeled (red) hourly PM2.5 mass concentration during study period over Delhi/NCR, Mumbai, Bengaluru, Chennai, Hyderabad, Patna, Agra and Lucknow. It can be seen that the SILAM model very well captures the temporal and diurnal variation associated with the synoptic-scale variability during the study period. The forecast verification for other major cities is also completed.



Figs. 23(a-h). Comparison between hourly mean PM2.5 forecast (red) and hourly mean PM2.5 averaged over cities air quality monitoring stations (black) on day one forecast at 5km horizontal grid spacing (left) over (a) Delhi/NCR, (b) Mumbai, (c) Bengaluru, (d) Chennai, (e) Hyderabad, (f) Patna, (g) Agra and (h) Lucknow respectively during 3rd Dec 2020 to 28th Feb 2021

TABLE 1

Performance statistics for mean PM2.5 forecast and skill score over India, Delhi/NCR, Mumbai, Bengaluru, Chennai, Hyderabad, Patna, Agra and Lucknow. Mean bias (MB), Pearson's correlation coefficient (r), normalized mean fractional bias (NMFB), normalized mean fractional error (NMFE) and Index of Agreement (IOA)

State	Variables	Seasons	Forecast Day	MB	NMFB (%)	NMFE (%)	r	IOA
India	PM_{25}_hourly	Winter	1st day	9.4	8.8	23.2	0.7	0.8
			2nd day	6.8	6.4	23.8	0.7	0.8
			3rd day	4.3	4.2	23.9	0.7	0.8
Delhi/NCR	PM_{25}_hourly	Winter	1st day	20.0	11.5	41.5	0.6	0.7
			2nd day	14.2	8.3	41.9	0.6	0.7
			3rd day	5.6	3.4	41.0	0.6	0.7
Mumbai	PM_{25}_hourly	Winter	1st day	3.1	3.8	29.4	0.4	0.6
			2nd day	3.9	4.7	30.1	0.4	0.6
			3rd day	2.8	3.4	30.5	0.4	0.6
Bengaluru	PM_{25}_hourly	Winter	1st day	-6.9	-18.3	35.6	0.5	0.7
			2nd day	-7.3	-19.3	35.8	0.5	0.7
			3rd day	-9.1	-24.3	37.8	0.5	0.7
Chennai	PM_{25}_hourly	Winter	1st day	13.2	28.1	44.0	0.4	0.5
			2nd day	13.4	28.2	44.8	0.4	0.5
			3rd day	14.1	29.2	45.1	0.4	0.5
Hyderabad	PM_{25}_hourly	Winter	1st day	0.0	0.0	22.9	0.6	0.8
			2nd day	-0.2	-0.02	23.4	0.6	0.8
			3rd day	-0.8	-0.13	23.8	0.6	0.8
Patna	PM_{25}_hourly	Winter	1st day	22.7	15.5	37.0	0.4	0.6
			2nd day	21.4	14.9	37.9	0.4	0.6
			3rd day	20.8	14.7	39.2	0.4	0.6
Agra	PM_{25}_hourly	Winter	1st day	-2.0	-1.5	36.3	0.6	0.7
			2nd day	-3.2	-2.4	38.4	0.6	0.7
			3rd day	-12.1	-9.5	40.4	0.6	0.7
Lucknow	PM_{25}_hourly	Winter	1st day	-26.8	-18.1	38.5	0.5	0.7
			2nd day	-29.7	-20.6	39.2	0.5	0.7
			3rd day	-23.7	-16.3	42.0	0.5	0.7

Updated Land Use/ Land Cover data at 10 meter resolution

High resolution LULC data over Delhi/NCR region are being developed for to high resolution urban meteorological and air quality forecast. (Fig. 24).

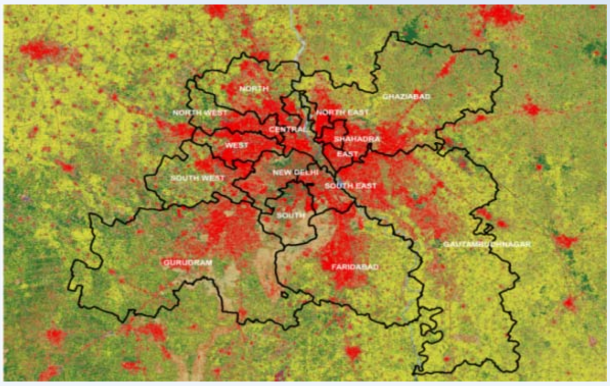


Fig. 24. Spatial distribution of land use/ land cover data of Sentinel satellite at 10 meter resolution over Delhi/NCR regions

High Altitude Background Climate Monitoring Station

Fig. 25. IMD Climate Monitoring Station Ranichauri

IMD maintains a Background Climate Monitoring Station Ranichauri, Uttarakhand (Fig. 25). Skyradiometer, Aethalometer, Differential Mobility Particle Sizer, Nephelometer, Solar Radiation monitoring equipment, Precipitation Chemistry and Surface Ozone Analyzer have been installed at the station. The online GHGs monitoring system has been installed at Ranichauri in 2020.

POLAR METEOROLOGICAL RESEARCH DIVISION (PMRD)

India Meteorological Department has been an integral part of all the Indian Scientific Expedition to Antarctica (ISEA) since the very first expedition during 1981. IMD started meteorological and ozone observations at Maitri station from January, 1990 (from 9th ISEA) and are ongoing till date. A meteorological observatory was commissioned in 2015 by IMD at Bharati, another Indian station in Antarctica (Fig. 26).

Polar WRF model is implemented to provide day-to-day 72 hours weather forecast for the Maitri and Bharati region in the Antarctica. The NWP products are routinely made available on the IMD web site to support of Antarctic Expedition.

Fig. 26. Meteorological Observatory at Bharati

The model set-up (selected domain Fig. 27) and validation of the model is summarized below:

NWP Model : Polar WRF (Hines and Bromwich 2008) version 4.1.1

Model Setup : A single static domain with 1100 × 900 grids at 3 km horizontal spatial resolution and 45 vertical levels for forecast 3 days in advance.

Initial and Boundary conditions : IMD GFS T-1534 at 12.5 KM spatial and 3 hourly temporal is used as initial and boundary condition to run Polar WRF mesoscale model.

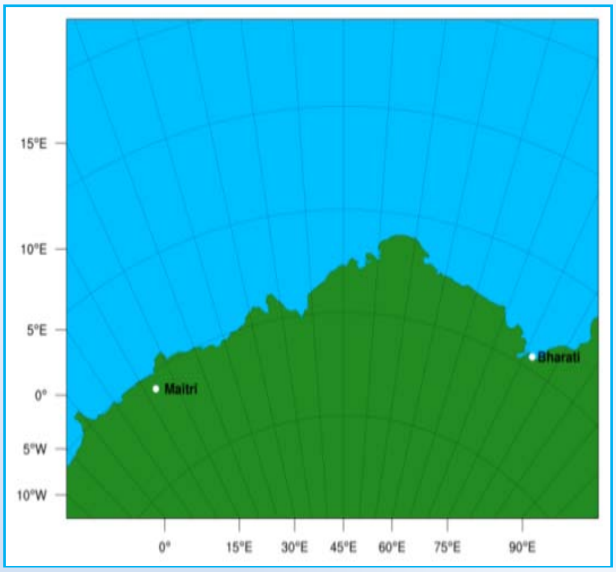


Fig. 27. IMD Polar WRF model domain

Physics options:

Microphysics – WSM 5-class scheme, Goddard short wave, RRTM long wave, Noah land-surface,

Planetary boundary layer – Mellor Yamada-Janjic and

Cumulus convection – Grell-Devenyi.

IN-SITU OBSERVATION

In-situ observations for meteorological variables are available at Maitri station (lat. 70° 45’ S, long. 11° 44’ E) and Bharati station (69° 24’ S, long. 76° 11’ E).

Fig. 28 shows that Polar-WRF model is slightly over-predicting surface wind speed, mean sea level pressure and relative humidity with mean bias 3.37 knots, 5.67 hPa and 10.85% respectively for Aug 2021. However, model is under-predicting surface temperature with mean bias -4.06 °C for the same period. Fig. 29 shows the comparison of win rose plots of model against observations. This figure reveals that easterly and north-easterly winds are dominating in the observed winds. However, southerly and south-easterly winds are dominating in model simulated winds. In addition, spatial distribution of mean sea level pressure, surface temperature, wind speed and relative humid are shown over Antarctica region in Fig. 30.

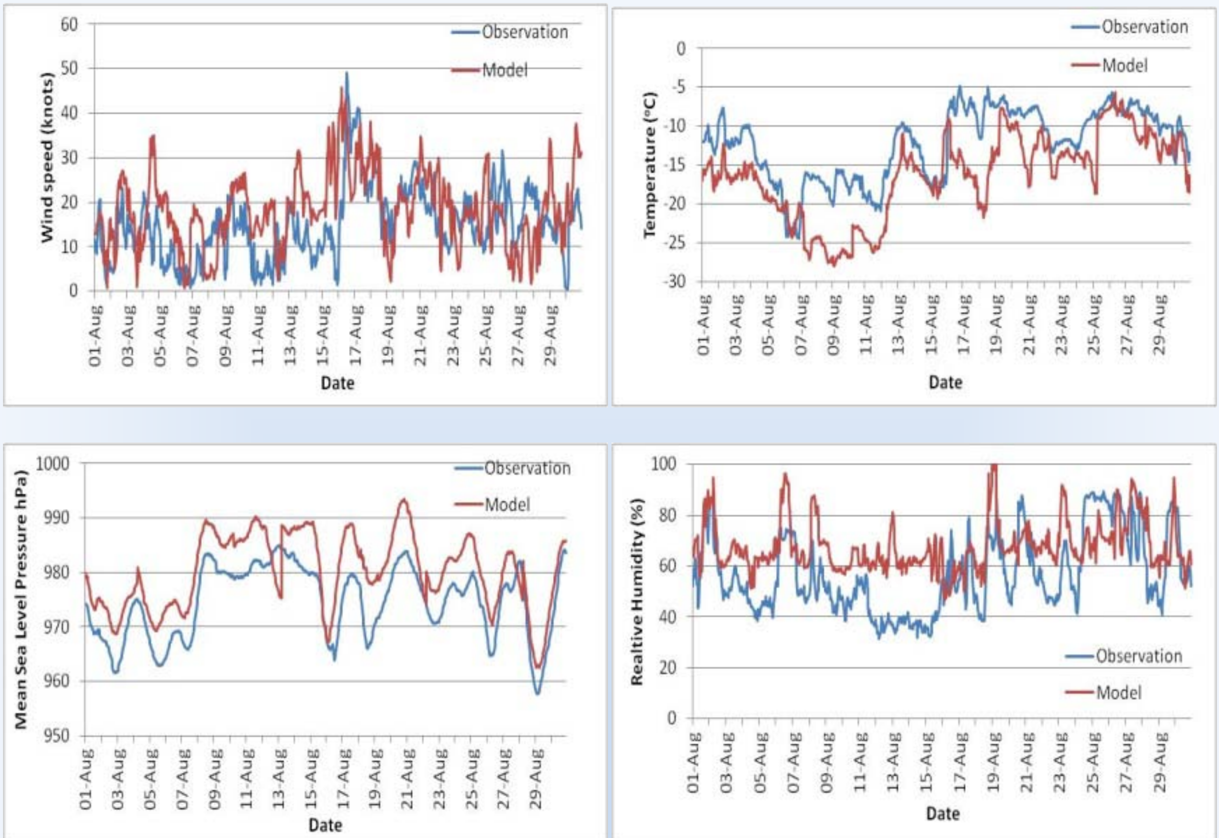


Fig. 28. Comparison of hourly simulated time series of (a) mean sea level pressure (hPa), (b) surface temperature (°C), (c) surface wind speed (knots) and (d) relative humidity (%) against observations for Aug 2021 at Bharati station

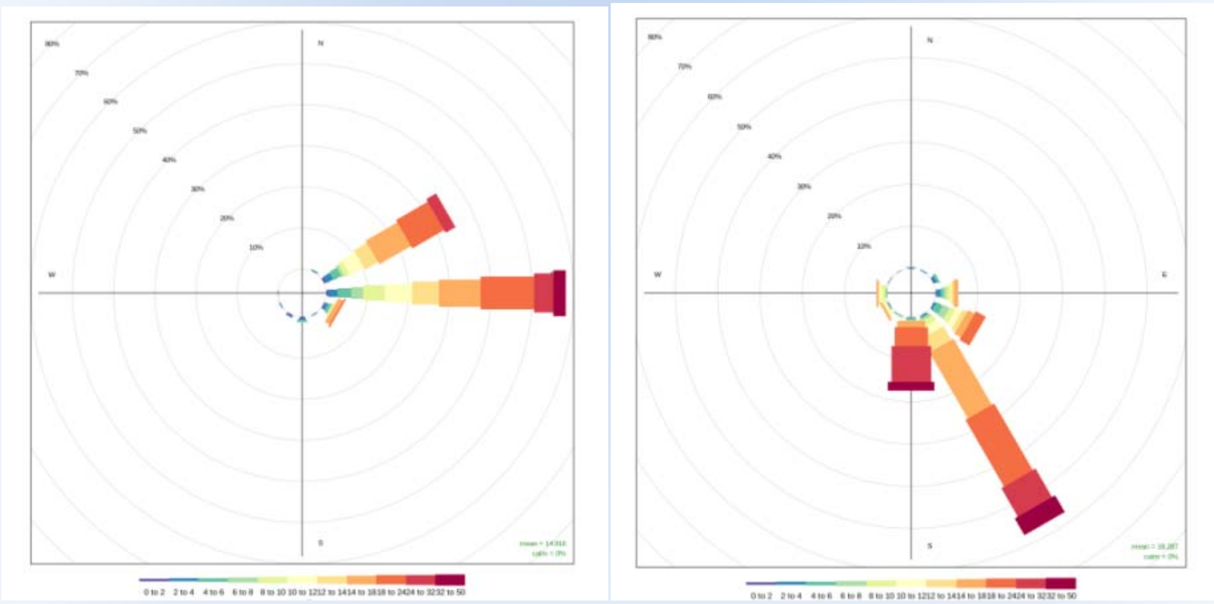


Fig. 29. Wind rose plots (a) observed winds and (b) model simulated windsfor Aug 2021 at Bharati station

IMD-HYSPLIT MODEL

IMD WRF-Hysplit is implementedto provide air flow mass into forward as well as backward direction every day 2 times with 00 and 12 hours initial data IMD WRF model for 32 selected cities: Delhi, Pune, Ranichauri, Guwahati, Jodhpur, Nagpur, PortBlair, Trivandrum, Visakhapatnam, Varansi, Kolkota, Ranchi, Bhuj, Amni, Chandigarh, Srinagar, Hyderabad, Gadanki, Nainital, Kalpakkam, Mumbai, Bhubneswar, Ahmedabad, Kota, Narora, Dhanbad, Tarapur, Kudankulam, Kaiga, Kakrapur, Dehradun, Goa. The NWP products are routinely made available (Fig. 31) on the IMD web site at

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

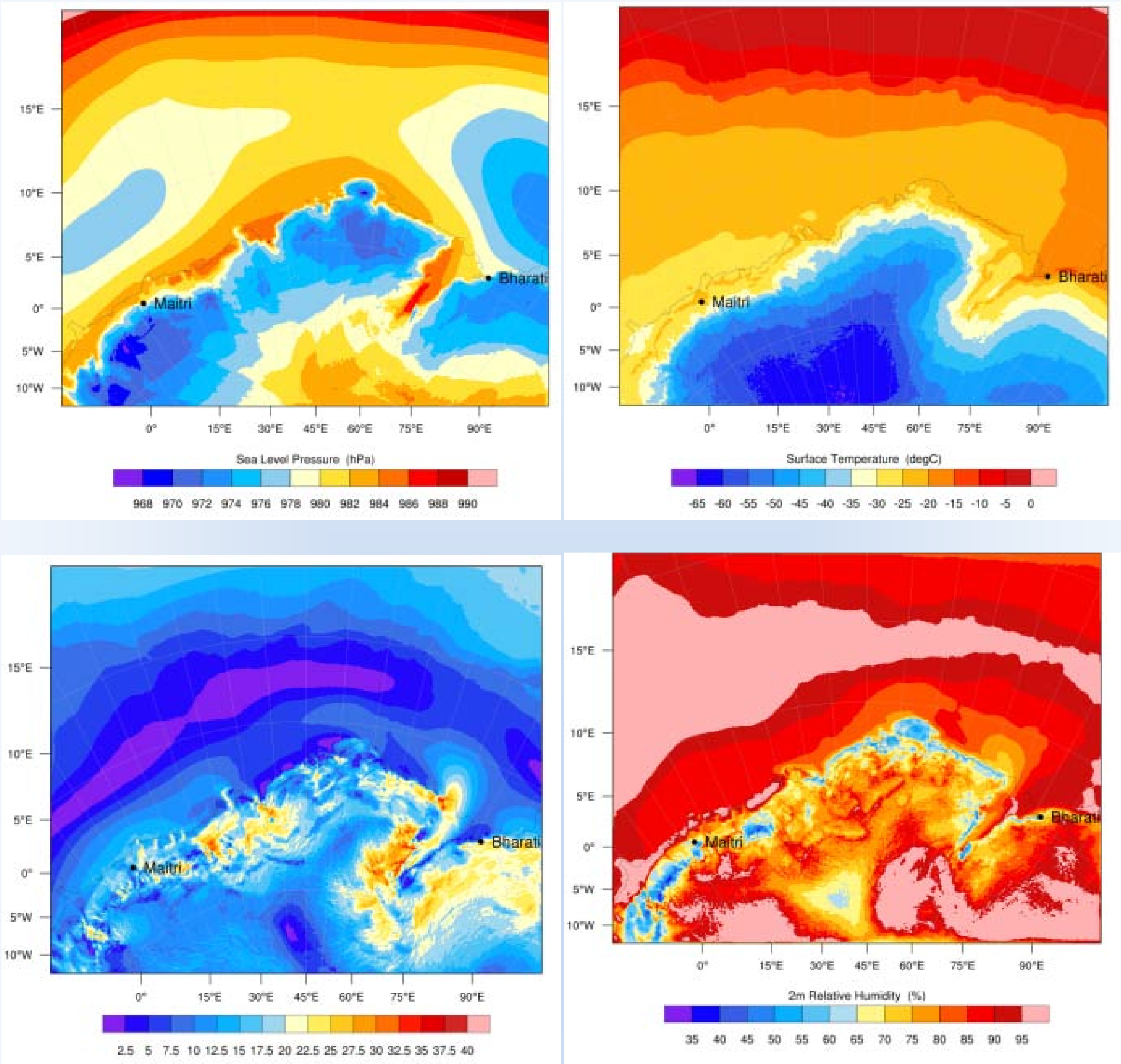


Fig. 30. Spatial distribution of model simulated (a) mean sea level pressure (hPa), (b) surface temperature (°C), (c) surface wind speed (knots) and (d) relative humidity (%) for Aug 2021 over Antarctica

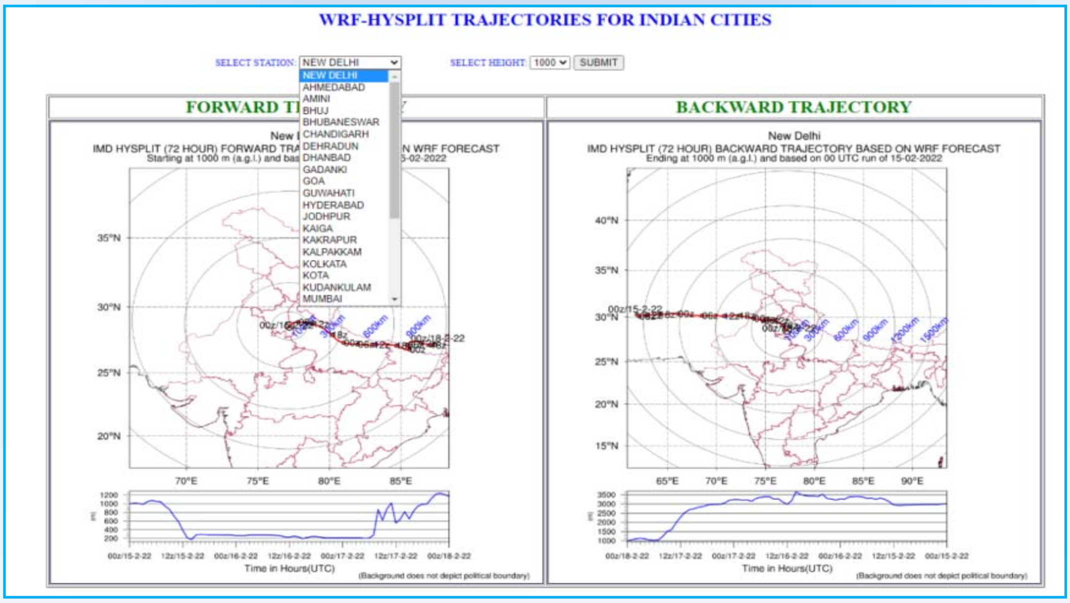


Fig. 31. IMD WRF-Hysplit forward and backward trajectories at Delhi

4.4. Radar Observations

(a) Network of Radars

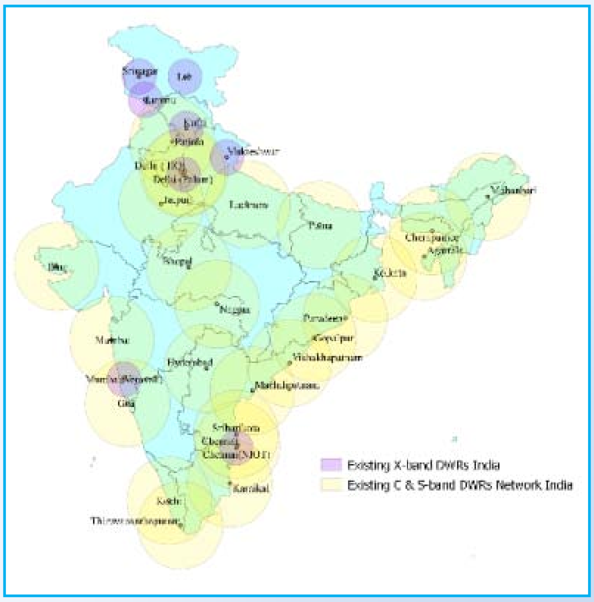


Fig. 32. Existing DWRs Network

IMD operates and maintains Doppler weather radar network consisting of thirty S, C and X-band DWRs all over India (Fig. 32). It includes twenty S-band, two sites with Polarimetric C-band and six X-band DWRs. Two indigenously manufactured X-band polarimetric DWRs have been installed at Veravali and Pallikarnai. IMD also utilizes the DWRs installed by ISRO at Thiruvananthapuram, Cherrapunji and Sriharikota.

(b) Proposed Dual Polarized X- Band DWRs

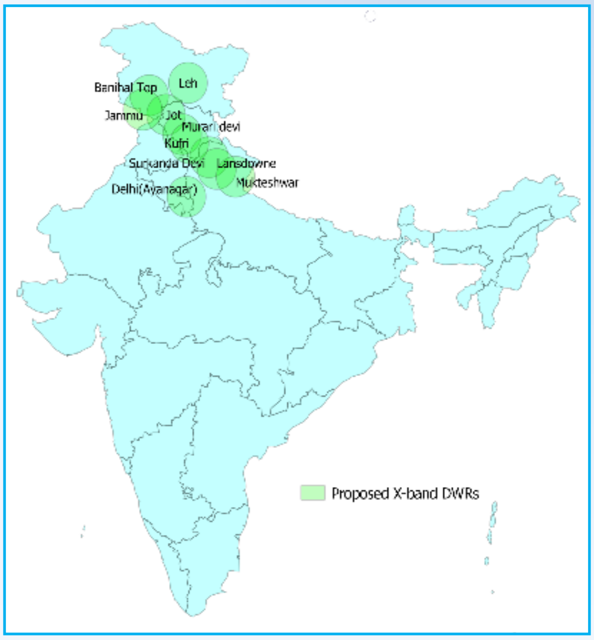


Fig. 33. Proposed X- Band DWR Network

Dual Polarized X-Band DWRs are proposed to be installed in India under Integrated Himalayan Meteorological Programme [5 DWRs have already been installed at Leh, Kufri, Mukteshwar, Jammu and Ayanagar (Fig. 33)]. All these radars are an example of achievement of self-reliance goal of the “Make in India-Atma nirbhar Bharat” vision of Hon’ble Prime Minister of India.

(c) Proposed Dual Polarised X-Band DWRs for North East region

08 Dual Polarised X-Band DWRs are proposed to be installed in North East region of India (Fig. 34).

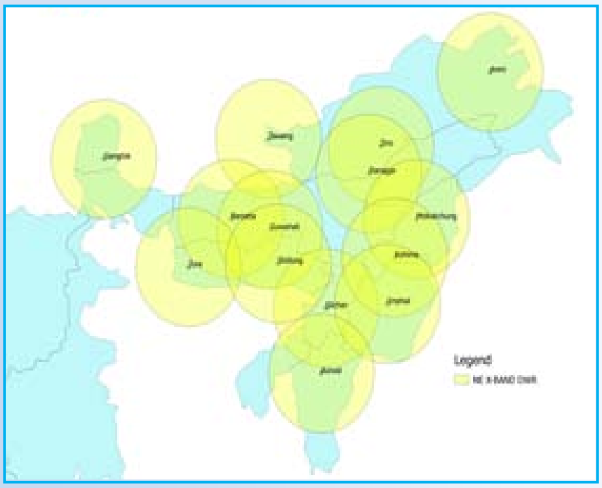


Fig. 34. Proposed X- Band DWR Network in North East

(d) Proposed Dual Polarized 11 C-Band DWRs

11 Dual Polarized C-Band DWRs are proposed to be installed over the mainland of India (Fig. 35).

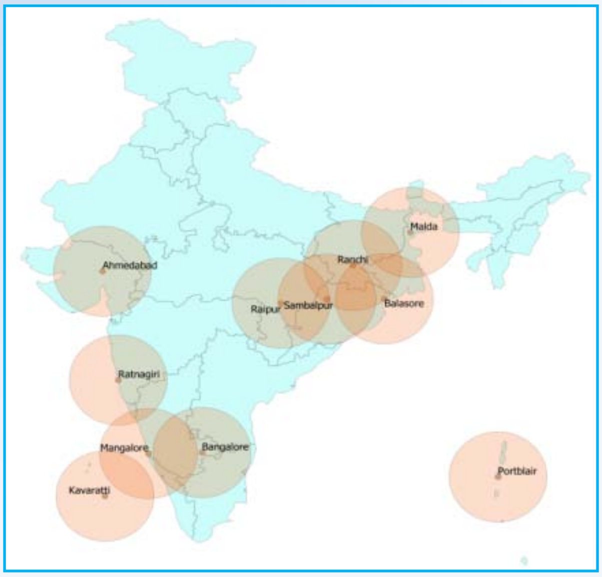


Fig. 35. Proposed C- Band DWR Network

A transportable X-Band Doppler Weather Radar mounted on mobile platform installed at Leh under Integrated Himalayan Meteorology Programme (IHMP) for Western and Central Himalayas (Fig. 36). This radar installed by IMD is at the highest altitude in India.

Fig. 36. Portable X-Band Doppler Weather Radar

A tower based X-Band DWR has been installed at Mukteshwar, Uttarakahnd (Fig. 37), Kufri, HP (Fig. 38), Jammu, J&K (Fig. 39) and Ayanagar, New Delhi (Fig. 40) under IHMP. Two indigenous DWRs, i.e., X-band DWR at Pallikarnai (Fig. 41) and C-band (Fig. 42) at Veravali have also been added in IMD network provided by ISRO.

Fig. 37. DWR at Mukteshwar in Uttarakahand

Fig. 38. DWR at Kufri in HP

Fig. 39. DWR at Mukteshwar in Uttarakahand

Fig. 40. DWR at Ayanagar in New Delhi

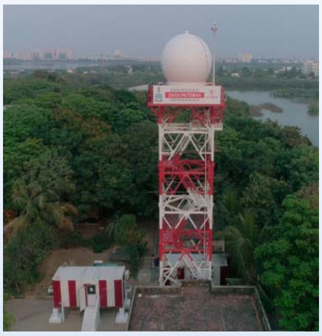


Fig. 41. DWR at Pallikarnai, Chennai in Tamil Nadu

Fig. 42. DWR at Veravali, Mumbai in Maharashtra

4.5. Satellite Observations

Space based observation Network & Services

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 2.0/2.0 PB (Main/ Mirror) & 324 TB SSD which will facilitate online sharing of processed data for all Indian meteorological satellites to the registered users as per IMD data policy Supply through Web based secured satellite Data System. All available past satellite datasets starting from 1983 will be kept in online mode in due course of time. The meteorological satellite data of INSAT is processed and disseminated by INSAT Meteorological Data Processing System (IMDPS) of India Meteorological Department (IMD) which was installed by M/s Antrix Corporation through an MOU with India Meteorological Department. 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. The Site Acceptance Test of Multi-Mission Meteorological Data Receiving and

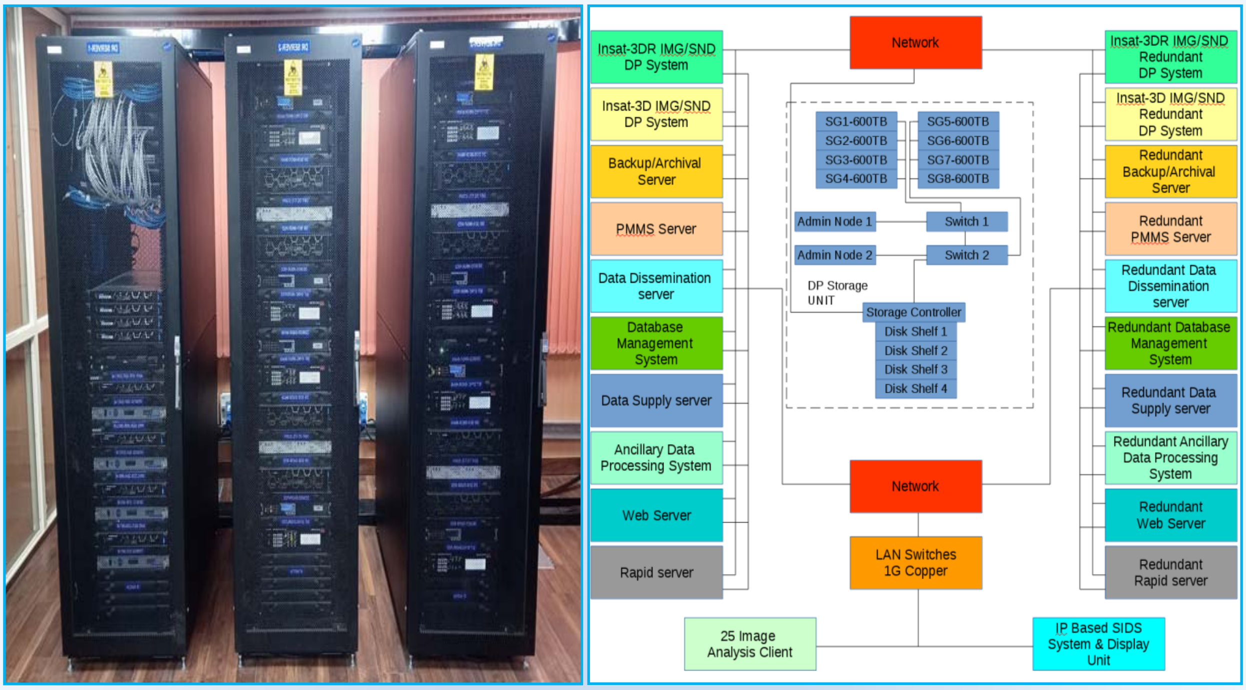
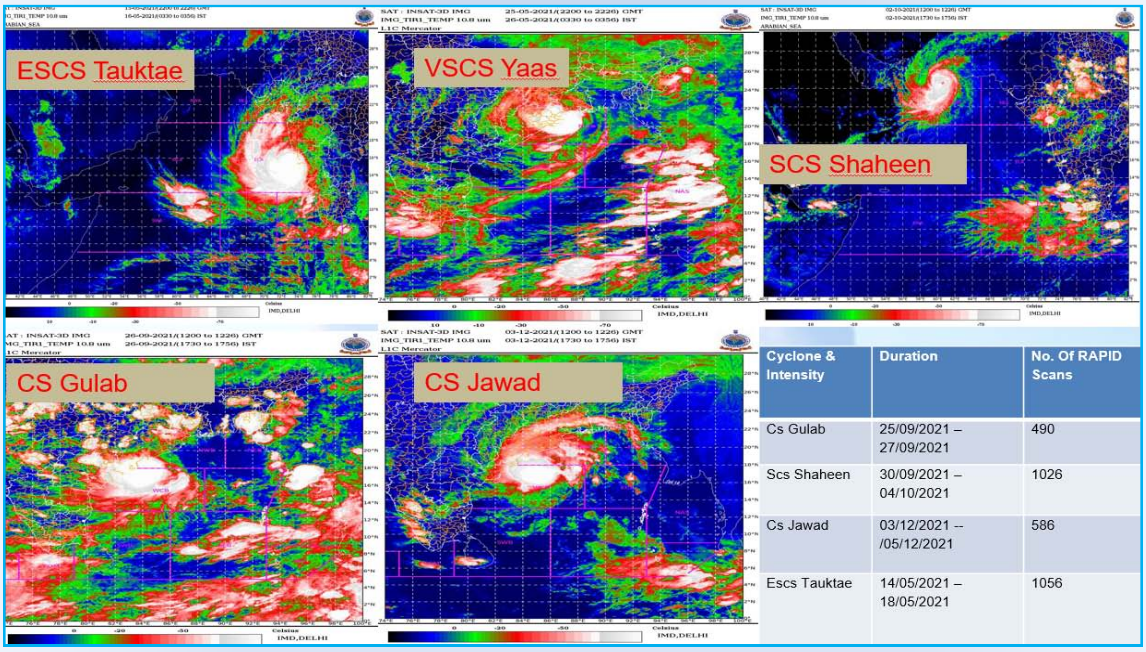


Fig. 43. Block diagram of MMDRPS system



Cyclone & Intensity	Duration	No. Of RAPID Scans
Cs Gulab	25/09/2021 – 27/09/2021	490
Scs Shaheen	30/09/2021 – 04/10/2021	1026
Cs Jawad	03/12/2021 -- /05/12/2021	586
Escs Tauktae	14/05/2021 – 18/05/2021	1056

Fig. 44. RAPID SCAN during cyclone events

Processing System (MMDRPS) is in progress and expected for the commissioning of the system by November 2020 (Fig. 43).

The Imager payload of INSAT-3D and INSAT-3DR is being used in staggered mode so that effectively 15 minutes temporal resolution is achieved. During extreme weather events, INSAT 3DR imager is used for RAPID scanning. Rapid scan has been conducted during major cyclonic events *i.e.* Tauktae, Yaas, Gulab, Shaheen, Jawad. The imageries of rapid scan conducted during cyclonic events are being disseminated through newly developed dedicated web page (http://satellite.imd.gov.in/rapid/rapid_scan.htm) (Fig. 44).

The products derived from the satellite data include: Cloud images in the Visible, Short wave Infra-red, Mid Infra-red, Thermal Infra-red, Water Vapour Channels and special enhanced images,

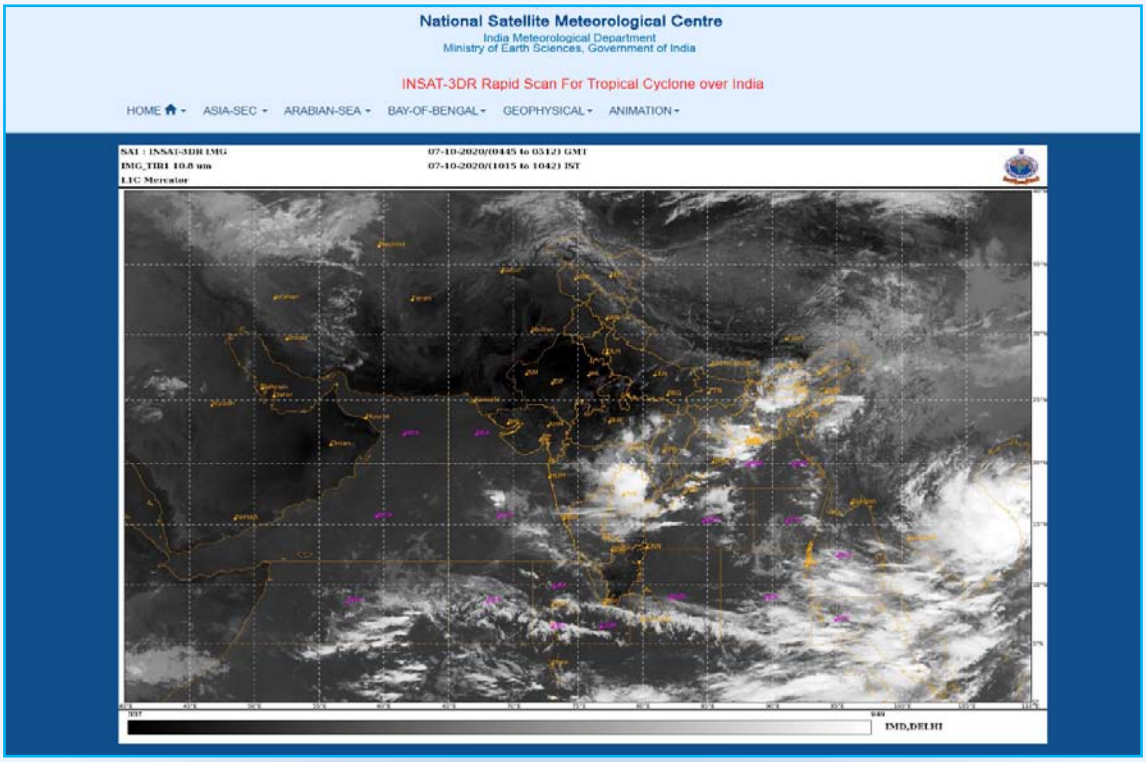
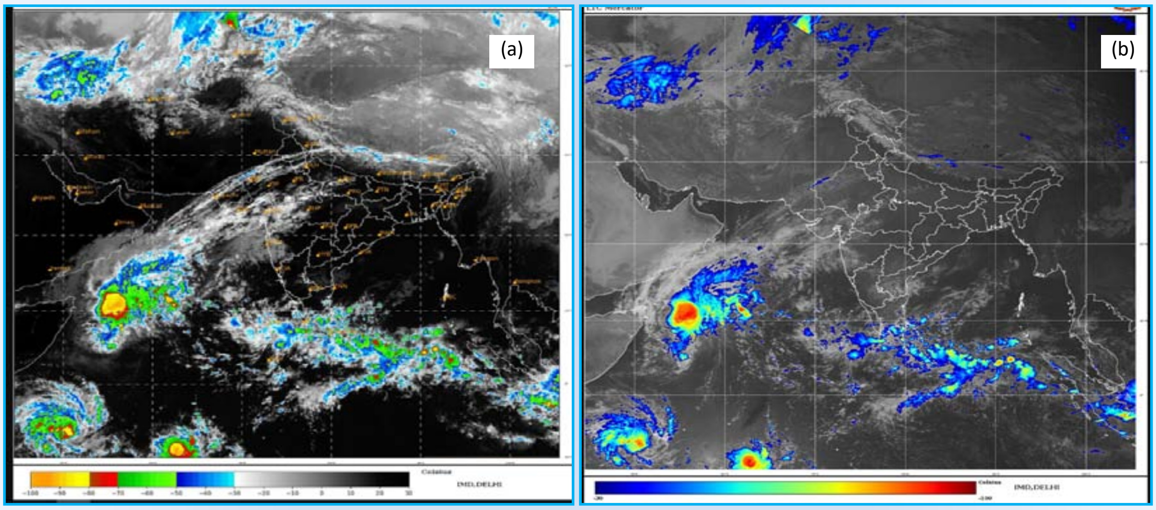


Fig. 45. New webpage of RAPID



Figs. 46(a&b). (a) IR1 BT Blended Image and (b)IR1-BT & Visible Sandwich Image

Atmospheric Motion Vectors (IR Wind, Water Vapour Winds, MIR and Visible Winds), Sea Surface temperature, Outgoing Long-wave radiation, Land Surface Temperature (LST), Insolation, Quantitative Precipitation Estimates, Night time Fog, Smoke, Fire, Snow Cover, Aerosol Optical Depth, Upper Tropospheric Humidity, Cloud top Temperature, Cloud top Pressure, Temperature & Humidity profiles, Total ozone, Total/Layer Precipitable Water Vapour, Stability Indices.In addition to these, IMD has also started generation of Wind derived products such as Vorticity (at 850 mb, 700 mb, 500 mb, 200 mb levels), Wind Shear, Mid-level Wind Shear, Shear Tendency, Low level Convergence and Upper Level Divergence using Imager Wind product and NCEP forecast file and T-phi gram at all district locations using Sounder data. All these images and products are disseminated in a real time basis through dedicated IMD website. Satellite observed radiances and winds are now being assimilated in NWP models to improve their forecast ability. Satellite images are used in monitoring Cyclones. Intensity and position ofcyclones is given to forecasters in real time using Dvorak technique. Satellitedataand images are also used

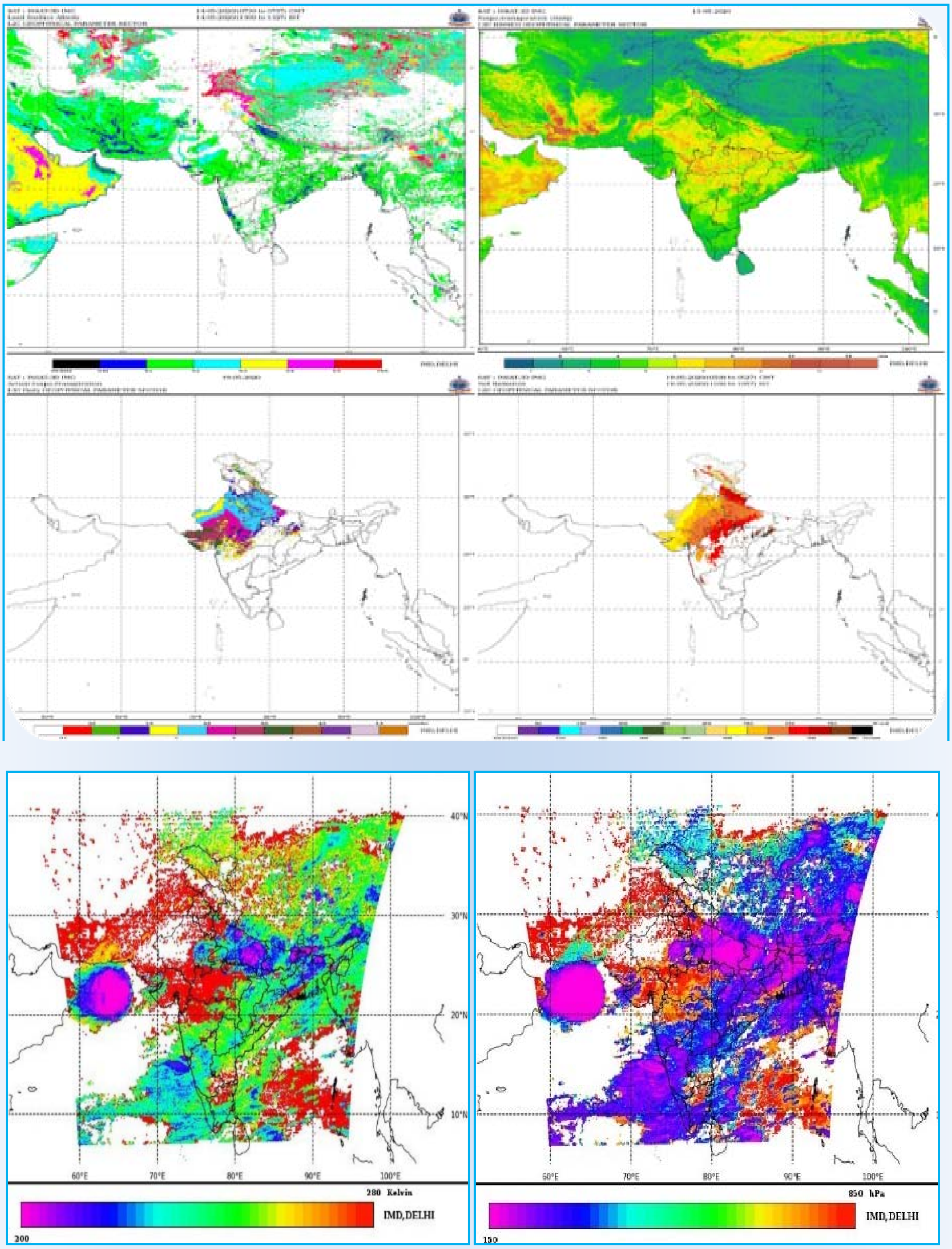


Fig. 47. New products generated from the MMDRPS system (https://www.satellite.imd.gov.in/agromet/agromet.htm)

in monitoring various other significant weather phenomena such as Fog and thunderstorms. Two new types of satellite Imageries IR-1 BT Blended Image & IR-1 BT & Visible Sandwich Image has been made operational which will be very useful for monitoring Thunderstorm events [Figs. 46(a&b)].

From MMDRPS system, following new products (Net Radiation, Potential evapo-transpiration, Actual Evapo-Transpiration, Land Surface Albedo, Shortwave Radiation over Ocean, Cloud Particle Effective Radius, Cloud optical Thickness, Improved IMSRA, Total Precipitable water over Ocean, High dens-sity visible winds over Ocean, INSAT 3D/3DR

Merged winds and 5 day composite winds from Imager and Cloud Top Temperature and Cloud Top Pressure from Sounder) are also being generated on an operational basis and being disseminated through a dedicated webpage (Figs. 47&48).

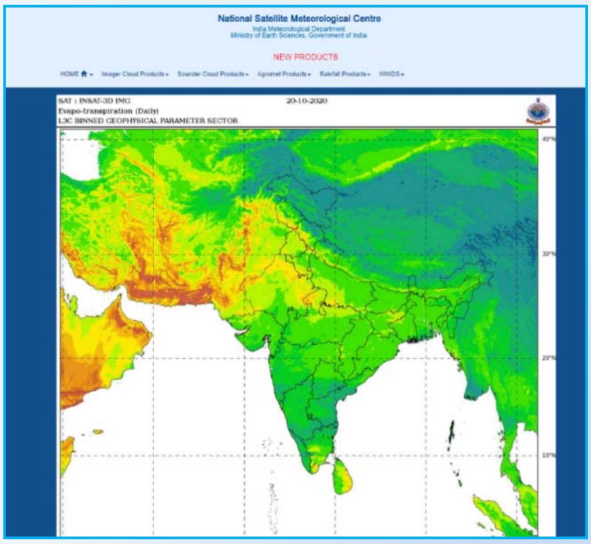


Fig. 48. Dedicated webpage for new products

The six-month satellite data validation exercise has been jointly carried out between IMD & SAC, ISRO. Various satellite products like Cloud Mask, Sea Surface temperature, Outgoing Long wave radiation, Atmospheric Motion Vectors (wind products) etc. Vertical Profile of temperature and humidity has been carried out and the feedback is used for fine tuning of algorithm of these products and calibration coefficients. IPWV estimated from GNSS network of twelve stations has been validated with GPS Sonde IPWV data during the period.

IMD has installed 682 Automatic Weather Stations (AWS) and other agencies have installed about 1200 AWS all over the country. IMD has also installed 1350 Automatic Rain Gauge (ARG) Stations. AWS and ARG services are operational by using the Data Relay Transponders (DRT) of INSAT-3D having global receive coverage with a 400 MHz uplink and 4504 MHz downlink frequencies with a data rate of 4.8 kbps for relay of Meteorological, Hydrological, Agro-Meteorological and Oceanographic data from unattended stations. The data collection is mostly carried out in Time Division Multiple Access (TDMA) mode to enhance the output. IMD is in process to upgrade its network using dual communication (Dual GPRS) mode which will ensure frequent data availability in all type weather. A total of 13 Satellite Id's for AWS/ARG were issued to various stakeholders during this period.

IMD's Area Cyclone Warning Centers generate special warning bulletins and transmit them every hour in local languages to the affected areas. During Recent past, in cases of Tauktae, Yaas, Gulab, Shaheen, Jawad, warnings were disseminated to all stake holders which resulted in minimumloss to human life. Advanced Dvorak Technique (ADT) software has been customized for INSAT-3D and implementedto determine the intensity of Tropical Cyclones.

To improve navigation accuracy, Fixed Grid Navigation and Automatic Template Based Registration package for INSAT-3D Imager was developed and operationalized at Space Application Centre, Ahmedabad and IMD, New Delhi. The Ancillary Data Products Generation Software (ADPS) capability enhanced to include XRIT products, AWS (Automatic Weather Station) Data Decoding, archival and report generation. Generation of Day Time Microphysics using Visible, SWIR and TIR1 spectral band and Night time Microphysics using MIR, TIR1 and TIR2 RGB composite Images have been started which are being used for cloud classification, operationally.

Space Application Centre, Ahmedabad has developed the Real Time Analysis Product & Information Dissemination (RAPID) which is a web based quick visualization and analysis tool for satellite data on a real-time basis and IMD has hosted it operationally since January 2015. This introduces Next Generation Weather Data Access & Advanced Visualization Application that touch the life of common man in one or other way ranging from weather events to atmospheric phenomenon. This has capability to visualize the Fog presence over railway track and highways & a pilot can see the position of clouds and fog of the entire route in real time basis interactively. This also have capability to generate, time series plot of different products derived from satellites along with measuring capability of distance, area of any cloud system and to display the digital value of different parameters over different types of maps. The following additional features have been added in RAPID such as Taluk boundaries, India Sub-Basins and FMO Basin and the following enhancement [Aviation colour enhancement

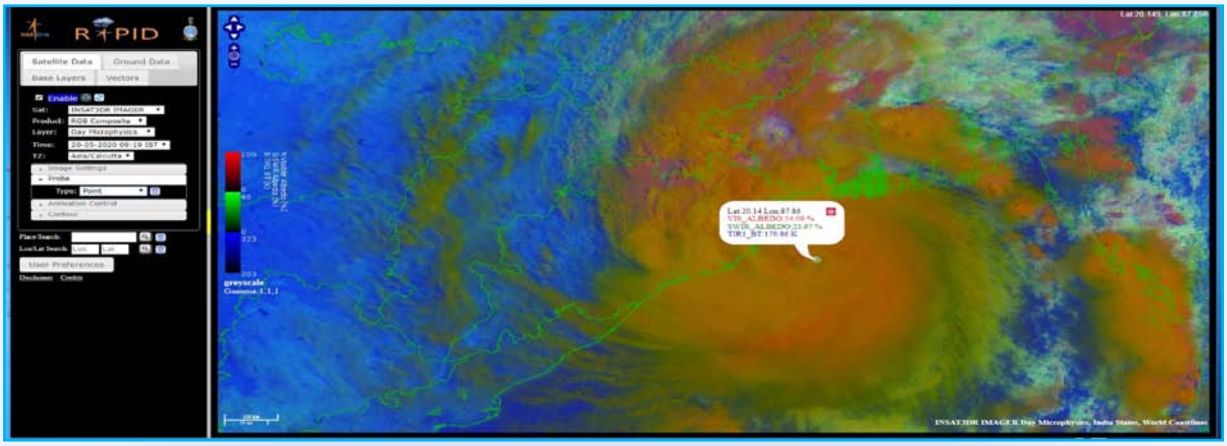


Fig. 49. Utilization of RAPID during a cyclonic event

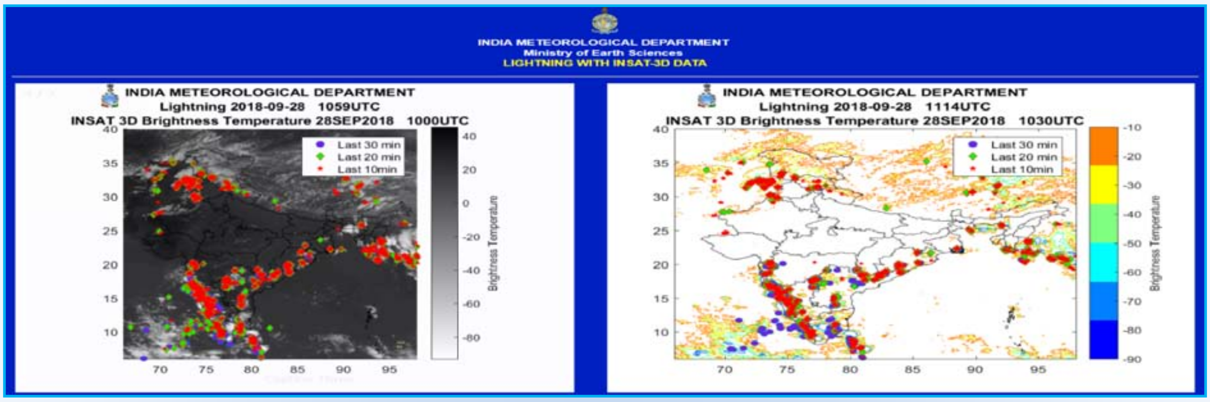


Fig. 50. Satellite and lightning merged products

(AVN), Funktop enhancement-to highlight intense areas of precipitation, Rainbow, i.e., colourful enhancement for a pretty image, new variation on the Rainbow enhancement curve - Colourful enhancement (RBtop)] are integrated in RAPID. **The rapid scans data and INSAT 3DR data has been integrated in RAPID since October 2019 for real time visualization and analysis of weather events.** Integration of NWP model and radar data in RAPID is in progress (Figs. 49&50).

IMD has set up a countrywide network of 25 nos. Global Navigation Satellite System (GNSS) stations for "Earth and Atmospheric studies" have been Installed and commissioned to drive integrated precipitable water vapor (IPWV). The IPWV data is being used for now casting and assimilated in NWP models to improve the weather forecasting. A dedicated website has been developed to access IPWV data of 25 GNSS site in real time. Graphical User Interface was also provided to visualize 15 min, hourly, daily, weekly and monthly IPW data along with Meteorological data and minimum and maximum value of IPW etc. IPWV data is being shared with NCMRWF in near real time basis for assimilation in NWP model.

A dedicated portal to access the satellite data has been developed in collaboration with SAC, ISRO and is in its final stage of implementation. The satellite data portal will be highly beneficial for the forecasters, researchers community to utilize the data products for further research.

The satellite and lighting merged products are also operationalized at IMD website. The merged lightening & satellite cloud top temperature operational product is a joint collaboration of IMD, IITM & IAF. Work is going on to merged (all 3 types of instrument data) Satellite+RADAR and Lightning data for the weather forecastSecurity audit of all the satellite webpages has been conducted from agency name and all vulnerability pointed out by the security audit team has been resolved successfully and security audit certificate obtained.

The satellite technology is of great use in meteorology and plays a very significant role in the improvement of weather forecasting and dissemination. In fact, the improvement in weather forecasting is mainly attributed to increasing use of satellite data.

4.6. FDP STORM Project - 2021

STORM Forecast Demonstration Project-2021

The STORM program was conceived as a multidisciplinary nationally co-ordinated research and development programme and has been carried out as a multi-year observational-cum modelling campaign with an objective to build appropriate operational early warning systems for highly damaging severe thunderstorms over various parts of India. In order to develop methods for improving the accuracy of nowcasting of Severe Thunderstorms, Hailstorms, Squalls & other associated phenomenon, India Meteorological Department conducts field experiments over entire country under STORM Forecast Demonstration Project (FDP STORM) during March to June every year. The programme was run as SAARC STORM project prior to 2017.

At the end of every FDP programme, an Annual STORM Report is compiled and published. It contains region wise detailed analysis of observed significant weather events, case studies, verification of Intensive Observation Periods (IOPs) issued during the FDP, as well as verification of 3 hourly Nowcasts issued round the clock throughout the season.

This year also STORM Fields Experiments covered the whole India. The monitoring period was uniform for entire country from 1 March to 30 June, 2021.

Under this project, FDP Bulletins were issued on daily basis with updated one in the evening, if required. The FDP Bulletin consists of four sections:

(*i*) Current Synoptic situations and satellite current & past 24 hrs observations over India,

(*ii*) NWP model Guidance from IMD GFS, IMD WRF and NCUM (NCMRWF) Models,

(*iii*) Radar reports of the past 24 hours

(v) Realized Thunderstorm reports

(*iv*) Intensive Observation Period (IOP) for thunderstorm and rainfall occurrence during next 24 hrs and 24-48 hrs for the meteorological subdivision and summary of the weather of the day.

A total of 122 FDP Bulletins were issued during the STORM Period-2021.

Nowcast Guidance Bulletins

In addition to FDP Bulletins during March to June - 2021, Nowcast Guidance Bulletins containing current Synoptic features and depicting potential areas for Severe Weather (Heavy Rainfall/ Thunderstorm & Associated Phenomenon/Fog) for next 24hours, in text as well as visual form based on 0830 IST observations were issued once a day (updated in the afternoon if needed) throughout the year. These bulletins provide significant guidance to the forecasters working at different RMCs/MCs, in keeping a watch over their areas of responsibility as mentioned in the Guidance Bulletins & issue Nowcast Bulletins accordingly.

Location Specific three hourly Thunderstorm (TS) Nowcast

Nowcasting of Severe Weather (thunderstorms, squalls and hailstorms, heavy rainfall etc.) has benefited from the recent improvement in monitoring & forecasting due to introduction of (*i*) digital and image information at 10 mins interval

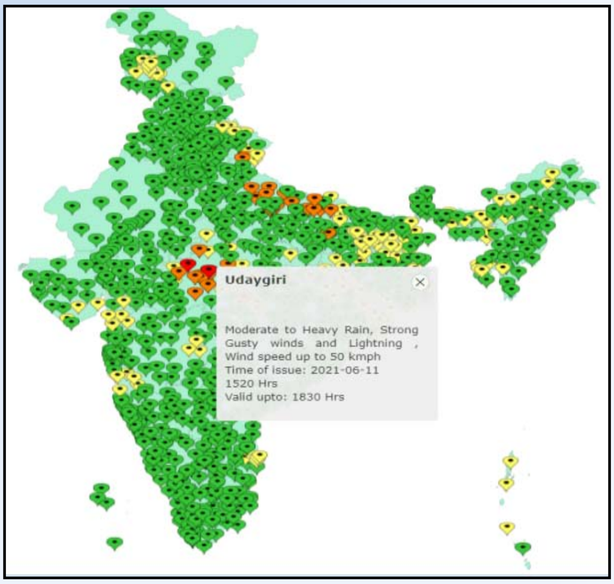


Fig. 51. Stationwise Nowcast Warning Page on IMD website
Link:https://mausam.imd.gov.in/imd_latest/contents/stationwise-nowcast-warning.php

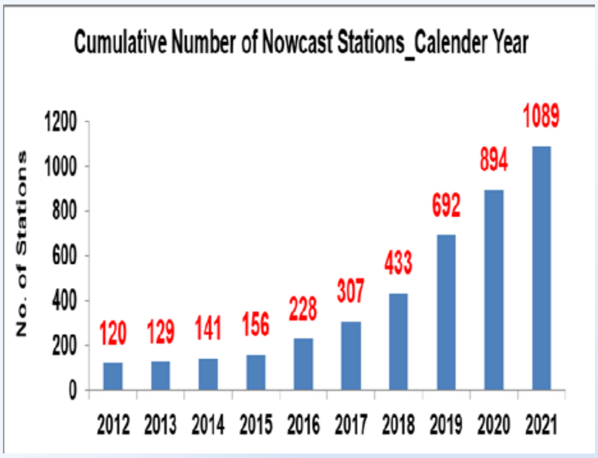


Fig. 52. Year-wise cumulative number of stations for three hourly thunderstorm Nowcast

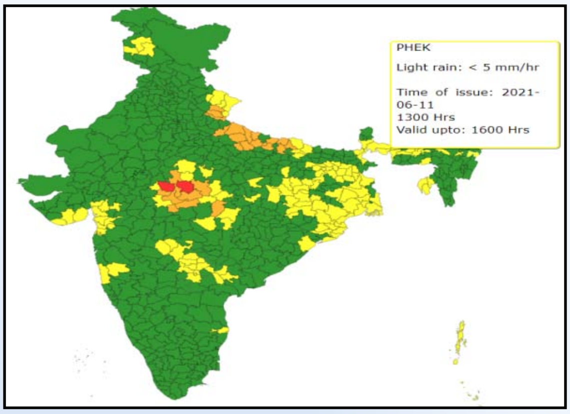


Fig. 53. Districtwise Nowcast Warning Web Page on IMD website Link:https://mausam.imd.gov.in/imd_latest/contents/districtwisewarnings.php

from a network of 34 Doppler Weather Radars, (*ii*) half hourly satellite observations from RAPID Satellite imagery, (*iii*) dense automatic weather station (AWS) network (*iv*) better analysis tools in synergy system at forecaster's workstation, (v) Ground based lightning network (*vi*) availability of mesoscale models and (*vii*) computational & communication capabilities. TS Nowcast of major towns is uploaded every 3 hourly interval utilizing Synoptic Data, Model outputs, Satellite products and finally various Radar outputs by the respective RMCs/MCs/ RWFCs under whose jurisdiction these stations are situated. During the year-2021, 195 new stations were added on All India Nowcast Warning page of IMD website for issuing three hourly thunderstorm nowcast, thereby, increasing the total number of nowcast stations to 1089 under 25 Nowcast Centers (RMC/RWFC/MC/CWC). Fig. 51 depicts the screen shot of Nowcast Warning Page on IMD website and Fig. 52 indicates the year-wise cumulative number of stations added onNowcast Warning page for three hourly thunderstorm Nowcast. In addition to stationwise nowcasting, district level nowcasting which was started in July, 2019 was also issued for all the 732 districts of India (Fig. 53). Considering the importance and reliability of DWR and satellite based information for nowcast of severe weather, all district headquarters/major towns/ tourist places and specific locations within capital cities (under Urban Meteorology and Climate project) in India are to be included for nowcasting of severe weather.

The stationwise and district wise nowcast is issued for about nineteen categories (Fig. 54) of different kinds based on severity of weather for lightning, thunderstorms, dust storms, hail storms, squalls, rain and snow etc. This nowcast warning page is available on new as well as old IMD websites. Alsoall other products related to thunderstorm forecasting are available on dedicated thunderstorm web page developed in 2019 (Fig. 55).

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)

Fig. 54. Different categories of Nowcast Warnings

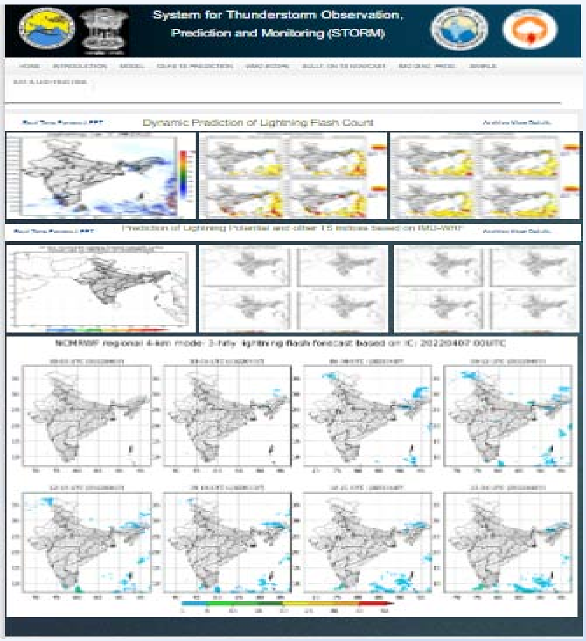


Fig. 55. New Web Page for Thunderstorm monitoring and forecasting Link:https://srf.tropmet.res.in/srf/ts_prediction_system/index.php

Category/Wind Speed	Structures	Communication & Power	Agriculture	Suggested Actions
Light Thunderstorm <41 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. Rooftops 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.

Fig. 56. Impacts associated with various types severe weather events

The new products, which provide short range forecast of weather phenomena associated with thunderstorms, have greatly aided in improving the short range forecast of thunderstorms over the Indian region. There has simultaneously been a conscious thrust from all Meteorological centres to provide impact based forecasts for thunderstorms over the Indian region. List of generalized impactsassociated with different categories of thunderstorms is also published through a forecast Circular No. 1/2019 (Fig. 56).

Verification of IOPs/TS Nowcast-2021

(i) FDP Bulletins

The thunderstorm and rainfall forecast issued for 24hours during **FDP STORM-2021** were verified with realised thunderstorm and rainfall data. The verification results for thunderstorm forecast are shown in Table 2 and graphically by Fig. 57. Fig. 58 indicates verification scores of 24 hr Thunderstorm IOP during 2016 to 2021 which shows a significant improvement in all the scores. Monthwise comparative Probability of Detection (POD) scores during 2016 to 2021.

TABLE 2

Skill sores for Thunderstorm verification for FDP STORM - 2021 (March to June)

Month	Ratio Score	POD	FAR	CSI	ETS	BIAS
March	0.82	0.85	0.47	0.48	0.37	1.60
April	0.74	0.85	0.40	0.55	0.31	1.40
May	0.70	0.87	0.29	0.64	0.20	1.22
June	0.72	0.86	0.30	0.63	0.25	1.23
FDP-2021	0.74	0.86	0.34	0.59	0.33	1.30

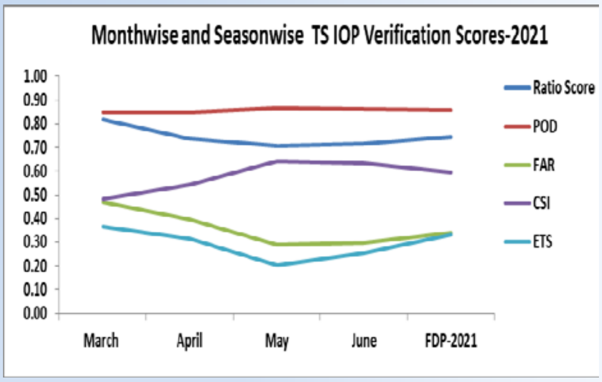


Fig. 57. Monthly and sesonal 24 hr Thunderstorm IOP verification scores during FDP STORM - 2021

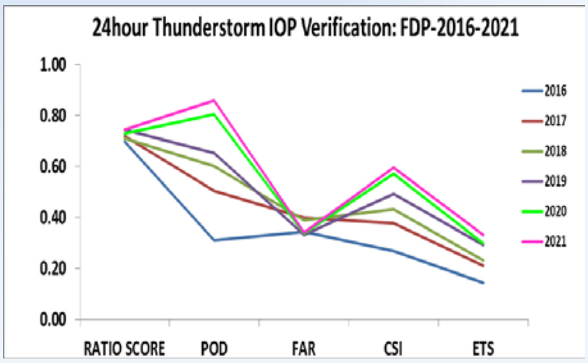


Fig. 58. Comparative 24 hr Thunderstorm IOP verification scores during FDP STORM - 2016 to 2021

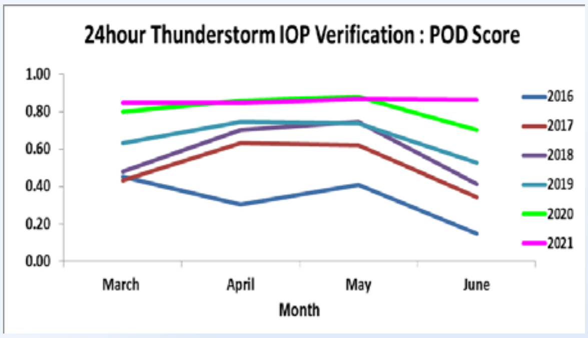


Fig. 59. Comparative POD Scores of 24 hr Thunderstorm IOP verification during FDP STORM -2016 to 2021

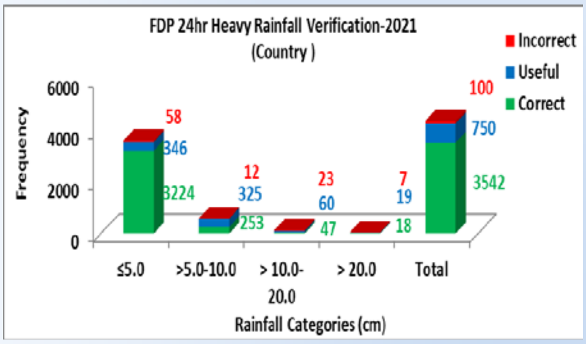


Fig. 60. Category-wise Rainfall Verification for FDP STORM - 2021 (March to June)

TABLE 3

Category wise Rainfall Verification FDP STORM - 2021 (March to June)

Rainfall Category	Within Range	Out by one Range	Out by two or more Range	Total RF Forecasts issued
	Correct	Useful	Incorrect	
≤5.0	3224	346	55	3628
>5.1-10.0	218	253	107	590
10.1-20.0	23	45	47	130
>20.0	2	5	19	44
FDP-2021	3467	649	228	4392

(Fig. 59) indicate that this year the thunderstorms were detected more accurately in all the months of the season as compared to similar result for all previous STORM seasons. The verification results for various forecasted rainfall categories are given in Table 3 and graphically by Fig. 60.

(ii) Three Hourly TS Nowcast

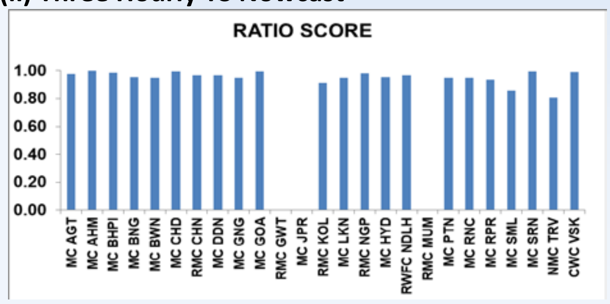


Fig. 61. MC-wise Ratio Score of Three Hourly TS Nowcast Verification during FDP STORM-2021

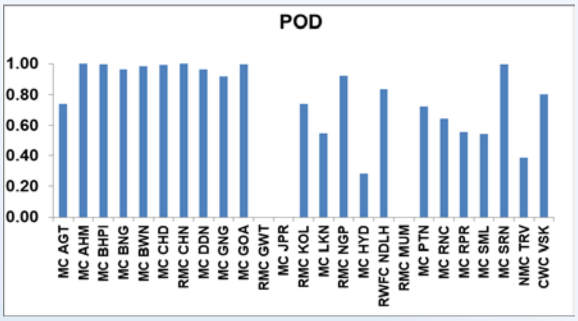


Fig. 62. MC-wise Probability of Detection (POD) of Three Hourly TS Nowcast Verification during FDP Periood-2021

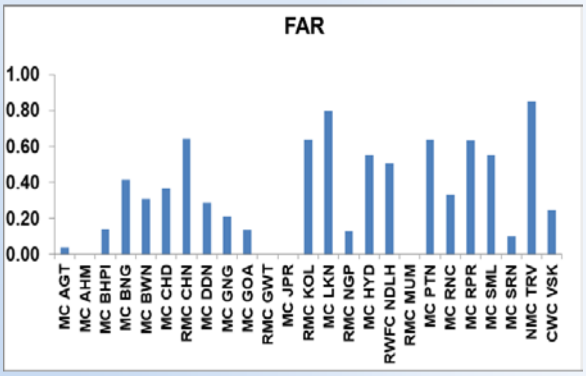


Fig. 63. MC-wise False Alarm Ratio (FAR) of Three Hourly TS Nowcast Verification during FDP Period-2021

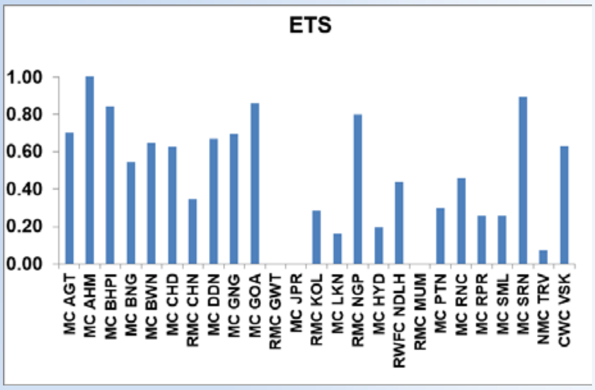


Fig. 64. MC-wise Equitable Threat Score (ETS) of Three Hourly TS Nowcast Verification during FDP Period -2021

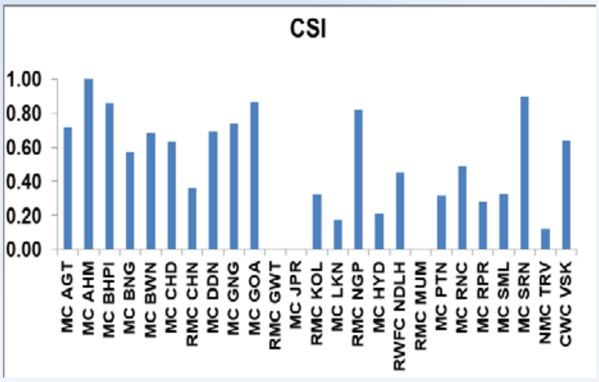


Fig. 65. MC-wise Critical Success Index (CSI) of Three Hourly TS Nowcast Verification during FDP Period-2021

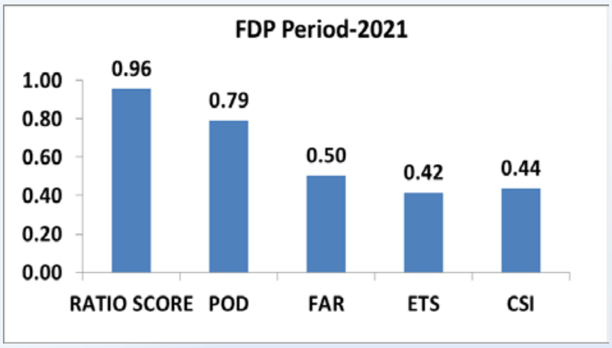


Fig. 66. All India 3 hourly TS Nowcast Verification Scores during FDP Period-2021

Figs.61-65 indicate respectively the Ratio Score, FAR, POD, ETS and CSI scores of three hourly TS Nowcasts issued by various RMCs/MCs during FDP STORM (March to June) for the year-2021 and Fig. 66 indicates All India Nowcast Verification Scores.

FDP STORM Report – 2021

A detailed STORM Report document, based on thunderstorm activities observed over India during March to June-2021, was prepared by Nowcast Division. It contains information on daily weather situation, important weather charts, severe weather events all through the campaign period, case studies and the bulletins issued during the period. The report has been published by IMD with publication no. MoES/IMD/FDP/Storm Report/01(2022)/13. Figs. 67-73 represent some of the salient features of the FDP STORM Report-2021.

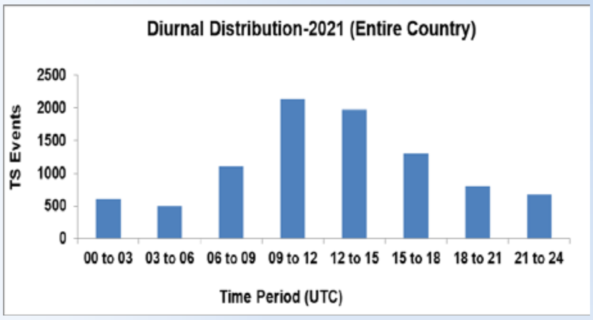


Fig. 67. Diurnal distribution of TS events over the country during FDP STORM -2021

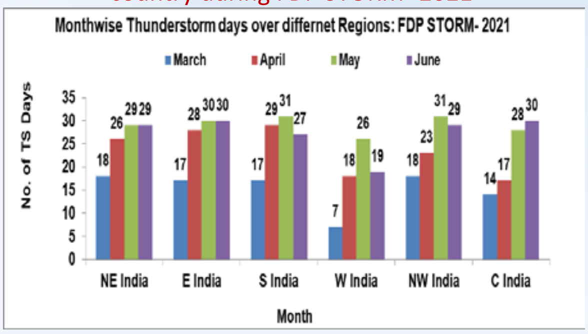


Fig. 68. Monthwise distribution of TS Days over different regions of India during FDP STORM-2021

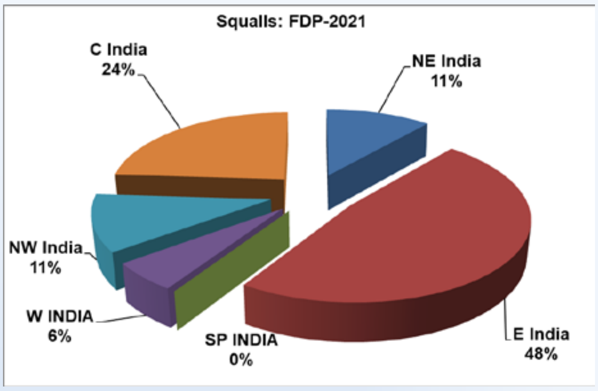


Fig. 69. Regionwise Distribution of squall events over the country during entire FDP STORM-2021

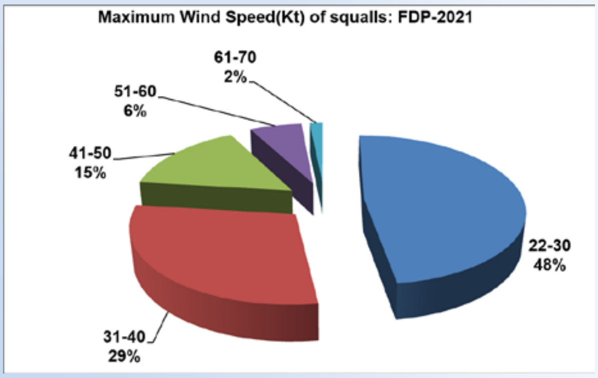


Fig. 70. Distribution of squalls over the country based upon max wind speed (Kt) during FDP STORM-2021

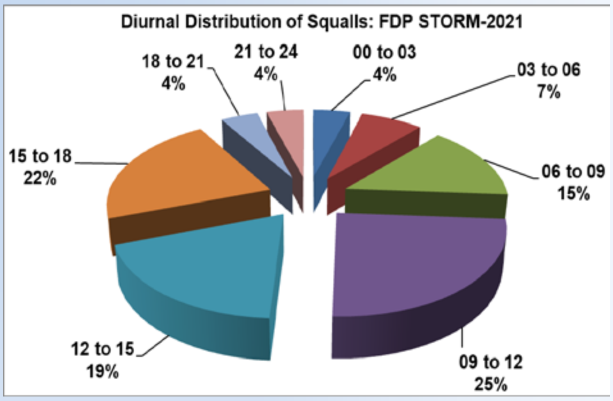


Fig. 71. Diurnal (time in UTC) distribution of thundersqualls during FDP STORM-2021

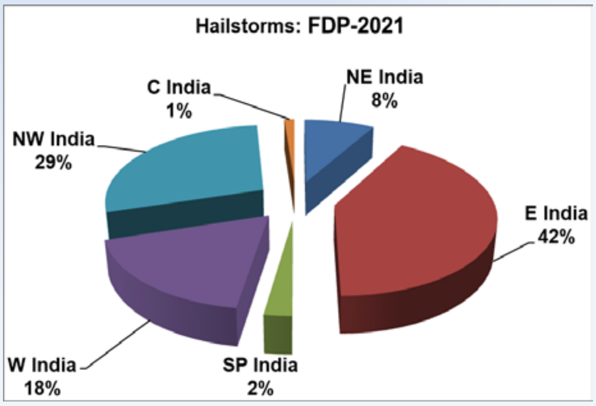


Fig. 72. Regionwise distribution of hailstorm events during FDP STORM-2021

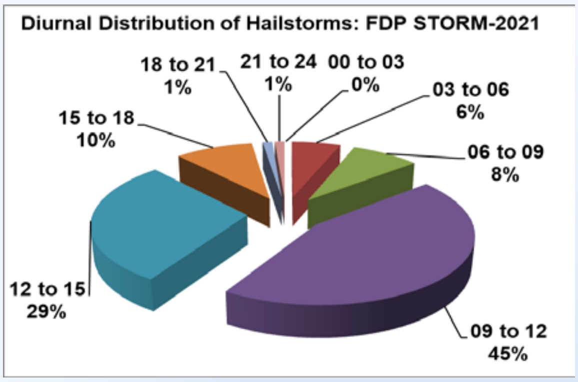


Fig. 73. Diurnal Distribution of Hailstorm Events over the Country during entire FDP STORM-2021

Short-range Warning of Intense Rainstorms in Localised Systems (SWIRLS)

SWIRLS is based on the extrapolation of radar echoes using the TREC (Tracking Radar Echoes by Correlation) technique. With a suitable choice of pixel array size on the radar reflectivity maps, the TREC vectors derived can be used to monitor and extrapolate echo motion right across the mesoscale spectrum, from individual convective cells, to supercells and clusters, and to groups of rain bands or squall lines.

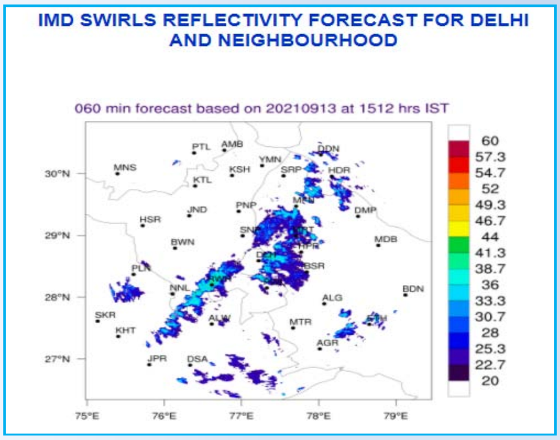


Fig. 74. SWIRLS Reflectivity Delhi
Link: https://nwp.imd.gov.in/swirls.php

On the basis of TREC, quantitative precipitation forecast (QPF) algorithms have been developed to produce high resolution forecast rainfall distribution maps over the local area. These maps provide useful objective guidance for forecasters to assess the likely rain scenario in the next 30, 60 & 120 minutes along with analysis and to facilitate decision-making in operating the Rainstorm Warning System. The first SWIRLS was installed and made operational at Delhi in October, 2018. At present the SWIRLS software is installed at 12 stations, viz; Delhi, Mumbai, Goa, Machilipatnam, Patna, Agartala, Mohanbari, Visakhapatnam, Patiala, Hyderabad, Lucknow and Kolkata. Fig. 74 shows IMD SWIRLS forecast for Delhi.

New Initiatives undertaken by Nowcast Unit

(i) New Graphical Interface for District Nowcast Warnings

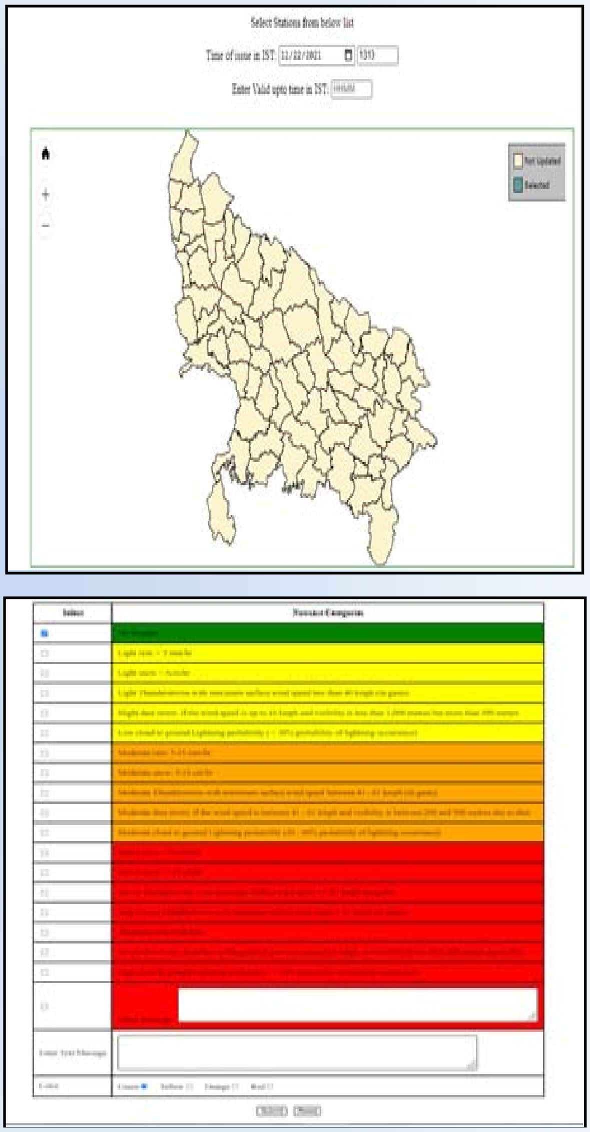


Fig. 75. New Graphical interface for three hourly District Nowcast Updation (Example: Uttar Pradesh)

Prior to July, 2021, 3hourly districtwise nowcast updation was a laborious job as the interface was in textual form & that too with district name in random sequence as well as a constraint to go to previous page in updating each warning for selected districts, making it very inconvenient and time consuming for a duty officer to select districts in a particular part of the state, particularly for big states like Uttar Pradesh, Madhya Pradesh, Rajasthan etc. having a large number of districts. However, in July, 2021, this old interface was replaced with GIS based new graphical interface with districtwise state map for each nowcast centre for all 732 districts of country including newly created districts, on which he can select multiple warnings for districts in any specific part of the state and that to in a single go for all the districts of the state of his domain. Also, keeping in view the future development, a separate login for each state was created to update district and station nowcast. Fig. 75 shows the screenshot of the new graphical interface to update district nowcast for Uttar Pradesh as an example.

(ii) Crowdsourcing:

The term “crowdsourcing” was first coined in 2006 by American journalist Jeff Howe who defined it as “the act of a company or institution taking a function once performed by employees and outsourcing it to an undefined (and general large) network of people in the form of an open call.

In recent years, with the improved understanding of the mesoscale nature of weather systems over Indian region, the constraints of the existing observatory network are sought to be supplemented by other sources of observations. This requirement has been partly met by remote sensed observations of weather by radar and satellite based instruments and the lightning detection network. However, in the absence of validation with ground data, the limitations of each instrument hamper the process of forming a clear picture of the weather occurred and its intensity and impact. The lack of clarity in observations causes uncertainty in forecasts of subsequent weather and its associated impact. With the widespread availability of smart phones, information regarding the state of the atmosphere can now be obtained from many non-traditional sources in text, audio and video form from sources such as citizen scientists (Wiggins and Crowston, 2011), amateur weather stations and sensors, smart devices and social-media/web 2.0 (Muller et al.).

Fig. 76. Crowdsourcing weather reporting Interface Link: https://city.imd.gov.in/citywx/crowd/enter_th_datag.php

Since 2021, IMD has started an online interface (Fig. 76) to collect the information of the weather that has occurred as well as the associated impact information for six weather events initially, viz.,Rain. Hail, Duststorm, Wind Speed, Thunderstorm/Lightning & Fog. The target weather reporters are (a) Class II, Class III observatories (any observatory not covered under MMR) (b) AMFU, KVK observatories (c) Railways Station Masters (d) Power discom maintenance staff & (e) General Public. Further, the interface has following features: (i) The reporting interface is without login requirement. (ii) The time of submission will be automatically recorded. (iii) The user machine address and time is automatically recorded. (iv) The user has the facility to record the Location, State, District of observation. There is also the facility to add photo or video proof of the event.

CHAPTER 5

WEATHER AND CLIMATE SERVICES OF IMD

WEATHER AND CLIMATE SERVICES OF IMD

The `**Climate Data Service Portal**', developed in-house at IMD Pune was made operational on WMO Day 23rd March, 2021. It was inaugurated by Dr. M. Rajeevan, Hon'ble Secretary of MoES.

As a part of the hardware component of the above project, this office received one Server along with Smart Rack and Network Attached Storage at a total cost of 90 lakhs (Approx.). The same was installed and commissioned.

The details of data supply are as follows:

NDC Annual Report 2021

		Category of the party / requester							
		Departmental (MoES)	Government Organisations	Student	Educational Institute / Researchers	Private/Commercial Firm/Individual	Media Correspondent	Foreign parties	Total
Registered Users		76	68	104	87	110	1	8	454
Number of Enquiries / Requests Received		495	238	221	712	566	11	34	2298
Number of Data Requests Completed		348	214	156	138	167	0	8	1031
Number of Data Records Supplied		161432995	5323760	14644893	1672748	363534	0	16719	183454649
Data Cost (without GST)	INR / USD	2,15,27,04,209	14,23,65,604	13,18,24,125	2,41,13,859	51,41,868	0	1,53,986	2,45,61,49,665
Data Charges Waived Off	INR / USD	2,15,27,04,209	14,23,65,604	13,18,24,125	2,26,24,915	0	0	0	2,44,95,18,853
Data Charges Collected	INR	0	0	0	24,55,063	64,43,590	0	---	88,98,653
	USD	---	---	---	---	---	---	3,942	3,942

Fig.1. Details of data supply

5.1. Hydromet Services

During 2021, IMD achieved some significant improvement in Flood Meteorological Services by improving Quantitative Precipitation Forecasts (QPF) skill by 5%, Increased the lead period of River Sub Basin wise QPF and Probabilistic QPF up to 5days, Increased DRMS Network from 4737 to 5204 rainfall stations and operationalisation of the flash flood guidance services for South Asia.

Major achievements

Preparation of Daily Rainfall summary/statistics for **695** districts.

Improvement of operational QPF by 5% in Day 1, Day 2 and Day 3 as compared to 2020.

Improvement of operational QPF over NWP Guidance (DMO) by 12%.

238 New Rain gauge stations were included in CRIS.

The Flash Flood Guidance Services was launched in South Asia on 23 Oct 2020 for providing impact based flash flood guidance bulletins every 6 hours to all stakeholders. This new service is now fully operational through regional and national collaborations. Regular Bulletins are being sent to

Flood Monitoring Offices				Flood Level		Quantitative Precipitation Forecast (QPF)														
						Day-1 (02/11/2021)*			Day-2 (03/11/2021)*			Day-3 (04/11/2021)*			Day-4 (05/11/2021)*			Day-5 (06/11/2021)*		
SNo	FMO	Basin	Sub-Basin	Severe Flood	Extreme Flood	26-50mm	51-100mm	>100mm	26-50mm	51-100mm	>100mm	26-50mm	51-100mm	>100mm	26-50mm	51-100mm	>100mm	26-50mm	51-100mm	>100mm
1	Bengaluru	Cauvery	Middle Cauvery	√																
2		Cauvery	Kabini			√			√			√								
3		East Flowing Rivers	Upper Vaigai			√			√											
4	Thiruvananthapuram	West Flowing Rivers	Periyar				√			√		√			√			√		
5		West Flowing Rivers	Bharathapuzha			√			√			√								
6		West Flowing Rivers	Lower Periyar				√			√		√								
7		West Flowing Rivers	Upper Periyar				√			√		√			√			√		
8		West Flowing Rivers	Chalakudi			√			√			√								
9		West Flowing Rivers	Meenachil				√			√		√								
10		West Flowing Rivers	Pamba				√			√		√			√			√		
11		West Flowing Rivers	Achankoil			√			√											

Fig. 2. Real-time Monitoring of QPF & Floods

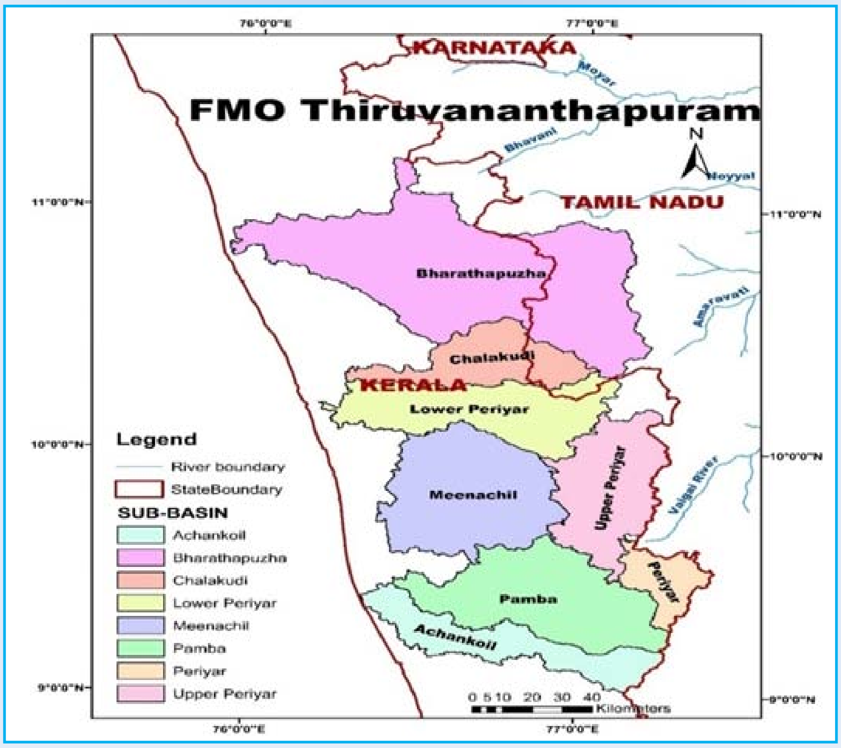


Fig. 3. Real-time Monitoring of QPF & Floods

allstakeholders via email, social mediaDaily Real-time monitoring of QPF & Flood situation over the country is given in Fig. 2.

Improved SASIAFFGS portal products with watersheds from 30000 to more than one (1) lakh High-resolution DEM delineation of watersheds with special coverage of coastal and hilly areas.

Established new FMO activity at Thiruvananthapuram for west flowing rivers in the State Kerala (Fig. 3).

Introduced Doppler Weather Radar based Precipitation Estimates (mm/hr) by integration of 18 Indian radars into SASIAFFGS.

Improvement in Merged Mean Areal Precipitation products by integration of 5204 DRMS data.

Published Standard Operations Procedures (SOP) & Checklists for Hydromet Services and Integrated SOI boundary information as l ayers into SASIAFFGS portal.

Mandate of Hydromet Division

Hydro-meteorological Division is established to fulfill the following mandates with various services being provided to support all stakeholders, Central/State Govt. organizations and other agencies in sector specific applications (Fig. 4).

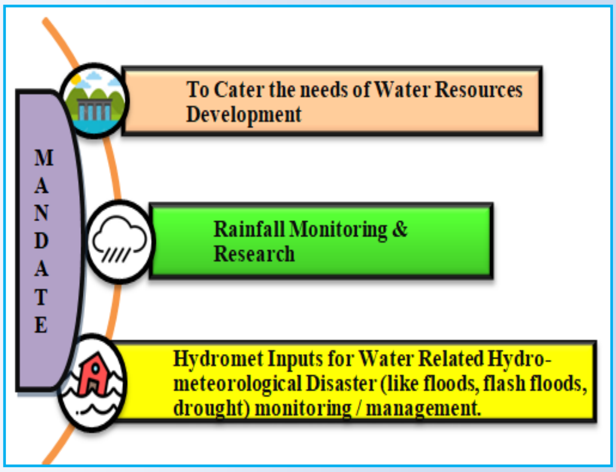


Fig. 4. Mandate of Hydromet Division

Overview of Hydro-meteorological Services of IMD

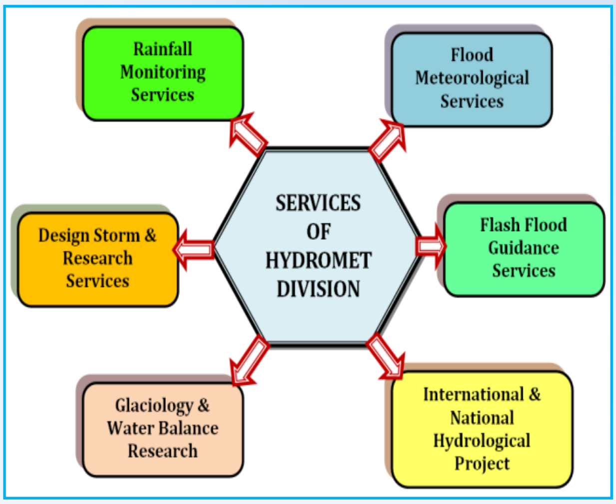


Fig. 5. Services of Hydromet Division

Flood Meteorological Services

The sub-basin- wise Quantitative Precipitation Forecasts (QPFs) were issued (daily on operational basis) by FMOs Agra, New Delhi, Asansol, Ahmedabad, Bhubaneswar, Guwahati, Jalpaiguri, Hyderabad, Lucknow, Patna, Chennai, Bengaluru, Srinagar and DVC Met Unit Kolkata during the flood season 2020 for their area of jurisdiction. These operational QPF were provided to the field offices of Central Water Commission for the use in their Flood Forecast Model.

During this year, the accuracy within same category of river sub-basin-wise QPF has improved by 5% in Day-1, Day-2 and Day-3 as compared to 2020 (Fig. 6).

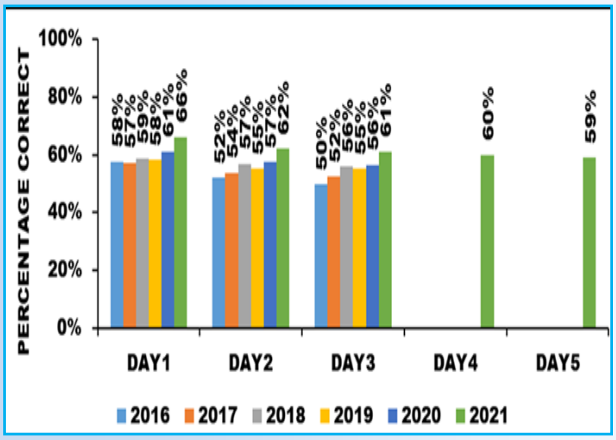


Fig. 6. Improvement in operational Quantitative Precipitation Forecast (QPF)

Customized bias corrected GFS (25kmx25km) for river Sub basin-wise DMO for Day-1, Day-2, Day-3, Day-4 and Day-5in experimental mode. (Fig. 7).

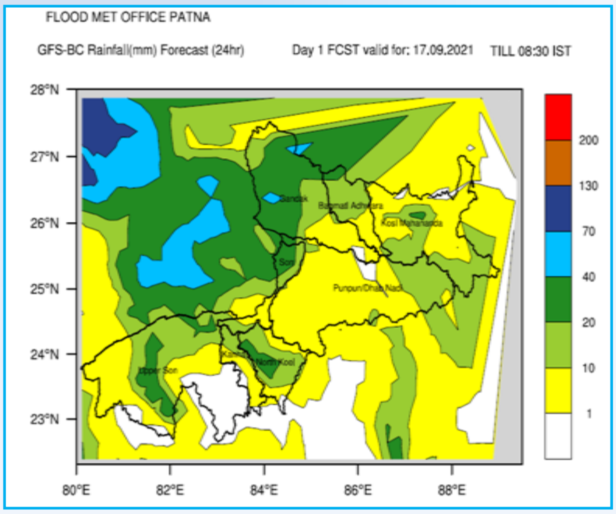


Fig. 7. Bias corrected GFS for river sub- basin wise NWP guidance (DMO)

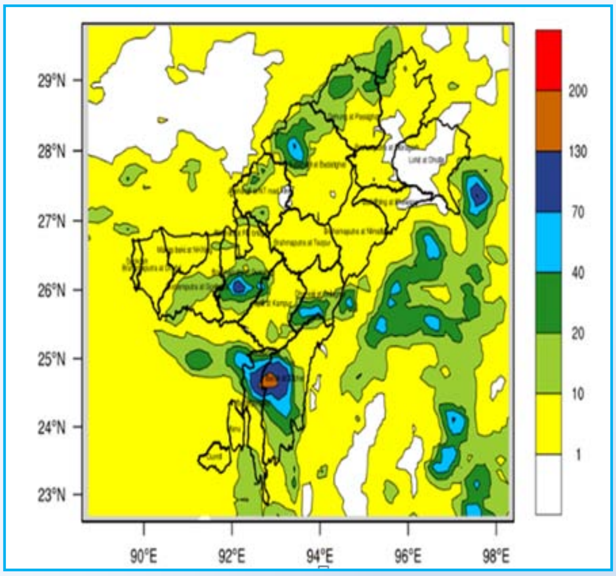


Fig. 8. IMD WRF Sub basin wise RainfallForecast – FMO Guwahati

Sub basin-wise Quantitative Precipitation Estimate for Day-1, Day-2, Day-3 using WRF ARW (3km x 3km) & NCUM-R (4km x 4km), for Day-1 to Day-7 using GFS (12km x 12km) & NCUM-G (12km x 12km) and for Day-1 to Day-5GFS-BC were uploaded in IMD website operationally for 153 river sub-basins (Fig. 8).

IMD provided gridded rainfall forecast data of the dynamical model operationally *viz*. GFS (12km x 12km) and WRF (3km x 3km) to Central Water Commission for the use in Hydrological modelling.

Verification of NWP models viz., WRF, NCUM-R, GFS and NCUM has been completed at sub-basin scale for day1, day2, day3, day4 and day 5 for the southwest monsoon season 2020.

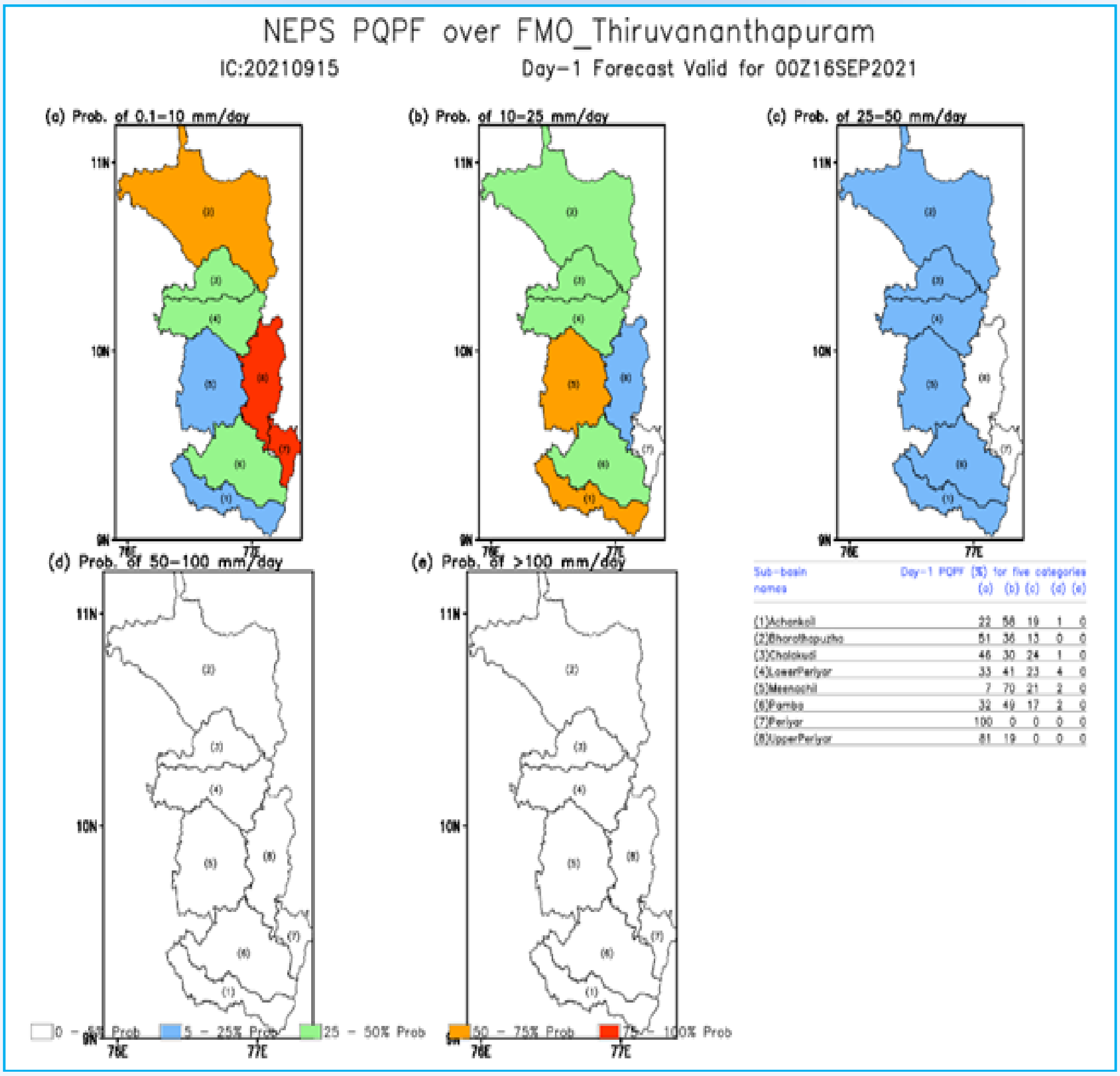


Fig. 9. River Sub-basin-wise NEPS based Probabilistic QPF

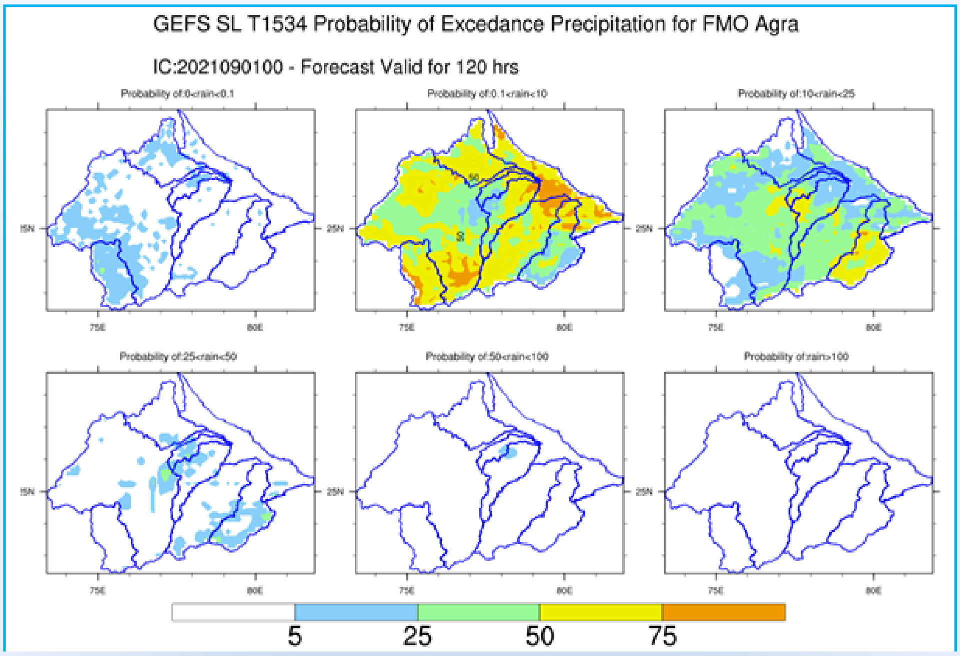


Fig. 10. River Sub-basin-wise GEFS based Probabilistic PQPF

Initiated Joint Advisories on Flood Status of the country by IMD, CWC and NDRF as suggested by MHA.

Daily monitoring of river sub-basin-wise Severe Flood Situation & high QPF provided to Central Agencies.

NWP models NEPS and GEPFS based Probabilistic QPF for day-1, day-2, day-3, day-4 and day-5 operationally uploaded in the IMD website (Figs. 9 & 10).

Design Storm Studies/Storm Analysis

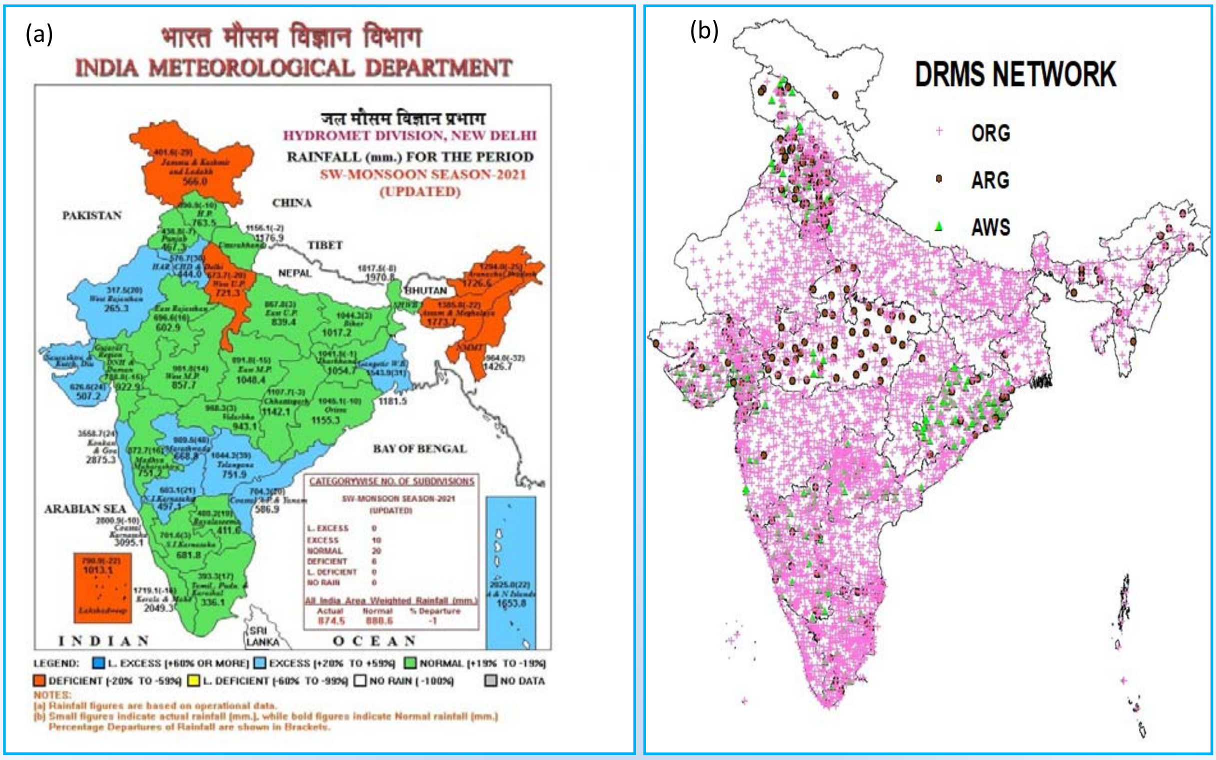
Design Storm Studies are being conducted to evaluate design storm estimates (rainfall magnitude and time distribution) for various river catchments/ projects in the country, for use as main input for design engineers in estimating design flood for hydraulic structures, irrigation projects, dams etc. on various rivers. This estimation of design values is required for safe and optimum design of storage and spillway capacity. On the request of Central Govt./ State Govt., Private Agencies, design storm values (Standard Project Storm, Probable Maximum Precipitation along with Time Distribution, IDF Curve) are being provided for users as main input. These studies are being carried out on payment basis. The detailed project reports are being sent in respect of the project authorities.

During the year 2021, design storm studies of fifteen (15) projects have been completed. Revenue of Rs.19,46,367/- (Rupees Nineteen Lakh Forty Six Thousand Three Hundred and Sixty Seven only) was generated.

Rainfall Monitoring Services

Major Services includes Real-time rainfall monitoring and summary day throughout the year. Brings out updated monthly, seasonal & annual rainfall statistics and publishes Annual Rainfall Report.

During year 2021, the summary prepared on daily basis for 695 Districts, 36 Met. Subdivisions, 37 States including UTs, 4 homogenous Regions and for the country as a whole. Besides this, rainfall statistics is also prepared for 61 selected River basins of India and the maps are uploaded on IMD website. This rainfall summary is being used by various stake holders for multiple purposes like Irrigation requirements, Relief measures, Agricultural planning and advisories, Crop yield forecast, Agricultural pricing, Estimation of Hydro-power Planning and many other economical and research activities. Recipients of rainfall statistics include higher authorities like Office of Hon'ble Prime minister and Secretary, Ministry of Earth Sciences (MoES) etc.



Figs. 11(a&b). Rainfall statistics of 5204 DRMS stations for the (a) SW-Monsoon - 2021 (b) Annual (Jan-Dec) - 2021

Fig. 12. Subdivision-wise rainfall map of India – 2021

Rainfall statistics for the SW Monsoon - 2021 prepared with an all India network of about 5204 DRMS stations. The rainfall for the country as a whole has been recorded as 874.5 mm against the normal rainfall for the annual as 880.6 mm (departure -1%). In all, 10 met subdivisions in category of Excess rainfall, 20 in Normal, 06 in Deficient rainfall and no any met subdivisions in Large Excess, Large Deficient and No Rain category.

Rainfall statistics for the Annual (Jan-Dec) -2021 prepared with an all India network of about 5204 DRMS stations. [Figs. 11 (a&b)].

The rainfall for the country as a whole has been recorded as **1236.4 mm** against the normal rainfall for the annual **as 1176.9 mm** (departure 5%). In all, 18 met sub-divisions in category of Excess rainfall, 13 in Normal, and 5 in defficient rainfall and no any met subdivisions in Large Excess, Large Deficient and No Rain category.

The subdivision-wise updated rainfall maps for the Annual (Jan-Dec) -2021 is given in Fig. 12.

Subdivision-wise rainfall (mm) distribution and categorywise no. of sub-divisions & % area (sub-divisional) of the country are given in Table 1.

TABLE 1

SUBDIVISION-WISE RAINFALL (MM) DISTRIBUTION

S. NO.	METEOROLOGICAL SUBDIVISIONS	ANNUAL (JAN-DEC)-2021			
		ACTUAL	NORMAL	% DEP.	CAT.
	EAST & NORTH EAST INDIA	1796.1	2006.0	-10%	
1.	ARUNACHAL PRADESH	2083.8	2913.6	-28%	D
2.	ASSAM & MEGHALAYA	1974.5	2604.7	-24%	D
3.	N M M T	1340.2	2168.5	-38%	D
4.	SHWB & SIKKIM	2616.7	2639.0	-1%	N
5.	GANGETIC WEST BENGAL	2112.7	1556.5	36%	E
6.	JHARKHAND	1444.8	1256.5	15%	N
7.	BIHAR	1512.7	1192.0	27%	E
	NORTH WEST INDIA	820.7	848.7	-3%	
1.	EAST U.P.	1078.1	945.0	14%	N
2.	WEST U.P.	750.7	813.2	-8%	N
3.	UTTARAKHAND	1664.5	1494.1	11%	N
4.	HAR. CHD & DELHI	686.7	534.4	28%	E
5.	PUNJAB	534.4	597.4	-11%	N
6.	HIMACHAL PRADESH	1037.6	1291.2	-20%	D
7.	J & K AND LADAKH	894.7	1258.7	-29%	D
8.	WEST RAJASTHAN	375.2	308.2	22%	E
9.	EAST RAJASTHAN	853.6	657.7	30%	E
	CENTRAL INDIA	1212.6	1105.3	10%	
1.	ODISHA	1420.8	1444.2	-2%	N
2.	WEST MADHYA PRADESH	1128.5	934.0	21%	E
3.	EAST MADHYA PRADESH	1046.0	1162.3	-10%	N
4.	GUJARAT REGION	909.5	960.5	-5%	N
5.	SAURASHTRA & KUTCH	708.2	539.7	31%	E
6.	KONKAN & GOA	4032.5	3051.6	32%	E
7.	MADHYA MAHARASHTRA	1136.5	889.7	28%	E
8.	MARATHWADA	1157.1	803.1	44%	E
9.	VIDARBHA	1095.9	1069.8	2%	N
10.	CHHATTISGARH	1309.6	1281.1	2%	N
	SOUTH PENINSULA	1473.5	1140.8	29%	
1.	A & N ISLAND	3493.4	2871.8	22%	E
2.	COASTAL A. P.& YANAM	1179.6	1046.1	13%	N
3.	TELANGANA	1208.5	949.5	27%	E
4.	RAYALASEEMA	1106.5	725.1	53%	E
5.	TAMIL., PUDU. & KARAIKAL	1379.9	939.3	47%	E
6.	COASTAL KARNATAKA	3892.2	3510.1	11%	N
7.	N. I. KARNATAKA	902.9	720.4	25%	E
8.	S. I. KARNATAKA	1430.1	1032.1	39%	E
9.	KERALA & MAHE	3606.3	2924.8	23%	E
10.	LAKSHADWEEP	1898.7	1563.4	21%	E
	COUNTRY AS A WHOLE	1236.4	1176.9	5%	

CATEGORYWISE NO. OF SUBDIVISIONS & % AREA (SUBDIVISIONAL) OF THE COUNTRY

CATEGORY	ANNUAL (JAN-DEC)-2021	
	NO. OF SUBDIVISIONS	SUBDIVISIONAL % AREA OF COUNTRY
LARGE EXCESS	**0**	**0%**
EXCESS	**18**	**48%**
NORMAL	**13**	**36%**
DEFICIENT	**5**	**16%**
LARGE DEFICIENT	**0**	**0%**
NO RAIN	**0**	**0%**

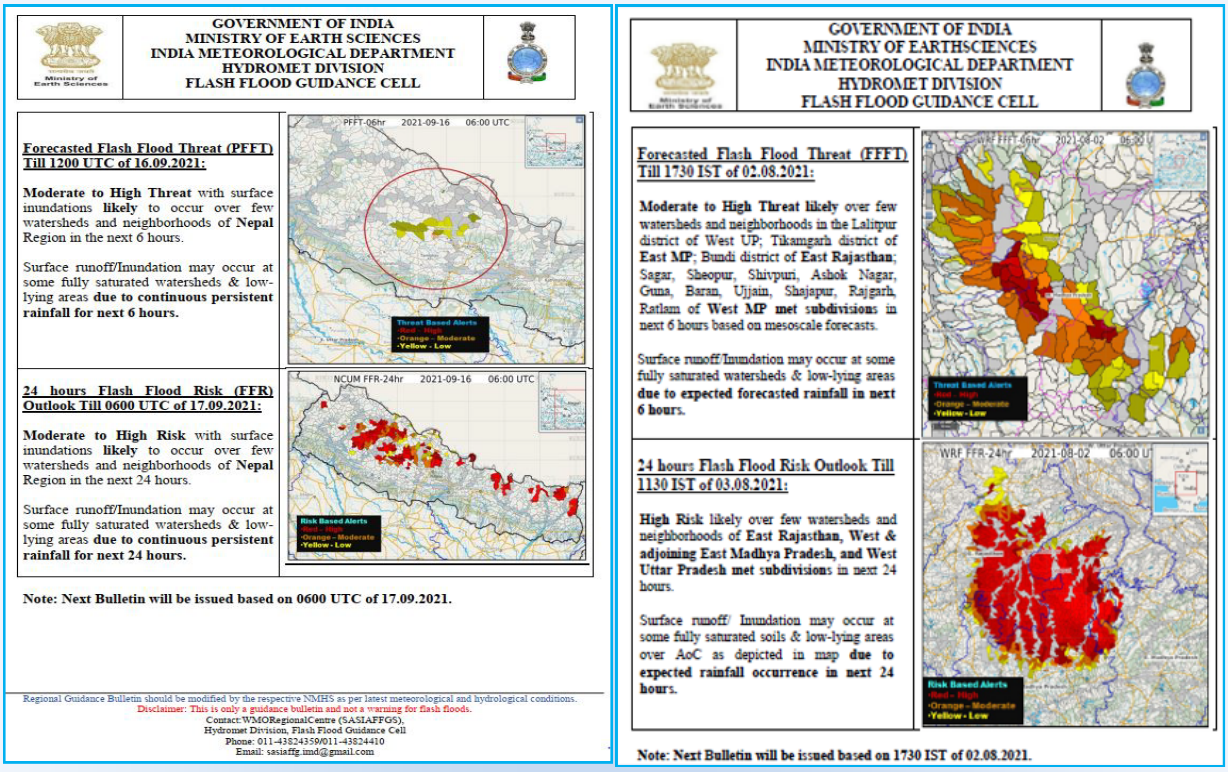


Fig. 13. Regional and National Bulletin

South Asia Flash Flood Guidance Services

Regional (South Asia) Flash Flood Guidance (SAFFGS) Bulletins up to district level 4 times a day are being issued to respective National Meteorological & Hydrological Service of Srilanka, Bhutan, Nepal & Bangladesh.

National Flash Flood Guidance Bulletins up to district level based on 0000, 0600, 1200, 1800 UTC are being issued to CWC Flood Directorate, National & State Disaster Management Authorities, Flood Control Room, Regional and National Met Centers, Flood Meteorological Offices, World Bank, etc. (Fig. 13).

Flood guidance's in the form of Risks with 24 hour lead time and in the form of threats with 6 hour lead time (Fig. 14).

Social Media platforms like Twitter, Whatsapp, Email are being utilized by dissemination of Flash

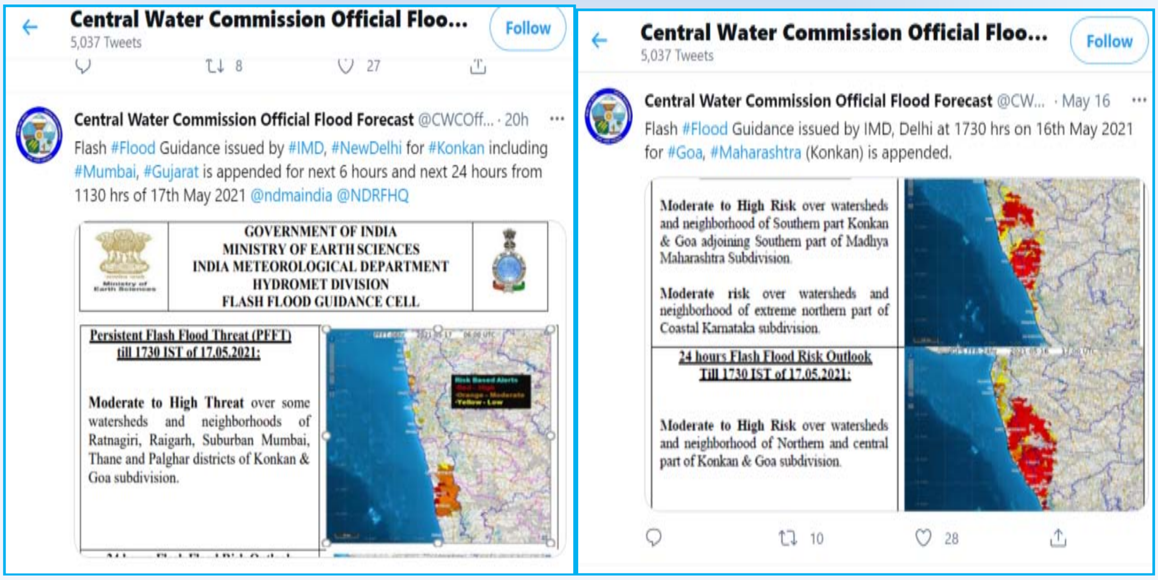


Fig. 14. Flash Flood Guidance alerts in Social Media platform

5.2. Agrometeorological Advisories Services

Agrometeorological Observatories & Data Management

(*i*) Agromet Division maintains a network of conventional agromet. observatories. Around 191 such agrometeorological observatories have uploaded Agrometeorological observations in the website of Agromet Division, out of which 166 observatories are updating regularly and remaining 25 observatories upload the same on a near real-time basis.

(*ii*) Around 190 new Agro-AWS have been established till December 2021 at newly established District Agromet Units (DAMUs) in the premises of Krishi Vigyan Kendras (KVKs) under the network of the Indian Council of Agriculture Research (ICAR).

The Agro-AWSs also have soil moisture and soil temperature sensors up to one-meter depth apart from the other sensors of a standard AWS.

(*iii*) Agromet data received from various stations have been scrutinized and are being archived at National Data Centre Pune.

Weather Services under Gramin Krishi Mausam Sewa (GKMS)

a. Preparation of Agromet Advisory Service (AAS) bulletins

(i) AAS bulletins have been prepared and issued at district and state levels every Tuesday & Friday and at National level every Friday to cater to the needs of users at various levels. AAS bulletins are prepared and issued by Agromet Field Units (AMFUs) located in State Agricultural Universities (SAUs), Indian Council of Agricultural Research (ICAR) institutes, Indian Institute of Technology (IITs), etc. and District Agromet Units (DAMUs) located at Krishi Vigyan Kendras (KVKs) under the network of ICAR and uploaded in Agromet Division's website. Block-level AAS bulletins, on biweekly basis; have been prepared by the AMFUs and DAMUs for the districts of their location on an experimental basis. The bulletins include past weather, medium-range weather forecast for the next 5 days and specific agromet advisories on field crops, horticultural crops, livestock, etc.

(ii) AAS bulletins are being issued for all the agriculturally major Districts (700 Districts) in the country.

(iii) Around 3100 block-level AAS Bulletins are being prepared by AMFUs and DAMUs on an experimental basis.

Fig. 16. Dissemination of Agromet Advisories through DD Kisan channel

b. Dissemination of agromet advisories

(i) Agromet advisories are being disseminated to the farmers through different multichannel dissemination systems like All India Radio (AIR) and Doordarshan, private TV and radio channels, newspaper and internet, SMS and IVR (Interactive Voice Response Technology) etc. Under Public-Private Partnership (PPP) mode, Reliance Foundation and Kisan Sanchar, etc. are disseminating agromet advisories in SMS format to the farming community.

(ii) Agromet Advisories have been disseminated in Regional languages through "mKisan portal" (http://mkisan.gov.in), launched by the Ministry of Agriculture & Farmers' Welfare, Government of India. In addition to that, several AMFUs have been sending agromet advisories through SMS in collaboration with various agencies of State and

Central Government. 43.37 million farmers received SMS and were benefitted by this service directly. At present, SMS are being sent to the farming community only during extreme weather events using “mKisan portal”.

(iii) Apart from SMS, Agromet advisories are directly disseminated by AMFUs and DAMUs to the farming community with the help of social media like WhatsApp. Agromet Advisories have been disseminated to 10,20,740 farmers in 1,02,366 villages in 3,441 blocks through 10,883 WhatsApp groups during December 2021 (Fig. 17).

(iv) Integration of Agromet advisories with the mobile apps and websites of various State Department (Madhya Pradesh, Chhattisgarh, Tamil Nadu, Gujarat, Nagaland) of Agriculture has been made to utilize their extension system to enhance the outreach of advisories up to village level (Fig. 18).

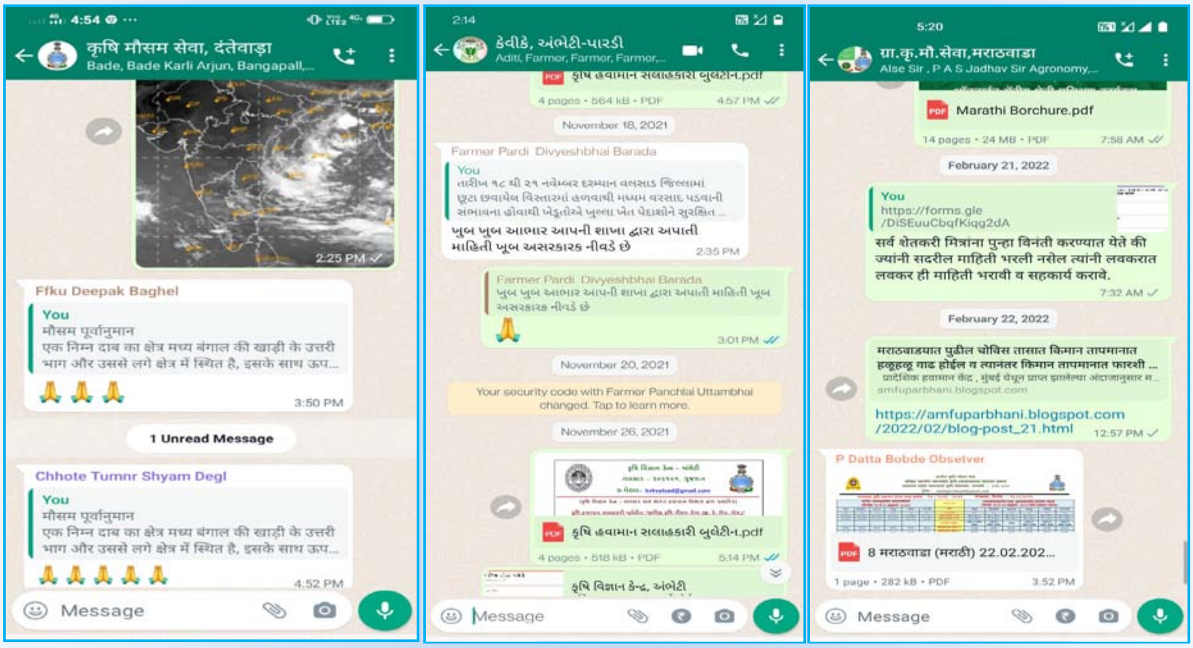


Fig. 17. Dissemination of Agromet Advisories in regional languages through WhatsApp

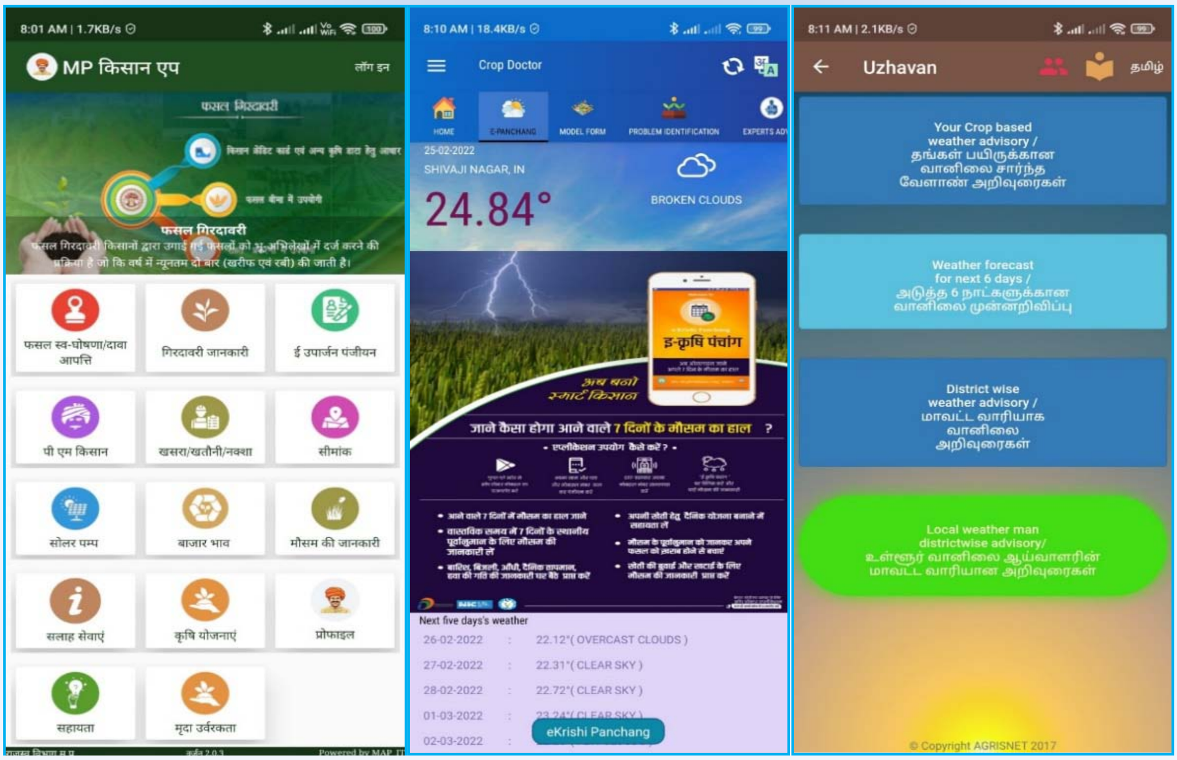


Fig. 18. Integration of Agromet Advisories with the mobile Apps of various State Govts. and Agril. Universities

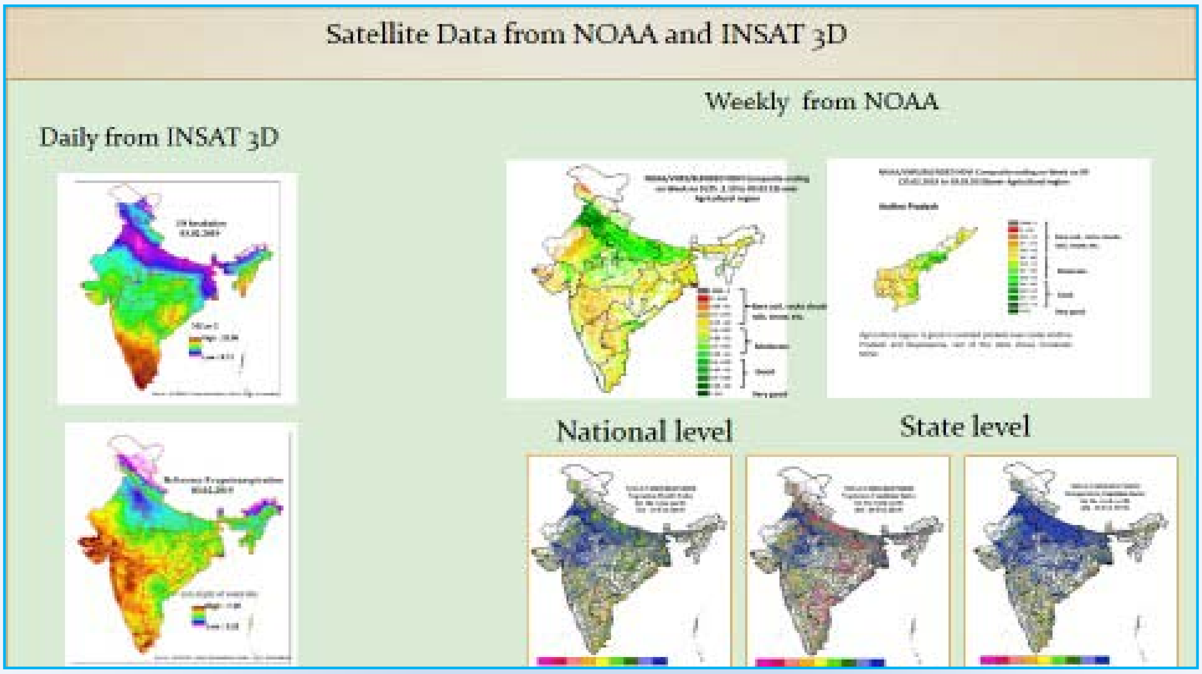


Fig. 19. Satellite Data Products

c. Agromet Products

Agromet Division continued the generation of the following agromet products for operational use in AAS. All these products are being generated under PAN India mode using geospatial technology and are uploaded to the Division's website and communicated to the AMFUs for preparation of more effective Agromet advisories at the district and block level.

(i) Spatial variation of weather parameters at different temporal scales.

(ii) Soil Moisture (SM): Estimated SM based on Realized information (Daily) and Forecast (twice a week on Tuesday & Friday).

(iii) Soil temperature on a daily and weekly scale.

d. Satellite products

(i) Normalized Difference Vegetation Index (NDVI).

(ii) Reference Evapotranspiration and Insolation maps by Satmet Division, IMD, New Delhi (Fig.19).

Fig. 20. Display of Spatial Weather parameters in Bhuvan Portal

(iii) Vegetation Condition Index (VCI).

(iv) Temperature Condition Index (TCI).

e. Display of Agromet Products in BHUVAN Portal of NRSC, Hyderabad

Agromet Division continued to display the spatial distribution of weather parameters at different temporal scales in BHUVAN Portal developed by National Remote Sensing Centre (NRSC), Hyderabad on daily basis (Fig. 20)

f. Support for managegement of Extreme weather events

During the year, Impact based forecast (IBF) as well as related SMS have been issued to the farming community by the respective Agromet Field Units (AMFUs) of the States to safeguard the crops from cyclonic storms and other extreme weather events in the form of Alerts and warnings along with Agromet Advisories. Number of farmers receiving the SMS during various extreme events are furnished below:

(i) Special Agromet Bulletins have been prepared and uploaded in the website of Agricultural Meteorology Division for cyclonic storm Taukte (13-19 May), Yaas (22-27 May), Gulab (25-28 September) and Jawad (3-5 December).

(ii) During the Extremely Severe Cyclonic Storm, 'Tauktae' in May 2021, alerts and warning messages were disseminated by different Agromet field units through M-Kisan portal of Ministry of Agriculture and other social media to 68,85,919 farmers of Tamilnadu, Karnataka, Maharashtra, Kerala, Gujarat, Rajasthan, Haryana & Uttar Pradesh.

(iii) During the Severe Cyclonic Storm, 'Yaas' in May 2021, alerts and warning messages were disseminated by different Agromet field units (AMFUs) through M-Kisan portal of Ministry of Agriculture and other social media to 29,84,653 farmers of Andaman & Nicobar, Odisha, West Bengal, Bihar and Jharkhand.

(iv) During the 'Deep Depression over Bay of Bengal' in September 2021, alerts and warning messages were disseminated by different Agromet field units (AMFUs) through M-Kisan portal of Ministry of Agriculture and other social media to 11,05,872 farmers of Madhya Pradesh, Odisha and Chhattisgarh.

(v) During the Cyclonic Storm, 'Gulab' in September 2021, alerts and warning messages were disseminated by different Agromet field units (AMFUs) through M-Kisan portal of Ministry of Agriculture and other social media to 87,32,126 farmers of Odisha, Andhra Pradesh, Maharashtra, West Bengal, Telengana, Chhattisgarh, and Gujarat.

(vi) During the 'Depression over Bay of Bengal' in November 2021, alerts and warning messages were disseminated by different Agromet field units (AMFUs) through M-Kisan portal of Ministry of Agriculture and other social media to 6,68,226 farmers of Andhra Pradesh, Karnataka, Kerala and Tamil Nadu.

(vii) During the Cyclonic Storm, 'Jawad' in November-December 2021, alerts and warning messages were disseminated by different Agromet field units (AMFUs) through M-Kisan portal of Ministry of Agriculture and other social media to 46,51,236 farmers of Andhra Pradesh, Odisha and West Bengal. The messages were also communicated to 23, 85,774 farmers through PPP mode and Social Media, respectively.

(viii) Impact Based Forecast (IBF) for Agriculture and Agromet Advisories based on the IBF have been issued for the states of Andhra Pradesh, Karnataka, Kerala, Tamil Nadu, Maharashtra and Gujarat in coordination with NWFC, New Delhi, RMCs/MCs, AMFUs and DAMUs for heavy rainfall during November 2021.

(ix) Impact based forecast (IBF) for Agriculture (Cold Wave/Hailstorm/Heavy Rainfall) and Agromet Advisories based on the IBF have been issued for the states of Chhattisgarh, Gujarat, Haryana, Himachal Pradesh, Jharkhand, Madhya Pradesh, Maharashtra, Odisha, Punjab, Rajasthan, Tamil Nadu, Uttar Pradesh, Uttarakhand and West Bengal in coordination with NWFC, New Delhi, RMCs/ MCs, AMFUs and DAMUs during Dec., 2021.

(h) Awareness Programmes

AMFUs and DAMUs organized 1923 Farmers' awareness programmes (FAPs) for the

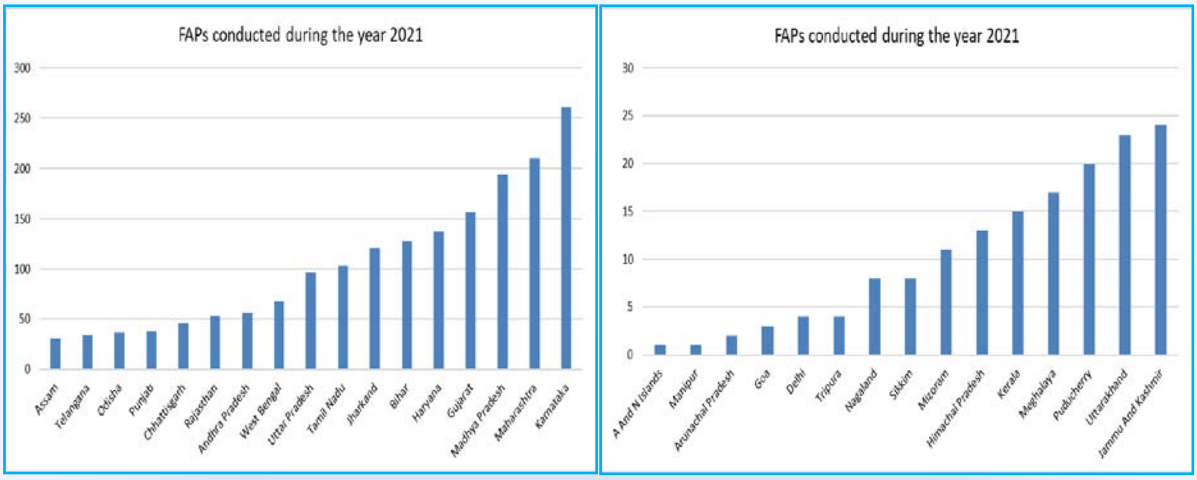


Fig. 21. Statewise Farmers' awareness programmes conducted during the year 2021

Fig. 22. Glimpses of FAPs

popularization of activities carried out under GKMS. 81827 farmers attended FAPs across the country (Fig. 21).

(i) 243 FAPs were organized by 59 AMFUs and 12381 farmers attended the FAPs.

(ii) 1680 FAPs were organized by 147 DAMUs and 69446 farmers attended the FAPs.

Outreach programs

Shri J.P Sable, Met. 'A' has participated in Krishi Darshan programme and discussed on 'Seasonal Forecast and crop management during the winter season in Maharashtra state' which was telecasted on DD Kisan, Sahyadri on 10th December, 2021.

Shri M. M. Choudhari, Met. 'A' gave bytes for Krishi Darshan programme of DD Sahyadri, Pune as quarterly schedule (July, 2021 to September, 2021) on subject 'Weather based pest and disease management in Kharif crop for Maharashtra state' on 23rd August, 2021 and same was broadcasted on DD Sahyadri on Friday, 27th August, 2021 and Monday, 30th August, 2021.

Bytes have been provided by Officers of Agromet Division, Pune on every Friday for disseminating weather information to the farmers of Maharashtra in the program "Hawamanacha Saptahik Andaj ani Krushi Tadnyancha Salla" telecasted live in Youtube Channel of Government of Maharashtra.

5.3. Positional Astronomy Services

At the time of independence India had a large number of different calendars with divergent methods of reckoning time. It was felt desirable to have uniformity in the calendar throughout the country for civic, social and other purposes. The Government appointed a Calendar Reform Committee in November, 1952, under CSIR with Prof. Meghnad Saha as Chairman with a view to develop a unified National Calendar on the basis of most accurate modern astronomical data for the interest of national integrity. The committee recommended preparation of the Indian

Ephemeris and Nautical Almanac calculated with most modern astronomical formulae, the National Calendar of India (using Saka Era) with timings of tithis, nakshatras, yoga etc, and also festival dates. The work of the Committee was taken up by the India Meteorological Department from 1st December, 1955. The work was entrusted to a unit named Positional Astronomy Centre at Kolkata. The unit undertook the preparation of 'The Indian Astronomical Ephemeris' for 1958, the first issue was published in 1957. Simultaneously the first issue of Rashtriya Panchang (containing data of National calendar along with usual panchang parameters to serve as a standard panchang for whole of the country) was started from 1879 Saka Era (1957-58 AD). Positional Astronomy Centre is the nodal office of the Govt. of India to generate data on Positional Astronomy and to publish the same in the form of annual publications, viz. The Indian Astronomical Ephemeris. It is also performing pivotal role in implementing the recommendations of two committees, one already mentioned earlier as Calendar Reform Committee and other one constituted later on and named as Peer Review Committee, through publication of Rashtriya Panchang in 14 languages. The centre issues the following 16 publications annually:

(i) The Indian Astronomical Ephemeris

(ii) Tables of Sunrise- Sunset, Moonrise-Moonset

(iii) Rashtriya Panchang in 14 languages namely - English, Hindi, Urdu, Sanskrit, Assamese, Bengali, Gujrati, Kannada, Punjabi, Malayalam, Marathi, Oriya, Tamil & Telegu.

The centre also:

- Fixes up dates of all India festivals for all communities for declaration of holiday by Central & State Governments.

- Meets specific data requirements of a large number of users including Government organizations, non Government organizations, professional astronomers, research scholars, various panchang makers, general public etc.

- Provides five years advance accurate calendric data to many leading panchang makers of the country for preparation of their own Panchangs.

- Contributes to a great extent in popularizing astronomy through publication of monthly astronomical bulletin and star charts (presently star charts are being prepared on computer), issuing press release on different astronomical events through various print media, attending live discussions on various electronic media etc.

- Takes observation on special astronomical events from time to time with the help of its portable telescopes at different places of the country.

ACTIVITIES DURING THE YEAR 2021

- The Indian Astronomical Ephemeris for the year 2022, an annual publication of Positional Astronomy Centre, which mainly contains positional data of the Sun, Moon and planets, basic data on yearly positions of fundamental stars, diary of celestial events, calendric data, eclipse data, explanatory text and other useful information on astronomy has been published both in hard copy and soft copy format.

- Fourteen language editions of Rashtriya Panchang of 1943 Saka Era (2021-22 AD) and Sunrise-Sunset and Moonrise- Moonset tables for 2022 have been published during the year 2021. These are important regular publications of the centre catering to daily need of users of almanac, Panchang makers and other users.

- Web based service has been continued by the centre by creation of electronic versions of 14 language editions of Rashtriya Panchang and Indian Astronomical Ephemeris which can be accessed by the users through the PAC Kolkata website.

- The centre has prepared monthly star charts and astronomical bulletins for 12 months during the year 2021 for giving useful guidance for watching celestial objects in the night sky. The bulletins contain brief texts explaining positions of objects in the sky and celestial diagrams showing positions for practical demonstrations.

- All India festivals for all communities for the year 2022 have been prepared in advance for declaration of holidays by the Govt. of India and other State Governments. Calendar data of Indian National Calendar along with Gregorian calendar data for the year 2022-23 has been prepared in advance for different stake holders.

- Five year advance panchang data has been prepared and supplied to different enlisted panchang makers.

- Press bulletin has been issued in advance for media for eclipse event in 2021 visible in India

- **Official language implementation:** Hindi Day was celebrated in the office on 14th September, 2021 in a befitting manner. Competition on Hindi essay writing, self composed Hindi poetry recitation; Hindi typing and Hindi dictation competition were held among the officers and members of staff of PAC Kolkata.

5.4. Climate Research & Services

(i) Operational Long Range Forecast and its Verification

Operational LRF System

In 2021, IMD has implemented a new strategy for issuing monthly and seasonal operational forecasts for the rainfall and temperature over the country by modifying the existing two state forecasting strategy. The new strategy uses the existing statistical forecasting system to generate these forecasts along with a newly developed Multi-Model Ensemble (MME) forecasting system based on coupled global climate models (CGCMs) from different global climate prediction and research centers including IMD's Monsoon Mission CFS (MMCFS) model. IMD issues operational long range forecasts for rainfall/precipitation during Winter (January to March), Southwest Monsoon (June to September) and Northeast Monsoon (October to December) seasons. Among these, forecast for monsoon season is most important as the rainfall received during this season accounts for 70-90% of the annual rainfall over most parts of the country and due strong positive association of monsoon season rainfall with both Kharif and Rabi crop production in the country. Table 2 shows various long range forecasts issued during the year. Since 2012, as additional forecast guidance, IMD started to use the experimental forecasts for the monsoon rainfall generated by the dynamical model approach developed by Indian Institute of Tropical Meteorology (IITM), Pune. The present dynamical model forecasting system is based on the global climate forecasting system CFS) version 2. The CFS is a fully coupled general circulation model (CGCM) implemented by IITM under Monsoon Mission project launched by the Ministry of Earth Sciences (MoES) (Saha et al., 2014). The global monthly and season forecasts for rainfall and temperature prepared using Monsoon Mission CFS (MMCFS) is updated 15th of every month is

TABLE 2

Various operational forecasts issued by IMD

S. No.	Forecast for	Region for which forecast issued	Issued in	Method/Model
1	Winter Season (Jan- March) Precipitation	Northwest India	December	Statistical
2	Hot Weather Season Temperature for (March-May) & (April-June) seasons	Subdivision wise	March	MMCFS
3	SW Monsoon Season (June to September) Rainfall	Country as a whole	April	Statistical & MME
4	SW Monsoon Season (June to September) Rainfall	Country as a whole	June	Statistical & MME
5	South-West Monsoon Onset	Kerala	May	Statistical
6	SW Monsoon Season	Four broad geographical regions: Northwest India,	June	

	(June to September) Rainfall	Northeast India, Central India and South Peninsula and Monsoon core zone (MCZ)		MME
7	SW Monsoon Monthly Rainfall for July and JAS	Country as a whole	July	MME
8	SW Monsoon Monthly Rainfall for Aug and AS	Country as a whole	August	MME
9	SW Monsoon Monthly Rainfall for September	Country as a whole	September	MME
10	NE Monsoon Season (October to December) Rainfall and October	South Peninsular India	September	MME
11	Seasonal Outlook for Winter Temperatures and Rainfall Forecast for November 2021	South Peninsular India	November	MME
12	Seasonal Outlook for Winter Temperatures and Rainfall Forecast for December 2021	Country as a whole & South Peninsular India	December	MME

now available through IMD, Pune (www.imdpune.gov.in) and IITM (www.tropmet.res.in) websites. In 2018, CFS was used for issuing an outlook for seasonal temperatures over India during the hot weather seasons (March to May & April to June) and cold weather season (December to February. Details of the various long range forecasts issued by IMD and their verification are discussed in this report. The Performance operational forecast (1988-2021) is shown in Fig. 24.

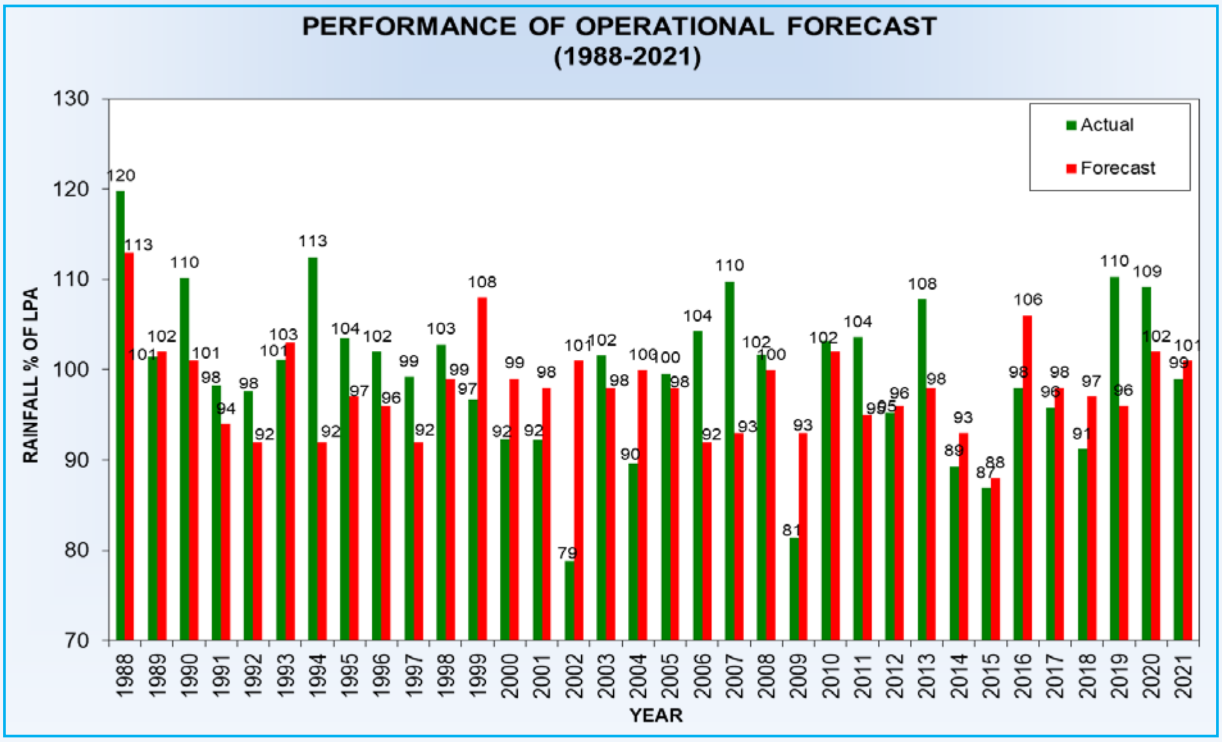


Fig. 24. Performance operational forecast (1988-2021)

(i) Winter Season (January to March, 2021) Precipitation over North India

The LRF for the 2021 winter season (January to March) rainfall over north India was prepared in the last week of December 2020. North India consisting of seven subdivisions (East U.P., West U.P. Uttaranchal, Haryana, Punjab, Himachal Pradesh, Jammu & Kashmir) receives about 17% of its annual rainfall during the winter season (January to March). The Jammu & Kashmir in particular receives about 30% of its annual rainfall during this period. The winter rainfall is very crucial for Rabi crops over the region. It is also crucial for the water management of the region. In view of these reasons, India Meteorological Department (IMD) has been issuing long range forecast outlook for the winter rainfall over north India. IMD also continuously works to improve the skill of the forecasting models. This year, for preparing the quantitative and probabilistic forecasts for winter season rainfall over the North India, a 4-parameter Principle Component Regression (PCR) has been used.

(ii) 2021 Hot Weather Season Temperature Forecast for Hot Weather (March- May & April - June) Seasons

The country experiences hot weather primarily during March to July. March to May season is known as the pre-monsoon season and April to June is known as Hot weather season. During these seasons, many parts of the country experience heat wave conditions (days with abnormally warmer temperatures) with many adverse consequences. Abnormally above normal temperatures can have devastating effects on human health, water resources and power generation and outage. There is a marked relationship between human mortality and thermal stress. India Meteorological Department (IMD), Ministry of Earth Sciences (MoES) has been issuing seasonal forecast outlooks for subdivision scale temperatures over the country for pre monsoon and hot weather seasons based on predictions from the Monsoon Mission Coupled Forecasting System (MMCFS) Model developed under MoES's monsoon mission project. The model hindcasts and forecasts were bias corrected using the probability distribution function (pdf) method.

The forecast for 2021 pre-monsoon season (March to May) was prepared using 31 ensemble member forecasts. IMD had issued the following seasonal forecast for March to May (MAM) 2021. Above normal seasonal maximum temperatures are likely over most of the subdivisions of north, northwest and northeast India, few subdivisions from eastern and western parts of central India and few coastal subdivisions of north peninsular India.

However, below normal seasonal maximum temperatures are likely over most of the subdivisions of south peninsula and adjoining central India. Above normal seasonal minimum temperatures are likely over most of the subdivisions of north India along the foot hills of Himalayas, northeast India, western part of central India and southern part of peninsular India. However, below normal season minimum temperatures are likely over most of the subdivisions of eastern part of the central India and few subdivisions of extreme northern part of the country. IMD had issued seasonal forecast for Hot Weather Season (April to June) using 36 ensemble member forecasts from MMCFS based on the 2021 March initial conditions. During April-May-June (AMJ) 2021, above normal seasonal maximum temperatures are likely over most of the subdivisions of north, northwest and few subdivisions of east central India. However, below normal seasonal maximum temperatures are likely over most of the subdivisions of south peninsular India and few subdivisions of east, northeast and extreme north India. Above normal seasonal minimum temperatures are likely over few sub-divisions along the west coast and west India. However, below normal season averaged minimum temperatures are likely over few subdivisions of northwest, central, east and extreme north India. The sub-division wise maximum and minimum temperature forecast issued by IMD for the 2021 Hot weather season (April to June) is shown in Fig. 25.

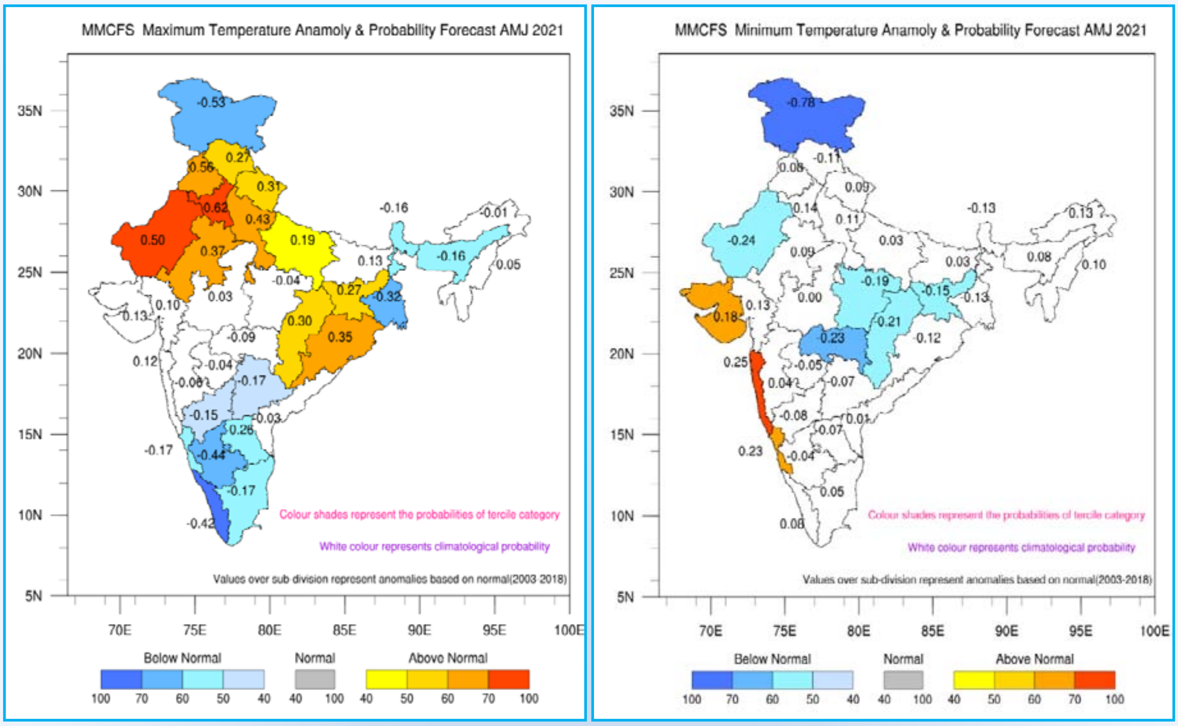


Fig. 25. Sub-division wise maximum and minimum temperature forecast issued by IMD for the 2021 Hot weather season (April to June)

(iii) Southwest Monsoon Season (June to September, 2020) Rainfall

The first stage forecast for the season (June-September) rainfall over the country as a whole issued in April was 98% of LPA with a model error of ± 5% of LPA. The update issued in June for this forecast was (101% of LPA) with a model error of ± 4% of LPA (Long Period Average). The actual season rainfall for the country as a whole was 99% of LPA, which are within the April and June forecasts limit respectively. Thus, the both the forecasts were correct.

Considering the four broad geographical regions of India, the forecasts issued in 1st June for the season rainfall over Northwest India, Central India, Northeast India and South Peninsula were Normal (92-108% of LPA), Above Normal (>106% of LPA), Below Normal (<95% of LPA) & Normal (93-107% of LPA) respectively. The newly introduced seasonal rainfall over Monsoon Core Zone (MCZ) was forecast as Above Normal (>106% of LPA). The actual rainfall over Northwest India, Central India, Northeast India, South Peninsula and Monsoon Core Zone were 96%, 104%, 88%, 111% and 107% of the LPA respectively. The monthly forecast issued for July, August and September were normal [94 to 106% of Long Period Average (LPA)], normal [94 to 106% of Long Period Average (LPA)] with a tendency to be in the positive side of the normal and above normal [> 110 % of Long Period Average (LPA)] respectively. The actual rainfall for the country as a whole for July was 93% of LPA, August was 76% of LPA whereas for September was135% of LPA. The forecast for the second half of the monsoon season (August - September) for the country as a whole was normal [95 to 105% of Long Period Average (LPA)] whereas actual rainfall was 99% of LPA.

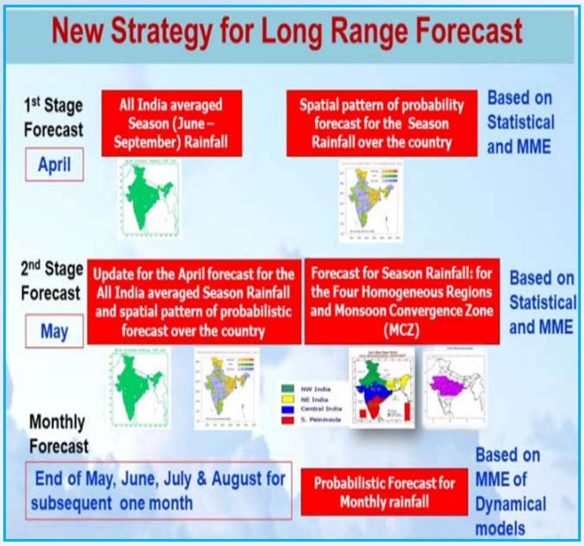


Fig. 26. Schematic diagram showing various operational forecasts for the southwest monsoon rainfall issued by IMD

Table 3

Verification of the operational forecast issued for the 2021 southwest monsoon rainfall

Region	Period	Forecast (% of LPA)		Actual Rainfall
		16th April	1st June	(% of LPA)
All India	June to September	96-104 98± 5	96-104 101± 4	99
Northwest India	June to September		92-108	96
Central India	June to September		>106	104
Northeast India	June to September		<95	88
South Peninsula	June to September		93-107	111
Monsoon Core Zone	June to September		>106	107
All India	July		94-106	93
All India	August		94-106	76
All India	August to September (issued on 31st July)		95-105	99
All India	September (issued on 1st September)		>110	135

The operational forecast for the onset of monsoon over Kerala was prepared using an indigenously developed statistical model. The model is based on the principal component regression (PCR) method using 6 predictors. The model for 2021 was trained using data for the period 1998-2020. The forecast for the date of monsoon onset over Kerala was predicted on 14th May 2021 that monsoon will set in over Kerala on 31st May with a model error of ±4 days. The RMSE of the model is about 4 days. Based on an indigenously developed statistical model, it was predicted on 14th May, 2021 that monsoon will set in over Kerala on 31st May with a model error of ±4 days. The actual monsoon onset over Kerala was on 3rd June and therefore the forecast was correct.

(iv) Northeast Monsoon Rainfall over South Peninsula (October to December, 2021)

The south Peninsular India consisting of five meteorological subdivisions (Tamil Nadu & Puducherry, Coastal Andhra Pradesh, Rayalaseema, Kerala and South Interior Karnataka) receives significant amount of rainfall during the month of December due to northeast monsoon. Utilizing the new strategy of the MME based forecasting system as discussed above, IMD had issued rainfall forecasts for the 2021 northeast monsoon season [October to December (OND)] and for the months of October, November and December. Actual rainfall over South Peninsula during the season (Oct-Dec) was 579.1 mm whereas Normal rainfall for the season (Oct-Dec) over South Peninsula is 338.4 mm. Thus the seasonal rainfall (Oct-Dec) was 171% of its long period average (LPA) over South Peninsula. Thus, the forecast for South Peninsula was significantly underestimated to the actual value.

(v) 2021 Cold weather Season (December to February) Temperatures

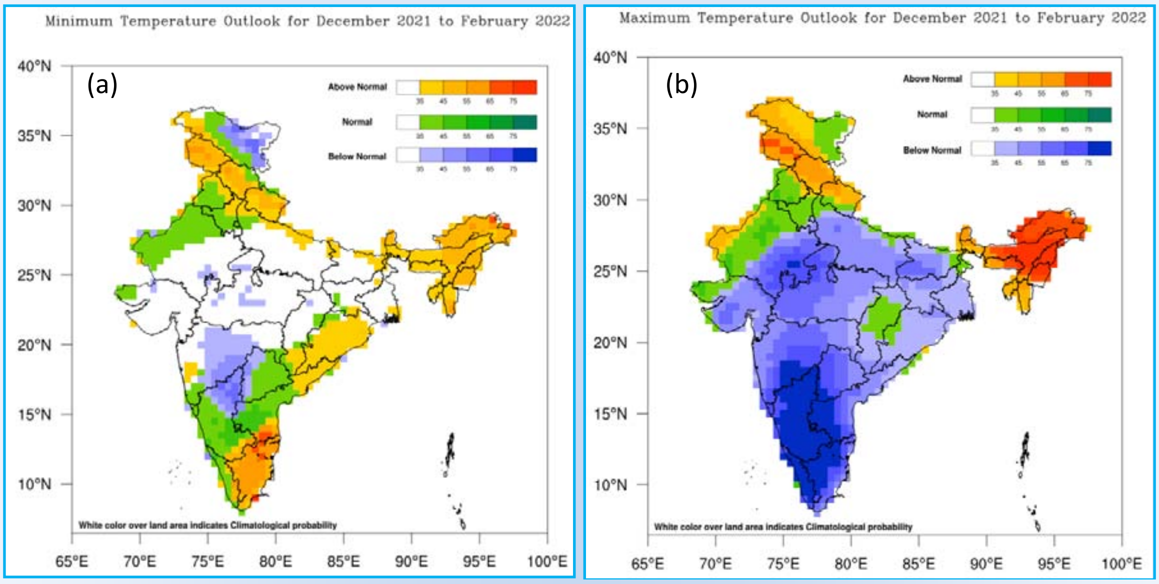
IMD had issued Seasonal outlook for the subdivision averaged temperatures for the last cold weather season (December, 2021 to February, 2022 on 1st December 2021, based on IMD's Multi Model Ensemble (MME) Model. The summary of forecast for the winter season (DJF) was as follows:

During the upcoming winter season (December 2021 to February 2022), normal to above normal minimum temperatures are most likely over many parts of northwest India, most parts of south and northeast India, and some areas along the foothills of the Himalayas. Below normal minimum temperatures are most likely over some parts of north interior peninsula. Below normal maximum temperatures are likely over most parts of the country except over some parts of northwest India and most parts of northeast India, where normal to above normal maximum temperatures are most likely.

(vi) Climate Monitoring

Temperatures

The annual mean temperature for the country was +0.44 °C above the 1981-2010 average, thus making the year 2021 as the fifth warmest year on record since 1901 (Fig. 42). The other 4 warmest years on record in order were: 2016 (anomaly +0.71 °C), 2009 (0.55 °C), 2017 (0.54 °C), 2010 (+0.539 °C). It may be mentioned that 11 out of the 15 warmest years were from the recent past fifteen years (2007-2021). In addition, the past decade (2011-2020/2012-2021) was the warmest decade on record with anomalies of



Figs. 27(a&b). Probability forecast & sub-division averaged (a) Maximum Temperature Anomaly forecast for Dec 2021 to Feb 2022 and (b) Minimum Temperature Anomaly forecast for Dec 2021 to Feb 2022

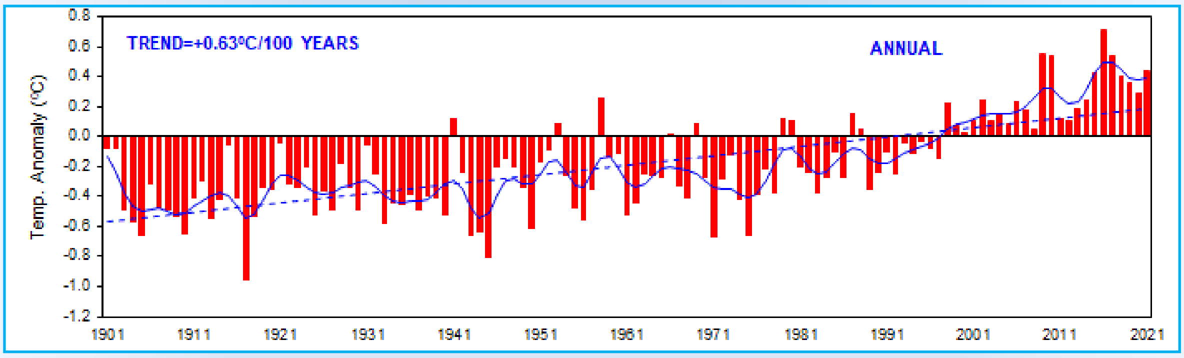


Fig. 28. Annual mean land surface air temperatures anomalies averaged over India for the period 1901-2021. The anomalies were computed with respect to base period of 1981-2010. The dotted line indicates the linear trend in the time series. The solid blue curve represents the sub-decadal time scale variation smoothed with a binomial filter

0.34 °C/ 0.37°C above average. During 1901-2021, the annual mean temperature showed an increasing trend of 0.63 °C/100 years with significant increasing trend in the maximum temperature (0.99 °C/100 years), and relatively lower increasing trend (0.26 °C/100 years) in the minimum temperature.

Rainfall

Rainfall activity over the country as a whole was above normal (105 % of LPA) during the year. Out of 36 meteorological subdivisions, 18 received excess rainfall, 13 received normal rainfall and remaining 5 subdivisions received deficient rainfall.

At the end of year, of the four homogeneous regions, South Peninsular India received 129% of its LPA, central India received 110% of its LPA, and Northwest India received 97% of its LPA while East and Northeast India received 89% of its LPA rainfall.

High Impact Weather Events

In 2021, five cyclonic storms formed over the north Indian Ocean. These are:

(1) Extremely Severe Cyclonic Storm TAUKTAE,
(2) Very Severe Cyclonic Storm YAAS,
(3) Severe Cyclonic Storm SHAHEEN (remnant of GULAB),
(4) Cyclonic Storm GULAB &
(5) Cyclonic Storm JAWAD.

Of these, three cyclones (YAAS, GULAB and JAWAD) formed over the Bay of Bengal. & the remaining two cyclones (viz., TAUKTAE & SHAHEEN) formed over the Arabian Sea.

Among these 5 cyclones, the most devastating was Extremely Severe Cyclonic Storm TAUKTAE (14 May to 19 May) which formed in the pre-monsoon season over the Arabian Sea, crossed Saurashtra coast on 17th May, claiming 144 lives from across the states in western India stretching from Kerala in the far southern part of the country to Gujarat in the northwest.

The Very Severe Cyclonic Storm YAAS, (23 May to 28 May) formed during the pre-monsoon season over the Bay of Bengal, crossed the north Odisha coast on 26th May, 2021 and claimed 9 lives from Odisha, Jharkhand, West Bengal & Bihar.

The Cyclonic Storm GULAB (24-28 September), formed during the southwest monsoon season & crossed north Andhra Pradesh-south Odisha coasts on 26th September, claiming 19 lives from Andhra Pradesh, Telangana, Odisha, Maharashtra.

The Severe Cyclonic Storm SHAHEEN (29 September to 4 October) formed over Arabian

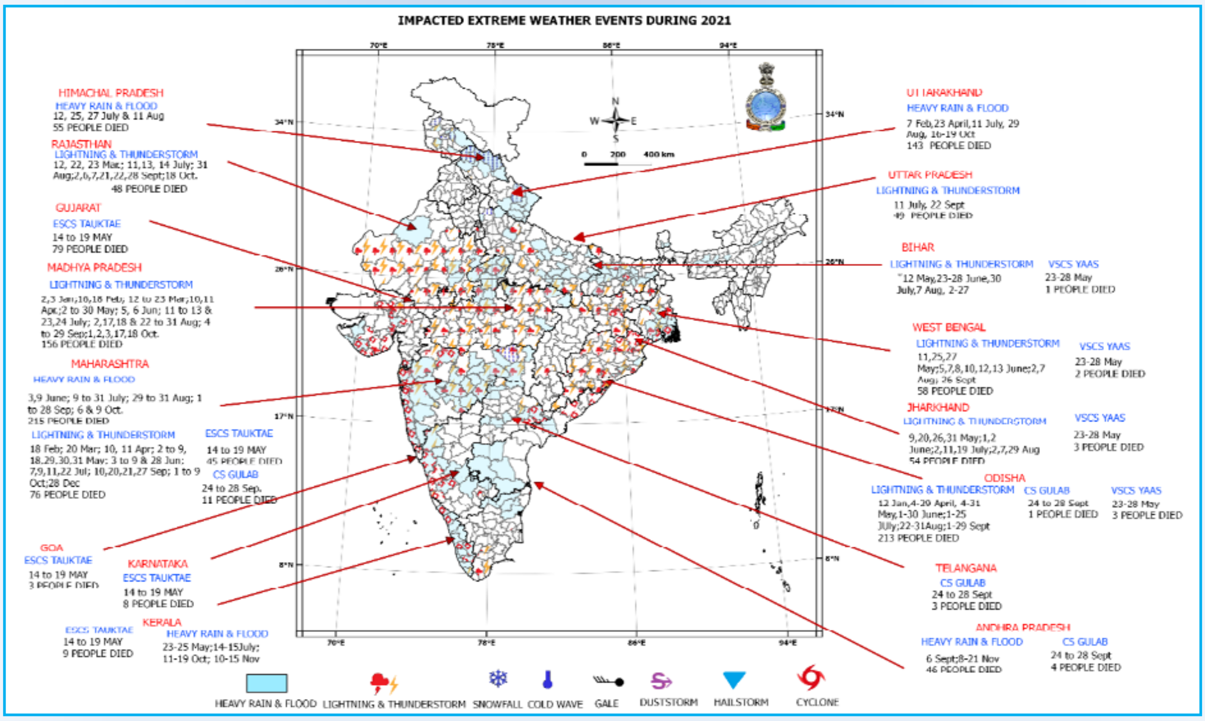


Fig. 29. Major extreme weather events occurred during 2021

Sea and moved away from Indian region towards Oman coast. The Cyclonic Storm JAWAD (2-6 December) formed over Bay of Bengal and weakened close to Odisha coast. However, these two systems do not have extreme impacts in India.

Heavy rain & flood related incidents reportedly claimed over 750 lives from different parts of the country during the pre-monsoon, monsoon & post-monsoon seasons. Of these, 215 lives were reported from Maharashtra, 143 from Uttarkhand, 55 from Himachal Pradesh, 53 from Kerala and 46 from Andhra Pradesh.

Thunderstorm & Lightning reportedly claimed over 780 lives from central, northeastern, northwestern and peninsular parts of the country throughout the year. Of these, 213 lives were reported from Odisha, 156 from Madhya Pradesh, 89 from Bihar, 76 from Maharashtra, 58 from West Bengal, 54 from Jharkhand, 49 from Uttar Pradesh and 48 from Rajasthan.

Significant weather events during 2021 and associated loss of lives are shown in Fig.29.

(vii) Regional Climate Centre (RCC) Activities

The CRS office of IMD, Pune is also recognized as the WMO Regional Climate Center (RCC) for south Asia. Presently the MMCFS is used for the following the RCC long range forecasting activities.

(a) Generate global monthly and seasonal (anomaly and probability) forecasts for the temperature and rainfall. This is updated every month.

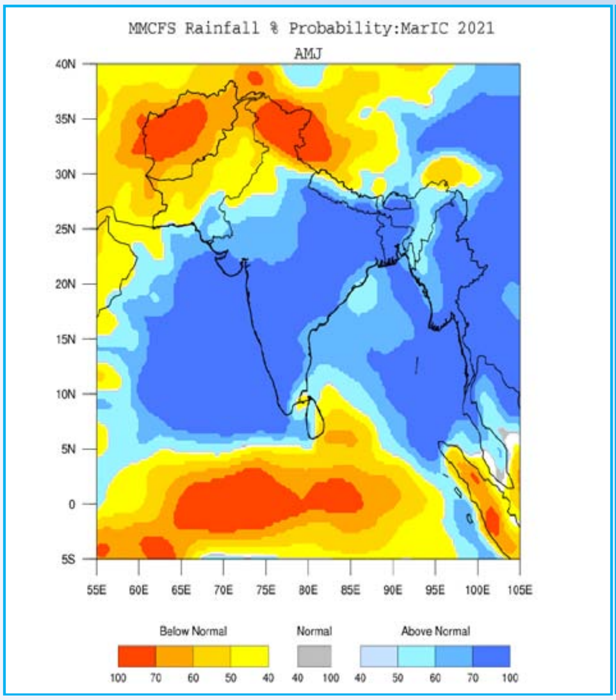
(b) Prepare Seasonal Climate Outlook for rainfall and temperatures over south Asia for the next 2 moving 3-month seasons (total 4 months) with monthly update.

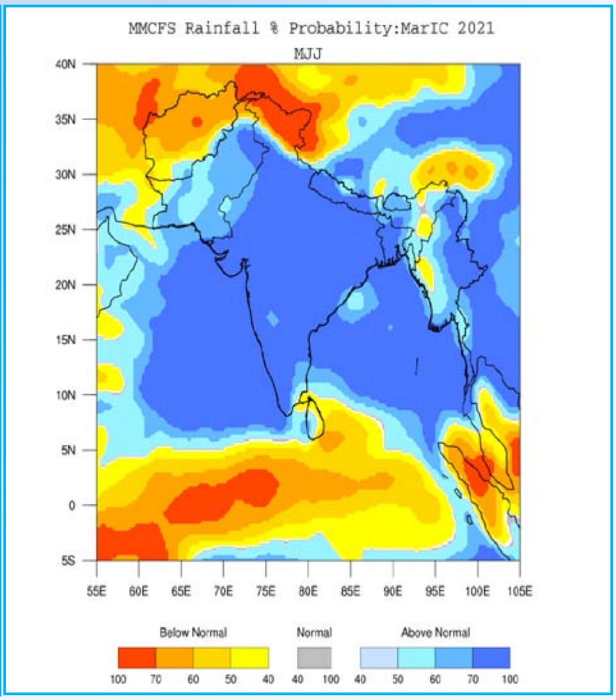
(c) Seasonal rainfall and temperature probability forecast for the 2021 AMJ and MJJ seasons issued in March 2021 is shown in the Figs. 30(a&b) and 31(a&b) respectively.

(d) Prepare ENSO & IOD bulletin every month providing statement on the global SST anomalies and probabilities forecast with emphasis on the ENSO and IOD conditions for the next 9 months prepared based with monthly update. Forecast issued May 2021 for Nino 3.4 and IOD plumes is shown in the Figs. 32(a&b). The corresponding probability forecast is given in Figs. 33(a&b).

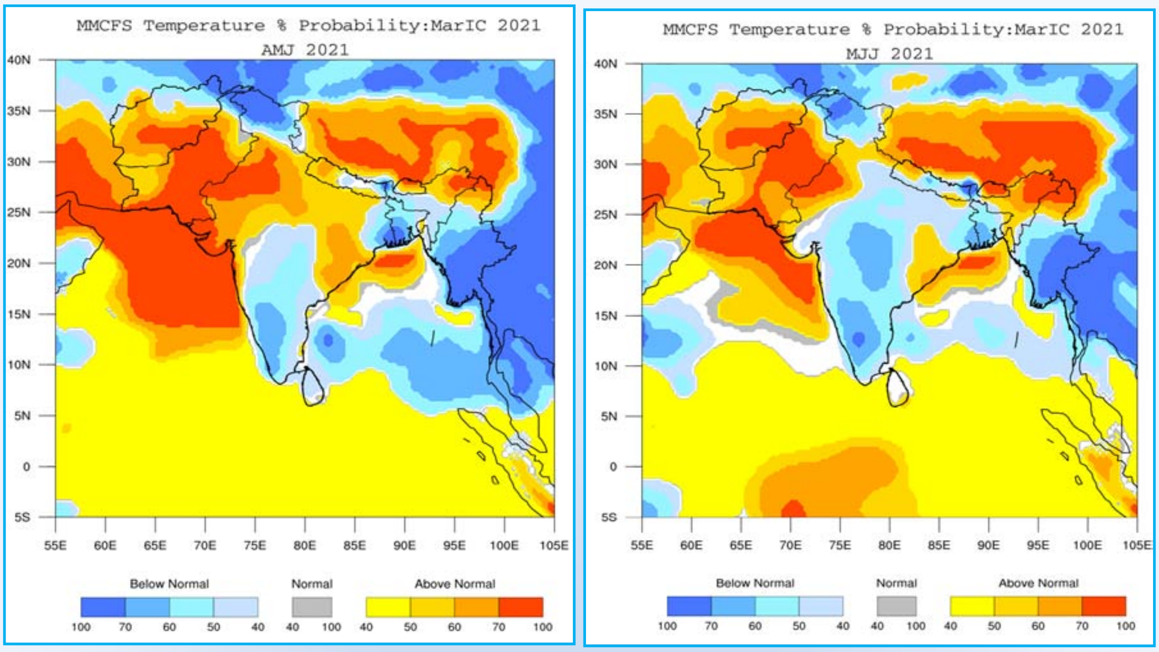
(e) Take lead role in preparing consensus forecast outlook for the monsoon season rainfall, northeast monsoon rainfall and winter rainfall over south Asia.

(f) Acting as Lead Centre in conducting South Asia Climate Forum Activities for RA II Region and Conducting SASCOF for generating consensus outlook for South Asian region for Summer Monsoon, Northeast Monsoon and December to February (DJF) Season.

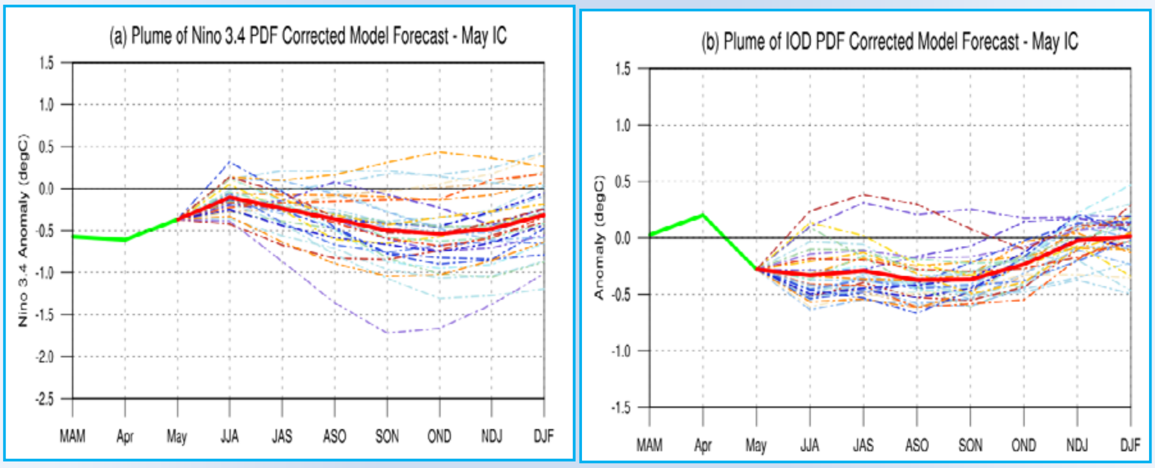




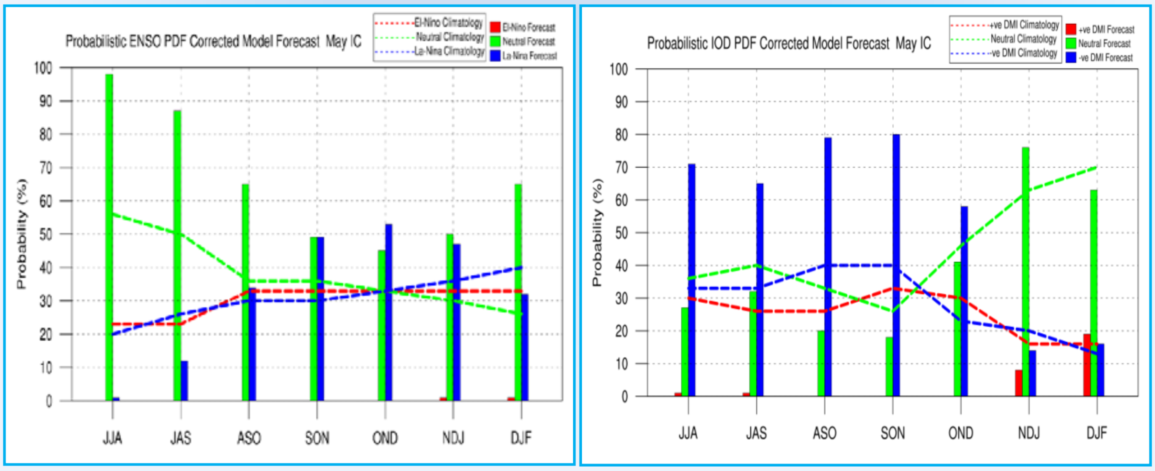
Figs. 30 (a&b). Seasonal probability forecasts of precipitation for (a) AMJ and (b) MJJ based on Initial conditions of March 2021



Figs. 31(a&b). Seasonal probability forecasts for mean temperature for (a) AMJ and (b) MJJ based on Initial conditions of March 2021



Figs. 32(a&b). Forecast issued May 2021 for (a) Nino 3.4 and (b) IOD plumes



Figs. 33(a&b). Probability forecast along with climatological probabilities of (a) Niño 3.4 and (b) Indian Ocean Dipole Mode Index from high resolution MMCFSv2.
Data source for Climatology probabilities: NOAA Extended Reconstructed SST V5.
Criteria used for Probabilistic ENSO Forecast: ≥ -0.5 La Niña, >0.5 to <-0.5 neutral, ≥ 0.5 El Niño.
Criteria used for Probabilistic DMI Forecast: ≥ -0.2 negative DMI, >0.2 to <-0.2 neutral, ≥ 0.2 positive DMI

5.5. Cyclone Monitoring & Prediction

5.5.1. Annual Characterstics of Cyclonic disturbances during 2021

10 Cyclonic Disturbances (CDs) (MSW≥ 17 kts) over the North Indian Ocean (NIO) including 7 over the Bay of Bengal (BoB) and 3 over the Arabian Sea (AS) against the normal of 11-12 CDs per year over the NIO based on the data of 1961-2020. Out of these, 5 intensified into Cyclonic Storms (CS) (maximum sustained wind speed (MSW≥ 34 kt) against the normal of 4.8 CS per year over the NIO based on the data of 1961-2020. Out of these 5 CS, 3 intensified into severe category storms (MSW ≥ 50 kt).

Considering the season-wise activity, post monsoon season was less active during 2021 with formation of 4 CDs including 1 CS against normal of 4.8 and 2.8 per season (October-December) based on the data of 1961-2020.

Considering the basin-wise activity, there were 3 CDs over the Arabian Sea including 1 depression and 2 CS against the normal of 2.3 and 1.2 respectively based on the data of 1961-2020. Over the BoB, there were 7 CDs including 4 depressions and 3 CS against the normal of 8.1 and 3.5 based on the data of 1961-2020. Thus, both the basins witnessed decreased frequency of formation of depressions. However, w.r.t. formation of CS, the activity was above normal over the AS and slightly below normal over the BoB.

Considering the track, out of 5 CS, 3 had recurving track (Tauktae, Shaheen & Jawad) and 2 had straight moving track (Yaas and Gulab).

Except cyclone JAWAD, the other 4 including Tauktae, Yaas, Gulab and Shaheen were landfalling cyclones against normal of 3.2 per year based on the data of 1961-2020.

Details of these CDs over the north Indian Ocean are listed below:

(i) Depression over north Andaman Sea during 02-03 April, 2021;

(ii) ESCS Tauktae over the Arabian Sea during 14-19 May, 2021;

(iii) VSCS Yaas over the Bay of Bengal (BoB) during 23-28 May, 2021;

(iv) Deep Depression over northwest BoB during 12-15 Sep., 2021;

(v) CS Gulab over the BoB during 24-28 September;

(vi) SCS Shaheen over the Arabian Sea during 30 Sep-04 Oct., 2021;

(vii) Depression over eastcentral AS during 07-09 Nov., 2021;

(viii) Depression over southeast BoB during 10-12 Nov., 2021;

(ix) Depression over southwest Bay of Bengal during 18 Nov- 19 Nov, 2021;

(x) Cyclonic Storm, "JAWAD" over the Bay of Bengal during 02 - 06 December, 2021.

The brief life history and operational forecast performance in respect of the cyclones during 2021 are presented in following sections:

5.5.2. Characterstics of Cyclonic Storms during 2021

5.5.2.1. Extremely Severe Cyclonic Storm TAUKTAE over the Arabian Sea (14th-19th May, 2021)

- A low pressure area formed over southeast Arabian Sea & adjoining Lakshadweep area in the morning (0830 hrs IST/ 0300 UTC) of 13th May, 2021. Under favourable environmental conditions, it concentrated into a depression over Lakshadweep area in the morning (0830 hrs IST) of 14th May, 2021. It intensified into the cyclonic storm "TAUKTAE" in the midnight (2330 hrs IST/1800 UTC) 0f 14th May over Lakshadweep area and adjoining southeast & eastcentral Arabian Sea. It reached its peak intensity of 100 kt in the morning (0530 hrs IST) of 17th May over eastcentral Arabian Sea.

- Continuing to move nearly northwards, it entered marginally unfavourable environment, weakened gradually and crossed Saurashtra coast near latitude 20.8° N and longitude 71.1° E, close to northeast of Diu (about 20 km northeast of Diu) during 2000-2300 hours IST of 17th May, 2021 with maximum sustained wind speed of 160-170 kmph gusting to 185 kmph. Moving north-northeastwards, it weakened into a well marked low pressure area over central parts of Rajasthan in the evening (1730 hrs IST) of 19th May.

Forecast Performance

- First information about development of low pressure area over southeast Arabian Sea and adjoining areas was given in the extended range outlook issued on 6th May (about 7 days prior to the formation of low pressure area over southeast Arabian Sea & adjoining Lakshadweep area on 13th May and 8 days prior to formation of depression over Lakshadweep area on 14th May).

- Subsequently, in the Tropical Weather Outlook issued on 10th May and national weather forecast bulletin issued at 1200 hrs IST, it was indicated that a low pressure area would form over southeast Arabian Sea around 14th May and would intensify further into a cyclonic storm (About 4 days prior to formation of cyclonic storm on 14th May).

- The extended range outlook issued on 13th May (about 4 days prior to landfall over Gujarat coast) indicated that the system would move towards Gujarat coast and would impact the areas including southeast, eastcentral & northeast Arabian Sea, Lakshadweep-Maldives area, Lakshadweep Islands, areas along & off Kerala, Karnataka, Goa, Maharashtra, Gujarat & south Pakistan coasts and also the coastal & adjoining districts of all these States. Accordingly, likely impact was also issued in the extended range outlook for fishermen, ships and ports along the west coast of India.

- The Press Release updated on 13th May (5 days prior to landfall) on development of low pressure area over southeast Arabian Sea. It indicated that the cyclonic storm over southeast Arabian Sea and adjoining Lakshadweep area would reach Gujarat coast on 18th May.

- In the first bulletin issued at 1245 hrs IST of 14th May, it was indicated that the system would intensify into a very severe cyclonic storm and reach Gujarat coast by 18th May morning (about 80 hours prior to landfall of TAUKTAE) (Fig. 34).

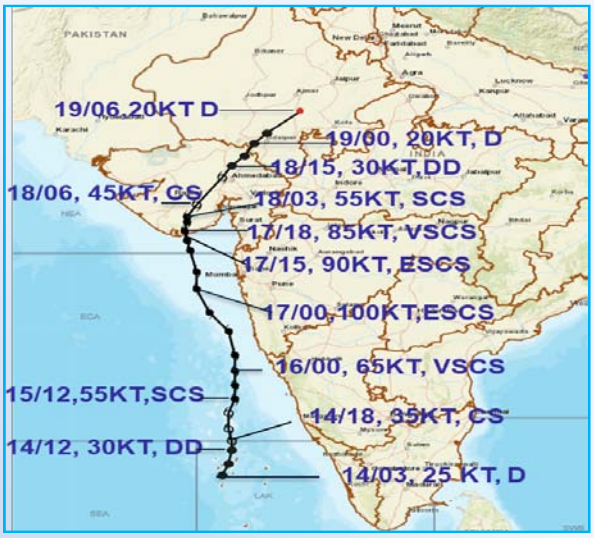


Fig. 34. Observed track of ESCS TAUKTAE during 14-19 May, 2021

- In the bulletin issued at 2030 hrs IST of 14th May (about 75 hours prior to landfall), it was indicated that the system would reach near Gujarat Coast in the morning of 18th May and that winds as high as 150-160 kmph gusting to 180 kmph would prevail along & off south Gujarat since late night of 17th.

- The landfall point & time was further updated in the bulletin issued at 0330 hours IST of 16th May (about 45 hours prior to landfall) that the system would reach Gujarat coast in the evening hours of 17th& cross Gujarat coast between Porbandar & Mahuva (Bhavnagar district) around 18th May early morning with wind speed of 150-160 kmph gusting to 180 kmph.

- In the bulletin issued at 0815 hrs IST of 17th May (about 15 hours prior to landfall), the warnings were further specified and it was informed that the system would reach Gujarat coast in the evening hours of 17th & cross Gujarat coast between Porbandar & Mahuva (Bhavnagar district) during the night (2000-2300 hrs IST) of 17th May as a Very Severe Cyclonic Storm with a maximum sustained wind speed 155-165 kmph gusting to 185 kmph.

Fig. 35 represents the observed and forecast track, intensity & landfall forecast issued at various lead times indicating accuracy in track, landfall and intensity forecast.

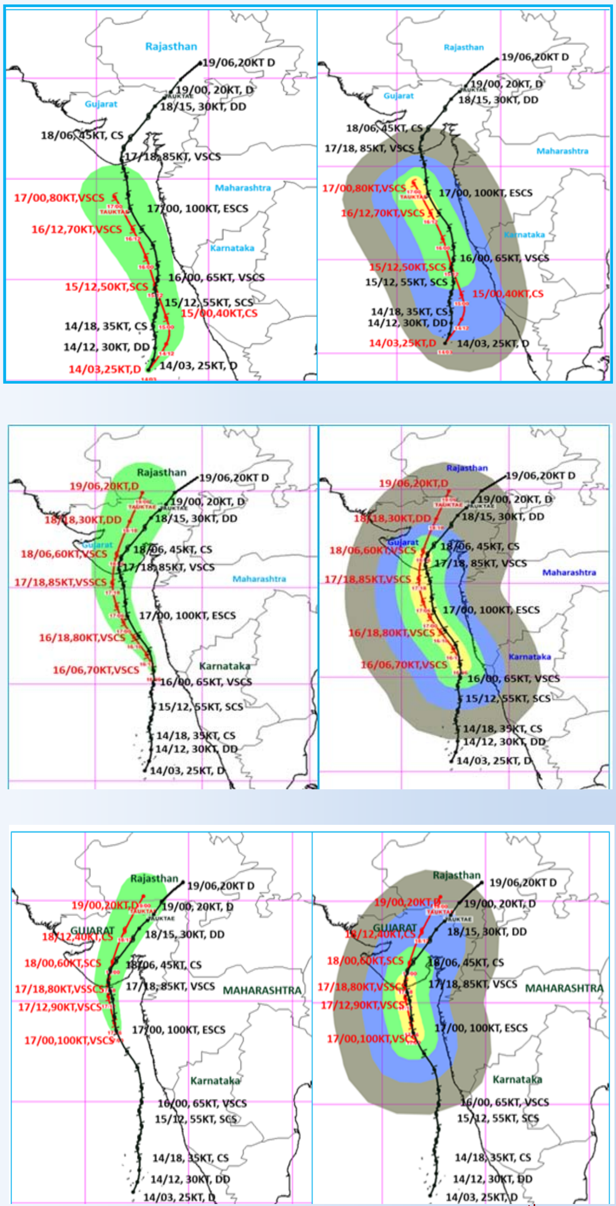


Fig. 35 (a-c). Observed and forecast track (a) 14th May based on 0830 hrs IST observations of 14th May (80 hours prior to landfall), (b) 16th May based on 1130 hrs IST observations of 16th May (about 36 hours prior to landfall) and (c) 17th May based on 0530 hrs IST observations of 17th May (about 15 hours prior to landfall)) of ESCS TAUKTAEindicating accuracy in landfall, track & intensity

Operational Track, Intensity and Landfall Point & Time Forecast Errors:

- The track forecast errors for 24, 48 and 72 hrs lead period were 73, 118, and 224 km respectively against the LPA errors of 77, 117 and 159 km respectively.

- The absolute error (AE) of intensity (wind) forecast for 24, 48 and 72 hrs lead period were 4.4, 8.9 and 15.5 knots against the LPA errors of 7.9, 11.4, and 14.1 knots during 2015-19 respectively.

- The landfall point forecast errors for 24 and 48 hrs lead period were 27 and 71km respectively against the LPA errors of 32 and 62 km during 2016-20 respectively.

- The landfall time forecast errors for 24 and 48 hrs lead period were 3.5 and 6.5 hours respectively against the LPA errors of 2.5 and 6.5 hours during 2016-20 respectively.

5.5.2.2. Very Severe Cyclonic Storm YAAS over the Bay of Bengal (23-28 May, 2021)

- A low pressure area formed over eastcentral Bay of Bengal (BoB) in the morning (0830 IST/0300 UTC) of 22nd May. Under favourable environmental conditions, it concentrated into a depression over eastcentral BoB in the noon (1130 IST/0600 UTC) of 23rd May, 2021. It moved northwestwards and intensified into the cyclonic storm “YAAS” in the early morning (0530 IST/0000 UTC) of 24th over the same region. It started moving northwards from the morning (0830 IST/0300 UTC) of 25th and intensified into a very severe cyclonic storm (VSCS) in the evening (1730 IST/1200 UTC) over northwest BoB. Thereafter, it moved north-northwestwards reached peak intensity of 75 kts and lay centred over northwest BoB about 30 km east of Dhamra Port, Odisha during early morning (0530 IST/0000 UTC) of 26th May. Continuing to move north-northwestwards, it crossed north Odisha coast

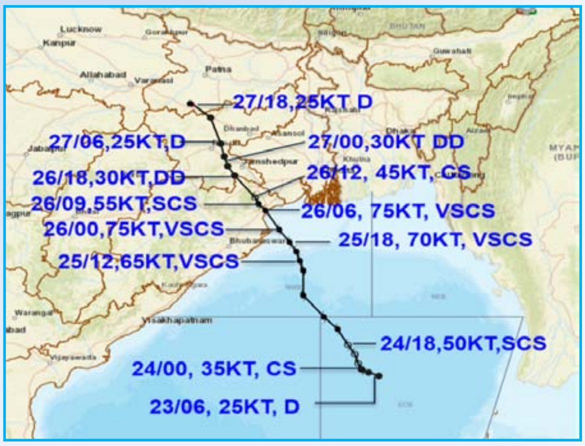


Fig. 36. Observed track of VSCS YAAS during 23-28 May, 2021

near latitude 21.35° N and longitude 86.95° E, about 20 km to the south of Balasore as a VSCS with maximum sustained wind speed (MSW) of 75 kts gusting to 85 kts (130 -140 kmph gusting to 155 kmph) between 1030-1130 IST (0500-0600 UTC) of 26th. It moved northwestwards and weakened into a well-marked low pressure area over Bihar and adjoining southeast Uttar Pradesh (UP) in the early morning (0530 IST/0000 UTC) of 28th May. Observed track of the VSCS YAAS is given in Fig. 36.

Forecast Performance

- First information about development of depression over eastcentral BoB with (1-33% probability) during 21-23 May was given in the extended range outlook issued on 13th May (**about 10 days prior to the formation of formation of depression** over eastcentral BoB on 23rd May).

- Subsequently, in the Press Release, Tropical Weather Outlook and national weather forecast bulletin issued at 1200 hrs IST of 19th May, it was indicated that a low pressure would form over north Andaman Sea and adjoining eastcentral BoB around 22nd May and that it would intensify further into a cyclonic storm. It was also indicated that the system would move northwestwards and reach Odisha-West Bengal coasts on 26th May (about 3 days prior to formation of low pressure area on 22nd May and 4 days prior to formation of depression on 23rd May).

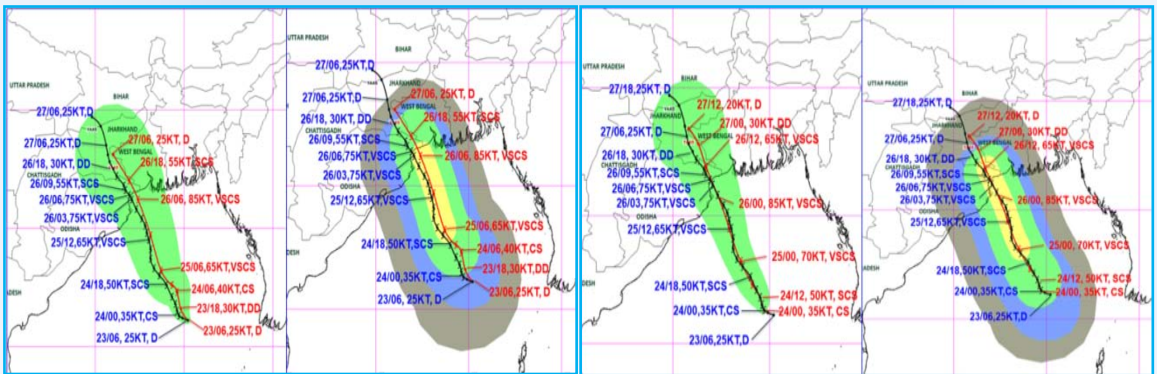
- The extended range outlook issued on 20th May (about 3 days prior to formation of depression on 23rd May and 6 days prior to the cyclonic storm reaching near Odisha-West Bengal coasts on 26th May) indicated with high probability (67-100%) that the system would move towards northwest BoB near Odisha-West Bengal coasts during 23-26 May. Accordingly, likely impact was also issued in the extended range outlook for fishermen, ships and ports along the east coast of India and adjoining Bangladesh & Myanmar coasts.

- In the first bulletin issued at 1245 hrs IST of 22nd May on formation of low pressure area over eastcentral BoB, it was indicated that the system would intensify upto very severe cyclonic storm and that the system would move northwestwards and reach north Odisha-West Bengal coasts around 26th morning (about 90 hours prior to YAAS reaching Odisha-West Bengal coasts on 26th morning).

- The first bulletin issued at 1350 IST of 23rd (about 72 hours prior to landfall around noon of 26th, it was indicated that the system would move north-northwestwards, reach close to north Odisha-West Bengal coasts around 26th morning and cross north Odisha coast by afternoon of 26th May.

- The bulletin issued at 0830 IST of 24th indicated that the system would cross coast close to south of Balasore, Odisha by afternoon of 26th as a very severe cyclonic storm (about 54 hours prior to landfall) with almost zero landfall point error.

- Actually, the very severe cyclonic storm YAAS moved nearly north-northwestwards and lay centred over northwest BoB about 30 km east of Dhamara Port, Odisha during early morning (around 0530 IST) of 26th May. Since first bulletin issued on 22nd May (about 90 hours prior to landfall) it was indicated that the system would reach north Odisha-West Bengal coasts around 26th morning.



Figs. 37(a&b). Observed track (23-28 May) and first forecast track issued at (a) 1350 hours IST of 23rd May based on 1130 hrs IST observations of 23rd May (about 72 hours prior to landfall) and (b) 0830 IST based on 0530 IST observations of 24th May (about 54 hours prior to landfall) demonstrating accuracy in track, intensity and landfall

- Also continuing to move north-northwestwards, YAAS crossed north Odisha coast near latitude 21.35° N and longitude 86.95° E, about 20 km to the south of Balasore as a VSCS with maximum sustained wind speed of 75 kts gusting to 85 kts (130-140 kmph gusting to 155 kmph) between 0500 & 0600 UTC (1030 IST) of 26th as indicated since 24th May (about 54 hours prior to landfall) with almost zero landfall point error (8 km) and about zero landfall time error (0.5-1.0 hour). Figs. 37(a&b) represents the observed and forecast track, intensity & landfall forecast issued at various lead times indicating accuracy in track, landfall and intensity forecast.

Operational Track, Landfall and Intensity Forecast Errors:

- The track forecast errors for 24, 48 and 72 hrs lead period were 24.1, 53.1 and 81.6 km respectively against the LPA errors (2016-20) of 77, 117 and 159 km respectively.

- The landfall point forecast errors for 12, 24, 48 and 60 hrs lead period were 7.8, 7.8, 7.8 and 38.9 km respectively against the LPA errors (2016-20) of 17, 32, 62 and 61 km during 2016-20 respectively.

- The landfall time forecast errors for 12, 24, 48 and 60 hrs lead period were 1.0, 1.0, 2.5 and 3.5 hours respectively against the LPA errors (2016-20) of 1.3, 2.5, 5.0 and 5.3 hours during 2016-20 respectively.

- The absolute error (AE) of intensity (wind) forecast for 24, 48 and 72 hrs lead period were 13.7, 12.9 and 14.1 knots against the LPA errors of 7.9, 11.4 and 14.1 knots during 2016-20 respectively.

- The errors in track and landfall point & time were exceptionally less as compared to long period average errors during 2016-2020.

5.5.2.3. Cyclonic Storm GULAB over the Bay of Bengal (24th – 28th September 2021)

- A low pressure area formed over east-central Bay of Bengal (BoB) and neighbourhood in the morning (0830 hours IST/ 0300 UTC) of 24th September. Under favourable environmental and Sea conditions, it concentrated into a **depression** over eastcentral and adjoining northeast BoB in the evening (1730 hours IST/1200 UTC) of 24th September. Moving west-northwestwards, it intensified into the Cyclonic Storm **"GULAB"** over northwest and adjoining west-central BoB in the evening (1730 hours IST) of 25th September, 2021.

- Thereafter, it intensified gradually and reached its peak intensity of 75-85 kmph gusting to 95 kmph around noon (1130 hours IST/0600 UTC) of 26th September. Continuing to move further westwards, it crossed North Andhra Pradesh and adjoining south Odisha coasts near Lat. 18.4° N/ Long. 84.2° E (20 km north of Kalingapatnam) with maximum sustained wind speed of 75-85 gusting to 95 kmph during 1930-2030 IST of 26th September.

- Thereafter, it weakened into a well marked Low pressure area over western parts of Vidarbha and neighbourhood around noon of 28th September.

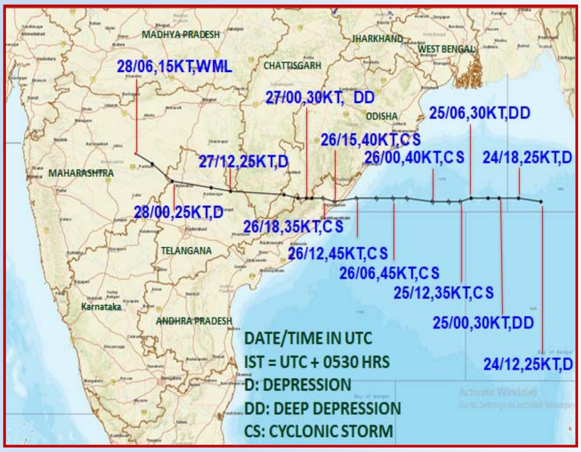


Fig. 38. Observed track of cyclonic storm "Gulab" during 24-28 September, 2021

Observed track of the cyclonic Storm Gulab given in Fig. 38.

Genesis, track, landfall and intensity forecast performance:

- First information about likely formation of low pressure area over central parts of BoB during the week 24th Sep. to 30th Sep. was given in extended range outlook issued on 16th September (about 8 days prior to formation of LPA over eastcentral BoB). It was also indicated that the system would move west-northwestwards towards Odisha coast.

- The tropical weather outlook issued at 1130 hours IST of 23rd further reiterated that an LPA would form over northeast and adjoining eastcentral BoB around 24th evening. It was also indicated that the system would move west-northwestwards towards Odisha coast during subsequent 48 hours (till 26th).

- Special Message issued at 1630 IST of 24th September on formation of WML indicated that it would intensify further into a depression within next 12 hours and move towards south Odisha-north Andhra Pradesh coasts. Fishermen were advised not to venture into eastcentral and adjoining northeast BoB on 24th& 25th Sep. and into westcentral BoB and along & off Odisha, West Bengal & North Andhra Pradesh coasts from 24th night till 27th September.

- The first bulletin issued at 2030 hours IST of 24th September (**about 48 hours prior to landfall**) indicated that system would cross coast around Kalingapatnam by 26th evening with maximum sustained wind speed of 70-80 gusting to 90 kmph. The bulletin also indicated that the system would cross coast around 26th evening.

- The bulletin issued at 2030 hours IST of 25th September (**about 24 hours prior to landfall**) further indicated that cyclone would cross coast with wind speed of 75-85 gusting 95 kmph. The maximum wind speed in gustiness has been reported as 95 kmph over Kalingapatnam at the time of landfall.

- Thus, the genesis, track, landfall and intensity could be predicted reasonably well with a lead period of 48 hours approximately. Typical observed and forecast track of cyclone Gulab demonstrating accuracy in track, landfall and intensity prediction are presented in Fig. 39.

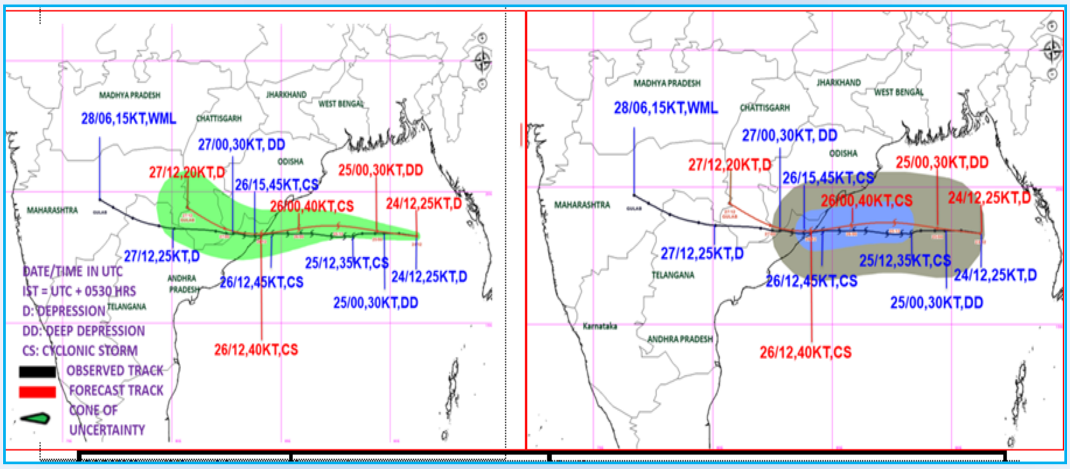


Fig. 39. Typical observed and forecast track along with (a) cone of uncertainty and (b) quadrant wind distribution based on 1730 hours IST (1200 UTC) of 24th September of cyclone Gulab demonstrating accuracy in track, landfall and intensity prediction

Operational Track, Landfall and Intensity Forecast Errors

- The landfall point forecast errors for 24, 36 and 48 hrs lead period were 31, 0 and 0 km respectively against the LPA errors (2016-20) of 31.9, 43.7 and 61.5 km during 2016-20 respectively. The landfall time forecast errors for 24, 36 and 48 hrs lead period were 0.5, 3.0, and 3.0 hours respectively against the LPA errors (2016-20) 2.5, 4.7 and 5.0 hours during 2016-20 respectively. For all lead periods, the landfall point errors were exceptionally less than the LPA errors during 2016-20. There was almost zero landfall point error for 36 and 48 hours lead period. Landfall time error was also significantly less for all lead periods from 24 to 48 hours.

- The track forecast errors for 24, 48 and 72 hrs lead period were 82.4, 65.9, and 110.0 km respectively against the LPA errors (2016-20) of 77.5, 116.8, and 158.8 km respectively. The track forecast skill was about 79%, 89% and 92% against the LPA skill of 64%, 76%, and 78% for 24, 48 and 72 hrs lead period respectively. The track forecast error for 48-72 hours lead period was significantly less than the LPA errors. Skill in track forecasting was better than LPA skill for all lead periods.

- The absolute error (AE) of intensity (wind) forecast for 24, 48 and 72 hrs lead period were 1.3, 2.2 and 5.0 knots against the LPA errors of 7.9, 11.4, and 14.1 knots during 2016-20 respectively. The skill (%) in intensity forecast as compared to persistence forecast based on AE for 24, 48 and 72 hrs lead period was 90%, 95% and 88% against the LPA of 52%, 72% and 75% respectively.

5.5.2.4. Severe Cyclonic Storm Shaheen over northeast Arabian Sea adjoining Kutch (30th September - 4th October, 2021)

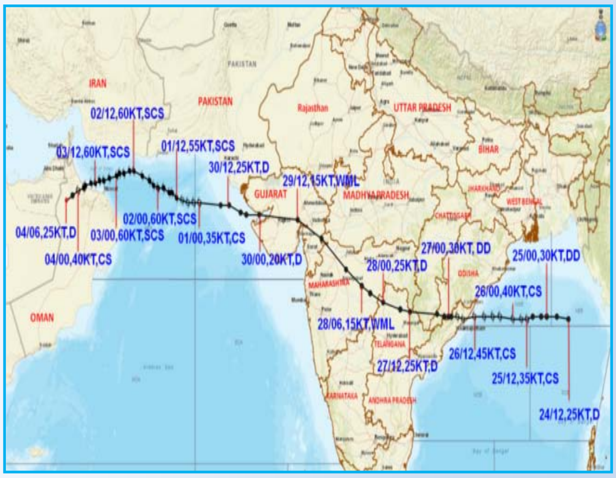


Fig. 40. Observed track of cyclonic storm Gulab (24th Sep - 28th Sep), its remnant (28th Sep - 30th Sep) and severe cyclonic storm, Shaheen (30th Sep - 4th Oct)

The remnant of cyclonic storm Gulab emerged as a well marked low pressure area into south Gujarat region & adjoining Gulf of Khambhat in the morning (0830 hours IST) of 29th September. Under favourable environmental and sea conditions, it concentrated into a depression over northeast Arabian Sea (AS) & adjoining Kutch, in the morning (0530 hours IST) of 30th September. It intensified into the cyclonic storm "Shaheen" over the northeast AS off Gujarat coast in the morning (0530 hours IST) of 1st October, 2021. It reached its peak intensity of 60 kts in the early morning (0000 UTC) of 2nd October. It crossed Oman coast during 0030-0130 IST of 4th October with wind speed of 95-105 gusting to 115 kmph. Itweakened into a well marked low pressure area in the evening (1730 hours IST) of 4th October over northeast Oman. Observed track of the system is given in Fig. 40.

Forecast Performance

- First information about likely emergence of remnant of cyclonic storm Gulab into northeast Arabian Sea was indicated in the All India Weather Inference issued at 1230 hours IST of 28th September. From 28th onwards, the fishermen were advised not to venture into north & adjoining central Arabian Sea and along & off Gujarat & north Maharashtra coasts during 30th September - 2nd November.

- The extended range outlook issued at 30th September indicated high probability of cyclogenesis over north Arabian Sea.

- The special Message issued at 1250 IST of 29th September indicated that the well marked low pressure area over south Gujarat & adjoining Khambat region would emerge into northeast Arabian Sea by 30th and intensify gradually into a cyclonic storm. It was also indicated that the system would move away from Indian coast and would not cause damage over Indian mainland. Since first bulletin issued at 0830 hours IST of 30th it was indicated that the system would move away from Indian mainland. Typical observed and forecast track issued at 0830 hours IST (0300 UTC) of 30th September alongwith cone of uncertainty and wind warnings is presented in Fig. 41(a). Typical observed and forecast track of cyclone Shaheen based on 1130 hours IST (0600 UTC) of 1st October (60 hours prior to landfall) demonstrating accuracy in track, landfall and intensity prediction are presented in Fig. 41(b).

Operational Track, Landfall and Intensity Forecast Errors:

- The landfall point forecast errors for 12, 24, and 48 hrs lead period were 2.2, 14.3 and 5.5 km respectively against the LPA errors (2016-20) of 25.4, 44.7 and 69.4 km during 2016-20 respectively. The landfall time forecast errors for 12, 24, and 48 hrs lead period were 0.0, 0.50, and 0.0 hours respectively against the LPA errors (2016-20) of 2.0, 3.0 and 5.4 hours during 2016-20 respectively. For all lead periods, the landfall point errors were exceptionally less than the LPA errors during 2016-20. There was almost zero landfall point error for 12, 48 & 60 hours lead period. Landfall time error was also significantly less for all lead periods from 24 to 48 hours. It was almost zero for 12 and 48 hours lead period.

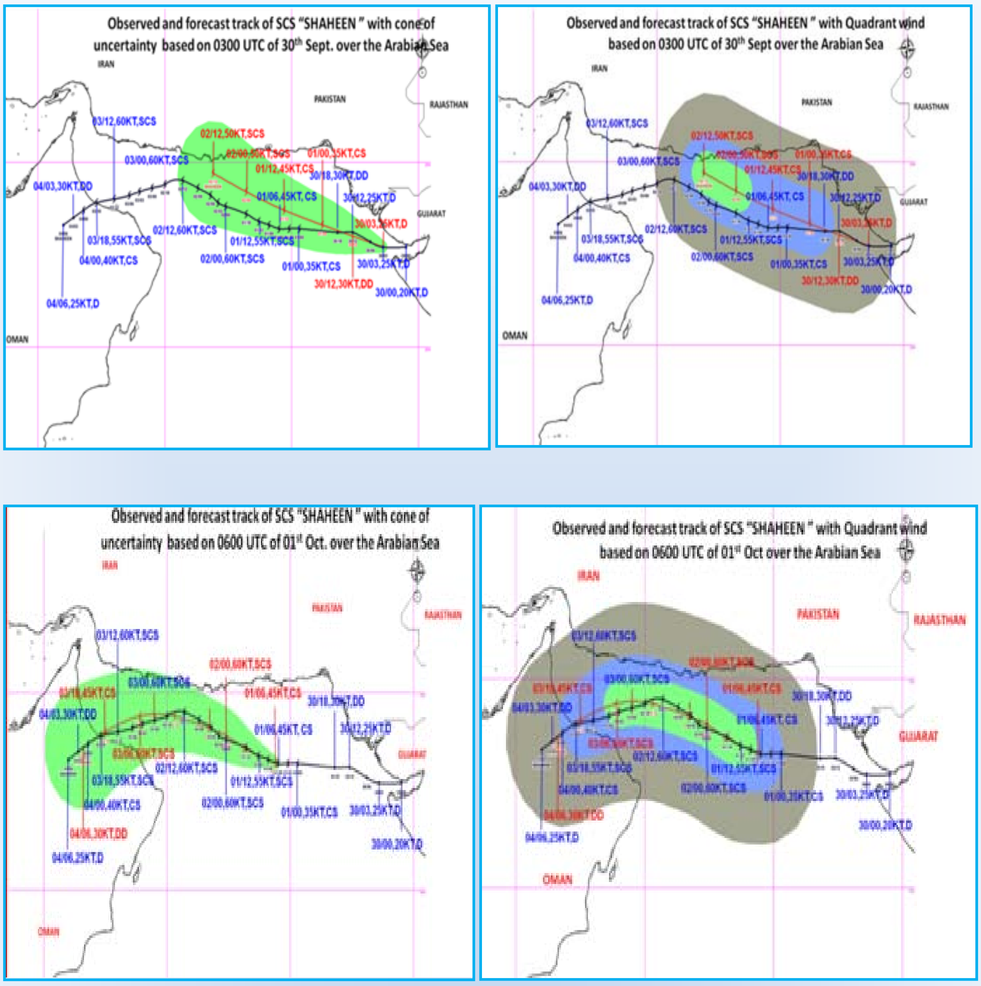


Fig. 41 (a&b). Typical observed and forecast track of severe cyclonic storm Shaheen (a) at 0830 hours IST (0300 UTC) of 30thSeptember and(b) 1130 hours IST of 1st October (about 60 hours prior to landfall) demonstrating movement of system away from Indian coast

- The track forecast errors for 24, 48 and 72 hrs lead period were 58.1, 107.2, and 120.1 km respectively against the LPA errors (2016-20) of 77.5, 116.8, and 158.8 km respectively [Fig.19(a)]. The track forecast skill was about 85%, 88% and 88% against the LPA skill of 64%, 76%, and 78% for 24, 48 and 72 hrs lead period respectively. The track forecast error for all lead periods were significantly less than the LPA errors. Skill in track forecasting was better than LPA skill for all lead periods.

- The absolute error (AE) of intensity (wind) forecast for 24, 48 and 72 hrs lead period were 5.0, 9.0 and 2.4 knots against the LPA errors of 7.9, 11.4, and 14.1 knots during 2016-20 respectively. The skill (%) in intensity forecast as compared to persistence forecast based on AE for 24, 48 and 72 hrs lead period was 55%, 70% and 98% against the LPA of 52%, 72% and 75% respectively.

5.5.2.5. Cyclonic Storm JAWAD (pronounced as JOWAD) over Bay of Bengal (2-6 December, 2021)

- A Low Pressure Area formed over South Thailand & neighbourhood in the forenoon (0830 hours IST/0300 UTC) of 30th November. It emerged into central parts of Andaman Sea in the same evening (1730 hrs IST/1200 UTC). It concentrated into a depression over southeast Bay of Bengal in the same evening (1730 hours IST/1200 UTC) and into the Cyclonic Storm "JAWAD" (pronounced as JOWAD) over westcentral BoB in the forenoon (1130 hours IST/0600 UTC) of 3rd December. It moved north-northeastwards and reached very close to Odisha coast, about 50 km southeast of Puri in the afternoon (1430 hours IST/0900 UTC) of 5th December and 30 km southeast of Paradip in the evening (1730 hours IST/1200 UTC) of 5th December as a depression (Fig. 42).

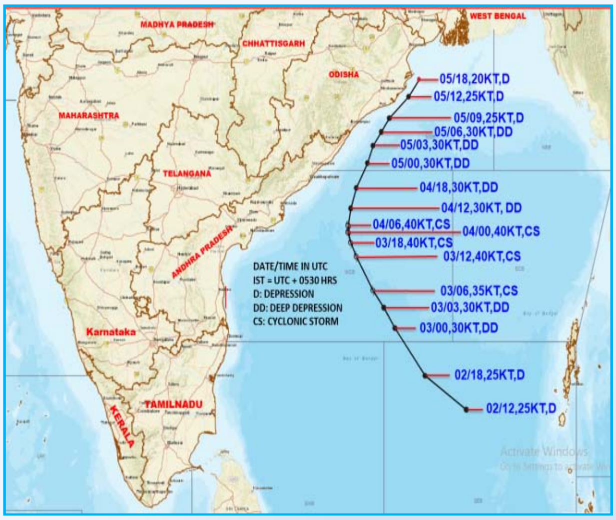


Fig. 42. Observed track of cyclonic storm JAWAD over Bay of Bengal (2- 6 December, 2021)

- Thereafter, it moved northeastwards and weakened into a well marked low pressure area over northwest BoB and adjoining West Bengal & Bangladesh coasts in the morning (0530 hours IST/0000 UTC) of 6th December, 2021.

Forecast Performance

- First information about likely cyclogenesis (low probability: 1-33%) over southeast BoB was given in the extended range outlook issued on 18th November, about 12 days prior to the formation of low pressure area over south Thailand and neighbourhood on 30th November and 14 days prior to formation of depression over southeast BoB on 2nd December.

Subsequent extended range outlooks issued on 25th November and 2nd December indicated initial northwestwards movement and then north-northeastwards recurvature of the system while moving parallel to east coast of India close to Andhra Pradesh-Odisha coasts.

- Since 25th November, fishermen warnings were issued for Andaman Sea area for 30th November (even before the emergence of low pressure area over south Andaman Sea on 30th in graphical form and also in the six hourly bulletins issued byNational Weather Forecasting Centre, New Delhi. Fishermen warnings were subsequently issued for entire BoB region in association with cyclone Jawad.

- First special message for the disaster managers was issued at 1400 hours IST of 30th November on formation of low pressure area over south Thailand and neighbourhood at 0830 hours IST of 30th November indicating that the system would emerge into Andaman Sea and subsequently intensify intro a cyclonic storm around 3rd December.

It was also indicated that the system would reach north Andhra Pradesh-Odisha coasts around 4th December morning. On 30th November, heavy rainfall warnings for Andaman & Nicobar Islands.

Typical observed and forecast tracks of cyclone JAWAD based on 0530 hours IST of 3rd December demonstrating accuracy in track, landfall and intensity prediction are presented in Fig. 43.

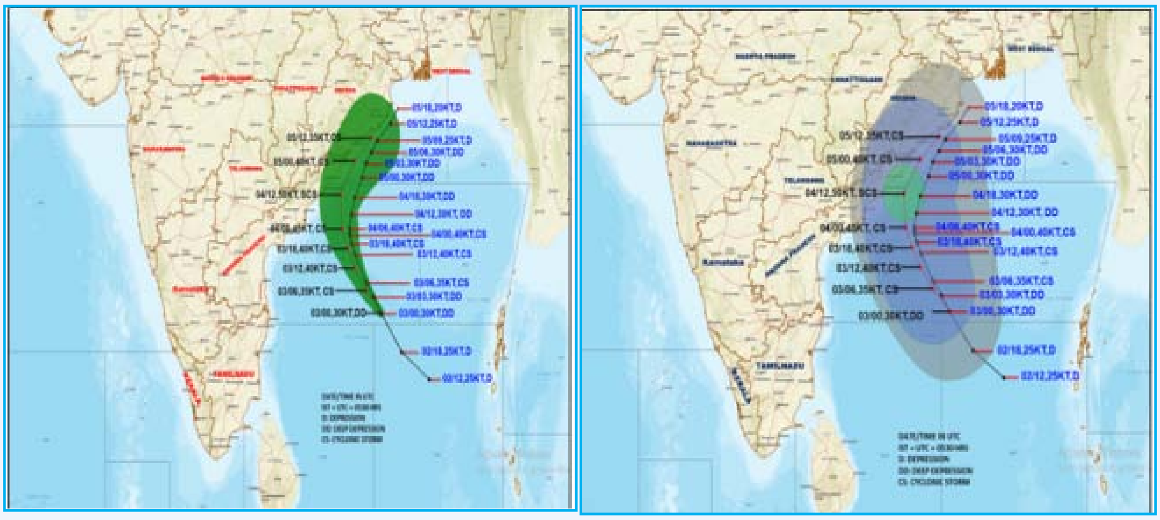


Fig. 43. Typical observed and forecast track of cyclonic storm JAWAD at 0530 hours IST (0000 UTC) of 3rd Dec. demonstrating accuracy in track, intensity and landfall of system

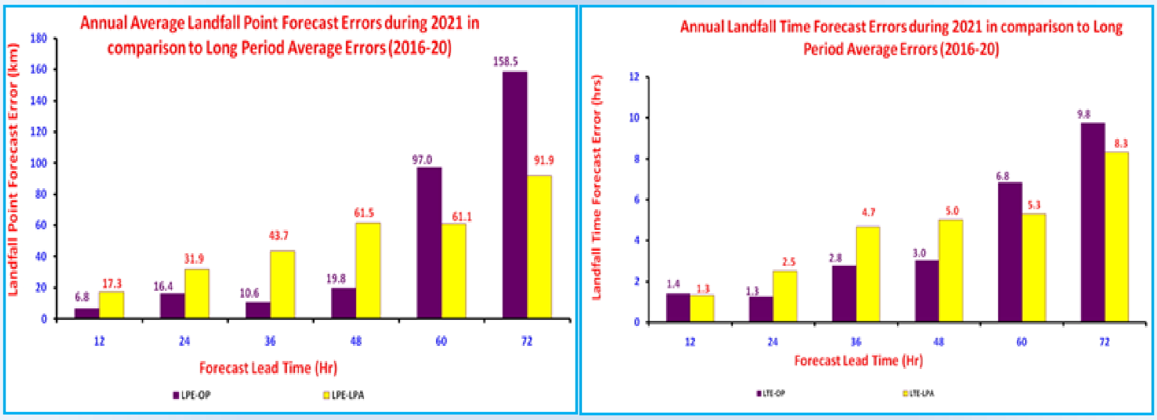
5.5.3. Annual Average Cyclone Forecast error and skill during 2021

5.5.3.1. Annual Track, landfall and intensity forecast error

- Track forecast

The annual average track forecast errors in 2021 have been 63 km, 91 km and 164 km, respectively for 24, 48 and 72hrs against the past five-year average error of 77, 117 and 159 km based on data of 2016-2020. The errors have been significantly lower during this year as compared to long period average (LPA) (2016-20). The track forecast skills compared to climatology and persistence forecast have been 75%, 82% and 68% respectively for the 24, 48 and 72 hrs lead period which is much higher than long period average of 2016-2020 (64%, 76% & 78% respectively). The annualaverage track forecast errors and skill during 2021 are presented in Fig. 44.

Figs. 44(a&b). Annual average (a) track forecast error (km) and (b) track forecast skill against the climatology and persistence forecast during 2021 as compared to that during 2016-2020



Figs. 45(a&b). Annual average (a) landfall point forecast error (km) and (b) landfall time forecast skill against the climatology and persistence forecast as compared to that during 2016-2020

- *Landfall forecast*

The annual average landfall forecast errors for the year 2021 have been 7 km, 16 km and 20 km for 12, 24 and 48 hrs lead period against the average of past five years of 17 km, 40 km and 61.5 km during 2016-2020. The landfall time forecast errors have been 1.4, 1.3 and 3.0 hrs for 12, 24 and 48 hrs lead period during 2021 against the average of past five years of 1.3, 2.5 and 5.0 hrs during 2016-2020. The annual average landfall point and time forecast errors are presented in Figs. 45 (a&b).

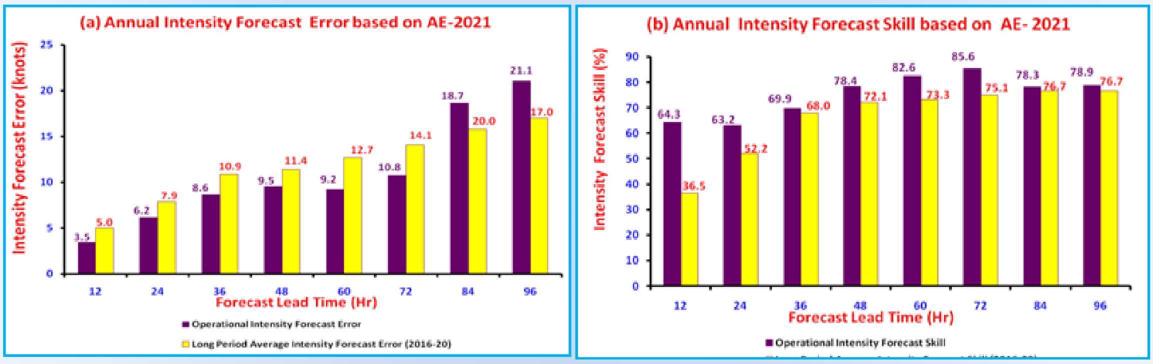
- Intensity forecast

The annual average intensity forecast error based on AE is the weighted mean of the absolute error for each cyclone. Similarly, the annual average error is calculated by persistence method. Based on these two errors, the intensity forecast skill with reference to absolute error is calculated. Errors and skills are calculated for 12, 24, 36, 48, 60, 72, 84, 96, 108 and 120 hour forecasts.

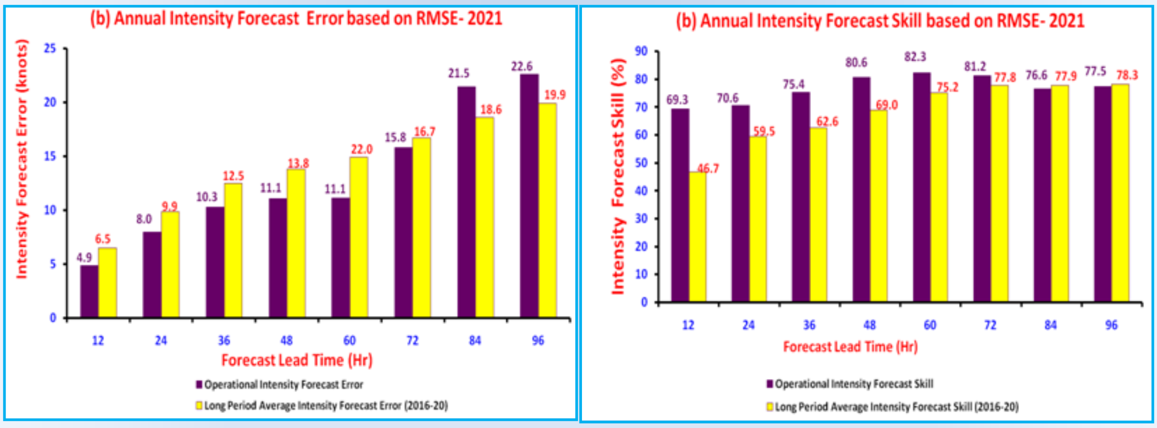
The annual average intensity forecast error based on RMSE is calculated by taking square root of the average of squared error between the forecast and observed intensity values for 12, 24, 36, 48, 60, 72, 84, 96, 108 and 120 hours forecast period for every six hourly forecast. Similarly, RMSE error based on persistence is calculated and hence the skill.

The annual average absolute error (AE) in intensity forecast error (Figs. 46 a&b) has been 6.2 knots, 9.5 knots and 10.8 knots respectively for 24, 48 and 72 hrs lead period of forecast against the past five year average of 7.9, 11.4 and 14.1 knots. The skill in terms of AE compared to persistence forecast was 63.2%, 78.4% and 85.6% as compared to long period average (2012-16) of 52.2%, 72.1% and 75.1% for 24, 48 and 72 hours lead period.

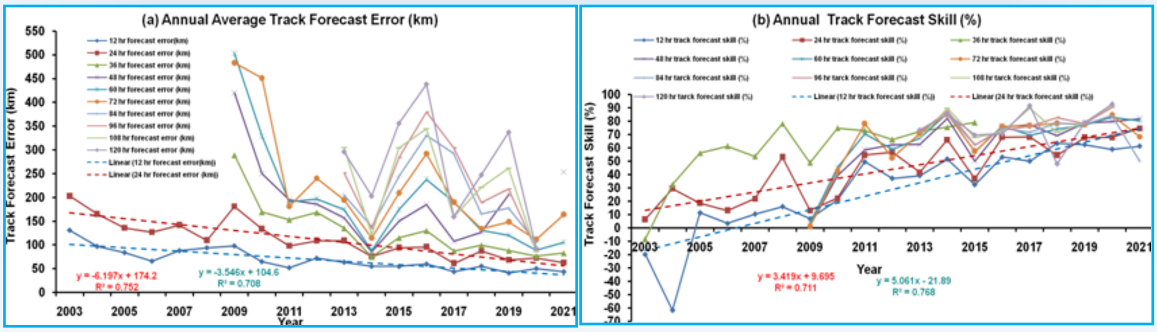
The annual average root mean squareerror (RMSE) in intensity forecast error [Figs.47 (a&b)] has been 8.0 knots, 11.1 knots and 15.8 knots respectively for 24, 48 and 72 hrs lead periodof forecast against the past five year average of 9.9, 13.8 and 16.7 knots. The skill in terms of RMSE



Figs. 46(a&b). Annual average (a) absolute error (AE) in kts and (b) skill in % during 2021 as compared to that during 2016-2020



Figs. 47(a&b). Annual average (a) root mean square error (RMSE) in kts and (b) skill in % during 2021as compared to that during 2016-2020



Figs. 48(a&b). Inter-annual average track forecast (a) errors and (b) skill during 2021 compared to persistence forecast was 70.6%, 80.6% and 81.2% as compared to long period average (2016-20) of 59.5%, 69% and 77.8% for 24, 48 and 72 hours lead period.

5.5.3.2. Interannual errors of TCs over north Indian Ocean

- **Track forecast error and skill**

Inter-annual errors and skill in track forecast since 2003 are presented in Figs. 48 (a&b). There has been significant improvement in annual average track forecast errors and skill due to modernisation programme of IMD in 2009 with respect to observation, analysis and prediction tools & techniques which has been further augmented through improvement in observations, mainly from DWR and satellite and in terms of improved numerical modelling including enhanced data assimilation, higher resolution, improved physics etc.

There has been continuous improvement in track forecast accuracy with decrease in track forecast errors at the rate of 6.2 km/year for 24 hrs lead period and increase in skill at the rate of 3.4% per year (34% in 10 years) since 2003. Similarly, for 12 hrs lead period, there has been improvement in track forecast accuracy with decrease in track forecast errors at the rate of 3.5 km/year (35 km in 10 years) and increase in skill at the rate of 5.1% per year (51% in 10 years) since 2003.

- **Landfall point and time forecast errors**

There has been an improvement in landfall point forecast accuracy at the rate of 15.3 km/year (153 km in 10 years) for 24 hrs lead period since 2003. Similarly, for 12 hrs lead period, there has been improvement in landfall point forecast error at the rate of 7.7 km/year (77 km in 10 years) since 2003. Considering the landfall time errors, there has been an improvement at the rate of 0.22 hrs/year (2.2 hrs in 10 years) for 24 hrs lead period since 2003. Similarly, for 12 hrs lead period, there has been an improvement at the rate of 0.28 hrs/year (2.8 hrs in 10 years) for 12 hrs lead period since 2003 [Figs. 49 (a&b)].

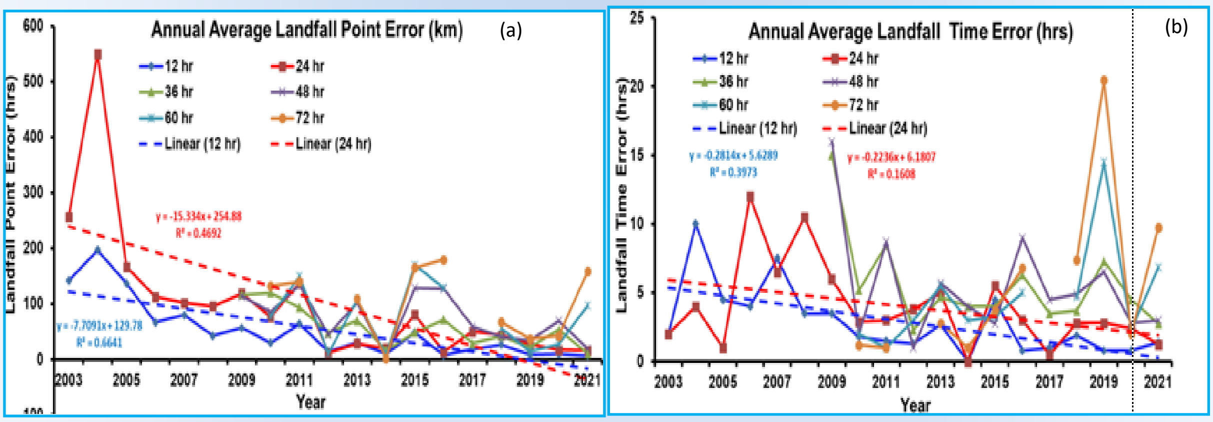
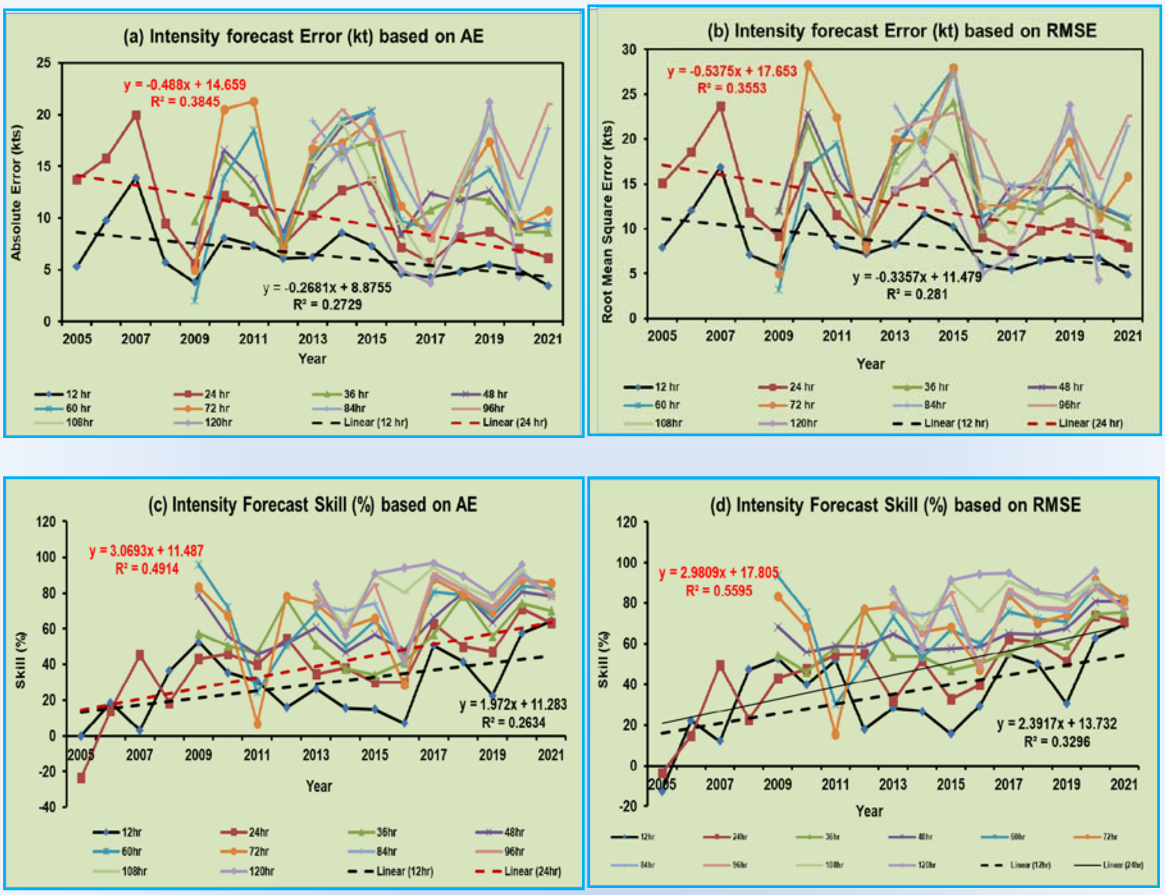


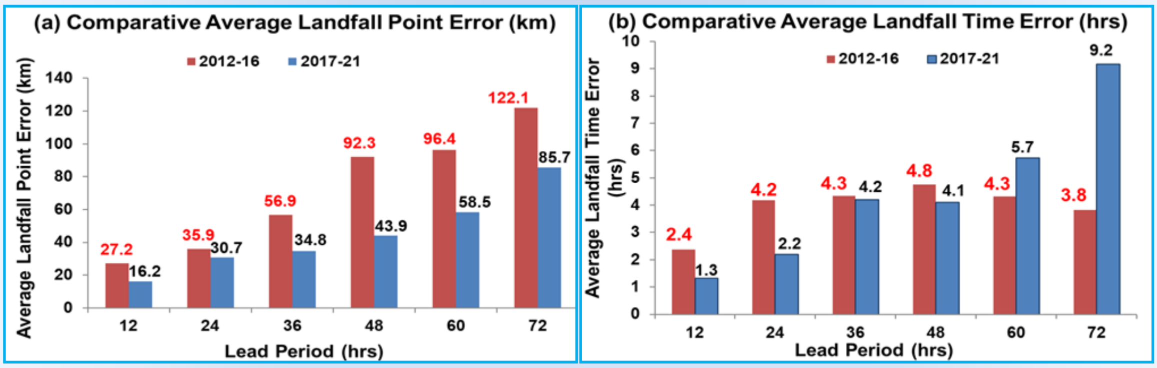
Fig. 49 (a&b). Annual average (a) Landfall Point errors (b) Landfall Time errors

- **Inter-annual intensity forecast error and skill**

Inter-annual errors and skill in intensity forecast since 2005 are presented in Figs. 50(a-d). As regards improvement in intensity forecast based on AE, there has been decrease in errors at the rate of 0.49 knots/year (4.9 knots in 10 years) for 24 hrs lead period and increase in skill at the rate of 3.1% per year (31% in 10 years) since 2005. Similarly, for 12 hrs lead period, there has been decrease in intensity forecast errors at the rate of 0.27 knots/year (2.7 knots in 10 years) and increase in skill at the rate of 2.0% per year (20% in 10 years) since 2003. As regards improvement in intensity forecast errors based on RMSE, there has been decrease in errors at the rate of 0.53 knots/year (5.3 knots in 10 years) for 24 hrs lead period and increase in skill at the rate of 3.0% per year (30% in 10 years) since 2005. Similarly, for 12 hrs lead period, there has been decrease in intensity forecast errors at the rate of 0.34 knots/year (3.4 knots in 10 years) and increase in skill at the rate of 2.4% per year (24% in 10 years) since 2003.



Figs. 50 (a-d). Annual average intensity forecast (kt) errors based on (a) AE (b) RMSE and intensity forecast skill (%) based on (c) AE (d) RMSE



Figs. 51(a&b). Comparative average landfall (a) point and (b) time forecast errors during 2017-21 vis-à-vis 2012-16

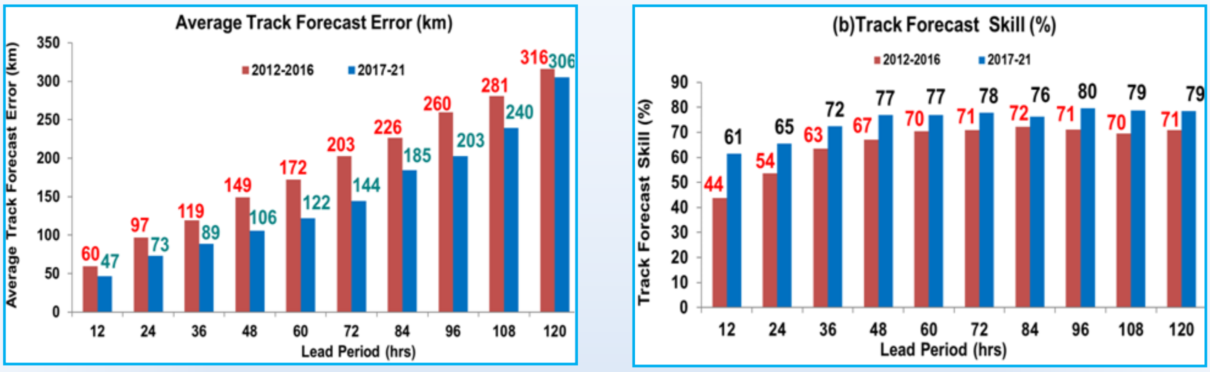
5.5.4 Comparative analysis of forecast accuracy in recent five years (2017-21) as compared to previous five years (2012-16)

5.5.4.1 Landfall Forecast Error

Comparative analysis of landfall point error (LPE) and landfall time error (LTE) during 2017-21 vis-à-vis. 2012-16 is presented in Figs. 51 (a&b). The LPE for 24, 48 and 72 hrs lead period during 2017-21 were 30.7 km, 43.9km and 85.7 km against 35.9 km, 92.3 km and 122.1 km respectively during 2012-16 which shows an improvement of 14.5%, 52.4% and 29.8% respectively. The LTEs for 24 and 48 hrs lead period during 2017-21 were 2.2hrs & 4.1hrs against 4.2hrs & 4.8hrs respectively during 2012-16 registering an improvement of 44.3% and 2.96 % for 24 and 48 hours lead period respectively.

5.5.4.2 Track forecast error and skill

The comparative analysis of average track forecast error and skill during 2017-21 and 2012-16 is



Figs. 52(a&b). Comparative Average track forecast (a) error and (b) skill during 2017-21 vis-à-vis 2012-16

presented in Fig. 52. The average track forecast errors during 2017-21 were 73 km, 106 km & 144 km against 97 km, 149 km & 203 km during 2012-16 for 24, 48 and 72 hrs lead period respectively. There has been an improvement of 25%, 29% & 29% in track forecast errors for 24, 48 and 72 hours lead period during 2017-21 with respect to 2016-2020. The 24, 48 and 72 hr average track forecast skill during 2017-21 were 65%, 77% and 78% against 54%, 67% and 71% respectively during 2012-16 with an improvement of 12%, 10% and 7% for 24, 48 and 72 hours lead period during 2017-21 with respect to 2016-2020.

5.5.4.3. Intensity forecast error and skill

The comparative analysis of average intensity forecast error and skill based on AE and RMSE during 2017-21 and 2012-16 are presented in Fig. 53 and Fig. 54. The average intensity forecast error based on AE for 24 hrs, 48 hrs and 72 hrs are 7.8 knots, 11.5 knots and 14.2 knots during 2017-21 against 10.7 knots, 15.5 knots and 16.3 knots during 2017-21. Based on RMSE the intensity forecast errors were 15.2 knots, 19.8 knots and 21.7 knots during 2017-21 against 14.4 knots, 20.8 knots, and 21.1 knots during 2012-16. It can be

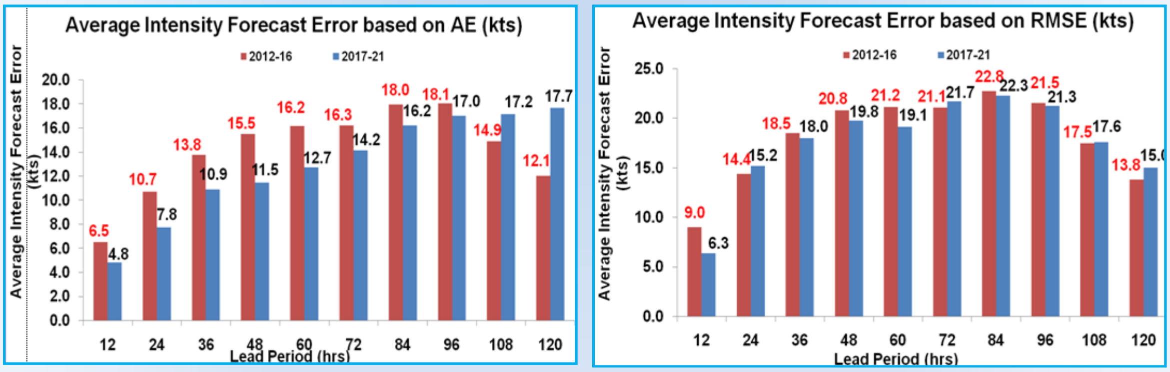


Fig. 53. Comparative Average Intensity forecast errors (kts) based on (a) absolute error and (b) root mean square errors during 2017-21 vis-à-vis 2012-16

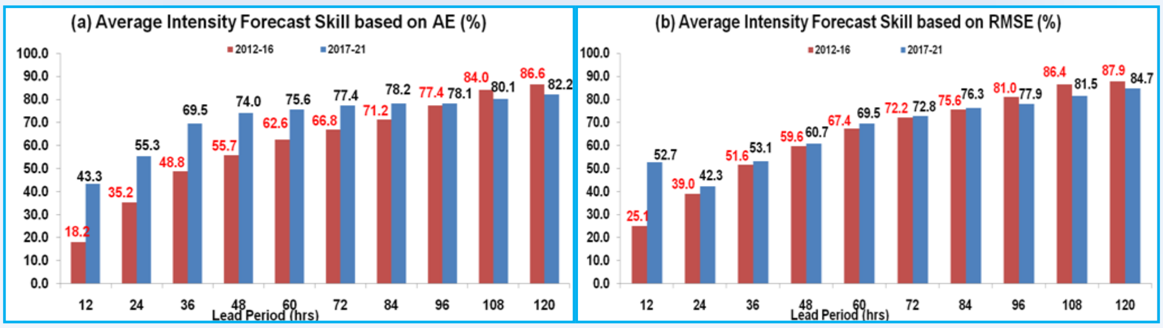
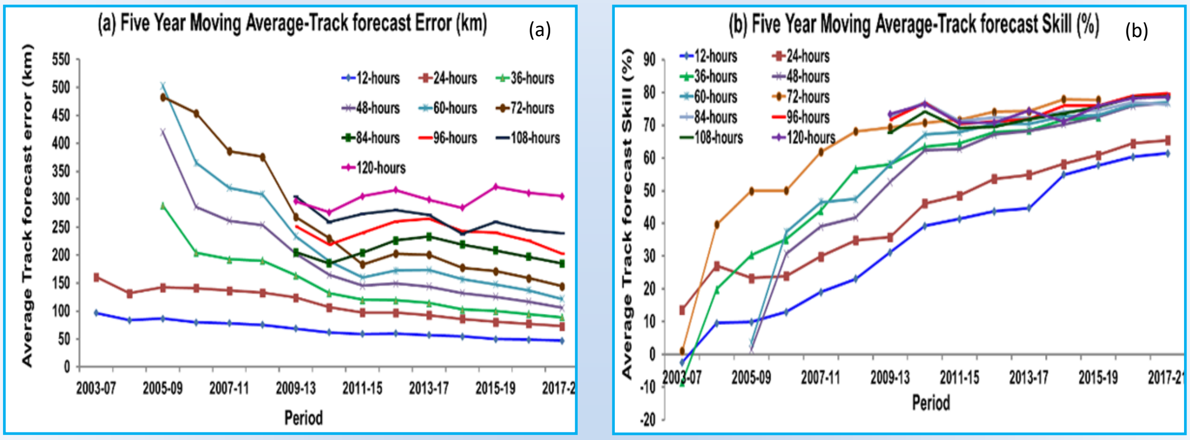


Fig. 54. Comparative Average Intensity forecast skill (%) based on (a) absolute error and (b) root mean square errors during 2017-21 vis-à-vis 2012-16

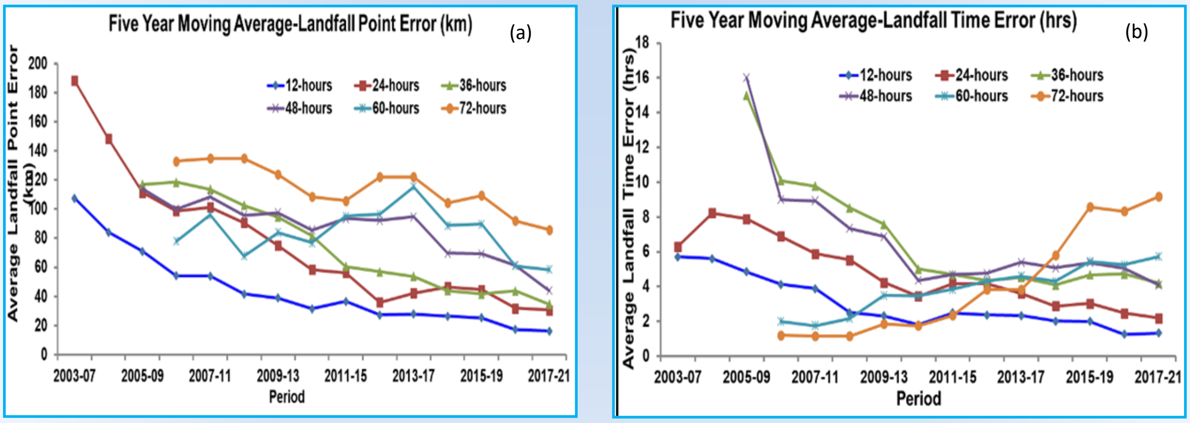
seen that there has been marginal improvement in intensity forecast during recent five years (2017-21) as compared to previous five years (2012-16).

Five Year Moving Average errors and skill over north Indian Ocean

It can be seen from Figs. 55-57 that there has been continuous improvement in forecast accuracy with decrease in landfall and track forecast errors and increase in skill over the years. Due to modernization programme of IMD and other initiatives of MoES, the improvement has been more significant since 2009. However, the rate of improvement in intensity forecast over the years has been marginal as can be seen from Figs. 57(a&b). The 36-72 hoursforecasts commenced from 2009 and it was further extended to 120 hrs from 2013 onwards.



Figs. 55(a&b). Five Year Moving Average (a) Track Forecast Error (km) and (b) Track Forecast Skill (%) of RSMC, New Delhi over North Indian Ocean

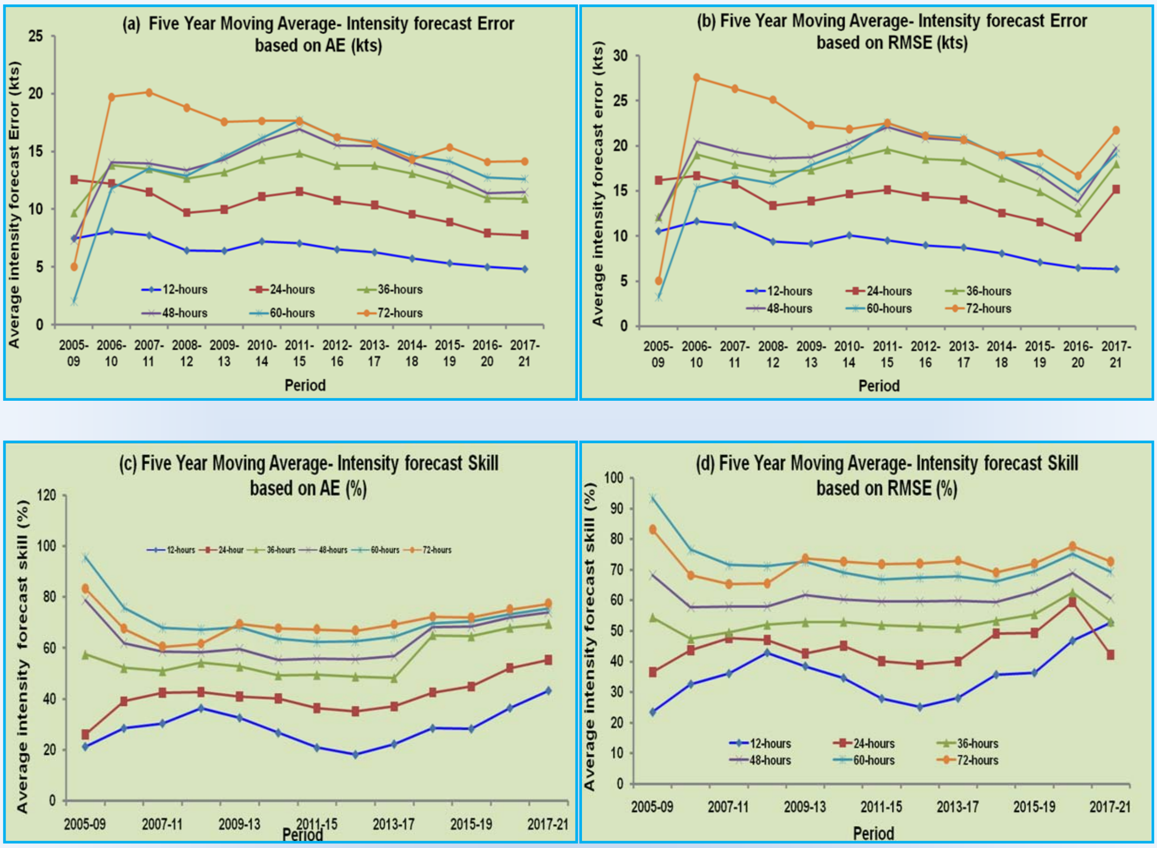


Figs. 56(a&b). Five Year Moving Average Errors in (a) Landfall Point (km) and (b) Landfall Time (hrs) of RSMC, New Delhi over north Indian Ocean

5.6. Drought Monitoring & Prediction

Drought Monitoring and Prediction is being done using different indices like SPI (Standardized Precipitation Index), AAI (Aridity Anomaly Index) and SPEI Drought monitoring using Aridity Anomaly Index (AAI). The SPI maps are being generated every week as well as every month to identify the regions with prevailing or beginning / ending of the Extremely/ severely/ moderately dry/ wet conditions. The detailed statistics of the SPI computed for the entire SW monsoon period helps the various state government agencies for initiating drought management. Weekly SPI maps and values is being sent to all the state authorities as demanded by them according to new Drought manual of Ministry of Agriculture.

Weekly Drought monitoring using Standardized Precipitation Evaporation Index (SPEI) has been



Figs. 57(a-d). Five Year Moving Average Intensity Forecast (a) Absolute Error (kts) and (b) Root Mean Square Error (kts) of RSMC, New Delhi over the NIO and Five Year Moving Average Intensity Forecast skill based on (c) AE and (d) RMSE of RSMC, New Delhi over North Indian Ocean

done in the year 2020. Prediction of one-week advance SPI and AAI maps is being done during SW monsoon and NE monsoon using IMD GFS district rainfall forecast. SPI Forecast maps for one week to four weeks are also being generated using ERFS data.

Climate services for water sector

Weekly monitoring and prediction of basin averaged rainfall and volume of water for 101 river sub basins of India based on ERF has been started in the year 2019 and are being regularly uploaded in IMD Pune website.

Climate services for Health sector

Climate information for Health bulletin viz., temporal evolution of spatial distribution of transmission window for Vector borne disease and probabilistic outlook about prevalence of climatic suitability for VBD occurrence based on extended range weather forecast on weekly basis started in the 2nd week of May, 2017 is continued on every Friday. The regions which are likely to get maximum/ minimum temperature within threshold maximum / minimum temperature of above VBD transmission windows during succeeding two weeks are indicated.

CHAPTER 6

CAPACITY BUILDING, PUBLIC AWARENESS & OUTREACH PROGRAMME

IMD's major initiative in 2021 was to provide capacity building for its officers and staff, personnel from the other organizations in the country as well as from foreign countries particularly personnel from Asia pacific regions through organised training programmes, user workshops, conferences etc. Salient details are as under.

"Brain Storming Workshop on Monsoon 2020" was jointly organized by MoES, IMD, IITM and NCMRWF on 18th January, 2021.

"**Familiarization Workshop**" for officials of Central and State Pollution Control Boards was organized by IMD and IITM, Pune in collaboration with CPCB on 1st February, 2021.

IMD Organized 1st National Workshop on "**Impact Based Weather Forecasting**" during 30th August-3rd September, 2021 with participation of 166 Scientists from IMD, IITM, NCMRWF, GSI, NCCR, INCOIS (https://internal.imd.gov.in/press_ release/ 20210828_pr_1211.pdf). **Dr. M. Mohapatra**, DG IMD inaugurated the workshop.

IMD organised 7th WMO International Workshop on Monsoons (IWM-7) (Online) Training Workshop on Sub-Seasonal to Seasonal (S2S) Prediction of Monsoons on 1st November, 2021.

IMD participated in the 2nd Project Monitoring Committee Meeting for National Super Computing Project (NSM) "**Urban Modelling**" for development of Multi-Sectoral Simulation Lab and Science based decision support frame-work to address Urban Environment Issues on 18th March, 2021.

Dr. M. Mohapatra, DG, IMD attended first meeting of "**Planning Committee of Space Applications Management System (PC-SAMS)**" under chairmanship of Principal Scientific Adviser to GOI on 18th June, 2021.

Dr. M. Mohapatra, DG, IMD,**Dr. Kamaljit Ray**, Sc. 'G', **Dr. Ashish Mitra**, **Dr. S. D. Attri**, Sc. 'G', **Shri K. S. Hosalikar**, Sc. 'G', **Dr. D. R. Pattanaik**, Sc. 'F' and **Dr. R. K. Giri**, Sc. 'F' participated in the "**17th Regional Association-II**" from 27-30 September, 2021.

Dr. M. Mohapatra, DG, IMD and other officials during "17th Regional Association-II"

Dr. Mrutyunjay Mohapatra, DG, IMD participated in the meeting of '**Executive Council-74 of WMO**' to follow-up on the "**Decisions of Cg. Ext. (2021)**" through Video Conference on 25th and 27-28 October, 2021.

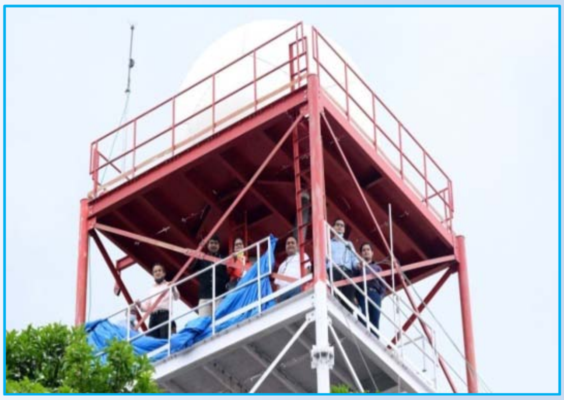
Dr. S. D. Attri, Sc. 'G' represented India as **Principal Delegate** in Meeting of the "**Commission for Weather, Climate, Water and Related Environmental Services & Applications (Services Commission or SERCOM)**" organized by WMO during 22-26 February, 2021. The meeting was also attended by Dr. Ashish Mitra, Sc-G & Head NCMRWF, R. K. Giri, Sc. 'E' and other Officers.

A Virtual Training Programme was organised on **"Preparation of Weather Maps using QGIS"** and **"Weather Bulletins Warning Graphics in Local Languages"** under the chairmanship of DG, IMD, New Delhi was held on 24th February, 2021.

To best utilize '**Grammarly Premium**' a training followed by Question and Answer session, for the users of IMD has been conducted through Webinar on 3rd August, 2021.

To best utilize resource of '**DERCON (Digital Earth Consortium), 'MoES**', for the Scientist/Researchers and other users of India Meteorological Department a one-hour training of the **Nature.com platform** followed Question & Answer session and a training by Elsevier to "**Accelerate research planning using Scopus**" followed Question & Answer session on 20th September, 2021 & for "**Effective research execution using Science Direct & Mendeley**" on 21st September has been conducted through Webinar on 13th September, 2021.

Five IMD officers have been imparted DWR hardware training with regard to **newly installed X-band dual polarized DWRs**. The training was conducted in factory location of M/s Astra Microwave Private Limited, Hyderabad during September, 2021.



DWR hardware training at M/s AMPL, Hyderabad

WEBINAR

328 Farmers' Awareness Programs have been conducted by Agromet Advisory Services Division during the quarter ending on 31st March, 2021 under the **GKMS Scheme**.

Pre-Cyclone Exercise Meet

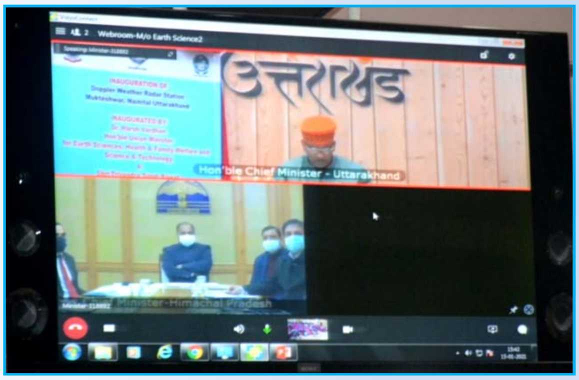
Pre-Cyclone Exercise was conducted by IMD through its Cyclone Warning Division, New Delhi and various Cyclone Warning centres of the country during April 2021. As a part of it, a pre-cyclone exercise meeting was organised by Cyclone warning Division IMD, New Delhi on a virtual platform, on 1st April under the chairmanship of **Dr. Mrutyunjay Mohapatra**, Director General of Meteorology (DGM), IMD to review the preparedness, take stock of requirements, plan for the cyclone season April-June, 2021 and share new initiatives by IMD with stakeholders. There were around 100 participants including experts from IMD, National Centre for Medium Range Weather Forecasting (NCMRWF), Indian Air Force (IAF), Indian Navy (IN), Central Water Commission (CWC), Indian Institute of Technology (IIT) Delhi, Indian National Centre for Ocean Information Services (INCOIS), National Disaster Management Agency (NDMA), National Disaster Response Force (NDRF), Deptt. of Fisheries, Punctuality Cell, Indian Railways and Central Water Commission (CWC) and senior level officers from State Governments including all the coastal states of India.

"**Signing ceremony of Country Hydromet Diagnostics (CHD) Report of WMO**" prepared jointly by IMD & Maldives was held on 7th June, 2021.

Dr. Jitendra Singh, Hon'ble Minister of Earth Sciencesvisited IMD on 18th July, 2021.

IMD FOUNDATION DAY, 2021

India Meteorological Department celebrated its 146th Foundation day on 15th January, 2021. **Dr. Harsh Vardhan**, Hon'ble Union Minister for Earth Sciences, Health & Family Welfare and Science & Technology graced the occasion as the Chief Guest, **Shri Trivendra Singh Rawat**, Hon'ble Chief Minister of Uttarakhand and **Shri Jai Ram Thakur**, Hon'ble Chief Minister of Himachal Pradesh participated as the **Guest of HonourDr. Madhavan Nair Rajeevan**, Secretary, Ministry of Earth Sciences presided over the function. **Dr. M. Mohapatra**, DG, IMD welcomed the distinguished guests and highlighted the achievements of IMD during the year 2020. Hon'ble Union Minister dedicated two Doppler Weather Radars installed at Mukteshwar, Uttarakhand and Kufri, Shimla, Himachal Pradesh to the nation.



72nd REPUBLIC DAY

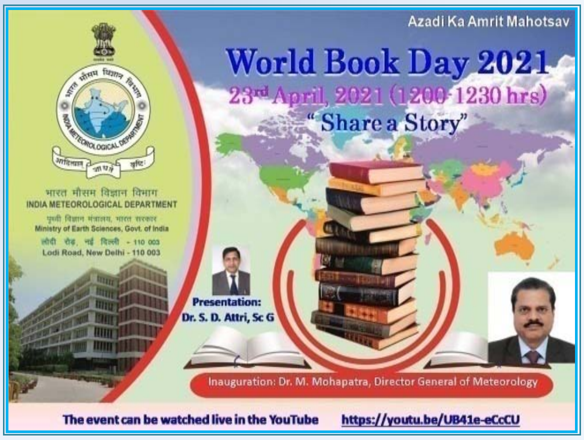
72nd Republic Day of India was celebrated and National Flag was hoisted at H.Q., IMD and all sub-offices of IMD across India on 26th January, 2021. On this occasion, all heads of the offices hoisted National Flag and sang National Anthem and other patriotic songs along with officers and staff members.

WORLD METEOROLOGICAL DAY 2021

India Meteorological Department celebrated **World Meteorological Day** on 23rd March, 2021 at HQ New Delhi nd its field offices in the country. On this occasion, **IMD** released Climate Data Service Portal, 21 Standard Operation Procedure Manuals on various forecasting services of IMD and a series of brochures/templates highlighting the services rendered by various divisions and offices of IMD.

World Book Day

World Book Day was celebrated in IMD on 23rd April, 2021 highlighting knowledge resources of IMD and its online services to the scientific community and public which was chaired by DGM.



The **19th South Asia Climate Outlook Forum** and **Climate Services Users Forum** was jointly organised by UKMO, RCC, IMD and RIMES during 26-29 April, 2021. On 26th April, 2021,

Dr. Madhavan Nair Rajeevan, Secretary MoES and **Dr. Trilochan Mohapatra**, Secretary DARE & DG ICAR GoI jointly chaired meeting on "**Effective implementation of Gramin Krishi Mausam Sewa (GKMS) scheme**" for the benefit of farming community in the country on 27th April, 2021 which was also attended by DGM, Principal Secretaries and senior officers of Sate Departments of Agriculture, ICAR, Agric. Universities, ATARIs, AMFUs, DAMUs and IMD.

Swachhta Pakhwada was held at **IMD** from 1-15 July, 2021. This included **tree plantation programme** in the office compound, drawing competition for children, essay competition on Swachhta for officers and staffs and overall cleaning of the office.

Launching of "**Pune Live weather App**" by **Dr. M. Rajeevan**, Secretry MoES on 27th July, 2021 in presence of **Dr. M. Mohapatra**, DG IMD and other senior delegates on the occasion of MoES Foundation day Celebration. The App is developed by Surface Instrument Division under CRS Pune.

Urban Metrological Services for Delhi NCR Region was inaugurated on 30th July, 2021.

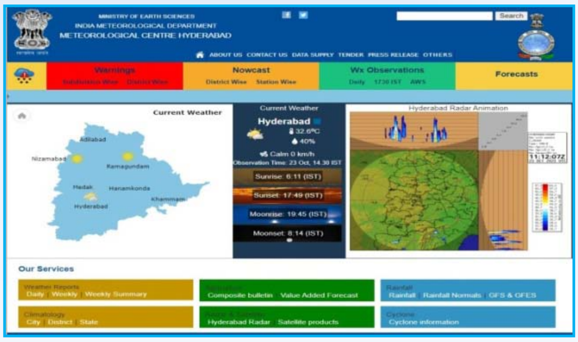
CELEBRATION OF AZADI KA AMRIT MAHOTSAV

To commemorate the 75th anniversary of Independence of India, India Meteorological Department celebrated Iconic week during 18-24 October, 2021 as a part of '**Azadi Ka Amrit Mahotsav**'. During this period, Lecture series, webinars and drawing, poem and quiz competitions on the theme of weather and climate were organised by the IMD at its various offices located throughout India.

Dr. Jitendra Singh, **Hon'ble Minister of State** (Independent Charge), Ministry of Science & Technology and Earth Sciences, Minister of State, Prime Minister's Office, Ministry of Personnel, Public Grievances and Pensions, Department of Atomic Energy and Department of Space, Government of India has inaugurated tower based dual polarized X-band Doppler weather radar (DWR) and Indigenous GPS based Pilot Sonde at Meteorological Office Jammu at on 5th September, 2021.

Inauguration of pilot-sonde system by Hon'ble Minister Dr. Jitendra Singh

IMD has introduced uniform website of Regional Meteorological Centers and Meteorological Centers.



IMD **and** GMDA, Govt. of Haryana signed LoA on 6th December, 2021 at IMD New Delhi in the presence of DGM and senior officers of IMD & GMDA for Setup an Environment and Climate Monitoring System.

India Meteorological Department (IMD) organized the on-line pre-cyclone exercise meeting on 25th October, 2021 under the chairmanship of **Dr. Mrutyunjay Mohapatra**, DG, IMD to review the preparedness, take stock of requirements, plan for the cyclone season October-December, 2021 and share new initiatives by IMD with stake holders. Various national and state level disaster managers including experts from Ministry of Home Affairs (MHA), National Disaster Response Force (NDRF), National Disaster Management Agency (NDMA), Department of Fisheries, Central Water Commission (CWC), Indian Air Force (IAF), Indian Navy (IN), Ministry of Port & Shipping, Ministry of Oil Industry, Ministry of Defense, Ministry of Petroleum & Natural Gas, Ministry of Health & Family Welfare, Ministry of Railways, All India Radio, Doordarshan, Coast Guard, Government of West Bengal, Odisha, Andaman & Nicobar Islands, Andhra Pradesh, Tamil Nadu, Puducherry, Kerala, Karnataka, Goa, Maharashtra, Gujarat, sister organizations of IMD including National Centre for Medium Range Weather Forecasting (NCMRWF), Indian National Centre for Ocean Information Services (INCOIS), Indian Institute of Tropical Meteorology, Pune, Indian Institute of Technology (IIT) Delhi, Area Cyclone Warning Centres (CWC) of IMD at Chennai, Mumbai, Kolkata, Cyclone Warning Centres at Bhubaneswar, Visakhapatnam, Thiruvananthapuram and Ahmedabad, Radar Divisions at various coastal states and experts of IMD at Delhi Office participated in the meeting. DGM IMD briefed the participants about new initiatives in warning services of IMD that has helped minimize loss of life to less than 100 in recent years.

Vigilance Awareness Week was observed during 26th October, 2021 to 1st November, 2021 at IMD in respective division and all the officials took pledge pertaining to integrity.

IMD observed **Samvidhan Diwas (Indian Constitution Day)** on 26th November, 2021. The preamble was read and an online quiz on Constitutional Democracy was held and certificated were provided to the participants.

India Meteorological Department (IMD) is one of six Regional Specialised Meteorological Centres (RSMCs) in the world recognised by the World Meteorological Organisation (WMO) under a global system for issue of warnings and advisories in association with cyclonic disturbances over north Indian Ocean to 13 WMO/ Economic and Social Commission for Asia and Pacific (ESCAP) Panel member countries. In addition, IMD also conducts training for cyclone forecasters in the region annually as part of capacity building measure. IMD started conducting tropical cyclones forecasters training since 2005. This year, the WMO's Tropical Cyclones Forecasters Training 2021 was conducted by RSMC, New Delhi during 06-18 October, 2021 through Web-Ex. This was the 17th such training programme for the cyclone forecasters of the member countries. There were 56 participants including 22 International participants from Thailand, Myanmar, Sri Lanka, Maldives, Pakistan, Iran, Oman, Yemen, Saudi Arabia, and 34 participants from various sub-offices of IMD.

CHAPTER 7

RESEARCH PUBLICATIONS

MAUSAM (Formerly Indian Journal of Meteorology, Hydrology & Geophysics), established in January 1950, is the quarterly research journal brought out by the department. It is a premier scientific research journal in the field of Meteorology, hydrology & Geophysics for publication of original scientific research work. MAUSAM is being indexed and abstracted by Thomson Reuter U.S.A. For the year 2020 it has an IMPACT FACTOR (IF): 0.636 and 5-year Impact factor 0.499 calculated by Thomson Reuter U.S.A. The rating score given by National Academy of Agricultural Sciences (NAAS) for the year 2020 is 6.24. IMD Scientists published 113 research paper/books in Mausam/Met. Monograph/Met Reports and National & International Journal during 2020.

7.1. RESEARCH CONTRIBUTIONS PUBLISHED IN 'MAUSAM'

Mrutyunjay Mohapatra, Monica Sharma, S. V. J. Kumar, **Sunitha S. Devi**, and **Bharati S. Sabade**, "**Frequency of Genesis And and fall of Different Categories of Tropical Cyclones Over theNorth Indian Ocean**", *Mausam*, **72**, 1 (January, 2021), 1-26, https://doi.org/ 10.54302/mausam.v72i1.119.

D. R. Pattanaik and **M. Mohapatra**, "**Evolution of IMD's operational extended range forecast system of tropical cyclogenesis over North Indian Ocean during 2010-2020**", *Mausam*, **72**, 1 (January, 2021), 35-56, https://doi.org/ 10.54302/mausam.v72i1.124.

S. Saranya Ganesh, S. Abhilash, S. Joseph, Manpreet Kaur, , A. Dey, R. Mandal, R. Phani, R. Chattopadhyay, **D. R. Pattanaik** and A. K. Sahai, "**A review of the development and implementation of a tropical cyclone prediction system for North Indian Ocean in a multi-model ensemble framework**", *Mausam*, **72**, 1, 57-76, https://doi.org/10.54302/ mausam.v72i1.126

S. D. Kotal and **S. K. Bhattacharya**, "**Evolution of tropical cyclone forecasts of dynamical - Statistical Cyclone Prediction System (CPS) over the North Indian Ocean during the decade (2010-2019)**", *Mausam*, **72**, 1 (January, 2021), 87-106, https://doi.org/10.54302/ mausam.v72i1.128.

Medha Deshpande, Radhika Kanase, R. Phani Murali Krishna, Snehlata Tirkey, P. Mukhopadhyay, V. S. Prasad, C. J. Johny, V. R. Durai, **Sunitha Devi** And **M. Mohapatra**, "**Global Ensemble Forecast System (GEFS T1534) evaluation for tropical cyclone prediction over the North Indian Ocean**", *Mausam*, **72**, 1 (January, 2021), 119-128, https://doi.org/10.54302/mausam.v72i1.123.

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M. Sateesh, **Chinmay Khadke**, **V. S. Prasad** and Suman Goyal, "**Validation of satellite estimated convective rainfall products: A case study for the summer cyclone season of 2020**", *Mausam*, **72**, 1 (January, 2021), 229-236, https://doi.org/ 10.54302/mausam. v72i1.137.

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Amit Kumar, Anil Kumar Singh, **R. K. Giri** and J. N. Tripathi, "**Inundation mapping using SENTINEL-1 data in the aftermath of super cyclone Amphan: A case study**", *Mausam*, **72**, 1, 253-264, https://doi.org/10.54302/ mausam.v72i1.140.

R. Bibraj, K. Ramachandra Rao, **Prayek Sandepogu**, **Vkl Ganeswara Rao**, Ch. Ramana and **K. C. Saikrishnan**, "**Automatic Weather Radar Based Geo-Specific Severe-Weather Alerting System (R-Alert)**", *Mausam*, **72**, 2, 291-300, https://doi.org/10.54302/mausam. v72i2.617.

S. G. Narkhedkar, **S. N. Dutta**, V. Anilkumar, S. Mukherjee and G. Pandithurai, "**Rainfall Characteristics and Its Variability Over A High-Altitude Station in Western Ghats During Southwest Monsoon Of 2015 - A Case Study**", *Mausam*, **72**, 2 (April 2021), 331-348, https://doi.org/10.54302/mausam.v72i2.621.

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A. **Kashyapi** and **V. K. Shripad**, "**Cyclonic storms and Depressions over the north Indian Ocean during 2020**", *Mausam*, **72**, 3 (July 2021), 531-544, https://doi.org/10.54302/ mausam.v72i3.1304.

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K. K. Dakhore, A. S. Rathod, D. R. Kadam, G. U. Shinde, Y. E. Kadam and **K. Ghosh**, "**Prediction of Kharif cotton yield over Parbhani, Maharashtra : Combination of extended range forecast and DSSAT-CROPGRO-Cotton model**", *Mausam*, **72**, 3 (July 2021), 635-644, https://doi.org/10.54302/ mausam.v72i3.1313.

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7.4. OTHER PUBLICATIONS

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CHAPTER 8

FINANCIAL RESOURCES AND MANAGEMENT PROCESS

8.1. Budget Outlay of approved schemes of IMD

IMD receives its budget allocation under two categories namely, budget for implementation of Central Sector schemes and budget for Establishment related expenditure. Budget Estimates (B.E.)/ Revised Estimates (R.E.) during Financial Year 2021-22 are as follows:

Budget Estimates 2021-22 (Rs. in Crores)			
	Central Sector Schemes	**Establishment**	**Total**
BE	**255.40**	**438.16**	**693.56**
RE	183.46	465.19	648.65

Atmospheric & Climate Research - Modelling Observing Systems & Services (ACROSS)

Following sub-schemes under the umbrella scheme ACROSS are being implemented in IMD.

1. Commissioning of Polarimetric Doppler Weather Radars (PDWR)
2. Upgradation of Forecast System (UFS)
3. Weather and Climate Services (WCS)
4. Atmospheric Observations Network (AON)

The ACROSS scheme pertains to the atmospheric science programs of MoES. The overarching objective of the 'ACROSS' scheme is to conduct R&D or improving forecast of weather, climate and other hazardous events in real time for delivery of a reliable weather and climate service. This requires

a. Augmentation of atmospheric and oceanic observations and their assimilation into weather and climate models.

b. Understating the physical processes through field/observational campaigns.

c. Developing and using of high resolution weather and climate prediction models for giving forecasts in all temporal and spinal scaled.

d. Translating science to service and its delivery to society

All the sub-schemes along with other sub-schemes under ACROSS were evaluated by Independent Review Committee (IRC) taking the domain experts from various national Institutes/ Departments.The committee evaluated the sub-schemes in terms of importance of the schemes in the context of national development, mechanism of implementation, achievements corresponding to the objectives of the scheme, key bottlenecks/issues & challenges surfaced during the implementation, assets created/services provided to the beneficiaries and Direct/indirect employment generation. Financial review on allocation and expenditure of the scheme was also made.

The IRC recommended continuation of all the four schemes of IMD along with the other schemes under ACROSS from the 14th Finance commission (2017-20) to the 15th Finance Commission.

Budget Estimate for the period 2021-22 to 2025-26 for sub-scheme being implemented by IMD under ACROSS is as follows:

S. No.	Name of the Scheme/Project	Budget Outlays(Rs. in Crores)
1.	Atmospheric observations Network (AON)	387.0
2.	Upgradation of Forecast System (UFS)	357.0
3.	Weather & Climate Services (WCS)	386.0
4.	Commissioning of Polarimetric DWRs	130.0
	Total	**1260.0**

The projects under ACROSS-IMD are continuing programs from previous Plan periods encompassing various activities in an integrated manner to ensure the sustenance & augmentation of observations & enhancement of facilities required for the weather forecasting services. The programs are being implemented by various Offices/Divisions across the country having long and requisite experience in the required fields. Various scientists have been assigned for implementation of the activities. With the Delegation of Enhanced Financial Powers to Heads of RMCs, MCs and CDRs/DWRs etc. & stand-alone offices headed by Group 'A' officers and Remote Offices in India Meteorological Department, execution of the scheme is being done at all offices across the country and expenditure is incurred by RMCs, MCs and other offices of the Department for successful implementation of the scheme. The implementation of the activities is under the overall guidance of the Director General of Meteorology and other senior scientists.

8.2. REVENUE GENERATED DURING THE YEAR 2021

Sale of Meteorological Data

RCs/MCs	Total revenue received by sale of meteorological data during the month (Amount in Rupees)											
	Jan	Feb	Mar	Apr	May	Jun	Jul	Aug	Sep	Oct	Nov	Dec
DGM, New Delhi												
DGM SATMET	NIL	NIL	NIL	NIL	NIL	NIL	NIL	NIL	NIL	NIL	NIL	NIL
DGM HYDROLOGY	NIL	183967	467083	NIL	283115	659348	170826	NIL	128185	53843	NIL	NIL
DGM (Publication)	26475	16675	34475	16950	8450	8225	675	38825	12000	4225	NIL	225
RMC, New Delhi												
New Delhi	17394	122398	25401	99381	4861	12555	34100	48938	38036	28161	15056	7376
Jaipur	3496	21574	18246	NIL	NIL	86501	30595	46409	11937	4602	47519	14842
Lucknow	76996	27266	33194	NIL	2538	11426	15358	4544	4956	12582	52917	22056
Srinagar	19900	24993	36702	6690	8614	11399	7511	48946	1888	3953	4130	20156
Chandigarh	NIL	1802	13008	10637	8673	2093	5410	20979	23294	22268	8013	NIL
Shimla	NIL	NIL	NIL	NIL	NIL	NIL	NIL	NIL	NIL	NIL	NIL	NIL
Dehradun	7242	26385	33929	11317	NIL	35976	70260	46726	21712	28289	38912	26665
RMC, Mumbai												
Mumbai	18321	22171	7899	38838	NIL	24480	70181	31795	36909	7410	27312	15653
RMC, Nagpur												
Nagpur	55829	43727	5337	8247	33130	64075	45499	60560	47571	28132	51832	37375
Bhopal	NIL	NIL	NIL	NIL	NIL	NIL	NIL	NIL	NIL	NIL	NIL	NIL
RMC, Kolkata												
RMC Kolkata	70109	NIL	43490	13719	90253	7198	30527	13990	10742	9290	27101	1912
PAC Kolkata	NIL	NIL	6109	NIL	13465	10503	8364	NIL	13096	NIL	30032	NIL
Patna	13343	5290	7788	6892	NIL	NIL	NIL	NIL	17562	39705	28480	6366
Bhubaneswar	52276	8514	5074	63943	NIL	47988	34188	NIL	NIL	38686	73319	NIL
Gangtok	13090	6199	4132	13598	NIL	6750	NIL	18575	NIL	17700	7080	NIL
Ranchi	5802	1260	9940	5192	NIL	12965	5518	11751	10315	17410	NIL	NIL
RMC, Guwahati												
Guwahati	96550	82299	74722	10097	6084	25896	77475	14926	88475	12738	NIL	42536
Agartala	NIL	NIL	NIL	NIL	4610	3778	4309	4934	1145	15686	11277	NIL
RMC, Chennai												
Chennai	89000	61065	104861	65478	3024	23443	48624	88754	81290	57820	70373	51903
Thiruvananthapuram	53276	153644	22956	45740	10380	14126	28339	14673	18206	3798	17700	7080
Hyderabad	243899	236159	253445	22567	5315	32384	72538	94698	33531	234912	16110	17476
Bangalore	92033	26601	144493	6514	1880	165259	52128	30428	109637	120750	123955	166132
ACWC Chennai	13496	10122	3374	NIL	NIL	4126	3374	6992	NIL	8850	NIL	NIL
CWC Visakhapatnam	NIL	NIL	NIL	5599	1543	2515	3661	2225	NIL	21874	3661	NIL
CRS, Pune												
Pune	938404 US $68	1778643	1128588 US $594	471430 US $695	229487	729868	877489	604161	403089	340805 US $123	566638 US $923	830051 US $1539

CHAPTER 9

राजभाषा नीति का कार्यांवयन

संसदीय राजभाषा समिति द्वारा निरीक्षण

माननीय संसदीय राजभाषा समिति द्वारा निरीक्षण की दूसरी उपसमिति द्वारा दिनांक 23.08.2021 को मौसम केंद्र- गोवा का गोवा में राजभाषायी निरीक्षण किया गया। इस निरीक्षण कार्यक्रम में मुख्यानलय से डॉ. के. के. सिंह, वैज्ञानिक 'जी' तथा श्रीमती सरिता जोशी, सहायक निदेशक (राजभाषा) ने भाग लिया। मुख्यालय की वरिष्ठा अनुवाद अधिकारी, श्रीमती कल्पना श्रीवास्तव भी निरीक्षण में सहयोग के लिए उपस्थित रहीं।

माननीय संसदीय राजभाषा समिति की दूसरी उपसमिति द्वारा दिनांक 26.10.2021 को मौसम केंद्र - गंगटोक का निरीक्षण किया गया। इस निरीक्षण में मुख्यालय की तरफ से डॉ. शिव देव अत्री, वैज्ञानिक 'जी' ने भाग लिया। श्री बीरेन्द्र कुमार, वरिष्ठ अनुवाद अधिकारी भी निरीक्षण के दौरान उपस्थित रहे।

राजभाषायी निरीक्षण

दिनांक 12.01.2021 को मौसम केंद्र-पटना, मौसम केंद्र-राँची तथा खगोल विज्ञान केंद्र- कोलकाता का श्रीमती सरिता जोशी, सहायक निदेशक (रा.भा.) द्वारा राजभाषायी ई- निरीक्षण किया गया।

दिनांक 22.02.2021 को मौसम केंद्र-लखनऊ, मौसम केंद्र - शिमला, मौसम केंद्र - चंडीगढ़ तथा मौसम केंद्र - श्रीनगर का राजभाषायी ई निरीक्षण किया गया। पृथ्वी विज्ञान मंत्रालय के संयुक्त निदेशक (रा.भा.) श्री मनोज आबूसरिया तथा मुख्या।लय के वैज्ञानिक 'जी' डॉ. के. के. सिंह और सहायक निदेशक (राजभाषा) श्रीमती सरिता जोशी द्वारा ई-निरीक्षण किया गया तथा आवश्यमक दिशानिर्देश दिए गए।

सहायक निदेशक (रा.भा.) श्रीमती सरिता जोशी द्वारा दिनांक 03.03.2021 को केंद्रीय क्रय एकक का राजभाषायी निरीक्षण किया गया तथा आवश्यक दिशानिर्देश दिए गए। निरीक्षण में वरिष्ठ अनुवाद अधिकारी श्रीमती कल्पना श्रीवास्तव तथा श्री बीरेन्द्र कुमार भी उपस्थिात रहे।

दिनांक 27.05.2021 को प्रादेशिक मौसम केंद्र - नई दिल्ली तथा मौसम केंद्र - जयपुर का राजभाषायी निरीक्षण किया गया। पृथ्वीं विज्ञान मंत्रालय के संयुक्तं निदेशक (रा.भा.) श्री मनोज आबूसरिया तथा मुख्याकलय के वैज्ञानिक 'जी' डॉ. के. के. सिंह और सहायक निदेशक (राजभाषा) श्रीमती सरिता जोशी द्वारा ई-निरीक्षण किया गया तथा आवश्य क दिशानिर्देश दिए गए।

दिनांक 18.06.2021 को प्रादेशिक मौसम केंद्र - कोलकाता, मौसम केंद्र - भुवनेश्वर तथा जल अनुसंधान सेवाएं, पुणे का ई निरीक्षण किया गया। पृथ्वी विज्ञान मंत्रालय के संयुक्तत निदेशक (रा.भा.) श्री मनोज

आबूसरिया तथा मुख्यालय के वैज्ञानिक 'जी' डॉ. के. के. सिंह और सहायक निदेशक (राजभाषा) श्रीमती सरिता जोशी द्वारा ई-निरीक्षण किया गया।

दिनांक 16.07.2021 को प्रादेशिक मौसम केंद्र, मुंबई द्वारा किए गए मौसम कार्यालय नासिक, औरंगाबाद और पवन गुब्बारा वेधशाला रत्नागिरी तथा दिनांक 12.08.2021 को डी. डब्यूयाल. आर - भुज, मौसम कार्यालय - राजकोट तथा मौसम कार्यालय-भावनगर के राजभाषायी ई निरीक्षण में मुख्यालय से श्रीमती सरिता जोशी, सहायक निदेशक (रा.भा.) उपस्थित रहीं और संबंधित कार्यालयों को आवश्यक दिशानिर्देश दिए।

प्रादेशिक मौसम केंद्र गुवाहाटी द्वारा दिनांक 09.09.2021 को मौसम कार्यालय - सिलचर, तेजपुर तथा धुबरी का राजभाषायी ई निरीक्षण किया गया।

दिनांक 12.10.2021 को प्रादेशिक मौसम केंद्र -नागपुर, मौसम केंद्र-भोपाल तथा मौसम केंद्र - रायपुर का श्रीमती सरिता जोशी, सहायक निदेशक (रा.भा.) द्वारा राजभाषायी निरीक्षण किया गया।

दिनांक 13.10.2021 को प्रादेशिक मौसम केंद्र - कोलकाता तथा मौसम केंद्र - गंगटोक का श्रीमती सरिता जोशी, सहायक निदेशक (रा.भा.) द्वारा राजभाषायी ई-निरीक्षण किया गया।

विमानन मौसम कार्यालय - पंतनगर का दिनांक 17.11.2021 को श्रीमती सरिता जोशी, सहायक निदेशक (रा.भा.) द्वारा राजभाषायी निरीक्षण किया गया।

दिनांक 21.12.2021 को प्रादेशिक मौसम केंद्र-नागपुर द्वारा मौसम कार्यालय - ग्वालियर, मौसम कार्यालय - जबलपुर तथा मौसम कार्यालय - जगदलपुर का राजभाषायी ई निरीक्षण किया गया जिसमें सहायक निदेशक (रा.भा.) श्रीमती सरिता जोशी उपस्थित रहीं और आवश्यक दिशा निर्देश दिए।

ई -हिंदी कार्यशाला

दिनांक 19.03.2021 को एक दिवसीय ई हिंदी कार्यशाला का आयोजन किया गया जिसमें विभाग के दिल्ली सहित विभिन्न उपकार्यालयों के लगभग 125 कार्मिकों ने भाग लिया। कार्यशाला का शुभारंभ महानिदेशक महोदय डॉ. मृत्युंजय महापात्र के संबोधन से हुआ। कार्यशाला में पृथ्वी विज्ञान मंत्रालय के संयुक्त निदेशक (रा.भा.) , श्री मनोज आबूसरिया, केंद्रीय हिंदी प्रशिक्षण संस्थान के सहायक निदेशक श्री राम सकल सिंह , श्रीमती सरिता जोशी , सहायक निदेशक (रा.भा.) तथा वरिष्ठक अनुवाद अधिकारी श्रीमती कल्पना श्रीवास्तव ने व्याख्यान दिए।

दिनांक 23.06.2021 को ई हिंदी कार्यशाला का आयोजन किया गया जिसमें दिल्ली सहित विभिन्न उपकार्यालयों के लगभग 100 कार्मिकों ने भाग लिया। कार्यशाला का शुभारंभ महानिदेशक महोदय डॉ. मृत्युंजय महापात्र के संबोधन से हुआ।

सम्मान

भारतीय भाषा एवं संस्कृति केंद्र, दिल्ली द्वारा भीमताल, नैनीताल में मनाए गए 37वें अखिल भारतीय राजभाषा सम्मेलन एवं प्रशिक्षण शिविर में भारत मौसम विज्ञान विभाग को 'राजभाषा शिरोमणि' पुरस्कार से सम्मानित किया गया। दिनांक 17.11.2021 से 19.11.2021 तक भीमताल, नैनीताल में आयोजित इस सम्मेलन में सहायक निदेशक (रा.भा.) श्रीमती सरिता जोशी तथा वरिष्ठ अनुवाद अधिकारी, श्रीमती कल्पना श्रीवास्तव ने भाग लिया। सहायक निदेशक (रा.भा.) श्रीमती सरिता जोशी ने भारत मौसम विज्ञान विभाग की ओर से सम्मान को ग्रहण किया।

हिंदी दिवस समारोह

- कोविड-19 की परिस्थितियों को ध्यान में रखते हुए मुख्यालय में दिनांक 14.09.2021 को हिंदी दिवस समारोह का सफलतापूर्वक आयोजन किया गया। हिंदी दिवस समारोह की अध्यक्षता डॉ. मृत्युंजय महापात्र महानिदेशक ने की तथा इस समारोह के मुख्य अतिथि सुप्रसिद्ध गज़लकार श्री दीक्षित दनकौरी रहे।

- हिंदी दिवस/हिंदी पखवाड़ा 2021 के दौरान आयोजित की गई 6 प्रतियोगिताओं के 30 विजेताओं को महानिदेशक महोदय डॉ. मृत्युंजय महापात्र एवं मुख्य अतिथि श्री दीक्षित दनकौरी तथा हिंदी दिवस समारोह समिति के अध्यक्ष डॉ. के. के. सिंह वैज्ञानिक 'जी' के हाथों से पुरस्कार एवं प्रमाण-पत्र प्रदान किए गए।

- हिंदी दिवस समारोह 14.09.2021 के अवसर पर राजभाषा हिंदी में सर्वश्रेष्ठ कार्य करने हेतु वर्ष 2020-21 के लिए राजभाषा चलशील्ड केंद्रीय विमानन मौसम प्रभाग को प्रदान की गई।

- महानिदेशक महोदय द्वारा हिंदी दिवस के अवसर पर मुख्यालय में कार्यरत 6 कार्मिकों को सरकारी कामकाज मूलरूप से हिंदी में करने के लिए प्रमाण- पत्र प्रदान किए गए।

- उपकार्यालयों में कार्यरत 10 कार्मिकों को सरकारी कामकाज मूलरूप से हिंदी में करने के लिए महानिदेशक महोदय द्वारा हस्ताक्षरित प्रमाण-पत्र प्रेषित किए गए।

आजादी का अमृत महोत्सव

- भारत मौसम विज्ञान विभाग द्वारा 18 से 24 अक्तूबर 2021 तक 'आजादी का अमृत महोत्सव' से संबंधित आयोजनों हेतु दृष्टि वाधित छात्रों और दिव्यांग छात्रों के लिए व्याख्यान से संबंधित कार्यक्रम हेतु डॉ. के. के. सिंह, वैज्ञानिक 'जी' तथा सहायक निदेशक (रा.भा.) श्रीमती सरिता जोशी को समन्वयकर्ता का कार्यभार सौंपा गया।

- इस संबंध में दिल्ली तथा आस पास के संबंधित विद्यालयों से संपर्क किया गया।

- दिनांक 21.10.2021 को दृष्टि वाधित छात्रों के लिए आयोजित वेबिनार में महानिदेशक महोदय द्वारा ब्रेल लिपि में तैयार की गई सामग्री का विमोचन किया गया ।

माननीय मंत्री महोदय द्वारा अनुमोदित 7 सूत्री चार्टर

- दिव्यांग छात्रों हेतु दिनांक 22.10.2021 को वेबिनार आयोजित किया गया जिसमें मूक बधिर छात्रों को सांकेतिक भाषा में समझाने हेतु सांकेतिक भाषा विशेषज्ञ को आमंत्रित किया गया। दोनों वेबिनार अत्यंत सफल रहे।

- माननीय मंत्री महोदय द्वारा अनुमोदित 7 सूत्री चार्टर के कार्यान्वयन के संबंध में दिनांक 25.05.2021 को नोडल अधिकारियों तथा सभी उपकार्यालयों/ मौसम केंद्रों तथा मुख्यालय की राजभाषा कार्यान्वयन समिति के सदस्यों की ऑनलाइन (वर्चुअल) बैठक आयोजित की गई। श्रीमती सरिता जोशी, सहायक निदेशक (रा.भा.) ने इस बैठक का सदस्य सचिव के रूप में आयोजन किया।

- माननीय मंत्री जी द्वारा अनुमोदित 7 सूची चार्टर के अनुपालन के संबंध में दिनांक 27.08.2021 को महानिदेशक महोदय की अध्यक्षता में वर्चुअल बैठक आयोजित की गई जिसमें श्रीमती सरिता जोशी, सहायक निदेशक (रा.भा.) ने सदस्य सचिव का दायित्व संभाला। बैठक में लगभग सभी प्रादेशिक मौसम केंद्रों, मौसम केंद्रों के प्रतिनिधि उपस्थित रहे।

- माननीय मंत्री जी द्वारा अनुमोदित 7 सूत्री चार्टर से संबंधित सभी उपकार्यालयों तथा मुख्यालयों क के अनुभागों से प्राप्त आँकड़ों के आधार पर रिपोर्ट तैयार करके नोडल अधिकारियों के अनुमोदन के उपरांत पृथ्वी विज्ञान मंत्रालय को भेजी गई।

CHAPTER 10

STATUS OF SC/ST/OBC AS ON 01.01.2021

(i) Status of SC/ST/OBC as on 01.01.2021 (Group wise)

	Representation of SCs / STs/ OBCs as on 1.1.2020				Appointments by Promotion during the calendar year		
Groups	No. of Employees	SCs	STs	OBCs	SCs	STs	Total
Group A	177	31	14	49	2	1	8
Group B (Gaz.)	1000	207	111	89	Nil	Nil	Nil
Group B (Non- Gaz.)	1867	288	141	652	Nil	Nil	Nil
Group C	1208	207	111	89	Nil	Nil	Nil
TOTAL	3352	733	377	879	2	1	8

(ii) Status of SC/ST/OBC as on 01.01.2020 (Pay Scale Wise)

	Representation of SCs / STs / OBCs as on 01.01.2019				Appointments by promotion during the calendar year		
Pay Scale in Rs.	No. of Employees	SCs	STs	OBCs	SCs	STs	Total
PB-3 + GP 5400	6	1	1	2	0	0	0
PB-3 + GP 6600	60	8	4	22	1	1	4
PB-3 + GP 7600	6	1	1	3	0	0	0
PB-4 + GP 8700	58	13	6	19	0	0	0
PB-4 + GP 8900	40	8	2	3	1	0	4
PB-4 + GP 10000	6	0	0	0	0	0	0
75500-80000	1	0	0	0	0	0	0
TOTAL	177	31	14	49	2	1	8

CHAPTER 11

MISCELLANEOUS

11.1. HONOURS AND AWARDS

IMD Awards

India Meteorological Department (IMD) presented following awards on 146th IMD foundation day on 15th January, 2021 for the year 2020-21:

Best MC – MC, Lucknow; **Best MWO/AMO/AMS -** AMO, Palam; **Best RS-RW/ PBO -** Hyderabad; **Best DWR -** DWR, Mohanbari; **Rajbhasha Shield -** RMC, Guwahati;

Best Group 'A' Officers - (*i*) Dr. G. N. Raha, Sc. 'E', MC, Gangtok, (*ii*) Shri R. Bibraj, Sc. 'C', CWC, Vishakhapatnam.

Best Group 'B' Officials - (*i*) Shri N. Chandrahas, Met. 'A', CWC, Vishakhapatnam (*ii*) Dr. Hari singh Sisodia, Met. 'A', RS/ RW, Jodhpur, (*iii*) Shri Rajesh Kumar, MACP, DGM (*iv*) Shri Awadhesh Kumar, S. A., MC Patna, (*v*) Shri Sharoj singh, S. A., DGM.

Best Group 'C' Officials : (*i*) Ms. Shaik Akhtar, U.D.C., RMC Chennai, (*ii*) Shri S. S. Rengade, Mech. Gr.I, CRS, Pune, (*iii*) Shri Pandurang N. Jhalake, MTS, RMC, Nagpur.

MoES AWARD 2020-2021

30th Biennial MAUSAM Award

The 30th Biennial MAUSAM Award consists of a Citation and cash prize of Rs.50,000/- (Rs. Fifty Thousand only) were conferred upon **D. R. Pattanaik, A. K. Sahai, Raju Mandal, R. Phani Muralikrishna, Avijit Dey, Rajib Chattopadhyay, Susmitha Joseph, Amar Deep Tiwari** and **Vimal Mishra**for their research paper entitled, **"Evolution of operational extended range forecast system of IMD: Prospects of its applications in different sectors"** published in the **April 2019 (Vol. 70, No. 2)** issue of MAUSAM.

Appreciation Received

IMD received appreciation from the General Manager Oil & Natural Gas Corporation for frequent and accurate updates on cyclone Shaheen over Arabian Sea that helped in boosting the confidence of top management and also the morale of personnel working off shore. The excerpt of appreciation received is given below:

Appreciation from ONGC

To all officials / scientists of IMD:

Offshore oil field operations are affected by the vagaries of nature. Timely, accurate and dependable cyclone forecasts and advisories are essential for taking adequate precautionary measures which ensure the safety of personnel, operations, environment and assets.

We are grateful to all of you for providing us with cyclone forecasts and advisories through this forum that helped us to activate Emergency Response Plans and taking adequate precautionary measures as per ERP. The forecasts provided by IMD also helped us to instill confidence in our top management and keep the morale of the personnel working offshore.

Mahesan Balakrishna Pillai, Chief General Manager, ONGC Mumbai

DGM IMD Dr. Mrutyunjay Mohapatra received appreciation from the Secretary General of World Meteorological Organisation for organising the tropical cyclones forecasters training and for dedicated lectures during the training. The excerpt of appreciation received is given below:

Appreciation to DGM IMD for organising Tropical Cyclones Forecaster's Training and Delivering lectures

Dear Dr Mohapatra,

I wish to express our sincere thanks to you and to your Government for hosting the World Meteorological Organization (WMO) Tropical Cyclones Forecasters Training Workshop, online, from 6 to 18 October 2021, for PTC Members with focus on tropical cyclones and related storm surge and impact-based forecasting.

I would also like to extend our gratitude to the India Meteorological Department (IMD) the RSMC New Delhi and your staff for the invaluable support and contribution in organizing the training workshop and delivering lectures.

Special thanks to you for making yourself available to deliver four dedicated lectures and address the workshop with many commitments to support PTC Members during your very busy schedule.

Dr Elena Manaenkova
for the Secretary-General, WMO

PNV Group conferred "**6th Edition of Showcase Odisha Award**" upon **Dr. Mrutyunjay Mohapatra**, DG, IMD on 10th October, 2021 for his **exemplary services in improvement of cyclone warning services of IMD** that helped in significant reduction of death toll over India and WMO/ESCAP Panel member countries.

Dr. M. Mohapatra, DG, IMD has been elected as Chairman of Executive Council of South Asia Hydrometeorological Forum.

Dr. Mrutyunjay Mohapatra, DG, IMD being conferred by PNV Group

Dr. O. P. Sreejith, Sc. 'E' received the Certificate of Merit Award 2021 for scientists in "**Atmospheric Science & Technology, Ocean Science & Technology, Polar Science & Technology**".

11.2. MEDIA INTERACTION

Dr. M. Mohapatra, DG, IMD attended live Interview by **Bloomberg TV**, **Reuters**, **News Rise** on "**Southwest monsoon**" on 5th and 6th, 8th July, 2021 respectively.

Dr. M. Mohapatra, DG, IMD gave an Interview to **Ershot Media Group**, **Krishi Jagran media group** and **DD Shillong** on "**Southwest monsoon**" on 13th July, 29th July and 4th August, 2021 respectively.

Correspondent of Russian TV interviewed **Dr. M. Mohapatra**, DG, IMD on 4th August, 2021 regarding "**Southwest monsoon rainfallin India**".

Ms. Nivedita Khandekar, Journalist, IANS, interviewed **Dr. M. Mohapatra**, DG, IMD on 11th August, 2021 regarding "**Southwest monsoon**".

Dr. M. Mohapatra, DG, IMD was interviewed by **Mr. Ishaan Kukreti**, Environment Journalist regarding "**Evolution of IMD**" on 18th August, 2021.

Special Weather Bulletins (Informatory Messages), Press Releases, Port Warnings and Fishermen Warnings were issued to State Govt Offices, Media and General Public and all concerned users during 22-24 July, 2021 in connection with **formation of Well-Marked Low Pressure Area over north West Bay of Bengal off north Odisha West Bengal coasts** and during 26-27 July, 2021 due to **formation of Low Pressure Area over North Bay of Bengal and neighbourhood**, which further into Well-Marked Low Pressure Area over coastal Bangladesh and adjoining West Bengal.

Dr. M. Mohapatra, DG, IMD participated in live discussion organized by the Indian Express on the subject "**Weather forecasting and climate change**" on 28th July, 2021.

Shri C. S. Patil, Sc. 'D' sent 30 Nos. of Audio bytes in Kannada and English on weather on daily basis to All India Radio Bengaluru, Kalaburgi and Dharwad for broadcasting daily during the month of July 2021.

Dr. Kripan Ghosh, Sc. 'F' and **Shri R. Balasubramanian**, Sc. 'E' attended Media interaction meeting for Maharashtra on 7th September, 2021. **Shri R. Balasubramanian**, Sc. 'E' presented on the topic "**Agrometeorological Services for farmers**" in the meeting.

Dr. S. Balachandran, Sc. 'F' gave an interview on "**Tropical Cyclones**" in Hindi to Bhavatal you tube channel on 25th May, 2021.

All India radio and **DD Kisan** broadcasted Special Interview of **Dr. Mrutyunjay Mohapatra**, DG, IMD on the evening of '**Azadi ka Amrit Mahostav**' celebrations by IMD on 17th October, 2021.

Engage Embrace Enrich, Correspondent, Asian Media Group, interviewed **Dr. Mrutyunjay Mohapatra**, DG, IMD on the monsoon season 2021 on 30th October, 2021.

Dr. S. Balachandran, Sc. 'F' gave talk, in Tamil, in the **All India Radio**, Chennai on "**Evolution of Indian Meteorological services during the past 75 years**" on 23rd October, 2021 as a part of "**Science for Society**" programme on the occasion of celebration of '**Azadi Ka Amrit Mahotsav**' Iconic Week during 18-24 October, 2021.

Shri C. S. Patil, Sc. 'D' delivered talk on services of IMD on AIR during '**Azadi Ka Amrit Mahotsav**' on 25th October, 2021.

11.3. ADDRESSES OF VARIOUS REGIONAL METEOROLOGICAL CENTRES & METEOROLOGICAL CENTRES

RMC New Delhi	RMC Chennai	RMC Mumbai
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RMC Kolkata	**RMC Nagpur**	**RMC Guwahati**
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भारत मौसम विज्ञान विभाग

INDIA METEOROLOGICAL DEPARTMENT

पृथ्वी विज्ञान मंत्रालय, भारत सरकार

Ministry of Earth Sciences, Govt. of India