*Proc Indian Natn Sci Acad* **82** No. 3 July Spl Issue 2016 pp. 1021-1037

DOI: 10.16943/ptinsa/2016/48501

***Institutional Report***

# India Meteorological Department

S I LASKAR*, KIRAN JASWAL, M K BHATNAGAR and L S RATHORE
*India Meteorological Department, New Delhi 110 003, India*

(Received on 29 March 2016; Accepted on 25 June 2016)

## Introduction

India Meteorological Department (IMD) under Ministry of Earth Sciences is the principal Government agency in all matters relating to Meteorology, Seismology and allied disciplines and provides weather and climate services to the public and specialized sectors. It was setup in 1875 by the Government of India with an objective to study systematically the climate and weather in India as a whole with its headquarters at Kolkata. In view of geophysical and meteorological diversity to meet administrative and operational requirements, presently whole India is divided into six regional meteorological centres with headquarter located at New Delhi.

From a modest beginning, IMD has progressively expanded its infrastructure for meteorological observations, communications, forecasting and weather services and has achieved a parallel scientific growth. IMD operates a network of hundreds of surface and glacial observatories, upper air

*Author for Correspondence: E-mail: si.laskar@imd.gov.in

stations, ozone and radiation observatories and meteorological radar stations. Additional data is received from India's constellation of satellites, such as Kalpana-1, Megha-Tropiques and instruments on board the IRS series and the INSAT series of satellites. IMD was the first weather bureau of a developing country to develop and maintain its own satellite system. Data and observations are also reported into the IMD network from meteorological instruments on board Indian merchant marine and Indian Navy ships. 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. IMD has continuously ventured into new areas of application and service. It has simultaneously nurtured the growth of meteorology and atmospheric science in India. IMD is also one of the six regional specialized meteorological centres of the World Meteorological Organization (WMO). It has the responsibility for forecasting, naming and distribution of warnings for tropical cyclones in the Northern Indian Ocean region, including the Malacca Straits, the Bay of Bengal, the Arabian Sea and the Persian Gulf. Today, meteorology in India is poised at the threshold of an exciting future.

**Vision**

The vision of India Meteorological Department is to nurture the science and technology of meteorology to provide increasingly more efficient Weather and Climate Services for safety of life and property and to contribute to the cause of national development.

**Mission**

- To take meteorological observations and to provide current weather and weather forecasts/ 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, dust storms, heavy rains and snow, cold and heat waves, etc. which cause destruction to life and property, agriculture etc.
- To provide Climatological information 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.

**Major Services of the Department**

The meteorological services have significant impact on every sphere of life. The demand for accurate prediction of weather and climate at short and long time scales is increasing due to the increased awareness of possible impacts of weather and climate. During recent years, the department has undergone a changeover from being a data provider to service provider. Improved and reliable forecast of weather and climate requires routine integrations of observations using very high resolution dynamical models with high complexity (e.g. coupled ocean - atmosphere - biosphere – cryosphere models). Acombined approach involving land, ocean and atmospheric processes hold the key to improve the forecasts at various temporal and spatial ranges for providing a credible policy tool. Intensive monitoring of various weather systems through different platform based observing systems including satellites provide not only the necessary information about weather systems but their assimilation in numerical models provides accurate forecasts.

***Hydro Meteorological Services***

IMD renders assistance and advice on the meteorological aspect of hydrology, water management and multipurpose river valley projects. The hydrometeorological services consist of compilation of rainfall statistics, meteorological analysis of different river catchments for project authorities and providing meteorological support for flood warning and flood control operations to field units of Central Water Commission.Hydromet division of IMD caters to the information on various rainfall products through its 'Customized Rainfall Information System' (CRIS) in the form of reports and maps on the CRIS portal.

Research Programmes in (i) Design Storm Analysis (ii) Rainfall Frequency Analysis and (iii) Quantitative Precipitation Forecast (QPF) are the ongoing hydrometeorological activities.The QPF provided by IMD is an important component which is utilized by Central Water Commission for flood prediction in rivers' catchments and their basins area. The sub-basinwise QPF is being issued (daily on operational basis) during flood season by 10 Flood Meteorological Offices (FMOs) and Meteorological Centre, Srinagar in flood prone areas to Flood Forecasting Division (FFDs) of Central Water Commission (CWC).

***Climate Data Monitoring & Services***

National Climate Centre is responsible for weather data management of IMD. Climate data products viz. daily gridded rainfall and temperature data CDs are supplied to different national & international institutes.

***Meteorological Services for Agriculture in India***

In order to provide direct services to the farming community of the country, an exclusive division of Agricultural Meteorology was set up in 1932 under the umbrella of IMD at Pune with the objective to minimize the impact of adverse weather on crops and to make use of favourable weather to boost agricultural production. It is also the centre for research programmes in agricultural meteorology and has field units in various parts of the country. Besides, forecasts and advisories for farmers are issued by IMD's forecasting offices located at different state capitals.

Services of the division are :

- Gramin Krishi Mausam Seva
- Dissemination of Agromet Advisories
- Feedback and awareness of Agromet service
- Training programmes forAgrometeorological Field Units.

District level AAS bulletins are prepared and issued by Agromet Field Units (AMFUs) located in State Agricultural Universities, ICAR institutes, IITs etc. At present these bulletins are issued for 633 districts in the country. Agrometeorological Division maintains a network of agrometeorological observatories, evapotranspiration observatories, evaporation observatories, dewfall recording observatories and soil moisture observatories. The data received from these observatories are scrutinized, archived and supplied to scientists, planners etc. through National Data Centre, Pune.

***Environmental Services***

In addition to routine weather monitoring and forecasting, the environment, air quality and air pollution monitoring are some other areas of responsibility of the Department. Information gathered through environmental monitoring is important to decisionmakers, inside and outside the government. IMD has taken initiatives to establish the environmental monitoring networks for environmental impact assessments and harmful effects on the natural environment. IMD provides environmental meteorological services to the Ministry of Environment, Forests and Climate Change and conducts environmental impact assessment of development projects. IMD also provides air quality forecast services to public under the project System for Air Quality Forecasting and Research (SAFAR) with IITM, Pune.

***Astronomical Services***

Positional Astronomy Centre (PAC) 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. This centre also prepares Rashtriya Panchang containing the Indian National Calendar data based on Saka Era as recommended by the Calendar Reform Committee and also All India Sidereal Solar Calendar dates based on Kali Era recommended by the Peer Review Committee along with other usual panchang parameters. Rashtriya Panchang is published annually in 14 different languages and all data in the publication are generated on modern scientific principle to promote panchang calculations throughout the country on correct scientific formulae. As such 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, Gujarati, Kannada, Malayalam, Marathi, Oriya, Punjabi, Tamil and Telegu.

Other services of the PAC are:

- The centre fixes up dates of all India festivals for all communities for declaration of holiday by Central and State Governments.
- The centre meets specific data requirements of a large number of users including Govt. organizations, non Govt. organizations, professional astronomers, research scholars, various Panchang makers, general public etc.
- The centre provides five years advance accurate calendric data to many leading Panchang makers of the country for preparation of their own Panchangs.
- The centre 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 and electronic media.
- The centre takes observations of special astronomical events from time to time with the help of its portable telescopes at different places of the country.

***Public Weather Services***

Public Weather Services (PWS) is one of the most vital components of National Weather Forecasting Services of IMD. It has the capability to generate weather forecast and warnings in the form of easily usable products (Digital, text and graphical format). The customized weather report and products are auto designed, generated and disseminated to various specialized users and general public. The system has the capability to disseminate the products on real time basis through various means of communication including SMS, Fax, email, FTP etc. Modernization of PWS has helped in reducing the time gap between observation, forecast generation and product dissemination.

***Cyclone Warning Services***

The Cyclone Warning Division/Regional Specialized Meteorological Centre (RSMC)-Tropical Cyclone, IMD with all its resources for monitoring and prediction of cyclonic disturbances over the north Indian Ocean issues three hourly warning/advisory bulletins to national disaster management agencies at regular intervals. It also issues advisories to World Meteorological Organization (WMO), Economic and Social Cooperation for Asia and the Pacific (ESCAP), panel member countries including Bangladesh, Myanmar, Thailand, Pakistan, Oman, SriLanka and Maldives during cyclone period. The main activities of RSMC are listed below:

1) Round the clock watch over the entire North Indian Ocean.
2) Analysis and processing of global meteorological data for diagnostic and prediction purposes.
3) Detection, tracking and prediction of cyclonic storms in the Bay of Bengal and the Arabian Sea.
4) Running of numerical models for tropical cyclone track and intensity prediction.
5) Issue of Tropical Weather Outlook once daily (at 0600 UTC) and an additional outlook at 1700 UTC in the event of a depression which is likely to intensify into a cyclonic storm.
6) Issue of cyclone advisories to the Panel countries 8 times a day.
7) Issue of storm surge advisories.
8) Implementation of the Regional Cyclone Operational Plan of WMO/ESCAP Panel.
9) Collection, processing and archival of all data pertaining to cyclonic storms viz. wind, storm surge, pressure, rainfall, satellite information etc.
10) Exchange of composite data and bulletins pertaining to cyclonic storms with panel countries.
11) Preparation of comprehensive reports on each cyclonic storm.
12) Continued research on storm surge, track and intensity prediction techniques.

Significant improvement in landfall forecast error of cyclone was observed during 2011-15 compared to that during 2006-10 due to implementation of modernisation programme in IMD in 2009 as is clear from Table 1.

**Table 1: Improvement in Landfall Forecast Error of cyclone**

| S.No. | Parameter | | Period | | % improvement during 2011-15 |
|---|---|---|---|---|---|
| | | | 2006-10 | 2011-15 | |
| 1 | Landfall Point Error (Km) | 24 Hrs Lead Period | 99 | 56 | 43% |
| | | 48 Hrs Lead Period | 100 | 94 | 6% |
| 2 | Landfall Time Error (Hrs) | 24 Hrs Lead Period | 6.9 | 4.2 | 39% |
| | | 48 Hrs Lead Period | 9 | 4.7 | 48% |
| 3 | Track Forecast Error (Km) | 24 Hrs Lead Period | 141 | 98 | 30% |
| | | 48 hrs Lead Period | 287 | 146 | 50% |
| | | 72 hrs Lead Period | 454 | 183 | 60% |
| 4 | Skill (%) | 24 Hrs Lead Period | 24 | 49 | 104% |
| | | 48 hrs Lead Period | 31 | 63 | 103% |
| | | 72 hrs Lead Period | 40 | 69 | 72% |
| 5 | Intensity Forecast Error (Knots) | 24 Hrs Lead Period | 12.2 | 11.5 | 6% |
| | | 48 hrs Lead Period | 14 | 16.9 | -21% |
| | | 72 hrs Lead Period | 19.7 | 17.6 | 11% |
| 6 | Skill in Intensity Forecast Error (%) | 24 Hrs Lead Period | 39.1 | 36.4 | 7% |
| | | 48 hrs Lead Period | 61.9 | 55.8 | 10% |
| | | 72 hrs Lead Period | 67.5 | 67.3 | 0.30% |

In recent years, IMD has been involved in the improvement of warning services as well as weather forecasts using the latest technology and tools and information technology. One such initiative is the introduction of the SMS based cyclonic warning system intended to provide alerts to the people on cyclones, tsunamis and other natural calamities related to the weather. The cyclone information system has already resulted in a reduction in loss of life and property. This is one step forward taken by the IMD in the Digital India Programme.

### *Meteorological Services for Aviation*

An important and crucial activity of IMD is the meteorological services rendered to International Air Navigation. This specialized and critical service is disseminated through four Meteorological Watch Offices (MWOs), a number of Aerodrome Meteorological Offices (AMO) and Aeronautical Meteorological Stations (AMS) located at various national and international airports of the country. In order to provide this service, IMD deploys and maintains a set of instruments, a dedicated telecommunication network and specially trained technical personnel who work in close coordination with the Air Traffic Controllers, Pilots, Flight Despatch Officials and together they ensure the safety, regularity and efficiency of flight operations within India airspace. Each flight which takes off from any airport mandatorily carries a set of weather charts, forecast and warning covering their intended flight path which is provided by IMD. Moving ahead with time, department has fully automated its briefing and documentation services called Online Briefing System (OLBS). This service is assessed by the designated personnel to get the very latest forecast and weather information required for planning, operation and flight management purposes.

Doppler Weather Radar and Satellite products are utilized to keep a continuous weather watch over the designated airspace and if specific weather phenomenon which can potentially endanger an aircraft is detected, then it is immediately relayed to the overflying aircrafts through predefined warning protocol.

In order to attain self sustenance in the field of aeronautical met instruments, IMD joined hands with National Aerospace Laboratories Bangalore in research, development and deployment of instrument suits required at an airport. Drishti Transmissometer which was developed under this project, is now a standard instrument deployed at a number of international airports.

***Earthquake Monitoring***

National Centre for Seismology (NCS), IMD under Ministry of Earth Sciences (MoES) is nodal agency of Government of India dealing with various activities in the field of seismology and allied disciplines. The broad and ultimate objectives of the NCS are:

- Provide earthquake (Magnitude: 3.0 and above) related information to all user agencies in shortest possible time.
- Provide earthquake hazard and risk related products of specific regions required by various agencies as mitigate measures for design and construction of earthquake resistant structures, land use planning and for enacting building bye-laws towards minimizing damage to property and loss of lives due to earthquakes.
- Carry out research in pure and applied seismology and earthquake precursory phenomena, earthquake processes and modelling.

***Extended Range Forecast***

IMD has been issuing experimental Extended Range Forecast(ERF) since 2009 using available products from statistical as well as multi-model ensemble (MME) based on outputs available from dynamical models from various centres in India and abroad. The MME forecast is being prepared once in a week with the validity for subsequent four weeks. The latest generation coupled models are found to be very useful in providing skilful guidance on extended range forecast. The performance of extended range forecasts for the southwest monsoon seasons clearly captured the delay/early onset of monsoon over Kerala, active/break spells of monsoon and also withdrawal of monsoon in the real time in providing guidance for various applications. On experimental basis the MME forecast on meteorological subdivision level up to two weeks are also being used in providing the agromet advisory for farming community. The MME based ERF also provides encouraging results in case of northeast monsoon rainfall over southern peninsula and tropical cyclogenesis over the north Indian Ocean during the post monsoon season from October to December (OND). In addition, the MME based ERF forecast also provides useful guidance pertaining to rainfall associated with Western Disturbances (WD) over northwest India during winter. The ERF forecast for minimum and maximum temperatures during winter and summer seasons are also found to be very useful.

The prospects of ERF's application in different sectors are also analysed. In order to further strengthen IMD's capability of real time ERF, it has started collaborative work with other national and international partners.

***Seasonal Forecast***

Under climate services activities, the operational and experimental seasonal forecasts for the country are issued from Climate Division of IMD, Pune. The first operational LRF of Indian summer monsoon rainfall for the region covering whole India and Burma was issued on 4$^{th}$ June, 1886 by Blandford who established IMD in 1875 and was the first Chief Reporter of IMD. Since then, the LRF of the monsoon rainfall became one of the important operational duties of IMD. Over the years, the operational LRF system in India underwent many changes in its approach and scope. New statistical models were introduced in 2003 and 2007. These models could accurately forecast the deficient southwest monsoon over the country as a whole during 2014 and 2015 and excess 2015 northeast monsoon season rainfall over the southern Peninsula.

Tentative annual time schedule for issuing various operational/experimental Long Range Forecast (LRF)/outlook from the LRF division is given in Table 2.

The average absolute error (difference between forecast and actual rainfall) during the last 13 years (2003-2015) was 5.92% of Long Period Average (LPA) compared to the average absolute error of 7.94% of LPA during the 13 years (1990-2002) just prior to that period. Similarly the Correlation Coefficient (C.C) between the actual and forecast rainfall for the periods (2003-2015) and (1990-2002) are 0.42 and –0.24 respectively. During recent 13 years (2003-2015), the forecast was within the ±8% of actual values during 10 years, with forecast within ±4% of actual values during 7 years. The operational forecast system has improved in the recent 13 years period compared to earlier 13 years period.

Since 2004, IMD has been generating experimental dynamical forecast for the southwest

**Table 2: Tentative Time Schedule for issuing forecasts/outlook**

| Forecasts/Outlook | Tentative Time of Issue |
|---|---|
| First stage forecast for the season (June-September) Rainfall over the country as a whole | Mid April |
| Date of monsoon onset over Kerala | Around 15th May |
| Second stage forecast consisting of update for the first stage forecast, forecast for monthly rainfall over the country as a whole for the months of July & August, and the season rainfall over four geographical regions of the country | Second half of June |
| Mid monsoon review and outlook for second half of season (August-September) | End week of July |
| Outlook for September Rainfall over the country as a whole | End week of August |
| NE monsoon season (October to December) rainfall for south peninsula. | End of September |
| Winter season (January - March) precipitation over north India. | End of December |

monsoon rainfall using the seasonal forecast model (SFM) of the Experimental Climate Prediction Centre (ECPC), USA. Recently under the Monsoon Mission project, with the help of Indian Institute of Tropical Meteorology (IITM), Pune a state-of-the-art Coupled Forecasting System (CFS) initially developed by the National Centre for Environmental Prediction (NCEP), USA has been implemented for the experimental seasonal forecast. In 2013, the latest high resolution research version of the coupled model (CFS Version 2) was introduced to generate the experimental forecast for the SW Monsoon season rainfall using the February initial conditions.

Currently CFSV2 is being used to generate Regional gridded Monthly and Seasonal rainfall and 2m temperature Forecasts and Country Averaged Monthly Forecasts. These products are available through IMD Pune website (*www.imdpune.gov.in)*. These forecasts are updated every month. These include,

- Forecasts of Global Sea Surface Temperatures (SST), *El Nino Southern Oscillations* (ENSO) and Indian Ocean Dipole (IOD) indices updated every month.
- Seasonal Climate Outlook for South Asia*:* From January, 2014, the division started to prepare and issue seasonal outlook for rainfall and temperatures over south Asia for the next 2 moving 3 month seasons (total 4 months).
- ENSO Bulletin*:* Since May 2015, the division started to prepare and issue the ENSO bulletin. The bulletin provides statement on the global SST forecast anomalies with emphasis on the ENSO and IOD conditions for the next 8 months prepared on the basis of the CFS model. The bulletin is updated every month.
- South Asian Climate Outlook Forum (SASCOF) activities*:* The main activity during all the SASCOFs is the preparation and issuing of a consensus forecast outlook for the southwest monsoon rainfall over South Asia.

**Service to Power Sector**

IMD is contemplating to provide weather and climate services to the power sector for efficient management of distribution across the country. Day-to-day weather variations affect demand for electricity as well as other aspects like energy generation and transmission. Prior knowledge of weather conditions can reduce losses and help save on the cost of production. Besides, storms, lightning and dense fog disrupt transmission as well as cause physical damage to the infrastructure. Hence weather related information is of importance to the power sector. The prediction of electrical load in different parts of the country was partly dependent on local weather. In the domestic sector, more heaters are expected to be used in areas with cold weather and more air-conditioners can be put on during hot weather. In the agriculture sector, more water will be lifted using pumps in rain-deficient areas for irrigation. Similarly, the demand would dramatically drop if the condition reverses. Some of these demands can add up under circumstances and produce a regional problem. The way out is to balance the excess and deficit across the country by effecting power transfer between components of the grid. The electricity demand of the region is somewhat

predictable if the power sector authorities know the kind of weather could prevail in a region. Hence, the provision of such forecasts under IMDs climate services programme is one of its future targets. The IMD will provide the power sector with weather data in the format and frequency that they require. This will include expected variations during the course of the day in terms of rainfall, temperature and wind among others. The power sector will also get information on the timings when the temperature may remain below or above normal and the number of hours it would remain like that.

### *Specialized Forecasts*

IMD took many initiatives to further improve its observational, analysis, forecasting and dissemination capability. It also organized many training programmes for international and national meteorological personnel to enhance their skills in meteorology and environment. The forecasting service has been extended to 324 cities with validity from 5 days to 7 days, while 5-day tourism forecast for 88 tourist destinations across the country has also been extended to 106 tourist destinations with 7-day special forecast. In addition, to expand the dissemination of the weather forecasts to tourists, the information regarding the prevailing weather and the forecast of various cities is also provided on toll free number 1800 180 1717 through Interactive Voice Response System (IVRS). IMD has also developed a mobile App called "Indian Weather" by which initially, current weather and 4-days forecast for 220 cities is being provided. At present 80 additional cities have been added with Graphical User Interface (GUI) totally re-designed for better navigation. IMD introduced Sector wise 7 daysspecial forecast & warnings for Western Himalayan Region for Indian Army and application of forecast for generating advisory for heat wave for railways and highways has been taken up. It also issued special forecasts for pilgrims of Char-DhamYatra, Kailash-Mansarovar Yatra, Sri Amarnathji Yatra and Kumbh Mela. IMD has recently started weather information for Mata Vaishno Devi Shrine comprising of (i) Yatra Route Weather Advisory (ii) current observation (iii) 6-hourly low level wind and temperature forecasts for helicopter operation and (iv) 3-day forecasts & warnings for Jammu Division.

## Achievements and Contributions

### *Advances in Environment Monitoring*

*System for Air Quality Forecasting and Research (SAFAR)* : The system for air quality forecasting and research (SAFAR) has been operationalized by IMD to monitor and forecast air quality in major cities. This is a joint project of Indian Institute ofTropical Meteorology(IITM),Pune and IMD. The ultimate objective of the project is to increase awareness among general public regarding the air quality in their city well in advance so that appropriate mitigation measures and systematic action can be taken up for betterment of air quality and related health issues. It engineers awareness drive by educating public, prompting self-mitigation and also to help develop mitigation strategies for policy makers.Basic Research in this area includes

1. To study the impact of air quality on Health and Eco-system.
2. To qualify microclimate of metropolitan cities.
3. To study the spatio-temporal, seasonal and long-term trends in weather parameters
4. To study atmospheric pollutants, chemical weather and inter-linkages
5. To deliver comprehensive seasonal air pollution scenarios and relative contribution of different emission sources for various metropolitan cities under study.
6. To identify the pathways of pollutants from neighbouring states and relative contribution between local versus distant sources along with its interpretation for different cities.
7. To elucidate the role of meteorology in the distribution of air pollutants and vice-versa by revealing the spatio-temporal behaviour of pollutants and their variability specific to the location.

### *SAFAR Monitoring Network*

The SAFAR observational network of Air Quality Monitoring Stations (AQMS) and Automatic Weather Stations (AWS) established within city limits represents selected microenvironments of the city including

industrial, residential, background/cleaner, urban complex, agricultural zones etc. as per international guidelines which ensures the true representation of city environment.Air quality indicators are monitored at about 3m height from the ground with online sophisticated instruments. These instruments are operated round the clock and data is recorded and stored at every 5 minute interval for quality check and further analysis. Pollutants monitored are, PM1, PM2.5, PM10, Ozone, CO, NOx (NO, NO2), SO2, BC, Methane (CH4), Non-methane hydrocarbons (NMHC), VOC's, Benzene, Mercury. Monitored Meteorological Parameters are UV radiation, rainfall, temperature, humidity, wind speed, wind direction, solar radiation.

This is the first of such network in India which continuously monitors all these parameters and maintain up to date data base with robust quality control and quality assurance.

### *System of Aerosol Monitoring and Research (SAMAR)*

SAMAR is a network of 16 Aethalometers, 12 Sky radiometers and 12 Nephelometers to study black-carbon concentration, aerosol radiative properties and environmental visibility respectively along with their climatological impacts.

Black Carbon Monitoring Network

The network is established at sixteen locations in India. A seven wavelength Aethalometer ($\lambda$ = 370, 470, 520, 590, 660, 880 and 950 nm) is used to measure the aerosol attenuation coefficient. While continuously collecting sample, the instrument measures optical absorption in real time. It converts optical absorption to mass concentration of Black Carbon (BC) and UV absorbing particulate matter (UVPM).

India-SkyNet

India-SkyNet is a network of skyradiometers consisting of twelve stations at different locations in India. The instrument takes measurement in eleven narrow wavebands in the ultraviolet, visible and infrared parts of the solar spectrum (315, 340, 380, 400, 500, 675, 870, 940, 1020, 1627, 2200).The instrument enables estimation of optical parameters of aerosols such as Aerosol Optical Depth (AOD), Single Scattering Albedo (SSA), Angstrom exponent, Phase function, Complex refractive index, Columnar size distribution of aerosols.

Nephelometer Network

IMD has established a network of Nephelometers at twelve different stations in India. It has the following applications:

1. Measurement of scattering coefficient.
2. Determining a variety of aerosol parameters used in climate change radiative models.
3. Visibility monitoring including haze, fog and smog.
4. Helping to determine the effect of humidity changes on aerosols.
5. PM2.5 correlation studies.
6. Dust and sandstorm monitoring.
7. Bush fire and wood smoke monitoring.

The instrument takes measurement at three different wavelengths: **Green** : 525 nm – most sensitive for the human eye. Best measurement for smog, fog, haze. **Red** : 635 nm – interacts strongly with large particulate matter (pollen, sea salt). **Blue** : 450 nm - interacts strongly with fine and ultrafine particulates (wood fires, automobiles).

### *Advances in Modelling of the Atmosphere: Operational Numerical Weather Prediction*

With the commissioning of High Performance Computing System (HPCS) in December 2009, National Centre for Environmental Prediction (NCEP) based Global Forecast System (GFS T574/L64) has been made operational incorporating Global Statistical Interpolation (GSI) scheme as the global data assimilation for the forecast up to 7 days. Currently, it runs twice in a day (00 UTC and 12 UTC). In addition to this, the meso-scale forecast system Weather Research and Forecasting(WRF) with 3DVAR data assimilation is being operated daily twice, at 27 km, 9 km and 3 km horizontal resolutions for the forecast up to 3 days using initial and boundary conditions from the IMD GFS-574/L64 (horizontal resolution over the tropics ~ 22 km). At ten other regional centres, very

high resolution mesoscale models (WRF at 3 km resolution) are made operational. Numerical Weather Prediction (NWP) based objective forecast products are prepared to support cyclone warning service. Doppler weather Radar and mesoscale dynamical model based nowcast system was made operational for the national Capital of Delhi. Polar WRF is implemented to provide day to day short range (48 hours) weather forecast for the Maitri region over Antarctica. District level quantitative five days weather forecasts based on Multi-Model Ensemble (MME) system are being generated to support Agro-Meteorological Advisory Service of India, making use of model outputs of state of the art global models from the leading global NWP centres.

The basic version of the model Hurricane WRF (HWRF) V(3.2+) which was operational at Environmental Modelling Centre of NCEP was ported on IBM P-6/575 machine, IMD, New Delhi with nested domain of 27 km and 9 km horizontal resolution and 42 vertical levels with outer domain covering the area of 800 x800 and inner domain 60 x60 with centre of the system adjusted to the centre of the observed cyclonic storm. The model has special features such as vortex initialization, coupled with Ocean model to take into account the changes in SST during the model integration, tracker and diagnostic software to provide the graphic and text information on track and intensity prediction for real-time operational requirement.

As part of efforts to translate research into operation and to meet the need of the operational forecaster, IMD developed and implemented an objective NWP based cyclone prediction system for the operational cyclone forecasting work. The method comprises of five forecast components, namely (a) Cyclone Genesis Potential Parameter (GPP), (b) Multi-Model Ensemble (MME) technique for cyclone track prediction, (c) Cyclone intensity prediction, (d) Rapid intensification and (e) Predicting decaying intensity after the landfall. District level quantitative five days weather forecasts based on MultiModel Ensemble (MME) system are being generated to support Agro Meteorological Advisory Service of India, making use of model outputs of state of the art global models from the leading global NWP centres. All these NWP products are routinely made available on the IMD web site www.imd.gov.in.

***Thunderstorm/NOWCAST Forecast for Cities Covered by Doppler Weather Radars***

Nowcasting in India has benefited from major developments in observational meteorology and computer based interactive data processing and display systems in IMD. In view of the recent improvement in monitoring and forecasting due to introduction of digital and image information at 10 minute interval from a network of Doppler Weather Radars, dense Automatic Weather Station (AWS) network, half hourly satellite observations from Kalpana and INSAT satellites, better analysis tools in Synergy system at forecaster's workstation, availability of mesoscale models and latest computational and communication capabilities, IMD implemented now casting of thunderstorms, squalls and hailstorms. The forecast was operational from December 2012. IMD issues now cast of 156 stations within 200 km radius of various Doppler Weather Radars. Thunderstorm now cast of these stations is uploaded every 3 hourly interval utilizing synoptic data, model outputs, satellite products and finally various Radar outputs.

***Satellite Observations***

After successful launch of INSAT-3D Satellite in July 2013 the INSAT-3D meteorological data system was upgraded and also being utilized to receive and process INSAT-3D Satellite data. BD - curve and NHC curve enhancement technique for use in determination of cyclone intensity and centre have been developed and implemented operationally. The retrieval algorithm of satellite derived wind products has been modified and implemented successfully resulting in generation of good quality wind products. A web based analysis and visualization tool called "Real Time Analysis and Product Information Dissemination" has been developed and implemented operationally with effect from 15$^{th}$ Jan. 2015. The tool is capable of displaying numerical values of satellite derived products, radiances brightness temperature provision of area measurement, zooming of images up to native resolution, running animation of desired sector, overlaying different products over different type of base map etc. The performance of the system has been maintained to the level of 98% operation efficiency (24 × 365 bases). The validation of atmospheric motion vector (wind products), sea

surface temperature, outgoing long wave radiations (OLR), vertical Profile of temperature and humidity have been carried out for the period of July, 2014 to October, 2015 and the feedback are used for fine tuning of algorithm of these products. The satellite based technique/tools for monitoring and forecasting of evolution of clouds cluster that leads to the severe weather has been developed and implemented operationally. The method is used to generate NOWCAST satellite images for next three hours on half hourly basis.

***SAARC Storm Project***

The Severe Thunderstorm Observations and Regional Modelling (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. During the pilot-phase of 2009, the domain was extended to include the neighbouring countries Nepal, Bhutan and Bangladesh through a newly established lead partnership with the SAARC Meteorological Research Centre (SMRC), Dhaka. In the SAARC STORM Project so far, four STORM field experiments have been conducted in Phase-I focusing on Norwesters in pre- monsoon seasons during 2009-2012. In Phase-II of SAARC STORM Programme which started in 2013, the STORM field experiments covered the whole SAARC region. During 2015 also Storm field experiments covered whole India. A Weather Advisory Group, established at the IMD was set up, whose main task was to watch the development of daily weather situation over the STORM campaign area during March-June, 2015.

***Strengthening of Meteorological Observational Network***

IMD has steadily built upon its infrastructure in its history of 141 years. Right from its establishment, the department has always been using the contemporary technologies like Satellites & telecommunication Systems, Doppler Weather Radars (DWR), Automatic Weather Station (AWS), High Performance Computing System (HPCS) etc. for upgrading its observational network and providing meteorological services to various users like farmers, fishermen, aviators, industrialists etc. The department has undertaken the Modernization Programme which is underway in a phased manner. The state-of-the-art technologies for surface instruments - AWSs and ARGs, Upper Air Instruments - Radiotheodolites, GPS radiosonde, sky radiometers etc. have been acquired by the department.

***Expansion of Observational Network of Doppler Weather Radars (DWRs)***

IMD has upgraded the conventional radars in the observational network with DWRs using digital technology. Indigenous efforts were also made to design and develop advanced Radar technology for cost effectiveness and self reliance. In second phase of modernization plan of IMD, 30 DWRs are proposed to be installed at various locations throughout India. There is a separate plan to install 9 DWRs at hilly regions under the scheme "Indian Himalayan Meteorology Programme" (IHMP) for Western and Central Himalayas.

***Expansion of Observational Network of GPS Based RS/RW Stations***

IMD's present upper air observational network comprises 39 radiosonde and 62 pilot balloon observatories spread all over the country. IMD, aiming on further improvement of upper air data quality, initiated the establishment of GUAN (WMO Global Climate Observing system Network) standard radiosounding observations at its six Regional Meteorological Centres. These stations are equipped with high quality GPS based radiosounding system. These systems are latest in sounding, fully automatic, user friendly, equipped with auto tracking of balloon (transmitter), auto detection of balloon launch and burst/termination, very light, portable and easy to maintain.

***Upgradation of Bharati Meteorological Observatory in Antarctica***

The Indian Antarctic Program is a multi-disciplinary, multi-institutional program under the control of the National Centre for Antarctic and Ocean Research, Ministry of Earth Sciences, Government of India. It was initiated in 1981 with the first Indian expedition to Antarctica. Antarctic holds scientific interest for global research due to a number of reasons: Origin of

continents, climate change, meteorology and pollution are among them. The ice–ocean and atmospheric interaction causes many ups and down global weather events and climate change. Understanding the weather pattern, climate of polar region and their connection with Indian Monsoon is a big challenge for which Department continued to shoulder its responsibilities as a member of scientific expedition team to Antarctica since beginning.

**Bharati Meteorological Observatory in Antarctica was Augmented by Installing Following Instruments**

(a) Digital Current Weather Instruments System (with data digitizer &data logger) (b) Radiation data logger (c) Stevenson's screen for maximum, minimum & dry bulb temperature (d) Snow Gauge (e) UV-A & Global Radiation sensor (f) Radiation data logger (g) The Global Positioning System (GPS) based Ozonesonde system for measurement of vertical distribution of ozone.

***Establishment of DTH Based Disaster Warning Dissemination Systems***

IMD has 352 numbers of Digital Cyclone Warning Dissemination System (DCWDS) spread over coastal boundaries of India which are used to disseminate cyclone warning generated from area cyclone warning centre (Chennai,Vishakhapatnam, Mumbai and Kolkata) in the affected region to carry out disaster management since 2002. The system is being upgraded with Direct to Home (DTH) based DCWDS through MoU between ISRO, Doordarshan, Bharat Electronics Ltd. and IMD along with further increase in number of stations to 500.

***Upgradation of Seismological Observation Stations and Installation of New Field Stations***

A project for up gradation of 44 existing seismological observatories and establishment of 34 new seismological observatories has been initiated. As on December, 2015, a total of 23 seismological observatories have been upgraded and one new observatory has been established. These observatories have been integrated with operational centre through VSAT communication facility established under the Integrated Seismic and GPS Network (ISGN).

**New Initiatives**

***Commissioning GPS Stations for Measurement of Integrated Precipitable Water Vapour (IPWV)***

IMD is in the process of setting up the Integrated Network of Global Navigation Satellite System (INGNSS) for IPWV measurements by installing additional 25 Global Navigation Satellite System (GNSS) receivers for atmosphere, ionosphere and seismic studies in 2015-2016, which is an expansion project of existing 5 GPS receiver at Chennai, Mumbai, Kolkata, Guwahati and New Delhi operational since 2007 as a pilot project to detect signal from multi-constellation GNSS satellites. This Project also has provision of using other GNSS network data of NGRI, INCOIS and other research institutes in real time basis, for augmenting the data spatial density and processing. IMD at present acquires IPWV with high temporal resolution for day to day weather forecasting and climate applications. The expected accuracy of GPS derived IPWV is of the order of 1 mm. The vital role of water vapour in the Earth's climate/weather system requires long-term stable and highly accurate measurements of the atmospheric IPWV. Key advantages of the current GNSS measurements are that apart from the IPWV measurement (i) the equipment is also installed with advanced meteorological sensors to measure Temperature, Pressure, Humidity of the station (ii) capable of working independently in all weather conditions with high temporal resolution (of the order of minutes) which is practically not possible by other existing methods.

***Seismic Hazard Assessment and Microzonation of Targeted Cities***

Seismic hazard assessment and seismic microzonation studies have emerged as major tools towards preparedness and mitigation of losses due to earthquakes. 'Seismic microzonation' is a process of classifying a region into zones of relatively similar exposure to various earthquake related effects and has helped in providing user friendly, GIS-based and site specific hazard and risk related information products. Microzonation of Delhi region on 1 : 50,000 scale is complete and being refined to 1 : 10,000 scale. In addition to this, National Centre for Seismology (NCS) has taken an initiative to carry out the seismic

microzonation studies for 30 major Indian cities having population more than half a million and lying in the seismic zone III, IV and V.

***Integrated Himalayan Meteorology Programme for Western & Central Himalayas (IHMP)***

After severe floods in Jammu and Kashmir and cloudburst in Uttarakhand, a Himalayan Meteorology Programme has been formulated for better understanding of weather in the mountainous states.The initiative will help in improving the forecasting of very short range phenomena up to 6 hours in advance and predicting severe weather phenomena up to 72 hours in advance. IHMP will cover four states Jammu & Kashmir, Himachal Pradesh, Uttarakhand, and Sub-Himalayan West Bengal with Commissioning of 9 Doppler Weather Radars (DWRs), 15 Micro Rain Radars (MRRs), 09 GPS based upper air systems along with GPS radiosonde, 230 Automatic Weather Station (AWS), Automatic Rain Gauge (ARG)& Snow Gauges, 12 Compact Severe Weather Detection Radar Systems to develop appropriate system of 24×7 monitoring and early warning for extreme weather.

***Hydrology Project***

A World Bank-aided Hydrology project covering a six year period is presently under implementation in IMD. This project aims at enhancing the physical infrastructure of hydrometeorological activities and data processing and management systems resulting in an enhancement of rainfall data quantity and quality. Eight southern states and five central agencies including IMD are involved in the project. IMD has an important and active role of providing technical guidance to concerned states/central agencies in procurement and installation of standardised equipments, inspection of existing and new raingauge stations and imparting specialised training to personnel at various levels in the states/agencies.

***Service to Power Sector***

IMD has initiated to provide weather information for better operational management of Indian Power System. In this regard a MoU has been signed between Earth System Science Organization-India Meteorological Department (ESSO-IMD) and Power System Operation Corporation Ltd. (POSOCO), a wholly owned subsidiary of Power Grid Corporation of India Ltd. on 18th May, 2015 at New Delhi. This MoU aims towards systematic use of Meteorological Information for better management of Indian Power System from generation to distribution and to increase overall efficiency of the power system operations.

***Long Range Forecast***

- Improvement of the existing statistical operational models for the seasonal forecasting of SW Monsoon Rainfall over the country, NE monsoon rainfall over South Peninsula and winter precipitation over north India.
- Start issuing temperature forecast outlook over the country for summer and winter seasons.
- Implementation of operational extended and long range forecasting based on coupled model forecasting system (IITM CFS).
- Develop forecasting tools for seasonal forecasting of rainfall and temperature over smaller regions (district/subdivisions wise) based on coupled model forecasting system using statistical downscaling and recalibration techniques.
- Develop tailor made seasonal forecast products for various sectors like drought indices, probability forecast with various thresholds, heat wave forecasts etc. for the country as well as for south Asia.

**Acknowledgement**

The authors are highly thankful to the scientists of the Department who have provided their valuable inputs for preparation of the report.

## Publications


Attri S D, Singh K K and Mall R K (2011) "Simulation of growth and yield attributes of wheat genotypes under changing climate in recent years in India", *Challenges and opportunities in Agrometeorology*, Springer, 221-234

Bhattacharya S N, Mitra S and Suresh G (2013) Shear wave velocity of the upper mantle beneath the Bay of Bengal, Northeast Indian Ocean from interstation phase velocities of surface waves *Geoph J Inter* **193** 1506-1514

Chakrabarty D K and Peshin S K (2011) Seasonal and diurnal behaviour of NO2 column density in Antarctica as observed by Mark IV, Brewer Ozone Spectrophotometer no. 153 *Advances In space research* **47** 86-93

Chattopadhyay N and Rathore L S (2013) Extreme Events Weather Services for Indian Agriculture *Geography and You* **13** July-August 2013.

Chattopadhyay N, Samui R P and Rathore L S (2011) Strategies for minimizing crop loss due to pest and disease incidences by adoption of weather based plant protection techniques *Challenges and opportunities in Agrometeorology* Springer 235-244

Dattatrayam R S, Suresh G, Baidya P R, Prakash Rajesh, Gautam J L, Shukla H P and Singh Dal, Standards and Methodologies of Seismological Data Generation, Processing and Archival & Guidelines for Data Sharing and Supply *Proc INS* **80** 679-696

Durai V R, Bhardwaj Rashmi and Rama Rao Y V (2015) Prediction Skill of Global Numerical Weather Prediction Model Deterministic Forecast over India during North East Monsoon, Vayumandal, 40, 1-2, 182-191.

DuttaSomenath, Vishwarajashree L,2011 "A pilot study on the energetics aspects of stagnation in the advance of Southwest Monsoon", Challenges and opportunities in Agrometeorology, Springer, 187-194.

GiriR K, Pradhan D and Sen A K, 2015, "Dust Storm – A case study over Patna & Neighbourhood", Indian Journal Science Research & Tech., 3, 2, 51-60. ISS-2321-9262.

Guhathakurta P, Sreejit O P and Menon P A, 2011 "Impact of Climate Change on extreme rainfall events and flood risk in India", J. Earth System Science, 120, June 2011, 359-373.

Guhathakurta P, Rajeevan M, Sikka D R and TyagiAjit 2014, "Observed changes in southwest monsoon rainfall over India during 1901–2011", Int. J. Climatology, Wiley Online Library, DOI : 10.1002 / joc.4095, 2014.

Gupta S, Mohnty W K, Prakash R and Shukla A K (2012) Crustal Heterogeneity and Seismotectonics of the National Capital Region, Delhi, India *Journal of Pure and Applied Geophysics* [( Impact Factor 1.787 as on (2011)]

Jain R, Panwar V, Johny C J, Jain S, Peshin S K, Mandal T K and Dhaka S K (2013) Tropopause and interchange of minor constituents in the upper troposphere and lower stratosphere (UTLS) region *Indian Journal of Radio and Space Physics* **42** 320-331

Kanawade V P, Tripathi S N, Singh D, Gautam A S, Srivastava A K, Kamra A K, Soni V K and Sethi V (2014) Observations of new particle formation at two distinct Indian subcontinental urban locations *Atmospheric Environment* **96** 370379 doi: 10.1016/j.atmosenv. 2014. 08.001. Impact Factor: 3.062

Kayal J R, Areûev SS, Baruah Saurabh, Hazarika D, Gogoi N, Gautam J L, BaruahSantanu, Dorbath C and Tatevossian R (2012) Large and great earthquakes in the Shillong plateau - Assam valley area of Northeast India Region: Pop-up and transverse tectonics *Tectonophysics* **532-535** 186-192

Kumar V (2011) Some aspects of the influence of North West Pacific Systems on Indian summer monsoon rainfall *The Journal of Indian Geophysical Union* **15** 35-44

Kumar N, Attri S D and Laskar S I (2015) Quantification in variation in temperatures over Northeast India during last century *International Journal of Earth and Atmospheric Science, International Journal of Earth and Atmospheric Science* **1** 58-64

Kundu B, Vissa N K and Gahalaut V K (2015) Influence of anthropogenic groundwater unloading in Indo-Gangetic plains on the April 25, 2015 Mw 7.8 Gorkha, Nepal Earthquake *Geophysical Research Letters* **42** DOI: 10.1002/ 2015GL066616

Laskar S I, Kotal S D, Roy Bhowmik S K and Sinha V (2012 ) Dynamical and thermo dynamical features as revealed by IMD GFS T574L64 in association with heavy rainfall event of east Rajasthan during 22-23rd August 2012 *Vayu Mandal* **38** 86-95

Laskar S I, Kotal S D, Bhattacharya S K and Roy Bhowmik S K (2014 ) Simulation of Heavy Rainfall Event over Gujarat during September 2013 In: Ray *et al*. (eds) - *High Impact Weather Events over the SAARC Region* Capital Publishing Company, New Delhi pp 266-275

Litta A J, Mohanty U C, Bhan S C and Mohapatra M (2011) Simulation of Tornadoes over India Using WRF-NMM Model *Challenges and Opportunities in Agrometeorology* Springer Publications 173-186

Mahajan A K, Shukla A K, Pandey A, Chauhan M, Chauhan N and Rai N (2011) Shear Wave Velocity Investigation for Ten Representative Sites of National Capital Territory, New Delhi, India *International Journal of Geotechnical*

*Earthquake Engineering* **2** 29-43, January-June, 2011, 29

Mandal H S, Khan P K and Shukla A K (2012) Soil responses near Delhi Ridge and adjacent region in Greater Delhi during incidence of a local earthquake *Journal of Natural Hazards* DOI 10.1007/s11069-0120098-4. [( Impact Factor 1.529 ) No pp 41-53

Mandal H S, Shukla A K, Khan P K and Mishra O P (2013) A new Insight into the Probabilistic Seismic Hazard Analysis for Central India *Pure and Applied Geophysics* DOI: 10.1007/s00024- 013-0666-x

Mandal M, Singh K S, Balaji M and Mohapatra M (2015) Performance of WRFARW model in real-time prediction of Bay of Bengal cyclone 'Phailin' *Pure and Applied Geophysics* 1-19 DOI: 10.1007/S00024-015-1206-7. Impact Factor 1.618

Mohanty U C, Osuri Krishna K, Tallapragada V, Marks Frank, Pattanayak D, Sujata, Mohapatra M, Rathore L S, Gopalakrishnan S G and Niyogi D (2015) A Great Escape from the Bay of Bengal - Super Sapphire-Phailin *Tropical Cyclone: A Case of Improved Weather Forecast and Societal Response for Disaster Mitigation*, Earth Interactions, 11/ 2015; DOI:10.1175/EI-D-14-0032.1, Impact Factor 1.84

Mohapatra M, Bandyopadhyay B K and Tyagi A (2011) Best track parameters of tropical cyclones over the North Indian Ocean: a review *Natural Hazards* DOI: 10.1007/s110-69 -011-9935-0

Mohapatra M (2015) Cyclone hazard proneness of districts of India *Journal of Earth System Science* **124** 515-526 DOI:10.1007/s12040-015-0556-y

Mohapatra M, Geetha B, Balachandran S and Rathore L S (2015) On the Tropical cyclone activity and associated environmental features over North Indian Ocean in the Context of Climate change *Journal of Climate Change* **1** 1-26 DOI: 10.3233/JCC-150001

Nath S, Kotal S D and Kundu P K (2015) Seasonal prediction of tropical cyclone activity over the North Indian Ocean using the Neural Network Model *Atmósfera* **28** 271-281

Osuri K K, Mohanty U C, Routray A, Kulkarni M A and Mohapatra M (2011) Customization of WRF-ARW model with physical parameterization schemes for the simulation of tropical cyclones over North Indian Ocean, *Natural Hazards* DOI: 10.1007/s11069- 011-9862-0

Pai D S, Sridhar L and Kumar M R (2015 ) Active and Break Events of Indian Summer monsoon during 19012014 *Climate Dynamics* 1-19 DOI: 10.1007/S00382-015-2813-9" (IMPACT FACTOR : 4.673)

Pai D S, Sridhar L, Badwaik M R and Rajeevan M Analysis of daily rainfall events over India using a new long period (19012010) high resolution (0.25 X 0.25) gridded rainfall data set *Clim Dyn* DOI: 10.1007/s00382-0142307-1

Pattanaik D R and Kumar A A Hybrid Model Based on Latest Version of NCEP CFS Coupled Model *Atmospheric Science Letter* DOI: 10.1002/asl2.513

Pattanaik D R Meteorological sub-divisional-level extended range forecast over India during southwest monsoon 2012 *Meteorology and Atmospheric Physics* DOI: 10.1007/ s00703-0140308-6

Pattanaik D R and Mohapatra M (2015) Seasonal Forecasting of Tropical Cyclogenesis over the North Indian Ocean *Journal of Earth System Science* Impact Factor 1.04

Peshin S K Surface Ozone scenario at Pune and Delhi during the decade of 1990s *Journal of Earth System Sciences* JESS-D-11-00138

Pradhan D (2015) Simulation of Severe Local Storm by Mesoscale Model MM5 and Validation Using Data from Different Platforms *International Journal of Atmospheric Sciences* Aricle ID 19804, p23

Pradhan D, Sen A K and Giri R K (2015) Study of Extreme Weather Events (Hot & Cold day wave) over Bihar Region *International Journal of Latest Research in Engineering & Science* **1** June-2015

Prakash R and Srivastava H N Thermal anomalies in relation to earthquakes in India and its neighbourhood *Current Science* **108** 11 June, 2015

Puviarasan N and Sharma A K (2015) Onset, Advance and Withdrawal of South - West Monsoon over Indian subcontinent: A study from perceptible water measurement using ground based GPS receivers *Journal of Atmospheric and Solar-Terrestrial Physics* **122** 45-57

Rajeswara V R (2011) Occurrence of extremely low cold points tropopause temperature during summer monsoon season: ARMEX campaign and CHAMP and COSMIC satellite observation *Journal of Geophysical Research* **116**

Ranalkar M R, Chaudhari H S, Hazra A, Sawaisarje G K and Pokhrel S (2015) Dynamical features of incessant heavy rainfall event of June 2013 over Uttarakhand, India *Natural Hazards* online, October 2015 DOI: 10.1007/s11069015-2040-z, 1-23

Rao N P, Ravi Kumar M, Seshunarayana T, Shukla A K, Suresh G, Pandey Y, Raju D, Pimprikar S D, Das C, Gahalaut K, Mishra P S and Gupta H (2011) Site Amplification Studies towards Seismic Microzonation in Jabalpur urban area, central India *Journal of Physics and Chemistry of the earth*

Rathore L S, Roy Bhowmik S K and Chattopadhyay N (2011) Integrated Agrometeorological Advisory services in India *Challenges and opportunities in Agrometeorology* Springer

195-206

Roy Bhowmik S K, Sen Roy S, Srivastava K, Mukhopadhaya B, Thampi S B, Reddy Y K, Singh H, Venkateswarlu S and Adhikary S (2011) Processing of Indian Doppler Weather Radar data for meso-scale applications *Meteorl Atmos Phy* **111** 133-147

Roy Bhowmik S K and Durai V R Development of multi-model ensemble based district level medium range rainfall forecast system for Indian region *Journal of Earth system Science* **121** 273-285

Saha U, Midya S K and Das G K The Effect of Variable Component of 10.7 cm Solar flux on the Thunderstorm frequency over Kolkata and its Relation with Ozone Depletion Mechanism *Pacific Journal of Science and Technology* **12** May 2011 (Spring), 591-597

Samanta S K, Roy D, Mukherjee S and Sarkar R (2015) Climate in Environment and their effects on Meteorology *Indian Journal* **4** 6, June 2015

Samui R P and Kamble M V (2011) Climate change adaptation and mitigation for drought prone areas in India *Challenges and opportunities in Agrometeorology*, Springer, 335-354

Samui R P, Kulkarni P S, Kamble M V and Vaidya N G A critical evaluation of sugarcane yield variation as influenced by climatic parameters in Uttar Pradesh and Maharashtra States of India *Time Journals of Agriculture and Veterinary Sciences* **2** 6369 January 2014

Sarkar J, Datre,Thorat G, Gore S D and Tyagi A (2011) Assessing drought scenario over India during Monsoon 2009 – An Approach based on standardized Precipitation Index *Asian Journal of Water, Environment and Pollution* **8** 47-59

Sen Roy S, SahaS B, Hashmi F, Roy Bhowmik S K and Kundu P K Evaluation of short-period rainfall estimates from Kalpana-1 satellite using MET software *Journal of Earth system Science* 121

Sharma B, Chingtham P, SutarA K, Chopra S and Shukla H P (2015) Frequency dependent attenuation of seismic waves for Delhi and surrounding area, India *Annals of Geophysics* **58** doi: 10.4401

Sharma N, Dhadwal V K, Kant Y, Mahesh P, Mallikarjun K, Gadari H and Sharma A, Atmospheric CO2 variations sites over India *Air Soil and Water Research* 761-768 DOI: 10.4137/ ASW, RS 13987

Shukla H P Vector digitization of historical seismograms *International Research Journal of Natural and Applied Sciences* **2** 8, August 2015 IF- 2.818 ISSN: (2349-4077)

Singh A, Rase D M and De U S (2011) Natural Hazards in relation with Landslides *International Journal of Meteorology* **36** March, 51-55

Singh P K, Rathore L S, Singh K K, Athiyaman B (2011) Analysis of rainfall variability and characteristics of rainfed rice condition in eastern India *Challenges and opportunities in Agrometeorology* Springer, 579-596

Singh S K, Pacheco J F, Ordaz M, Dattatrayam R S, Suresh G and Baidya P R (2012) Estimating tsunami potential of earthquakes in the Sumatra – Andaman Region based on broadband seismograms in India *Natural Hazards* **52**

Sonawane K, Sreejith O P, Pattanaik D R, Benke M, Patil N and Pai D S (2015) Simulation of Indian summer monsoon using the Japan Meteorological Agency's seasonal ensemble prediction system *Journal of Earth System Science* **124** 321-333

Soni V K, Pandithurai G and Pai D S (2011) Evaluation of Long Term Changes of Solar Radiation in India *International Journal of Climatology* DOI: 10.1002/joc.2294

Srinagesh D, Singh S K, Chadha R K, Paul A, Suresh G, Ordaz M and Dattatrayam R S (2011) Amplification of Seismic waves in the Central IndoGangetic Basin, India *Bulletin of Seismological Society of America* **101** 2231-2242 October 2011, doi: 10.1785/0120100327

Srivastava K, Bhardwaj R and Roy Bhowmik S K (2011) Assimilation of Indian Doppler Weather Radar observation for simulation of meso-scale features of a land-falling cyclone *Natural Hazards* **59** 1339-1355

Srivastava K, Bhardwaj R and Roy Bhowmik S K (2011) Impact of Indian DWR data for simulation of a land-falling cyclone using ARPS model *Natural Hazards* online DOI 1007/ s11069-04 -9835-3

Srivastava K, Gao Jidong, Brewster K, Roy Bhowmik SK Xue Ming and Gadi R (2011) Assimilation of Indian radar data with ADAS and 3DVAR techniques for simulation of a small scale tropical cyclone using ARPS model *Natural Hazards* **58** 15-29

Taneja K, Soni V K, Attri S D, Peshin S K, Vikram M and Sateesh M (2014) Seasonal Asymmetry of Aerosol Optical and Radiative Properties Over New Delhi, India using Ground based Observations *proceedings of conference* '*Global Sustainability Transitions: Impacts and Innovations*', JNU, New Delhi. ISBN: 978-93-83083-77-0.

Tiwari S, Pandithurai G, Attri S D, Srivastava A, Soni VK, Bisht D S, Kumar V A and Srivastava M K (2013) Aerosol optical properties and their relationship with meteorological parameters during wintertime in Delhi, India, Atmospheric Research, IASTA2012/ SESSION-I / O-021

Tiwari S, Srivastava A K, Bisht D S, Parmita P, Srivastava M K and Attri S D (2013) Diurnal and seasonal variation of black carbon and PM2.5 over New Delhi, India: *Influence of Meteorology, Atmospheric Research* 125-126 (2013) DOI: 10.1016/ j.atmosres.2013. 01.011, 50-62 (1.911)

Tiwari S, Pandithurai G, Attri S D, Srivastava A K, Soni V K, Bisht D S, Kumar V A and Srivastava M K (2015) Aerosol optical properties and their relationship with meteorological parameters during wintertime in Delhi, India *Atmospheric Research* **153** 465-479 doi: 10.1016/ j.atmosres.2014.10.003

Tiwari S, Hopke P K, Pipal A S, Srivastava A K, Bist D S, Tiwari S, Singh A K, Soni V K and Attri S D (2015) Intra-Urban variability of particulate matter (PM2.5 and PM10) and its relationship with optical properties of aerosols over Delhi", India *Atmospheric Research* **166** 223-232

Tongdi J and Krishnakumar G Assessment of Extreme Temperatures over North east and West Coast Regions of India *GEOADRIA*, July 2015 **20** 1

Tyagi A (2011) Modernization of Observation and Forecasting System in IMD in Support of Agromet Services *Challenges and opportunities in Agrometeorology* Springer, 1-12

Yadav R K, Nankali H, Kundu B, Patel P and Gahalaut V K (2015) Finite fault slip models for the 11 August 2012 Varzaghan-Ahar, NW Iran earthquakes (Mw 6.4 and 6.3) from nearfield GPS measurements of co-seismic offsets *Journal of Asian Earth Sciences* **115** 268-272

In addition to above publications IMD also brings out the quarterly research journal MAUSAM (Formerly Indian Journal of Meteorology, Hydrology & Geophysics), since January 1950. It is a premier scientific research journal in the field of Meteorology, Hydrology & Geophysics for publication of original scientific research work of national and international scientists. IMD also regularly brings out various Reports, Monographs etc.