MAUSAM, **67**, 1 (January 2016), 67-76

631 : 551.583 : 551.501 (540)

# *In-situ* observational network for extreme weather events in India

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**सार** – मौसम की चरम घटनाओं का जब दुर्बल मानव एवं प्राकृतिक प्रणालियों पर प्रभाव पड़ता है तो उससे कोई आपदा घट सकती है विशेषकर प्रतिक्रियात्मक सामाजिक प्रणाली के अभाव में भारी वर्षा, उष्णकटिबंधीय चक्रवात गर्ज भरे तूफान ओलावृष्टि, बादल का फटना, सूखा, लू और शीतलहर जैसे घटनाओं का सटीक और सही समय पर मानीटरन और पूर्वानुमान इसी प्रकार की घटनाओं के प्रभावी ढंग से किए जाने की आवश्यकता है मौसम की चरम घटनाओं के कारण देश के अधिकांश भागों में फसलों पर खराब असर पड़ता है जिससे कुल अनाज के उत्पादन, चारा, क्रेश क्रॉप सब्जियाँ और फलों की पैदावार कम होती है जिसकी वजह से हर किसान के जीवनयापन और आमदनी और साथ ही साथ देश की अर्थव्यवस्था को भी प्रभावित करती है। अत: मौसम की चरम घटनाओं के कौशल पूर्वक पूर्वानुमान के लिए प्रेक्षणात्मक संजाल एक मुख्य घटक है। मौसम की चरम घटनाओं के लिए वर्तमान प्रेक्षणात्मक आवश्यकता को उसी स्थान पर प्रेक्षणात्मक प्रणालियों और अंतरिक्ष पर आधारित प्रणालियों के माध्यम से पूरा किया गया है। प्रेक्षणात्मक संजाल निन्तर प्रगति विभाग के पास अब डॉपलर मौसम रेडार, स्वचालित मौसम स्टेशन, कृषि ए डब्ल्यू एस स्वचालित वर्षा मापी जी पी एस आदि का संजाल है इन प्रेक्षणों को अपारम्परिक (उपग्रह) ऑकडों के साथ इसतेमाल किया जा रहा है और एच पी सी एस पर इसके भूमंडलीय और प्रादेशिक संरचनात्मक पूर्वानुमान मॉडल के साथ चलाया जा रहा है इससे चक्रवात, प्रचंड गर्ज भरे तूफान, भारी वर्षा बाढ जैसी मौसम की चरम घटनाओं के लिए मॉनीटरन और पूर्वानुमान छमताओं में सुधार हुआ है। इस शोध पत्र में भारत मैं स्थान विशेष पर मौसम की चरम घटनाओं के प्रेक्षणात्मक संजाल की भूमिका को समझने का प्रयास किया गया है। संजाल और अन्य आवश्यकताओं को और मौसम की चरम घटनाओं और प्राकृतिक आपदाओं के लिए उन्नत करने के लिए ढॉचागत क्षमताओं को बढ़ाया गया है।

**ABSTRACT.** Extreme weather events, interacting with vulnerable human and natural systems, can lead to disasters, especially in absence of responsive social system. Accurate and timely monitoring and forecast of heavy rains, tropical cyclones, thunderstorms, hailstorms, cloudburst, drought, heat and cold waves, etc. are required to respond effectively to such events. Due to extreme weather events, crops over large parts of the country are adversely affected reducing production of total food grains, fodder, cash crops, vegetables and fruits which in turn affect the earnings and livelihood of individual farmers as well as the economy of the country. *In situ* observational network are the vital component for skilful prediction of extreme weather events. Current observational requirements for extreme weather prediction are met, to varying degrees by a range of *in-situ* observing systems and space-based systems. The augmentation of in-situ observational network is continuously progressing. IMD now has a network of Doppler Weather Radars (DWRs), Automatic Weather Stations (AWSs), Agro AWSs, Automatic Rain Gauges (ARGs), GPS upper air systems etc. These observations along with non-conventional (satellite) data are now being used to run its global and regional numerical prediction models on High Performance Computing Systems (HPCS). This has improved monitoring and forecasting capabilities for extreme weather events like cyclones, severe thunderstorm, heavy rainfall and floods in a significant manner. This paper provides an overview of the role of *in-situ* observational network for extreme weather events in India, framework for further augmentation to the network and other requirements to further enhance capabilities for high impact & extreme weather events and natural hazards.

**Key words** – *In-situ*, Atmospheric observation network, Extreme weather, WMO, DWR, AWS, ARG, Upper air system.

## 1. Introduction

Atmospheric observation network forms the backbone of any meteorological service and measurement of various atmospheric parameters through surface, upper air and satellite etc. is a prime requirement for monitoring and prediction of extreme weather events. Improved and reliable forecast of weather and climate requires high resolution dynamical models. Thus, intensive monitoring of various weather systems through different platform based observing systems provide not only the necessary information about current weather systems, their effective assimilation in numerical models provide important guidance for accurate forecasts. Improved efficiency of observation systems is critical for forecasting and early warning of severe weather events like drought, flood, heat and cold wave, thunderstorms, gale winds, hail, tracking of cyclones etc. IMD has established an observational network covering different parts of the country and further augmentation is progressing for extensive weather observation acquisition and collection platform to supplement the existing infrastructure. States-of-the-art DWRs were inducted into the network and further more to be inducted soon to cover other regions. The GPS based Radiosonde systems has improved the quality of upper air observations over India. Automatic systems such as AWSs and ARGs are complementing the SYNOP Observations and are strong means to provide the data from remote locations. High Speed Wind Recorders are able to contribute significantly in prediction of extreme weather events in coastal regions. Collection of observations in near real time is an integral part of observation system. *In-situ* observations and other meteorological data recorded in different parts of the world are exchanged through a telecommunication network. The observational aspects including weather radar for tropical cyclone monitoring were reviewed by Raghavan (2013) with respect to the various observational facilities and techniques which can be deployed for the detection, tracking and understanding of Tropical Cyclones (TC). He emphasized that the real test of the efforts in terms of technology is the performance of our forecasts in an operational context and also elaborated the steps needed in this regard. Bhatia & Sharma (2013) discussed the recent advances in observational support from space-based systems for tropical cyclones. According to them, R&D efforts of last several years have resulted in lot of improvements in the Quantitative products derived from the satellite data and these products have certainly improved the analysis of TC and prediction of the future intensity/movement of TCs. Mohapatra *et al*. (2013) discussed the outcomes and challenges of Forecast Demonstration Project (FDP) on landfalling cyclones over the Bay of Bengal. According to them, the comparison of observational systems before and after FDP indicates a significant improvement in terms of Radar, Automatic Weather Station (AWS), and High Wind Speed Recorders over the region and has resulted in reduction in monitoring and forecasting errors. Kumar *et al*. (2011) discussed the Technical & operational characteristics of Upper air GPS Radiosounding System installed in the upper air network of IMD. According to them, after the introduction of GPS Radiosonde in the network, data quality has improved substantially at these stations. WMO (2015) assessed the progress made against the actions set out in the GCOS Implementation Plan for the Global Observing System for Climate, while also providing a more generic assessment of the overall adequacy of the global observing system for climate and stated that there have been improvements in coverage for a number of longer established *in-situ* networks, including the main meteorological networks. The quality of measurements has also shown improvement. Some gaps in the coverage of networks over land have been reduced. Automation has increased the temporal frequency of observation and has enabled measurements to be made at additional remote locations. Zahumensky (2006) discussed the Integrated National *in-situ* Observational Network. According to him, in order to maximize the potential value and benefit of observations from different observation networks, there is a need to integrate the planning, operation, data management, system monitoring, and life cycle support (operation, maintenance and repair) to existing and future observations.

## 2. Methodology

The requirements for observational data may be met using *in situ* measurements and/or remote-sensing (including space-borne) systems, according to the ability of the various sensing systems to measure the elements needed. WMO Guide to Meteorological Instruments and Methods of Observation WMO No. 8 (2008) describes the requirements in terms of global, regional and national scales and according to the application area. The Global Observing System, designed to meet these requirements, is composed of the surface-based subsystem and the space-based subsystem. The surface-based subsystem comprises a wide variety of types of stations according to the particular application (for example, surface synoptic station, upper-air station, climatological station, and so on). The space-based subsystem comprises a number of spacecraft with on-board sounding missions and the associated ground segment for command, control and data reception. Present weather, past weather, wind direction and speed, cloud amount, cloud type, cloud-base height, visibility, temperature, relative humidity atmospheric pressure, precipitation, snow cover, sunshine and/or solar radiation, Soil temperature and Evaporation are observed at a station making *in-situ* surface observations. Instruments are used to measure all of these elements with desired accuracy, except cloud type. However, with current technology, instruments for present and past weather, cloud amount and height, and snow cover are not able to make observations of the whole range of phenomena, whereas human observers are able to do so. Some meteorological stations take upper-air measurements, measurements of soil moisture, ozone and

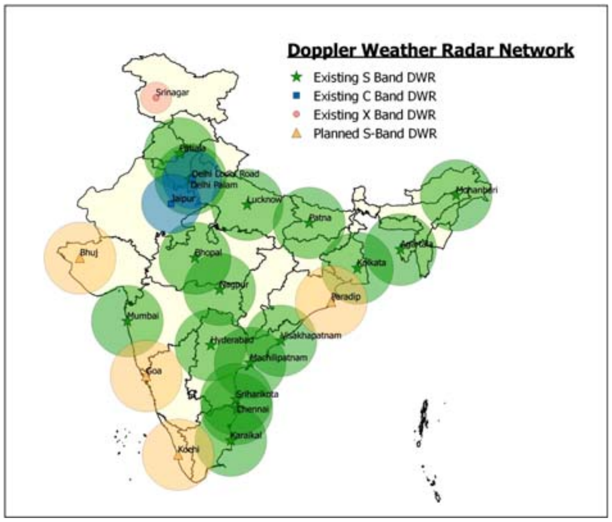


**Fig. 1.** Doppler weather radar network

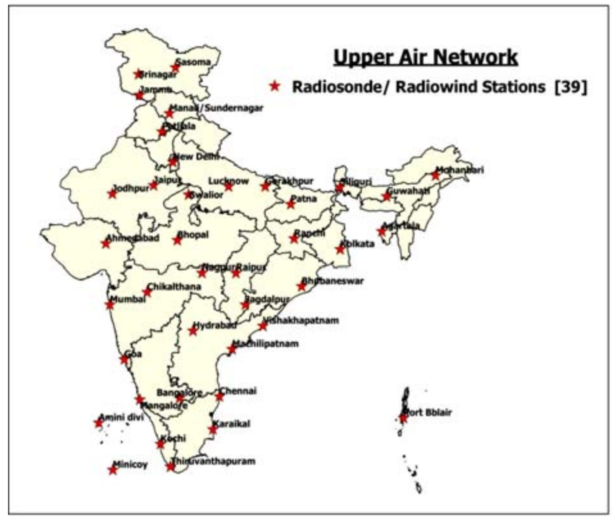


**Fig. 2.** Radiosonde/radiowind (RS/RW) network

atmospheric composition, and some make use of special instrument systems. Most of the elements required for synoptic, climatological or aeronautical purposes can be measured by automatic instrumentation. As the capabilities of automatic systems increase, the ratio of purely automatic weather stations to manned weather stations (with or without automatic instrumentation) increases steadily. Severe Weather Forecasting Demonstration Project (SWFDP) aims to contribute to capacity-building and for improving warnings of hazardous weather conditions and weather-related hazards. THORPEX (The Observing System Research and Predictability Experiment) programme under WMO is an international research programme to accelerate improvements in the accuracy of 1-day to 2-week high-impact weather forecasts.

## 3. Status of *in-situ* observational network

Atmospheric observations are sourced from the numerous meteorological and related observational networks and systems to provide current assessment & weather forecast for optimum operation of weather based service activities like agriculture, irrigation, shipping, aviation, offshore oil explorations, etc. including the warnings for severe weather phenomena like tropical cyclones, norwesters, duststorms, heavy rains, snow, cold and heat waves, etc., which cause destruction of life and property. Climate information are also required for agriculture, water resource management, industries, oil exploration and other nation-building infrastructure development activities. *In-situ* observational network consisting of different type of equipments covering different parts of the country has been established and further augmentation is progressing for extensive weather observation acquisition.

### 3.1. *Doppler weather radar network*

Doppler Weather Radar (DWR) observations are most important for prediction of extreme weather events because it can detect rain and severe weather even when it is cloudy or dark. Doppler radar sends out electromagnetic wave fields that can be reflected back to the radar by things in the air like precipitation. The amount of energy that is reflected back can indicate how heavy the rain might be or tell there is hail. The information of reflectivity, wind speed and spectrum width obtained from DWRs helps the forecasters in issuing forecast and warnings for extreme weather events. Doppler radar can also show how the wind is blowing near and inside the storm. This is helpful in understanding what kinds of hazards the thunderstorm might have (cyclones, thunderstorm, gale winds, hail, etc.) associated with it. It also helps to understand how the thunderstorm is feeding itself. Radar products form a very important guiding tool for improving the nowcasting system. IMD has implemented nowcasting of thunderstorms, squalls and hailstorms for the areas covered by DWRs. Agriculture sector are also benefitted by nowcast/forecast of severe weather as time of rain fall occurrence and quantum of rain may enable farmers to plan the agriculture activities which in turn may reduce/protect from the loss of inputs, enhance its use efficiency like pesticide spray, fertilizer application and thus yield more production. Doppler Weather Radars network of IMD (Fig. 1) has progressed over the years along with the real time data reception and dissemination to end users.

### 3.2. *In-situ upper air observational network*

IMD is operating a network of 39 Radiosonde / Radiowind (RS/RW) stations (Fig. 2) and 62

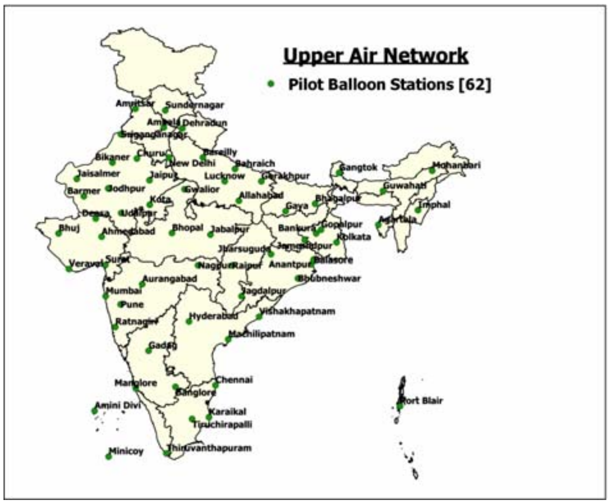


**Fig. 3.** Pilot balloon network


**Fig. 4.** Departmental surface observatories (203)

Pilot Balloon Observatories (Fig. 3) on operational basis. The radiosonde system provides a standard set of measurements of wind speed and direction, temperature and dewpoint temperature (TEMP reports). The dewpoint data provides information on moisture and is usually combined with the temperature data to provide the moisture information as relative humidity. Optionally a balloon-only ascent without the temperature measurements yields wind only (PILOT reports). *In-situ*

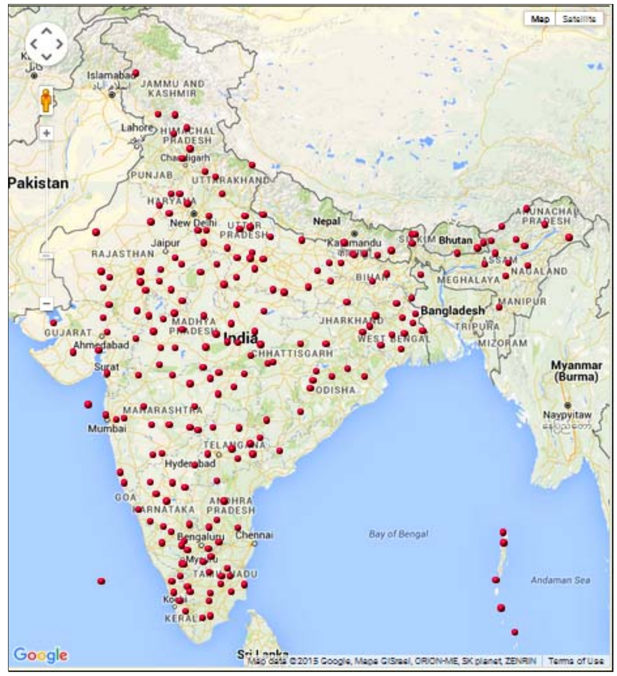


**Fig. 5.** Non-departmental surface observatories (247)

radiosonde measurements are providing data for NWP and meteorological data thus collected are used on real time basis for operational forecasting. Radiosonde profiles also provide ground truth validation for calibration of satellite sounding data through comparisons of collocated soundings. In recent years, the Upper Air Radiosounding System based on Global Positioning System (GPS) is used as an effective method. GPS receiving device in a radiosonde improves observation accuracy, allowing simplification of ground equipment. To get improved quality of upper air data, 6 Radiosonde stations upgraded to GUAN stations as per the WMO GCOS standards in 2015 at New Delhi, Chennai, Kolkata, Guwahati, Nagpur and Mumbai. Remaining stations except Sasoma also upgraded with GPS sonde systems.

3.3. *In-situ surface observational network*

*In-situ* Surface observational network consists of 1068 surface observatories (all types) and Automatic systems. The data is archived at National Data Centre (NDC), Pune for manual observatories from year 1790 onwards and for autographic charts from year 1940 onwards. The basic meteorological parameters measured from these stations includes Atmospheric pressure, Wind Speed & direction, Atmospheric Temperature, Atmospheric Humidity, Precipitation (rain or snow), Evaporation, Soil Temperature, Sunshine duration. In addition, visual observations of type & amount of cloud, height of the cloud base, atmospheric visibility, present &

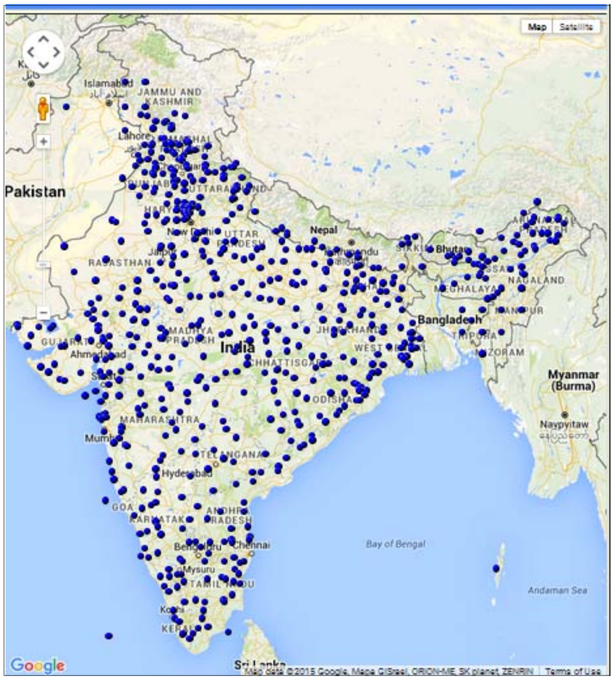


**Fig. 6.** Automatic weather stations (675)

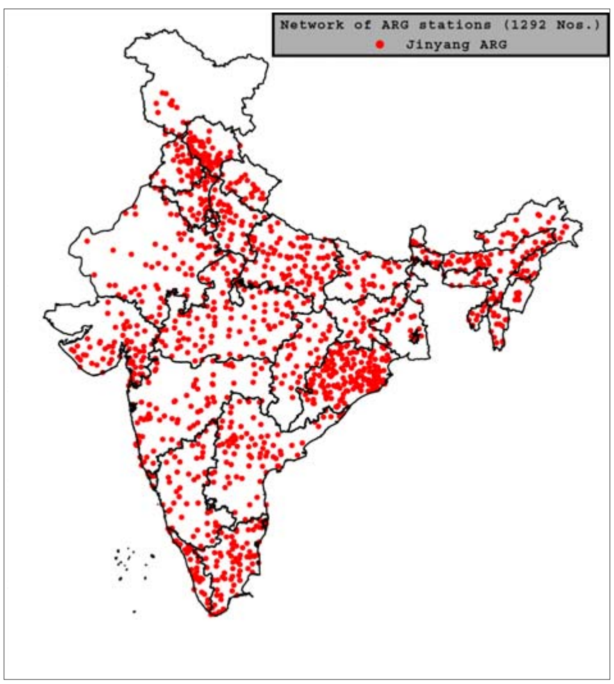


**Fig. 7.** Automatic rain gauges (1292)

past weather are also made at the station. The observations at the observatories are made round the clock (24×7×365). IMD network comprises 203 Departmental observatories (Fig. 4) and 247 Non-Departmental observatories (Fig. 5). Conventional surface measurements comprise land

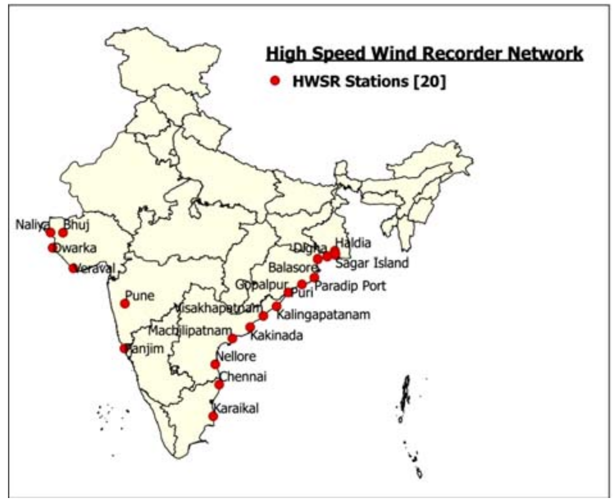


**Fig. 8.** High speed wind recorder network

SYNOP reports at observing stations over land and marine surface data from ships. Land synoptic reports have traditionally been provided by observers reporting meteorological variables such as wet and dry bulb temperatures, pressure, wind speed and direction, cloud type, cover and base height, and visibility. The need for weather reports from remote or inhospitable locations led to the establishment of automatic systems. There has been automation of the land surface network with 675 AWSs (Fig. 6) and 1292 ARGs (Fig. 7). AWSs have the advantage of being able to provide measurements much more frequently than human observers around the clock. A network of High Speed Wind Recorders has also been established to monitor wind movements & cyclone developments near coastal areas (Fig. 8). India Meteorological Department provides specialized meteorological services to the Airport Authority of India for ensuring aviation safety through the network of Automatic Weather Observing Systems (AWOSs) to acquire, process, and display real time data of Wind, Temperature, Pressure, Visibility & Runway Visual Range and Height of base of low clouds. IMD is also collecting and processing the meteorological observations of the Indian Ocean area north of 15° S bounded by the longitudes of 20° E and 100° E. Indian Voluntary Observing Fleets (IVOFs) are maintained through six Port Meteorological offices at Kolkata, Visakhapatnam, Chennai, Kochi, Goa and Mumbai. IVOF consists of ships of Merchant Navy, Indian Navy and Foreign ships. Meteorological Observations from the oceanic area are being collected on real time basis for operational forecasting. The earth receives a vast amount of energy from the sun in the form of solar radiation. Solar radiation data for a location represents the energy per unit area and provide information on how much of the sun's energy

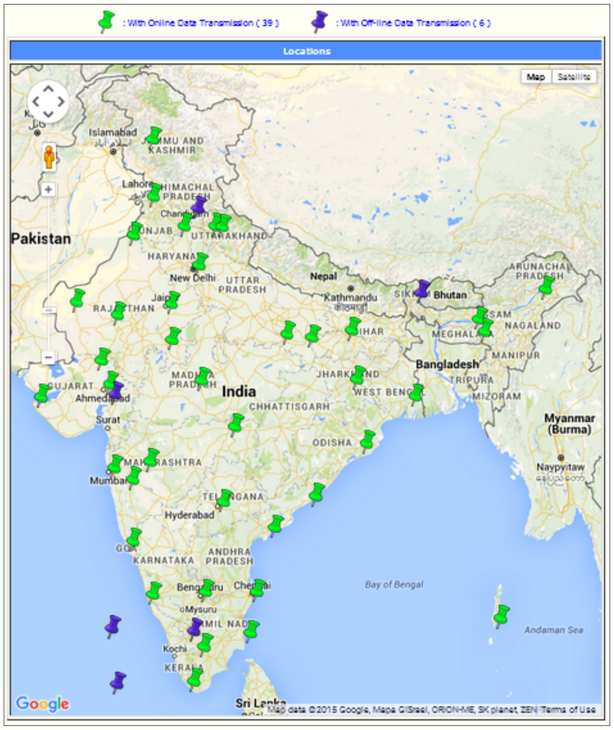


**Fig. 9.** Network of radiation observatories

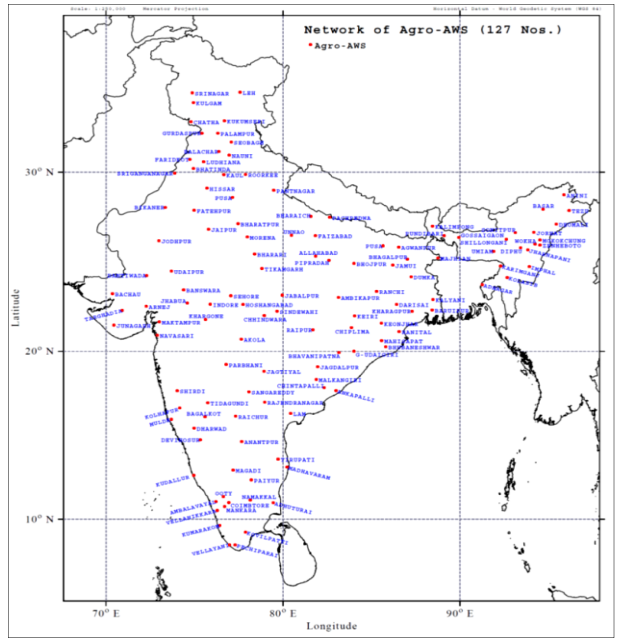


**Fig. 10.** Agro-AWS network (127)

strikes a surface at a location on earth during a particular time period. It also provides the information on the significant variations occurring naturally over the course of days, months, and years. Change in average weather conditions or in the time variation of weather around longer-term average conditions (*i.e.*, more or fewer extreme weather events) is linked to variations in solar radiation received by Earth. Central Radiation Laboratory, Pune is maintaining the Radiation Network of 45 stations (Fig. 9) to study the Heat budget of the atmosphere, Assessment of solar energy potential, Agricultural production and crop yield etc. It is recognized as a Regional Radiation Centre in RA-II Region of World Meteorological Organization.

### 3.4. *In-situ ocean observational network*

Indispensable to any forecasting system is an observational system that provides the data needed to build and validate models and makes available in near-real-time for assimilation into models. Improved and reliable forecast of weather and climate requires integration of observations of earth system using very-high-resolution dynamical models. A combined approach involving land, ocean and atmospheric processes hold the key to improve the forecasts at various temporal and spatial ranges. Indian National Centre for Ocean Information Services (INCOIS), an autonomous body under the Ministry of Earth Sciences, maintains the *in-situ* ocean observation network comprising surface moorings, current meters, AWSs and water-level recorders, wave-rider buoy, HF radar, buoys equipped with sensors for sea surface temperature (SST), surface air pressure, winds, and surface currents, Bottom-pressure recorders (BPRs), Ship-borne observations etc. Data received from *in-situ* platforms under Ocean Observing System provide the initial conditions to ocean-atmosphere coupled models used for the prediction and understanding of the extreme weather events.

### 3.5. *In-situ observational network for agro-meteorological services*

Agriculture is the backbone of the Indian economy and farming has always held a crucial place in the Indian economy and culture. The farmer is producing the most basic goods for human livelihood and providing social stability through his hard work and the particular structure of the rural society but his production is subject to the volatility of weather conditions. Even with large scale innovations and improvements in farming practices, genetic engineering, water technology and irrigation facilities, agriculture in India continues to be dependent on weather and climate. Farming is still a gamble for the Indian farmers because of extreme weather events and variability in the monsoon rains and in such cases crops over large parts of the country are adversely affected reducing total food grains and fodder production, which in turn affect the individual farmers as well as the economy of the country. A network of 127 Agro-AWS (Fig. 10) in

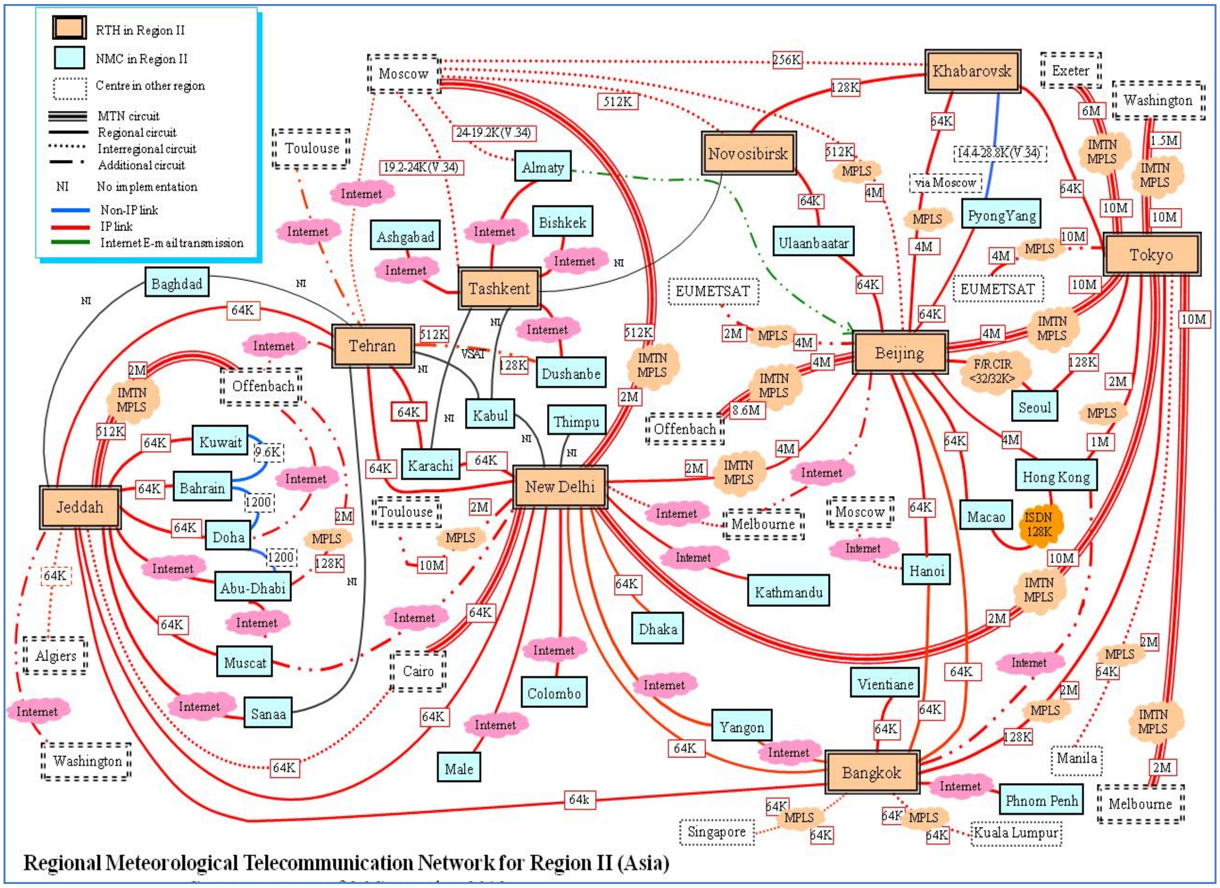


**Fig. 11.** Communication network

different agro-climatic zones of India have been equipped with agro-meteorological sensors to provide the Agrometeorological Advisory services (AAS) to farmers in collaboration with Agromet Field Units (AMFUs) located at State Agricultural Universities, Indian Council of Agriculture Research (ICAR) institutes, Indian Institute of Technology (IITs), M. S. Swaminathan Research Foundation (MSSRF) etc. Agro-AWS have additional sensors for parameters such as Soil Temperature, Soil Moisture, Leaf Wetness and Leaf Temperature. The network caters to the requirements of weather forecasting and agro-meteorological advisories. The hourly data is being disseminated to end users for operational utilization. In addition, there are 263 Agrometeorological Observatories, 219 Evaporation Stations, 42 Evapotranspiration Stations, 43 Soil Moisture Recording Station and 76 Dew Fall Recording Stations to generate different kinds of data on agromet parameters. Automation of data communication from these manual observatories to central location in IMD is underway.

### 3.6. *Global exchange of in-situ observations*

Efficient weather forecasting activity depends on a sound observing system, a communication network and a centre for analysis and prognosis of these data. Operational meteorology is a globally locked enterprise in which meteorological data recorded in different parts of the world are exchanged through a telecommunication system. Meteorological telecommunication of IMD consists of an integrated network of point-to-point circuits and multipoint circuits which interconnect meteorological centers within the country and the world for receiving data and relaying it selectively. It is mainly organized on a two level basis, the meteorological telecommunication network within the Global Telecommunication System (GTS) (Fig. 11) of World Weather Watch (WWW) program of World Meteorological Organization (WMO), and the National Meteorological Telecommunication Network. Global Information System Centre (GISC) has been installed at Pune under WMO WIS (WMO

Information System) programme. The Mirror RTH at Pune also acts as a disaster recovery centre for Regional Telecommunication Hub (RTH) New Delhi and maintains all meteorological data, products to meet the user requirements in case of failure of RTH New Delhi to follow the best practices of meteorological operations on 24 hour basis.

## 4. Non *in-situ* remote-sensing satellite systems

The satellite images and data are a vital need for forecasting and their use in weather forecasting is increasing day by day. The observations from satellites are a prominent source, and have become indispensable for forecasting the weather at all ranges, contributing to the downstream production of warnings and other information that support our continued social and economic wellbeing. INSAT-3D was launched carrying 6 channel imager, nineteen channel sounder, Data Relay Transponder (DRT) & satellite aided search and rescue payloads with several advanced features. IMD receives and processes meteorological data from the meteorological payloads of INSAT satellites namely Kalpana-1, INSAT-3A and INSAT-3D. The qualitative products generated after processing the satellite data are transmitted to users for use in Weather forecasting. *In-situ* station data is also merged with satellite data in preparing gridded data to analyze the extreme events. The replacement of existing analog and digital Cyclone Warning Dissemination system (CWDS) by Direct to Home (DTH) based CWDS system are accomplished at 222 locations. DTH based CWDS system will help in disseminating cyclone warnings to the affected coastal areas during the cyclone.

Real time Analysis of Products & Information Dissemination (RAPID), a web based quick visualization and analysis tool launched for satellite data on a real time basis, also helps to monitor extreme weather events. 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 to agricultural production. Through this, we can see the Fog presence over railway track and highways & a pilot can see the position of clouds, fog and visibility of the entire route in real time basis interactively. Moisture in atmosphere is the main source of all weather related phenomenon. Water content is measured conventionally by upper air soundings and estimated through satellite by Upper Tropospheric Humidity (UTH); Integrated Precipitable Water Vapour measurement which depicts the integrated amount of water vapour vertically over a place is fast being recognized as an important tool for weather monitoring and forecasting and is being used extensively worldwide. As a pilot project five GPS stations were installed at New Delhi, Mumbai, Chennai, Kolkata, Guwahati and another 25 stations to be inducted soon in the network.

## 5. Augmentation of *in-situ* observational network

In the Indian subcontinent context, the Himalayas govern the climate and weather of the region and drive the major weather systems, *viz*., Western Disturbances (WDs) during winter time and monsoon phenomenon during summer time. Heavy snowfall events over the Western Himalayan region and the subsequent avalanches over the region affect life and property of the habitats. Impact of the weather events are enhanced by topography which makes the area more prone to cloud bursts, flash floods and landslides. Integrated Himalayan Meteorology Programme for Western & Central Himalayas initiated covering four states namely Jammu & Kashmir, Himachal Pradesh, Uttarakhand, and Sub Himalayan West Bengal to improve mountain weather and climate monitoring and forecast services through installation of state of art systems like 9 Doppler Weather Radars (DWRs), 230 Surface Observing equipments consisting of Automatic Weather Stations, Automatic Rain Gauges & Snow Gauges, 7 GPS based upper air systems and 9 Heliport Automated Weather Observation Systems (HAWOS) etc. It is also planned to introduce new *in-situ* systems like Micro Rain Radars (MRRs) at 18 locations for the measurement of rain rate, liquid water content and drop size distribution from near ground to several hundred meters. It can be used for now-casting of precipitation, *i.e*., it may detect the start of rain from ground level to high above the radar several minutes before the start of rain at ground level. Development of High Impact Weather Forecasting System (DSWFS) is being implemented for development of state-of-art high resolution modeling framework for predictions of high-impact weather systems including Thunderstorms, Cyclone, Fog, Cloudburst & Heavy Rainfall for public safety and economic growth of the country.

The existing system comprises state of art observing systems with their networking and integration, utilizing them in high resolution numerical models in high performance computing facility, their visualization, archival and dissemination to the user community in a skilful manner. The observational network of IMD need to be further enhanced along with the coverage and density of observations for the entire country with a centrally connected digital observational data acquisition, processing and visualization systems to further enhance capabilities for monitoring and forecasting high impact & extreme weather events and natural hazards. While the existing network of DWRs in India is partial and there exist some gaps to meet the growing demand of more accurate monitoring of severe weather in the required temporal and spatial scale. More DWRs are required to be inducted in the network for forecasting and early warning of severe weather events. Timely warnings of severe weather events can save more lives and minimize the damages to properties. Induction of an adequate number of DWRs in the network would facilitate improvement in analysis. The availability of country wide weather radar coverage including overlapping regions and integration of the weather radar network would provide vital information for nowcasting purposes on meso-scale convective weather developments anywhere in the country. Some of the new observing systems need to be planned to include Wind Profilers & Microwave Radiometers to provide vertical profiles of boundary-layer wind, temperature & atmospheric humidity, column-integrated total amount of water vapour, liquid water, vertical profiles of cloud liquid water, and atmospheric stability (now-casting of convection, thunderstorms) and measurement of fog; Wind Lidar to provide wind velocity measurements with higher resolutions both in space and time. The cloud to cloud lightning is a good indicator of impending severe weather and helps in tracking the thunderstorm activity in real time and thus is very useful in nowcasting especially in aviation sector, planning sport events and functioning of high risk establishments etc.

## 6. Integration and quality control of *in-situ* observational network

National observational network consists of several separated networks of observing stations each of them with several sensors installed. Each separate network/system has been managed separately from the others. Many organizations already own *in-situ* networks; some States in India have also established the network of AWSs and ARGs and others are also in the process to implement the same. Data from few organizations is shared with IMD and used in weather forecasting but data from various other organizations are not the part of national observational network. If organized properly, data from such observation may help substantially in the prediction of extreme weather events. To overcome this and save the financial sources as well as maximize the potential value and benefit of observations, it is required to integrate the planning of existing and future observations. In combination with those, the integrated network (as an upgraded multilevel network) for monitoring the weather, water, climate variability and other environmental components should maintain a network size and station density that satisfies all major needs. The station spacing and interval between observations should correspond with the desired spatial and temporal resolution of the variables to be measured or observed. The total number of stations should, for reasons of economy, be as small as possible but large enough to meet the various users' requirements and should be expandable and adaptable to meet future users' needs and requirements on observations to provide coordinated data collection to minimize duplication, reduce costs and maximize data availability by ensuring high-resolution and accurate real-time data for all required applications. The network shall meet the established WMO standards for sitting and exposure, sensors/network performance and maintenance, data availability, data quality and required metadata.

The Quality Control (QC) of *in-situ* observational network is impossible without quality assurance implemented by a quality management system which shall operates continuously at all points of the whole observing system, from network planning, installation and operations to data transmission and archiving. Thus, quality assurance starts far before the installation of the sensors and ends providing data of high and known quality accompanied by corresponding metadata. Data quality to be maintained at the highest possible level at all times and data should be available in a timely and accurate manner. It is of the utmost importance to make adequate provision for QC of data to ensure that they are as free from error as possible and the quality of data is known in every level of the data obtaining process. Data validation to be implemented to determine how accurate data are, complete, consistent or reasonable and may also involve checking for compliance against applicable standards, rules, and conventions to identify the causes of the errors detected and to focus on preventing those errors from re-occurring. The real-time QC at the observing point is, however, of paramount importance since many of the errors introduced during the observation process cannot be eliminated later. QC Monitoring at the network level should be implemented and performed as real time quality control procedures have their limitations and some errors can go undetected, such as sensor drift or bias, as well as errors in data transmission. All possibilities for automatic monitoring of errors should be used to recognize errors in advance before they could affect the processed values.

## 7. Conclusions

*In-situ* observational networks continues to be the vital component for skilful prediction of extreme weather events and an essential complement, sampling depths and variables that are beyond the view from space and providing detailed structures and longer historical records. They also serve as anchor points that support the calibration and validation of satellite observations and derived data products. The existing *in-situ* observational system comprises state of art observing systems with their networking and integration, utilizing them in prediction of extreme weather events. The whole observational network particularly of DWRs need to be further enhanced along with the coverage and density of observations for the entire country along with the introduction of new observing systems such as Wind Profilers, Wind Lidars, Microwave Radiometers and Lightning Detectors etc. to meet the new challenges and enhance capabilities for high impact & extreme weather events and natural hazards.

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