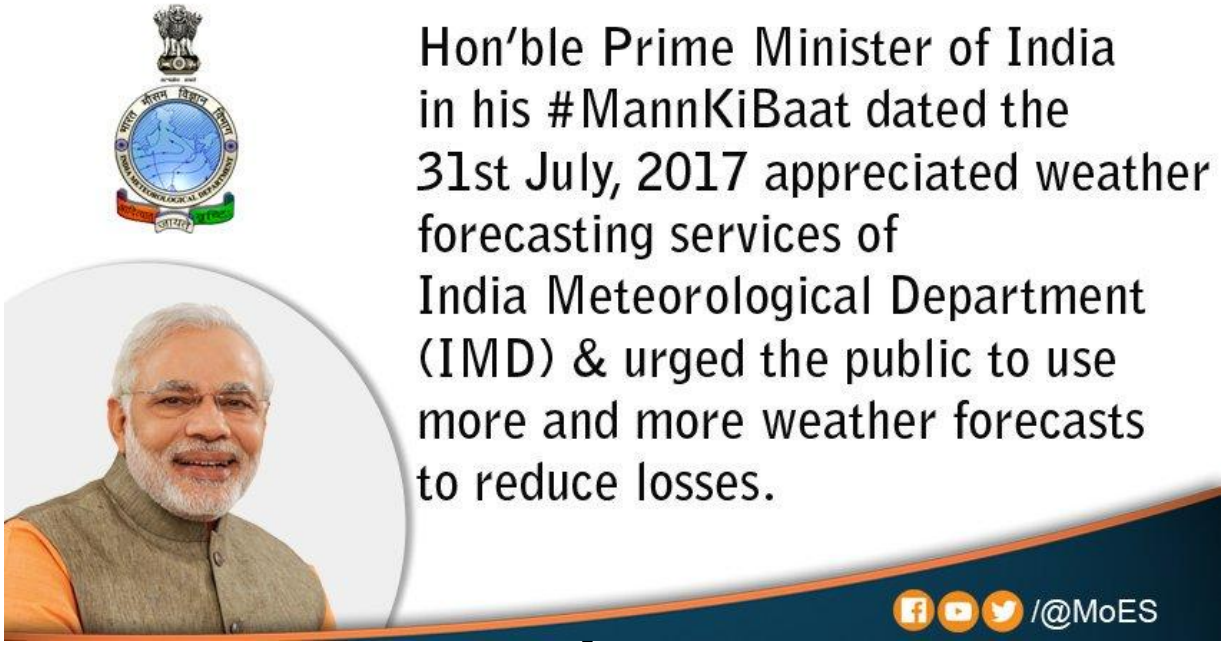
Ministry of Earth Sciences
Brief account of Four Years Achievements
2014-18

1. Introduction

The mandate of the Ministry of Earth Sciences (MoES) is to provide services for weather, climate, ocean and coastal state, hydrology, seismology, and natural hazards; to explore marine living and non-living resources in a sustainable way and to explore the three polar-regions (Arctic, Antarctic and Himalayas). Some of the most important achievements which include a wide variety of services that are relevant to the society over the past four years (2014-2018) are given below:

2. Natural Disasters- Early Warning Systems

The Indian region is frequently affected by a variety of hydro-meteorological disasters such as heavy rains, tropical cyclones, Tsunamis, storm surges, severe local storms like thunderstorms, hailstorms, cloudburst, tornadoes, floods, heat and cold waves, etc. There are 13 coastal states/UTs encompassing 84 coastal districts which are affected by tropical cyclones. The states falling within the periphery of "India Flood Prone Areas" are West Bengal, Orissa, Andhra Pradesh, Kerala, Assam, Bihar, Gujarat, Uttar Pradesh, Haryana and Punjab. Heat waves are more frequent over the Indo-Gangetic plains of India. Northern and eastern states are affected by cold waves. Thunderstorms are more frequent and intense over east and northeastern India and severe fog occurs over the Indo-Gangetic plains in the winter season.



India Meteorological Department (IMD) is the National Meteorological Service of the country responsible for monitoring and providing warnings for severe weather phenomena as mentioned above. INCOIS/MoES provides Tsunami warnings whenever such occasions arise.

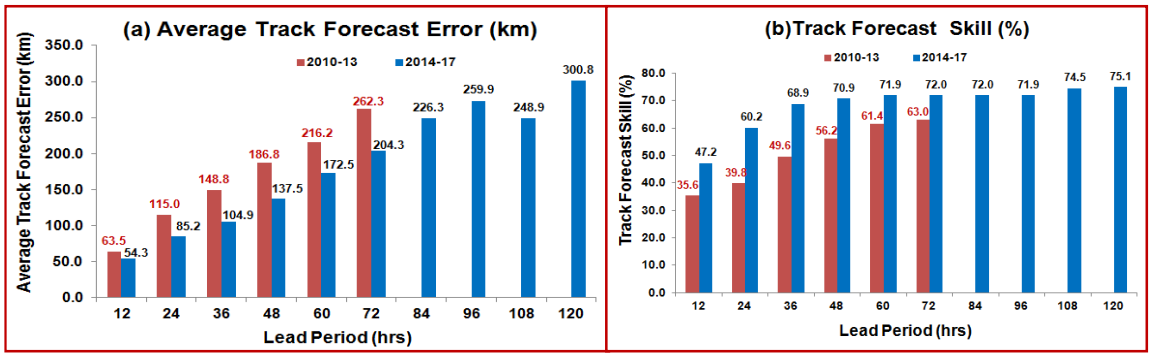
Over the last four years, IMD had improved the warning services by augmenting observational network, adopting weather prediction models of higher resolution and improved data assimilation. **There has been an enhancement of Doppler Weather Radar(DWR) network from 16 in 2014 to 24 in 2018.** The network of Automatic Weather Stations (AWS) has increased from 675 to 711 in 2018 and the network of Automatic rain-gauges has increased from 1160 to 1350. **There is also improvement in use of Satellite data for numerical weather prediction with recent launch of INSAT 3D/3DR satellites.**

Inauguration of Kochi DWR on 12th July 2017

In 2014, IMD was using a weather prediction model with 25 km resolution, which has been improved to the resolution of 12 Km in 2017. IMD now plans to use this higher version of the model with at least 20 ensembles to generate ensemble forecasts by June 2018 for generating probabilistic forecasts. With this effort, India will have the one of the best weather warning systems in the world.

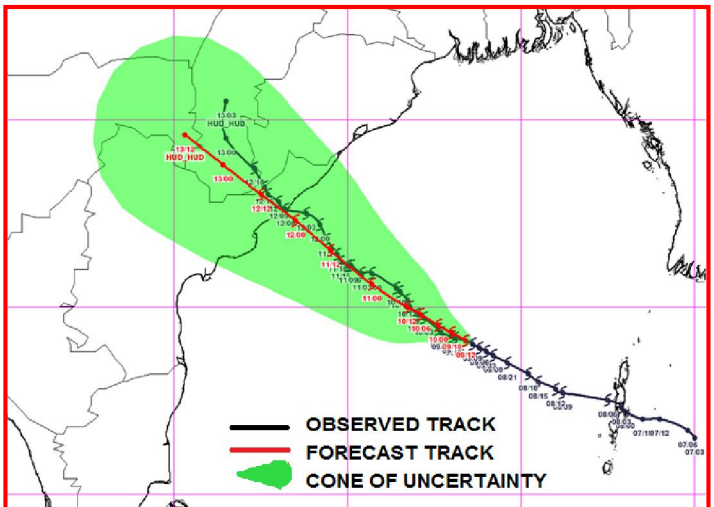
2.1 Cyclone warning services

There has been continuous improvement in forecast accuracy with decrease in track and landfall forecast errors and increase in skill over the last 4 years. During 2014-17, the 24, 48 & 72 hr track forecast errors were 85, 137 & 204 km respectively which are 22-26% less than the errors during 2010-13. The track forecast skill during 2014-17 for 24, 48 & 72 hr lead period was 60.2, 70.9 & 72% against 39.8, 56.2 & 63.0% during the period 2010-13.



Comparative analysis of (a) track forecast errors and (b) skill during 2010-13 and 2014-17.

Increase in lead period of forecast was increased from 72 to 120 hours for track, intensity and size forecasts. Issue of Probabilistic Genesis forecast was introduced up to a lead period of 72 hours from 2014. An example of improved forecast in case of cyclone Hudhud is demonstrated below, indicating negligible error in landfall forecast.



Observed & Forecast track of ESCS Hudhud along with cone of uncertainty

More importantly, there has been a significant reduction in loss of human life and reduction in the cost towards evacuation and payment of ex-gratia to affected people.

2.2 Tsunami Early Warning

The Indian Tsunami Early Warning Centre (ITEWC) monitored 143 earthquakes of magnitude ≥ 6.5 during the period April 2014 to March 2018. Out of these, 12 moderate earthquakes occurred in the Indian Ocean region. For these earthquakes, ITEWC disseminated the bulletins as per standard operating procedure to its regional (Indian Ocean Countries) and national (India) stake holders. The new Decision Support System (DSS) version 2016 was tested extensively during IOWave16 tsunami mock exercise and made operational in December 2016. The new DSS is integrated with the necessary metadata layers, latest version of Area of Service (AoS), Earthquake Source Zone (ESZ), CFPs and CFZs. As part of the Tsunami Warning System, **INCOIS/MoES has completed mapping the highly vulnerable coastal regions to natural disasters such as tsunami and storm surges using 3D GIS technique for several locations in the east coast of India.**

2.3 Heat wave warnings

Since 2016, IMD has started Hot Weather Season forecast outlooks of March-May temperatures. A bi-weekly outlook is also issued every Thursday. IMD also issues heat wave alerts and warnings for 5-7 days and outlook for subsequent 7 days with daily updates of Heat Waves experienced. Since 2016, Heat Action Plan is being implemented in cities across central India including Ahmedabad, Surat, Nagpur, Akola, Gondia, Chandrapur, Nanded, Jalgaon, Bhubaneswar and Cuttack. **It is a comprehensive early warning system and preparedness plan for extreme heat events which has resulted in the number of deaths.**

Heat Wave related Mortality in India since 2015	
2015	2422
2016	557
2017	220

2.4 Real Time Monitoring of Seismic Activity

National Center for Seismology (NCS) is the nodal agency of Government of India, primarily responsible for monitoring seismic activity in and around the country. The operational task of the Center is to quickly estimate the earthquake source parameters immediately on occurrence of an earthquake and disseminate the information to all the user agencies including the concerned State and Central Government agencies responsible for carrying out relief and rehabilitation measures. For automatic earthquake parameter dissemination, IndiaQuake, a mobile App was launched. It is a faster way for communicating earthquake information with no restrictions on the number of recipients.

NCS is maintaining a country-wide National Seismological Network (NSN). In 2014 a decision was taken to upgrade the national seismological network. This includes adding more seismological observatories and upgrading all analog observatories. **This has led to increase in observatories from 84 in 2014 to 110 as on date. This number will further increase to 116 by June 2018. We propose to increase to 150 by end of 2019.**

Towards mitigating seismic hazard in a few targeted cities lying in seismic zone III, IV and V, a project of seismic microzonation of 30 cities has been initiated by NCS. In 2016, NCS completed the seismic hazard microzonation of NCT Delhi. Microzonation of a few more cities (Jabalpur, Guwahati, Bengaluru, Kolkata and Sikkim state) has also been completed through MoES sponsored projects.

3. Environment and Climate Change

The world is facing the biggest environmental challenge our generation has ever seen. Over the past 100 years, we have changed the sensitive energy and ecological balance of our planet Earth by burning fossil fuels and many other human activities like deforestation. Conserving natural resources is a basic requirement for sustainable development and improving the quality of human life. The climate change has many adverse consequences like floods, droughts, heat waves, sea level rise, glacier and sea ice melting etc. Ministry of Earth Sciences is working on many facets of climate change including the basic sciences and future climate change projections

3.1 System of Air quality Forecasting And Research (SAFAR)

In view of growing societal importance in air pollution problem, MoES has introduced a major national initiative, "System of Air Quality and Weather Forecasting and Research" known as **"SAFAR"** for greater metropolitan cities(Delhi, Mumbai, Pune and Ahmedabad) of India to provide location specific information onair quality in near real time and its forecast upto 1-3 days in advance.

SAFAR-Ahmedabad an integrated early warning System of Air Quality, Weather and Health was dedicated to the Nation by Dr. Harsh Vardhan, Hon'ble Union Minister for Science & Technology and Earth Sciences along with several State Ministers and dignitaries on 12 May 2017 in Ahmedabad.

The current observations and forecasts are disseminated through various user-friendly communication media such as SAFAR-Air (Mobile app for Android and I-phone).

3.2 Climate Change Research:

The Centre of Climate Change Research (CCCR) was launched in 2009 with the support of the Ministry of the Earth Sciences, Government of India. The CCCR focuses on development of new climate modeling capabilities to address global and regional issues concerning the Science of Climate Change. The salient achievements made by the Centre are given below:

- The IITM Earth System Model (IITM-ESM) - a global modeling framework for long-term climate investigations was developed indigenously. **The IITM-ESM is the first climate model from India to contribute to the Coupled Modeling Inter-comparison Project Phase-6 (CMIP6) experiments and the Intergovernmental Panel on Climate Change (IPCC) Sixth Assessment Report (AR6).**
- The centre is the nodal agency for the Coordinated Regional Downscaling Experiment (CORDEX) – an International Project under the World Climate Research Programme (WCRP), World Meteorological Organization. CCCR has generated an ensemble of high resolution downscaled projections of regional climate and monsoon until 2100 for the IPCC climate scenarios (RCP4.5 and RCP8.5) at 50 km resolution.
- High resolution simulations were performed using a variable resolution global atmospheric model with telescopic zooming (grid-size ~35 km) over South Asia for the 20th century (1886-2005) and future projections for the 21st century following the IPCC scenario RCP4.5. The high resolution

experiments are also being used for detection and attribution of recent decadal changes in monsoon precipitation over India due to natural and anthropogenic forcing.

Dr. Harsh Vardhan, Hon'ble Union Minister for Ministry of Science & Technology and Ministry of Earth Sciences released a report "Climate Change over India" - an interim report in New Delhi on 27 July 2017.

This Interim Report on Climate Change over India prepared by the Centre for Climate Change Research (CCCR) in the Indian Institute of Tropical Meteorology (IITM) Pune, is intended to provide a brief overview of (a) Updated assessment of observed climate change over India (b) Future climate projections over India (c) Development of the IITM Earth System Model to better understand and quantify climate change and its regional impacts. The three topics, which are among the core research activities of the CCCR at IITM, have been presented as three chapters in this Interim Report, and an updated report is planned to be submitted early 2019.

3.4 Monitoring and mapping the Shoreline changes along Indian coast

India has more than 7500 km long coastline which undergoes change due to natural and human interventions. Regular monitoring of shoreline and its spatial and temporal trends are required to address the coastal erosion and management related aspects. The shoreline changes, its behavior, erosion, accretion status and related morphological characteristics of Indian coast is being monitored as baseline data using remote sensing, field and mathematical modeling and GIS tools. **A GIS based interactive database was created and 517 maps depicting cumulative shoreline changes for the years 1990-2016 were generated**. The shoreline changes vulnerability was classified in 7 classes i.e. 3 each for accretion and erosion and 1 for stable. The analysis of last 26 years data suggests that about 33%, 38% and 29% coast is eroding, accreting and is stable in nature respectively.

3.5 Coastal Water Quality

Quality (25 parameters) of coastal water is being monitored by MoES at 22 locations along the Indian coast to assess the health of coastal waters. Sea Water Quality Criteria (SWQC) for heavy metals have been prescribed for limiting the pollution levels to protect the marine organisms and being considered by the Ministry of Environment, Forests and Climate Change for notification in the Environment Protection Act (1985) amended in 1998.

3. Agriculture: Doubling farmer's income

Weather and Climate variability plays an important role on agricultural activities, like sowing, harvesting, applying irrigation and pesticides etc. **The Ministry of Earth Sciences (MoES) in collaboration with the Indian Council of Agricultural Research (ICAR) provides the Agromet Advisory Services (AAS) for the benefit of farmers.** Farmers make use of these services for planning the operations like sowing, irrigation, application of fertilizer and pesticide, harvest and protection of crops from weather disasters. The services carried out at 130 agro-met zones (cluster of 4-6 districts) now have been successfully extended to the district level and operated across 608 districts of the country. **Currently, about 24.0 million farmers are receiving crop specific agro-meteorological advisories in vernacular languages.** With the advancement of observational network and forecasting technology, it is planned to augment the Agomet Advisory Service (AAS) network to sub-district level by setting up of District Agro-Met Units (DAMUs) in 530 districts (including the 115 aspirational districts) in the premises of KVKs of ICAR, thus creating a network of 660 units for providing sub-district (block) agromet services to farmers in the country. **It is planned to increase the outreach to about 40 million farmers by the end of June 2018.**

The third party assessment by the National Council of Applied Economic Research (NCAER) on the agromet services provided by the ministry concluded that the annual economic benefit for the farmers cultivating 4 principal crops (Wheat, Rice, Sugarcane and Cotton) was Rs 42,000 Crore in 2015. These improved services with additional climate and soil information for rain-fed agriculture and irrigated agriculture of the country are expected to benefit farmers substantially and contribute to the Government initiative on doubling the income of farmers.

Position in 2014
About 7 million farmers were receiving AAS in vernacular languages
Position in 2018
About 24 million farmers are currently receiving

AAS in vernacular languages.

4. Water For All

Considering the importance of fresh water for islands, Low Temperature Thermal Desalination (LTTD) plants of 100 m^3/day capacities were established in the Kavaratti, Minicoy and Agatti Islands in the Union Territory of Lakshadweep, where cold water is moored from 400m water depths. Considering socio-economic advantages including health of the islanders, installation of LTTD-based desalination plants in six more islands of India including Amini, Chetlet, Kadamath, Kalpeni, Kiltan and Andrott is now undertaken by National Institute of Ocean Technology (NIOT), Chennai.

Desalination plant operational in three islands of Lakshadweep

NIOT has also taken up the challenge of establishing Ocean Thermal Energy Conversion (OTEC) powered desalination plant in Kavaratti Island of U.T. Lakshadweep in the near future.

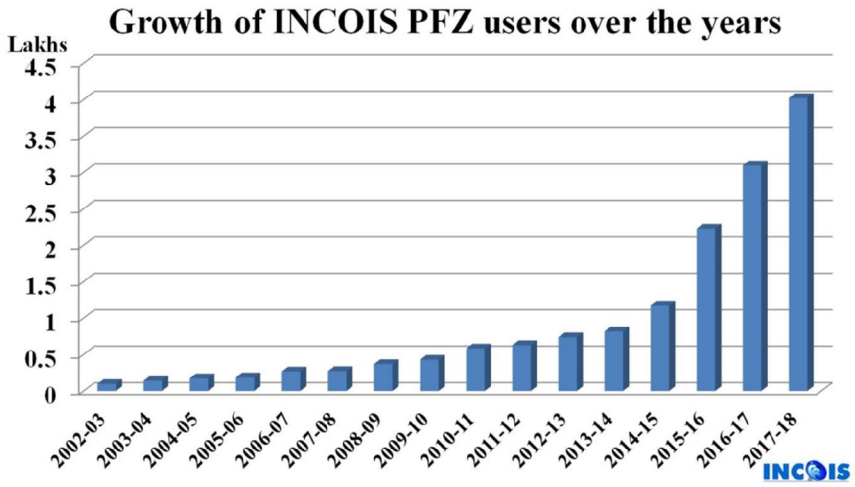
6. Blue Economy

Oceans cover 72% of the Earth and provide a substantial portion of the global population with food and livelihood. The blue economy encompasses sustainable use of ocean resources for economic growth, improved livelihoods and job and health of ocean ecosystem. It consists ofappropriate programs for sustainable harnessing of ocean resources, research and develop relevant sectors of oceanography, assess stock marine resources like minerals, introduce marine aquaculture deep sea/long line fishing and biotechnology and develop human resources.

6.1 Potential Fishing Zones (PFZ) and Tuna PFZ Advisories

Potential Fishing Zone advisory has evolved as a flagship programme of Indian National Centre for Ocean Information and Services (INCOIS) which directly benefit tens of thousands of fishermen and their family. The advisories are disseminated in smart map and text form on a daily basis, depending on satellite data availability except fishing-ban period and during adverse sea-state. **The PFZ advisories are now provided directly to more than 4 lakh users on every day.** INCOIS has adopted the state-of-the-art technologies and tools available in the country for the timely dissemination of PFZ advisories, Ocean State Forecast (OSF), High Wave Alerts and Tsunami early warnings through an **Integrated Information Dissemination System (IDS), named as 'Sagarvani'**

There are 3288 marine fishing villages and 1511 marine fish landing centres with marine fisher folk population of 3,999,214. About 927,120 fishermen were involved in actual fishing either full or part time. **There is a fourfold increase in number of users during last 4 years.**



Total annual net economic benefits due to the scientific identification of PFZs based on satellite information is estimated to lie in the range of Rs34,000 to Rs50,000 crore.

6.2 Ocean State Forecasts

Ocean State Forecasts (forecasts of waves, currents, sea surface temperature, etc.) to fisher folk, disaster management authorities, shipping industry, oil and natural gas industry, Navy, Coast Guard and other stakeholders have improved considerably during the last 4 years. INCOIS lso provides the OSF services to several Indian Ocean rim countries including Sri Lanka and Seychelles under the umbrella of Regional Integrated Multi-Hazard Early Warning System (RIMES) for the Afro-Asian Region. **At present, the ocean state forecasts are provided to approximately 16.7 lakh users on daily basis.**

6.3 Oil-spill Advisory

INCOIS/MoES has been providing oil spill advisories whenever such incidents of oil spill occur over the Indian Ocean. INCOIS/MoES issued the bulletins predicting the trajectory of the oil spill occurred, off Ennore port due to the collision of two ships on 28 January 2017 at 13.228° N, 80.363° E which spilled around 20 tons of HFO oil. **The Indian Coast Guard used these predictions to plan and execute the clean-up operations.**

6.4 Search and Rescue Aid Tool

INCOIS/MoES developed a Search and Rescue Aid Tool (SARAT) to track any objects/persons lost at sea. Predicted ocean currents and surface winds at the last known location, are used to estimate the probabilities of finding the missing object/person in the sea. Dr. Harsh Vardhan, Hon'ble Minister of Science & Technology and Earth Sciences dedicated SARAT to the Nation on 27 July 2016. INCOIS/MoES also developed a mobile App for handy use of SARAT. This App can assist with searching of over 64 types of missing 'objects' in the ocean including boats, ships, man-on-board etc. App is available for download from Google Play Store under the name "SARAT".

6.5 Ocean Minerals

Ocean is a rich source of living and non-living resources. Minerals such as gas hydrates, polymetallic nodules, polymetallic sulphides are abundant in Indian EEZ and Indian Ocean. Polymetallic nodules, which are rich in Cobalt, Nickel, Copper and Nickel, are available at about 5500 m water depth in the Central Indian Ocean Basin. An area of 75,000 sq.km has been allotted to India by the United Nations after India conducted an extensive survey of 150,000 sq. km of Central Indian Ocean. MoES is involved in exploration and harvesting of these resources. A crawler based mining machine with a flexible riser is being developed for the mining of the nodules from 5500 m water depth. As a first step towards harvesting the nodules, a seabed crawler based mining machine was developed and demonstrated at a 500m water depth. Based on the experience a mining machine is now being developed for 6000 m water depth. To test the strength of the soil at those depths an *in-situ* soil tester also has been developed and deployed up to a maximum depth of 5462 m at the polymetallic nodule site in the Central Indian Ocean. A deep water work class Remotely Operated Vehicle (ROV) was developed to aid the exploration of the deep ocean minerals at 5500 metre depth. **Thus MoES has acquired**

the capability of developing the submersibles capable of covering the entire depth of Indian Ocean depth (95% of maximum depth available) for scientific exploration, sampling and engineering intervention.

6.8 SHORE LINE PROTECTION

Coastline-specific solutions based on the sedimentation process and littoral drift were undertaken in various Indian ports for effective erosion control. Seawalls and groins are constructed by the Puducherry government at various timelines to mitigate the coastal erosion problem, but erosion shifted further North. To evolve long term shore protection measures for beach restoration, a detailed study was undertaken for long term shore protection which includes long term shoreline change analysis, detailed processed based measurement and numerical modelling. A hybrid solution with two submerged reefs and beach nourishment were identified to restore the lost beach along Puducherry..Currently, the beach hasalready formed south of wedge reef to an extent of 600m and with the steady progress of the project the city's coastline can soon travel back in time to its sandy past.

BEFORE IMPLEMENTATION

AFTER IMPLEMENTATION

6.9 Open Cage Culture

Large scale fish production through mariculture is the viable alternative to cope with the ever increasing demand for fish proteins. An open sea cage culture mooring system was designed and developed for commercially important marine finfishes suitable for Indian sea conditions to meet this demand with available marine engineering and biological expertise. A cage with multipoint mooring were deployed and tested in the North Bay (Andaman Island), Olaikuda (Tamil Nadu) and Kothachathram (Andhra Pradesh) representing fully protected, semi-protected and open sea environments, respectively). Besides this, an innovative concept of rearing post larval fishes in a specially designed nursery cage in open sea was developed and geospatial analysis of Indian Seas was conducted to estimate the fish farming potential of the country. The open sea cage culture technology seems to be an ideal alternative livelihood option for the coastal fishers, help generate considerable employment

opportunities in the country; to meet the fish food production targets of the nation.

6.10 Marine Living Resources:

Marine resources available in the Indian Ocean are scientifically documented which envisages exploration of marine hotspots, inventorying and documenting its biodiversity from intertidal region through all along the Indian EEZ. Also the areas beyond national jurisdiction (ABNJs) are taken up as regional initiatives to address the marine biodiversity of oceanic and coastal waters.

A comprehensive database containing about 1, 20,000 records of more than 6500 marine species have been created with complete details of location, depth, taxonomic classification and hydrographic data. The entire dataset is available at Ocean Biogeographic Information System (OBIS) hosted by IODE/IOC program. **A digital catalogue on new marine species including species which are described as new to science from the Indian Ocean region has been created**.

Andaman and Nicobar shelf system has been identified as one of the 'hot spot' for benthic fauna. Area off Diglipur, 13°15'N, 93°15'E in the Andaman Sea, at a depth of 670m was found to be a heavy sponge bed with rich and highly diverse deep sea fauna.

5. Digital India

The Digital India is a flagship programme of the Government of India with a vision to transform India into a digitally empowered society and knowledge economy. Ministry of Earth Sciences have been implementing many programmes and activities supporting Digital India Initiative, which are illustrated below:

7.1: High Performance Computing (HPC)

The Ministry of Earth Sciences has augmented its HPC facility to 6.8 Peta Flops (PF) which has been installed at two of its constituent units namely, Indian Institute of Tropical Meteorology (IITM), Pune with 4.0 Peta Flops capacity and National Centre for Medium Range Weather Forecasting (NCMRWF), Noida with 2.8 Peta Flops capacity. **The HPC facility 'Pratyush' at IITM and "MIHIR" at NCMRWF were dedicated to the nation by Dr. Harsh Vardhan, Minister for Earth Sciences on 8 January 2018 and 30 January 2018, respectively.** The HPC facilities at the Ministry have been substantially augmented by upgrading to the capacity of 1100 Teraflop. With this facility, a paradigm shift in weather and climate modeling activity for operational weather forecast has been achieved.

The HPC system will be a national facility for improving weather and climate forecasts and services under the umbrella of the Ministry of Earth Sciences (MoES), Govt. of India. India's ranking has moved from the 368th position to around the top 30 in the Top500 list of HPC facilities in the world. India is now placed at the 4th position after Japan, UK and USA for dedicated HPC resources for weather/climate community.

This facility is part of Ministry's continuous endeavor to provide world class forecast services to the citizens of India through its various operational and research and development activities. The Ministry of Earth Science has developed several services for societal benefits catering to a variety of sectors of economy by building state-of-the-art systems for multi-hazard risk reduction from cyclones; floods/droughts; heat/cold waves; earthquakes; tsunamis; etc.

7.2: Digital Ocean

Digital Ocean is a dynamic frame work of set of applications to efficiently integrate and manage heterogeneous ocean data and to provide advanced visualization and analysis tools to facilitate improved understanding of oceans in multi-disciplinary approach. In a nut shell, the Digital Ocean is the representation of the ocean that is georeferenced and connected to all diversified digital data archives on ocean parameters (for example, temperature, salinity, oxygen, acidity, etc.). In addition, the Digital Ocean built on the real relief of ocean characterized by abyssal plains, ridges, trenches, continental slopes, continental shelf, coasts, etc. will help in viewing the evolution of ocean parameters in time and space (in 3D).

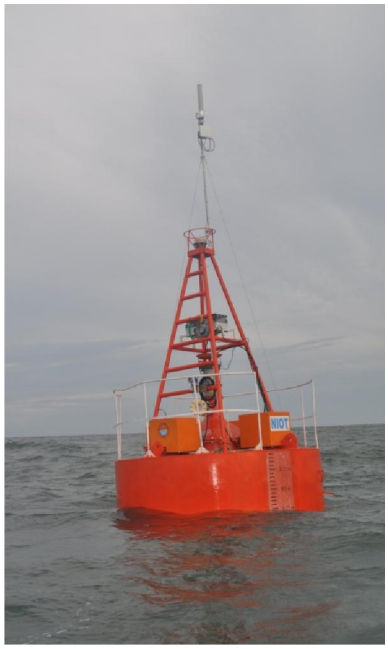
The Digital Ocean will be fed by data generated by diverse platforms and sensors. The idea of Digital Ocean is that all data irrespective of source, sensor or platform should be made available for analysis on a single platform so that the analyst can develop better

feel for data and improve his understanding on the working of oceans. The alpha version of the application is under progress and the project is expected to be completed by Jun 2018.

6. Make in India

The Make in India initiative was launched by Prime Minister in September 2014 as part of a wider set of nation-building initiatives. The achievements made by the Ministry of Earth Sciences are illustrated below.

8.1: Floating wave powered navigational buoy



As part of the efforts to install a floating wave powered device to power loads or to meet the lighting requirements of coastal areas or remote locations, National Institute of Ocean Technology (NIOT) team has been working on Oscillating Water Column (OWC) principle based wave energy devices since last few years. In the current development, NIOT team has successfully demonstrated an all-weather floating buoy in sea for powering a beacon lamp on top of the buoy and oceanographic related components using energy extracted from the ocean waves. This floating buoy is sized for the navigational requirements which can be used as a navigational buoy in ports and harbours.

This completely indigenous navigational buoy can be used in place of imported solar powered buoys. Efforts are on to put some more buoys in a few ports and then transfer technology to industry.

8.2 Hydrokinetic turbine generating electricity using ocean currents

In the field of ocean current turbines, NIOT team has developed a small ocean current turbine for harnessing kinetic energy from seawater currents which was tested in Macpherson Strait in Andaman in 2016 successfully. All the sub-components were indigenously designed and fabricated locally. The open sea testing has paved the way for scaling up for off grid units for remote coastal locations. The forest outposts in Andaman

have a requirement for small off grid power modules of under 5 kW capacity and turbine of this size is currently under production for deploying at Andaman.

8.3 Ocean drifters have been developed for the measurements of sea surface temperature and other parameters. **Trial production by the Indian industries (Astra Microwave-Hyderabad and Komaline Industries, Ahmedabad) is underway.**

8.4 Autonomous Underwater Profiling Drifters have been developedfor measuring salinity and temperature upto 2000m water depths. **Trial production by the Indian industry (Data Patterns, Chennai) is underway.**

8.5 Remotely Operable vehicles (ROV)
An agreement was signed for transferring the Deep water Remotely Operated Vehicle (ROV) technology to the Indian industry (L&T Heavy Industries, Mumbai) through NRDC. These ROVs can be used for carrying out scientific investigations up to 6000m water depths.

8.6 Robo coastal observer are used for data collection in coastal waters and aiding in rescue/assisting of swimmers. **An agreement has been signed for transferring the Robo Coastal Observer to CT Control Technology through NRDC**

8.7 Met-ocean buoy systemhas been developed to collect surface meteorological and oceanographic parameters. The developed system is being operated and maintained in the Indian seas.

9. Targeted Basic Research
Ministry of Earth Sciences also carry out significant research on basic science on different themes. This is aimed to improve and advance fundamental knowledge and it remains as a source of most new scientific ideas and innovation. Basic research is incredibly important because it lays the ground for major discoveries.

9.1 Monsoon Mission and Improved Monsoon Predictions

Accurate prediction of monsoon rainfall is very crucial as it impacts many sectors like agriculture, water resources, power generation, transport and even the Indian economy. The Monsoon Mission was launched in 2012 with an allocation of Rs 400.00 crore to develop the capability of dynamical model prediction systems for short range to seasonal forecasts and to improve the monsoon forecasts. Under the Monsoon Mission, MoES has implemented two state-of-the-art dynamical prediction systems for short range to medium, extended range and seasonal forecasts. All these initiatives have helped to improve the skill of monsoon forecasts over the country. **For the first time, India Meteorological Department used the Monsoon Mission dynamical model to prepare operational seasonal forecast of 2017 monsoon rainfall over India.**

After the success of the Monsoon Mission Phase I, the second phase of the mission has been launched in 2017 with the objectives of developing suitable applications and also to improve the prediction of weather and climate extremes.

9.2 Observational Campaigns

Many observational campaigns have been taken up during the past four years as special atmospheric observations help us to understand model deficiencies and to improve prediction models. To address the issue of better *measurement and understanding of small-scale processe*s that drive the variability, seasonality and predictability in the South Asian Monsoon, a large-scale joint India-UK observational campaign was carried out during the period June-July 2016. The campaign involved the deployment of UK's BAe-146-301 atmospheric research aircraft with sophisticated scientific instruments and India's SagarNidhi and SindhuSadhna research ships.

Hon'ble Minister of Science and Technology and Ministry of Earth Sciences, Dr Harsh Vardhan, along with the UK & Indian scientists with the Research Aircraft.

9.3 Scientific Deep Drilling

Scientific Deep Drilling in Koyna which started in 2016 is aimed atsetting up of borehole observatory (s) at depth for directly measuring the in-situ physical properties of the rocks, pore-fluid pressure, hydrological parameters, temperature and other parameters of an intra-plate, active fault zone in the near field of earthquakes - before, during and after their occurrence, leading to a better understanding of the mechanics of faulting, physics of reservoir triggered earthquakes and preparing a predictive model.

Borehole Geophysics Research Laboratory (BGRL), Karad has undertaken scientific deep drilling and associated investigations in the Koyna seismic zone, Maharashtra. **In 2017, the pilot hole of 3 km depth has been drilled with the technical help of International experts.**

Detailed geophysical measurements carried out in the borehole provided critical new information regarding the subsurface geology, temperature, physical and mechanical properties and the state of stress to 3 km depth in the seismogenic zone.

9.4 Antarctic Expedition

India is successfully cooperating two research stations, Bharati and Maitri in Antarctic to enhance our understanding glaciology, polar atmosphere, paleo-climate and polar biology. Annual scientific expeditions to Antarctica are being done with scientists drawn from different scientific institutions. The scientific projects included projects on upper atmosphere, astrophysics, geophysics, meteorology, glaciology, geology, biology, environmental sciences, human physiology and medicine. **Yoga was recently introduced as part of a scientific programme.**

9.5 Himalayan Research Station

National Centre for Antarctic and Ocean Research (NCAOR), Goa, under the Ministry of Earth Sciences established a high altitude research station in Himalaya called HIMANSH (literally meaning, a slice of ice), situated above 13,500 ft (> 4000 m) at a remote region in Spiti, Himachal Pradesh in 2016. This station provides the much needed support to the researchers and is equipped with many scientific instruments.

9.6 Arctic Research

MOES also continued scientific activities in Arctic at the research Station Himadri, Ny-Ålesund, Svalbard, Norway.. One of the main activities was launching the Indian Arctic mooring (IndARC-II). The Ambient Noise Measurement System with a single hydrophone and a data acquisition system were deployed on IndARC-II. The IndARC-II collected more than 116 parameters and worked continuously in the Arctic waters. Glaciological field studies in Arctic are conducted essentially in two glaciers (VestreBroggerbreen and Feiringbreen) in Svalbard as a part of Indian Arctic Expeditions.

9.7 Cloud Aerosol Interaction and Precipitation Enhancement Experiment(CAIPEEX)

CAIPEEX program has two main objectives a) to advance research on the aerosol-cloud and precipitation interactions and b) to conduct cloud seeding experiments by using this background data for planning rain enhancement experiments for protocols of cloud seeding. The CAIPEEX project has resulted in 820 hours of airborne cloud, aerosol and rain microphysics observations over Indian region and several key results have been published.

9.8 High-Altitude Cloud Physics Laboratory (HACPL)

The HACPL was set up at Mahabaleshwar with advanced measurement facilities for observing the cloud, aerosol, precipitation and radiation parameters to understand *aerosol-cloud-precipitation interactions*. Using the observations, the indirect effect of atmospheric particulate pollution on cloud properties using HACPL observations and better understanding on role of aerosol physical and chemical properties on cloud activation is established. Long-term continuous measurements of cloud, precipitation and aerosol will provide test-bed for testing/improvement of physical processes relevant to **orographic convection, cloud activation and effect of aerosol on precipitation** in numerical weather prediction models.

9.9 Cloud Physics Observatories

The National Centre for Earth Science Studies (NCESS) has established 3 cloud physics observatories in the coastal, mid and high altitude locations in the Western Ghats. The high altitude cloud physics observatory was inaugurated at Rajamallay in Munnar, Kerala on 9th June 2017. The observatory is situated at an altitude of 1820 m above mean sea level and is the highest elevation cloud physics observatory in the Tropical region over the south Asia.

Continuous monitoring of clouds, atmosphere profiles, lightning and rainfall will be improving the knowledge about the convective cloud propagation, mountain weather and lightning. The data collected from this observatory will be used for basic research on heavy rainfall, thunderstorm, monsoon, satellite and aircraft measurements validation and high resolution super computer based weather forecasts validation.

10. International Cooperation

MoES extensively engages with the best institutes overseas in the field of Earth system Sciences to solve some of the key challenges in weather and climate related to the Indian region.

Cooperation with NOAA,USA

Under the MoU between MoES and the National Ocean and Atmospheric Administration (NOAA) ten joint research and development activities have been undertaken in the field of monsoon, ocean observations, tropical cyclone, Tsunami, INSAT 3D, Predictive Capabilities on Marine Fisheries and Harmful Algal blooms, development of an ocean wave modeling and assimilation system for the Indian Ocean Region.

Cooperation with UK Met Office(UKMO)

In 2016 MoES signed a Consortium Agreement with the U. K. Met Office (UKMO), Korea Meteorological Administration (KMA), the Commonwealth of Australia through its Bureau of Meteorology and the Commonwealth Scientific Industrial and Research Organization (CSIRO) and National Institute of Water and Atmospheric Research Limited, New Zealand for Core partnership on Unified Model (UM)" for weather and climate forecast. This MoU enables robust collaborative partnership on joint developmental programs among all the international partners of the UM system (UK, Korea, Australia, India) under a common governance structure.

Cooperation with NERC, UK

Under this MoU, three implementing agreements (IA) have been signed with NERC UK.

1) Predicting the Variability of the South Asian Monsoon
2) Atmospheric Pollution and Human Health in an Indian Megacity
3) Sustaining Water Resources for Food, Energy & Ecosystem Services in India

Cooperation with Belmont Forum Countries

An MoU was signed between MoES and the Belmont forum Countries to support Indian Scientists for international collaborative research through joint calls in societally relevant global environmental change challenges. MoES is participating in 4 Collaborative Research Areas(CRA) namely Coastal Vulnerability, Food Security, Biodiversity and Climate Predictability and Inter-regional linkages.

Cooperation with International Seabed Authority (ISA)

The Council of the International Seabed Authority (ISA) on 10th August 2017 approved the extension of contract between Ministry of Earth Sciences (MoES), Government of India and the ISA (an Institution set up under the Convention on Law of the Sea to which India is a Party) for exploration of Polymetallic Nodules (PMN) for a further period of 5 years (2017-22). By extending the contract, India's exclusive rights for exploration of PMN in the allotted Area of 75,000 sq km in the Central Indian Ocean Basin (CIOB) will continue and would open up new opportunities for resources of commercial and strategic value in area beyond national jurisdiction.

Regional Integrated Multi-Hazard Early Warning System for Africa and Asia (RIMES)

RIMES is an international and intergovernmental institution, owned and managed by its 33 Member and Collaborating States, for building capacities in the generation and application of user-relevant early warning information. Currently, the Government of India serves as the Council Chair. The 9th RIMES Council Meeting and the 3rd RIMES Ministerial conference was held at Port Moresby, Papua New Guinea during 23-25 August 2017. It focused on discussions issues relating to enhancement of multi-hazard early warning capacities and to broadening of the RIMES institutional development process. Afghanistan, Djibouti, Mozambique, Tonga, and Yemen joined as the new

RIMES Member States. INCOIS started providing OSF(Ocean State Forecasts) services to various countries including Comoros, Mozambique and Madagascar.

11. **Human Resources Development**

Human resource in Science and technology is a major driver for India's emergence as a knowledge super power. India needs to build a critical mass of well trained scientific and technical personnel to meet the challenges of national development and international competitiveness.

International Training Centre for Operational Oceanography (ITCOocean)

ITCOocean is aimed at promoting the development and optimization of scientific base, technology and information system for operational oceanography at national, regional and global scales.The facility helps in promoting excellence in integrated multidisciplinary oceanography on a global scale. It is also expected that the legacy of the training programme will endure far in to future as it will help building a future ocean system which directly serves the needs of mankind through improved marine monitoring and enhanced stewardship of the seas.

ITCoocean established under the Indian National Centre for Ocean Information Services (INCOIS), MoES has been conducting courses since 2013. As of date 27 courses were conducted involving students, researchers, administrators, policy makers and persons involved in operational centres. In total 793 students including 116 students from 36 different countries were trained as a part of ITCOO activities. These countries include Australia, Belgium, Kenya, Nigeria,Togo, South Africa, Italy, Comoros, Madagascar, Mauritius, Bangladesh, Sri Lanka, Oman, Ghana, Tanzania, Malaysia, Romania, South Korea, Indonesia, Iran, Maldives, Morocco, Mozambique, Egypt, Saudi Arabia, Cambodia, Myanmar, Vietnam, Cameroon, Norway, France, Russia, China, Seychelles and Thailand.

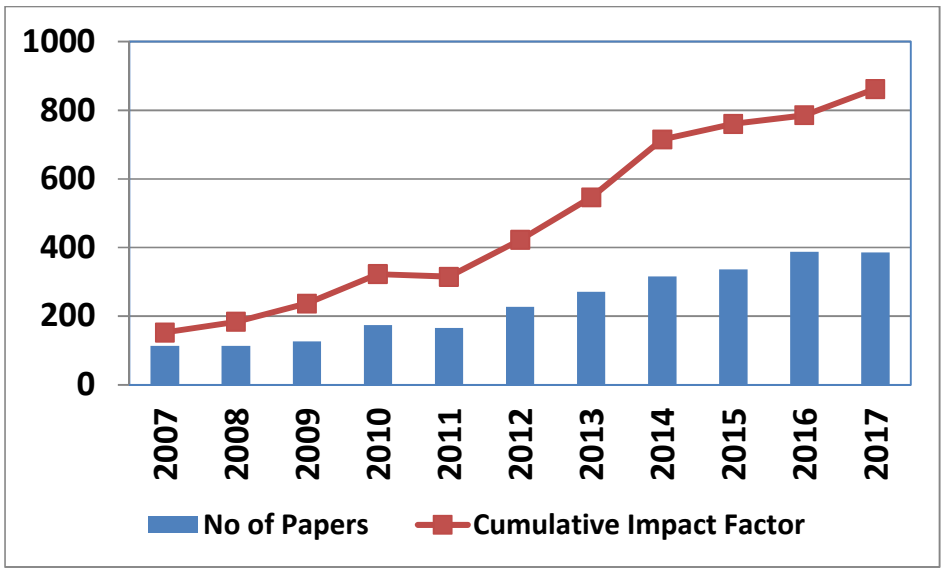
This centre was recently conferred category 2 center (C2C) by UNESCO and this was approved by Government of India. The centre is now gearing up for short term courses (spanning 4 months) starting this year which leads a certification course to students in operational oceanography.

Human Resource development & Capacity Building at MoES:
Considering the need to continuously upgrade knowledge through assimilation of new ideas and application of new knowledge in the field of earth Sciences and to address the issue of depleting scientific manpower in the field of Earth Sciences, the Ministry has taken several steps for human resource development which include funding of M.Tech, M.Sc and Ph.D programmes at premiere institutes of the country, establishment of MoES Chairs at IIT's and IISER, opening of Centers of Excellence at various Universities with state-of the art research facilities. An MoU on co-operation in Polar Research between

NCAOR and NPI has paved the way for Norway to support Indian scientists, in the form of fellowship for carrying out research in the Arctic region. The award of the proposed fellowship to Indian student in NPI, Norway is aimed at capacity building in the field of Cryosphere.

11. Scientific Publications:

There has been an exponential growth in number of research publications by the scientists of the Ministry during the past few years. A total number of 398 research papers (with a cumulative impact factor of 862) were published during 2017 by MoES scientists and under various programs of the Ministry



Number of research papers and cumulative impact factor year wise

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