Research and Systematic Observation

Chapter 4

India's agrarian economy, under favourable tropical climatic conditions of the Asian summer monsoon and with a majority of the population engaged in agriculture, has necessitated a closer linkage with weather and climate since the Vedic period. This necessitated a very early interest in weather observations and research. Ancient Indian literature by Varahmihir, the *'Brihat-Samhita'*, is an example of ancient Indian weather research.

Modernized meteorological observations and research in India was initiated more than 200 years ago, since 1793, when the first Indian meteorological observatory was set up at Madras (now Chennai). A weather network of about 90 weather observatories was established when IMD was formally set up in 1875. It was decided to create a separate agricultural-meteorology directorate in the IMD in 1932 to further invigorate the observation network. Many data and research networks have been established over the last century for climate-dependent sectors, such as agriculture, forestry, and hydrology, rendering a modern scientific background to atmospheric science in India. The inclusion of the latest data from satellites and other modern observation platforms, such as automated weather stations (AWS), and ground-based remote-sensing techniques strengthened India's long-term strategy of building up a self-reliant climate data bank.

India's observational and research capabilities have been developed to capture its unique geography and specific requirements, and also to fulfil international commitments of data exchange for weather forecasting and allied research activities.

RESEARCH

The Government of India attaches high priority to the promotion of R&D in multidisciplinary aspects of environmental protection, conservation and development including research in climate change. The MoEF is the nodal ministry for the subject of climate change in India. Several central government ministries/departments promote, undertake and coordinate climate and climate related research activities and programmes in India through various departments, research laboratories, and universities (Figure 4.1). Research at autonomous institutions of excellence such as the Indian Institutes of Management (IIMs), Indian Institutes of Technology (IITs), and Indian Institute of Science (IISc); and non-governmental and private organizations provide synergy and complementary support. Indian researchers have contributed significantly to assessment reports of the IPCC for over a decade. The ensuing sub sections provide some details of climate and climate-change research being carried out in various modes.

Institutional arrangements

The MoEF, Ministry of Science and technology (MST), Ministry of Agriculture (MoA), Ministry of Water Resources (MWR), Ministry of Human Resource Development (MHRD), Ministry of Non-conventional Energy (MNES), Ministry of Defence (MoD), Ministry of Health and Family welfare (MoHFW), and Indian Space Research Organization (ISRO) are the main ministries of the Government of India which promote and undertake climate and climate change-related research in the country. The ISRO is under the direct governance of the prime minister and support all the above agencies with satellite-based passive remote sensing.

The MoEF, MST, MHRD and MOA are operated under the umbrella of coordinate many premier national research laboratories and universities. The most prominent being the 40 laboratories of the Council of Scientific and Industrial Research (CSIR),

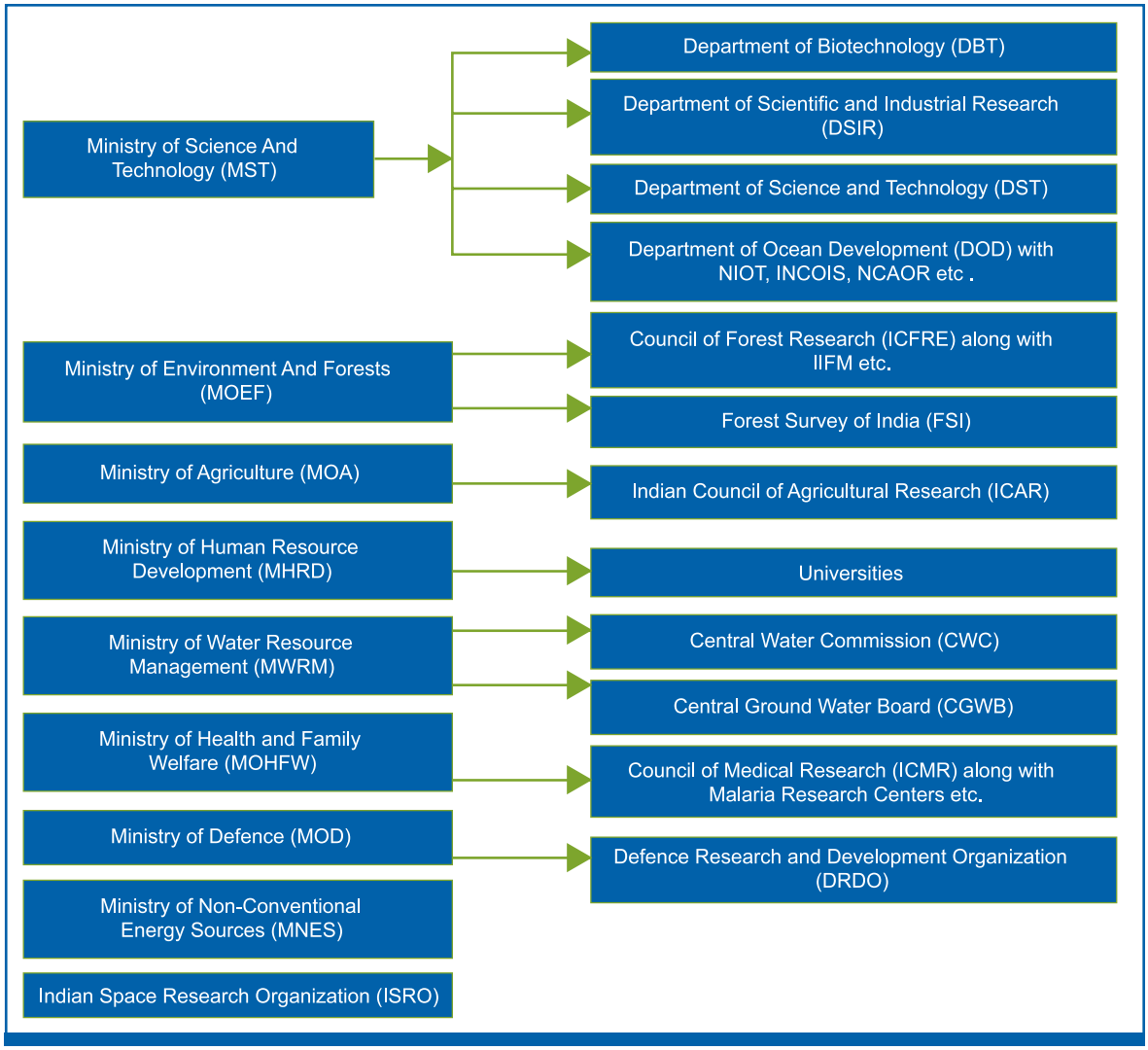


Figure 4.1: Climate and climate change research institutions in India.

an autonomous body under the MST; and the vast network of the Indian Council of Agriculture Research (ICAR) under the MOA. The CSIR is the national R&D organization which provides scientific and industrial research for India's economic growth and human welfare. It has a countrywide network of 40 laboratories and 80 field centres. The ICAR network includes institutes, bureaus, national research centres and project directorates employing about 30,000 personnel. 30 state agricultural universities employ about 26,000 scientists for teaching, research and extension education; of these over 6,000 scientists are employed in the ICAR supported/ coordinated projects.

The Department of Science and Technology (DST) under the MST coordinates advanced climatic and weather research and data collection over the Indian landmass. There are three premier institutions under DST that are solely dedicated to atmospheric science viz. the IMD, the National Centre for Medium Range Weather Forecast (NCMRWF) and the Indian Institute of Tropical Meteorology (IITM).

The IMD possesses a vast weather observational network and is involved in regular data collection basis, data bank management, research and weather forecasting for national policy needs. The NCMRWF conducts atmospheric and climatic research with particular emphasis to develop indigenous, customized GCMs and RCMs for the Indian subcontinent and to forecast the medium-range

weather for socioeconomic sectors that are directly affected by climate, such as agriculture and tourism for short-term policy-making. The NCMRWF is also engaged in agriculture-meteorological advisory services to farmers through in-house modelling and forecast (on a daily basis) for different Indian crop systems. It runs an agro-advisory services network with ICAR, which provides daily weather forecasts to farmers. The IITM is involved in various kinds of advanced climate and weather research; including climatology, hydrometeorology, physical meteorology and aerology, boundary layer, land surface processes, atmospheric electricity, climate-simulations, climate and global modelling/ simulations. Research in advanced instrumentation and observational techniques is also being carried out at the IITM along with other theoretical studies.

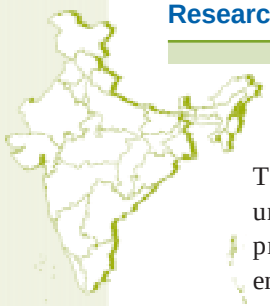
In addition to these dedicated atmospheric research institutes, the DST funds a parallel research network under the aegis of CSIR which has several research institutions for various scientific disciplines dedicated to applied scientific and industrial research. Atmospheric, environmental and oceanic research is one of its areas of focus and has been taken up by its institutions like the National Physical Laboratory, the National Environmental Engineering Research Institute, the Centre for Mathematical Modelling and Computer Simulations (of National Aeronautical Laboratory), the National Institute of Oceanography, and the National Geophysical Research Institute.

The Department of Ocean Development (DoD) was established in 1981 to create a deeper understanding of the oceans, to develop technology and technological aids for harnessing resources, and to understand various physical, chemical and biological oceanic processes. The DoD regularly conducts atmosphere and ocean-related research and observational experiments over the vast Indian coastal zone, and provides real-time data for cyclones and storm surges to the government and other organizations. The DoD supports national, regional and international data generation and exchange programmes. The DoD also maintains the Indian Antarctic Station—*the Maitri* and has set up a dedicated research institution in India to undertake research for the pristine Antarctic environment and climate. In order to fulfill the objectives of the international ocean policy, the department has been promoting, funding and implementing major R&D programs through various agencies, NGOs and universities.

Integrated environmental, ecological and forestry research vis-à-vis climate change is coordinated by the MoEF. Under the aegis of ICFRE, the ministry runs several research institutions dedicated to environmental, forestry and ecological research. The ICFRE mandate is to organize, direct and manage the research and education in the Indian forestry sector. It is actively engaged in advanced research with focused objectives of the ecological and socio-economic human needs of present and future generations towards climate-related objectives of water and the microclimate. Research on absorption of GHGs (carbon sinks and reservoirs) and mitigation of global warming through increasing forest reserve, are among the focused agenda of ICFRE. It is committed to protect forests against the harmful effects of pollution, including air-borne pollutants, fires, grazing, pests and diseases, in order to maintain their full multiple values.

Agriculture production sustainability, enhancement and related research are thrust areas of research under the MOA. The ICAR, as the premier institution for agricultural R&D, is working on different aspects of agriculture sustainability and meteorological research, including field research and modelling for Indian crop systems under the projected climate change.

The MWR coordinates surface and groundwater-related data generation, management and dissemination; technology implementation and all other related research activities through its organizations, such as the Central Water Commission, the Central Ground Water Board, the National Water Development Agency, the National Institute of Hydrology, the Central Water and Power Research Station, the Central Soil and Materials Research Station, and various river boards. The ministry also funds advanced research programs of universities, autonomous research institutions (such as IITs) and NGOs for water-related activities. The ministry, through its National Commission for Water Resources Development and other collaborative research activities, is conducting water resource assessment, including evaluation of impacts of climate change on Indian water resources.



The MHRD, through academic institutions like universities and IITs, operates several research programmes on weather, climate, atmosphere, environment, ecology, agriculture, forestry and related issues. These institutions are involved in climate research by developing infrastructure, participating in atmospheric observations, and modelling efforts on climate simulations using various internationally recognized GCMs/ RCMs. They conduct project-related and need-based atmospheric observations from time to time.

The MoHFW, through the Malaria Research Centre, has initiated climate change related research due to the threat of the spread of anthropogenic health and vector-borne diseases, and efforts for eradication of these diseases. The Centre works in collaboration with various institutions that are actively involved in mainstream climate-change research.

The MOD conducts atmospheric and oceanic research with particular focus on defence interests. In addition, the ministry also funds other agencies for advance research on weather, climate, environment and oceans.

Other than these mainstream research initiatives, the MHRD funds the academic set-up in India, including universities and the IITs. These are involved in climate research either by developing the infrastructure, or by participating in observations or by the effort of climate simulations using various internationally recognized GCMs / RCMs. They carry out some object-oriented atmospheric observations from time to time for their research need. The universities and IITs are generally engaged in project-mode, objective-oriented research-programmes.

Other than the government ministries, several autonomous institutions and NGOs are engaged in climate change-related research. IIM, Ahmedabad and IIT, Delhi are front-runners. The Indira Gandhi Institute of Development Research, an institution established by the Reserve Bank of India (RBI) is engaged in the estimation of the climatic factors that may affect India's development pathways. NGOs like The Energy and Resource Institute, Winrock International India, Development Alternatives, Centre for Science and Environment, and the Society for Himalayan Glaciology, Hydrology, Ice, Climate and Environment operate in project-based research mode on climate change vulnerability, impacts and mitigation.

Apart from the Indian initiatives, climate change research promoted by international organizations like the World Climate Research Program (WCRP), International Geosphere Biosphere Programme (IGBP), International Human Dimension Program (IHDP) and DIVERSITAS are being strongly supported by various Indian agencies like Indian Climate Research Program (ICRP) under DST, National Committee- International Geosphere Biosphere Programme (NC-IGBP) constituted by Indian National Science Academy (INSA) and Geosphere-Biosphere Program (GBP) of ISRO. Agencies like CSIR, also provides infra-structural and financial support to carry out research in the area of global change.

Atmospheric trace constituents

In India, a number of research activities related to the measurements of atmospheric trace constituents are being carried out by different national laboratories, institutions and universities to investigate various research problems, individually as well as jointly, by the financial support provided by different government and international agencies. A classic example of such a research endeavour is the methane emission measurement from Indian rice paddy fields, which was initiated as a result of a national campaign in 1991 in which several institutions collaborated. Over a period of time, measurements of methane emission from rice paddy fields have been continuing with the involvement of new institutions. The impact of this cooperative study in the international scenario was overwhelming, by establishing that the total methane emission strength from Indian rice paddy fields is about 4 Mt which is much lower than the initial international estimates of about 37 Mt.

The determination of GHG emissions from different sectors such as energy, industries, enteric fermentation, manure management, forestry, land use, land-use change and waste, are being carried out by a number of research organizations in India. These include the National Physical Laboratory, the National Chemical Laboratory, the Indian Institute of Science,

the Central Fuel Research Laboratory, the Jadavpur University, Kolkata University, the Central Leather Research Institute, the National Dairy Research Institute, the Indian Agriculture Research Institute, the Regional Research Laboratory, the Central Rice Research Institute, and the Central Mining Research Institute, among others. However, considering the vast coverage these studies need to address, due to the diverse mix of technology, geographical and social parameters, these studies are just a beginning and would require strengthening both in terms of institutions and financial resources to meet the research requirement.

For the measurement of aerosols and precipitation and their associated properties and impacts, a number of research organizations are well-equipped, for example, the National Physical Laboratory, the Physical Research Laboratory, the Bhabha Atomic Research Centre, IIT, Mumbai and Chennai, the Indian Institute of Tropical Meteorology, the Regional Research Laboratory-Bhubaneswar, the Space Physics Laboratory, IISc, the Dayalbagh Educational Institute and Rajasthan University. Several Indian research organizations are participating in a new ISRO-GBP activity (Indian Space Research Organization's Geosphere Biosphere Program, which also supports global change related studies), named as Aerosol Budget and Radiation Studies (ARBS) program to measure ambient concentrations of atmospheric trace gas species and aerosols and their properties in India.

Aerosol size distribution measuring equipment—QCM cacade impactor at one of the Indian laboratories.

High volume sampler and aerosol chemical analyser of one of the Indian laboratories.

Efforts have also been made in India to establish different monitoring sites at key locations to monitor ambient trace gas and aerosols concentrations and their trans-boundary flow. In this direction, the National Physical Laboratory, with the help of several other institutions, is in the process of establishing four monitoring stations at Hanle in Laddakh using the infrastructure facilities developed by the Indian Institute of Astrophysics, at Darjeeling at the High Altitude Research Center of Bose Institute; at Sunderbans with Jadavpur University; and at Port Blair with Central Electro-Chemical Research Institute. The Physical Research Laboratory and Space Physics Laboratory have also established monitoring facilities at Port Blair.

Climate Related Environmental Monitoring (CREM) is a multi-agency project to monitor GHGs and aerosols in India on which policy decisions regarding climate management can be based in future. The project aims at establishing a network of stations in India to generate primary data on GHGs and aerosols on a long-term basis. Such data is of vital interest

High altitude Hanle observatory in Ladakh is being proposed to be used for monitoring ambient trace gas and aerosol concentrations.

with regards to climate change studies and to create a sound database that can be used in future climate change negotiations in the UN framework.

CREM is a programme to be implemented by IMD as a nodal agency in a collaborative mode involving the following participating agencies.

- Indian Institute of Tropical Meteorology (IITM), Pune.
- Jawaharlal Nehru University (JNU), New Delhi.
- National Physical Laboratory (NPL), New Delhi.
- Regional Research Laboratory (RRL), Bhubaneshwar.

A pilot project in CREM is being implemented by establishing on-site monitoring station at GB Pant University of Agriculture and Technology, Ranichauri, Tehri Garhwal (Uttaranchal), for GHGs, and at Delhi for aerosols in the first year. It is planned to create a network of such facilities covering the entire country. This network will monitor gases like CO_2, CH_4, N_2O, O_3 and aerosols.

Under the aegis of the Asia Least-cost Greenhouse Gas Abatement Strategy (ALGAS) study and subsequently the Initial National Communication project, India-specific emission coefficients have been developed, such as those for methane emissions from paddy cultivation, CO_2 emissions from Indian coal, road transport, and cement manufacturing. Prior to these, extensive methane measurements were undertaken in major paddy growing regions of the country under different rice environs for the whole cropping period in 1991.

Consequently, measurements of physiochemical parameters of atmospheric chemical composition and aerosol loadings at three different environments (Delhi, Pune and Darjeeling) are in progress to improve our understanding of the anthropogenic processes of atmospheric pollution, apart from the dynamics of atmospheric composition.

Reconstruction of past climate

The project is aimed to focus on the late Quaternary evolution and the palaeoenvironmental changes trend history of the Lower Narmada basin during the late Quaternary period. Based on the detailed geomorphic, sedimentological and stratigraphical studies, it has been established that the Narmada basin in Gujarat is a reactivated sedimentary basin, where interactions between sedimentary processes, tectonics, and climate and sea-level changes have influenced the nature of sediments.

The Birbal Sahni Institute of Palaeobotany (BSIP) has been exploring plant fossils that are reliable marks of plant climates. The palaeo-signals can be explored to decipher plants and possibly to predict future climatic changes. The BSIP has undertaken and completed studies on the causes and effects of deterioration of forest cover during the Holocene with particular emphasis of mangrove vegetation and Shola forests. Pollen analysis from lake sediments have revealed that around 3,000 B.C., the Eastern Himalayas experienced warm temperate climates, and during 1,000 B.C., it turned more humid, before changing to the climate we experience today. The institute has also prepared a master tree ring chronology of C*edrus deodara* and data obtained can be used to infer climate change/variations, particularly drought cycles, during the past centuries.

The Indian Institute of Geo-magnetism (IIG) has correlated short-term weather changes with solar activity and geomagnetic field variations in the Indian region. This suggests that part geomagnetic field and climate should also be correlated. Variations of temperatures in the scale of a 100 to a 1000 years are being studied.

Climate variability and change

India's climate is dominated by the summer monsoon, which shows spatial, interannual and intra-seasonal variability. Climate variability has tremendous impact on agricultural production and water availability. Recognizing the role of land, atmosphere and oceanic processes in modulating the monsoon variability, a multi-disciplinary, decade-long Indian Climate Research Program (ICRP) has been evolved to study the climate variability and climate change issues in the Indian context. The ICRP envisages land-ocean atmosphere field experiments, the analysis of available past data sets on climate and agriculture, and climate modelling.

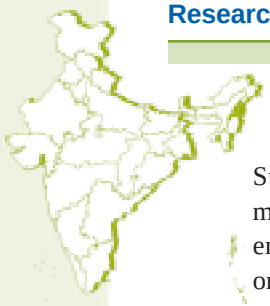
A number of research projects were supported to implement the inter-disciplinary and multi-institutional coordinated subprograms of the ICRP. The available land-based, ocean-based and space-based data sets are being analyzed towards improving our understanding of the monsoon variability in different socioeconomic sectors. Field experiments were conducted to validate the crop simulation models in different agro-climatic conditions. Also methane and NO_2 emissions were monitored under different ecosystems. Different global, regional and mesoscale models are being run to predict monsoon systems. In order to understand the regional and locally predominant variability, several processes-oriented field campaigns have also been organized.

Studies related to the physics and dynamics of monsoons, land-ocean-atmosphere coupled system, and indigenous development of technology for atmospheric science application, are being supported under MONTCLIM programme. In order to study the effect of weather and climate in tropics, efforts are being made to improve parameterization of land-ocean-atmospheric processes though the AOGCMs. Agrometeorological studies related to crop-weather relationships are also being sponsored under the MONTCLIM.

An organized Indian climatic research with a collaborative multi-institutional approach was begun as early as 1970s, with the launch of the Indian-Soviet monsoon experiment (ISMEX, 1973). During the summer months, six research vessels (four from the USSR and two from India) obtained meteorological and oceanographic measurements over the Arabian Sea, for the equatorial region and southern Indian Ocean. With the help of data, important insights into the onset of the monsoon, active and break of monsoon periods and oceanographic phenomenon were deduced.

In 1977, the Monsoon-77 experiment was organized to collect surface and upper air observations over the vast oceanic areas surrounding the Indian subcontinent for unraveling the peculiarities of monsoon circulation. It was executed as a forerunner of the experiment on sub-regional scale—Monsoon Experiment (MONEX) run as a subprogramme of the First Global GARP Experiment (FGGE). It was jointly conducted by India and the USSR for an intensive study on different scales for monsoon disturbances and for numerical simulations of the general atmospheric and ocean circulation in the monsoon regime. The routine observational programme over India was augmented during MONEX by arranging additional upper air observations over Bay of Bengal and Arabian Sea during the monsoon months, and by arranging increased radio-sonde flights from 16 existing upper air observational stations. MONEX was conducted over the oceanic regions near India with an objective to understand the ocean energy and its influence on different phases of monsoon. MONEX provided a comprehensive data set from a large area around India, where surface and upper air networks were augmented to meet the requirements. The upper air network was either augmented or newly established at nine observatories for radio-sonde observation in the existing network. In addition, upper air observations were also established at eight more stations for the purpose of MONEX; three surface observatories were also established. Efforts were also made to collect observations from commercial ships. Advantage was also taken of the observing network of FGGE with a fleet of about 20 ships. Upper air observations were also managed from these ships, along with deploying three more research ships in the Arabian Sea to meet MONEX requirements.

Hydrographic observations on board the Indian research vessel were made in a selected area of four squares in the east central Arabian Sea in relation to different phases (pre-monsoon, onset and post-onset) of the monsoon over the study area.



Stabilized platforms were provided to ships for making wind observations. MONEX provided enough data to establish the structure of the monsoon onset vortex.

During the 1990s, the Monsoon Trough Boundary Layer Experiment (MONTBLEX) was conducted during the monsoon months at four stations along the monsoon trough to understand the boundary layer behaviour during active and break phases. A huge data bank was generated for further utilization and model validations.

The late 1990s witnessed the grand Indian Ocean Experiment (INDOEX). INDOEX was a focused field experiment in the Indian Ocean with international participation from the developed world and other Asian countries. A three-month intensive field phase (IFP) was made with research aircraft, ship cruises and observations on the land surface. With almost the similar objectives as INDOEX, the Bay of Bengal Monsoon Experiment (BOBMEX) was conducted during 1999. BOBMEX particularly focussed on the intra-seasonal variability of organized convection in the atmosphere, and on the role played by ocean-atmosphere interactions in monsoon variability. Special observational platforms like deep-water meteorology-oceanography buoys, research ships, weather radars and satellites were used, together with conventional meteorological observatories to collect data on the variability of the monsoon and ocean-atmosphere system.

To understand the role of land surface and the model validation, the Land Surface Process Experiment (LASPEX) was carried out at five stations during 1997-1998 in the western Indian region. The major objective was the development of the Land Surface Model and its validation. Other major objective was inclined to Agricultural Meteorology modelling. The analysis of the LASPEX data set observed the double mixing of line structure developed during the monsoon at Anand and no gradient in the surface sensible heat flux within the LASPEX area.

A multi-institutional and multi-technique field experiment namely, the Arabian Sea Monsoon Experiment (ARMEX), has been designed under the ICRP since 2002, and is planned for execution in two phases. The main purpose of this experiment is to study offshore trough and vortex that play important roles in modulating monsoon activity over the west coast of India.

A two-dimensional interactive chemical model of the lower and middle atmosphere has been developed to study the atmospheric chemistry-climate interactions. The radiative forcing due to the growth of GHG due to human activities for the past three decades has been simulated. The ozone over the Indian Ocean is marked by significantly low values of ozone (10-20 ppb), followed by an increasing trend in the mid-troposphere and a steep gradient near the tropopause.

The Cloud Physics Laboratory in Pune University is presently a unique facility which carries out cloud studies in similar conditions in the atmosphere. The availability of such a facility for cloud-related research would be of paramount interest to physicists in the relevant field.

Other than these major efforts, many small scale projects have been and are being carried out. Some are also proposed in the near future to better understand the Indian weather and climate. For example, to understand the nature of coupled ocean-atmosphere system, an experiment has been executed over Indian oceanic region. The focus of research was the Bay of Bengal. The experiment has given insights into tropical convection. The results will have a major impact on our understanding of the coupling of the monsoons to the warm oceans and modelling of climate.

Under the focus of upcoming major programmes for research related to oceans; under the ARGO project, 150 floats have to be deployed in the Indian oceans between 2002-2007. A set of 12 floats have already been deployed. The temperature and salinity profiles are expected to improve the understanding of the oceanic processes and contribute to an improved prediction of climate variability.

The management of natural resources like soil and water is being carried out at eight central research institutes and two project directorates, three national research centres and 15 all-India coordinated research projects of ICAR.

Realizing the importance of environmental information, the Government of India, established the Environmental Information System (ENVIS) as a planned programme in December 1982. ENVIS is a decentralized system with a network of distributed subject-oriented centres ensuring the integration of national efforts in environmental information collection, collation, storage, retrieval and dissemination to all concerned (*http:// www.envis..nic.in*). The ENVIS centres have been set up in different organizations/establishments in the country for assessing the environment for pollution control, toxic chemicals, central and offshore ecology. Besides collecting data, ENVIS supports environmentally sound and appropriate technology, bio-degradation of wastes and environment management research. The ENVIS focal point responded to 363 queries and the ENVIS centres over 19,694 queries. The major subject areas on which the queries were responded to pertain to laws, waste management, Coastal Regulation Zones (CRZ), environmental education and awareness, air and water pollution, wetlands, etc.

The ENVIS Focal Point implements the World Bank assisted Environmental Management Capacity Building Technical Assistance Project (EMCBTAP), which aims to strengthen the ENVIS scheme of the ministry. The ENVIS sub-component of the EMCBTA Project is slated for a period of 18 months from January 2002 to June, 2003. The project aims at broadening the ambit of ENVIS to include varying subject areas, and status of information/data pertaining to environment, and has been achieved through the participation of academic institutions, organizations, state governments and NGOs. The participating institutions, called ENVIS-Nodes have been assigned specific subject areas in the field of environment and are responsible for the collection, the collation and dissemination of relevant information through the web.

A portal on the environmental information system at http://www.envis.nic.in has been developed under the EMCBTA Project. It would act as a mother portal for all the 80 operative ENVIS centres and nodes, as well as 16 other nodes planned. The portal would act as a catalyst for inter-nodal interaction and information on seven broad categories of subjects related to the environment, under which the centres and nodes have been classified. The websites of the ENVIS centres and nodes can also be directly accessed from the home page of the portal.

In addition, various programmes for future needs like biomass energy, coal-bed methane recovery for commercial usage, energy efficient technology development, improvement of transport systems, small-scale hydro-electric power stations, and development of high-rate bio-methanation processes as a means of reducing GHG emissions are already being conducted or proposed.

Climate modelling research

Using various established climate models from the global front, different organizations are simulating the climate for India, with special attention to the Indian summer monsoon. GCMs from Laboratoire de Meteorologie Dynamique (LMD), Florida State University (FSU), ECMRWF, Center for Ocean, Land and Atmosphere (COLA), NCMRWF, and many more are being taken from the sources and are in the main front of global climate simulations in India. Regional models like the MM5, RegCM3 and Eta Model, are the forerunners in the regional climate simulations, with inputs from various GCMs.

For generating the past climate, a few statistics-based palaeo-climatological models are also in the forefront. Studies on the intra-seasonal and interannual variability of the monsoon, role of moist processes and orography in the GCM, and simulation of the monsoon. The results of these all the simulations are available to user groups for various scientific and practical requirements.

Agricultural meteorological modelling for Indian crop system with various models is the most accepted research method in India. Institutions like Indian Agriculture Research Institute, NCMRWF and various university-level research departments are carrying out such simulations. Through extension programmes like the Agro-Advisory Services of DST, the output information is transferred directly to the practical level, to farmers. The results are found to be encouraging at the farm level.

Field experiments were carried out at Palampur to

generate all the relevant data on various crop parameters required for calibration of CERES-rice and wheat models. The models were validated using the observed data from the field experiments. The results indicated that the development stages are well simulated and grain yields are satisfactory. The validated models were used to simulate the effect of various management practices over a number of years on the yields of rice and wheat varieties.

At Anand, field experiments were undertaken during 1999-2000 and 2001-2002 wheat-growing periods. Crop, soil and micrometeorological data were used to estimate the land surface parameters. The radiation budget, sensible heat flux, latent heat flux, soil heat fluxes at different phenophases of the wheat crop were also computed. Initiated experiments of validate a COTTAM (cotton crop growth and yield simulation) model under Punjab and the plantation cropping system at Thiruvananthapuram.

A comprehensive programme on Indian Ocean Dynamics and Modelling (INDOMOD) was also launched during the Ninth Five-Year Plan, to develop a variety of wide-range coupled ocean-atmosphere models for application of the monsoon variability studies and ocean state forecast. The premier participating institutes in the INDOMOD are IISc, Bangalore; Centre for Mathematical Modelling and Computer Application Studies, Bangalore; IIT, Delhi and Indian Institute of Tropical Meteorology (IITM), Pune. The modelling activity will also be continued during the Tenth Plan period in a much more focused way, including the validation of models with *in-situ* data. Using the ship of opportunities, 70 drifting buoys were deployed for the acquisition of surface met-ocean parameters in real-time, using CLS ARGOS data transmission. For understanding upper ocean variability of heat content in the Indian ocean, XBT surveys in three shipping routes: (a) Chennai- Port-Blair-Kolkata; (b) Chennai-Singapore; (c) Mumbai-Mauritius are being carried.

In addition, there is a suite of algorithms/models for retrieval of ocean atmospheric parameters from Indian and foreign satellites under the department's project Satellite Coastal oceanographic research (SATCORE) executed by the SAC, Ahmedabad. During 2001-2002 a pilot study was conducted on an experimental ocean state forecast, based on the models developed under SATCORE and INDOMOD projects for dissemination of four parameters in the Northern Indian ocean, viz. sea surface winds, sea surface temperatures, surface waves and mixed layer depth. These models and multidisciplinary data, currently available at INCOIS, Hyderabad, will also contribute to the various national projects implemented under the Indian Climate Research Programme viz., ASRMEX, INDOEX, which would require a great deal of data from upper ocean and surface meteorological parameters.

Satellite monitoring data for research

Satellite-based data has enriched and enhanced research on Indian forest cover, water resources, agriculture crops and climatic impacts on these resources. Ground truthing is used to validate and complement satellite data for a more robust analysis. For example, Indian remote-sensing satellite (IRS-1A/1B/1C & 1D) data relating to the entire Bhagirathi river watershed upstream of Devprayag on a 1:250,000 scale; for the Gangotri glacier area in particular on a 1:50,000 scale for the years 1997, 1998, 1999, 2000, 2001 and 2002; and pertaining to the peak accumulation and ablation period of each year, have been visually interpreted for snow cover assessment and mapping. The temporal monitoring of the variations in spatial extent of snow cover have also been statistically tabulated and graphically plotted. This has enabled monitoring the variations in snow cover in the entire Bhagirathi river watershed upstream of Devprayag and also in Gangotri sub-watershed in particular during the past decade or more.

The integration of satellite-derived information with collateral data has enabled monitoring the fluctuations in the position of the snout of the Gangotri glacier during the last decade and this in turn, has enabled monitoring the rate of retreat of the snout in recent times with greater accuracy. A digital analysis of topographic information has enabled the generation of the digital elevation model for the Gangotri glacier area as viewed from different visible angles. This has been prepared through the contours of the Gangotri glacier area by using the ARC/INFO GIS package.

Climate change-related impacts, vulnerability and adaptation research

India has reasons to be concerned with climate change. The vast population depends on climate-sensitive sectors like agriculture and forestry for livelihood. The adverse impact on water availability due to the recession of glaciers, decrease in rainfall and increased flooding in certain pockets would threaten food security, cause die-back of natural ecosystems including species that sustain the livelihood of rural households, and adversely impact the coastal system due to sea-level rise and extreme events. Apart from this, the achievement of vital national development goals related to other systems, such as habitats, health, energy demand, and infrastructure investments, would, be adversely affected.

Preliminary research has been initiated on vulnerability assessment due to climate change on various socioeconomic sectors and natural ecosystems in India during the preparation of India's Initial National Communication to the UNFCCC. Indian climate change scenarios at the sub-regional level were developed to estimate impacts on ecological and socioeconomic systems. This document represents the extant scientific capacity and consolidates the contemporary literature, besides shedding light on the vulnerability of different sectors and regions of the country to climate change, the need for devising adaptation responses, and demonstrates India's firm commitment to the objectives of the UNFCCC.

Many ministries of the Government of India have also initiated research on sectoral vulnerability assessment due to climate change. The MST, through the ICAR, has established an 'agro-meteorological data bank' for collecting, compiling and archiving various types of agro-meteorological data and has developed a website to access the data. Coordinated field experimental data available with the IMD is being analyzed to develop crop-weather relationship models to study climate change impacts on Indian agriculture. Studies have also been initiated on micro-regional (district as unit) rainfall variability and its influence on crop production in eastern Uttar Pradesh and plains of Bihar.

Many case studies have also been conducted, such as habitat diversity patterns of rarity in the terrestrial vegetation of North-Eastern Uttar Pradesh; species diversity in the Central Himalayas, patterns and relationships with ecosystem characters; seed characteristics, regeneration and growth improvement of deciduous trees of the Central Himalayas; biodiversity in response to disturbance gradient in the forest of Kumaon Himalayas.

In a project, during the course of exploration, more than 226 species of fern and fern-allies have been collected so far from Kumaon region and it has been observed that 52 species are under threat mainly due to habitat destruction and climatic changes. Out of these, 12 taxa are endangered.

GHG abatement research

This component has two prominent components. The first is the economic and environmental modelling based research for estimating future emissions, and alternate policy assessments to assist India in international negotiations. IIM Ahmedabad, The Energy and Resources Institute, Indira Gandhi Institute for Development Research, Jadavpur University, and National Chemical Laboratory, are some of the forerunners. These institutions employ many internationally used top-down and bottom-up models, such as Second Generation Model, Edmonds-Barns-Reilly model, MARKAL family of models, and Asia Pacific Integrated Model (AIM) family. This work promotes international collaboration among eminent Indian and foreign research institutes and researchers considerably. Indian researchers have been published in international journals and many prominent researchers have also contributed significantly to the IPCC assessments and reports since the last decade.

The second component covers the development of technologies for energy efficiency improvement, renewable energy, and sustainable development, thus in turn promoting GHG emission abatement. These encompass wide scientific and engineering disciplines. The IITs, CSIR laboratories and the IISc are at the forefront of this research. Some examples include efficient lighting appliances, wind turbines from low wind speeds with accelerating nozzles for irrigation and electric power generation, battery operated city cars, 4-stroke engines for two- and three-wheelers, efficient stand-alone microhydel-based

power generation, solar power reliability and output enhancement, biofuels, waste to energy, coal-bed methane, non-coking coal beneficiation, ash utilization, multi stage hydrogenation technology for converting coal to oil, fuel cell technology, production of fuels and chemicals from methane and CO_2, in-situ infusion of fly ash with CO_2, soft coke technology, and energy efficient steel making technology.

SYSTEMATIC OBSERVATION NETWORKS

India has a long tradition of systematic observations, dating back centuries in different fields, including meteorology, geology, agriculture, sea level and land-survey, including mapping. Government departments, setup for specific purposes, have carried out these observations since the early 19 century. Observational networks have undergone changes according to evolving needs, and have also been modernized to a fair extent. Developments in space-based systems have contributed considerably to observational capabilities. India has also participated in international observational campaigns, both regionally and globally, to further the understanding of the climate and its variability.

Atmospheric monitoring

There are 22 types of atmospheric monitoring networks that are operated and coordinated by the IMD (Table 4.1). This includes meteorological/ climatological, air pollution and other specialized observation of trace atmospheric constituents. Meteorological observations began in India as early as 1793, when the first observatory was established at Madras (now Chennai). The IMD formally setup in 1875, is the principal agency that monitors the weather and climate. IMD maintains 559 surface meteorological observatories (see Figure 4.2 for distribution of raingauge stations), and about 35 radio-sonde and 64 pilot balloon stations for monitoring the upper atmosphere. Specialized observations are made for agro-meteorological purposes at 219 stations and radiation parameters are monitored at 45 stations. There are about 70 observatories that monitor current weather conditions for aviation.

Although, severe weather events are monitored at all the weather stations, the monitoring and forecasting

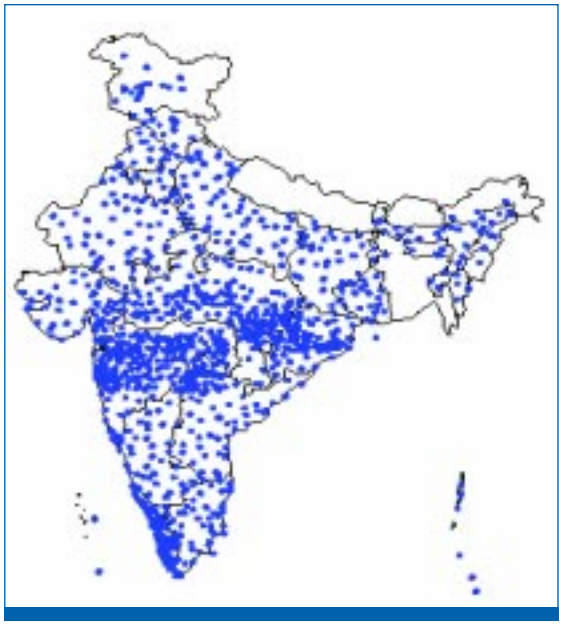


Figure 4.2: Distribution of raingauge stations in India.

One of the automated surface observatories of the India metrological department measuring radiation, temperature, humidity, rainfall, wind direction and speed and transmitting this information on real time basis.

Table 4.1: Atmospheric monitoring networks.

1	Surface observatories	559
2	Pilot balloon observatories	65
	a RS/RW observatories	34
	b Only RS observatories	1
3	Aviation current weather observatories	71
4	Aviation forecasting offices at national and international airports	19
5	Regional area forecast centre	1
6	Storm detecting radar stations	17
7	Cyclone detection radar stations	10
8	High-wind recording stations	4
9	Stations for receiving cloud pictures from satellites	
	a Low-resolution cloud pictures	7
	b High-resolution cloud pictures	1
	c INSAT-IB cloud pictures (SDUC stations)	20
	d APT Stations in Antarctica	1
	e AVHRR station	1
10	Data Collection Platforms through INSAT	100
11	Hydro-meteorological observatories	701
	a Non-departmental rain gauge stations	
	i Reporting	3540
	ii Non-reporting	5039
	b Non-departmental glaciological Observations (non-reporting)	
	i Snow gauges	21
	ii Ordinary rain gauges	10
	iii Seasonal snow poles	6
12	Agro-meteorological observatories	219
13	Evaporation stations	222
14	Evapotranspiration stations	39
15	Seismological observatories	58
16	Ozone monitoring	
	a Total ozone and Umkehr observatories	5
	b Ozone-sonde observatories	3
	c Surface ozone observatories	6
17	Radiation observatories	
	a Surface	45
	b Upper air	8
18	Atmospheric electricity observatories	4
19	(a) Background pollution observatories	10
	(b) Urban Climatological Units	2
	(c) Urban Climatological Observatories	13
20	Ships of the Indian voluntary observing fleet	203
21	Soil moisture recording stations	49
22	Dew-fall recording stations	80

Source: http://www.imd.ernet.in

of tropical cyclones is specially done through three Area Cyclone Warning Centres (Mumbai, Chennai, and Kolkata) and three cyclone warning centres (Ahmedabad, Vishakhapatnam and Bhubaneshwar), which issue warnings for tropical storms and other severe weather systems affecting Indian coasts.

Storm and cyclone detections radars are installed all along the coast and some key inland locations to observe and forewarn severe weather events, particularly tropical cyclones. The radar network is being upgraded by modern Doppler Radars, with enhanced observational capabilities, at many locations

Data archival and exchange

The tremendous increase in the network of observatories resulted in the collection of a huge volume of data. The IMD has climatological records even for the period prior to 1875, when it formally came into existence. This data is digitized, quality controlled and land archived in electronic media at the National Data Centre, Pune. The current rate of archival is about three million records per year. At present, the total holding of data is about 9.7 billion records. They are supplied to universities, industry, research and planning organizations. The IMD prepared climatological tables and summaries/ atlases of surface and upper-air meteorological parameters and marine meteorological summaries. These climatological summaries and publications have many applications in agriculture, shipping, transport, water resources and industry.

The IMD has its own dedicated meteorological telecommunication network with the central hub at New Delhi. Under the WWW Global Telecommunication System, New Delhi functions as a Regional Telecommunication Hub (RTH) on the main telecommunication network. This centre was automated in early 1976, and is known as the National Meteorological Telecommunication Centre (NMTC), embracing the Regional Telecommunication Hub (RTH) New Delhi. Within India, the telecommunication facility is provided by a large network of communication links.

The website of IMD (*http://www.imd.ernet.in*), operational from 1 June, 2000, contains dynamically updated information on all-India weather and

forecasts, special monsoon reports, satellite cloud pictures updated every three hours, Limited Area Model (LAM) generated products and prognostic charts, special weather warnings, tropical cyclone information and warnings, weekly and monthly rainfall distribution maps, earthquake reports, etc. It also contains a lot of static information, including temperature and rainfall normals over the country and a brief overview of the activities and services rendered by IMD.

Over the last three decades, the MST has successfully completed a few major research and data collection experiments through its autonomous body IITM, other allied institutions and foreign collaborations through several field experiments such as IIOE, ISMEX-73, MONSOON-77, MONEX-79, MONTBLEX, INDOEX, BOBMEX, and ARMEX. Along with these, the IITM undertakes regular oceanic expeditions on research vessels, Antarctic expeditions and field campaigns.

The IMD, in collaboration with the NPL plays an important role for climate change-related long-term data collection at the Indian Antarctic base-*Maitri*. Continuous surface meteorological observations for about 22 years are now available for Schirmacher Oasis with National Data Centre of IMD (NDC). Long-term environment-related GHG data is also available with NPL.

The IMD collects meteorological data over oceans by an establishment of cooperation fleet of voluntary observing ships (VOF) comprising merchant ships of Indian registry, some foreign merchant vessels and a few ships of the Indian Navy. These ships, while sailing on the high seas, function as floating observatories. Records of observations are passed on to the IMD for analysis and archival.

Another climate change-related data archival effort is at NPL *(www.npl-cgc.ernet.in)*, that holds a variety of data collected under different national and international programmes such as Indian Ocean Experiment (INDOEX), Asia Pacific Network for Global Change supported research projects. Another off-line data archival centre is emerging at IIM, Ahmedabad for the data generated during India's Initial National Communication Project *(www.natcomindia.org)*.

Satellite-based observations

Currently, several operational meteorological satellite systems are providing global and regional observations. The Indian Space Programme, initiated in the mid-1970s, selected meteorology and weather forecasting as one of the thrust areas. One of the earliest satellites 'Bhaskara' had a microwave payload SAMIR to study the atmosphere and ocean. The Indian National Satellite (INSAT) series was conceptualized as a multi-purpose geostationary satellite system for communications, meteorology, oceanography, and weather services. Table 4.2 provides information on the development and deployment of satellites in India.

Data, related to meteorology, obtained by INSAT is processed and disseminated by the INSAT meteorological data-processing system (IMDPS) of IMD. Information on upper winds, sea surface temperatures and precipitation index are regularly obtained at 0600H GMT. The 0300H GMT full disc infrared pictures are obtained as radio facsimiles for reception in the neighbouring countries and for national news network for weather reporting.

The INSAT 1 series launched in late 1980s carried a Very High Resolution Radiometer (VHRR) payload that operated in two spectral bands—visible (0.55-0.75 mm) and thermal infrared (10.5-12.5 mm). The INSAT system is designed to provide the following services:

- Round the clock surveillance of weather systems including severe weather events around the Indian region.
- Operational parameters for weather forecasting—cloud cover, cloud top temperature, sea surface temperature, snow cover cloud motion vector, out-going long-wave radiation, etc.
- Collection and transmission of meteorological, hydrological and oceanographic data from remote/inaccessible areas through Data Collection Platforms.
- Timely dissemination of warning of impending disasters such as cyclones through Cyclone Warning Dissemination Systems.
- Dissemination of meteorological information including processed images of weather systems through SDUCs.

Table 4.2: Information on development and deployment of Indian satellites.

Satellite	Launch Date	Achievements
Aryabhata	19.04.1975	First Indian satellite. Provided technological experience in building and operating a satellite system.
Bhaskara-I	07.06.1979	First experimental remote-sensing satellite. Carried TV and microwave cameras.
Bhaskara-II	20.11.1981	Second experimental remote-sensing satellite similar to Bhaskara-1.
Ariane Passenger Payload Experiment (APPLE)	19.06.1981	First experimental communication satellite. Provided experience in building and operating a three-axis stabilized communication satellite.
Rohini Technology Payload (RTP)	10.08.1979	Intended for measuring in-flight performance of first experimental flight of SLV-3, the first Indian launch vehicle. Could not be placed in orbit.
Rohini (RS-1)	18.07.1980	Used for measuring in-flight performance of second experimental launch of SLV-3.
Rohini (RS-D1)	31.05.1981	Used for conducting some remote-sensing technology studies using a landmark sensor payload.
Rohini (RS-D2)	17.04.1983	Identical to RS-D1. Launched by the second developmental launch of SLV-3.
Stretched Rohini Satellite Series (SROSS-1)	24.03.1987	Carried payload for launch vehicle performance monitoring and for Gamma Ray astronomy. Could not be placed in orbit.
Stretched Rohini Satellite Series (SROSS-2)	13.07.1988	Carried remote sensing payload of German space agency in addition to Gamma Ray astronomy payload. Could not be placed in orbit.
Stretched Rohini Satellite Series (SROSS-C)	20.05.1992	Launched by third developmental flight of ASLV. Carried Gamma Ray astronomy and aeronomy payload.
Stretched Rohini Satellite Series (SROSS-C2)	04.05.1994	Identical to SROSS-C. **Still in service.**
Indian National Satellite (INSAT-1A)	10.04.1982	First operational multi-purpose communication and meteorology satellite procured from US. Worked only for six months.
Indian National Satellite (INSAT-1B)	30.08.1983	Identical to INSAT-1A. Served for more than design life of seven years.
Indian National Satellite (INSAT-1C)	21.07.1988	Same as INSAT-1A. Served for only one and a half years.
Indian National Satellite (INSAT-1D)	12.06.1990	Identical to INSAT-1A. **Still in service.**
Indian National Satellite (INSAT-2A)	10.07.1992	First satellite in the second-generation Indian-built INSAT-2 series. Has enhanced capability than INSAT-1 series. **Still in service.**
Indian National Satellite (INSAT-2B)	23.07.1993	Second satellite in INSAT-2 series. Identical to INSAT-2A. **Still in service.**
Indian National Satellite (INSAT-2C)	07.12.1995	Has mobile satellite service, business communication and television outreach beyond Indian boundaries. **Still in service.**

Satellite	Launch Date	Achievements
Indian National Satellite (INSAT-2D)	04.06.1997	Same as INSAT-2C. Inoperable since 4 October, 1997 due to power bus anomaly.
INSAT-2E	03.04.1999	Multipurpose communication and meteorological satellite
Indian Remote Sensing Satellite (IRS-1A)	17.03.1988	First operational remote-sensing satellite.
Indian Remote Sensing Satellite (IRS-1B)	29.08.1991	Same as IRS-1A. **Still in service.**
Indian Remote Sensing Satellite (IRS-1E)	20.09.1993	Carried remote-sensing payloads. Could not be placed in orbit.
Indian Remote Sensing Satellite (IRS-P2)	15.10.1994	Carried remote-sensing payload.
Indian Remote Sensing Satellite (IRS-1C)	28.12.1995	Carries advanced remote-sensing cameras. **Still in service.**
Indian Remote Sensing Satellite (IRS-P3)	21.03.1996	Carries remote-sensing payload and an X-ray astronomy payload. **Still in service.**
Indian Remote Sensing Satellite (IRS-1D)	29.09.1997	Same as IRS-1C. **Still in service.**
Kalpana	2003	Exclusive meteorological satellite, VHRR, **Still in service.**

Source: http://www.isro.org/sat.htm

The INSAT 1 series consisted of four satellite missions with VHRR payload giving visible images with 2.75 km resolution and thermal data with 11 km resolution, with the capability to provide three hourly images and half-hourly images in sector scan mode.

The INSAT 2 series that followed was designed based on user feedback and consists of five satellites to ensure the continuity of services in an enhanced manner. INSAT 2A and 2B launched in 1992 and 1993 carried VHRR payload with improved resolution of l2 km in visible, and l8 km in thermal band. The imaging capability included three modes, viz. full frame, normal mode and sector mode of five minutes for the rapid coverage of severe weather systems.

INSAT 2E launched in 1999 carried an advanced VHRR payload operating in three channels – visible l (2 km), thermal and water vapour (8 kms.). The water vapour channel operating I 5.7-7.1 m is capable of giving water vapour distribution and flow patterns in the lower troposphere. Besides this, INSAT 2E also carries a CCD camera with three channels—visible, near infrared and short wave infrared with one km. resolution to map the vegetation cover.

Recently, METSAT, the first exclusive Indian Meteorological satellite in geostationary orbit, was successfully launched, and carrying advanced VHRR operating in visible, infrared and water vapour channel. INSAT 3A will have identical payloads as INSAT 2E; INSAT 3D planned in the future will carry an atmospheric sounder for temperature and water vapour profiles and split thermal channels for accurate sea surface temperature retrieval.

At present, repetitive and synoptic weather system observations over Indian oceans from geostationary orbit are available from the INSAT system. The INSAT-VHRR data is available in near real-time, at 32 meteorological data dissemination centres (MDDC) in various parts of the country. With the commissioning of direct satellite service for processed VHRR data, MDDC data can now be provided at any location in the country on a real-time and archived basis.

A centre for exchange of satellite data in the field of earth and atmospheric sciences has been established at IMD New Delhi as a part of Indo-US bilateral programme. Dedicated communication links have been established from this centre to the corresponding

centre in NASA, US. The Indian scientists from different institutes are using data products available through this data centre for research activities.

A 100 meteorological data collection platforms (DCP) have been installed all over the country and at the Indian base in East Antarctica (Schirmacher Oasis-Maitri Station). The CWC and Snow and Avalanche Study Establishment (SASE) are also using INSAT facilities for real-time hydro-meteorological data collection in the Mahanadi and Chambal basins, respectively.

Measurements of trace constituents and air pollution monitoring

The Central Pollution Control Board (CPCB) initiated a nation-wide programme in 1984, called the National Ambient Air Quality Monitoring (NAAQM), with a network of 28 monitoring stations covering seven cities for air quality monitoring as an integral part of the air pollution control programme. Over the years, the number of stations has increased and presently, the network comprises 290 stations spread over 92 cities/towns distributed over 24 states and four Union Territories UTs (Figure 4.3).

Figure 4.3: National Ambient Air Quality Monitoring network.

Source: CPCB, Government of India.

In addition to the NAAQM programme, operated by CPCB, many state boards have set up their own Ambient Air Quality Monitoring (AAQM) programmes. Its objectives are to:

- Strengthen the existing air monitoring system with the adoption of state-of-the-art methodologies to monitor the air quality.
- Monitor the criteria pollutants depending on the locations.
- Determine present air quality status and trend.
- Provide background air quality data as needed for industrial sighting and town planning.
- Control and regulate pollution from industries and other sources to meet the air quality standards.

In addition to direct government controlled monitoring, the National Environmental Engineering Research Institute (NEERI) monitors ambient air quality in 30 stations covering 10 major cities. Major industries have also set up their own monitoring stations near their production units as part of the compliance of the consent conditions.

The pollutants monitored are Sulphur dioxide (SO_2), Nitrogen dioxide (NO_2) and Suspended Particulate Matter (SPM), besides the meteorological parameters, like wind speed and direction, temperature and humidity. In addition to the three conventional parameters, NEERI monitors special parameters like Ammonia (NH_4), Hydrogen Sulphide (H_2S), Respirable Suspended Particulate Matter (RSPM) and Polyaromatic Hydrocarbons (PAH).

In another atmospheric observation initiative, the IMD established 10 stations in India as a part of World Meteorological Organization's (WMO) Global Atmospheric Watch (GAW, formerly known as Background Air Pollution Monitoring Network or BAPMoN). The Indian GAW network includes Allahabad, Jodhpur, Kodaikanal, Minicoy, Mohanbari, Nagpur, Portblair, Pune, Srinagar and Visakhapatnam. Atmospheric turbidity is measured using hand-held Volz's Sunphotometers at wavelength 500 nm at all the GAW stations. Total Suspended Particulate Matter (TSPM) is measured for varying periods at Jodhpur using a High Volume Air Sampler. Shower-wise wet only precipitation samples are collected at all the GAW stations using specially designed wooden precipitation collectors fitted with stainless steel or polyethylene funnel precipitation collectors. After each precipitation event, the collected water is transferred to a large storage bottle to obtain a monthly sample. Monthly mixed samples collected from these stations are sent to the National Chemical Laboratory, Pune, where these are analyzed for pH, conductivity, major cations (Ca, Mg, Na, K, NH_4^+) and major anions (SO_4^{2-}, NO_3^-, Cl^-).

Marine observations

Climate variability in the recent past has caused a great deal of impact on the weather pattern, resulting in droughts and extreme heat events in various countries of the Indian Ocean. Climate predictability is an imperative need for India that is heavily dependent on monsoons for its economy. Although the oceans play an important role in the climate change, the symbiotic connection between ocean and atmosphere, particularly in terms of exchange of heat and mass is not yet well understood. This could be due to a lack of systematic observational network in the seas around India.

The history of sea-level measurement in India goes back to the period 1806-1827 when the first tidal

Ocean measurements being carried out in the Arabian Sea.

observations work was undertaken by James Kyd at the Khidirpur (Kidderpore) docks, Hooghly River and continued at Sagar Island during 1828-1829. In 1877, the Government of India entrusted the responsibilities of carrying out systematic tidal observations to the Survey of India to determine mean sea level for establishing the data for the Vertical Control of India. Since then, numerous tidal stations have been established. At present, there are 22 functional tidal stations under the technical control of the Survey of India.

The department of the Ocean development has instituted national facilities for Oceanographic research which include Ocean research vessels like Sagar Kanya, Sagar Sampata, Sagar Purvi, Sagar Paschimi and some data buoy vessels and new technology demonstration vessels.

Recognizing the importance of information and knowledge of the seas around India, the DoD formulated an integrated programme called 'Ocean Observation and Information Services (OOIS)' for implementation during the Ninth Five-Year Plan (1997-2002). It comprised the integration of ongoing projects and launching of new ones implementing the OOIS programme. OOIS consisted of four components, viz., Ocean Observations, Information Services, Modelling and Satellite research projects. OOIS aims at: (a) development of wide range ocean-atmospheric and coastal models; (b) generation of algorithms for retrieval of satellite parameters; (c) augmentation of ocean observations including *in-situ* and satellite measurements; and (d) operationalization of ocean advisory services.

Box 4.1: Oceanographic Infrastructure – National Facility

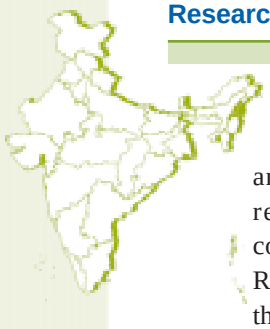
- ORV Sagar Kanya
- FORV Sagar Sampada
- CRV Sagar Purvi
- CRV Sagar Paschimi
- New data buoy vessel - for deployment, operational and maintenance of ocean observational networks such as moored ocean buoys, ARGO, Drifting buoys, XBTs, current meter array and other oceanographic research activities.
- New technology demonstration vessel

In view of the contribution of data generated through observational platforms for weather/ climate forecasting and other coastal development activities, it is proposed to strengthen and augment the observational network during the Tenth Five-Year Plan (2002-2007) by deployment of a variety of state-of-the-art technology buoys and floats. Several national agencies, such as, the National Institute of Oceanography (NIO) at Goa, the National Institute of Ocean Technology (NIOT) at Chennai, and the Survey of India at Dehradun have been involved in the generation of data pertaining to coastal and open seas of India. Towards collating and archival of the data and effective dissemination of information to the end users through a single window, a dedicated centre called the Indian National Centre for Ocean Information Services (INCOIS) was established at Hyderabad in February 1999. Accomplishments of this scheme are:

An ocean research vessel *Sagar Kanya* of the Department of Ocean Development.

Ocean Observing Systems

The ocean observations, both *in-situ* and satellite measurements, play a vital role in understanding the ocean atmospheric processed. Systematic time-series surface metrological and oceanographic observations are essential primarily to improve oceanographic services and predictive capability of short- and long-term climate changes. The time series observation data on waves, wind, currents, air temperature, pressure



and others are required for carrying out basic research and developmental activities in the coastal/ ocean areas and to study ocean processes. Recognizing the importance of these measurements, the DoD has proposed to augment the observational network during the Tenth Five-Year Plan by deployment of a set of state-of-the-art profiling floats and moored ocean data buoys.

Moored Ocean Data Buoy Programme

The primary objectives are to support national, regional and international programmes relating to ocean sciences and technology by providing real-time and archived data and related information and to provide real-time data for programmes relating to the prediction of movement of cyclones and consequent storm surges that are devastating in nature.

During the Ninth Five-Year Plan, the DoD established a 12-ocean buoy network in the areas around India, with partial financial assistance from the Norwegian Agency for Development Cooperation (NORAD), Norway. The data buoys are equipped to record the data on atmospheric temperature, humidity, pressure, sea surface temperature, and salinity and wave parameters through their sensors. They are transmitted to the International Maritime Satellite (IMMARSAT) and received at NIOT. Data is regularly disseminated to users like IMD for weather predictions. The other user groups include, Climate Research Group in Department of Science and Technology, the IISc, the Navy, and Ports. The NIOT is currently operating 14 moorings, out of which 12 are providing real-time data. In order to attain self-reliance, the NIOT is under an advanced stage of indigenous production of these data buoys, including the critical central processing unit, and the satellite transmitter and transceiver for INSAT, which has been jointly developed by NIOT and the SAC, Ahmedabad.

Indian Array for Real-time Geotropic Oceanography (ARGO) Project

The International ARGO project envisages the deployment of 3,000 profiling floats in the global ocean at approximately 3^0x3^0 (300 km x 300 km) resolution. About 20 countries including India, have committed resources to the project. The floats in ARGO will provide temperature and salinity data over the entire world's ocean at 10-day intervals. These floats are designed to dive up to 2,000 m depth to make measurements and transmit the data through satellite to ground stations, when they reappear. Each float is capable of making 200 profiles over a period of five years.

Under this programme, 450 ARGO floats are to be deployed in the Indian Ocean region. India holds a major share of such buoys in the Indian Ocean region, thus acquiring a leadership in the regional climate programme. The DoD has made a commitment for the deployment of about 150 in the northern Indian Ocean north of 10^o South over a period of five years (2002-2007), of which 12 have already been deployed. For the first time in the Indian Ocean, India conducted a 3-ARGO float mission with 10 days, five days, and 10 & five-day cycles to capture the inter-annual variability in the region. Data from these floats is being received and made available on the website for users after the real-time quality checks. The Indian National Centre for Ocean Information Services, the National Institute of Ocean Technology and the IISc are the other institutions involved in this programme.

In the long run, the ARGO data would help to greatly improve our knowledge of scientific problems such as the interaction of atmosphere and ocean on interannual time scales, as well as providing a highly useful set of measurements that will be relevant to more practical problems associated with shipping, fisheries and environmental assessment applications. This will also contribute to various national projects being undertaken by India, through the Indian Climate Research Program (ICRP). These temperature and salinity profiles are expected to improve our understanding of the oceanic processes and contribute to improved prediction of climate variability.

Data from the global array of profiling floats would be put on the GTS immediately to enable its use in operational forecasting. Delayed mode data, after detailed quality control checks by the ARGO data centres, would be available within a few months via the Internet. One-year time series data collected from the Canadian Float deployed by India were analyzed and developed to decide the ARGO Float design for the Indian Ocean region.

A website for the India ARGO Programme with Web GIS and query facilities and for coordination of ARGO float deployment in the Indian Ocean was set up. Data from about a 100 floats (about 2,600 temperature and salinity profiles) deployed by various countries in the Indian Ocean is available on the INCOIS website for the scientific community. Data from 600 floats have also been archived. Under a joint project of INCOIS and CAO/IISc, the hydrographic structure of western Arabian Sea was studied, using the data from ARGO floats in the region. A software package for on-line real-time quality control of ARGO data, incorporating 21 quality checks approved by the International Agro Science Team was developed.

There are three autonomous bodies of the DoD viz., the National Institute of Ocean Technology, Chennai; the Indian National Centre for Ocean Information Services (INCOIS), Hyderabad and the National Centre for Antarctic and Ocean Research (NCAOR), Goa which are primarily responsible for deployment, operation and maintenance of ocean observation platforms and ships for promoting the ocean observations. In addition, the National Institute of Oceanography, Goa and the Survey of India, Dehradun had executed projects for acquisition of oceanographic data, under the Ocean Observing System of the DoD.

Considering the importance of the data and its utility to various national programmes, the DoD has proposed to strengthen the observational network during the Tenth Plan by deployment of state-of-the-art technology ARGO profiling floats in the Indian ocean north of 10^0 south for real-time collection of temperature and salinity data up to a depth of 2000 m. A set of 10 ARGO floats out of the proposed 150 floats has already been deployed in the Bay of Bengal. The moored data buoy network will be increased to 40. Under the sea-level programme, 10 Float type digital tide gauge stations were established in major ports of India for systematic, accurate and long time measurements of sea level.

Indian National Centre for Ocean Information Services (INCOIS)

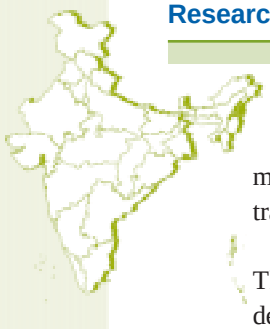
In order to coordinate the various projects and to generate and supply data products effectively to the users through a single window, an autonomous body known as the Indian National Centre for Ocean Information Services (INCOIS) was established in 1999, at Hyderabad. The mandate of INCOIS is to synthesize, generate, promote, provide and coordinate various activities for ocean science observations, information and advisory services. Further, synergy and knowledge networking with centres of excellence in ocean atmospheric sciences, space application centres and information technology as well as translating the scientific knowledge into useful products are primary goals of INCOIS. This centre is marching ahead with a mission to provide the best possible ocean information and advisory services to society, industry, government agencies and scientific community research. Within a short span of its existence, the INCOIS has been recognized as an institution focusing on providing advances in space and ocean sciences to help the common man. Further, the initiatives taken by INCOIS during the last two years with respect to the International ARGO programme and the Global Ocean Observing System have enabled India to gain a significant niche in the global scenario. INCOIS has also been recognized as the Regional ARGO data centre for Indian Ocean.

Terrestrial observations

Cryospheric observations

A systematic study of glaciers was begun by the Geological Survey of India (GSI) during 1907 to 1910, as part of an international programme to study glaciers. In 1974, it established the Glaciology Division for northern region, with its headquarters at Lucknow and the Eastern Region Division established at Kolkata in 1979.

The GSI carried out glaciological studies in Jammu and Kashmir (Neh-Nar, 1974-1984; Harmuk and Rulung); Himachal Pradesh (Gara, 1973-1983; Gor Garang, 1975-1985; Shaune Garang; 1981-1991); Uttar Pradesh (Tipra Bamak, 1980-1988; Dunagiri, 1984-1992); and Sikkim (Zemu and Changme Khangpu glaciers). It also carried out snow cover assessment of Beas basis, Dhauliganga valley, and Sind Valley. The GSI has thus completed the first generation glacier inventory of UP, HP, J&K and Sikkim. They have largely confined their study to



mass balance, glacier recession, suspended sediment transfer and geomorphological studies.

The Survey of India (SOI), the oldest scientific department of the Government of India, set up in 1767, is the national survey and mapping organization of the country. The most significant contribution of SOI in the study of glaciers, is the accurate demarcation of all glaciers on topographical maps that can provide a vital data source for glaciological research.

The IMD established the glaciology Study Research Unit in Hydromet Directorate in 1972. This unit has been participating in glaciological expedition organized by the GSI and the DST. The unit was established for the: (a) determination of the natural water balance of various river catchment areas for better planning and management of the country's water resources; (b) snow melt run-off and other hydrological forecasts; (c) reservoir regulation; (d) better understanding of climatology of the Himalaya; and (e) basic research of seasonal snow cover and related phenomena. The IMD has established observing stations over the Himalayan region to monitor weather parameters over glaciers.

The Snow and Avalanche Study Establishment (SASE), a defense research organisation has been working in the field of snow avalanches since 1969. The emphasis has been the mitigation of snow avalanche threat by various active and passive methods. Avalanche forecasting and avalanche control measures form the front-line research areas of this establishment. The basic research in snow physics, snow mechanics and snow hydrology naturally followed in pursuit of the solutions to problems related to snow avalanches. SASE has established about 30 observatories in western Himalayan region, which are very close to the glacier environment. The data collected at these observatories mostly pertains to weather, snow and avalanches. In addition, a chain of 10 Automatic Weather Stations (AWS) has been established at different places in the western Himalayan region. Of these, two have been installed right on a glacier.

In addition, these several other academic and research institutions, like the Wadia Institute of Himalayan Geology (WIHG), Physical Research Laboratory (PRL) and the Jawaharlal Nehru University (JNU) have actively taken part in studying of the Himalayan glaciers.

Satellite-based observations of the glaciers and their mass balance characteristics are also being carried out regularly by the SAC.

Ecosystems

India by virtue of its varied topography, climate and habitats, is very rich in biodiversity resources right from cold deserts to the tropical littoral forests. It is also rich in its folk and traditional knowledge of properties and uses of these resources. Biodiversity resources are valued directly, such as food for humans, fodder for animals, energy sources as fuel, nutrients like leaf manure and structural materials like pharmaceuticals, fibre, fragrances, flavours, dyes and other materials of special interest.

A record of India's plant wealth indicates that there are approximately 17,500 species of angiosperms, 48 species of gymnosperms, 1,200 species of ferns, 6,500 species of algae, 14,500 species of fungi, 2,500 species of lichens, 845 species of liverworts and 1,980 species of mosses. Several organizations are involved in the observational and research aspects of the flora and fauna of the country, as also the different ecosystems.

The FSI, an organization under the MoEF, has been undertaking assessment of forest resources in the country since 1965. As per its current mandate, the FSI has to assess the forest cover of the country in a two-year cycle, which is published regularly in the form of 'State of Forest Report' (SFR). The latest SFR 2001 reports the forest cover of the whole country at a 1:50,000 km scale, using a combination of remote sensing satellite data and field survey. Study improvements have resulted in a complete picture of the extent of forest and tree cover in India. The present assessment shows that forest covers (20.55 per cent) and tree cover (2.48 per cent) constitute a healthy 23.03 per cent of the country's geographical area. For the first time, an error matrix has been generated by comparing the classified forest cover with the actual forest cover on the ground, at 3,680 locations spread throughout the country to arrive at the accuracy of forest cover classification. The present assessment

shows that mangrove cover in the country occupies an area of 4,482 sq. km of which 2,859 sq. km is dense mangrove.

Many research institutions and Agricultural Universities under the ICAR are engaged in data collection and research in the agriculture sector. The agronomy division of the ICAR, over the past 50-60 years, has gathered soil parameters for agricultural resource management. Agriculture-related weather data and grain-wise agricultural yield data are collected at the local level at evenly distributed sites all over the India.

Hydrological observations

The Centre Water Commission (CWC) under the MWR, operates a national network of about 877 hydrological observation stations. The data observed at field units is processed at various levels and archived. The CWC is also imparting training to various research institutions, universities, central and state pollution control boards for the systematic collection of river water samples.

The Central Ground Water Board (CGWB), another institution under the MWR, monitors the groundwater levels from a network of 14,995 stations (mostly dug wells) distributed evenly throughout the country. Dug wells are being gradually replaced by Piezometers for water-level monitoring. Measurements of water levels are done four times during the year in the months of January, April/ May, August and November. The ground water samples are collected during April/May for analyses of chemical changes. The generated data is used to prepare maps of groundwater-level depths, water-level contours and changes in water-levels during different time periods. The data is also used to prepare long-term changes trends in water levels. The CGWB has categorized the Indian subcontinent into 12 basins. At the basin level, several parameters are being monitored and are available with the CWC for various national research needs (Table 4.3).

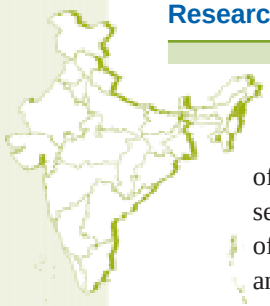
Conclusion

India has invested heavily in scientific infrastructure with the view that a strong science and technical base is key to industrial development and self-reliance. This included setting up independent institutes of higher education in science and engineering, as well as a complex of national laboratories under the umbrella of the CSIR, the ICAR and other autonomous research institutes of excellence under various ministries and departments. India now has one

Table 4.3: Basin-wise hydrological and sediment observation.

States/Regions	G*	GD*	GDS*	GDW*	GDSW*	Total
East-coast rivers of Andhra Pradesh	24	59	0	24	50	**157**
Brahmaputra basin	64	27	14	0	12	**117**
East-coast rivers of Tamil Nadu	0	3	0	13	14	**30**
East-coast -rivers of Orissa and West Bengal	27	15	0	1	24	**67**
Ganga basin, Damodar basin and Kangsabati	92	110	6	29	89	**326**
Indus basin	1	15	9	0	0	**25**
West-coast rivers of Kerala	0	0	0	3	16	**19**
Rivers of Meghalaya	0	4	0	0	0	**4**
West-coast rivers of Gujarat	18	25	0	9	32	**84**
Rivers of Mizoram and Manipur	5	5	1	0	0	**11**
Barak and other rivers of Tripura	4	11	11	0	0	**26**
West-coast rivers of Maharashtra, Goa and Karnataka	1	7	0	1	2	**11**
Total	236	281	41	80	239	**877**

*G=Gauge, GD= Gauge Discharge, GDS=Gauge Discharge and Silt, GDW= Gauge Discharge and Water Quality, GDSW=Gauge Discharge, Silt and Water Quality.



of the largest scientific manpower in the world. This serves as a backdrop for understanding the potential of Indian science to address climate change research and assessment. Collaborative activities among these groups are rarely catalyzed by institutional or programmatic structures. Of late, there have been some efforts by the DST to coordinate climate research through its Indian Climate Research Programme (ICRP, launched in 1996), which has successfully mounted observational efforts (BOBMEX, ARMEX) to understand the Indian south-west monsoon variability. New programmes to bring together research groups to solve common problems have also been initiated by the MoEF. There is however, a strong need to integrate the research efforts to focus on climate change issues of relevance for the region.