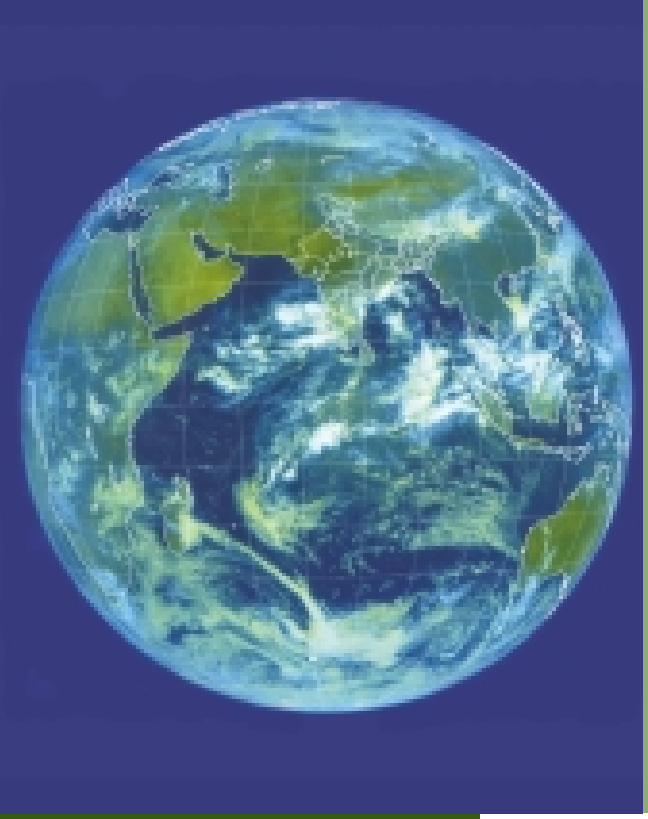

Enhancing scientific understanding

7

The most important step towards meeting the challenge of climate change is to understand its causes, processes, and impacts. Climate change is a phenomenon that occurs on a global scale over a time frame of centuries. Predicting this phenomenon is made highly difficult by the non-linearity, uncertainty, and inertia in the earth's climate system.

Several efforts are being made in India by government institutions, independent agencies, and individuals to improve scientific understanding about climate change. Some of these are described below.

Weather and climate monitoring

India has one of the richest repositories of climate data in the region. The IMD (India Meteorological Department) has systematic weather records dating as far back as 1850 for many locations in the country. Over time, the IMD has progressively expanded its infrastructure for meteorological observations, communications, forecasting, and weather services. It collects surface and upper air observations for climate parameters throughout the country. The observational network includes 559 surface observatories, more than 8000

rainfall monitoring stations, 100 satellite-based data collection platforms in remote areas, 203 voluntary observing ships, 10 cyclone detection radars, and 17 storm detection radars (IMD 2002). The IMD uses data from the Indian satellite, INSAT, to obtain cloud imageries in the visible and infrared channels, for deriving cloud motion vectors, sea surface temperatures, and outgoing long wave radiation. The country's first dedicated weather satellite was launched by the ISRO (Indian Space Research Organization) in September 2002.

Since 1983, regular meteorological observations have also been carried out at the Indian Antarctic station, *Maitri*.

IMD is replacing the existing cyclone detection radars with state-of-the-art Doppler weather radars in a phased manner. The cities of Calcutta, Chennai, and Sriharikota have been the first to witness their use, to be followed by Paradip, Visakhapatnam, and Machilipatnam. An indigenous Doppler weather radar is being developed under a collaborative programme of ISRO and the IMD.

Indian scientists have contributed to a number international scientific experiments that have included ground-breaking observational activities, such as the IIOE (International Indian Ocean Expedition), the ISMEX (Summer Monsoon Experiments), and the MONEX (Monsoon Experiment) and, more recently, the INDOEX (Indian Ocean Experiment).

Climate modelling and impacts

The DST (Department of Science and Technology), Government of India, has been supporting and fostering research in the area of atmospheric sciences, including meteorology and climate change. Through its SERC (Science and Engineering Research Council), the DST has supported training activities in advanced techniques of atmospheric sciences and modelling, and capacity building for greater understanding of local and global climate systems. It particularly supports advanced research, development, and training on problems of relevance to the Indian subcontinent, such as improving life-sustaining quality, agriculture, ecology, and understanding of aerospace and ocean–atmosphere environments.

The DST also supported the monitoring of the Indian Ocean region as part of the international TOGA-I (Tropical Ocean Global Atmosphere) Programme. To enhance understanding of the physical processes involved in climate variability, it supported multi-disciplinary and multi-institutional field observational programmes, like the MONTBLEX (Monsoon Trough Boundary Layer Experiment) and the LASPEX (Land Surface Process Experiment). The ICRP (Indian Climate Research Programme) has been launched to study climate variability at different time scales and its impact on Indian agriculture and economy. The programme consists of the following.

- Analysis of observational data from ground-, ship-, and satellite-based measurements
- Modelling studies with coupled ocean-atmospheric general circulation models
- Identification of the climate component of agricultural productivity, impact of climate on environment, global warming and climate change.

The implications of climate change for India could include greater monsoon variability and tropical cyclone formation. Models have been developed for long-range forecasting of south-west monsoon rainfall over India.

To study the air–sea interaction processes and monsoon variability, a major multi-institutional ocean-atmosphere field experiment known as the BOBMEX (Bay of Bengal Monsoon Experiment) was successfully implemented, and is to be followed by the ARMEX (Arabian Sea Monsoon Experiment).

A number of research and academic institutions in India have active programmes in climate science. The Indian Institute of Tropical Meteorology, Pune, is engaged in climate modelling, with the aim of developing a general circulation model to predict climate at seasonal scales. Scientists from the National Centre for Medium Range Weather Forecasting, the Indian Institutes of Technology, and the IISc (Indian Institute of Science) are also involved in climate impact modelling.

Indian scientists and institutions are actively involved in all three international science programmes in global change—

(1) World Climate Research Programme, (2) International Geosphere-Biosphere Programme, and (3) International Human Dimensions Programme.

With a view to understanding the behaviour of glaciers and their interaction with the climate and hydrological system, the Himalayan Glaciology Programme was launched. An additional aim of this programme is to train manpower and create R&D-related facilities in this area. Himalayan glaciological studies are being undertaken by many organizations in the country, such as the Remote Sensing Applications Centre, Uttar Pradesh.

India has introduced several programmes for long-term monitoring of oceanographic parameters, including the Sea Level Monitoring and Modelling Project, the National Data Buoy Programme, the Satellite and Coastal Oceanographic Research Project, the Experimental Ocean State Forecast Programme, and Indian Ocean Modelling and Dynamics. India also supports and participates in one of the

'O Mother Earth! Sacred are the hills, snowing mountains, and deep forests, be kind to us and bestow upon us happiness. May you continue supporting people of all races and nations!'

Atharva Veda

International Geosphere-Biosphere Programme's core projects, Land–Ocean Interactions in the Coastal Zone. Launched in India in 1995 for the integrated management of the coastal environment, this programme is aimed at determining the effects of global change on the coastal zone and improving the ability to predict changes.

The ongoing Indo–UK Climate Change Impacts Programme supported by the MoEF aims to develop climatic and socio-economic scenarios for India and assess the impacts of climate change on agriculture, forestry, coastal areas, water resources, health, energy, industry, and transport. The ICAR (Indian Council of Agricultural Research) has established an agro-ecological zone-wise Special Climate Change Impact Study Programme. The United Nations Environment Programme–ICAR project has been initiated to map climate vulnerability by developing vulnerability indices. Vulnerability and adaptation studies for various sectors are also part of India's NATCOM project. The project intends to identify regions of higher vulnerability to climate change in the country, conduct case studies, and develop possible adaptation measures in selected sectors. Across the country, 34 institutes are undertaking activities under the vulnerability and adaptation component of the NATCOM project.

Finally, Indian researchers have been involved with the IPCC since its inception and have contributed to its three assessment reports as well as a number of technical papers.

Greenhouse gas emissions estimation

It is also essential to understand the causes of climate change and estimate GHG emissions from various sources. A national inventory of GHG sources and sinks was prepared under the ALGAS (Asia Least-cost Greenhouse Gas Abatement Strategy) study for India, part of a 13-country project funded by UNDP-GEF and executed by the ADB. It was completed in 1998 and developed India's GHG inventory for the energy, industry, agriculture, land-use change and forestry, and waste sectors for 1990. This inventory used country-specific emission factors that were developed for methane emissions from paddy cultivation and carbon dioxide emissions from Indian coal.

Detailed work on estimation of sectoral GHG emissions and development of country-specific emission factors is being undertaken as part of the country's initial NATCOM to the UNFCCC. The major activities include the preparation of a national inventory of anthropogenic emissions by sources and removal by sinks of all GHGs not controlled by the Montreal Protocol using comparable methodologies. The GHG inventory for India is being prepared for the base year 1994, and covers five sectors—(1) energy, (2) industrial processes, (3) agriculture, (4) forestry, and (5) waste. Measurements are been undertaken for the following sectors.

- Power
- Cement
- Lime production
- Steel
- Breweries
- Nitric acid production
- Coal mines
- Transport
- Agriculture
- Forestry
- Municipal solid waste.

A network of institutes has been created for the preparation of sectoral GHG inventories, and for uncertainty reduction in activity data and emission co-efficients for key source categories.