

National Centre for Antarctic and Ocean Research

RASIK RAVINDRA*

National Centre for Antarctic and Ocean Research, Vasco-da-Gama, Goa 403 804, India

The National Centre for Antarctic & Ocean Research (NCAOR) was established in 1998-99 as an autonomous Institution of Ministry of Earth Sciences to provide scientific logistic and infrastructure facilities for the Indian Antarctic expeditions. Since then, NCAOR has been playing a major role in national Antarctic programs. It is credited with pursuing cutting-edge studies in the field of earth, environment, life, space and other subjects of Polar sciences in collaboration with research communities of India and abroad. India's commitment to pursue world class research in Antarctica while preserving its pristine environment, was given a concrete shape with the establishment of the first polar R&D lab at NCAOR, including a Class 100 clean ice laboratory. The Centre has been equipped with some of the State-of-art laboratories for ice core studies, microbiological, environmental research and related subjects.

The Centre is the nodal organization for the co-ordination and implementation of the Indian polar program that includes Antarctic, Arctic and Southern Ocean studies as also encompassing the maintenance of India's permanent stations in these areas. In addition, the Centre has brought visibility to Indian Scientific activities by taking leadership role in the international committees concerned with Polar sciences such as SCAR (Scientific Committee on Antarctic Research), COMNAP (Council of Managers of National Antarctic Programs), AFoPS (Asian Forum for Polar Science) etc. It represents the country in ATCM (Antarctic Treaty Consultative Committee Meeting), IASC (International Arctic Science Committee), Ny-SMAC (Ny Alesund Science Management Committee) and several other forums and plays an important role in international global observations.

In recent years, NCAOR has taken initiatives for long term studies in several contemporary disciplines such as glaciology, microbiology, palaeoclimatology, solid earth geophysics, nature of continental shelf and studies on deep crustal structures across Indian continental margin, EEZ studies etc. NCAOR has also initiated a major national

program on Southern Ocean to understand processes of air-sea interaction, aerosol radiative forcing, nature of the frontal zones and biogeochemistry. Additionally, NCAOR is the nodal agency for IODP (Integrated Ocean Drilling Program), under which it has facilitated participation of young Indian researchers in international oceanographic expeditions. NCAOR also manages the Oceanic Research Vessel *ORV Sagar Kanya*, the flagship of India's fleet of oceanographic study vessels.

Indian Antarctic Programme

Realising the immense scope Antarctica offers for scientific research in the frontier-realms of earth sciences, biology, climate change, and human physiology, India embarked on an ambitious project of establishing a research base on the icy continent which would facilitate the scientists to sustain their scientific observations during both the austral summer and winters. During the initial years of the Antarctic Expeditions, the scientific investigations were carried out from camps on the ice shelf as well as from the expedition vessel. With establishment of Dakshin Gangotri and Maitri as India's permanent stations, the focus was shifted to interior mountain ranges of Central Dronning Maud Land (CDML). The major scientific themes being covered include:

- a) Atmospheric and meteorological science.
- b) Earth Sciences (including geological, geophysical, glaciological, palaeo-climatology and geodesy etc.).
- c) Biosciences and Environmental Sciences.
- d) Human physiology.
- d) Cold region engineering which includes communication, energy, water, refrigeration as part of logistic support system.

Antarctic expeditions are a classic example of joint endeavor of major scientific and research institutions of India, where different organizations and universities

*Author for Correspondence: E-mail: rasik@ncaor.org

participate to explore the icy continent. Some of the highlights of the Antarctic programme in the last five years include:

- a) Completion of geological mapping in hitherto unmapped areas of CDML between 4°E and 15°E longitudes on 1:50,000 scale extending the coverage to over 19000 sq. km.
- b) Absolute gravity measurements; Establishment of a broadband seismological laboratory; setting up of a 3-station magnetometer chain for geomagnetism.
- c) Continuous and periodic ozone profiling by mm wave radio-spectrometer and ozonesonde ascents.
- d) A number of new species of bacteria have been identified from cold habitats in Antarctica, 30 out of 240 new species discovered so far have been reported by Indian scientists.
- e) Studies were carried out to determine cognitive performance by prolonged duration in polar environment. Findings indicate positive as well as neutral effect on cognitive performance of winter over residents.
- f) Palaeoclimatic studies of Antarctic lakes.
- g) Long Term Monitoring of Snow-Ice, Glaciers in different Antarctic Basins and Atmospheric Studies using Satellite Images.
- h) Study of VLF phenomena through Direction Finding Techniques in Antarctica.

NCAOR initiated commissioning a state-of-the-art research base at Larsemann Hills in 2009. The station building has been made operational in March 2012.

One of the most remarkable achievements in the year 2010 was the successful Expedition to the South Pole. A meticulously planned, one month round trip from Maitri to Scott-Amundsen South Pole station and back, highlighted the grit and dogged determination of the NCAOR to scale new heights. The success of the expedition has established capability of India in positioning its scientists anywhere in Antarctica for the purpose of collection of scientific data.

Polar Remote Sensing Laboratory (PRSL)

Scientists of the PRSL division monitor critical manifestation of climate and atmospheric changes, such as mapping of the Antarctic sea ice extent, motion of ice sheets, temporal variability of wind stress in different ocean sectors, and application of satellite remote sensing techniques in the polar glaciology. The major studies

conducted during the last four years are given below:

- a) Role of atmospheric and ocean forcing on sea-ice extent and role of bottom topography in modulating sea ice extent in the Indian Ocean Sector.
- b) Extraction of Polar Spatial information and Digital Elevation mapping of Larsemann Hills.
- c) Spectral index ratio-based Antarctic land-cover mapping using hyperspatial 8-b and WorldView-2 imagery.
- d) Quantitative and comparative study of semiautomatic extraction of Antarctic lake features using hyperspatial imagery.
- e) Recent Volume changes of Lambert Glacier-Amery Ice Shelf using Satellite Laser Altimetry.
- f) Quick SCAT-based Momentum Flux analysis over the Southern Ocean and turbulent heat flux in the Tropical Indian Ocean.
- g) Upper-Ocean Hydrodynamics along Meridional Sections in the Southwest Indian Sector of the Southern Ocean during Austral Summer 2007 and 2008.

Atmospheric Science

Study of atmospheric and planetary boundary layers over Antarctica has since been undertaken by NCAOR. The planetary boundary layer programme provides the basic atmospheric parameters and features of Antarctic climate. The atmospheric studies includes; collection of data on various parameters of the atmospheric boundary layer and planetary boundary layer using satellite data and the automatic weather station; ozone phenomenon over Antarctica using ozonesondes and Modelling of Polar stratospheric ozone using non-linear methods. The Meteorological studies include meteorological observations for support to scientists and logistics, especially flying. Such data sets are being used in model validation, assimilation and climate studies.

Cryosphere Studies

During 2007-12, snow and ice core studies were continued as a part of long term program at NCAOR. In order to understand the biogeochemical processes in polar regions as well as to reconstruct the environmental variables during recent and past periods with annual to sub-annual resolution. Two ice cores were drilled in Antarctica and several snow core and surface snow samples were collected from Antarctic and Arctic regions. Large numbers of ice core and snow and samples collected during the various Antarctic expeditions are being analyzed for detailed

measurements of major ions, trace metals, dust/particles and isotopic parameters. In addition, microbiological studies have been conducted from snow samples to examine the bacterial diversity and geochemical composition from three depths of an ice core from coastal Dronning Maud Land (DML), East Antarctica.

Indian Arctic Programme

India began its scientific endeavours in the Arctic in 2007 when a team of five scientists visited the International Arctic Research Facilities at Ny-Ålesund to initiate studies in the fields of Arctic microbiology, atmospheric sciences and geology. Following the success of this initial step, the Ministry embarked on a long-term program of regular scientific activities in the Arctic in the frontier realms of polar biology, glaciology and earth and atmospheric sciences. Till now, 88 scientists from 20 national institutions, organisations and universities have participated in the Indian Arctic Programme, which is being co-ordinated and implemented by NCAOR on behalf of the Ministry. The focus areas of research by the Indian scientists at Ny-Ålesund are confined to some of the frontier areas of polar sciences of special relevance to the Arctic realm, such as glaciology, atmospheric science, biology and climate change.

To facilitate the Indian activities, a station building at Ny-Ålesund has been taken on lease to serve as India's Research Base in the Arctic. This station building christened "Himadri" was inaugurated by Shri. Kapil Sibal, the then Minister of Earth Sciences on the 1st July 2008. The station has adequate living and work space for a total of 8 scientists. Concurrently, a Memorandum of Understanding was also signed between NCAOR and the Norwegian Polar Institute (NPI) for scientific co-operation and collaborative research in the fields of Geological mapping and allied earth science studies, Biogeochemistry of sea-ice ecosystems, Atmospheric Physics and Chemistry, Glaciology and Paleoclimatology.

A comprehensive long-term Science Plan of research activities by Indian scientists in the Arctic realm has been developed by the Centre. This Science Plan was unveiled and presented by NCAOR at the 29th Meeting of the Ny-Ålesund Science Managers Committee (NySMAC) – the apex body responsible for coordinating and advising all the Member Nations on scientific projects at Ny-Ålesund in November 2008. Following the presentation, the Science Plan was unanimously adopted and India was formally elected as the newest Member of NySMAC. Some of the major initiatives by Indian scientists in the Arctic are described below:

a) Snow-pack production of carbon monoxide and its diurnal variability at Arctic.

- b) Crustal deformation studies in the Arctic.
- c) Glaciological studies.
- d) The biogeochemical programme.
- e) Biological diversity.
- f) Long term monitoring of the Kongsfjorden system for climate variability studies.

Southern Ocean

Polar Regions have been identified as the areas where signatures of global changes are more pronounced. Improved understanding of the links between Southern Ocean processes, global climate, biogeochemical cycles and marine productivity will be critical for society to respond effectively to the challenges of climate change, sea level rise, ocean acidification and the sustainable use of marine resources. Research in the Southern Ocean realm underlines the sensitivity of this region to climatic variations and its importance in understanding the global climate at large. India already has a strong presence in Antarctica for the past 30 years. But, as compared to the scientific and logistics expertise gained by the country in Antarctica over the years, a wide gap exists in our knowledge of the Southern Ocean.

Out of the five expedition launched to the Southern Ocean, three expeditions have been launched in the Indian sector of the Southern Ocean since 2009. These expeditions were launched from January to April 2009, January-March 2010 and January-March 2011 involving about a dozen leading institutions in the country to understand the complexity of the Indian Ocean Sector of the Southern Ocean.

The following scientific results obtained from the Indian expeditions to Southern Ocean have given new insights about the processes in the Southern Ocean.

- a) Influence of ridges on frontal positions.
- b) The presence of conventional and microbial food chain operating, making distinct biological zones in the same frontal region has been established. This is the first study from the region, which looks at the variation in biological productivity from the Polar Front.
- c) Large spatial variations in biogenic and terrigenous flux in Southern Ocean.
- d) Relations between sedimentation (biogenic & terrigenous) and oceanic fronts established.
- e) Studies initiated to know the biogenic diversity and the importance of Coccolithophores and Diatoms in the biogeochemical cycling in the region.

- f) Some cyclic pattern observed in the biogenic and terrigenous sedimentation during the geologic past.
- g) Significant changes in the position of Polar Front – shifted to south by few degrees.
- h) A sudden drop in heat content from subtropical to polar region was identified. This can affect the meridional heat transfer which is crucial to the studies related to climatic variability.

Investigations are in progress to understand the carbon cycle in the Indian sector of the Southern Ocean. The inputs of carbon from different sources into the SO play a major role in the carbon biogeochemistry and ocean acidification. Southern Ocean is known as a sink for carbon, but intensive and long term studies are required to understand the processes that are involved in carbon generation and utilization so as to arrive at net carbon availability in the system. The data collection in the Southern Ocean will be continued while future plans include putting current meter moorings and sediment traps for a comprehensive understanding of the seasonal and inter-annual variability of the physical, geological and biological parameters.

Geo Science

Exclusive Economic Zone Program

The importance of the oceans and the seas, which occupy more than 70 % of the Earth's surface, in shaping the lives of mankind by controlling climate and weather conditions; transportation, recreation and tourism; and providing minerals, petroleum and food resources to the mankind have led to significant cooperative and coordinated endeavors on the part of the international community. The United Nations Convention on the Law of the Sea (UNCLOS), which sets out a comprehensive regime for the governance of the oceans, have introduced the concept of Exclusive Economic Zone (EEZ) and has a profound impact on the management and conservation of the resources of the oceans. Under the provisions of EEZ, the coastal states are bestowed with the right to exploit, develop, manage and conserve all resources - fish or oil, gas or gravel, nodules or sulphur - to be found in the waters, on the ocean floor and in the subsoil of an area extending 200 nautical miles (NM) from its shore. India, having a long coastline of 7516 km, has an EEZ of nearly 23, 72,298 sq. km in area which is the 12th largest EEZ in the world. The seafloor of the EEZ of India is covered by wide variety of living and non-living resources. In addition to the vast offshore deposits of sand and gravel, vast deposits of oil and natural gas as well as huge heavy mineral deposits containing strategic minerals like ilmenite, rutile, zircon, monazite, and magnetite are located in the coastal regions

of India. The offshore sediment pile is also well known as an important repository which can decipher the paleoclimatic history of Indian peninsula. Realizing the need to be cognizant about India's EEZ for the optimum utilization of the resources available in the India's oceanic region and to enhance our knowledge about the scientific issues related to the Indian Peninsula, a comprehensive scientific project has been initiated. Ministry of Earth Sciences (MoES) has made National Centre for Antarctic and Ocean Research (NCAOR, Goa) as the nodal agency for the implementation of this project. NCAOR has so far completed multibeam bathymetric survey of an area of ~ 591435 sq.km. , thus covering more than 30% of the deep-water blocks. Many sub-sea features like seamounts, abyssal hills, knolls, channel-levees, ridges etc. have been mapped and identified during the course of these surveys. Detailed analysis and interpretation of the data in terms of morphological and tectonic aspects are in progress. More than 50 nos. of sediment core samples also have been collected from the surveyed area. Samples have been analyzed to understand the provenance, environmental aspects, elemental distribution, paleo-climatic scenario etc.

Indian (Legal) Continental Shelf Programme

The Indian Continental Shelf Project which commenced during November 1999, is a multi-institutional and multi-disciplinary national mission that seeks to gather, analyse and document the requisite scientific and technical information that would help define the country's extended shelf boundaries beyond 200 NM as per the UNCLOS provisions. The Indian endeavors towards this ultimate goal are being spearheaded by the National Centre for Antarctic and Ocean Research (NCAOR). Underpinning our efforts has been a comprehensive multi-institutional marine geophysical survey and data analysis programme comprising state-of-the-art multi-channel seismic reflection, refraction, gravity and magnetic data profiling. The data acquisition work was initiated through a contractual agreement on the 17th July 2002 and was completed on the 7th February 2004. Spread over 385 days of fair-weather period, around 31,000 km of seismic reflection, gravity and magnetic data were collected in and off the EEZ of India. In addition, for the first time in the country, 90 state-of-the-art Ocean Bottom Seismometers (OBS) were successfully deployed along several seismic transects to constrain the velocities from the reflection data as well as to develop a crustal model of the area.

Considering the scope of the work, the post-processing and interpretation of the geophysical data was undertaken by three of the leading National Institutes, viz., NCAOR, NGRI and NIO. The National Hydrographic Office (NHO) was the lead agency for the acquisition, processing, interpretation and documentation of the

bathymetric data pertaining to delineation of the 2500-m isobath as well as the foot of the continental slope. Other Indian Agencies involved in the Project during the data acquisition phase were the ONGC, GSI and the DGH. All the policy aspects related to the delineation exercise are being handled by the Ministry of Earth Sciences and the External Affairs.

On the 11th May 2009, India submitted to the UN Commission on the Limits of the Continental Shelf (CLCS), the country's first partial submission for an extended continental shelf under the provisions of Article 76; Technical documentation for a second partial submission under the provisions of the Statement of Understanding has also been provided to the Ministry of External Affairs for submission to the CLCS. On the 16 August 2010, a six-member delegation led by Secretary, MoES made a formal presentation of India's submission before the Commission on the Limits of the Continental Shelf at the UN Headquarters, New York.

Marine Geophysical Database

During the course of Indian continental shelf Programme as well as other geophysical cruises in the Indian Ocean region, a huge volume of marine geophysical data has been gathered and archived at NCAOR. Considering the immense volume of data and its intrinsic value, a state-of-the-art National Marine Geophysical Data Centre with state-of-the-art archival and retrieval facilities of data in a structured database has been established at NCAOR. The web-based database facilitates customized GIS-based interface for easy retrieval of data from a NAS, queries based on different scientific inputs, and web based input/output interface to facilitate the application to run on internet/ intranet with login authentication. The database format is also flexible enough to allow for both vertical and lateral growth.

While the scientific and technical information gathered would admirably serve its primary purpose of delineating the outer limits of India's continental shelf beyond 200 NM, the surveys have also furnished invaluable data that could form the cornerstone of the country's planned endeavours in the oceanic realm. Further detailed studies on the data collected are expected to provide the scientific community with answers to some of the long-debated questions as the origin and evolution of such enigmatic features as the 85° East Ridge in the Bay of Bengal, the Laxmi and Laccadive Ridges in the Arabian Sea, the Gulf of Mannar, the offshore extent of the Deccan volcanics, the reasons for the association of gravity lows in the Bay of Bengal with structural highs, the development of the fans vis-à-vis the origin and growth of the Himalayas etc. The studies also open a new vista in the exploration

for hydrocarbons in the offshore areas of the continental shelf beyond 200 NM. With two of the world's thickest accumulations of sediments on the seabed (the "Indus Fan" in the Arabian Sea and the "Bengal Fan" in the Bay of Bengal) derived from the Himalayas, the data gathered is expected to provide specific insights related to such areas as marine ecosystems, unconventional energy, and offshore mineral resources. An increased understanding of the history and processes of the continental margin around us will also improve the assessment of hazards resulting from extreme events such as earthquakes, submarine landslides and tsunamis.

Geological and Structural Characterization of Andaman-Nicobar Subduction Zone

The Western Andaman-Nicobar forearc region which marks the subduction boundary between the Indian and Burmese plates is significant not only in terms of its geological complexity but also because of the occurrence of frequent earthquakes in the region. The devastating December 26th, 2004 tsunamigenic earthquake in the region with tragic loss of lives and property not only underlined the need to understand the source processes and rupture characteristics of the region but also led to a resurgence in the studies related to tsunami warning using tide gauges and ocean bottom pressure sensors, GPS monitoring of crustal deformation, seismic monitoring of earthquakes, tsunami modelling, run-offs measurements etc. Closely allied to these studies is the ongoing initiative of NCAOR to carry out a comprehensive geological and structural characterisation of the Andaman-Nicobar subduction zone and a comparative evaluation of the present-day set-up of the region with the pre-Tsunami configuration. Geophysical data set collected prior to the Tsunami and available at NCAOR are being utilized to study the pre-Tsunami set-up of the region while the new data set planned to be acquired will suffice the post-Tsunami configuration studies. As a prelude to the offshore studies, land-based studies were taken up in the two contrasting geological mileux- the obduction-related ophiolite and volcanic suite of rocks in the South Andaman Island followed by studies of the subduction-related volcanics of the Barren and Narcondam islands.

Integrated Ocean Deep Program (IODP)

Considering the cutting edge science include in the IODP operations and the Indian interest in the ocean domain, the Ministry of Earth Sciences (MoES), Government of India took an initiative during 2008-09 towards India joined IODP as an Associate Member. On behalf of MoES, the National Centre for Antarctic and Ocean Research, Goa has been designated as the nodal agency to deal with various facets of the IODP program in India. Since joining this

consortium, NCAOR has been involved significantly in this international endeavour. India is member of Science Advisory Structure (SAS) as well as Science Planning Committee (SPC) of this multi-national mission. Indian scientists have been participating on various IODP expeditions around the world. Nominations of these scientists are invited from across the country and selected based on their field of expertise in tandem with the scientific objectives of each expedition. The Indian scientific participation onboard IODP platforms has been one of the most significant aspects of the IODP membership as scientists from various disciplines and expertise have been able to get hands-on experience of scientific drilling in the ocean. So far, 15 young Indian scientists have participated in IODP expeditions. With their first hand experience, these would provide a great potential for the capacity building in the years to come. All of these scientists have initiated research programs based on the exclusive sediment cores obtained through respective IODP expeditions. The IODP is entering into a new phase from late 2013 and drilling in the Indian Ocean for some of the active proposals a strong possibility in the early 2014. An International Workshop to discuss the relevant scientific themes in an emerging scenario from the Indian Ocean sector was organised in

Goa on 17-18th October, 2011. The workshop was jointly convened by the National Centre for Antarctic and Ocean Research (NCAOR); Australia IODP and IODP-MI.

New Horizons

The process for acquisitions of a new Ice Breaker Polar research Vessel, that will make Indian Polar Programs self sufficient, is in advanced stage. The Centre was entrusted with the job of construction of a new research station at Antarctica. It identified Larsemann Hills in east Antarctica as a suitable site and obtained environmental clearances from ATCM- the apex body overlooking such matters. The construction of the station was taken up in 2009 and is progressing as per strict timelines. The first phase of the construction was over in March 2011. Station has been commissioned in March 2012. NCAOR proposes to take up several new studies in the 12th Five Year plan. Some of these are the 'Cryosphere Processes and Climate Change (CryoPACC)' to understand the biogeochemistry of cryosphere and "GEOTRCE"- an international programme aiming to improve the understanding of biogeochemical cycles and large-scale distribution of trace elements and their isotopes in the marine environment. The laboratory complexes are being expanded to take up such tasks.

Significant Publications

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