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Institutional Report

ESSO–National Centre for Antarctic and Ocean Research

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Introduction

The National Centre for Antarctic and Ocean Research (NCAOR) under the Earth System Science Organization (ESSO) of the Ministry of Earth Sciences is the nodal agency to coordinate country's entire activities in the polar regions and oceans as well as to carry out independent research activities in specialised areas. The major mandates of NCAOR include: (a) Overall planning, co-ordination and implementation of the scientific programmes mounted in Antarctica, Arctic, Southern Ocean and the Himalayas; (b) Implementation of the ocean surveys and mineral resources programs of the MoES such as geoscientific surveys of India's EEZ, Indian Continental Shelf Program, technical management of oceanographic vessels as well as exploration for hydrothermal mineralization in the Indian Ocean Ridge areas.

The mission objectives of NCAOR are however, not merely restricted to the scientific, technical and logistics management of the Indian Polar programs nor to facilitating of the implementation of the other mandated responsibilities entrusted to it by the Ministry. The Centre has a well-focused scientific mandate of initiating and supporting basic and applied research in a variety of scientific disciplines and themes that are otherwise not being pursued by any institution or laboratory in the country. This scientific mandate recognizes, as its backdrop, the need to understand the relationships of the polar, cryospheric, atmospheric,

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geological and oceanic realms vis-à-vis global processes, the importance of the polar regions for our understanding of the global environment, the need to understand these regions as unique entities, and the opportunities presented by these realms as research platforms.

India's commitment to pursue world class research in polar regions, while preserving its pristine environment, was given a concrete shape with the establishment of the first polar research laboratory at NCAOR, including specialised low temperature and clean room facilities. The Centre has been equipped with some of the state-of-art laboratories for ice core studies, microbiological, molecular and environmental research and related subjects. The centre also houses the National Antarctic Data Center that archives all kinds of polar kinds of data obtained as part of the Indian activities in polar regions. To enable the scientific and research activities in polar regions, the Centre is also managing two wintering research stations in Antarctica (Maitri and Bharati) and another station in Arctic (Himadri). Presently the Centre is also establishing its first high altitude research station in Lahaul-Spiti valley in western Himalaya. The Centre is also managing the ORV Sagar Kanya, India's primary oceanographic research platform.

In addition to the scientific activities, the Centre has brought visibility to Indian polar activities by taking leadership role in several 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), IASC (International Arctic Science Council), Ny-SMAC (Ny Ålesund Science Management Committee), 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 international forums and plays an important role in international global observations. Recently, NCAOR has also become an associate partner in the Svalbard Integrated Arctic Earth Observing System (SIOS) - the Norwegian initiative for integrated studies of the Svalbard archipelago, which forms a part of the roadmap of the European Strategy Forum on Research Infrastructures (ESFRI). India's bid for observer status in the Arctic Council was accepted in May 2013, along with that of five other countries — China, Italy, Japan, South Korea and Singapore at a meeting of the Arctic council in Sweden.

Indian Antarctic Expedition

It has been almost thirty-five years to date from the time the Indian scientists took their first cautious steps on the frozen continent of Antarctica. We have certainly come a long way since then, both in terms of our scientific accomplishments as well as on the logistics front. The growth of NCAOR is commensurate with the growth of scientific and logistic activities in Antarctica. India has now two year round research bases in East Antarctica, namely Maitri and Bharati about 3500 km apart and are catered for annual supplies once a year by chartered Ice Class vessel. With the commissioning of Bharati station in Larsemann Hills in 2012, India's Polar programme has come up to age and is bound to take flights to newer heights. The Antarctic Logistics division at NCAOR handles multi modular responsibility as enabler of scientific research in Antarctica; manages Indian infrastructure in Antarctica; and is responsible for planning of resource including team building & trainings; maintaining public relations, collaborations with national and international agencies and as national representative to the Council of Managers of National Antarctic Programmes.

Bharati Station was commissioned on the 18th of March 2012, and is an intelligent building with a floor area of 2200 sq meters with 12% (270 Sq m) dedicated laboratory space was constructed with rigorous planning of three years and actual construction in 124 days at a cost of INR 450 Crores without any cost escalation and time overrun. Bharati is equipped with modern facilities and provides opportunity for year round scientific research at and around Bharati. The station can support 47 personnel on twin sharing basis in the main building during summer as well as winter with an additional 25 in emergency shelters/summer camps during summers and thus making the total capacity as 72. The station consists of one main building, fuel farm, fuel station, sea water pump house, a summer camp and a number of smaller containerized modules.

The focus areas of Antarctica research include: Atmospheric Sciences, Biological Sciences,

Fig. 1: Newly commissioned Indian Antarctic station "Bharati" in Larsemann Hills

Cryospheric Sciences, Earth Sciences and Environmental Sciences, with an overarching theme of *Climate Change*. Studies on Human Physiology and Medicinal aspects are also made on the scientific and logistic personnel staying at the Indian research stations to understand the physiological characteristics and also the effect of staying away from their respective families and friends in one of the harshest continent. Apart from these main topics, ESSO-NCAOR has continued to encourage young students to participate in the Indian Antarctic Programme under the Student's Participation Scheme. The Indian Scientific Expeditions to Antarctica is a wonderful example of multi-disciplinary work carried out by more than 20 national research organizations and universities.

Indian Arctic Expedition

Climate change is felt first and fastest in the Arctic and the Arctic processes have been referred to as the "drivers" of the tropical climate. Due to this, the systematic study of Arctic is of special importance for tropical countries like India. Major thematic areas of the Indian research activities in the Arctic include: a) Kongsfjorden monitoring; b) Atmospheric studies; c) Glaciological studies.

Kongsfjorden is an Arctic fjord in the North West coast of Spitsbergen in the Svalbard archipelago is an established reference site for Arctic marine studies. The Centre has been continuously monitoring the Kongsfjorden since 2010 and a major milestone in India's scientific endeavours in the Arctic region has been achieved in 2014 when IndARC, the country's first multi-sensor moored observatory was deployed in the Kongsfjorden. IndARC is programmed to collect sea truth data at close temporal scales even during the harsh Arctic winter. Under the rapid and most significant impacts of global warming that Arctic is exhibiting, quantification of changes in precipitation rate and its underlying processes, precipitation characteristics are some of the striking issues that were addressed for better and more accurate prediction of the future climate. In addition, transport of atmospheric aerosols from low latitude regions to the Arctic atmosphere and subsequent deposition in Arctic snow/ glaciers and ice sheets has been a major scientific concern in the recent years. Towards this, NCAOR has setup the Gruvebadet Atmospheric Observatory in Ny-Ålesund for the last few years streaming in data at very high temporal resolution. Indian researchers are also periodically conducting measurements on the accumulation/ablation and mass balance of the Vestre Broggerbreen and Feringbreen glacier during summer and winter seasons. Another aspect of the measurements is the measurement of

Fig. 2: IndARC multi-sensor moored ocean observatory being deployed in the Kongsfjorden, Svalbard, Arctic

glacier velocity and ice thickness thereby computing ice flux.

Southern Ocean Expedition

The Southern Ocean expeditions supported by the Ministry of Earth Sciences have been undertaken by NCAOR as nodal agency since 2004, using multiple research platforms. This multidisciplinary expedition programme was undertaken with a scientific focus on air-sea interaction, hydrodynamics, biological productivity, carbon dynamics, ocean acidification and paleoclimatic variabilities in the Indian Ocean sector of Southern Ocean. Four expeditions have been implemented during 2010-15, with the active participation from several national and international research organizations and universities. The long-tem studies on the identified focal areas shall lead us to understand the influence of the SO ecosystem processes on the regional and global climatic variabilities.

The Southern Ocean programme generated high quality research output and led to NCAOR's memberships in international bodies like GO-SHIP and SOOS.

Himalayan Expedition

As part of the Ministry of Earth Science's initiative in Himalaya, NCAOR has initiated a major initiative in Himalaya since 2013. Unlike the previous studies in Himalaya, the MoES project aims at an integrated mass/energy/hydrological balance studies using various field based and automated facilities over the glaciers, river basin and the valley to better understand the response of glaciers to the ongoing changes and the role of glaciers and snow cover on the hydrological balance of the basin. The focus of the program is to monitor six benchmark glaciers in the Chandra Basin, Western Himalayas. To achieve the ambitious goals, a research station has also been established in Sutri Dhaka valley in western Himalaya. Several Automatic Weather Stations were installed over glaciers and several water level recorders have been established all along the Chandra River. Extensive installation of stakes has been made over the glaciers that would support the glaciological and geodetic mass balance measurements of the glaciers in the basin.

Fig. 3: Establishment of a new research station in Sutri Dhaka, Lahaul-Spiti region, Western Himalaya

Polar Sciences

Atmospheric Science

Observations and General Circulation Models unambiguously show that the climate of the earth is changing. A host of processes on different time scales articulate these changes. These ranges from large scale processes such as atmospheric/oceanic general circulation, watermass formations, sea-ice characteristics, various modes of climate variability (like SAM, ENSO, IOD) to small scale processes like ocean and atmospheric turbulence. The research plans of the Atmospheric Sciences group in NCAOR are focussed on trying to find answers to some of these problems. During the past few years, the studies at NCAOR have contributed to the understanding of:

- Impact of tropical–polar teleconnection on southern high latitude precipitation and sea – ice variability.
- Mechanisms of winter time precipitation in Arctic.
- Turbulence, atmospheric waves in Antarctic atmosphere
- High frequency variability at the southern sub tropical front.
- Sources of fresh water in the Southern Ocean.

In order to facilitate the above research, NCAOR has established several long-term monitoring facilities in Antarctic and Arctic sites. In Ny-Ålesund, Arctic, routine monitoring facilities (like nephelometer, Aethalometer, micro rain radar, Ceilometer, radiometer profiler) for measurements of precipitation, clouds and atmospheric temperature has been established.

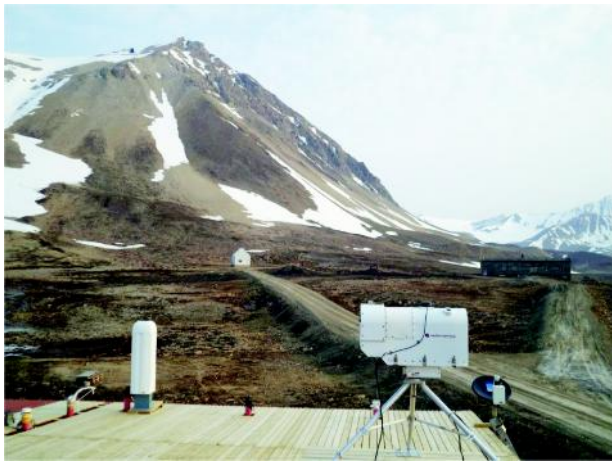

Fig. 4: Gruvebadet Atmospheric Observatory established by NCAOR in Ny-Ålesund, Arctic

In Antarctica, a wind profiler radar operating at 54.5 MHz called Movable Atmospheric Radar for Antarctica (MARA) was installed during 2013-14 near Maitri station in Schirmacher Oasis for monitoring Antarctic boundary layer to mesosphere. The main objectives of the study are: (a) study the subgrid scale processes like turbulence, wave structures, vertical mixing, associated with exchange between stratospheric and tropospheric airmass, (b) troposhperic folds and associated dynamical changes; (c) ice cloud layers in polar summer mesosphere, and (d) monitoring of polar mesospheric summer echoes (PMSE).

Fig. 5: MARA Radar set up in Schirmacher Oasis, Antarctica

Biological Science

Assessment of terrestrial biodiversity is a thrust area of research for understanding the survival strategy in extreme environment and for the prospect of biotechnology in Antarctica. Indian contribution to the study of terrestrial biology in the Antarctica is mainly centred around the Schirmarcher Oasis and Larsemann Hills where the Indian Research Stations 'Maitri' and Bharati are situated.

To understand the distribution and diversity pattern of flora in terrestrial and hydro-terrestrial environments, a systematic sampling of lichens, mosses, algae and fungi were made from ice free areas of the Schirmacher Oasis (SO) and Larsemann Hills (LH). A total of 54 species of lichens were encountered in the SO and 25 species in the region of LH. Most lichens known from these two areas are microlichens. The studies on moss flora contributed 12 species in 8 genera and 5 families from SO and neighboring Nunataks. The sub-fossil moss *Pohlia nutans* was recorded from lake sediment cores at SO. A total of 109 species of cyanobacteria belonging to 30 genera and 9 families were recorded from SO. The cyanobacterial populations showed the presence of 4 dominant genera (*Phormidium, Schizothrix, Nostoc* and *Plectonema*) in the area of SO. Fungi belonging to 5 genera (*Acremonium*, *Aspergillus*, *Cladosporium*, *Fusarium*, *Trichoderma*) were recorded from SO soils, and 5 species of yeasts (*Cryptococcus albidus, C. Antarcticus, Mrakia blollopis Rhodotorula microsporus*, *Thelebolus microspores*) from LH. Furthermore, *Thelebolus microsporus* was characterized for adaptation strategies and biotechnological potentials. Investigations on micronutrient status of SO soils have also been carried out, and large variations were observed among different soils in their nutrient composition and concentration.

Cryospheric Science

Cryosphere is a vital part of the Earth system with important linkages and feedbacks generated through its influence on surface energy and moisture fluxes, clouds, precipitation, hydrology, atmospheric and oceanic circulation. Since a better understanding of the various cryospheric systems (Antarctic, Arctic and Himalayas) is crucial for an Earth System perspective, the Ministry of Earth Sciences has also initiated the project "Cryosphere and Climate" since 2013. The project is an integrated and trans-hemispheric effort to understand the role and response

of the global cryosphere.

Major areas of Antarctic cryospheric research include: (i) Ice core based climate studies; (ii) Sea ice variability studies; (iii) Cryobiology and biogeochemistry; and (iv) Dynamics of the ice shelves and its responses/role to climatic and sea level processes.

As part of the first Indian Scientific Expedition to South Pole during (2010-11), 20 snow cores were collected along the Maitri to South Pole transect. During the 33rd Indian Scientific Expedition to Antarctica (2013-14), an ice core of 101.4 m length was retrieved from the central Dronning Maud Land region at an elevation of 1506 m. Ice core proxy based reconstruction by the Centre revealed significant changes in Southern Hemispheric climate during the past several hundreds of years. To understand the fundamental air-snow transfer processes in Antarctic ice sheet and to improve the utility of the ice cores as reliable climate archives, Indian researchers have conducted sustained field measurements and spatially distributed snow sampling along strategically placed transects. The diverse cryospheric studies being carried out by the Centre in Antarctica thus contribute significantly to the global community's ongoing efforts to better understand the functioning of cryospheric systems and how they might respond to future changes as a result of climate change.

The cryospheric studies by Indian scientists in Arctic have been initiated recently and are mainly focussed on the glaciological monitoring in the Ny-Ålesund region in Svalbard. To understand the dynamics and mass budget of Arctic glaciers in the context of climate change, mass budget, snout and dynamics of two representative glaciers (Vestre Broggerbreen and Feiringbreen) from Svalbard region are being continuously monitored and studied.

As part of NCAOR's initiative in Himalaya, field studies of six benchmark glaciers have been taken up since 2013 in the Chandra Basin, Western Himalayas. Recent studies in the Chandra basin of Lahaul-Spiti valley in Western Himalaya have shown some interesting characteristics on the response of debris covered and clean-ice (debris free) glacier to the ablation processes. Specific mass balance measurements at Batal and Sutri Dhaka glaciers revealed that the vertical gradient of ablation rate in ablation area is contrastingly opposite in these two glaciers, reflecting significant control of debris thickness and their distribution over glacier surface on the ablation rates.

During the period, NCAOR has also established a metal-free clean laboratory - named ISOTRACE Laboratory – with major analytical facilities and necessary paraphernalia for conducting trace metal and isotope studies in completely metal-free conditions. ISOTRACE Lab is one of its kinds in the whole country and would help us to make reliable estimate of trace metals in the global ocean, without the worry of contaminants.

Fig. 6: Establishment of ice core drilling camp by the NCAOR team in 2013-14 at Antarctica

Fig. 7: Establishment of Automatic Weather Station over Sutri Dhaka glacier, Lahaul-Spiti region, Western Himalaya

Environmental Monitoring Studies

India has signed Antarctica Treaty in year 1983 and thereafter in year 1998, Protocol on Environmental Protection to Antarctica Treaty, which is also known as "Madrid Protocol", has been ratified. Environmental monitoring is integral part of Environmental Impact Assessment (EIA). According to the Protocol on Environmental Protection (article 8 and annex I), Environmental Impact Assessment (EIA) procedure has been developed for activities undertaken in the Antarctic. NCAOR being the nodal agency that carries out Indian Antarctic Expeditions are also responsible and mandated to undertake detailed and continuous EIA studies in areas where Indian scientific activities are being undertaken.

Scientific and Logistic activities may have the potential to generate pollution and may degrade the pristine environment of Antarctica. Use of fossil fuel in Antarctica is required for logistics services and survival as modern material are also required to sustain in adverse climatic condition; however use of fuel and material, generates emission and waste. Realizing the importance of environmental monitoring a long-term programme has been developed, referring various guidelines of SCAR, COMANP, CEP and ATCM. Relevant indicators were also selected which can demonstrate the change in environment due to anthropogenic impact and possible demarcation can be done with natural and manmade emission. Since environmental monitoring is multi-disciplinary study, other national institutions have also been collaborated. Aerosol study inclusive of black carbon, SPM, PM_{10}, $PM_{2.5}$, SO_2 and NOx measurement at Maitri as well as Bharati station have been carried out every year. Few parameters have also been monitored on continuous mode for all through the year. In order to understand the long-range transportation of mercury, observations of Total Gaseous Mercury (TGM) in air and total mercury analysis in lake water also been initiated. Both the stations are surrounded by numerous fresh water lakes and the spatial and temporal water analysis of many lakes carried out to assess the change in water characteristics. Study of other contaminants and their pathway are also under progress.

Antarctic areas, which possess, geological, biological and environmental values and represent some unique characteristics have been designated as

Fig. 8: Environmental monitoring installation in Maitri station, East Antarctica

Fig. 9: Advance Water water Treatment System Installed at Maitri Station, Antarctica

Antarctica Specially Protected Area (ASPA) and area which are being managed with certain objectives are knows as Antarctica Specially Managed Area (ASMA). Indian is managing ASPA-163 (Dakshin Gangotri) and party to ASPA-174 (Stornes, Larsemann Hills) and ASMA-6 (Larsemann Hills). While environmental monitoring is essential for decision makers, it also required to implement the measures to mitigate adverse impacts. Following the recommendations in environmental management plan a comprehensive plan has been prepared to improve the environmental quality of Maitri station and implements during year 2014-2016.

Polar Remote Sensing Studies

Polar remote sensing studies focus on monitoring, mapping and elucidating bipolar sea ice variability, ice sheet topography changes using digital elevation models (DEM) and application of satellite remote sensing techniques in the polar glaciology. Some of

the major milestones during the period have been achieved in the follows areas of research:

DEM Products with Improved Accuracy for Larsemann Hills and Schirmacher Oasis

The study designed a first generation accurate digital elevation models (DEMs) for Larsemann Hills and Schirmacher Oasis, East Antarctica, using interferometric and photogrammetric techniques. Synthesized a precise DEMs by synergistic use of multitemporal Radar Antarctic Mapping Project (RAMP), Cartosat-1 (Indian satellite) Geoscience Laser Altimeter System (*GLAS*) instrument aboard Ice, Cloud, and land Elevation (*ICESat*) satellite and ground reference data (Differential GPS).

Development of New Applications of DEM in Cryospheric Land-cover Classification

Utilized of RISAT-1 C-band imagery for geospatial mapping of cryospheric surface features in the Antarctic environment. Further, geospatial mapping of vegetation in the Antarctic environment was undertaken using very high resolution (0.5 m PAN and 2 m multispectral) data. Developed new geospatial methods for geo-information extraction in the cryospheric environment.

Bathymetry Extraction of Antarctic Lakes Using DEM and Multispectral Satellite Data

Mapped shoreline of more than 100 lakes on Larsemann hills and 10 lakes on Schirmacher oasis with an accuracy of 1meter, as a reference data for validation of algorithms for semi-automatic extraction of lake features using satellite data. Developed new geospatial methods for geo-information extraction in the cryospheric environment, *viz.* spectral index ratio method, ensemble classification method, and customized normalized difference water index (cNDWI) methods for lake feature extraction.

Monitoring Antarctic Sea Ice

Using a 34-year long record of satellite passive-microwave measurements during 1979-2013, sea ice extent analysis is carried out for five Antarctic sectors consisting of the Weddell Sea, Indian Ocean, western Pacific Ocean, Ross Sea, and Bellingshausen and Amundsen Seas. While all the sectors show positive trends, the Weddell Sea sector exhibits a highest negative trend.

Palaeoclimatology* and *Palaeoceanography

As part of NCAOR's efforts to understand the past climatic conditions and their relevance to the future, several types of natural archives and a variety of organic and inorganic proxy records were explored. For the first time, during the 33rd Indian Scientific Expedition to Antarctica (2013-2014), around 17 high quality sediment cores were collected from seven lakes in Larsemann Hills using a state-of-the-art piston coring device (UWITEC Instruments). Multi-proxy work on the sediment cores is being carried out with an aim to reconstruct high-resolution past climatic variations in Larsemann Hills during the Holocene.

Studies from the Southern Ocean and coastal revealed the utility of biological proxy indicators in reconstruction of oceanographic and nutrient conditions. New species of planktic species have been identified that have significant implications for the past climatic reconstruction. Stable isotopic studies carried out on planktic foraminiferal samples of plankton net and core top sediments collected during the first Indian expedition to the Southern Ocean finds that the productivity increases polewards possibly due to the influx of nutrients via melting ice

High resolution records of multi-proxy parameters from two well-dated sediment cores Southern Ocean revealed inverse relationships between the calcite and opal productivity, indicating the inûuence of shifting nutrient regimes. The enhanced opal productivity during the glacial periods

Fig. 10: Antarctic lake sediment coring in Larsemann Hills during 2013-14 using the UWITEC piston corer

north of the Polar Front is attributed to the northward shifting of oceanic fronts and associated transfer of nutrients. Studies also revealed that the dust-derived Fe input had apparently inûuenced the palaeoproductivity north of the modern Polar Front, but had a minor inûuence on opal productivity south of it. A diatom based paleoclimatic study suggests a glacial shift in the Antarctic winter sea-ice limit and Polar Front respectively up to the modern day Polar Frontal Zone of Indian sector of Southern Ocean.

The phytoplankton abundance and community structure in the Indian sector of Southern Ocean appears to be controlled by physical parameters, nutrient concentrations and also by the micro-heterotrophs (ciliates and dinoflagellates), which exert a strong grazing pressure. From Southern Indian Ocean, five *Emiliania huxleyi* morphotypes were recognized for the first time. Each *E. huxleyi* morphotype observed to show preference to specific environmental settings. Studies based on the stable isotopic composition of planktic foraminiferal samples of plankton net and core top sediments collected during the first Indian expedition to the Southern Ocean provided vital insight into the foraminiferal preservation characteristics in the Indian sector of the Southern Ocean. Foraminifera from sediment samples faithfully record the frontal structures, as revealed by the inter-comparison of the plankton net and sediment samples; hence the past fluctuations in the extent of various fronts can be reconstructed using down-core foraminiferal isotopic content in this region.

Based on the environmental magnetic properties of sediments deposited in Sandy Lake in the Schirmacher Oasis, Antarctica, glacial-interglacial climatic variation was reconstructed for the past 42.5 cal. ka B.P. This was the first report of a detailed environmental magnetic record of glacial–interglacial climatic variations from the Schirmacher Oasis. Organic geochemical and sedimentological data from sediments deposited in Long Lake (L-27), Schirmacher Oasis, provided a history of glacial-interglacial climatic variations during the last 48,000 cal. years B.P. The results showed that Long Lake's response to Antarctic climate is reflected in its response to the ice-cover conditions which regulates the productivity and sedimentation in the lake system.

Several studies were also undertaken to carry out centennial-scale reconstruction of sea surface temperature (SST) from the eastern Arabian Sea related to the Indian summer monsoon precipitation since mid-Holocene. The study found that long-term trend of the Indian summer monsoon precipitation shows a decline similar to the solar activity indicating a strong correlation between them. On a shorter timescale, precipitation reduced during periods of recent solar minima. A multi-Proxy study on a core from the western Arabian Sea does not support a steadily decreasing productivity during the Holocene implying that productivity is not in phase with insolation.

Southern Ocean Studies

The Southern Ocean (SO) is the source and sink for several intermediate and deep water masses of the world oceans. Despite its importance for global climate change, adequate information and understanding of the processes controlling the rate of formation of water masses and its response to climate change are lacking primarily due to lack of high resolution sea truth observation. Moreover, studies in the Indian sector of SO are limited and more systematic scientific investigations should be conducted for a comprehensive understanding regarding the physical and biogeochemical changes occurring in this region. Therefore, large-scale, detailed, multiship, synoptic sea truth observations of this area deserve highest priority in any program of observational studies of the Indian Ocean sector of Southern Ocean/Antarctic Ocean. Further the SO circulation is linked with the Indian Ocean circulation through Agulhas current, Antarctic Circumploar Current, West Australian current and South Equatorial current systems. Hence the exchange of heat and mass through these currents shall affect the variabilities of the Indian monsoon.

Main focus of the NCAOR study is to understand the role and responsibility of Southern Ocean on regional and global climatic variabilities. Some of the salient achievements of the Southern Ocean studies during 2010-15 are:

- The zones of sink (52°S) and ventilation (45°S) of CO_2 have been identified
- The fast degree of warming and freshening of the AABW could be due to southward meandering of ACC as well as the glacier melting

Fig. 11: Physical oceanographic measurements in Indian sector of the Southern Ocean

Fig. 12: Operation of Multiple Plankton Net in Southern Ocean

- Southward movement of subtropical water due to eddies influencing the plankton community structure in the SO.
- The range of atmospheric forcing (4.8-6.2 W/ m2) indicates that the anthropogenic component to extinct the solar radiation is more or less same from tropics to polar regions.
- Enhanced productivity due to upward movement of bottom water masses in the SWIndian ridge region
- Phytoplankton blooms in the coastal and open ocean due to influence of melt water during the positive phase of SAM

In addition to the regular research vessel based oceanographic campaigns, regular monitoring of the Southern Ocean has been undertaken by taking advantage of cargo vessels chartered for the Indian Scientific Expedition to Antarctica. In addition to meteorological data, expendable CTD probes were deployed from the cruising ship at half degree intervals between Cape Town and Prydz bay, Prydz bay and India bay, and India bay to Cape Town during austral summer (December- March) every year to record density structure of the upper 1 km of the ocean layer. The objectives are to use the surface data for validation of numerical weather forecasts and other satellite data products. Hydrographic data are used to study meandering of the hydrological fronts, changes in the upper ocean heat and salt content, characterization of water masses and their role in mixing and genesis of water masses. Significant results showed that nearly 50% of the Antarctic Circumpolar Current transport is confined to the 100-500 m layer. Studies also revealed that the heat and salt content along Cape Town-India Bay in the recent decade (after 2000) have increased by about 7% and 8%, respectively, compared to that in 90's.

Geosciences

Scientific Drilling in the Arabian Sea: IODP Expedition 355

India, through Ministry of Earth Sciences (IODP-India), had submitted a complementary project proposal for scientific drilling in the Arabian Sea to decipher links between Himalayan and Tibetan Orogeny and Asian Monsoon over long period. NCAOR had been in the forefront of this entire proposal and processes. After the peer review process, scientific drilling in the Laxmi Basin, Eastern Arabian Sea was carried out during March-May 31, 2015. Drilling and coring was accomplished (IODP Expedition 355 "Arabian Sea Monsoon") at two Sites in the Laxmi Basin using drilling platform *JOIDES Resolution* where 30 international shipboard scientists including 11 Indian scientists took part to collect more than 1700m long sediment and basement cores from Sites U1456 and U1457. During this expedition, for the first time cores from the igneous basement were retrieved which would eventually enable scientists to unravel nature of the crust in the Laxmi Basin. Determining crustal affinity of Laxmi Basin has

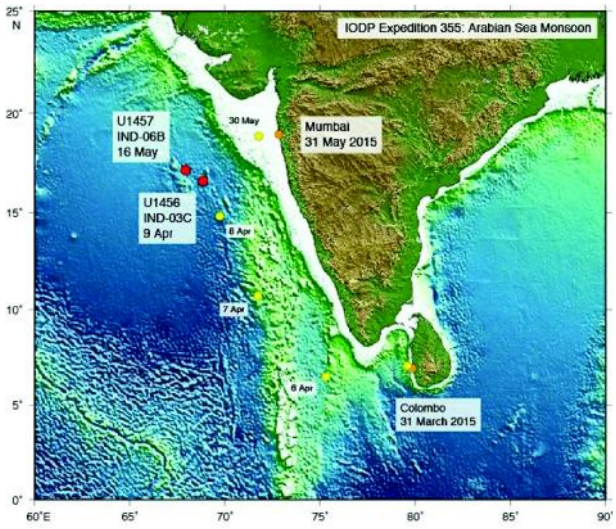

Fig. 13: Map showing the IODP drilling sites in Arabian Sea

Fig. 14: Excitement on board JOIDES RESOLUTION after the recovery of igneous basement rock during IODP 355 expedition

significant implications for paleogeographic reconstructions of Arabian Sea. The Expedition was led by co-chiefs from India and USA.

The primary scientific objectives this expedition envisages are to:

- Test whether Greater Himalayan exhumation is correlated with proposed monsoon intensification after 23 Ma;
- Determine if the monsoon strengthened or weakened at 8 Ma;
- Constrain the timing of the Himalayas and Tibetan plateau uplift by dating the initiation of fan sedimentation; and
- Decipher the nature of the basement in the Laxmi Basin (eastern Arabian Sea) to constrain the early rifting process and its relation to the emplacement of the Deccan Flood Basalts along the western continental margin of India.

The expedition 355 drilled two sites in the Laxmi Basin of the Eastern Arabian Sea. Site U1456, lies within the Laxmi Basin and was cored until the Miocene. However, Site U1457 penetrated to the igneous basement in the transition zone between the Laxmi Basin and the Laxmi Ridge. In total ~1700m of sediment and sedimentary rock, as well as 16m of igneous basement was drilled. The preliminary scientific report from this expedition is already published on the IODP expedition page http://dx.doi.org/10.14379/ iodp.pr.355.2015

Exploration of Seafloor Hydrothermal Deposits in Indian Ocean

Sea-floor massive sulphides are deposits of metal-bearing minerals that form on and below the seabed as a consequence of the interaction of seawater with a heat source (magma) in the sub-sea-floor region. The discovery of such systems in the deep oceanic realm along the mid-ocean ridges has kindled a lot of interest primarily on account of the high concentration of base metals (Cu, Pb, Zn) and many noble metals (Au, Ag, Pd, Pt) in them. Apart from their economic potential, active hydrothermal vent fields are also significant because of the presence of diverse types of living organisms around the vent sites and its biological evolution in anoxic environment which provide us the first evidence of the evolution of life on the Earth.

Discoveries of fossil and active hydrothermal system along Central Indian Ridge (CIR) and South West Indian Ridge (SWIR) as well as evidence of hydrothermal plume and mineralization signatures in this region suggest the possibility of many polymetallic sulphide mineralization zones in the region. This prompted India's aspirations to undertake a comprehensive research and exploratory programme, aims in identification of new locals of hydrothermal

activity, and also to address the complex physical-chemical-biological-geological scenario of the hydrothermal systems and thus entailing the genesis, environment and distribution of hydrothermal plumes and mineralization in the region. NCAOR is in the forefront of research and development activities related this exploration activity.

As a first step towards achieving the aforesaid goals, systematic geophysical surveys including multibeam eco-sounder (MBES) bathymetric mapping, magnetic, gravity, SBP surveys and CTD operations in few selected areas in the proposed region were carried out in three phases during 2014-15 in the proposed exploration area in CIR and SWIR. Sampling was carried out along the selected locations using rock-dredging, grabs and gravity corers and recovered altered rocks, mafic-ultramafics rocks comprising of basalts, gabbros, Fe-Mn crusts, metalliferous sediments and sulphides. Preliminary petrographic, mineralogical and geochemical studies were carried out on selected rock samples, sediments and Fe-Mn crusts representing all the clusters in order to characterize them and to understand the nature and degree of alteration and to identify the signatures of sulphide mineralization prevailing in the area. Initial petrographic studies indicates hydrothermal alteration of olivine and pyroxene to serpentine and secondary infilling of opaque minerals (usually Cr-spinel and magnetite) along the fractures plane, veins lines and within the minerals and can be considered as a good signature of hydrothermal activities in the region.

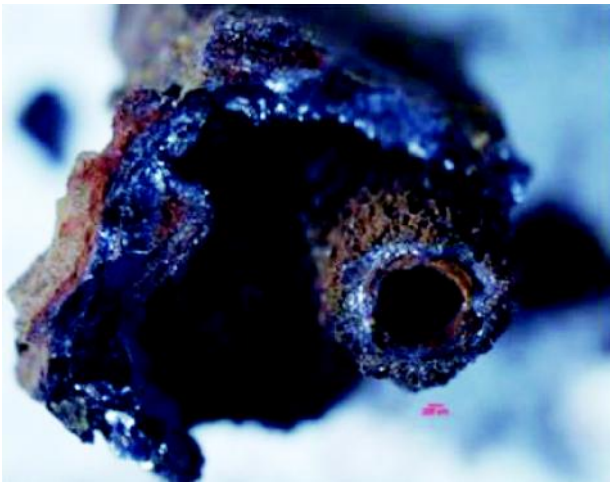

Fig. 15: Recovery of igneous basement rock during IODP 355 expedition

The promising outcome of the preliminary analysis and interpretation of the data which resulted in identification of many locals of hydrothermal activity in the region, paved way for submission of India's application to the International Seabed Authority (ISA) in May 2013 for grant of license for initiating exploration activities near the active and fossil hydrothermal vents fields in part of CIR and SWIR. Twentieth Annual session of ISA held in July 2014 also granted an approval for the plan of work submitted by India and now India will enter into an agreement with ISA for undertaking the 15 years of exploration work in the region.

Geoscientific Studies of the Exclusive Economic Zone

The United Nations Convention on the Law of the Sea (UNCLOS), sets out a comprehensive regime for the governance of the oceans, and introduced the concept of Exclusive Economic Zone (EEZ) that 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 living and non-living resources in an area extending upto 200 nautical miles from its shore. Realizing the need to be cognizant about India's EEZ (about 2.2 million km^2 area along 7,500km long coastline) for the optimum utilization of the marine resources and better understanding of the scientific issues related to the Indian Peninsula, a major scientific endeavour for mapping the entire Indian EEZ by utilizing state-of-the-art technologies of swath bathymetric multibeam echosounder is being implemented by NCAOR, under the aegis of Ministry of Earth Sciences.

NCAOR is entrusted as the nodal agency with the participating organisations and undertaking surveys in deep water (DW) regions (>500m). ESSO-NIOT and CSIR-NIO are entrusted for surveys in shallow water (SW) regions (<500m) for the East coast (EC) including Andaman & Nicobar Islands and West coast (WC) regions, respectively. The Marine & Coastal Survey Division (MCSD) of Geological Survey of India (GSI), under MoU, shall also undertake surveys in specific SW as well as DW regions.

A multitude of analysis is being undertaken with the geophysical datasets for research purposes, including identification of various geomorphological

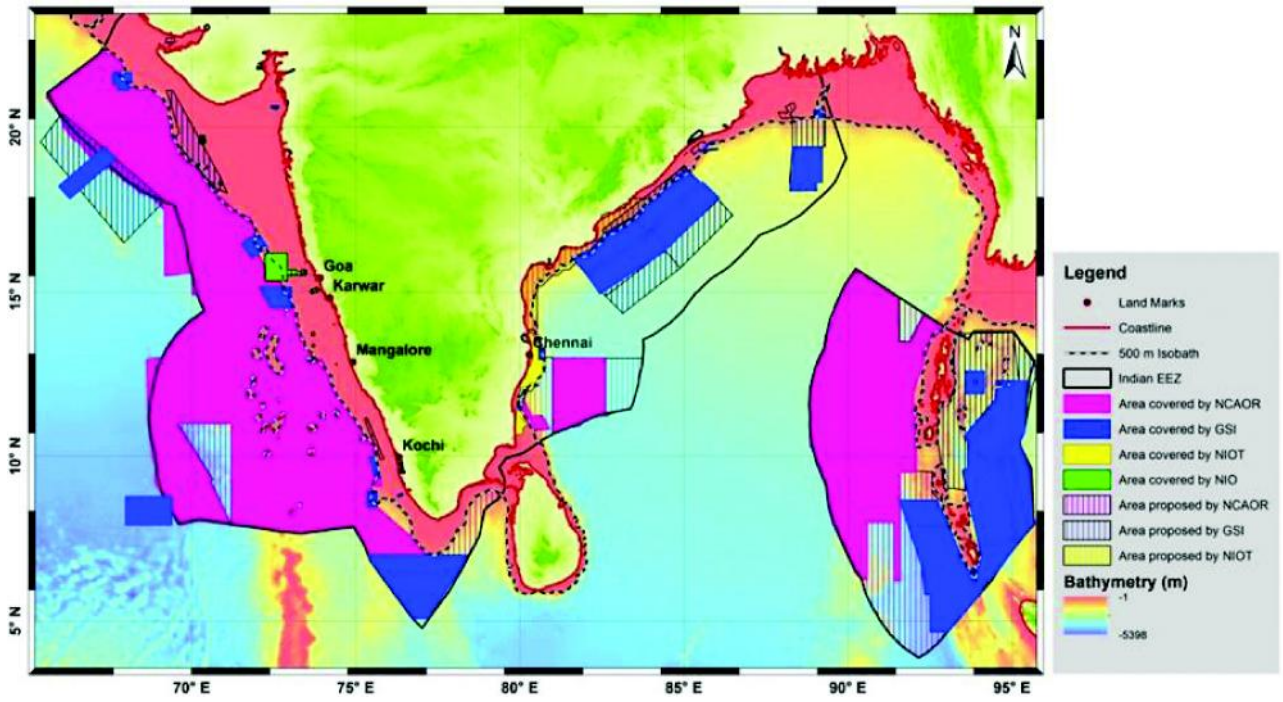

Fig. 16: Map showing the areas of coverage and priority area for EEZ surveys by NCAOR and other institutions

features such as Channel levee, submarine landslides, seamounts, guyots, knoll etc. Geomorphological analysis of these features is being undertaken to understand their emplacement and origin. The newly identified features were identified based on publication No. B-6 of International Hydrographic Organisation (IHO). The geological samples obtained have been subjected to geochemical and sedimentological analysis for insight on provenance, spatial distribution of various elements and the paleoclimatic regime of the region. All the digital datasets acquired under the programme shall be archived at the 'Marine Geoscientifc Database' under development at ESSO-NCAOR.

Legal Continental Shelf Program of India

The Indian Continental Shelf Project commenced during November 1999, as a multi-institutional national endeavour that aims to gather, analyse and document the requisite scientific and technical information that would help define the country's extended shelf boundaries beyond 200 M as per the provisions of the United Nations Convention on the Law of the Sea (UNCLOS). The Indian endeavours towards this ultimate goal are being spearheaded by NCAOR under Ministry of Earth Sciences. In this regard, NCAOR has undertaken comprehensive marine geophysical surveys and data analyses that comprise of state-of-the-art multi-channel seismic reflection, refraction, gravity and magnetic data profiling. As the nodal agency, NCAOR, has been systematically involved in data acquisition and preparation of formal documentation with respect to the implementation ofthe LCS Program of India. Based on the analyses and interpretation of marine geophysical data acquired by NCAOR, India has submitted its first partial submission to the Commission on the Limits of the Continental Shelf (CLCS). Since then, NCAOR has been constantly working on gathering more knowledge and technical data to support Indian continental shelf endeavour.

Exploration of the Indian Ocean Geoid Low

Many theories have been postulated for the origin of global geoid undulations. These geoid lows/highs have also been associated with various mechanisms like roll back after early Mesozoic subduction, Mantle upwelling above grave slab-yard, undulations in Core-Mantle boundary and its interaction with mantle dynamics, Moho depth variation, density void and heterogeneity in lower mantle, etc. Temporal variation of geoid may also be related to variation of water

volume due to melting of solid water bodies in the globe. Still the precise reasons behind such anomalous feature are largely unknown. Even the role of crustal deformations on geoid undulation is yet to be systematically studied. To find out a conclusive point in understanding such unusual structures and mechanisms responsible for the largest feature (IOGL), the different layers of the earth are being studied in a segregative approach from uppermost layer to deeper layers of Earth's Mantle. As a pilot study NCAOR has recently deployed Ocean Bottom Seismometers besides collecting deep penetrating multi-channel seismic data in the IOGL region to characterise upper crustal variations. Analyses of deep seismic data will help us determine the images of entire crust in the region which will form the basis for further investigations.

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