This project has received funding from the European Union via the Seventh Framework Programme under GA no. 295092

PROJECT FINAL REPORT

Grant Agreement number: 295092

Project acronym: INDO-MARECLIM

Project title: **INDO-EUROPEAN RESEARCH FACILITIES FOR STUDIES ON MARINE ECOSYSTEM AND CLIMATE IN INDIA**

Funding Scheme: Coordination and support action

Period covered: 1st February 2012 to 31st July 2015

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1. Executive summary

INDO-European Research Facilities for Studies on MARine Ecosystem and CLIMate in India (INDO-MARECLIM) was the first India-EU joint research initiative under the 7th Framework programme of EU to be co-ordinated by the Indian partner. The overall objective of INDO-MARECLIM was to use and extend the research infrastructure at Nansen Environmental Research Centre India (NERCI) in order to strengthen scientific cooperation within climate and marine scientific cooperation between sceintists and students from India and Europe. Thematically the research topics focused on studies of the impact of monsoons and climate change on the marine ecosystems of the northern Indian Ocean, with emphasis on the coastal zone. The project was designed to exploit and expand the bilateral Indo-Norwegian cooperation built up since 1998 at the Nansen Environmental Research Centre India (NERCI) in Cochin, Kerala and capitalizing from collaboration with other Indian research organizations and agencies, including Indian National Centre for Ocean Information Services (INCOIS), Anna University, Cochin University of Science and Technology (CUSAT), Kerala University of Fisheries and Ocean Studies (KUFOS), and TocH Institute of Science and Technology (TIST). The European partners included leading research institutions from Norway, the Nansen Environmental and Remote Sensing Center (NERSC), IFREMER in France, Plymouth Marine Laboratory (PML) in UK, Euro-Mediterranean Center on Climate Change (CMCC) in Italy, and ALTERRA in the Netherlands.

With a mandate to study the effect of climate change on marine ecosystems of the coastal waters of Kerala (including the wider oceanographic context), and the socio-economic impacts thereof, the project had several major goals: **Enabling goals** developed the basic infrastructure essential for the project. They included enhancement of research infrastructure and of e-infrastructure. **Training goals** developed the capacity of the human infrastructure, through workshops and training courses on selected research topics. **Networking goals**, achieved by bilateral exchange of scientific personnel, helped raise awareness among both Europeans and Indians scientist and students of the possibilities and challenges of cooperation. **Research goals** were established to address outstanding issues related to monsoon and climate change. These included monsoon variability, marine ecosystem and variation in primary production, and effect of rising sea level on the socio-economical condition of artisanal fishermen of the Kerala coast. **Continuity goals** dealt with facilitating the sustainability of the work under INDO-MARECLIM by writing competitive research proposals for future support and cooperation. In order to sustain the cooperation the network of associated partners associated with NERCI was expanded.

Generally, positive outcomes have been achieved under all of these scientific and managerial goals. The infrastructure at NERCI has been strongly enhanced during the lifetime of the project, improving the platform for scientific cooperation. Two training courses and three scientific workshops were held in India, on primary production, coastal zone management and monsoons. On the Indian side, individuals from outside the partner group were also able to profit from the courses offered, helping to extend the networking benefit. Under networking, sixteen Indians made working visits to European research centres, and sixty-six Europeans to India, either for the workshops or scientific exchange visits. Memoranda of Understanding or Agreements of associated partnership were signed between NERCI and all European partners to facilitate future long-term scientific cooperation including development of joint projects. The research goals have given rise to fourteen peer review scientific publications and another twelve publications are underway to be published after the completion of the project. 15 scientific proposals have been submitted both to bilateral, EC and international calls for funding. The current agreement under Horizon2020 that Indian partners will be funded from Indian agencies for joint Indo-EU projects, has limited the possibilities for joint projects announced by the European Commission. The legacy of INDO-MARECLIM includes a strong research infrastructure at NERCI, a pool of trained young and established scientists at NERCI and in India able to continue the research, an increased awareness among European scientists of the potential of India as a research focus and capacity, and the contributions from the project to increased knowledge and to the scientific literature. Noteworthy examples of the benefits of an Indo-European cooperative initiative include the Working Group on Primary Production, developed from a workshop on primary production held under INDO-MARECLIM, with the aim of designing and implementing a system to monitor primary production in the northern Indian Ocean; establishment of an Agreement of Associated partnership with Nansen Scientific Society, Norway leading to implementation of Nansen Fellowship to two young PhD fellows at CUSAT; the successful project Study of Harmful Algal Blooms and other Aspects of Sardine Habitats around the Indian sub-continent (SHABASHI), managed by NERCI, supported by the Partnership for Observation of the Global Oceans (POGO) and the Nippon Foundation, in which Indian and Sri Lankan scientists study ecosystem variability, harmful algal blooms and implication for fisheries; recognition of NERCI scientists as approved research supervisors at KUFOS. In this respect INDO-MARECLIM has contributed to capacity building among and beyond the project partnership. Another development relevant to the legacy of the project is that one of the European partners, Prof. Dr. Trevor Platt, has been awarded a prestigious Jawaharlal Nehru Science Fellowship by the Government of India to work in Kochi during four months in each of three consecutive years. The networking, research and training of young scientists initiated under INDO-MARECLIM will be sustained and developed further under the Nehru Fellowship, POGO project and Nansen Fellowship.

2. Summary description of project context and objectives

2.1 GENERAL CONTEXT

The overriding context for the work carried out under INDO-MARECLIM was a marine system, encompassing the Indian sub-continent, on which a large population relies for its livelihood, which will be impacted to an unknown degree by the effects of climate change, and in which there are competing interests to reconcile, such as those of fishing and tourism. How could ecosystem-based management be applied to such a system, for which the existing knowledge base was scattered and unorganised, the research capacity under-developed and the communal interests jealously protected? The challenges are many fold – like changes in the monsoon, sea level rise, coastal erosion, changes in primary productivity and biodiversity. Indian scenario is very complex, with some states like Kerala having literacy and life expectancy comparable with those in developed countries although the gross domestic product is very much lower (Amartya Sen, 2005); and some maritime states having well advanced oceanographic education and research facilities, which are at par with world's leading institutes. Despite these advancements, aspects of its economy and of the related social fabric, are vulnerable to the impacts of climate change now underway. INDO-MARECLIM contributed to build strategic R&D partnerships between institutions in Europe and India, wherein the infrastructure of NERCI provided a platform for EU partners to share, learn and gain knowledge on the potential negative impacts of climate change on marine ecosystem, particularly fisheries and its repercussions on the socio-economic scenario. Research on Indian marine ecosystem was expected to bring together leading marine institutions in India and EU through a network developed by the Indian co-ordinator NERCI.

2.1.1 Background

The "INDO-European Research Facilities for Studies on MARine Ecosystem and CLIMate in India (Indo-MARECLIM)" project was submitted with the intention to capitalize and exploit the bilateral Indo-Norwegian cooperation built up since 1998 at the Nansen Environmental Research Centre – India (NERCI) in Cochin, Kerala with additional support from other collaborators in India, including Indian National Centre for Ocean Information Services (INCOIS), Anna University, Cochin University of Science and Technology (CUSAT), Kerala University of Fisheries and Ocean Studies (KUFOS), and TocH Institute of Science and Technology (TIST). It was designed to facilitate and improve cooperation by European Union Member States and Associated Countries with India in the research areas of marine ecosystems and climate, including the impact on the society. A major goal of INDO-MARECLIM was to address some of the challenges of the Indian Ocean and the Indian sub-continent (such as monsoon variability, sea level rise, coastal erosion, changes in primary production, fisheries and biodiversity) under past, current and future global change. A related goal was to facilitate building strategic R&D partnerships between institutions in Europe and India. The infrastructure and expertise at NERCI would provide a platform for interaction with European partners, initially from the UK, France, Italy, the Netherlands and Norway and expanding the European partnership of NERCI (see Fig. 1).

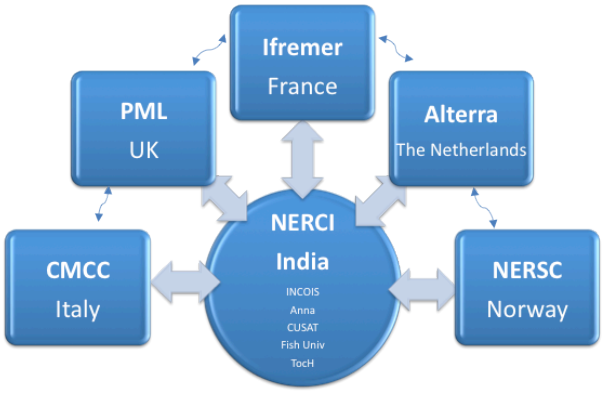

Fig. 1: The initial INDO-MARECLIM Indo-European networks of cooperation.

2.2 SPECIFIC CONTEXTS

At the outset, a number of specific issues were identified as requiring particular emphasis. First and foremost among these was the variability of the monsoon system, on which the terrestrial and marine ecosystems of India are so strongly dependent. The monsoon is a variable phenomenon between years, principally as a response to inter-annual modulation in physical forcing. It was considered vitally important to assess what further modifications might be expected as a consequence of global warming and climate change. A related issue was that of sea-level rise. With a low-lying coastal fringe, state of Kerala where the co-ordinating institution is located, is especially vulnerable to the effects of rising sea level. The artisanal fishing economy is at risk, and also the embryonic tourism industry. Hand in hand with sea-level rise, we can expect increased coastal erosion, antagonistic to both artisanal fisheries in the coastal fringe and to development of tourism. Recognition of the high significance of both monsoon variability and sea-level rise led to the requirement for research in physical oceanography as a priority in INDO-MARECLIM.

A second priority to be identified was the effects of climate change on the marine ecosystem. Here, the principal focus was on primary production, on which the entire ecosystem depends. Advantage was to be taken of the rapidly-developing use of visible spectral radiometry (ocean colour) and remote sensing to study regional, seasonal and inter-annual variations in primary production as a starting point for ecosystem analysis, in particular the effects on biodiversity, especially fisheries.

These programmes in physical oceanography and in marine ecosystem analysis were to be conducted always with an eye on the potential social relevance and impacts of the results. The focus of the coastal zone related research was to assess the impact of monsoon and climate variability on coastal livelihood. The impact of coastal upwelling on the fishery resources and sustainability of stock in the coastal sector in selected fishermen villages and landing centres was investigated by reviewing census data and analysing different interviews and questionnaires. In addition the impact of seasonal variability on the economic status of fisher folk was studied.

2.2.1 General objectives

Against the context presented above, INDO-MARECLIM had several objectives. They may be classified under various headings:

Enabling Objectives. Here, the emphasis was on strengthening and consolidating the research infrastructure at NERCI, for example in the establishment of a facility for marine optics in support of the estimation of primary production. In parallel, another target was to develop the computing facility at NERCI to enable more sophisticated numerical modelling for physical oceanography and ecosystem analysis. Access to historical data for the region was also seen as a priority, leading to the objective of digitizing historical data from archival paper documents.

Building Objectives. In this section are included activities designed to build capacity for future research. First and foremost are included networking activities to facilitate joint execution of projects by Indian and European partners. This was to be achieved by three thematic workshops on the research areas of interest and by exchange visits of key personnel. Another major activity was the provision of two training courses and one winter school. Overall, 642 scientists and students participated in the INDO-MARECLIM network events.

Engagement with the Community. Since the social impact of climate change (sea level, fish stock) was a major concern of INDO-MARECLIM, it was considered of prime importance to engage the relevant community (the artisanal fishing community) first hand. Talking to the affected people in a systematic manner and analyzing their input was therefore the other major objective.

Continuity objective. The continuation of the network of co-operation established through INDO-MARECLIM was given due importance in the project. During the tenure of the project itself, 15 proposals including bi-lateral and multi-lateral national and international calls were submitted for funding. The proposals were framed so as to fill the research gaps identified during the project.

2.2.2 Specific objectives

To fit the above mentioned general objectives into a clear functional mode, the project was divided into 6 work packages, including one on Management (fig. 2).

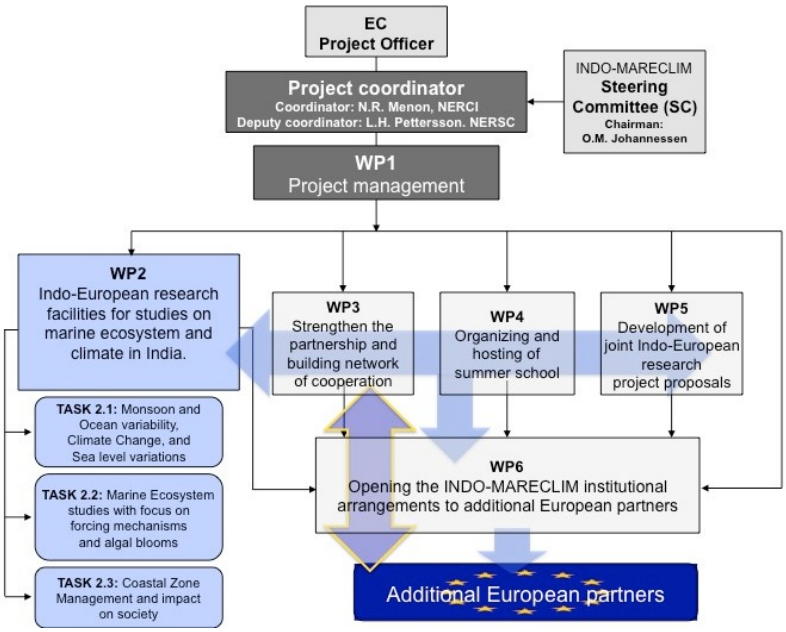

Fig. 2: The interrelations between the INDO-MARECLIM project and EC project officer and the project structure, including its interaction with external European partners.

The specific objectives are itemized below.

1. **WP 1. Project Management**

- The goal of this WP is to implement appropriate management and organizational activities to monitor the short and long term development and implementation of INDO-MARECLIM according to its objectives, through; efficient administrative/financial project management; providing the contact and information flow between the project consortium, reviewing and assessing project progress; implementing robust quality control routines for the project deliverables; and communicating internally in the consortium, with additional partners to the Indo-European research community and to the general public.

2. **WP 2. Indo-European Research Facilities for studies on marine ecosystem and climate in India**

- To develop, strengthen and sustain Indo-European scientific research co-operation and the NERCI research facilities in the areas of (i) climate studies of the Asian summer monsoon, (ii) the marine ecosystem and (iii) coastal zone management studies, with focus on the role of the Indian Ocean, including the consequences on the society in India.

3. **WP 3. Strengthen the INDO-MARECLIM partnership and building network of co-operation between Europe and India**

- To consolidate and strengthen the initial network among the INDO-MARECLIM project partners and expand this to include additional European partner institutions and stakeholders.
- To strengthen the NERCI research infrastructure to make it attractive for European users and future partners.

4. **WP 4. Organising and hosting summer schools for PhD students and Post-docs.**

- Plan, organize and host one thematic summer (winter) school gathering European and Indian PhD (and Master) students aimed at fostering Indo-European cooperation within studies of marine ecosystem and climate research focusing on the Indian Ocean.

5. **WP 5. Development of joint Indo-European research project proposals**

- Define, prepare and submit competitive new joint scientific research projects in cooperation between Indian and European research institutions, within each of the three scientific areas of INDO-MARECLIM (ref. WP2).
- To continue the sustainable utilization of the research facilities of the partner institutes to fill the gaps identified in this present project.
- **WP 6. Opening the INDO-MARECLIM institutional arrangements to additional European partners**
- To open up the research facilities and network of scientific cooperation of the INDO-MARECLIM consortium to scientific institutions and stakeholders in additional EU member states and associated countries to increase their scientific cooperation with India.

3. Summary Description of the main S&T results/foregrounds

3.1. MONSOON AND OCEAN VARIABILITY, CLIMATE CHANGE AND SEA LEVEL VARIATIONS

Leader: PV. Joseph, NERCI, Co-leader; Annalisa Cherchi, CMCC

Participants: **NERCI:** Ajith Joseph, Bindu.G, Abish.B, Syam Sankar, Harenduprakash. L & Swapna George

CMCC: Satyaban Bishoy Ratna, Materia S, D'Errico M.

IFREMER: de Boyer Montegut C**.**

NERSC: Ola M Johannessen, Lea Svendsen, Yongqi Gao

3.1.1 ISM in relation to ENSO and IOD

The Indian summer monsoon (ISM) varies at many timescales, from intra-seasonal to inter-decadal, and it is modulated by external factors like the El Nino Southern Oscillation (ENSO) and the Indian Ocean Dipole (IOD). A study by Cherchi and Navarra (2013) showed that (a) the ISM characteristics in El Nino/La Nina years or in positive/negative IOD events are not exactly symmetric. While during La Nina and negative IOD year the monsoon anomalies are almost uniform within the summer season, in the opposite cases the anomalies in the demise phase of the monsoon change sign compared to the onset period. (b) In AMIP-type ensemble experiments, where the atmospheric model is forced with inter-annually varying SST, the monsoon intensity is directly influenced by the simultaneous SST in the Pacific Ocean and its biennial characteristics are not captured because of the lack of air-sea interactions in the Indian Ocean. (c) In the reanalysis as well as in the coupled model most of the positive IOD events co-occurred with an El Nino, while that is not the case for La Nina. When years with pure IOD or ENSO events are separated from years with co-occurring ENSO and IOD, the SST anomalies in the Indo-Pacific sector and 200 mb velocity potential anomalies over India are larger in the latter cases than in the pure ones. (d) The potential predictability of monsoon is defined as the ratio of the ensemble mean over the standard deviation among the members. In the sample analyzed (AMIP-type ensemble) about half of the more predictable extreme monsoon years coincide with an El Nino co-occurring with a positive IOD event.

3.1.2 Climate Change in Jet streams

During the monsoon season (JJAS), the equatorial upper troposphere over Indian Ocean at 200 hPa has warmed due to the rapid warming of the equatorial Indian Ocean SST during the period 1950-2009. At the same time, a cooling has taken place over the Tibetan anticyclone region. These changes reduced the meridional temperature gradient in the upper troposphere, which is directly related to the strength of the Tropical Easterly Jetstream (TEJ) through the thermal wind relation, leading to a weakening of the TEJ (Abish et al, 2013). A study of six decades with reanalysis data (1950-2009) revealed that the subtropical jet

stream (STJ) at 200 hPa of the northern hemisphere, between longitudes 0°E and 180°E, has strengthened during both the boreal winter (January, February) and summer (July, August) seasons. The excessive convection over the equatorial Indian Ocean due to its rapid warming has heated the equatorial upper troposphere. At the same time, large amplitude cooling over the Asian region centered over China caused by anthropogenic sulphate aerosols has resulted in increased north-south thermal gradient over the subtropical upper troposphere that generates the STJ. Due to the increased meridional thermal gradient on the equatorial side, STJ winds strengthened. Meanwhile, in the southern hemisphere the high concentration of green house gases warmed the mid-latitude upper troposphere, causing a decrease of the meridional temperature gradient and as a consequence, the weakening of the STJ (Abish et al., 2015).

3.1.3 Moisture Trend over the Arabian Sea

The Indo-Pacific Ocean (i.e. region between 30°E and 150°E) has been experiencing warming since the 1950s while the large-scale summer monsoon rainfall over India is decreasing. The observed decreasing trend of moisture over the East Africa/Arabian Sea coincides with an increasing trend of moisture over the western Pacific region. This is accompanied by the strengthening (weakening) of the upward motion over the western Pacific (East Africa/Arabian Sea) that consequently, contributes to modulate the western Pacific - Indian Ocean Walker circulation. At the same time, the low-level westerlies are weakening over the peninsular India contributing to reduce the moisture transport towards India. Therefore a negative rainfall trend over the Western Ghats is observed. Since 2003 moisture over the East Africa/Arabian Sea started to increase and this is accompanied by the strengthening of convection due to increased Sea Surface Temperature (SST) over the western Arabian Sea. Despite the moisture increase over the Arabian Sea, the moisture transport is still weakening across the Indian landmass and contributing to the decreasing trend of precipitation over the southern part of the Western Ghats in the very recent decade (Ratna et al., 2015).

3.1.4 Cold Pool of the Bay of Bengal

During summer monsoon, oceanic upwelling takes place along the southwest coast of India. Part of the upwelled cold waters is carried by the strong ocean currents (summer monsoon current) into the Bay of Bengal region forming the Cold Pool of Bay of Bengal. This Cold Pool has an important role in monsoon intra-seasonal oscillation – the active - break cycle. The intra-seasonal variations in the surface winds associated with the active-break cycle is found to have a role in the variability of Cold Pool's SST. During the break periods of Indian summer monsoon an increased cooling of SST in the Cold Pool region is observed. A study of the changes in the daily wind stress and SST over the area for the monsoon seasons of 2001-2009 showed that there is intra-seasonal variation in the Cold Pool SST during summer monsoon, closely associated with the active- break cycle (George, PhD dissertation, 2015).

3.1.5 Barrier Layer and Upwelling in the Arabian Sea

The barrier layer (BL) - salinity stratification embedded in the upper warm layer - has the potential to significantly alter the air–sea interactions in the Northern Indian Ocean. The spatio-temporal structure of BL occurring in the central Arabian Sea during summer monsoon has been investigated. This season is indeed a key component of the Asian climate. Based on in situ data and an ocean general circulation model, it was found that BL events do exist in the central Arabian Sea during summer. However, it is highly heterogeneous in space and time. These BLs are probably too short-lived to significantly affect the monsoonal air–sea interactions (de Boyer Montégut et al., 2014).

Summer upwelling SST off the coasts of Somalia has been shown to have an important role in the inter-annual variability of the monsoon precipitations along the Indian Western Ghats. We use a coupled model to investigate the inter-annual variability of the mixed layer heat budget in the Somalia upwelling region, a region with strong air-sea interactions. From analysis of inter-annual variability of heat budget, summer SST anomalies in the Somalia Upwelling region are mainly driven by ocean dynamics, while atmospheric fluxes are secondary. The main ocean dynamics contribution comes from the sub-surface term (vertical mixing and advection through the mixed layer slope), but horizontal advection from the south always counteract the latter and strongly modulates the amplitude of the SST anomaly (de Boyer Montégut et al., ongoing work). A high resolution ocean general circulation model (NEMO at 1/12th degree resolution) has been run at global scale from 1990 to 2014. Study and analysis of the model outputs are now conducted to understand the

dynamics of upwelling along Kerala coast and its variability. It is planned to pursue a collaborative work on this between French institutes and NERCI under CEFIPRA (Indo-French Bilateral Programme).

3.1.6 Sea level rise – Indian Ocean

Due to sea level rise resulting from global warming about 70% of the world's sandy shorelines have retreated. Further erosion is expected as sea level continues to rise. These changes combined with changes in the frequency and intensity of severe storms due to climate change will increase the risk of coastal flooding and erosion. Using the Earth system models (IPCC) Ola et al. (2015) estimated that at the end of this Century, the sea level rise along the coast of Kerala in the south-western part of India in an RCP 4.5 scenario will potentially be 0.55 m where the ocean warming will contribute 42%, melting of ice sheets 35%, melting of glaciers 27% and isostatic adjustments -4%. Using the RCP 8.5 scenario the sea level rise is only slightly larger, 0.60 m.

3.1.7 Monsoon Onset over India

Monsoon onset over India is an important event for agricultural planning, food production and life of over one billion people. Because human and agricultural activities strongly depend on the onset of the rainy season and its northward progression, which are highly variable from year to year, prediction of the monsoon onset is of paramount importance for India. For almost a century the criteria for deciding the date of monsoon onset did not consider specific quantitative thresholds and was subjective. Recently, IMD adopted an objective identification of the monsoon onset using chosen thresholds of precipitation, low level winds and Outgoing Longwave Radiation (OLR). The transition towards the monsoon onset typically shows the reinforcement of the circulation to the southwest of India coupled with enhanced moisture transport to the convection area over the Bay of Bengal. Comparison of two sets of retrospective forecasts performed with the CMCC seasonal prediction system, different just in terms of initialisation, shows the importance of realistic initial conditions for the predictability of the monsoon onset. A biased equatorial westerly circulation and a too weak moisture transport from the Somali jet to the eastern equatorial Bay of Bengal induce a systematic premature monsoon onset. In contrast, a more realistic onset sequence during May is found due to the better representation of the atmospheric initial state (Alessandri et al., 2015).

3.1.8 Statistical Downscaling for precipitation forecasting

Since Global Climate Models have better forecast skill for circulation based fields than for precipitation, downscaling models are developed by relating observational rainfall data with large-scale circulation features. This technique, known as statistical downscaling, has been widely used in areas where complex geography does not allow global models to correctly simulate climate. The domain of predictands is in the Terai regions, a flat territory between northern India and Nepal, where the best large-scale predictor for precipitation is zonal winds over peninsular India at 850 hPa. To avoid synoptic noise, five-day averages for both variables are used by Materia et al. (ongoing study, 2015). In the first stage, statistical characterization of the region throughout cross-correlation between predictand and predictor, making use of statistical techniques such as principal component regression is carried out. It is planned to develop a perfect prognosis model that will be applied to seasonal forecasts.

3.1.9 Aerosols and monsoon

The CMCC atmosphere-ocean-sea ice climate model coupled to an aerosol module is able to reproduce a realistic annual cycle of modelled absorbing aerosol optical depth and of precipitation over India. The peak of the monsoon rainfall corresponds to a minimum loading of aerosols. The annual cycle of aerosol optical depth is characterized by a maximum in April that follows their accumulation in the dry season. On the other hand, the minimum in the summer is associated with the rapid removal of most aerosols from the atmosphere during the rainfall season, due to wet deposition. When an increased aerosol loading occurs in the Himalayas slopes in spring, the early monsoon season experiences intensified rainfall over India (Lau and Kim, 2010; D'Errico et al., 2015). The surface cooling due to solar dimming, associated with the presence of more dust brought by increased westerly flow results in a reduction of the monsoon rainfall over northern India in the late monsoon season (D'Errico et al., 2015).

3.1.10 Teleconnection between monsoon and the Mediterranean

Boreal summer subsidence over the Mediterranean has been shown to be related to the westward propagating Rossby waves, generated by the diabatic heating associated with the summer monsoon rainfall in South Asia, through the so-called "monsoon-desert mechanism". Despite large spatial diversity in monsoon heating, descent over the Mediterranean is coherently located and realistic in intensity in CMIP5 historical simulations. Column integrated heating over both the Bay of Bengal and Arabian Sea provides the largest descent in the eastern Mediterranean. Most models are able to capture the dominant role of horizontal temperature advection and radiative fluxes in balancing descent over the Mediterranean (Cherchi et al., 2014). The summer precipitation over South Asia is projected to increase in the 21st century. Contemporarily, over the Mediterranean the maximum of subsidence is projected to move westward, toward the center of the basin. Projected changes in mid-tropospheric meridional wind and horizontal temperature advection are consistent with the changes in subsidence, in agreement with the processes at the base of the monsoon-desert mechanism (Cherchi et al., 2015).

3.1.11 Indian Ocean Warming

The Indian Ocean (IO) had experienced a distinct change in the warming pattern after 1979. Compared to the years before 1979, there has been a consistent basin wide warming of the IO during both warm (El Niño) and cold (La Niña) ENSO events. After 1979, a shift in the atmospheric circulation anomalies associated with both El Niño and La Niña events induced favourable conditions for the basin wide warming. Concurrent changes in the atmospheric circulations and latent heat flux after 1979 is the likely cause of this enhanced exchange of heat into the ocean leading to an increase in sea surface temperature (SST). A corresponding warming of the Indian Ocean is evident from the positive anomalies in the upper ocean heat content and in the temperature profiles (Abish et al., 2015, ongoing study).

3.1.12 Indian Ocean Dipole

Analysis of SST data from two different sources (ERSST and HadSST) during the period 1875 to 2007 for the monsoon season evidenced that the frequency of IOD events as well as their intensity increased during the period 1961-2007. Analysis using OLR and precipitation data also helped to show the increasing trend of convection/precipitation over the western Indian Ocean and decreasing trend of convection/precipitation over southeast equatorial Indian Ocean (Sankar et al., 2015, ongoing study).

Scientific publications with acknowledgement to INDO-MARECLIM contributions:

Abish B, Joseph P V and Johannessen O M (2013): Weakening trend of the Tropical Easterly Jetstream of the boreal summer monsoon season. J. Climate, 26, 9408-9414

Cherchi A and Navarra A (2013): Influence of ENSO and of the Indian Ocean Dipole on the Indian summer monsoon variability, Climate Dynamics, 41, 81-103

Cherchi A, Annamalai H, Masina S and Navarra A (2014): South Asian summer monsoon and the eastern Mediterranean climate: the Monsoon – Desert mechanism in CMIP-5 simulations, J. Climate, 27, 6877-6903.

de Boyer Montégut C., F. Durand, R. Bourdallé-Badie and B. Blanke (2014): Role of fronts in the formation of Arabian Sea barrier layers during summer monsoon, Ocean Dynamics, 64, 809–822

Alessandri A, Borrelli A, Cherchi A, Materia S, Navarra A, Lee J Y and Wang B (2015): Prediction of Indian summer monsoon onset using dynamical sub-seasonal forecasts: effects of realistic initialization of the atmosphere, Mon Wea Rev, DOI: 10.1175/MWR-D-14-00187.1

Ratna S B, Cherchi A, Joseph P V, Behera S K and Abish B (2015): Moisture variability over the Indo-Pacific region and its influence on the Indian summer monsoon rainfall, Climate Dynamics, DOI 10.1007/s00382-015-2624-z

Abish B, Joseph P V and Johannessen O M (2015): Climate Change in the Subtropical Jetstream during 1950-2009. Advances in Atmospheric Sciences, 32, 140-148

George M S (2015): Modelling and observations of upwelling along the southwest coast of India and its intrusion into the Bay of Bengal, during summer monsoon, Dissertation for the degree of Philosophiae Doctor (PhD), University of Bergen, Norway, 91 pages

Johannessen O M (2015): Indian Ocean and Sea Level rise and the potential impact from the Greenland Ice Sheet, World Ocean Science Congress(WOSC) , Kochi, India, February 05 to 08, 2015.

Cherchi et al. (2015): 21st century projected summer mean climate in the Mediterranean interpreted through the monsoon-desert mechanism. Clim. Dyn. (under review)

D'Errico et al (2015) Asian monsoon and the elevated-heat-pump mechanism in coupled aerosol-climate model simulations, J Geophys Res-atmospheres (under review)

Abish et al. (2015) - ongoing study

Sankar et al., (2015) ongoing study

3.2. MARINE ECOSYSTEM STUDIES, INCLUDING ALGAE BLOOMS.

Leader: Annette Samuelsen, NERSC **Co-leader: Nandini Menon, NERCI.**

Participants: **NERCI:** Syam Sankar, Shalin Saleem, Smitha A, K. K. C. Nair, Mathew K. A, Ajin Madhav

NERSC: Lasse Pettersson, Anton Korosov

PML: Trevor Platt, Shubha Sathyendranath, Stephane Saux Picart, Stefano Ciavatta, Icarus Allen, Marie Fannie Racault

Anna University (Third party): Kanmani Shanmughapriya, Ramakrishnan. S, Balaguru

ToCH Institute of Sci. & Tech (Third party): Suresh. K

A project plan was developed covering specific objectives related to the marine ecosystem including (i) establishment of bio-optical research laboratory at NERCI, (ii) performing satellite Earth Observation data validation and application studies, (iii) making a primary production atlas for the Indian waters, (iv) Synergistic utilisation of ocean colour and other EO data to study eddy-induced algal blooms (v) impact of climate change on primary production, and (vi) implementation of a marine ecosystem model for the Indian Ocean.

3.2.1 Bio-optical research facility

The monitoring of the status of marine ecosystem and the prediction of its evolution are the major challenges of present-day marine research. Strengthening the observational and modeling facilities to meet the needs of the scientific community was the priority for implementing the INCO-LAB programme entitled INDO-MARECLIM. With this intention, a 240 sq. ft. research laboratory facility was established at NERCI (co-ordinator) to accommodate the joint research activities of project consortium members during the tenure of INDO-MARECLIM and beyond. Important equipment acquired under this project include a hyperspectral radiometer, UV-visible spectrophotometer, specialised microscopes and laboratory equipment for phytoplankton analyses.

The established lab facility is being regularly used by the researchers at NERCI, students of the EU partner PML and students of the third party KUFOS for primary productivity and ecosystem research.

3.2.2 Satellite EO data validation and application studies for Indian waters

In INDO-MARECLIM, focus of the research was to integrate satellite observations with *in situ* data and the outcomes of numerical models to monitor the ocean variables that are crucial to define and understand the physical and biological marine environment in the short and long terms. Marine primary production was identified as the key process influenced by the biogeochemical variations in ocean and could be studied on synoptic scales by ocean colour remote sensing.

3.2.3 Primary production (PP) model

Several authors have computed primary production from remotely-sensed data on ocean colour, but application of a highly resolved time series, has not been attempted. The spectral non-uniform biomass model adopted by Platt et al. (2008) for estimation of primary production from remotely-sensed visible spectral radiometry uses a simple procedure to assign the required parameters on a pixel by-pixel basis. It is simple because the two predictor variables used (chlorophyll concentration and SST) are both accessible to remote sensing and it can be implemented by non-specialists to produce fields of primary production on a routine basis. This method was applied to south eastern Arabian Sea (70-78^{o}E longitude, 5-12^{o}N latitude) for the period 1998 to 2009 using the following remote sensing data sets.

1) merged chlorophyll from ESA-CCI (MERIS, SeaWiFS & MODIS)

2) SST from AVHRR

3) PAR from SeaWiFS

4) P-I parameters – in situ data

5) Bathymetry data

6) Profile parameters (sigma, zm, rho) associated with Longhurst provinces

The production was found to be low in the offshore regions during the pre-monsoon period (March). High production (1600-2000 mg C m^{-2} d^{-1}) was observed in the coastal and offshore region during the southwest monsoon especially during August and September. The results obtained were compared with the *in situ* data available. (Smitha et al., ongoing study)

3.2.3.1 Sensitivity of Primary Production in the Arabian Sea to the available light

Strong seasonality in cloud cover over the Arabian Sea is found to cause correspondingly high seasonality in solar radiation at the sea surface. Human-made aerosols enhance scattering and absorption of solar radiation that also lead to a significant reduction in the solar irradiance reaching earth's surface. Preliminary studies have shown that water column primary production responds to changes in photosynthetically available radiation (Fig. 3). The effect of aerosol optical depth (turbidity) on the direct and diffuse irradiance for a 1^{o} x 1^{o} location (74-75^{o}E longitude/10-11^{o}N latitude) in the Arabian Sea for selected sun zenith angles was studied in the project. Direct and diffuse spectral irradiance at 61 wavelengths between 400 to 700 nm for clear-sky conditions were computed for 4 sets of angstrom turbidity coefficients (β_1 values: 0.049, 0.1324, 0.1814, 0.2501). Based on these plots, the impact of aerosols on direct, diffuse and total irradiance at the sea surface, both with respect to magnitude and shape of irradiance spectra at the sea surface and their angular distribution as indicated by direct and diffuse components could be elucidated. These results can be applied to study impact on primary production in the Arabian Sea. This work will continue in collaboration with PML beyond the project (Smitha et al., ongoing study).

3.2.4 Retrieval of optical water quality consituents in Indian waters

To circumvent the problems associated with retrieval of chlorophyll in case 2 waters using NASA algorithms, Korosov et al. (2009a) used the BOREALI algorithm for retrieval of major water colour producing agents from level 2 of the NASA SeaWiFS and MODIS-Aqua data in case 2 waters. The BOREALI algorithm is based on the Levenberg-Marquardt multivariate optimization procedure to retrieve chlorophyll-a, suspended minerals and dissolved organics in optically complex (Case 2) waters. During INDO-MARECLIM the BOREALI algorithm was tested in Indian waters.

AQUA MODIS level 2 satellite data were processed with BOREALI algorithm by applying the four hydro-optical models (Lake Michigan, Lake Ladoga, Lake Ontario and North Sea) to retrieve the ocean colour modifying agents for the south eastern Arabian Sea. Periods which had low chlorophyll (March), as well as those when there were blooms (September and October) between 2008 to 2013 were used. Monthly means for all data sets were calculated by averaging the output parameters.

The problem with implementing BOREALI effectively in the Arabian Sea was the unavailability of satellite observations due to persistent cloud cover, even during March. With the bio-optical data retrieved using radiometer, attempts are being made to calibrate the Boreali algorithm and produce an Arabian Sea hydro-optical model similar to the ones made for Lake Michigan, Lake Ladoga and North Sea (Mathew et al., ongoing study)

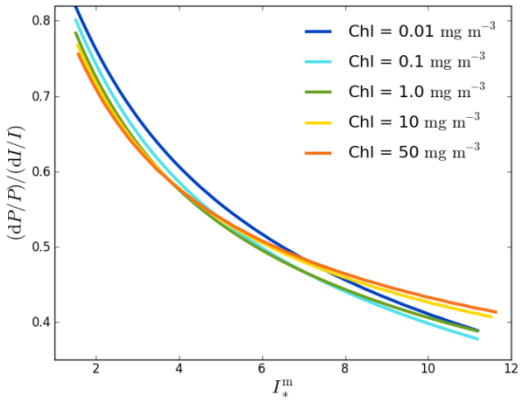

Fig. 3: Sensitivity of PP to surface irradiance

3.2.5 Synergistic utilisation of ocean colour to study eddy induced algal blooms

The increased incidences of harmful algal blooms in the Indian waters underline the necessity of remote sensing techniques to study their occurrence and propagation (Menon et al., 2014). Ocean colour data from MERIS, SeaWiFS and MODIS and other EO data such as Sea Level Anomaly were used to study the upwelling signals in the Arabian Sea, which are found to coincide with the initiation of algal blooms. Intra-seasonal variations were clearly observed in the area average plot (72-77^{o}E, 8-14^{o}N) of the estimated monthly PP. Hovmoller plots of monthly PP for the region were created for these years to understand the spatial distribution of PP. From the plots the inter-annual variations and the varying offshore extent of the bloom especially during the southwest monsoon period were visible.

Monthly climatology of sea level anomaly (obtained from merged data produced using up-to-date datasets with up to four satellites at a given time from Jason-2 / Jason-1 / Envisat / Topex/Poseidon / GFO) and the depth of the 20^o isotherm (1x1 degree resolution provided in the World Ocean Atlas 2009) were used to determine the seasonal large-scale patterns of upwelling in the Arabian Sea. The presence of negative sea level anomaly and a shallow depth of the 20^o isotherm are both indicators of upwelling and these were found to coincide with the initiation of algal blooms.

Strong cyclonic eddies in the Sea Level Anomaly maps indicate the presence of upwelling whereas anti-cyclonic eddies indicate downwelling in the ocean. During the southwest monsoon period, the sea level anomaly in the south-eastern Arabian Sea was found to be negative and it reached the minimum during July (-12 cm) indicating upwelling in this region. The occurrence of high production in the south-eastern Bay coincided with the low sea level anomaly during southwest monsoon season. By November the negative anomaly was replaced by positive anomaly (anti-cyclonic eddies) and it persisted during the northeast monsoon and pre-monsoon till April. Positive anomaly was high during December-February indicating downwelling phenomena in the south-eastern Arabian Sea.

3.2.6 Marine ecosystem model for the Indian Ocean to simulate ecological indicators

ERSEM-2004 version (Blackford et. al. 2004), which is a modification of the European Regional Seas Ecosystem Model (ERSEM) developed by PML was selected for this study. The 1-D formulation of ERSEM was coupled to a physical turbulence model (General Ocean Turbulence Model, (GOTM). The work focused on the phytoplankton related parameters and investigated the sensitivity and uncertainty of ERSEM in simulating the minimum concentration of oxygen, a widely used ecological indicator in the study area. The GOTM-ERSEM coupled model was set up in the central Arabian Sea centred at the location 65^{o}E, 13^{o}N which falls within the Arabian Sea OMZ region.

The validated GOTM-ERSEM model was subjected initially to a screening sensitivity analysis, called the Morris method, to identify qualitatively the ERSEM model pelagic parameters that are most important in the simulation of the minimum oxygen concentration in the central Arabian Sea. Those groups found to be more important on the basis of their performance in the Morris screening were subjected to a Monte Carlo sensitivity/uncertainty analysis. The model configuration that was used had 337 pelagic parameters. The sensitivity analysis (SA) and uncertainty analysis (UA) showed that bacteria-related parameters are the most important among the pelagic parameters in the simulation of the OMZ (Sankar et al., 2014). This result was consistent with the previous observations that bacteria are the principal contributors to community respiration in the pelagic ecosystem.

3.2.7 Automatic zoning of Northern Arabian Sea

In marine systems, geographical distinctions between major habitats are not easily determined. The spatial and temporal variability of marine autotrophs expressed as chlorophyll concentration that can be detected from space may indicate distinct ecosystem provinces or zones. An automatic zoning method was applied to the northern Arabian Sea (50 – 75^{o} E and 15 – 30 ^{o} N) based on the Chlorophyll-a (Chl) fields from the satellite sensor MODIS / AQUA during the winter months (November – March). Principal Component Analysis (PCA) and Cluster Analysis (CA) were used for automatic zoning; PCA identifies principal components of variability (PC) and CA clusters out groups based on similar features. Based on 4 PCs, the study area was clustered into 8 zones; the eight zones were further classified to groups based on the chlorophyll time series in each zone (Fig. 4). The chlorophyll variability within the group was then related to physical factors: Sea Surface Temperature (SST), Photosynthetically Active Radiation (PAR), wind speed, and Mixed Layer Depth (MLD). The analysis showed that in all zones, low SST, high PAR and high MLD coincided with high values of Chl; the strongest factors being Chl and SST. In the open ocean zones there was a lag of 1-3 weeks between MLD maxima and high Chl, indicating the influence of high nutrient availability on productivity. Analysis of climatological nitrate showed increased nitrate concentrations during the period of mixed-layer deepening. In the coastal zones, low wind stress was found to result in high Chl with a 0-2 week lag (Saleem et al., under submission).

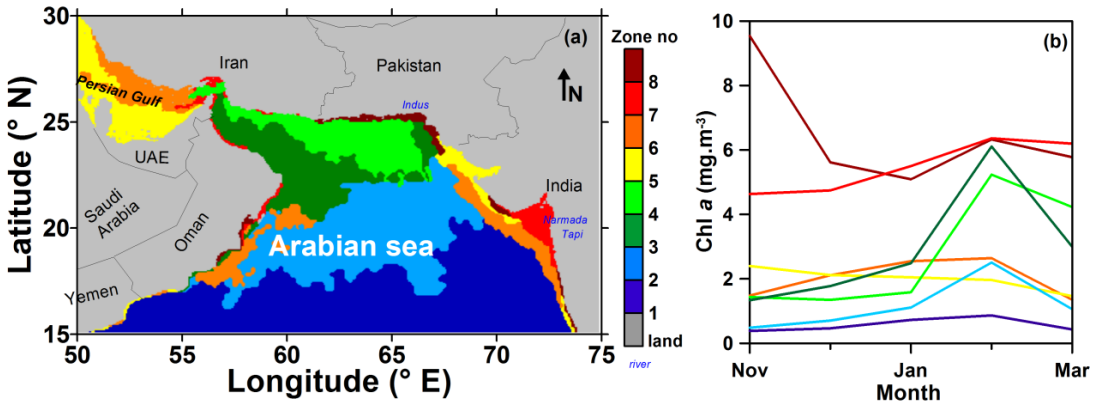

Fig.4: a) Map of 8 zones obtained after PCA and CA. b) Variability in chl. among the 8 zones

3.2.8 Metadata on *in situ* primary production

Realising the relevance of data archives in calibration and validation of remote sensing studies, metadata on *in situ* primary production and auxiliary parameters of the entire Indian Ocean were formulated. The area of study selected was 20 – 120^{o}E; and 60 – 31^{o}N. All available data sources were scanned and data were extracted into a prescribed format so as to make it easier for the use of future researchers.

Data sources from which the metadata has been formulated:

1. National Oceanographic Data Center / World Ocean Database 2013 (NODC / WOD 13)
2. Worldwide Ocean Optics Database (WOOD)
3. National Institute of Oceanography (NIO)

4. Joint Global Ocean Flux Study (JGOFS)
5. SeaWiFS Bio-Optical Archive and Storage System (SeaBASS) / NASA bio-Optical Marine Algorithm Dataset (NOMAD) – Chl and PP alone extracted.
6. International Indian Ocean Expedition 1 (IIOE 1) report (Saleem et al., 2015)

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Mathew et al., ongoing study

Smitha et al, ongoing study

3.3. COASTAL ZONE MANAGEMENT AND IMPACT ON SOCIETY

Leader: N.R. Menon, NERCI, Co-leader; Eddy Moors, ALTERRA

Participants: **NERCI:** Sachin Pavithran, Ajith Joseph, V. Kesavadas, Nandini Menon

ALTERRA: Annemarie Groot, Tanya Singh, Kirstin van Riel, Obbe Tuinenburg

KUFOS (Third party): M. S. Raju, Ambilikumar. V

3.3.1 Introduction

In the last six decades, marine fish production in India has increased from 0.5 in 1950 to 3.2 million tonnes in 2009 (Devaraj and Vivekanandan, 1999; CMFRI, 2010). The decadal growth rate of production increased until the mid-1990s, but slowed thereafter. The phenomenon of mechanisation, which was introduced since the mid-'60s in the Kerala waters, led to gradual marginalisation of the traditional fishermen, whose small vessels were unable to compete with the trawlers (Chekutty, 2010).

The focus of the coastal zone related INDO-MARECLIM research was to assess the impact of monsoon and climate variability on coastal livelihood. The impact of coastal upwelling on the fishery resources and sustainability of stock in the coastal sector in selected fishermen villages and landing centres was

investigated by reviewing census data and analysing different interviews and questionnaires. In addition the impact of seasonal variability on the economic status of fisher folk was studied.

3.3.2 Physical and socio-economic drivers

The problems of the coastal zone in Kerala are unique due to the high density of population, loss of land due to coastal erosion, mining of beach sand for industrial purposes, drastic morphological and shoreline changes due to shore structures like harbour breakwaters, destruction and reclamation of wetland including mangroves, saline intrusion into the water table, depleting fish stocks, competition among stakeholders for sharing the limited resources, high intensity of degradation of the environment, and violation of the provisions of Coastal Regulation Zone (Pavithran et al., 2014).

Climate change has additionally started showing its negative impact on the fishery sector. Analysis based on focus group discussion amongst different stakeholders such as traditional fishermen, fish traders, motorized fishermen, trawler fishermen, middle men, and exporters revealed highest vulnerability for the traditional fishermen. This was caused by hazards as sea level rise, increasing sea surface temperature, monsoon and upwelling variability, illnesses and algae bloom growth. Least effected seem to be the trawler fishermen and the middlemen (Pavithran, 2015, personnel communication). Sea level rise is at the moment often not considered as an issue from an occupational stand point, i.e. it does not affect fishing activities directly.

According to Sathiadas (2005), the increase in the number of people depending on fisheries for their livelihood, declining production and the stagnation in the total income generated from fisheries, severely affected fishing labourers with drastic reduction in their per capita earnings. This triggered a need for finding out alternative employment opportunities (Sathiadas, 2005). However, in 2006 only 5.6% of fishermen were educated above secondary level of school education. Because of this low percentage of education and the large number of fishermen, relocating with alternate employment is possible only by providing the fishermen with higher education for skilled jobs and to improve their societal status (Vivekanandan, 2006).

3.3.2.1 Present state

In the INDO-MARECLIM study that covered the nine coastal districts of Kerala, households were selected using a stratified random sampling method. In total 1050 respondents were interviewed for data collection. The outcome of the study showed that fisherfolk are well aware of climate change. Change in temperature is the indicator noted by most (48.1%) and could have been one of the causes for the observed changes in fish catch. According to 70.1% of the respondents, monsoon is the prime season of marine fishing in Kerala. However, it also happens recently that, during monsoon, due to the flow of water from south to north direction, the volume of fish catch decreases considerably. The fisher folk observed a decline in catch during the dry season (43.52%), monsoon (39.05%) and during post monsoon (30.19%). Experience shared by the fishermen brought to light that certain species are not at all available for the last few years, for instance, Anchovies, *Aries* and *Johnius* (big sized). See also Fig. 5 showing a decline for the total fish production in Kerala over the last 10 years.

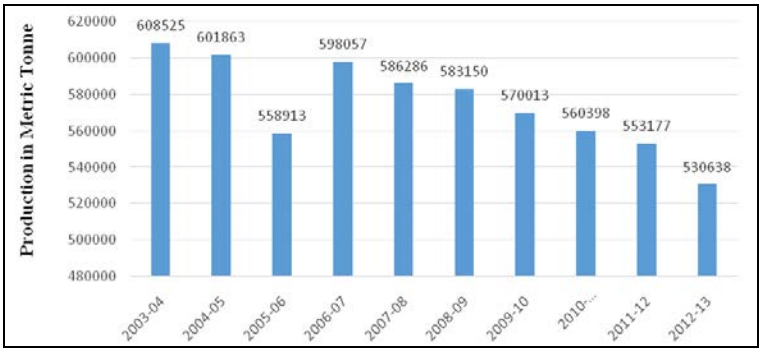

Fig. 5: Fish production in Kerala during the period 2003-04 to 2012-2013. (Source: Department of Fisheries, Government of Kerala, Facts and Figures 2012 & Kerala Economic Review, 2014.)

The INDO-MARECLIM study also revealed that 63% of the fisher folk is below poverty line. 23% of the fisher folk remained unemployed, hence the monthly income of majority of the households was found below

Rs.5000. Only 28% of the fisher folk were seen engaged in fishing. Because of the uncertain and low earnings from this avocation, youngsters, in general, are reluctant to choose fishing as an occupation for livelihood. By virtue of the reducing fish catch and the resultant hardships in their livelihood enterprises, a large number of fisher folk do not consider fishing and related activities a strong source of earnings. Poor hygiene, polluted source of drinking water, habit of liquor consumption, poor health and very poor savings habits inherent with their living conditions were also noted during the study.

3.3.2.2 Future scenarios

As was recommended by earlier studies (e.g., Vivekanandan, 2006), the present study also recommends to initiate strong efforts in order to improve the education level of children of the fishermen community, facilitating them to seek employment in other sectors. This measure will help them to improve their living standards. Fig. 6 shows the present state of income diversification in the 9 districts researched by INDO-MARECLIM. Taking into account fishery resources depletion as a result of increasing population pressure in this sector and climate change, it becomes highly necessary to reasonably limit the activities in the fishery sector. Side by side, diversification of occupational enterprises needs to be encouraged to tide over the crisis.

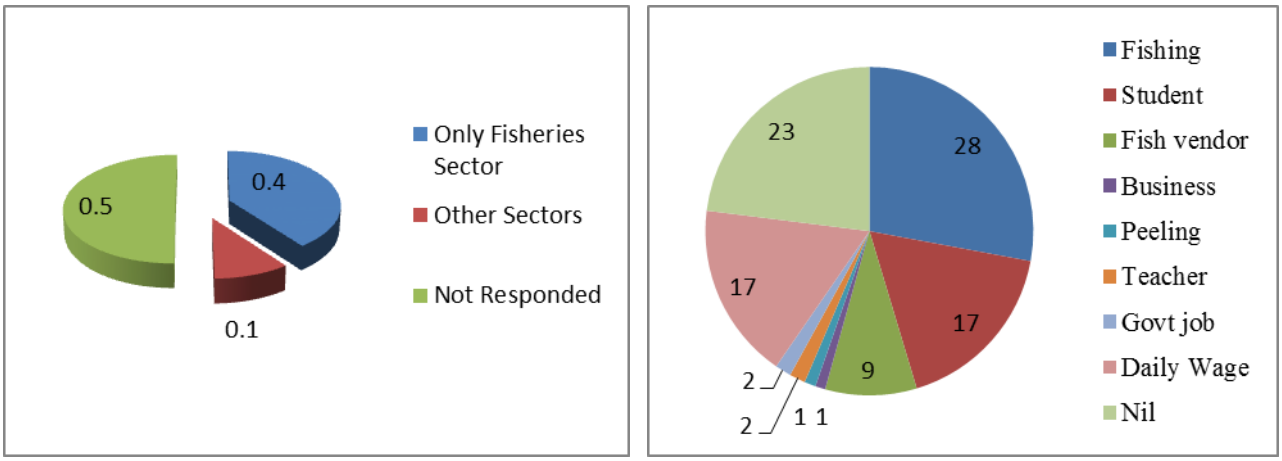

Fig. 6: (Left) Sources of income and (Right) distribution of respondents' family members based on occupation in the 9 districts selected for the INDO-MARECLIM study.

In order to support its complex research activities the INDO-MARECLIM project made use of the scenario development method (van Dijk et al., 2014). It provides a means of dealing with multifaceted and uncertain issues around climate change, income development, and technical and consumption pattern changes in the formulation of policies that are dependent on future expectations. Scenarios are storylines with a coherent set of assumptions that describe plausible futures and are usually developed together with stakeholders, helping to analyse future developments or trends. A Participatory Vulnerability Analysis (PVA) was conducted in Kerala, with the goal to understand and assess the main drivers related to the vulnerability of fishery resources and climate change as well as to determine how individuals perceive and respond to this changing situation in light of their anticipation of the future. As a result the main factors identified as affecting the fishery sector were: i) overexploitation and overcapacity associated with an increase in fishing effort and the mechanised unit; ii) increased sea surface temperature; changes in the intensity and frequency of monsoon rains, iii) and increase in salinity. All of the groups involved (local fishing communities and representative from state level departments) in the scenario analysis were of the opinion that certain fish populations will continue to decline. The level of awareness regarding the potential future risk of climate change differed amongst local fishing communities and experts. The extent to which climate change might have an impact on the livelihoods of fishermen did not seem to be of concern to them at the moment. Many in the community were more concerned with day-to-day survival rather than long-term changes in the future (van Riel, 2013). It further pointed out the necessity for state authorities, the affected communities and fisheries and climate change experts to come together to discuss future climate change related events, so that they can take

appropriate action to mitigate their effects. The analysis showed further the need to improve current management plans and strategies for dealing with climate change.

3.3.3 Measures

Projections on fish distribution and abundance catches need to be developed for planning better management adaptation measures. For the fisheries sector, climate change notwithstanding, there are several issues to be addressed. Reducing fishing mortality in the majority of fisheries, which are currently fully exploited or overexploited, is the principal means of reducing the impacts of climate change. Some of the most effective actions by which we can tackle climate impacts are to deal with the familiar problems such as overfishing, and adopt Code of Conduct for Responsible Fisheries and Integrated Ecosystem-based Fisheries Management.

Other urgently needed options to overcome the decrease in income for the fisher folk are by migration or diversification of income sources to increase livelihood options. An INDO-MARECLIM study suggested (community-based eco) tourism, apiculture, fish processing and value addition, aquaculture, duck, quail and rabbit farming, mushroom culture and product diversification and value addition in coconut products (e.g. oil extraction, coir and mat making, handicrafts from coconut shells, coir pith) as alternative livelihood options (Pavithran et al., 2014).

Regarding the eco-based tourism option, participation by the local community is needed. This is essential to ensure the long-term prospects of the sector. Furthermore, a limit to the number of visitors in each tourism destination is needed, so that the natural environment can withstand the pressures.

3.3.4 Better use of indigenous knowledge

However, although the traditional fisher folk of Kerala seems to be a vulnerable group in the fishing sector, they possess a rich resource of ancient knowledge and traditional wisdom which they make use of in their day to day fishing activities. These local fisher communities over centuries, have developed experience that have enabled them to reduce vulnerability to climate variability. For example, by observing the changing colours of the water, fishermen can estimate what to expect from the sea. Presence of small and frequent bubbles on the sea surface would be an inclination of the movement of oil sardine. When oil sardine feed at the sea bottom, air bubbles are released, giving enough hints about the type of fish swimming below. The fishermen also know that if currents flow from the northern direction, it is an indication of less fish abundance and if the current flow is from the southern direction more fish will be available. Furthermore, when the wind blows from the sea side more fish is available and when the wind blows from the land side, less fish is available. Very clear water indicates less fish abundance and the contrary holds when currents are low. Another example of their observation is that, with rising temperature fishes move to deeper waters and when heavy rains (see Fig. 7) are followed by calmer days then incidence of small pelagic fish catch is more.

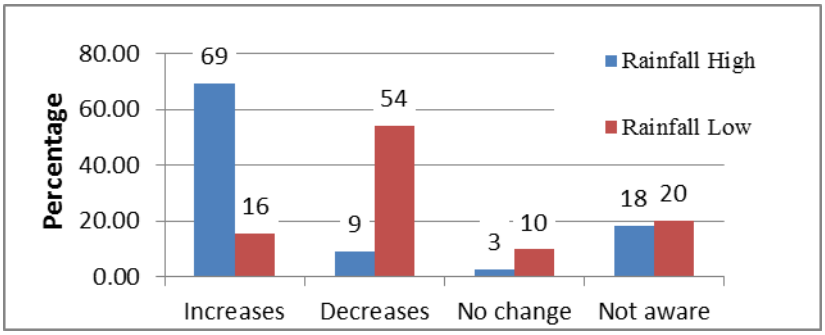

Fig. 7: Relationship between level of rainfall and availability of fish based on indigenous knowledge.

3.3.5 Pathways towards a sustainable coastal development

During the lifetime of the project also Indian and European researcher came together in a workshop on ‘coastal zone management and its impact on society’ to discuss amongst others major gaps in coastal zone research. In the following the major outcomes of the discussion are described.

The need of a multidisciplinary approach to coastal zone management–related research was highlighted. Future research should aim at technological, ecological, governance and social-economic solutions for coastal zone issues. There is a need to educate coastal and fishing communities through stepwise status assessment, awareness, and empowerment programs that are flexible in time and space and acceptable to all stakeholders.

To tackle bio-physical coastal zone issues, such as erosion, salinity intrusion and water quality effectively, a better understanding of ocean dynamics is required. This knowledge will enable e.g. the use of eco-system based solutions. The application of technologies related to remote sensing and geo-information services offer prospective opportunities for the transfer of knowledge into implementation of these solutions.

Potential alternative income sources next to fisheries could be ecotourism, ornamental fisheries and coastal cage culture. Research on how to develop this transition in a sustainable manner is required.

To bring about practically implementable legal frameworks for coastal zone management joint efforts by local, regional, and national research institutions, fishermen societies, and policy makers are needed. Developing a long-term vision such as has been done in the "Delta Plans" of e.g. the Netherlands and Bangladesh are recommended as a method to develop robust planning alternatives for the coastal zone in South-West India bringing together safety and food security.

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3.4 NETWORK BUILDING BETWEEN EUROPE AND INDIA

Leader: Ajith Joseph, NERCI, Co-leader: Shubha Sathyendranath, PML

Participants: All partners

As part of the network building activity, three thematic workshops were organised, one each for the three chosen scientific areas of research.

Scientific network, execution of exchange visits, publishing and eventually consortia agreements to continued cooperation are the cardinal components of the INDO-MARECLIM project. The scientific network building that has happened during the execution of the project includes various areas of climate research, marine ecosystem studies and coastal zone management. The five work packages have seen in the process in action. The different workshops, winter school, seminars and scientific exchanges have been crucial in understanding the relevance of scientific cooperation in solving major marine and climate research challenges like the Indian monsoon, upwelling and climate, the importance of primary production and the role of algal blooms in eutrophic situations, economic relevance of coastal zones and fisheries, policy making in the fisheries sector etc.

During the course of INDO-MARECLIM a total number of 138 scientists from approximately 60 Indian and 33 European research institutions have been involved in events and exchange of scientific cooperation and partnership. Additionally 450 young scientists and students in recruitments positions have been invited to scientific networking activities and the hosted winter school. The outcome of these events has been documented in other project deliverables. These Indo-European events of research cooperation have founded the basis for future scientific cooperation between both established and emerging scientists in both Europe and India.

3.4.1 India-EU Workshop on Marine Primary Production from March 12-15th, 2013 at Cochin

Convenor – Dr. Nandini Menon, NERCI Co-convenor – Prof. Trevor Platt, PML

Time & Venue: March 12 – 15, 2013 at Cochin, India

This was the first of a planned series of coordinating workshops conducted under the INDO-MARECLIM Project. The meeting was attended by dignitaries like Vice-chancellors, Directors of Central Govt. institutions involved in Marine research in India and consortium partners. Altogether, around 80 participants including scientists and students from India and EU participated in the workshop. Most of the major Indian institutes working on primary production were represented.

The scientific programme had three major elements. First was a series of tutorial lectures on various aspects of measuring primary production, interpreting the results and applying them to questions on biogeochemistry and fisheries. These were delivered by scientists from Europe as well as India. The second element was a set of shorter talks, delivered by Indians and Europeans, intended to survey the status of primary production studies in Indian waters. The third element was a discussion session aimed at developing the outline of a plan for assessing the primary production of the Indian Ocean.

The complete set of presentations is available on the project website.

In the discussion sessions, participants considered the possible structure of a plan for regular assessment of primary production in the Indian Ocean. This proved to be a fruitful use of the available time, leading to a plan with five principal components:

(1) Inventory of existing data on primary production in the Indian Ocean. It was thought that NERCI could take the lead in preparing this inventory, which would have four parts:
   (a) Inventory of data from observations at sea
   (b) Inventory of primary production estimates made using satellite observations
   (c) Inventory of primary production estimates made from ecosystem modelling
   (d) Inventory of Indian institutions engaged in primary production work

(2) Re-definition of the ecological provinces of the Indian Ocean, a project with two parts:

(a) Reassess the ecological provinces of the Indian Ocean, taking into account the influence of seasonality, and considering the relevant southern boundary of the Indian Ocean in the context of primary production studies
(b) Establish a monitoring programme for the redefined provinces, in all seasons, taking advantage of the monitoring sites and supersites.

(3) Establish a measurement programme for photosynthesis-response parameters, with related environmental and bio-optical properties: This work, which is essential to ensure the synergy between models and observations, would include the extract of photosynthesis parameters from existing profiles of in situ primary production, as well as new measurements of the photosynthesis-light curve. This work could build on the programme already developed by SAC.
(4) Develop training and personnel-exchange programmes to extend expertise in India. Training is required in the following areas at least: measurements of the light-saturation curve; phytoplankton taxonomy; image analysis and used of remotely-sensed data; HPLC; flow cytometry.
(5) Application of data on primary production to management of marine systems and resources: The principal application discussed was the assessment of fishery resources, a scientific question of high interest and extreme economic importance. Ideally, this component would be conducted jointly with relevant laboratories from ICAR.

Fig. 8: Participants of the India-EU workshop on Marine Primary Production

3.4.2 India-EU Workshop on Monsoon and Ocean variability, climate change and sea level variations

Convenor – Dr. P. V. Joseph, NERCI Co-convenor – Dr. Annalisa Cherchi, CMCC

Time & Venue - November 11-13, 2013 at Cochin

The second India-EU workshop was a three-day event to discuss the current status of scientific work on monsoon and ocean variability in the context of global warming and climate change. One of the objectives of the workshop was to explore possibilities for future collaborations among the participants.

The workshop was centered around 3 major topics:

1) Role of Indian Ocean in Monsoon Variability,

2) Rapid warming of Indian Ocean, and

3) Sea level changes in the Indian Ocean.

During the workshop aspects of the role of upwelling in the development and intra-seasonal fluctuations of the cold pool of Bay of Bengal, understanding the causes of the rapid warming of the equatorial Indian Ocean, its influence on the Indian summer monsoon and its global teleconnections and change in the sea level particularly over the Indian Ocean were discussed. The workshop was attended by 69 participants including 15 from EU. There were 12 invited talks and 11 contributed talks from participants. The structure of the workshop was similar to the first one: i) a series of tutorial lectures, ii) series of short presentations by the participants iii) round table discussions to identify research gaps and possible funding. By the end of the workshop, the participants identified 8 topics that needed immediate attention from the scientific community.

- Indian Ocean Monsoon and Arctic teleconnections
- Indian Ocean warming and Its impact on ISMR
- Impacts of Somali cooling on Indian Monsoon - model study of effects
- Modelling of cold pool in Bay of Bengal
- Understanding of regional sea level variations
- Impact of Greenland and Antarctic ice sheet melting on sea level in the Indian Ocean
- Influence of monsoons and climate on the biology of the Indian Ocean

Fig. 9: Participants of the India-EU workshop on Monsoon and Ocean variability, climate change and sea level variations

3.4.3 India-EU Workshop on Coastal Zone Management and its impact on society

Convenor – Prof. N. R. Menon, NERCI Co-convenor – Dr. Eddy Moors, ALTERRA

Time & Venue - October 6 – 9, 2014 at Alleppey, India.

This was the third of the planned series of coordinating workshops held by NERCI under the INDO-MARECLIM Project. Around 80 scientists, post docs and PhD students with broad disciplinary strengths and interests from India and EU participated in the workshop, which addressed the following four thematic issues: 1) oceanographic facets of coastal zone management, 2) technological aspects in coastal zone, 3) socio-economic issues in the coastal zone and 4) coastal zone governance. The complete set of presentations are available on the project website.

Fig. 10: Participants of India-EU workshop on Coastal zone Management and its impact on society

The programme had four sections:

i) Invited lectures by Indian and European experts in various facets of coastal zone management issues and solutions and their impact on society
ii) 24 short presentations by participating scientists addressing the four thematic issues.
iii) A field trip to the fishing village of Arthungal, a coir factory and Andhakaranazhi, the nearby tidal inlet, which helped the participants to get an impression of the living conditions of the fisher folk from Kerala
iv) Round table discussions on the major themes of the workshop, aimed at identifying research gaps on which participants are willing to collaborate together. This led to the formation of several ideas:

A) Technical aspects of CZM which should be investigated further:

- Sediment dynamics and how they affect the bio-physical environment need to be better understood. For this a three step process - 1. Predicting, 2. Protecting and 3. Mitigating - should be followed. To be able to predict, open access to data for the scientific community is crucial. Furthermore, in order to validate models, more monitoring and empirical data sets from research sites are required. An integrative multi-disciplinary approach is required when developing technological solutions. Engineers and ecologists need to work together with socio-economists and government experts. By means of establishing community based monitoring it can be achieved that also locals are involved.
- Regarding protecting and mitigation several design aspects can be explored further, such as offshore wave breaking, use of hybrid systems (integrate soft and hard measures in a smart way in a spatial zonation), integration of ecosystems into design.
- For developments in the future there is a strong need for regional sea level projections (next to IPCC) in order to specify what will happen to the Indian coast.

B) Socio-economic aspects of CZM which should further be investigated:

- What are traps which could lead to a tipping point?
- Windows of opportunities should be grasped at the right moment. What would be such opportunities? When should we make use of them and how should we use them?
- Alternative income for fishermen could be searched for in the field of ecotourism, coastal tourism, ornamental fish, green boats / green growth, small-scale industry (home based production).
- How does climate affect livelihoods of the fishing community?
- What possibilities are there for sustainable fisheries?
- What is the trade-off between preserving livelihoods vs. ecological protection?
- For future research, data collection is essential on: Traditional ecological knowledge , data on life history of fish (e.g. age at maturation), socioeconomics, fishing practices / best practices (from different areas and compare those), using cell phones as research device, WTP (willingness to pay) vs. WTA (willingness to accept)

C) Governance aspects of CZM which needs more investigation:

- Water quality criteria framework needs to be revised and implemented, which has a big effect on the wellbeing of the coastal community
- Maps including detailed and valid data is a good tool to have information on the coast and to understand how to implement certain government measures and schemes
- For island areas a different governance framework is needed, no attention is put on that at the moment.
- More effort should be put into building local and regional institutions that will be linked to national institutions. Local institutions need more funding and research facilities. However, for this purpose, they need to be recognized first.
- A continuous model is needed that predicts areas suitable for industry along the coast. More attention is needed in future on finding space for such operations.
- Transboundary issues need to be solved/eased

- More efforts should be put in to establish public private partnerships.

3.4.4 Advanced training Course on Satellite Data Management and Application of Cloud Computing

Convenor – Dr. Bindu. G, NERCI **Co-convenor – Lasse Pettersson, NERSC**

Time & Venue - February 9 – 13, 2015 at Cochin.

Satellite data processing and management is a great challenge to modern day Information and Communication technologists particularly the space application scientists and doctoral students. The problems faced in data sharing are:

- Difficulty in locating data
- Long time for downloading
- Requirement of large disc space
- Heavy processing load on local servers

In this scenario, a training course was conducted by NERCI with the technical support of Nansen Environmental Remote sensing centre, Bergen, Norway, to provide awareness among the young researchers about the Nansen-cloud developed by NERSC. Dr. Anton Korosov and Dr. Morten W. Hansen from NERSC led the training programme. Nansen cloud is a centralised data repository (cloud storage) that utilises simple data mining and access via a sequential data base. During the training, a prototype system using Python, Nansat, and the Django web framework were demonstrated. The advantage of Nansen Cloud being an open source service made it more attractive to the young scientists. The training was well received by the major scientific institutions in India like INCOIS, CMFRI, Indian Navy etc.

Fig. 11: Participants of Cloud computing training course

3.4.5 Training programme on Fast Repetition Rate Fluorometry (FRRf)

Convenor – Dr. Nandini Menon, NERCI **Co-convenor – Dr. Shubha Sathyendranath, PML**

Time & Venue - December 15-16, 2014 at CMFRI/NERCI, Cochin.

A two day training workshop on Fast Repetition Rate Fluorometry (FRRf) was organised to provide theoretical and working expertise on the FRRf instrument for the young researchers. Dr. Mark Moore, expert from University of Southampton, UK was the subject expert tutor. 16 young researchers and scientists from various institutes attended the training programme convened at laboratories of CMFRI, Kochi and NERCI.

Dr. Mark Moore taught the theory by way of two lectures – 1) Introduction to chlorophyll fluorescence and the FRRf method and 2) FRRf field measurements for estimation of electron transport rate (ETR) and quantification of photosystem II reaction centres. The lecture gave precise insight into theory of absorption of light by chlorophyll and subsequent fluorescence emission as one of the mechanisms of utilization of photon energy. He also emphasised the advantages of FRRf over radiometry for estimation of primary

productivity. This included the need to utilize photons of specific frequency to excite photosystems in the chlorophyll and successive measurement of fluorescence for estimating the number of reaction centres. Citing examples from published literature FRRf technique was shown to have better application in the estimation of primary productivity using remote sensing.

The second lecture was conducted along with demonstration using fluorescence measurement results of algal cultures for validation. Precautions to be taken during operation of the instrument were also dealt with. Dr. Moore demonstrated the working of the instrument both in the laboratory as well as in the field. The field trip was conducted in the near shore waters off Kochi, gathering data at each stage of deployment and familiarizing the protocol. The sampling was organized in such a way to measure fluorescence at one station and continuing the measurements at the same station at increasing intensity of solar radiation. Different possible measures to be followed for effective use of instrument during operation were also shown during the field trip.

Fig. 12: Participants of the FRRf training operating the instrument during field trip

This training programme proved to be an initiative to develop strong collaboration for NERCI with various Indian institutes to study primary production and auxiliary parameters in Indian waters. The institutions that have agreed to collaborate in the study include Central Institute of Fisheries Technology (CIFT), Central Marine Fisheries Research Institute (CMFRI), Centre for Marine Living Resources & Ecology (CMLRE), National Institute of Oceanography (NIO) and National Remote Sensing Centre (NRSC).

3.4.6 India-EU workshop on INDO-MARECLIM report preparation

Convenor – Dr. Ajith Joseph, NERCI Co-convenor – Prof. N. R. Menon, NERCI

Time & Venue - 21 – 23 April, 2015 at Cochin.

This fourth India-EU workshop was held mainly to discuss the preparation of the final report and assess the progress of different work packages. The three day workshop was inaugurated by Dr. Venkitaraman, Director, Zoological Survey of India, Calcutta, India who gave a scientific lecture on Climate change impacts on coral ecosystem. 25 participants including scientists from the partner institutions attended the workshop. The steering committee headed by Prof. Ola Johannessen reviewed the progress achieved in different work packages and gave expert opinions on the work to be finished. Mr. Lasse Pettersson chaired the session which discussed on the preparation of final project report and gave inputs regarding the financial and scientific report preparation.

Fig. 13: Participants of the IV India-EU workshop on report preparation

3.4.7 India-EU concluding workshop

Phase I - 16th & 17th June 2015 at PML, UK Convenor – Dr. Shubha Sathyendranath, PML Co-convenor - Dr. Ajith Joseph, NERCI

Phase II - 30th & 31st July 2015 at Cochin, India Convenor – Dr. Ajith Joseph, NERCI Co-convenor – Dr. B. M. Kurup, KUFOS

Phase I of the concluding workshop was held at Cornwall Hotel, Plymouth, UK and was attended by representatives from all consortium partners. Objective of the workshop was to discuss and finalise the contents of final and periodic reports to be submitted. A detailed discussion took place over the first draft of the final report.

The draft report prepared by Dr. Nandini Menon and Dr. Ajith Joseph was presented and each item was discussed upon in detail by the consortium partners. Modifications to be incorporated in the report were suggested. It was decided to circulate the modified report among all partners for finalisation of the report. Research ideas that were formulated as a continuation of the INDO-MARECLIM work would also be included in the project, so that there would be better chances for future research funding. Financial matters were also discussed. .

Preparation of periodic report to be submitted was also discussed. It was decided to make a template similar to that of the first periodic report and respective work package leaders were advised to take lead in the preparation of the draft.

The internal workshop also allotted time for self-appraisal of the work done by each partners. In general, the partners expressed happiness over the performance in the project and the team spirit among all the members involved in the project. Hiccups like delay in data collection, delivery of results by third partners were all overcome by the co-operation among the partners.

Fig. 14: Participants of the India –EU Concluding workshop (Phase I) at Plymouth, UK

Realising the need to publicise the INDO-MARECLIM activities and project the research gaps identified,

phase II of the Concluding workshop was held at Ramada Resort, Cochin on 30 and 31, July 2015. The workshop was held in association with the third party KUFOS, who contributed significantly to the work on Coastal Zone Management and its impact on Society. An exhibition to show case the infrastructure developed as part of INDO-MARECLIM was also arranged by NERCI and KUFOS. Scientific results, research gaps identified and future research avenues were presented before renowned marine scientists like Prof. T. J. Pandian, Dr. B. Madhusoodana Kurup, Dr. E Vivekanandan. The presentations were followed by a plenary session in which consortium partners like Mr. Lasse Pettersson, NERSC and Dr. Eddy Moors, ALTERRA also interacted through video conferencing. The outcome of the workshop aided in improving the quality of the final and periodic reports.

സമുദ്രപഠനത്തിൽ യൂറോപ്യൻ യൂണിയനുമായി സഹകരണം: സംയുക്ത ശില്പശാല 30 മുതൽ

കൊച്ചി: സമുദ്ര മേഖലയിൽ പരസ്പര സഹകരണത്തോടെ ഗവേഷണം മെച്ചപ്പെടുത്തുന്നതിനും ശാസ്ത്രപഠനങ്ങൾ ജനകീയവത്കരിക്കുന്നതിനുമായി കൊച്ചിയിൽ ഇന്തോ-യൂറോപ്യൻ യൂണിയൻ സംയുക്ത ശില്പശാല സംഘടിപ്പിക്കുന്നു. വ്യാഴാഴ്ച ഉച്ചയ്ക്ക് 2ന് ഫിഷറീസ് മന്ത്രി കെ. ബാബു ഉദ്ഘാടനം ചെയ്യും.

കേരള ഫിഷറീസ് സമുദ്രപഠന സർവകലാശാലയും (കുഫോസ്) നാൺസൻ എൻവയൺമെൻറൽ റിസർച്ച് സെൻറർ (നെർസി) ഇന്ത്യയും ചേർന്നാണ് രണ്ട് ദിവസത്തെ ശില്പശാല സംഘടിപ്പിക്കുന്നത്.

സമുദ്രപഠനവുമായി ബന്ധപ്പെട്ട് യൂറോപ്യൻ യൂണിയൻ അംഗ രാജ്യങ്ങളും ഇന്ത്യയും സംയുക്തമായി നടത്തുന്ന ഇന്തോ-മാരിക്ലൈം ഗവേഷണ പദ്ധതിയുടെ കീഴിലാണ് കൊച്ചിയിലെ ശില്പശാല.

Fig. 15: Paper cutting in Malayalam on the Concluding workshop

Fig. 16: Participants of the phase II of the Concluding workshop at Ramada Resort.

3.5 CONDUCTING INDO-MARECLIM WINTER SCHOOL

Leader: Nandini Menon, NERCI; Co-leader: Annette Samuelsen, NERSC

Time & Venue: 2 – 7 November 2013, Bolgatty Palace and Island Resort, Cochin (India)

A one-week winter school was held at Bolgatty Palace and Island Resort, Cochin (India) from 2 – 7 November 2013. The winter school was an inter-disciplinary training programme, in which a select group of instructors from India and Europe provided lectures and practical training on recent advancements in the global understanding of marine ecosystems, climate change and their socio-economic impacts. Participation was invited from PhD students, post-doctoral fellows and young scientists from all over Europe and India. Out of the 70 applicants, 30 were shortlisted by the expert committee consisting of scientists from all partner institutions. Students from UK, Sweden, Netherlands, Croatia, Norway, Belgium and India participated in the winter school, creating a truly international environment in which new friendships were formed.

Winter school lectures were organised in a manner to cover all the three focal areas of research of INDO-MARECLIM. Under each of the focal area, there was a key note lecture followed by 3-4 related lectures and a practical training session.

Short practical sessions were also conducted, one each in all 3 focal areas of INDO-MARECLIM. Dr. Marcello Vichi (CMCC, Italy) taught how to use the numerical Biogeochemical Flux Model (BFM) using three examples - simple equilibrium of the oceanic carbonate system, a batch culture experiment with a model phytoplankton *Isochrysis galbana* and a model ecosystem of a well-mixed temperate water column.

Dr. Annemarie Groot (ALTERRA, Netherlands) conducted an exercise on 'Participatory Vulnerablilty Assessment Tools' with the help of Ms. Tanya Singh, Junior Researcher at ALTERRA. Students were divided into three groups and each one practised one of the following tools: 'Climatic hazard trend analysis', 'Livelihood resource vulnerability assessment', 'Vulnerability assessment'.

Dr. Jan Even Nilsen (NERSC, Norway) made the students work out the relative sea level change for Cochin based on the various causative factors he taught during his tutorial.

Apart from the tutorial and practical sessions, students were divided into 5 groups and each group was assigned a topic on which they were asked to prepare a report based on the literature provided before-hand as pre-reads as well as by discussing with the resource persons. The topics assigned were:

1. Role of Ocean Atmospheric Processes on the Monsoon Activity over the Indian subcontinent.
2. Timescales of Indian monsoon variability
3. The limits to marine ecosystem management - What is the best balance between local and regional actions to achieve sustainable use of marine resources, and the need to adapt to global-scale processes?
4. Sverdrup's Hypothesis and the initiation of blooms
5. Vulnerability of the fishery dependent communities to climate changes in Kerala state: recommendations for increasing adaptive capacity

All participants took time to go through the pre-reads provided and came up with good reviews. Each group prepared the reports by seeking advice and guidance from resource persons, who also co-operated and interacted with the students helping them in the process. The projects given to the students in fact created an opportunity to brush up the basics and have a deep understanding of the phenomena that governs monsoon and marine ecosystem dynamics. The social impact of climate change was also well addressed by one of the groups.

Fig. 17: Participants of the INDO-MARECLIM winter school

4 Potential Impact (including the socio-economic impact of the project)

The INDO-MARECLIM project has succeeded in making a significant impact on the scientific community in India. The active participation and interaction of the consortium members have ensured that the objectives listed out in the 6 WPs were achieved, and that the new knowledge generated was disseminated to professional scientists and students as well as to laymen.

4.1 DEVELOPMENT OF INFRASTRUCTURE

One of the aims of the INCO-LAB programme under which INDO-MARECLIM is funded was to improve the infrastructure of NERCI to meet the research needs of Indian and EU partners. A full-fledged laboratory was established as a facility for marine optics in support of the estimation of primary production. In parallel, a high computing facility with ArcGIS and MATLAB software, and a high memory HP server were installed at NERCI to enable more sophisticated mathematical modelling for physical oceanography and ecosystem analysis.

The Satlantic Profiler II (radiometer) used for bio-optical measurements is the only one of its kind among the marine research institutions in Cochin. Possession of this instrument helped NERCI to widen its scientific co-operation with other renowned marine research institutions in India such as SAC, NRSC, CMFRI, CUSAT and INCOIS.

The well-equipped laboratory at NERCI is being exploited by graduate / post graduate and doctoral students of CUSAT, KUFOS, ToC H Institute of Technology, Institute of Remote Sensing of Anna University, SRM University and Karunya University for their dissertation work. This in turn has led to the recognition of NERCI as an approved research centre of KUFOS and research guideship was awarded by KUFOS to two of the scientists at NERCI, Dr. Ajith Joseph and Dr. Bindu. G.

4.2 IMPROVED SCIENTIFIC CO-OPERATION

The major impact of INDO-MARECLIM was the signing of Agreement of Associate Partnership with four of the EU consortium partners and with Nansen Scientific Society, a new partner outside the consortium. The co-ordinator, NERCI, already has a functional MoU with the Norwegian partner NERSC, being a member of the Nansen Group of Institutions.

i) MoU between ALTERRA and NERCI: Dec. 1, 2014: MoU would focus on collaboration for higher education and research in the field of Coastal Zone Management.

Fig. 18: From Left: Dr K. Ajith Joseph(NERCI) Ir. C.T. Slingerland (Director, Environmental Science Group, Alterra) and Prof. Dr. Ir. Eddy J. Moors (Head of the Climate Change and Adaptive Land & Water Management (CALM), Alterra-Wageningen University) after signing the MoU

ii) MoU between CMCC and NERCI: Nov. 24, 2014. Signatories were Dr.Antonio Navarra, the President of CMCC, Prof. N. R. Menon (Co-chairman, NERCI) and Dr. K. Ajith Joseph (Executive Director, NERCI). The main objective of this MoU is to develop long term Indo-European cooperation in research and higher education between NERCI and CMCC in the field of "Rapid

warming of the Indian Ocean" and the impacts of Indian Ocean dipole and El Nino on Indian Climate using Ocean-Atmospheric coupled modelling.

Approval

This MOU is signed in two originals one to each party.

For CMCC

CENTRO EURO-MEDITERRANEO SUI CAMBIAMENTI CLIMATICI S.C.a.R.L. IL PRESIDENTE

The President and Legal Representative
Dr Antonio Navarra

Lecce, Italy

For NERCI

Executive Director
Dr. K. Ajith Joseph

Kochi, Kerala,India

For NERCI

Prof. N. R. Menon
Coordinator, INDO-MARECLIM
&Co-Chairman, NERCI Board
Kochi, Kerala, India

NATIONAL ENVIRONMENTAL RESEARCH INSTITUTE NERCI KOCHI-16 INDIA

Indo-EU MoU as of November 2013 4

Fig. 19: MoU document with CMCC

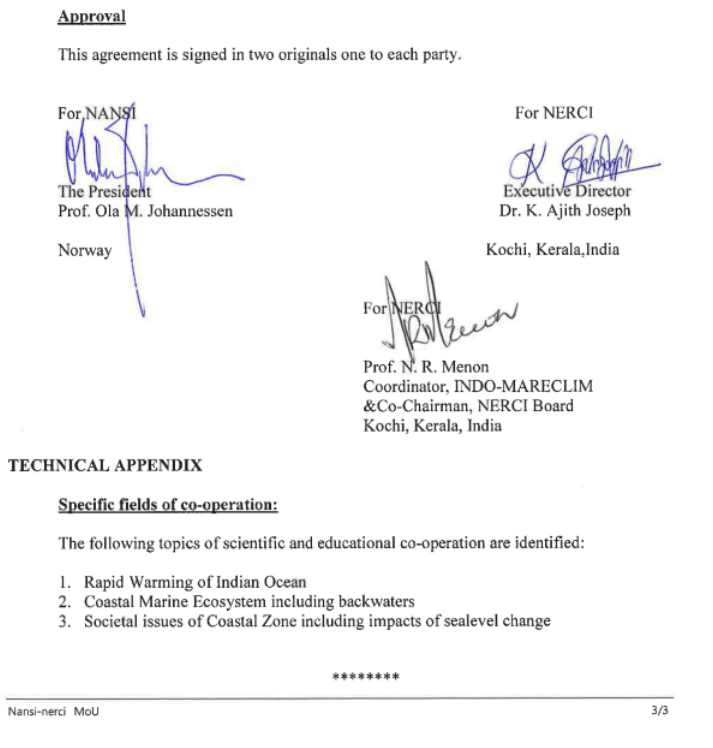
iii) MoU between PML and NERCI: June 12, 2015. The area of scientific collaboration would be Marine Ecosystem studies. The scientific contact point at PML would be Dr. Shubha Sathyendranath and the counterpart at NERCI would be Dr. Nandini Menon.

Fig. 20: Dr. Ajith Joseph, NERCI and Dr. Stephen De Mora, Director, PML signing the MoU

iv) Collaborations with IFREMER: An increased cooperative work has been done in the field of regulating mechanisms of SST in the Arabian Sea, especially in upwelling regions (Somalia and Kerala coasts). One final goal is to better understand the role of the oceans in the Indian monsoon system. This collaboration is now being pursued through the exchange of models outputs, and it should lead to a joint application to a CEFIPRA call in 2016, in collaboration with some French colleagues from IRD.

v) MoU between Nansen Scientific Society (NSS) and NERCI: June 16, 2015. Signatories were Prof. Ola M Johannessen (NSS), Prof. N. R Menon and Dr. Ajith Joseph (NERCI). MoU is focussing on supporting the exchange visits of students / post doc candidates between the participating institutions and initiating joint research projects between scientist of both parties in the area of marine climate research. The Nansen PhD fellowship programme implemented at CUSAT, India was a major step towards joint PhD programmes. The inception of the 2 PhD fellows helped in better achievements of the objectives of the INDO-MARECLIM project.

In addition to the partners, IMARES, Wageningen University, Netherlands has shown interest in associating with NERCI. Research Head of IMARES, Dr. Robert Trouwborst held discussions with Dr. Ajith Joseph, NERCI about collaboration under ballast water studies, coastal protection measures and CZM. A letter of intent was signed to confirm the willingness of NERCI to collaborate with Wageningen University in the programme titled 'Responsible life-sciences innovations for development in the digital age: Environmental Virtual Observatories for Connective Action (EVOCA) for crop, wildlife and disease management'. The collaborative research programme intends to apply for funding from INREF of Wageningen University for Sandwich PhD programme.



Approval

This agreement is signed in two originals one to each party.

For NANSI

The President
Prof. Ola M. Johannessen

Norway

For NERCI

Executive Director
Dr. K. Ajith Joseph

Kochi, Kerala,India

For NERCI

Prof. N. R. Menon
Coordinator, INDO-MARECLIM
&Co-Chairman, NERCI Board
Kochi, Kerala, India

TECHNICAL APPENDIX

Specific fields of co-operation:

The following topics of scientific and educational co-operation are identified:

1. Rapid Warming of Indian Ocean
2. Coastal Marine Ecosystem including backwaters
3. Societal issues of Coastal Zone including impacts of sealevel change

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Nansi-nerci MoU 3/3

Fig. 21: MoU with Nansen Scientific Society, Bergen, Norway

In addition to the European partners, MoUs have been signed with Indian institutions like Sathyabama University, Chennai. Very productive scientific contacts have been established even outside the institutions covered under MoU for joint research ventures. The above efforts have become part of the process of building cooperation with new partners and expanding the research fields for cooperation.

4.3 INDO-EUROPEAN KNOWLEDGE EXCHANGE

The networking among Indian and EU scientists was a mutually beneficial experience. For e.g., the atmospheric, oceanic, primary production and ecosystem models developed by the EU consortium partners were put to test in the Indian context. Working on Indian conditions helped in the fine tuning as well as calibration of the models. Furthermore, the EU scientists benefitted from the expert knowledge of the Indian

scientists in the regional and local context, for e.g., monsoon variability and dynamics and the socio-economics of the fishing community of Kerala.

i) The CMCC atmosphere-ocean-sea ice climate model (Fogli et al., 2009) coupled to an aerosol module (HAM; Stier et al., 2005) was able to reproduce a realistic annual cycle of modeled absorbing aerosols optical depth and of precipitation over India (D'Errico et al., 2015).
ii) CMIP5 (Coupled Model Inter-comparison Project; Taylor et al., 2011) with the state of the art coupled models to study the rapid warming of Indian Ocean in used by CMCC was tested. A preliminary analysis of SST for the period 1951-2004 in both observations and 20th century experiments from 18 available CMIP5 model experiments helped to select 11 CMIP5 models (i.e. MPI-ESM-LR, NorESM1-M, CCSM4, FGOALS-g2, IPSL-CM5A-MR, bcc-csm1-1, CESM1-CAM5, MIROC-ESM, CMCC-CMS, GFDL-ESM2G, HadGEM2-CC), closer to the observed linear trend of SST over the Indian Ocean for further studies.
iii) The BOREALI algorithm developed at the Nansen Centre in St. Petersburg & Bergen (Korosov et al., 2009) to retrieve major water colour producing agents - chlorophyll-a, suspended minerals and dissolved organics in optically complex (Case 2) waters - was implemented for the Arabian Sea.
iv) ERSEM-2004 open source version (Blackford et. al. 2004), which is a modification of the European Regional Seas Ecosystem Model (ERSEM) developed by PML was set up in central Arabian sea and sensitivity analysis to simulate oxygen minimum zone was tested successfully.
v) The model developed by Platt and Sathyendranath (PML) for estimation of marine primary production at large scales using satellite derived ocean colour data was implemented at NERCI for the northern Indian Ocean.
vi) Application of NANSAT software developed by NERSC for acquisition, processing and analysis of satellite Earth Observation data was implemented at NERCI. Principal Component Analysis and Cluster analysis done using the software to do automatic zoning of northern Arabian Sea to provinces based on spatial and temporal distribution of chlorophyll.

4.4 SCIENTIFIC NETWORK INVOLVING EUROPEAN AND INDIAN INSTITUTIONS

Through the workshops, training programmes and winter school conducted as part of the INDO-MARECLIM project, India- EU network of scientific co-operation has been widened. In addition to the existing consortium partners, new partners have initiated collaborations with Indian institutions.

i) Formation of a PP working group: Based on the deliberations of the PP workshop, a working group representing a network of institutions and scientists involved in Primary Production related activities was formed. The purpose of the Working Group is to develop an action plan for assessing the primary production of the Northern Indian Ocean, and to consider ways and means for implementing the plan. The group is being headed by Prof. N. R. Menon, NERCI and Dr. Shubha Sathyendranath, PML. The group has been actively involved in submitting proposals to various funding agencies, including the IIOE-2.

ii) Dr. Elisa Berdalet, Vice chair person, GEOHAB and scientist, CSIC, Spain has expressed interest in collaborating with NERCI and has been actively involved in joint proposal preparation and helping researchers associated with NERCI in toxic algal studies.

iii) Networks were established during the EU road shows and development summits held frequently in India. One such meeting led to the establishment of MoU with Sathyabama University, Chennai, India, to conduct collaborative research programmes in the field of Marine Biology and Oceanography. Joint proposals have also been submitted by this partnership to Indian funding agencies.

iv) Scientific collaboration with CMFRI, Cochin, India improved with the receipt of the prestigious Jawaharlal Nehru fellowship (DST, Govt. Of India) by Prof. Trevor Platt, PML. This has enabled in joint research work with CMFRI, undertaking cruises for sampling together and utilising the young researchers for further joint work.

v) More scientists from IFREMER are taking interest in working with NERCI and two new proposals –

to NSF, USA and CEFIPRA, France will be prepared.

vi) With the award of NF-POGO project to Dr. Nandini Menon, NERCI along with other Indian and Sri Lankan scientists, the network of scientific co-operation in the area of primary production studies has attained significant international status.

vii) Scientists from PML (Platt and Sathyendranath) and NERSC (Pettersson and Johannessen) have initiated new collaborations not only with NERCI, but also with other Indian institutions, notably CMFRI, SAC, NIO, INCOIS, NRSC, CIFT and PRL.

viii) Interactions with ZSI have led to the organisation of a summer school on Coral reefs and Climate Change along with NERSC in 2017.

4.5 BENEFITS TO YOUNG RESEARCHERS

During the tenure of INDO-MARECLIM, three thematic workshops and one winter school were conducted. All these programmes received overwhelming response and around 200 Indian students and 38 EU students had the opportunity to learn from the tutorial lectures and hands on training offered during the events.

In addition to the workshops and winter school, two training programmes, dedicated to the use of FRRf equipment and Nansen Cloud computing were also conducted by the INDO-MARECLIM team. FRRf training programme paved the way for better collaboration with NRSC, a leading scientific institution in India and the Cloud Computing program made the interaction with INCOIS, another renowned Indian institute, more active.

Even before the implementation of a formal MoU, to help the INDO-MARECLIM consortium in its scientific endeavours, Nansen Scientific Society initiated a PhD fellowship programme at CUSAT, India. The selected candidate has an official and formal supervisor appointed by Cochin University of Science and Technology, with additional supervisors from the two Nansen Centres in Kochi and Bergen. Mr. Nashad M was selected to work on the topic «Monitoring and modeling of harmful algal blooms including the applications of satellite remote sensing» and Ms. Shinu Sheela Wilson was selected to work on the topic «The role of Ocean circulation and interaction with the atmosphere». The inception of the 2 PhD fellows helped in better achievements of the objectives of the INDO-MARECLIM project.

The four project fellows associated with Prof. Platt's Jawaharlal Nehru Fellowship are getting trained in the remote sensing and modelling techniques used in INDO-MARECLIM project. The legacy of the project would be continued through their close interaction with NERCI in the coming years.

4.6 SOCIO-ECONOMIC IMPACT

As part of the INDO-MARECLIM project, surveys were conducted among the fisherfolk by the third party KUFOS. This helped in identifying the grievances and problems faced by fishing population against the backdrop of climate change, sea level variations and increased occurrences of HABs.

The resultant publications (dailies in the vernacular, English, short communications in EoS and Current Science) will certainly have an impact on the next amendment of the Coastal Regulation Zone rules of Govt. of India. The survey results are being shared with Kerala State Fisheries Department who work for the betterment of fishermen community.

മലയാള മനോരമ 2014 ഒക്ടോബർ 7 ചൊവ്വ

മടവീഴ്ചയോ, എന്താണത്?

കുട്ടനാട്ടിലെപ്പോലെ സമുദ്രനിരപ്പിൽ താഴെയാണു കൃഷിയെങ്കിലും നെതർലൻഡ്സിൽ മടവീഴ്ചയില്ലെന്നു ഡോ. എഡ്ഡി മൂർ

എം.എ. അനൂജ്

ഡോ. എഡ്ഡി മൂർ

തീരമേഖലാ വികസനം സംബന്ധിച്ച രാജ്യാന്തര ശിൽപശാലയ്ക്കു തുടക്കം

തീര പരിപാലന നിയമം നടപ്പാക്കുന്നത് അതതിടത്തെ സാഹചര്യങ്ങൾ നോക്കിയാകണം: ഡോ. ഷേണായി

Fig. 22: Paper cutting of Eddy Moor's press conference and inauguration of CZM workshop in Oct. 2014

4.7 INVENTORY OF MARINE BIO-RESOURCES

Realising the need to compile the data lying scattered globally, INDO-MARECLIM undertook the task to inventorise the in situ information on marine primary production and auxiliary data. All available data sources providing in situ observations on PP and auxiliary parameters in the entire Indian Ocean were scanned, extracted and stored as metadata in the server of NERCI.

Digitised inventorisation of the IIOE – 1 data on primary production and related parameters was also conducted. This data has also been extracted and formulated into metadata and is stored in the server of NERCI.

Information on the biology and distribution of marine invertebrates and vertebrates which are of interest in the light of marine invasions has been compiled from the archives of Indian libraries, and has been digitised.
NERCI server now hosts a wide range of information as metadata that could be of use to future research. Scientists from institutions such as CMFRI and NRSC are making use of the data for validation purposes.

4.8 INTRODUCTION OF NEW ACADEMIC PROGRAMMES

KUFOS, a third party in the INDO-MARECLIM launched new academic programmes with the help of experts from NERCI. The scientific work done in INDO-MARECLIM helped to identify potential areas of Marine Sciences that require more detailed study at the graduate level. With the help of NERCI scientists Prof. N. R. Menon, Dr. P. V. Joseph, Dr. Ajith Joseph and Dr. Nandini Menon, KUFOS introduced new courses including:

- M.Sc. Physical Oceanography and Ocean Modelling
- M.Sc. Biological Oceanography and Biodiversity
- M.Sc. Ocean Remote Sensing and GIS
- M.Sc. Climate Science
- M.Tech. in Integrated Coastal Zone Management
- M.Tech. in Ocean and Coastal Safety Engineering

As part of the dissemination activities of INDO-MARECLIM, the scientists at NERCI also help in teaching these courses.

Dr. Ajith Joseph of NERCI is involved in the curriculum restructuring of M.E. Remote Sensing & Geoinformatics conducted by Institute of Remote Sensing (IRS) of Anna University. He is also a member of the doctoral committee of IRS, Anna University.

4.9 PROVIDING EXCELLENCE IN HIGHER EDUCATION

PhD and graduate students working in universities like CUSAT and KUFOS, which are third parties in the INDO-MARECLIM project, were funded for part of their studies. This activity was undertaken by the consortium members and helped in providing good opportunities to young researchers to get exposed to the state of the art techniques being used in marine research.

i. Mathew, K. A, JRF in INDO-MRECLIM was selected by NF-POGO for 10 months training at the NF-POGO Centre of Excellence in Observational Oceanography with the help of Prof. Platt and Dr. Shubha Sathyendranath, PML.

ii. Mr. Sachin Pavithran, JRF in INDO-MARECLIM was selected for the The Nansen-NVP PhD and Post-doc Summer school 2013 in Svalbard Norway on SHIPPING IN ARCTIC WATER: The interaction of sea ice, ship technology, climate change, economy and other operational conditions with the help of NERSC.

iii. Ms. Smitha, A, JRF in INDO-MARECLIM was awarded the POGO-SCOR fellowship for Satellite data processing, interpretation and the modelling of primary production at PML in 2013 with the help of Prof. Platt and Dr. Shubha Sathyendranath, PML.

iv. Dr. Nandini Menon, WP leader in INDO-MRECLIM was made a member of NANO by attending the POGO regional training on HAB at Philippines with the help of Prof. Platt and Dr. Shubha Sathyendranath, PML.

v. Mr. Jabir and Mr Shaffeique, Research Scholars at CUSAT were selected for the NANSEN International winter school at Bangladesh with the help of Mr. Lasse Pettersson, NERSC.

vi. Ms. Maria Thottan, Ms. MonaLisha, Ms. Anis Daniel and Mr. Shaffeique, JRFs working under Trevor Platt's Jawaharlal Nehru scheme were sent to PML for training with the help of NERCI.

vii. 6 Masters' students of Physical Oceanography and 5 Masters'students of Biological Oceanography of KUFOS were guided and funded by NERCI scientists Dr. Ajith Joseph and Dr. Nandini Menon

for their M.Sc dissertation.

viii. Kirstin Van Reel, M. Sc Environmental Sciences student of Wageningen University, did her dissertation work on Vulnerability of fishery dependent livelihoods within Kerala State with the help of Prof. N. R. Menon, NERCI.

ix. Zarko Kovac (Croatia), participant of the first INDO-MARECLIM PP workshop, visited CMFRI, India and PML, UK for follow-up work on theoretical modelling of PP as part of his PhD work.

x. Nansen Scientific Society is funding 2 Indian students for their PhD work at CUSAT, India, which includes annual visits to NERSC to carry out part of the research work.

xi. 2 M. Tech students of IRS, Anna University did their dissertation work using the INDO-MARECLIM research facility at NERCI.

xii. Ms. Lea Svendsen, PhD student at NERSC attended the CORDEX Monsoon workshop at IITM, Pune in 2012 and presented a paper based on her thesis work 'studies on monsoon variability'.

xiii. Ms. Severine Fournier, PhD student of Dr. Montegut at IFREMER attended the Primary production workshop at Cochin in 2013 with the help of IFREMER. Her PhD thesis entitled 'Spatio-temporal coherence between space borne measurements of salinity and optical properties in river plume region' received partial funding from INDO-MARECLIM.

xiv. Mr. Morten W. Hansen and Natalia Ivanova, NERSC attended the PORSEC 2012 conference at Cochin with help from NERSC.

5 Main dissemination activities and exploitation of results

INDO-MARECLIM team has worked strenuously to spread excellence and dissemination of knowledge acquired during the project. The dissemination activities were designed to reach as large an audience as possible, covering all the Marine Research Institutions in India and maximum number of institutions in EU and Associated Countries. The dissemination activities aimed to provide the target beneficiaries with information on Research and Technology Development that is relevant to their specific interests. The major dissemination channels and tools are listed below.

5.1 PROJECT LOGO

The INDO-MARECLIM logo helped to create a strong visual identity of the project activities. It helped in identifying and distinguishing the 'brand' in the mind of researchers and stakeholders.

Fig. 23: INDO-MARECLIM logo

5.2 PROJECT WEBSITE

The INDO-MARECLIM website (http://indomareclim-nerci.in) was constructed at the beginning of the project and all activities of the project have been updated in the website.

The website is freely accessible to all. Publications in pdf, brochure, newsletters, tutorial lectures delivered during the workshops and winter school, announcements of events like workshops, winter school, training programmes are all published via the website. The project deliverables are accessible only to the consortium members, with access secured by a password.

In addition to the website, INDO-MARECLIM is active in social media platforms such as Facebook and WhatsApp. This has been used as the most effective method for dissemination of information on workshops, training programmes and winter schools. Web-dissemination of project results, including methodology,

scientific results and popular science information have been published throughout the tenure of the project through Euraxess links, Research Gate, academia.edu, ILS networks (e.g., https://www.loceanpsl.upmc.fr/index.php?...**gateway,** https://www.ifremer.fr/lpo/actu/api/seminars/invite/335) and so on.

5.3 BROCHURES AND NEWSLETTERS

For publicizing the project, a brochure has been designed which is widely distributed to all possible future collaborators and exhibited at international symposia that the consortium partners are attending.

Three issues of newsletters (i) July 2013 ii) January 2014 and iii) June 2015 have been published as part of the INDO-MARECLIM project, which gave a bird's eye view of the events and developments in the project.

5.4 PARTICIPATION IN EXHIBITIONS

INDO-MARECLIM put up exhibition stalls in connection with the international symposia held in Cochin.

i) Coordinated Regional Downscaling Experiment (CORDEX) South Asia Training Workshop - October 2012.
ii) INDO-MARECLIM scientists Prof. Ola Johannessen, Mr. Lasse Pettersson and Dr. P. V. Joseph actively participated in the pre-workshop conference held in March 2012 at the Indian Institute of Tropical Meteorology (IITM), Pune. The workshop in October was attended by scientists from NERCI and NERSC and INDO-MARECLIM brochures were distributed. Pan Ocean Remote Sensing Conference (PORSEC 2012) – Nov. 5-9, 2012.

iii) Pan Ocean Remote Sensing Conference (PORSEC 2012) – Nov. 5-9, 2012.

INDO-MARECLIM convened two technical sessions in the conference – one was on *Intra-seasonal variability of Asian Summer Monsoon* which was co-ordinated by Dr. P.V.Joseph, NERCI and co-convened by Prof.Ola M. Johannessen, NERSC and Dr. Annalisa Cherchi, CMCC. There were 2 invited papers and 4 contributed papers in this session. A Poster was presented by the INDO-MARECLIM researchers in this session.

The second session was on *Remote sensing applications in marine ecosystem studies.* Session Coordinator was Prof. N.R. Menon, NERCI and Co-Convenors were Lasse H.Pettersson, NERSC, Prof. Trevor Platt and Dr. Shubha Satyendranath, PML. There were 2 invited papers, 4 contributed papers, 26 oral presentations and 9 posters by participants.

iv) Marine Ecosystems - Challenges and Opportunities (MECOS2) – 2-5 Dec. 2014.

INDO-MARECLIM received attention right from the inaugural ceremony. INDO-MARECLIM activities were exhibited in a stall that was set up as part of the symposium. The stall set up at a symposium where most of the Indian marine research institutions working on ecosystems were represented gave a high impetus to the project. INDO-MARECLIM researchers also presented posters at the symposium.

Fig. 24: Clockwise from left: Prof. Platt inaugurating the MECOS 2 symposium, Prof. N. R. Menon, co-ordinator INDO-MARECLIM being felicitated for participating in IIOE-1 research programmes and INDO-MARECLIM booth at MECOS 2 symposium.

v) World Ocean Science Congress (WoSC) – 5-8 February 2015

INDO-MARECLIM stall was set up at the exhibition held in connection with the event. Prof. Ola. M. Johannessen, NERSC was the key note speaker for the workshop. There was active participation from scientists of NERCI and NERSC at the workshop.

Fig. 25: INDO-MARECLIM stall at WoSc and view of the audience.

In addition to these, Dr. Ajith Joseph participated and made presentations about the INDO-MARECLIM activities at

i) Awareness Raising and Information Campaign on Research & Innovation Cooperation with Europe Tuesday 18 September, 2012 at the Trident, Cochin
ii) IAPSO – AHS joint assembly from July 21-28, 2013 in Gotheiborg, Sweden as part of network building. In addition to a presentation on INDO-MARECLIM activities, a poster was presented on the topic " Identification of river plumes of Ganga- Brahmaputra-Meghna (GBM) river basin in the Bay of Bengal using Satellite Altimetry" co-authored by Arunmozhi, P and Ramalingam, M., of Institute of Remote Sensing, Anna University, Chennai (third party partner for INDOMARECLIM)
iii) ILN Workshop organised by APRE, Italy, on 27-28 Nov. 2014 to bring together the research institutes funded by EU and located in third countries as a catalyst to structure and increase the cooperation with third countries.

iv) India-SI House (India-EU joint house for science and Innovation workshop) on 5th June 2013 at New Delhi

5.5 PRESS RELEASES, POPULAR SCIENCE ARTICLES AND OUTREACH LECTURES

Press releases and press conferences were held during the workshops and seminars to present project milestones and key results to the scientists, stakeholders and policy makers and networks. EU consortium partners also gave interviews in local dailies on topics related to climate change, disaster management etc.

An INDO-MARECLIM fact sheet, which illustrated the project objectives, challenges and expected results, was contributed to the catalogue on the FP7 projects on Climate Change at International Conference on Regional Climate jointly organised by European Commission- World Climate Research Programme (WCRP) at Brussels from 4-7 November 2013

Events like the thematic workshops were reported in popular science journals – both national and international:

Nandini Menon, N., T. Singh and L. H. Pettersson (2014), Integrated Research Approaches to Coastal Zone Management, Eos Trans. AGU, 95(49), 463, doi:10.1002/2014EO490009.

Arindam Chakraborty (2014), Integrated coastal zone management: a sustainable way to manage the coastal zone. Meeting report in Current Science, Vol. 17 (10): 1637 – 1638.

Prof. Trevor Platt and Dr. Shubha Sathyendranath, PML conducted outreach lectures at colleges in Kerala like Farooq College, Calicut, St. Joseph's college, Irinjalakuda and Adi Sankara College of Engineering, Kaladi on topics such as 'Colour of the sea' and 'Oceans from space' which triggered interest among the young generation in Advancements in Marine Sciences.

Fig. 26: Outreach lecture by Dr. Shubha Sathyendranath at a women's college in Kerala, India

5.6 TRAINING AND EDUCATIONAL MATERIAL

All the lectures that were delivered during the workshops and winter school were given to the participants in DVDs. The pre-reads for the winter school, which were peer-reviewed articles on specific topics were also supplied to all participants.

Paper on Coastal zone Management in Malayalam prepared by Prof. N. R. Menon *(Theeradesa paripalanam)*to create awareness among the Members of Legislative Assembly of Kerala about the coastal zone issues.

Prof. Trevor Platt and Dr. Shubha Sathyendranath gave training on Ocean colour Remote sensing at International Training Course On "Ocean Colour Remote Sensing – Data, Processing and Applications at INCOIS in November 2014.

The lecture given by Prof. Ola M. Johannessen at the WoSC at Cochin in 2015 on Indian Ocean, sea level rise and the potential impact from the Greenland Ice Sheet.

The standard protocols for phytoplankton identification, estimation of primary production, nutrients and bio-optical parameters which has been compiled as a pdf by the NERCI scientist Nandini Menon as part of the NANO project SHABHASHI would be made available through the INDO-MARECLIM website also.

These dissemination activities are in addition to the scientific publications that have been made out of the project (details given in Table 2A1) and the workshops, winter schools and training programmes held (details in Table 2A2) during the tenure of INDO-MARECLIM workshop.

5.7 BENEFICIARIES

The beneficiaries of the dissemination activities are the young researchers, especially the students who got chance to interact with EU scientists, exchange ideas and get trained.

Three doctoral students are working full time for their PhD under the INDO-MARECLIM project. The work is being carried out under the joint guidance of scientists at NERCI and faculty of CUSAT.

INDO-MARECLIM fellow and Part time PhD student at NERSC, Bergen was awarded doctoral degree for her thesis entitled "Modelling and observations of upwelling along the southwest coast of India and its intrusion into the Bay of Bengal, during summer monsoon" from Geophysical Institute, University of Bergen, Norway in Jan. 2015.

Four students working with Prof. Trevor Platt in his Jawaharlal Nehru Fellowship Scheme are being trained on the scientific aspects attended to in INDO-MARECLIM so that the legacy of the project and the partnership is continued beyond its term.

NERCI, an SME, also received international exposure as being the co-ordinator of the project and could develop into a contact point between Indian and EU researchers.

The INDO-MARECLIM project was a highly successful project with excellent team work and co-operation among the consortium partners. The scientific interactions were beneficial to all partners, that all EU consortium partners signed MoUs with the co-ordinator to continue joint research in the area of Marine climate and ecosystems. 15 proposals have been submitted both to bilateral, EC and international calls for funding. The research facility established at NERCI would continue as a platform for future collaborative research with EU institutes. Attempts to expand the network beyond the consortium have been successful with the sanctioning of an Indian-Sri Lankan project by Partnership for Observation of the Global Oceans and the Nippon Foundation to Dr. Nandini Menon. The Working Group on Primary Production, developed from a workshop on primary production held under INDO-MARECLIM is expanding the network among Indian institutions, by way of joint proposals to national agencies and to IIOE 2, the most recent India-EU initiative in marine research. Implementation of Nansen Fellowship by Nansen Scientific Society paves the way for young researchers to get trained in recent advancements in Marine Science. Another development relevant to the legacy of the project is that one of the European partners, Trevor Platt, has been awarded a prestigious Jawaharlal Nehru Science Fellowship by the government of India to work in Kochi during four months in each of three consecutive years. These along with the outreach activities that will continue with the third party KUFOS and the consortium partners will carry the legacy of INDO-MARECLIM forward.