

**Vision and Prospective Plan for 10 years in  
Ocean Sciences & Services**

**prepared for**

**The Ministry of Earth Sciences,**

**Government of India,**

**New Delhi**

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**Executive Summary**

This document, prepared for the Ministry of Earth Sciences, Government of India, New Delhi, articulates a vision and prospective plan for the country in the area of ocean sciences and services during the next decade. The document focuses on the following key areas (themes): role of the ocean in monsoon climate; routine forecasting of conditions in the Indian EEZ; natural hazards; environmental impact assessment ; and, biogeochemistry. For each theme and their sub-themes 2-, 5-, and 10-year goals are identified keeping in view present capabilities amongst institutions dealing with ocean sciences. The document identifies the infrastructure that will need to be developed to achieve the goals and lists desirable roles for different institutions in the country. A major hindrance to progress today is lack of adequate manpower. The document proposes setting up of a National School of Oceanography to overcome the problem.

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## **1. Introduction**

In mid-2009, the Ministry of Earth Sciences (MoES) constituted different committees to elucidate a vision of the ministry to meet its mandate, which is summarised below.

1. Develop and improve capability to forecast critical ocean-atmospheric parameters, processes, and phenomena of significant societal, economic, and environmental benefits.
2. Provide scientific and technical support for climate-change studies and ecosystem-based management for sustainable use of resources.
3. Define and deploy satellite-based and in situ atmospheric, oceanic, and lithospheric observing systems to support forecasting and ecosystem-based management system.

The scope of the exercise undertaken by MoES may be gauged from the number of areas in which similar plans are sought by MoES: (i) atmospheric science, information, and services, (ii) geosphere and seismological hazards, (iii) polar science and cryosphere, (iv) ocean technology, (v) coastal and marine ecosystems, (vi) climate science, (vii) non-living resources (ocean), (viii) research vessels, (ix) R&D in earth sciences, (x) outreach, and (xi) ocean sciences and services.

The terms of reference of these committees were as follows.

1. To identify critical elements of science and technology relating to the ocean.
2. To identify national research themes and priorities of societal benefit.
3. To identify goals for 2, 5, and 10 years for each research priority.
4. To define observing systems and sensors.
5. To draw up implementation strategy.
6. To identify infrastructure needs.
7. To suggest requirement on human resources.
8. To define role of central, state, and international agencies, research and educational institutions, the private sector, and NGOs.

The present document deals with *ocean science and services*. The OM constituting this committee is given in Annexure I.

Outlining a vision with a prospective plan is a daunting task. It requires one to be specific, while avoiding being restrictive. Outlining vision in one area (“ocean science” in this case) as a part of a larger exercise is even more challenging because of an added constraint: avoiding duplication of work that others, with a larger knowledge base, could do better.

Keeping in perspective the topics distributed amongst the committees constituted by MoES, we found it convenient to divide the vast spectrum of ocean science into five themes.

- Role of the ocean in monsoon climate;
- Forecasting in the Indian EEZ;
- Natural hazards;
- Environmental Impact Assessment (EIA); and
- Biogeochemistry

The first theme comes under the broader heading of climate, which is vast enough to demand a separate vision document. We deal with only one aspect of climate: the role of the ocean in determining the weather and climate of the Indian subcontinent. Given this focus, we have avoided discussing issues related to climate change and associated paleoclimate studies. We have two reasons for doing so. First, India has recently gone through an elaborate exercise of identifying eight missions related to climate-change issues. Second, MoES is in the process of setting up a centre that would examine the science of climate change. Paleoclimate studies would form an integral part of such a centre, whose vision is now being elucidated. The sixth MoES committee listed above (*climate science*) would be the appropriate forum for the science of climate change.

There is another topic that we could have included in the discussion here, but decided against it. This is marine living resources. We feel that this topic is best discussed by the committee dealing with marine and coastal ecosystems. Of course, some aspects of coastal ecosystems will invariably appear in the coastal biogeochemistry that has been discussed here under the theme of biochemistry. However, the focus here is on developing quantitative models for how the coastal ecosystem works rather than its potential to provide living resources.

Three of the five themes discussed here - Forecasting in the Indian EEZ; natural hazards; and, Environmental Impact Assessment (EIA) - can be grouped under the term *coastal environment*, which encompasses all aspects of life in the coastal zone. The environment is critical for the huge population that resides in this region. Of course, the local climate determines the local environment, and the environment, in turn, can affect climate. Environmental degradation in a region can, apart from impacting the people in the region directly, also influence local climate if the degradation is sustained over a period of time. Resources also impact the environment because the finding of, say, oil or gas in the neighbouring marine environment leads to considerable industrial activity in the region, directly affecting the environment. The increase in economic activity and the rise in local population also tend to add to the stress on the local environment. The industrial machinery set up for exploiting these resources, in turn, become a part of the larger environment because of the dependence of man on their survival and maintenance. This expansion of the environment to

include machinery on the coast or at sea demands, in turn, good coastal-ocean science and technology to sustain them. The economic activity and its dependence on the local environment leads to the need for routine forecasting of conditions in the Indian EEZ, the need to guard against natural disruptions of civil society leads to the need for studying natural hazards, and the need to ensure sustainable development that does not degrade the environment leads to the need for good environmental-impact assessments of our industrial activity.

Proper assessment of the impact of anthropogenic activity, either in coastal areas or elsewhere, requires sound understanding of biology and chemistry of marine environment, and interaction between them in the presence of sediments in the ocean column and on the ocean floor arising from geological and other processes. The fifth theme discussed in this document is therefore dedicated to biogeochemistry of both coastal and open-sea regime. The latter includes high altitude oceanic areas such as polar seas.

These five themes are discussed in the next five sections (2–6) of this document. For ease of organizing the document we have identified sub-themes. Table 1 gives an overview of the themes and the sub-themes. For each of the five themes or its sub-themes, we identify 2-, 5- and 10-year goals. Meeting these goals would require action on two fronts, infrastructure development and human resource development. These issues are discussed in Sections 7 and 8, respectively. We conclude this document with Section 9 that discusses the roles that we see for different agencies in meeting the objectives envisioned in the document.

<b>Theme</b>	<b>Sub-theme</b>
Role of the Ocean in Monsoon Climate	
Routine forecasting of the conditions in the Indian EEZ	Tides
	Estuaries
	Waves
	Currents, temperature and salinity
	Acoustics
Natural hazards	Storm surges
	Tsunamis
Environmental Impact Assessment	
Biogeochemistry	Coastal
	Open-sea
	Climatology
	Polar seas

**Table 1:** An overview of the themes and sub-themes used to organize this document. For a theme or a sub-theme, 2-, 5-, and 10-year goals have been identified.

## **2. Role of the ocean in monsoon climate**

The seas around India (the Arabian Sea, the Bay of Bengal, and the rest of the Indian Ocean to at least 10S) have an impact on the Indian Summer Monsoon. While it is not doubted that there exists a coupling between the Indian Ocean and the monsoon, and between phenomena like ENSO (El Nino and the Southern Oscillation) in the Pacific Ocean and the monsoon, the nature of the interactions is still unclear over the vast range of time and space scales involved in the process. Progress in unravelling these interactions and building the science base for prediction demands hypotheses that can be tested with observational programmes and a modelling strategy.

### *2-year goal:*

1. A major lacuna in ocean research is the absence of data from the Indian Ocean except for that available from satellite-based sensors. It is imperative that the moored-buoy programme of the National Data Buoy Programme (NDBP) be revived. An important 2-year goal is the deployment and successful maintenance of (say) 20 buoys equipped with sensors for sea surface temperature (SST), surface air pressure, winds, and surface currents. Deploying some of these buoys in the neighbourhood of NIO's (National Institute of Oceanography) sub-surface buoys would allow a mapping to be developed between the sub-surface slope currents and the surface currents.
2. A 50-year coupled-ocean-atmosphere General Circulation Model (GCM) simulation has been run on the supercomputer at Computational Research Laboratory (CRL), Pune in collaboration with the Indian Institute of Science (IISc), Bangalore. Given the difficulty of making such simulations, it is imperative that the output of such simulations, whether coupled or purely oceanic, are rigorously analysed for a variety of problems. It provides an opportunity for good student dissertations and can catalyse interaction between the university programmes and major MoES-funded initiatives in climate and ocean modelling. Building competence in analysing such large model outputs is a step towards building modelling capabilities. Hence, such "data" have to be available for download at an Indian climate data centre.

### *5-year goal:*

1. Consensus is emerging that the central problem in monsoon prediction revolves around the intraseasonal northward and westward propagations across the Bay of Bengal. It is not disputed that the ocean plays a role in these propagations, but the nature of this role is not clear. Deciphering the role of the ocean will plug a major lacuna in our understanding of the intraseasonal variability of the monsoon. In order to achieve this goal, a key pre-requisite is the ability to simulate the ocean's intraseasonal variability. SST is the key variable in this case, but

its accurate simulation demands an accurate simulation of the wind-forced surface circulation, temperature, salinity, and mixed-layer depth. We need to have a quantitative description of this variability and the ability to simulate it before we can make sense of the coupled system. This goal is common to both elements, climate and environment.

2. Quantitative description of intraseasonal variability in the north Indian Ocean depends almost exclusively on satellite-derived data at present. It is imperative that the moored-buoy programme gradually evolve to providing reliable data on a real-time basis and that these data be available to the research community.
3. The present moored-buoy programme involves only a few sensors, there being practically no sub-surface temperature measurements, and provides limited ability to estimate fluxes. Moorings of the kind deployed by the Woods Hole Oceanographic Institution (WHOI) in the central Arabian Sea or the TRITON buoys deployed by the Japanese in the equatorial Indian Ocean are needed in the seas around India. These moorings will invariably require international collaboration because of the vast area that has to be covered.
4. The coupling between the ocean and the monsoon will eventually lead to coupled atmosphere-ocean models replacing atmospheric models as the main forecasting tools. Building capacity for this modelling activity is critical for progress.

*10-year goal:*

1. Progress in achieving the 5-year goals should lead to a better coverage of the north Indian Ocean with moored buoys of the WHOI/TRITON type. The huge data output by such a programme demands a dedicated scientific community that analyses these data and makes use of them for modelling and prediction.
2. In 10 years, there should be a group in India that designs moorings. Achieving this goal will require a dedicated engineering group apart from the ones that deploy moorings and collect and disseminate data.
3. In 10 years, there should be a few groups in India that can run coupled models.

### **3. Routine forecasting of the conditions in the Indian EEZ**

Of interest in a forecast of the oceanic conditions in the Indian EEZ are the following phenomena and variables: waves (significant wave height, seas, and swells), currents (both tidal and wind-forced), temperature and salinity, and biogeochemical variables. Our ability to make such forecasts depends on the current state of the science underlying such forecasts. At present, we have a good understanding of the variability at seasonal time scales, but have a poor knowledge of the variability

of even the physical variables at time scales ranging from days to weeks. One reason for this lack of knowledge is the dearth of observations that resolve these time scales in the Indian seas. Hence, in order to make forecasts, it is necessary to build first the science underlying such a forecasting system. This science involves both observations and modelling.

This theme is subdivided into sub-themes on the basis of the variable to be forecast.

### ***Sub-theme 1: Tides***

Of the variables described above, sea level and currents associated with tides are perhaps the most viable as short-term forecasting goals. At present, the Indian National Centre for Ocean Information Services (INCOIS) makes available an experimental forecast of tides in the Bombay-High region based on a tidal model developed at NIO.

#### *2-year goal:*

1. A viable 2-year goal is to extend this model forecast to the rest of the Indian EEZ. The model domain will have to cover the entire Indian Ocean, and the model must be validated using the historical tide-gauge data and the few current-meter measurements available from the Indian shelf. One model that is a good candidate for forecasting tides is ROMS (Regional Ocean Modelling System) because it can be used in two ways: as a fully 3D model, baroclinic model, and as a 2D, purely barotropic model. ROMS permits forcing by tides as well as by winds.
2. A regional tidal model is critical for the success of the Indo-French altimeter Altika. Tidal corrections made to other altimeter data (like TOPEX/Poseidon) can also be improved with a good regional tidal model.
3. It is important that the data from tide gauges along the Indian coast be available in near-real-time at INCOIS, even if these data cannot be disseminated immediately. Achieving the goal of telemetering the tide-gauge data will involve appropriate modifications to the existing tide-gauge network maintained by the Survey of India.

#### *5-year goal:*

1. Augment the current-meter data on the Indian shelf to assemble a reasonable database on tidal currents.
2. The NIO model is a finite-difference model with a uniform grid spacing. To enable the high resolution needed near the coast, this model can be modified to include a finer grid over the Indian shelf, but finer grid spacing in shallow waters is easier done with finite-element models. Hence, a viable 5-year goal is to develop, validate, and use (for forecasting) a finite-element

tidal model for the Indian Ocean. If a project is funded now to develop a finite-element model, it should be possible to switch to this model for forecasting within 5 years.

*10-year goal:*

1. In some regions of interest (like the northern Bay of Bengal and the broad shelf regime of the Bombay-High region), the tidal model can be extended to include baroclinic tides. Appropriate boundary conditions will be needed to force such a model and the cost implies that it will be viable only in regions of strong economic and environmental impact. Again, the advantage of a model like ROMS is obvious.

*Infrastructure needs:*

1. Tide gauges.
2. Real-time data transmission.
3. Tidal models.

***Sub-theme 2: Estuaries***

Estuaries are the backbone of the coastal zone, but remain poorly studied in India. A beginning has been made by NIO with the Mandovi and Zuari estuaries in Goa, the Kochi backwaters in Kerala, and the Gautami-Godavari estuaries in Andhra Pradesh. There are, however, several others, including the several estuaries in the vast delta that constitutes the Sunderbans.

*2-year goal:*

1. Identify two estuaries, one on each coast, with a college in the neighbourhood, and fund an intensive, inter-disciplinary study of the kind carried out by NIO.

*5-year goal:*

1. Extend the study to more estuaries across the country. Involve universities and colleges in this effort.
2. Identify institutions and colleges that can carry out a similar programme for the Sunderbans. Fund a comprehensive inter-disciplinary project.
3. Build capacity for estuarine observations and modelling.

*10-year goal:*

1. Use moored platforms for automating data collection in the better-studied estuaries.

*Infrastructure needs:*

1. Instruments: portable CTD, water sampling and analytical tools for chemistry and biology, and access (boats) to the estuary.
2. Moored platforms and real-time data transmission for the 10-year goal.
3. Estuarine models.

***Sub-theme 3: Waves***

Of the conditions at sea, the one most important for navigation is the roughness of the surface: waves. At present, ships in the Indian Ocean are supposed to get forecasts from the India Meteorological Department (IMD), but the present forecasts do not match the expectations of the merchant navy, which is used to getting much more sophisticated forecasts elsewhere in the world oceans. Efforts are on at INCOIS to forecast waves.

*2-year goal:*

1. Set up a few waverider buoy stations off the Indian coast to collect the wave data needed to validate wave models. One possibility that can be considered is to deploy these buoys in the vicinity of existing oil/gas rigs to ensure their viability.
2. Set up a wave model for the Indian Ocean. Use existing waverider buoy data to test various real-time wind products, called analyses, from atmospheric GCMs (AGCMs) in hindcast mode.
3. Forecast waves in the Indian EEZ and put in place a mechanism to test quality of the forecasts by the end of the 2-year period.

*5-year goal:*

1. Real-time transmission of wave data from at least a few waverider buoys in the Indian seas and enlarged effort to test quality of the forecasts.
2. Extend the forecasts to the rest of the Indian Ocean.
3. Assemble a suite of models to make forecasts in both shallow and deep waters.
4. Build capacity for assimilating data into wave models.

*10-year goal:*

1. Wave forecasts using models with data assimilation.

*Infrastructure needs:*

1. Waverider buoys.
2. Wave models for shallow and deep waters.
3. Data assimilation system for wave models.

***Sub-theme 4: Currents, temperature, and salinity***

Indispensable to any forecasting system is an observational system that provides the data needed to build and validate models and provides data that are available in near-real-time for assimilation into models. Equally indispensable are a modelling framework that can simulate these observations and a sound theoretical foundation for this framework.

The observations made till recently in the Indian seas can be used to describe only the seasonal cycle of the circulation, and the theoretical framework also therefore explains only the seasonal cycle. Hence, one major need, now being met under the INDOMOD programme, is to set up a system to make long-term measurements that resolve the variability at periods of days to weeks of the variables of interest in the shelf and slope waters off India.

Achieving success with the first element of ocean science, climate, is predicated on achieving success with this sub-theme. Unless we are able to quantify and simulate the variability of the ocean over a range of time and space scales, it is inconceivable that we will have success in quantifying the role of the Indian Ocean in our climate system. Hence, the goals of the climate element can be met only by meeting the goals of this sub-theme.

*2-year goal:*

1. Deploy sub-surface moorings, with upward-looking Acoustic Doppler Current Profilers (ADCPs), on the shelf and slope at three locations each on the west and east coast of India. These observations would provide the much-needed current time series capable of resolving the variability at periods of days to weeks. It is necessary to quantify this variability and make the data available to modellers.
2. A few intensive hydrographic cruises are needed in select regions off the Indian coast to provide the data to complement the current data from the ADCP moorings; each such observational programme would last a month and include a 15-day time series and sections to map the hydrography in the region. Along with these hydrographic surveys, we need measurements of currents in the near-coastal shelf regime using surface moorings and of winds and sea level

using Automatic Weather Stations (AWSs) and tide gauges. These observations will be complemented by biogeochemistry observations to provide a comprehensive, inter-disciplinary data set.

3. Use an Oceanic GCM (OGCM) to simulate the above (physical) observations.
4. Complement these OGCM simulations with a suite of simpler process models to unravel the science underlying the observed variability. Just as simple models were needed to build the theoretical framework for the seasonal cycle, they will be indispensable for building the science underlying variability at higher and lower frequencies.
5. Test various AGCM products (model analyses providing the wind, air temperature, and humidity fields as input to ocean models) to see which is most suitable for simulating the observations using the OGCM. Note that such tests against observations need to be carried out regularly: it is not enough to test a product just once.
6. Continue to improve the forecasts issued by INCOIS and achieve the goal of forecasting the 3-dimensional ocean. One or two groups in the country should be encouraged to address specific
7. Fund projects that lead to the goal of forecasting: the projects need to build our knowledge of variability across a range of time and space scales and the OGCMs used need to be tested against the data collected under the complementary observational programmes. A key problem in forecasting is the prescription of appropriate initial conditions, and this problem has to be addressed irrespective of whether the model includes data assimilation or not.

*5-year goal:*

1. Continue the intensive one-month-long observational programme initiated by NIO.
2. Deploy AWSs along the coast to complement the wind data from satellites and AGCM analyses. The wind data from scatterometers are not reliable in the near-coastal regime and will have to be complemented by AWSs.
3. Explore the possibility of transmitting the current observations in near-real-time. (There is an attempt in China to do so from sub-surface buoys.) Another possibility that needs to be explored is the deployment of a few surface buoys with current meters and ADCPs for long-term measurements.
4. Ensure viability of the NDBP data-buoy network assembled by the National Institute of Ocean Technology (NIOT) and extend it and the Argo programme to enable a reasonable coverage of the north Indian Ocean.
5. Fund a mathematics group to build a data-assimilation system (adjoint model) for the forecasting system. The assimilation system has to be built for an OGCM that has been proven to work well without assimilation in order to ensure that the best available OGCM is used for

forecasting. To begin with, assimilate only those data whose near-real-time availability is assured at present. Test the assimilation system in hindcast mode using a variety of wind products: satellite-derived winds, model reanalyses, etc., and then extend the tests to real-time forcing products (model analyses).

6. Use the OGCM with data assimilation for experimental forecasts at the end of 5 years. To achieve this goal, the engineering involved (receiving real-time atmospheric and oceanic data at INCOIS) will have to begin earlier. It may be necessary to involve the private sector in this engineering effort.

*10-year goal:*

1. Near-real-time data transmission from the moored-buoy network.
2. In 10 years, there should be a group in India that designs moorings. Achieving this goal will require a dedicated engineering group apart from the ones that deploy moorings and collect and disseminate data.
3. Forecasts with an OGCM with data assimilation.

*Infrastructure needs:*

1. Sub-surface moorings with upward-looking ADCPs and current meters.
2. Surface moorings with ADCPs, current meters, thermistor chains, and salinity sensors.
3. AWSs and water-level recorders.
4. Ship-borne observational programme.
5. A suite of models, including an OGCM.
6. A data-assimilation system (adjoint model for the OGCM).

***Sub-theme 5: Ocean acoustics***

The use of sound to study oceanographic parameters and processes (including biological processes) has been an important tool in the hands of oceanographer all over the world. However, this field is yet to take firm roots in the country. Remote measurement of sea-state parameters, bottom properties, internal waves, rainfall and many other unknowns is possible through acoustical techniques. SONAR systems are used to remotely sense the interior of the ocean and new types of specialised systems and analytical techniques are being developed. Currently in India, only very few groups (such as the ones at NIOT and IIT, Delhi) are working in this area. It is essential to build capacity to carry out research in this field.

*2- year goal:*

1. Development and deployment of passive detection (ocean ambient noise measurement) systems, and their analysis.
2. Deployment of monitoring systems, time series measurements at strategic locations along the coast, and analysis of such data to draw inferences about the phenomena that the data record.
3. Acoustic signal processing and analysis for influencing parameters of noise such as wind, wave, rain, biological, etc.

*5- year goal:*

1. Training to run sound propagation models that are proven and freely available and use them for local oceanographic application.
2. Capacity building for undertaking (1).

*10- year goal:*

1. To be decided on the basis of experience in meeting 2-and 5-year goals.

#### **4. Theme: Natural hazards**

The natural hazards considered here are storm surges and tsunamis.

##### ***Sub-theme 1: Storm surges***

Storm surges are more important for the Indian east coast. These models are similar to tidal models, but are forced by the wind. In both cases, tides and storm surges, the key variable to be observed is sea level. Hence, given that the observational tools are also the same, i.e., tide gauges, this sub-theme has a lot in common with the tides sub-theme of the forecasting theme.

*2-year goal:*

1. It is important that the data from tide gauges along the Indian coast be available in near-real-time at INCOIS, even if these data cannot be disseminated to the public. Achieving the goal of telemetering the tide-gauge data will involve appropriate modifications to the existing tide-gauge network maintained by the Survey of India.
2. A viable 2-year goal is to make forecasts for the Indian east coast. For operational simplicity, it will be useful to ensure that the same numerical model base is used for both tides and storm surges. The model must be validated with the historical tide-gauge data and any shallow-current-meter measurements available from the Indian shelf. It should also be tested against

record of sea level during storm surges using appropriate wind fields. As with tides, a good candidate is ROMS because it can be forced by both tides and winds.

*5-year goal:*

1. The finer grid spacing needed in shallow waters can be managed with finite-element models. Hence, a viable 5-year goal is to develop, validate, and use (for forecasting) a finite-element storm-surge model for the Indian Ocean.

*Infrastructure needs:*

1. Tide gauges.
2. Real-time data transmission.
3. Storm-surge model.

***Sub-theme 2: Tsunamis***

The hazard posed by tsunamis hit home on 26 December 2004, forcing the oceanographic community into urgent work on this till-then-ignored phenomenon. The tsunami research, however, needs careful coordination to ensure progress towards viable societal goals.

Tsunami forecasting depends on models, which are of three kinds. The first kind of models, which simulate tsunamis on the scale of a basin like the Indian Ocean, are similar to tidal models, but are forced by an initial sea-level disturbance. These models provide an estimate of the sea level in the near-coastal region and model sea level is usually tested against tide-gauge measurements. The second kind of models computes the run-up on the coast, which determines the potential inundation and actual damage to coastal property. Both these models are called forward models, in that they start with an initial condition and simulate the propagation of the tsunami forward in time. The third kind of models used in tsunami forecasting is backward-in-time models, which start from an observation of sea-level displacement and work backwards to trace the source of the tsunami rays. These ray-tracing models are an important component of a tsunami-forecasting system as the “correct” initial condition or initial sea-level displacement is not known until much after (several days to weeks) the event because it takes time to process the seismic data for the slower seismic waves. Hence, tsunami forecasting relies heavily on scenario databases (based on hypothetical tsunamis) and real-time, bottom-pressure data from the vicinity of the tsunami source.

At present, different groups in India use a variety of models, with most depending on models developed elsewhere in the world. All run-up models used in India are of foreign origin.

*2-year goal:*

1. In order to ensure rapid development of a tsunami model, it will help to use for modelling tsunamis (on the basin scale) the same (forward) numerical model base used for tides and storm surges. All that needs to be modified is the forcing. The finite-difference model developed at NIO has now been tested for the 2004 tsunami and the 1945 Makran tsunami and presents a viable prototype for the forward model, but the parallel version of this model needs to be set up for the Indian Ocean and made more easy to use.
2. A run-up model has to be set up and tested against available data. It should be made to work in association with the basin-scale tsunami model.
3. The network of bottom-pressure recorders (BPRs) has to be made viable to ensure its usefulness in a tsunami forecast. In order that the system works, it is important that its data be used for other purposes too so that a check is kept on the data from these buoys.
4. Since the number of these buoys is small, their location has to be optimised to ensure the best possible configuration for tsunami warning. Ray-tracing models have to be made “operational” so that they can be used easily in the event of a tsunami being recorded by the BPRs.
5. If the network of BPRs works, then it, along with the backward and forward models, presents the best possible forecasting option for a specific tsunami. A viable forecasting system can be assembled by testing this suite of observational and modelling tools against hypothetical BPR records provided by the tsunami simulation database.

*5-year goal:*

1. The finer grid spacing needed in shallow waters is better managed with finite-element models. Hence, a viable 5-year goal is to develop, validate, and use (for forecasting) a finite-element tsunami model for the Indian Ocean.
2. The suite of models involved in operational forecasting need to be engineered such that they can be run quickly in the event of a tsunami. The main concern here is the ease with which the forecasting system can be put into operation when a tsunami-earthquake occurs. In short, how ready-to-go is the forecasting system? Dummy testing at intervals is necessary to keep the system functional because tsunami events are infrequent. (It is this infrequent nature of this hazard that makes it useful to use the same base model for tsunamis as is used for tides and storm surges. First, the tidal and surge models will always be operational, and the model is guaranteed to be functional at any time. Second, it allows sharing of human resources across programmes and allows a viable career option for tsunami researchers and forecasters. The appetite for a tsunami warning will decline over time, making it necessary to make the difficult

choice between allocating scarce resources (especially human) to tsunami warnings and to forecasting tides or the more regular hazard of storm surges.)

3. Create a database of regions where tsunamis are possible and the potential run-up is a serious threat.

*Infrastructure needs:*

1. Bottom-pressure recorders (BPRs).
2. Tide gauges.
3. Real-time data transmission from tide gauges.
4. Tsunami models: basin-scale models, run-up models, and ray-tracing models.
5. Tsunami-simulation database.

### **5. Theme: Environmental impact assessment (EIA)**

Environmental impact assessment (EIA) is becoming important owing to the growth in the Indian economy. Its importance cannot be overemphasised: a bad assessment of the environmental damage of a potential activity can add to the overall cost to society. It has often been noted that, though the objective of EIA is not to model the environment in all its infinitely complex detail, the practical goal in impact assessment *must be to apply to decision making the knowledge we already have*. According to Erikson, potential impacts are those impacts that are reasonable in light of theory or general understanding, and probable impacts are those that are reasonable in light of theory and site-specific conditions. The identification of potential and probable impacts on the physical environment depends on an informed understanding of specific dynamical processes. EIA is therefore one of the most important applications of our knowledge of shallow-water processes like waves, tides, currents, and biogeochemistry in the coastal zone. Hence, this theme can be considered an application of several of the sub-themes of the other two themes: it is also the one whose impact on society is felt most by the general public, even if this impact is restricted to the coastal zone.

EIA forms a major component of the work done in, and cash flow into, institutions like NIOT, NIO and the National Environmental Engineering Research Institute (NEERI). Given the number of EIA projects undertaken annually, one would assume that they apply to decision-making using the knowledge we already have, or take to the field the knowledge gained through basic research. Yet, there seems to be little interaction between these two activities, with little of the research done being applied to EIAs, and the EIAs, in turn, having almost no impact on research. This situation

needs to change. In order to make EIAs more reliable, it is important that they are based on an informed understanding of specific dynamical processes.

Several EIA studies now include modelling at least of the physical system to simulate the observations made as part of the assessment. The most popular model used in these studies is MIKE-21, an industry-standard code for EIAs. The model is used to simulate waves and currents and the resulting transport of pollutants and sediments. For the purpose of EIAs, the model domain invariably covers a small region, at most a couple of degrees latitude by longitude, and uses available data to provide the required boundary conditions. The model is usually forced by tides at the boundaries (derived from tide-gauge observations at a few locations and extrapolated to the rest of the boundary) and by winds (derived from coastal observations made by IMD or by satellites). The connection to the research envisaged in the first theme on routine forecasting is obvious. Yet, neither is a basin-scale tidal model usually used for providing the boundary conditions for the limited-domain model, nor do most of the EIA tidal modelling studies contribute to progress in research. Similarly, the research on wind-forced surface circulation has had no impact on EIA studies, and these studies, in turn, have had no impact on such research.

We provide here but one instance of the significance of basic research for EIA studies that involve measurement and simulation of wind-forced currents. Available EIA reports show that most of the measurements are made in water depths of around 10 metres and the size of the simulation domain rarely exceeds 200 km by 200 km. The simulations are usually found to be reasonable for the tidal component of the current, but are not as good for the wind-forced component because they include, at best, the effect of forcing by local winds. Remote forcing is known to have a significant impact on the circulation along the Indian coast, and it has recently been shown that remote forcing is important even in water depths as shallow as 10–20 metres on the Indian west coast. Hence, to simulate even the local environment the model domain needs to be much bigger than in present-day EIA studies: it may even be necessary to use basin-scale model outputs to provide the boundary conditions for the regional wind-forced simulations.

In order to build a bridge connecting basic research and EIAs, the following strategy is proposed. There must be long-term water-level and current measurements at a few locations (say, industrial-activity “hot-spots”) along the Indian coast. These long-term measurements can be used for research on near-coastal circulation, and modelling groups working on EIAs should be encouraged to prove their skills by validating their simulations with these observations. Doing so would lead to quality research that has direct application to EIAs. The EIAs, in turn, would have access to longer

data records (on payment to the agency making these long-term measurements if the EIA study is commercial) in some regions to complement their short-duration measurements made specifically for the project. These shorter data records would also be more useful than they are at present because of the longer record against which they can be “calibrated”. Deployment of shallow-water “environmental buoys”, as done earlier under the NDBP programme, in major ports and industrial hot spots would also provide a long time series of data useful for EIAs and associated research. The atmospheric analog of the oceanic buoys are micrometeorological towers, a set of which can be maintained by a college with a strong programme in environmental science. These data can be used to study much-neglected but important phenomena like the sea breeze and its effect on the local climate.

*2-year goal:*

1. Deploy shallow-water “environmental buoys” in major ports and industrial hot spots. Make these data available for research and for EIAs (for a user fee if necessary).
2. Deploy long-term surface buoys with current meters and thermistors at one location each on the east and west coast. Make these data available for research and for EIAs (for a user fee if necessary).
3. Encourage those who do EIAs to use these data to validate their models.
4. Involve universities and colleges, particularly engineering colleges with an environmental science/engineering programme, in the region, in this effort to build a viable buoy programme.

*5-year goal:*

1. If the above experiment is successful, extend the buoy network to cover all ports and major industrial hot spots.
2. The scientists involved in EIAs are to researchers what practising doctors are to those involved in medical research. Just as a doctor is expected to keep abreast of developments in the field, so are EIA specialists. A doctor has three major sources of knowledge: published literature, medical representatives of the pharmaceutical companies, and refresher programmes that bring together the medical community, with more established practitioners passing on their knowledge to the others. Private companies that build EIA models fulfil the role of medical representatives in the EIA field, but it is evident from the current state of EIA practice in India that the EIA specialists do not consider it necessary to keep themselves abreast of modern research, the exception being new measurement technologies. Hence, short-term courses, conducted by practising researchers but designed for EIA specialists, would go a long way towards improving the quality of EIAs in India. The quality of EIA has to improve as the Indian economy grows

because the economic and social consequences of bad decisions will prove more costly as income rises in India.

## **6: Biogeochemistry**

This theme is divided into sub-sections based on geography because the approach varies depending on the location. We start with the coastal region and then go on to examine the open-sea regime.

The third sub-section examines issues related to assembly of a reliable climatology of variables of interest in biogeochemical studies. The section concludes with a discussion on biogeochemical of polar seas.

### ***Sub-theme 1: Coastal Ocean Biogeochemistry***

Coastal Biogeochemistry is very complicated owing to its connection with land and the direct influence of anthropogenic inputs. Recent studies suggest that short-term or episodic events related to either natural or anthropogenic causes are important for biogeochemical processes in the coastal ocean, but it is almost impossible to capture these processes using shipboard observations alone. Given the present state-of-the-art in biogeochemical observations, it is possible to envisage large-scale biogeochemical processes and material cycling in the ocean. Therefore, several moorings should be deployed along the Indian coast with real-time transmission of data to enable monitoring the ecosystem response to the natural (such as cyclone, depression, heavy rainfall, etc.) and anthropogenic activities, nutrients inputs, acidic/basic chemical disposal through sewages, freshwater discharge, fertilizers, etc.

#### *2-year goal:*

1. It is important to set up at least two mooring, one on each coast, with real-time data transfer to INCOIS and disseminate this information to the public. Unlike the physical sensors, biogeochemical sensors are prone to drift due to biofouling, which have a major influence on light-based sensors. Such threat is more for the coastal ocean than for the open ocean; this threat also varies in space and time. In addition is the problem of vandalism. Therefore, enough background work should be carried out keeping the above issues in mind. Achieving this goal also requires appropriate training on sensor calibration, maintenance, etc.
2. INCOIS is maintaining several mooring to study wave height and periodicity in the coastal ocean with real-time data telemetry. For operational simplicity, it will be useful to keep the biogeochemical sensor suite at the same location, but the data will have to be calibrated more frequently (at least once a month).

3. In addition to the mooring, in situ sampling should be done for targeted tracer measurement to understand the processes, which is not always possible using sensors alone.

*5-year goal:*

1. Increase the mooring locations to at least three on each coast. Using these data, efforts should be made to construct forecasting models.
2. The forecasting models should be tested against real-time data and required improvements should be made.
3. Deliver the data to the public via Internet to give warnings on relevant issues, such as the time and area for good fishing, time and area of occurrence of harmful algal blooms, trends in ecosystem changes in given region (climate sensitive regions), and potential reasons and possible solutions for changes in ecosystem structure.

*10-year goal:*

1. Near-real-time data transmission from the mooring buoy network.
2. Forecasting models should be made operational: shifts in the ecosystem structure, changes in chemical composition, influence of extreme atmospheric events, and human interferences should be monitored on-line in real-time mode.
3. In 10 years, there should be a group in India to design and develop biogeochemical mooring and calibration methodologies.

*Infrastructure needs:*

1. Mooring equipment
2. Real-time data collection sensors for biogeochemistry

***Sub-theme 2: Open Ocean Biogeochemistry***

Oceanic response to climate change is one of the important issues and requires special attention. Such issues can be answered only through systematic time-series observations of physical and biogeochemical parameters. Such time-series observations have been operational for the last two and a half decades in the Pacific and Atlantic Oceans. The Intergovernmental Panel on Climate Change (IPCC) reports mainly depend on the oceanic trends shown in these three time-series sites (mainly Hawaii Ocean Time-series Station (HOTS), Station PAPA, and Bermuda Atlantic Time-series Station (BATS)). No such time-series station has been established so far in the Indian Ocean. It is time to initiate such observation stations, one each in the Arabian Sea and Bay of Bengal, in the

open ocean, far from the land-ocean-interaction zone. In such time-series locations, all biogeochemical processes from nutrients to genes have to be studied, and time scales from the diurnal to decadal should be covered. Since it is not possible for this study to be done by one group or one laboratory, these time-series observation sites should be developed as test bed for several experiments by interested national and international scientists. Setting up of such stations requires committed ship availability at regular intervals.

*2-year goal:*

Set up one time-series station in either Bay of Bengal and Arabian Sea with monthly observations at a deep station (water depth greater than 2000 m). Deep moorings may be set up at the time-series location with several biogeochemical sensors. Develop calibration methodologies.

*5-year goal:*

Increase the time-series locations and deep-moorings and automatized sampling using remote access samplers so that high frequency sampling can be carried out. Develop models and test them at the test-bed to understand influence of climate change, climatic events such as ENSO and Indian Ocean Dipole, and decadal oscillations on biogeochemical cycling of material in the ocean.

*10-year goal:*

In 10 years, the model should be able to reproduce actual variability and provide insight into future changes of atmospheric green houses gases, oceanic absorption capacity, and ecosystem changes etc. to help policy makers to take decisions.

*Infrastructure needs:*

1. Dedicated research vessel
2. Mooring equipment
3. Real-time data collection sensors for biogeochemistry

***Sub-theme 3: Biogeochemical climatology***

Despite three decades of ocean research in India, we are at a stage that we do not have a good climatology of basic biogeochemical parameters such as nutrients, oxygen, and chlorophyll. The climatology made by the National Ocean Data Centre (NODC) has several gaps in space and ~80% of the Indian Ocean region was sampled just once or two times. A good climatology is essential in order to construct biogeochemical models and to test their performance. This goal can be achieved

in a simple manner at least for surface data. MoES owns ~25 ships and each has a different cruise plan every year. INCOIS has plans to install AWSs on board to collect surface meteorological data along the cruise tracks. Therefore, it would be interesting to have biogeochemical sensors, such as dissolved oxygen, chlorophyll, partial pressure of carbon dioxide, nutrients, and pH, and to transfer these data in real time to INCOIS. In addition, several organizations, universities, and colleges utilize MoES ships to fulfill the objectives of their projects. Even though national institutions mostly submit their data to the data divisions, most of the data collected by the universities or colleges may not be reaching the data repositories. It is important to ensure that the investigators submit data to INCOIS. Such a strategy will enable not only the construction of a climatology of the Indian Ocean biogeochemical parameters, but also an examination of the long-term trends that are important for climate change.

*2-year goal:*

1. Installation of sensors on at least 5-10 ships and establishment of real-time data transfer mode.
2. Archival of data from earlier cruises made by different participants and their quality control.

*5-year goal:*

1. Installation of sensors on more or all ships of MoES.
2. Completion of data archival.
3. Update data sets and prepare climatology of biogeochemical parameters.

*10-year goal:*

1. Increase the coverage in time and space to make the climatology more robust.
2. Use the climatology for modelling.
3. Use the data to study influence of climate change on biogeochemical responses.

*Infrastructure needs:*

1. Real-time data collection sensors for biogeochemistry, such as underway pCO<sub>2</sub>, Optodes, fluorometers, and in situ autoanalyzers.
2. AWSs.
3. MoES ships.

#### ***Sub-theme 4: Polar ocean biogeochemistry***

The Southern Ocean is the most important region on the earth surface with reference to material cycling. This region absorbs, for instance, huge amounts of atmospheric carbon dioxide at the surface and transports it to the deep ocean. Model studies show that the Southern Ocean's absorption capacity for atmospheric carbon dioxide is decreasing in recent years and some regions have already turned into mild sources of carbon dioxide to the atmosphere. These model inferences are not, however, supported by observational evidence owing to a lack of systematic studies in this region. Furthermore, the warming of the Southern Ocean has a significant impact on circulation as well as material transport, and the composition of atmospheric aerosols has a significant impact on Southern Ocean biogeochemistry. Therefore, systematic studies are required to examine how this sensitive region is responding to climate change.

##### *2-year goal:*

1. Systematic repeat hydrographic sections study should be conducted to understand seasonal and interannual variations in physical and biogeochemical cycling of material in the Southern Ocean.
2. The size distribution of atmospheric aerosols should be studied and their source should be tracked.

##### *5-year goal:*

1. Most of the studies on the intraseasonal variability in the Indian sector of Southern ocean depend mainly on satellite-derived data. Hence, moorings should be used for providing reliable data on a real-time basis and these data should be available to the research community. Since we have no experts for moorings at high latitude, we will require international collaboration.
2. Continue the repeat hydrography data collection to assemble a large biogeochemical data set..
3. Based on the mooring, repeat hydrography, and remote sensing data sets, models may be developed to understand large-scale features with reference to climate change.

##### *10-year goal:*

1. Based on such large data sets, explore the correlation between Southern Ocean climate change and Indian monsoon system.
2. Establish how key ocean processes are expected to change and what are the biological and climatic consequences.
3. Show how the ocean's absorption capacity (for CO<sup>2</sup>) is changing due to climate change.

*Infrastructure needs:*

1. Dedicated polar research vessel.
2. Mooring equipment.
3. Real-time data collection sensors for biogeochemistry.

## **7. Infrastructure demands**

There are four major infrastructure requirements in view of the plan discussed in Section 2-6. These are :

1. It is clear that observational programmes are moving increasingly towards automated, mooring-based collection of data. Hence, mooring technology will have to be mastered.
2. Ocean and coupled models are likely to be run by a few groups, but there will be many more who are interested in the results of their simulations. Hence, these data have to be made available over (say) the National Knowledge Network (NKN); doing so demands a data centre that disseminates the results (output) of major simulations over the Internet.
3. Ocean and climate modelling is a major component of the plan, implying the need for computers that can run the required models. Such computing facilities have to be available at all major ocean research centres in India and adequate computing facilities available at all institutions teaching oceanography.
4. Another key area is the management of our ocean research vessels. We have two suggestions:
  - a) As in the United States (US) and the European Union (EU), it is important that we quickly reach a stage in which cruise plans are laid out in advance and the cruise schedules are made public. Given the cost, both financial and human, of maintaining these vessels, it is important that they be treated as national facilities, but with the task of daily management divided among different agencies or institutions. A national ocean-research-vessel committee to oversee the implementation of the cruise scheduling and implementation is critical. Indeed, no observational programme, even those based on automated mooring-based sensors, can be viable in the absence of a coordinated vessel management plan.
  - b) It would help if the company handling the vessels has officers and crew dedicated to the research vessels, as is the case in the US and EU. Though this goal seems unviable at present, it might become viable in 5–10 years. Having officers and crew who are familiar with the vessel will permit better maintenance and will make it easier to conduct experiments because the ship staff will have the required experience.

## **8. Human resource demands**

The most important bottleneck in implementing any vision for ocean sciences in India today is the acute dearth of trained, competent manpower. Traditionally, the teaching of oceanography was confined to the two initial centres, Andhra University in Visakhapatnam and CUSAT in Kochi. Most of the oceanographers in India had been trained in these two universities. Over the years other universities started departments dedicated to oceanography in general (Goa University, Behrampur University, etc.) or in certain sub-disciplines of oceanography (for example, physical oceanography at IIT-Delhi and Indian Institute of Science, Bangalore).

A well developed and well-rounded programme in oceanography, i.e. a programme that emphasizes multidisciplinary nature of the field and provides facilities for both observational and theoretical studies, requires infrastructure that is not easy to set up. It requires access to a ship, large faculty (due to the multidisciplinary nature of modern oceanography), a large library, specialized equipment that can be deployed at sea, and specialized analytical and computing laboratories. The central problem of creating adequate ocean science manpower is the following. The only place in India that has the infrastructure to teach a well-rounded programme in oceanography is the National Institute of Oceanography (CSIR), the oldest and largest institution dedicated to ocean science research in this part of the world. Its mandate, however, does not include teaching of degree-granting programmes. The institutions and universities whose mandate includes teaching of such programmes do not have adequate infrastructure to produce a well-rounded teaching programme leading to Master's and Doctoral degrees.

If we were to correct the above situation, we must first accept some basic realities and then act to develop programmes that are consistent with these realities. First, ocean science institutions in the country are almost exclusively funded by the government. Relevance and growth of these institutions depend on quality of the manpower in these institutions. Hence it is in the interest of government (in this case most important stakeholder is the Ministry of Earth Sciences, Government of India) to ensure that students who enter an oceanography education programme have the competence to go through the programme and then become productive oceanographers. Second, the quality of students who enter a programme of education depends primarily on confidence they have in prospects of jobs on successful completion of the course. The quality can be further enhanced if the student is offered a fellowship that is monetarily more attractive than the norm. Third, in the opinion of this committee, ocean science education in India is best imparted either after a master's degree in sciences or after a bachelor's degree in engineering. This is primarily because the bachelor's degree programmes in sciences are not as well developed to ensure easy passage into a

multidisciplinary and demanding subject.

Keeping in mind the above three points, in particular the second point, it is necessary to make an estimate of the minimum number of ocean scientists that government-funded institutions can absorb in a sustained manner in the long run. This we now attempt by using the following principle. If  $N$  is the number of sanctioned positions of ocean scientists in government institutions in India, and if  $Y$  is the number of years an ocean scientist is expected to spend in an institution, then once a 'steady-state' is reached, the country will need to produce about  $(N/Y)$  number of ocean scientists every year to assure that all the sanctioned positions will remain filled in spite of retirements, resignations, etc. We look at this number,  $(N/Y)$ , as the number of well-rounded oceanographers that the government should strive to produce every year by setting up a National School of Oceanography (NSO) with infrastructure that is at par with the best schools of oceanography in the world. Note that when our institutions are at a growing phase, the number of scientists that can be recruited per year can be at a level that is higher than  $(N/Y)$ .

In order to compute the number  $(N/Y)$  we need an estimate of  $N$ . We take this to be what is usually referred to as "sanctioned positions" in government institutions that require oceanographers at Master's (we will call them as M.Tech. in the proposed school of oceanography) and at Ph.D. level. Table 2 gives our estimates of sanctioned positions for different institutions dealing with ocean sciences in the country. In estimating  $Y$  we have assumed that typical hiring of a doctorate holder will be at Scientist-C level (in CSIR system) at the age of around 30. This gives the recruit about 30 years of service; but we have taken  $Y$  for Ph.D. holders to be about 25 to account for those who might leave earlier for various professional or personal reasons. In similar fashion we assume that an M.Tech. graduating from the proposed school will be hired at the age of about 25 and should be able to put in total service of 35 years. In the table we have taken  $Y$  for them to be 30 years. Table 2 is strictly a "back of the envelope" calculation and should be modified as more reliable data becomes available. However, it does provide numbers to determine annual intake of students in the proposed NSO, and that graduates from the school (M.Tech. and Ph. D. holders) can be virtually guaranteed employment in government-funded institutions in the country.

Institution	Biol. Ocean.		Chem. Ocean.		Geol./Geophy. Ocean.		Phys. Ocean.	
	Doct.	Mast.	Doct.	Mast.	Doct.	Mast.	Doct.	Mast.
NIO	50		50		50		50	
INCOIS	2	3	2	3	2	3	25	25
NIOT	5		5		5		10	10
NCAOR	10		10		10	10	15	
NPOL/Navy							10	15
IITM	5		5		5		20	
CESS	5	10	5	10	5	10	5	10
IISc							10	
IIT-Delhi							5	
CUSAT, Kochi	5		5		5		5	
Andhra U.	5		5		5		5	
Jadavpur U.	5		5		5		5	
Coastal State Govts.		10		10		10		10
<b>N</b>	92	23	87	23	92	33	175	70
<b>Y</b>	25	30	25	30	25	30	25	30
<b>(N/Y)</b>	4	1	4	1	4	1	7	2
<b>Class size entering School</b>	<b>5</b>		<b>5</b>		<b>5</b>		<b>9</b>	

**Table 2:** A “back-of-the-envelope” estimate of the number of students that should enter the National School of Oceanography annually to ensure appropriate employment opportunities on completion of the course.

We propose that admission to the NSO should be through a national competition, and couple of dozen selected candidates should be offered a fellowship that carries a stipend that is higher than that offered by other fellowships (NET, ISRO, etc.). This will help to attract more talent to the school. One who completes M.Tech. or Ph.D. programme of the NSO should be guaranteed either a Scientist-B (for those who complete M.Tech. course) or a Scientist-C position (for those who complete Ph.d. programme) on signing of a suitable bond. The best suited agency for making this commitment is the Ministry of Earth Sciences, which in turn will benefit immensely from the manpower generated by the school.

As noted earlier, the only institution in India that at present has the necessary infrastructure (laboratories for physical, chemical, biological and geological oceanography, library, ships, etc.) and a large enough body of scientists with specializations in physical, chemical, biological and geological oceanography to take up the task of setting up the NSO is NIO. The NSO could be initiated here without much investment. This potential needs to be tapped.

While the role of NSO will be to assemble the core competence in the multidisciplinary field of modern oceanography, the school will not be able to meet the demand from various institutions that are still growing and are yet to have manpower that is close to their “sanctioned strength”. We expect that the needs beyond what NSO can meet will need to be met by institutes and universities that have oceanography teaching programmes at the present. These programmes, however, will need to focus on those areas of teaching where they have the adequate infrastructure.

In addition to the above, what has been suggested in Section 2-6 of this document cannot be met unless other efforts are made towards training of manpower in the country. Here we list some steps that need to be taken up:

- 1) There is a need for short-term, focussed courses on specific topics to help scientists and engineers improve their skills. Short-term courses, conducted by practising researchers but designed for EIA specialists, would go a long way towards improving the quality of EIAs in India. The quality of EIA has to improve as the Indian economy grows because the economic and social consequences of bad decisions will prove more costly as income rises in India. It is likely that EIAs will gradually become important for insurance too.
- 2) Though a number of groups in India are now running GCMs (see Table 3), there is very little interaction among them. Given that no single group has the critical mass necessary for ensuring reasonably quick progress, it is imperative that MoES/INCOIS serve as a catalyst to bring these groups together on an annual basis to ensure that we acquire the critical mass at least on a cross-institutional, national basis. Such a meeting, with a carefully planned agenda, would help the more accomplished GCM groups share their expertise and knowledge with the others, leading to more rapid growth than has been possible so far.
- 3) One field in which there is a major shortage of skilled manpower, and in which the shortage is going to prove critical, is the mooring programme. There exist no training programmes for mooring engineers or technicians, making it difficult even to sustain existing programmes. A training programme, coordinated by NIOT and NIO, would help.
- 4) In research institutions in the west, the lynchpin of research is the post-doctoral fellow (PDF). A PDF has gone through the rigours of a Ph.D. and is familiar with the process of

Institution	Ocean model						
	MOM	POM	ROM	HYC	LOM	LCS	RGM
Indian Institute of Science, Bangalore	●		●		●		
NIO, Goa	●					●	●
CMMACS, Bangalore	●						
IITM, Pune	●	●					
INCOIS, Hyderabad	●		●	●			
CDAC	●		●	●			
IIT, Delhi		●					
IIT, Kharagpur			●				
NCAOR, Goa		●					
SAC, Ahmedabad	●						
Allahabad University, Allahabad	●	●					
Jadavpur University, Kolkata			●				

**Table 3:** Institutions in India that run ocean models and the models being used by them. MOM: Modular Ocean Model developed at GFDL, Princeton; POM: Princeton Ocean Model developed at GFDL, Princeton; ROM: Regional Ocean Modelling System (ROMS); HYC: Hybrid Coordinate Ocean Model (HYCOM); LOM: 4.5-LOM is the 4.5-layered reduced-gravity-type model; LCS: LCSM is the linear, continuously stratified model; RGM: 1.5-layer RGM is the 1.5-layer reduced-gravity model. Though the last three models above also apply to the whole Indian Ocean, they are not normally classified as GCMs. Their limited vertical resolution implies they run faster on a given computer and are therefore often used for analysing processes.

## 9. Role of various agencies

Sections 2-6 defined the research programmes we should have, Section 7 described the physical infrastructure that will be required to meet the goals of the research programmes, and Section 8 proposed how the country should generate manpower to implement the research goals. All these proposals will ultimately need to be met through appropriate institutions. In this concluding section we summarize what we feel ought to be the key mandate of each of the major ocean science and technology institutions in the country to be consistent with the ideas generated in this document in Section 2-8.

The primary mandate of INCOIS is forecasting.

- i. Its research activities should be geared towards taking the basic research results and

building on them to engineer a forecasting system. Given its present staff strength, INCOIS has to focus its work carefully to ensure that the required critical mass is available to deliver results in each of the forecasting fields.

- ii. As an ocean services hub, INCOIS is also responsible for archiving and disseminating oceanic data from a variety of sources. Building this data centre will require careful thought, and, as with forecasting, focus in order to ensure delivery of data to the users.
- iii. At present, the focus of INCOIS is primarily on building a viable forecasting system and funding projects. It does, however, have an important role to play in catalysing interaction between the various modelling groups to build the critical mass across the country.

NIOT's mandate is ocean technology, which seems to include two elements.

- i. The first element is development of new technology. As noted earlier, it is important to prioritise to ensure that critical mass of manpower and resources is available for new instrument or technology sought to be developed. This requirement demands focussing on a few technologies that are commercially viable or are needed owing to strategic reasons.
- ii. The second element is deployment of automated platforms for gathering data. The data reception and dissemination can be done by INCOIS.

NCAOR's primary mandate is research on Antarctica and the southern ocean. One major impact of the southern ocean is on climate, and this link is going to become more important with the problem of "climate change."

With forecasting being the mandate of INCOIS and technology that of NIOT, the key mandate of NIO then becomes the large observational and modelling programmes that depend on and also feed the programmes at INCOIS and NIOT. NIO, however, does need to expand its mandate to contribute more to education in ocean sciences (see Section 8).

- i. NIO has to interact closely with INCOIS. For example, the research that is needed to build the science underlying a forecasting system can be done at NIO, with the applied research, building on these results and engineering a forecasting system, being done by INCOIS. The needs of INCOIS will enable NIO to focus its priorities too in order to avoid frittering away its resources on too many fronts. This symbiotic nature of the relationship demands closer interaction between the two institutions and would benefit both.

- ii. The data collected by the NIOT-deployed moorings would be critical for the research at NIO (and at IITM). In turn, NIO, with its research needs, should drive some of the technology programmes at NIOT.
- iii. NIO, with its focus on combining observations, especially those made using ships, with theory, forms a good setting for teaching oceanography. Hence, NIO needs to extend its mandate to include teaching.

The oceanographic focus of IITM will undoubtedly be on the monsoon and therefore on the role of the ocean in our climate, the first of the three elements of ocean science. Hence, it is important that IITM work in close collaboration with NIO. It is also important for IITM (like NIO) to contribute to the effort in ocean science education.

The premier ocean research university in India today is IISc, Bangalore. IISc has a few oceanographic faculty. There are some other universities (most notably CUSAT, Kochi, and Andhra University, Visakhapatnam) that have ocean science faculty. The ocean science faculty from all these institutions need to collaborate with their counterparts in NIO, INCOIS, and IITM in major programmes. Such a collaboration is essential for students to get a first-hand experience of making observations at sea.

The private sector's involvement in ocean sciences at present seems to be restricted to IT projects in some of the institutions and to EIAs. While the latter is likely to continue and should be encouraged, it is important that their skill levels be enhanced in order to improve the quality of EIAs. The short-term courses envisaged for EIA specialists should help bring them abreast of current research trends and to build viable collaborations between them and the scientists. In the ideal scenario, the knowledge input, not merely data input, to the private sector should be provided by the scientists from MoES and sister institutions like NIO.

Building a forecasting system involves considerable engineering work that is not the domain of people trained in ocean research. The private sector, especially the Information Technology (IT) sector, has a major role to play here.

It is important to see if the deployment of moorings can be outsourced to the private sector. A key challenge is to ensure accountability because of the problems invariably encountered with moorings, especially loss due to vandalism. If this problem can be solved, then much of the energy of the MoES and allied institutions can be devoted to planning the moorings and their deployment,

and to the analysis and application of the data, the actual deployment task being outsourced to industry.

The role of NGOs is critical in two aspects. The first role of NGOs is in disseminating knowledge and data beyond the community that can be reached by the Internet. It is important that results of research useful to a user community actually reach it. This task is best done in collaboration with an NGO that has grassroots access and support. The second role of NGOs lies in helping ensure that the automated mooring platforms are not vandalised. This goal is unlikely to be achieved completely, but NGOs can help build the required rapport between the mooring and fishing communities.

One last point concerns the funding of projects, perhaps the most important function of MoES, because all else hinges on funding the right projects and then monitoring and evaluating them to ensure delivery of results. Once MoES has a formal vision document and has clearly outlined its goals for the next 10 years, project funding should be restricted to two classes of projects. The most important segment should be projects that are in accordance with the goals of MoES. It is necessary that the goals be articulated well so that proposals are prepared accordingly. Without a reasonably clear statement of the objectives, it is not possible to attract focussed proposals or to monitor projects. The second segment should consist of projects that go beyond or stretch the goals of MoES, but do so constructively and are necessitated by the advances made in the field. Such proposals may be invited by MoES based on a new need (like tsunami research after December 2004) or be proposed independently by a scientist. These proposals can be of two types: (a) The proposal may advance knowledge through basic research. (b) The proposal may have a direct and immediate application. Finally, in order to take up research proposed in Sections 2-8, MoES, in its role as the most important funding agency for ocean science and technology in the country, should establish an efficient system to evaluate the research proposals, monitor progress of those that are funded, and ensure that results derived from the funded research reaches the potential users.

## Annexure I

भारत सरकार  
GOVERNMENT OF INDIA  
पृथ्वी विज्ञान मंत्रालय  
MINISTRY OF EARTH SCIENCES  
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MoES/36/PMO/2008

4<sup>th</sup> February 2009

### Office Memorandum

Sub: Constitution of an Expert Committee to prepare a Vision and Prospective Plan for 10 years of the Ministry of Earth Sciences.

Consequent upon the formation of Ministry of Earth Sciences (MoES) by integrating existing agencies of both Atmospheric and Ocean sciences, the ministry had initiated a number of policies to focus its activities in areas such as Oceanography, Meteorology, and Seismology. The vision of the MoES would be to emerge as a knowledge and information technology enterprise for the earth system sciences (atmosphere, hydrosphere, cryosphere and geosphere) realm, for the Indian Sub-continent & Ocean. The primary missions of the MoES are to (i) Develop and improve capability to forecast critical ocean-atmospheric parameters, processes and phenomena, of significant societal, economic and environmental benefits (ii) Provide scientific & technical support for climate change studies and ecosystem-based management for sustainable use of resources. (iii) Define, deploy satellite and in-situ based atmospheric, ocean and lithosphere observing systems to support forecasting and ecosystem-based management system.

2. The ministry's activities mainly contribute to various societal benefits in the areas of Weather (General), Weather advisories specific to agriculture, aviation, shipping, sports, etc, Monsoon, Disasters (cyclone, earthquake, tsunami, sea level rise), Living and non-living resources (fishery advisory, poly-metallic nodules, gas hydrates, etc), Coastal and Marine Ecosystems and Climate Change. The Ministry has been implementing a wide range of programmes for monitoring and presentation, the activities are classified broadly into the following categories viz, (i) Atmospheric science, information & services, (ii) Ocean science & services (iii) Geosphere & seismological hazards(iv) Polar science & cryosphere (v) Ocean technology(vi) Coastal and marine ecosystems(vii) Climate science (viii) Non-living resources (ocean) (ix) Research vessels (x) R&D in Earth Sciences and (xi) Outreach.

3. Although the Oceans play an important role in the earth climate, the existing understanding on the oceanic processes is not adequate to determine its impacts. This could be partly due to lack of adequate information/data from the seas particularly around India. In the last decade, by virtue of advent in the digital communication technology, it has been possible to develop a wide range of state-of-the-art technology equipment for acquisition of data from the seas in real time, Argo,

Buoys, moorings etc., . This has contributed significantly to the understanding the oceanic process particularly in the seas India. However, it is important to make use of the information for operational services both in Atmospheric and Ocean areas.

4. In order to prepare an implemental document on the Vision and Prospective Plan for 10 years of the Ministry of Earth Sciences, an Expert Committee has been constituted with the following composition.

1. Dr. Satish R. Shetye, Director, NIO	-	Chairman
2. Dr. Debasis Sengupta, IISc, Bangalore	-	Member
3. Dr. D. Shankar, NIO, Goa	-	Member
4. Dr. VVSS Sarma, NIO, Vizag,	-	Member
5. Dr. Prakash Chauhan, SAC, Ahmedabad	-	Member
6. Dr. G. Lata, NIOT, Chennai,	-	Member
7. Dr. M. Ravichandran, INCOIS, Hyderabad	-	Member
8. Dr. T. Balasubramanian, Annamalai University	-	Member
9. Dr. Anil Kumar, NCAOR, Goa	-	Member
10. Dr. Ramesh, PRL, Ahmedabad	-	Member
11. Representative from NPOL, Cochin	-	Member
12. Dr. V. Sanjeevan, CMLRE, Cochin	-	Member
13. Representative from Marine Wing, GSI	-	Member
14. Dr. K. Somasundar, MoES	-	Member-Secretary

5. The Terms of Reference of the committee is as follows:

- To identify critical elements of science and Technology relating to ocean.
- To identify national ocean research themes and priorities of societal benefit
- To identify goals for 2, 5 and 10 years for each research priorities
- To define observing systems and sensors
- To draw up implementation strategy
- To identify infrastructure needs
- To suggest requirement on Human Resource
- To define role of central, state and international agencies and research, educational institutions and private sector and NGOs.
- To prepare a document for submission to the ministry by June 2009.
- The Chairman may co-opt or invite any expert member for the meeting.

6. The expenditure for organizing the meetings including TA/DA for non-official members will be borne by the Indian National Centre for Ocean Information Services (INCOIS), Hyderabad.

  
(Krishan Kumar)

Under Secretary to the Government of India