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A Roadmap for Unified Ocean Modeling and Forecasting system for INCOIS

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Abstract

INCOIS, being the nodal organization to provide operational oceanographic services, is actively involved in the numerical modeling of ocean circulation, waves, tsunami and storm-surge as well as regional coupled ocean-atmosphere models for the prediction of track and intensity of tropical cyclones. In order to optimise the models used in INCOIS for these activities and to make a seamless prediction system from global to regional domains, it was decided to have a revisit on the ocean modeling efforts of INCOIS. Outcome of this review as well as a proposal to develop a seamless prediction system is documented in this report. It is envisaged that this document will be used as a guideline for the future ocean modeling efforts in INCOIS.

1.0 Background

Taking the responsibility to provide ocean analysis, reanalysis and forecasts, INCOIS has been spearheading the research in numerical ocean modeling and ocean data assimilation in India for the past several years. This has led to the successful implementation of the High-resolution operational Ocean Forecast and reanalysis System (HOOFS)[1], in which a suite of configurations of Regional Ocean Modeling System (ROMS)- to model the regional and coastal ocean processes- are setup and integrated with the data assimilation scheme, known as the Localized Ensemble Kalman Filter (LETKF)[2]. HOOFS takes boundary conditions from a global model, a relatively low resolution Modular Ocean Model (version 4.0), with a data assimilation system based on 3D-VAR (Global Ocean Data Assimilation System GODAS)[3]. Another ocean analysis and forecast system being run at INCOIS is based on HYCOM model and data assimilation using Tentral Statistical Interpolation Scheme[4]. HYCOM configuration for the global ocean at a lower resolution provides boundary conditions for the Indian Ocean configuration of HYCOM. These Ocean General Circulation models simulate key physical oceanographic variables such as temperature, salinity and currents at various spatial, temporal and depth scales that are being used for operational forecasting applications as well as the ocean analysis. Efforts are underway to simulate biogeochemical parameters using ROMS and ECOLAB/MIKE models with the ultimate aim of forecasting potential fishing zones and water quality parameters in the near future.

Forecasts and early warning of wave parameters are being provided by the global configuration of WAVEWATCH III (WWIII) and the regional configuration of SWAN models[5-7]. For the early warning of swell surges, (Simulating Waves Nearshore) SWAN model is nested within the Advanced Circulation Model (ADCIRC) model[8] and takes boundary conditions from WWIII. Storm surge forecasts are generated using ADCIRC model configuration[9]. Operational tsunami advisories in the Indian Ocean are provided based on a large database of pre-run scenarios – Open Ocean Propagation Scenario Data Base (OOPSDB) generated using the Tohoku University's Numerical Analysis Model for Investigation of Near-field Tsunamis (TUNAMI N2) model, 2006, for other than Indian Ocean tsunamigenic earthquakes Tohoku University's Numerical Analysis Model for Investigation of Far-field Tsunamis (TUNAMIFF) 2011 is used for the real-time tsunami propagation scenarios (IOC. Manuals and guides 35). While INCOIS has recently acquired the capability to run ADCIRC model in real-time to issue tsunami warnings for the global oceans, outside Indian Ocean. General NOAA Operational Modeling Environment (GNOM) is used for oil spill trajectory prediction[10]. Efforts are underway to develop an extended prediction of wave-induced coastal erosion using a combination of WWIII and Xbeach model.

Over a period of time, scientists in INCOIS have acquired expertise in using/customizing different ocean general circulation models such as ROMS, HYCOM, MOM, etc. As mentioned earlier, different models are being used now in INCOIS to simulate general circulation parameters in coastal, regional and global scales. The reasons for this approach are;

- expertise in using a specific model by individuals or a group of scientists
- vertical coordinate systems of different models which are suitable for different applications
- user requirements (like IITM/IMD need GODAS for monsoon mission while IMD needs HYCOM for initializing HWRF-HYCOM for cyclone prediction)
- development/availability of data assimilation systems

While this approach has helped INCOIS to develop expertise in using different models, it has introduced severe pressure on human capital and only a few scientists are now available to work on any given model. It has also caused severe pressure on high performance computing resources, storage and analysis capabilities. Operational ocean forecasting centres world-over use a finite set of models to cater to all their forecasting needs. However, attempts to bring down the number of ocean general circulation models used in INCOIS in the past have not succeed due to several reasons. Inter-comparison exercises to choose the best model among the several (MOM/ROMS/HYCOM) have also not succeeded as the capability of models to simulate different oceanographic parameters are typically 'mixed' and no model configuration emerges as the 'best one' to choose. Also, the efforts to eliminate some model configurations by removing the duplication have failed since different modeling/data assimilation systems have progressed at different speeds. It is now clear that, it is high time that all possible resources at INCOIS are focused towards implementing a unified ocean modelling and forecasting system that caters to its operational and research needs.

The suite of models presently being used in INCOIS are summarised in the table below

Model & DA configuration	Domain & resolution	Purpose	Status	Purpose
ROMS 3.7 + LETKF	Indian Ocean (1/12 degree, 40 vertical sigma levels)	Regional analysis Regional forecasts	Operational	Provides boundary conditions for high-resolution coastal ROMS Indian Ocean forecasts/applications by OSF R&D in academic/ scientific organizations
ROMS 3.7	Eastern Arabian Sea and Bay of Bengal (1/48 degree, 40 vertical sigma levels)	Coastal forecasts	Operational	Coastal forecasts by OSF R&D applications
ROMS 3.7 + Biogeo	Indian Ocean (1/12 degree, 40 vertical sigma levels)	Indian Ocean Biogeochemical	Experimental	Boundary conditions for High-resolution coastal ROMS R&D applications
ROMS 3.7 + Biogeo.	Eastern Arabian Sea and Bay of Bengal (1/48 degree, 40 vertical sigma levels)	Coastal Biogeochemical	Experimental	PFZ forecast Coastal ecosystem modeling R&D applications
HYCOM + TSIS DA	Indian Ocean (1/16 degree, 29 vertical hybrid levels)	Indian Ocean analysis and forecasts	Operational	Boundary and initial conditions for IMD HYCOM-HWRFcyclone prediction system OSF applications R&D applications
HYCOM + TSIS DA	Global Ocean (1/4 degree, 29 vertical hybrid levels)	Global Ocean analysis	Operational	Provide boundary conditions for Indian Ocean HYCOM. R & D activities
MOM5 + LETKF	Global Ocean (1/8 degree, 41 vertical z* levels)	Global Ocean analysis Climate projections	Development	Provide boundary condition for Indian Ocean models (ROMS, MOM)

				Sea level projections Upgrade for Monsoon Mission model R&D applications
INCOIS-GODAS (MOM5 + 3D VAR) and also with Altimeter assimilation	Global (varying resolution, 40 vertical ‘z’ levels)	Global ocean analysis	Development	Provide initial conditions for Monsoon Mission Provide boundary and initial conditions for regional ocean model (ROMS) Upgrade for Monsoon Mission model R&D in academic/scientific institutes
MOM5 + LETKF	Indian Ocean (1/20 degree, 41 vertical z* levels)	Indian ocean analysis and projections	Development	Downscaling of sea level projection Simulation of biogeochemical parameters R&D applications
INCOIS-GODAS (MOM4p0d + 3D VAR)	Global (varying resolution, 40 vertical ‘z’ levels)	Global ocean analysis	Operational	Provide initial/ conditions for Monsoon Mission Provide boundary and initial conditions for regional ocean model (ROMS) R&D in academic/scientific institutes
WAVE WATCH III	Global multi grid (resolution varying from 1 degree to ~ 5	Wave forecasts, High wave warning, swell	Operational	Global and regional wave forecasts

	km)	surge warning		Wave climate projections R&D applications
SWAN (coupled with ADCIRC)	Coastal ocean (varying resolution from ~ 5km to 250m)	Wave forecasts, high wave warning, swell surge warning	Operational	Coastal wave forecasts by OSF Consultancy projects R&D
ADCIRC	Regional ocean (varying resolution)	Storm surge predictions	Operational	Real-time storm surge and inland inundation prediction
ADCIRC	Regional ocean (varying resolution)	Tsunami predictions	Experimental	Real-time tsunami propagation and inundation prediction
TUNAMI N2	Regional	Tsunami predictions	Operational	Scenario simulations of tsunami propagation, used to generate OOPSDB.
TUNAMI FF	Global	Real-time tsunami predictions	Operational	Real-time tsunami propagation scenario simulations of global tsunamigenic earthquakes.
ECOSIM	Coastal/estuary	Ecosystem nowcast/forecast	Configuration	Predict water quality parameters
GNOME	Regional	Oil spill trajectory prediction	Operational	Predict oil spill trajectory for the benefit of coast guard.
SW model/Mike	Coastal	Wave hindcast and return period analysis	need based	consultancy projects for coastal industries

Although these models have been configured for specific purposes, there have been certain overlapping in their domain/application. While all these models were validated with respect to available observations as well as other global system (wherever available), there were no systematic intercomparison between these models as well as w.r.t other systems or standard set of observations to assess their relative performance in different regions/scenarios. For example, the skills of GODAS, RAIN, HOOFS and ITPOSI in simulating/predicting the sea surface temperature over India are quite high in the Arabian Sea and Bay of Bengal (with correlation above 0.9 in most regions and RMSE less than 0.5 ^{o}C), while the skills are relatively low for the eastern parts of the equatorial Indian Ocean (correlation values fall below 0.5). Similarly, in all the models, the RMSE of temperature near the thermocline region are quite high (ranging from 1.5-2^{o}C), mostly due to the presence of diffused thermocline. The skills of these models in simulating the equatorial currents are very good with correlation values ranging from 0.8 to 0.9 and RMSE in the order of 10-15 cm s^{-1}. At the same time, skills of the models in simulating the currents in the Bay of Bengal are relatively poor in all the models. HOOFS configuration has a good skill in simulating the variation in coastal currents, with correlation values ranges from 0.4 to 0.7, but the RMSE values are relatively high compared to the observed standard deviation (of the order of 30-40 cm s^{-1})[1].

2.0 A brief account on the global systems

Most of the leading operational agencies like Mercator Ocean, UK Met Office, ECMWF, Bureau of Meteorology (Australia), US Navy, and NCEP, have developed seamless prediction systems from global to regional ocean for operational ocean prediction (www.godae-oceanview.org). While the systems in Europe are mostly based on the NEMO model, Bluelink, the operational system of Australia, is based on the Modular Ocean Model. There are several ocean prediction systems in the US, but the leading systems like the US Navy use the HYCOM model for their ocean prediction system. While NCEP also uses the HYCOM framework for most of their operational prediction systems, they use the Climate Forecast System with its ocean component based on MOM for their climate applications. Several operational agencies outside Europe use ROMS or FVCOM[11] for coastal/shelf sea/marginal seas predictions. There are considerable differences in the data assimilation schemes used in these centres also. For example, European centres use the NEMOVAR assimilation system, while Blue link uses the Ensemble Optimal Interpolation scheme. 3D VAR and LETKF are the other data assimilation systems being used widely by ocean prediction centres. Most of the operational centres in the world use WW III (developed by NCEP) or WAM (ECMWF) as their operational model for wave forecasts. Global ocean forecasting centres like NCEP and Bureau of Meteorology (Australia) are also working towards developing regional coupled ocean-atmosphere modeling systems for short to extended range forecasts.

A major change in the numerical modeling framework has happened with the development of MOM6[12], which has the flexibility to use the physics options of MOM5 and coordinate structure equivalent to MOM5, HYCOM and ROMS. This eliminates the requirement to have multiple models to cater to varying needs of the operational centres. With the development of WW III with an unstructured grid, it has become easier to use this model seamlessly for predicting wave parameters for global to coastal applications.

3.0 INCOIS requirements: operational ocean services's point of view

Based on the statistics prepared by INCOIS, it appears that most users require wave/swell/surge parameters with good accuracy for their operations in the sea. Other parameters which users seek frequently are the surface currents followed by sea surface temperature. Ocean currents in the coastal area have paramount operational importance for oil/chemical spill trajectory predictions, search and rescue operations, back trajectory predictions, larval dispersal, etc. Predicting the temperature gradient has high significance for potential fishery zones. Takers for other general circulation parameters such as temperature/salinity structure, sea level etc. are highly specialized users and academia. However, the ocean analysis (both global and regional) are extremely important for IMD to issue weather and climate forecasts. Extended range forecasts of ocean parameters are now in demand for planning operations of off-shore industries in the sea. Although the frequency in which the storm surge forecasts and tsunami travel time and inundation forecasts are issued are relatively low, they are extremely important to protect the life and livelihood of millions of people in the coastal area. With the increasing demand on INCOIS to provide nowcast/forecasts of ecosystem and water quality parameters for the coastal waters and predictions of specific events like rip currents, the need for more accurate modelling of coastal physical and marine ecosystem parameters has increased. Similarly, the ecosystem parameters from these models will also provide necessary inputs for species level forecasts of fish stock. Another important obligation of INCOIS is to provide more accurate estimates of sea level changes along the coastal regions of India as well as Indian Ocean rim countries. This may require scenario based sea level projections and model downscaling to the coastal levels.

Considering all these requirements, INCOIS should strive to spearhead the ocean modeling activities in the country as well as in the region, as most countries in the Indian Ocean rim are not equipped with sufficient manpower, infrastructure and resources to invest in this important branch of oceanography. At the same time, as the resources, including the infrastructure and manpower available with us are limited, it is important to optimize our modeling activities and carry out focused R&D in the modeling of important parameters of the oceans. Hence, in order to cater to the needs of various users while keeping ourselves on par with the global community, the modeling activity at INCOIS should focus on implementing a unified ocean modelling and forecasting system that caters to all its operational and research needs comprising of the following components:

- Seamless modeling of ocean general circulation with data assimilation capabilities, which can be run at global/regional scales and provide boundary conditions or coupled with other specialised coastal/shelf sea/estuary models.
- An integrated suite of high-resolution coastal/shelf sea/estuary models for physical and biogeochemical parameters including modelling system for currents, waves, tides, storm surges, tsunamis, water quality, dispersal processes, etc., to meet the ever increasing research and forecasting needs of INCOIS.

  In addition, an attempt towards developing a regional coupled ocean-atmosphere modeling system for short-range forecasts of oceanographic parameters, particularly during tropical cyclones also should be made by INCOIS.

4.0 Selection of models

We need to keep the following points in mind while selecting our suite of models

- **Coastal/shelf sea/estuary models for specific applications:** For these applications (like predicting the waves, currents, tides, marine ecosystem including fisheries and water quality, storm surge and tsunami, oilspill trajectory as well as search and rescue operations), very high resolution models with flexible meshes (finite elements) to represent the coastline features more realistically are required. Using a flexible mesh will also enable computational efficiency by allowing variable grid sizes in the open ocean and coastal areas. Also, wherever possible, we need to choose models that can be used for multiple applications (e.g., ADCIRC for both tsunami and storm surge) so that the overall number of models can be reduced and hence more scientists can work on the same set of models. Considering the availability of large computing facilities of MoES, we should now aim at using models that can run at real time within the required timeframe to issue warnings for tsunami and other short-fuse hazards. To the maximum possible extent, we should use open source models so that we have the flexibility to include additional model physics and assimilation systems, which are important for Indian coastal waters. The selection of models should also take into consideration the ease with which they can be coupled with other models that simulate a different parameter, or take boundary conditions seamlessly from other models being run for larger domains. Selection of model domain for the coastal/shelf sea used for simulating the general circulation features should be done in such a way that the unique dynamics of Bay of Bengal and Arabian Sea are represented well in this model.

- **Global/regional models for simulation of Ocean General Circulation:** As the most important scientific reason for selecting different models for different domains so far at INCOIS was the choice of vertical coordinate systems, we should now adapt an OGCM, which can cater to all the domains/regions of interest. This will help us to allocate more manpower to improve one model. We may adopt a data assimilation system that can be easily portable to the new model chosen. Ecosystem modelling in OGCMs should be limited to the simulation of key biogeochemical parameters and lower trophic levels only. For the simulation of higher trophic levels in the food web, a suitable stand-alone model, which can take initial/boundary conditions from the selected ecosystem model may be chosen. This will allow the scientists who have domain expertise, but do not have expertise in general circulation modeling, to get involved in the modeling of higher trophic levels.

Considering all the above points, following is the proposition for the new modeling framework for INCOIS leading to the discontinuation of operational systems based on multiple models in a phased manner.

- ADCIRC+SWAN model should be used for storm surge and tsunami predictions including inundation levels. Tunami N2/F2/N3 may be discontinued gradually.

- WAVEWATCH III should be used for global to coastal wave forecasts. As research in coupling WW III with ADCIRC is in the initial stages only, SWAN model should be limited to only areas where ADCIRC model requires wave parameters for accurate forecasts of storm surges. SWAN can be discontinued when WW III eventually gets coupled with ADCIRC. Coupling WW III to ocean circulation model configurations will help us to represent Stokes drift in the models.

- FVCOM should be used to set up very high resolution (sub kilometer) coastal/shelf-sea/estuary prediction systems. Ocean general circulation and biogeochemical modeling upto lower trophic level can be done using FVCOM, which should be coupled with the high-resolution global/regional model. Operational use of ROMS and Mike models should be discontinued gradually. However, INCOIS may continue to use Mike model for meeting the requirements of consultancy projects, until the open source models are customized to meet such requirements.

- For global to regional models, the options available are (a) HYCOM (b) MOM (c) NEMO. Among this, NEMO is mostly used among European community and the support for this model is limited. Good elements of HYCOM and MOM (and to some extent of ROMS also) are now merged into MOM6, in which options of different vertical coordinate systems are available for global to regional level ocean analysis and forecast. Hence, we should choose MOM6 as the future work-horse for our modeling framework for global to regional levels at a spatial resolution of about 10km. Major operational ocean forecast systems like Bluelink and NCEP are also now moving in this direction.MOM6 may be run with the biogeochemical module so that it can provide boundary conditions of biogeochemical and physical parameters to coastal FVCOM. MOM4 + 3DVAR set up (INCOIS-GODAS) may be discontinued gradually.

- For applications that require high-resolution general circulation parameters (such as PFZ forecast, high-resolution surface and subsurface currents for off-shore industries, oil-spill/search & rescue operations), we should configure a higher-resolution MOM6 (with horizontal resolution of about 3-5 km) for the northern Indian Ocean and nest with the global MOM6. Biogeochemical module in the configuration can also cater to the water-quality forecast system. This configuration can also be used to downscale the future sea-level projections for the Indian coasts. Operational use of ROMS + LETKF set up (RAIN) can be discontinued gradually.

- The regional high-resolution model configuration of MOM6 should be used for R&D in fine-tuning different parameterisation schemes/physics options. Again, it is advisable for all to test their model physics in this regional study setup so that the outcomes from these studies can be directly translated to the operational global setup.

- As a part of Monsoon Mission, INCOIS is already a part of developing LETKF based DA in MOM6. Hence, it will be easy for us to implement LETKF based DA in the global configuration of MOM6. We may explore the implementation 3DVar based DA for MOM6 to introduce a hybrid DA system. In situ observations of temperature, salinity as well as bio-geochemical parameters, satellite observations of SST, SSS, SSH and observations of currents from drifting buoys as well as moored buoys may be assimilated into the ocean models for producing daily ocean analysis in regional and global scale. In addition, surface currents from HF radar may be assimilated in the models for coastal applications.

- As IMD’s HWRF-HYCOM is using initial and boundary conditions from INCOIS HYCOM, we may explore the possibility of extracting these data in the required format from MOM6 based ocean analysis/forecast system. Similar exercise may be done to provide initial and boundary conditions to IITM/IMD if they delay changing over from existing MOM4-GODAS to MOM6 based system. Operational use of HYCOM + DA setup of INCOIS (ITOPSI) may be discontinued gradually.

- Considering the requirement to have prediction of oceanographic parameters during the development of tropical cyclones, it is also necessary to develop a ocean-wave-atmosphere coupled modeling system in INCOIS. This system can have regional configuration of MOM6 as the ocean component, WWIII as wave model component and WRF/HWRF as the atmospheric model component.

Advantages

- Models such as ADCIRC, FVCOM, SWAN and unstructured WWIII use the same kind of model grids. This will make it easy to set up the models using the same Bathy and Topo database.
- More manpower will be available to address different aspects of the same model. This will speed up development of the modelling and forecast system.
- Usage of computational resources can be optimised.
- A seamless system will be easier to handle by the operational team than multiple model setups.
- DA system is already available, and it can be ported to the new model configuration with minimum effort.

Challenges

- Required specific training in different models (like MOM6, FVCOM)
- Scientists need to re-align with the new modeling framework
- Require additional manpower in specific areas like coastal circulation modeling, global wave modeling, biogeochemical modeling, coupling of WWIII with ocean model (ADCIRC,), HPC administration, etc.

Ways to overcome some of the challenges.

- A good fraction of scientists in INCOIS are already familiar with the MOM framework. However, specific training may be required for MOM6. A short course by one or two experts under the framework of ITCOocean will be required.

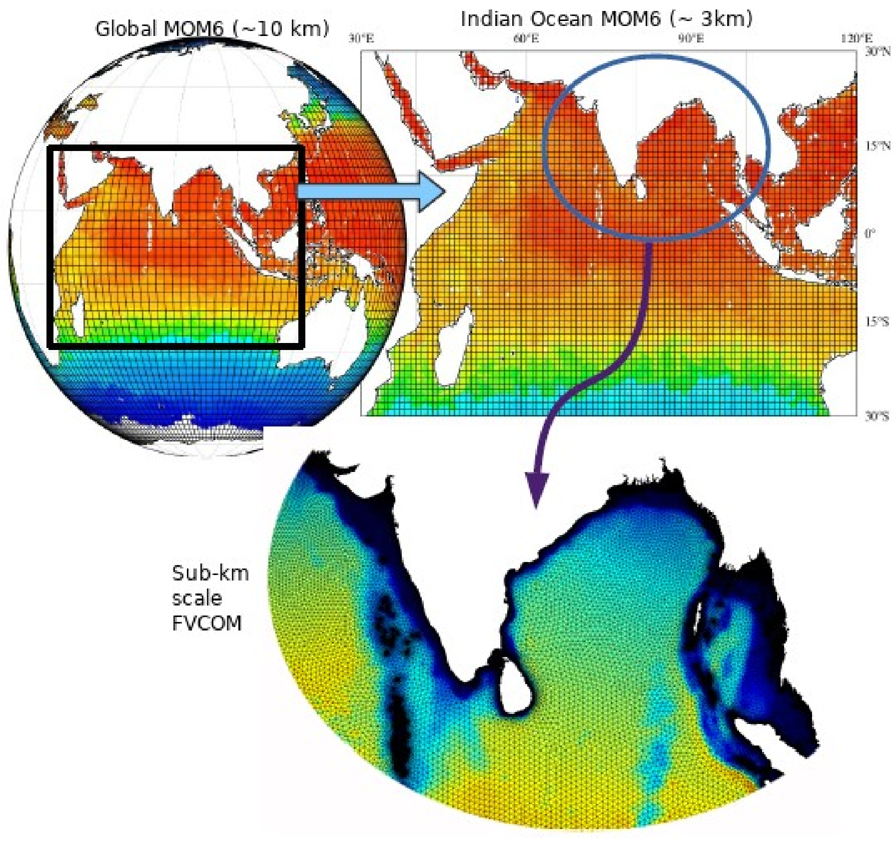
- Training in FVCOM, including biogeochemical models will be required. Again, a short training with an expert will be required.

- Additional manpower will be needed to implement this modelling frame work, some of which can be met by re-assigning scientists who are currently working in models that have been identified to be gradually discontinued. In addition, scientists working in other relevant domains can be partly re-assigned to implement this modelling framework. For instance, closer involvement of scientists from the observation team will be sought in fine tuning the model parameters/developing new schemes to parameterise physics. Similarly observational campaigns should be planned together with a modeling team. Any other requirement of specific expertise will be met by recruiting manpower on project mode.

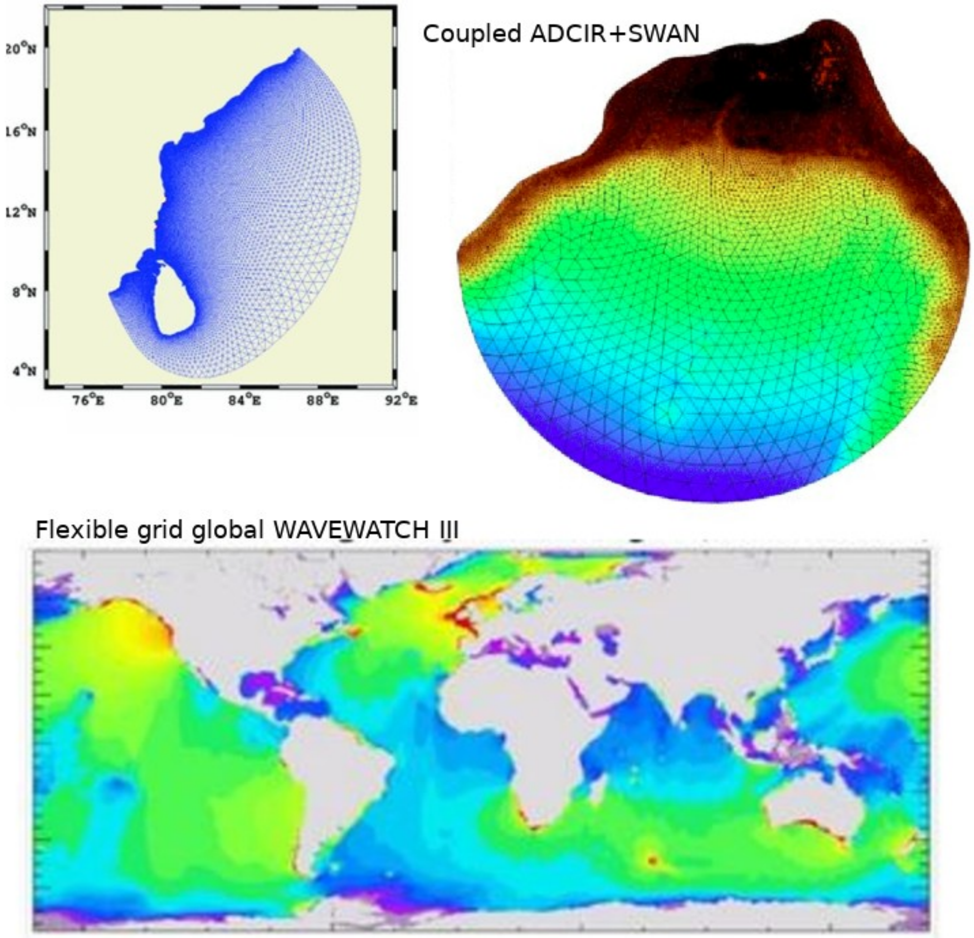
- Collaboration with foreign labs / institutions working on ocean modelling and forecasting such as NOAA will be pursued under the NOAA-MoES collaborative framework for exchange of expertise and capacity development.

- Focussed time-bound projects with other national institutions will be taken up for implementing specific modules, if required.

- While majority of computational needs will be met through HPC resources at IITM and NCMRWF, it is proposed to establish the basic computational systems and storage required for setting up of test bed, pre and post processing of model data, as well as configuration of set up for operational services.



Proposed framework for circulation Models



Proposed framework for hazard modelling

5.0 Proposed modules of modeling framework

Work Package (WP)	Module	Description
WP1: Global/regional models for simulation of Ocean General Circulation for ocean analysis/ reanalysis	MOM6 toy model (learning purpose only)	Configuration of a low-resolution limited area MOM6 setup for learning purpose
	MOM6 global physical model global analysis/reanalysis/ forecasts, climate projections	Configuration of MOM6 for global domain. This includes preparation of 1. Selection of model domain and resolution 2. Grid for selected model domain 3. Initial/boundary conditions 4. Fine-tune model physics 5. Selection of model forcing 6. Selection of model coefficients such as (viscosity, drag, diffusion etc.)
	MOM6 for Indian Ocean high-resolution regional-scale downscaling of short-	Configuration of MOM6 for NIO domain, which will be providing initial/boundary conditions for FVCOM. This includes preparation of 1. Selection of model domain and resolution. 2. Grid for selected model domain

	term forecasts and climate projections Focused R&D in model physics like air-sea flux estimates, mixed layer parameterisation schemes (interior ocean mixing due to internal waves, Langmuir circulation induced mixing), testing of newly derived coefficients/physical processes with process specific observations etc.	3. Initial/boundary conditions 4. Fine-tune model physics 5. Selection of model forcing 6. Selection of model coefficients such as (viscosity, drag, diffusion etc.) 7. Inclusion of river discharge 8. Testing of new coefficients in physical parameterisation schemes 9. Introduction of new model physics in existing physical parameterisation schemes etc.
WP2: Coastal/shelf sea/ estuary models for specific applications	**FVCOM (Physical)** Fine-resolution coastal/ shelf sea/ estuary applications	Configure and fine-tune FVCOM for the coastal/shelf sea/estuary applications. This includes 1. Selection of model domain 2. Preparation of finite element grid 3. Preparation of initial/boundary conditions 4. Fine-tune the physics options 5. Identify model coefficients 6. Fixing barotropic/baroclinic tides 7. Coupling with hydrological models/inputs
	ADCIRC (Tsunami) Real-time prediction of tsunami waves and associated inundation levels and extent	Fine-tune the ADCIRC model configured for the real-time prediction of tsunami in Indian Ocean and associated inundation levels.
	ADCIRC (Storm surge) Real-time prediction of storm surge and associated inundation levels and extent	Fine-tune the ADCIRC model configurations for the east and west coast of India for the prediction of storm surge and associated inundation levels and extent. Identify/prepare the most appropriate wind-forcing for the storm surge model. Identify the regions where wind-waves are playing a critical role in the extent of storm surge
	SWAN to provide wave-parameters required for ADCIRC storm surge configuration in selected areas	Setup and fine-tune limited area SWAN for the regions where the ADCIRC model requires inputs on wave-parameters to predict the extent of storm surge. Extraction of boundary-conditions from Wavewatch III to force SWAN at lateral boundaries.

		Fine tune model parameters
	WAVEWATCH III Wave and swell forecasts for global to coastal level, wave climate projections in the coastal waters of India and Indian Ocean rim countries.	Configure and fine-tune flexible mesh wavewatch III from global to coastal regions with varying horizontal resolution for the prediction of wind wave parameters. This includes 1. selection of model domain/subdomains 2. setting up of flexible grid model configurations 3. Fine tune model parameters 4. Include the effect of wave-current interaction
WP3: Biogeochemical modeling for global, regional and coastal applications	**FVCOM (Biogeochemical)** Fine-resolution coastal/ shelf sea/ estuary applications such as nowcast/ forecasts of biogeochemical parameters, initial/boundary conditions higher-trophic level ecosystem model.	Setup and fine-tune bio-geochemical module in FVCOM configuration, which will be providing initial/boundary conditions for higher-trophic level ecosystem models
	MOM6 (global) biogeochemical initial/boundary conditions for regional NIO configuration	Setup and fine-tune bio-geochemical module in global domain, which will be providing initial/boundary conditions for the high-resolution northern Indian Ocean (NIO) model.
	MOM6 (Indian Ocean) biogeochemical (regional level nowcast/ forecasts of biogeochemical parameters, initial/boundary conditions for shelf-sea/ coastal/estuary model and higher-trophic level ecosystem model.	Setup and fine-tune bio-geochemical module in MOM6 NIO configuration, which will be providing initial/boundary conditions for FVCOM and/or initial/boundary conditions for higher-trophic level ecosystem models
WP4: Data assimilation in ocean general circulation and wave models	**Data Quality control**	Quality checks for data used in data assimilation and model forcing Daily monitoring of incoming data for assimilation and model forcing Gap filling to the maximum possible extent, if required.

		Archival and retrieval of model outputs, forcing and other quality controlled data as per the data policy
	Data assimilation Ocean analysis/reanalysis in global to regional circulation models	Setup LETKF based DA system (physical and biogeochemical) in global and regional (NIO) configurations of MOM6 Setup 3DVAR based DA (physical) in global MOM6 for hybrid DA. Data assimilation in Wavewatch III
WP5: Downscaling of Atmospheric Forcing to force high-resolution models	**Downscaling of Atmospheric Forcing** to force high-resolution coastal models	Statistical or dynamical downscaling of atmospheric forcing Blend atmospheric forcing from models with observations This workpakage will be executed in collaboration with NCMRWF/IITM.
WP6: Evaluation and synthesis of observations and model simulations for model improvements.	**Model Evaluation** Validation of model simulations	Extract model parameters to validate the simulations with suitable observations Prepare statistics/error estimates/skill-scores of model simulations Identify the potential areas where models require improvements Provide feedback and suggestions to model developers.
	Analysis and Synthesis of Observations and model simulations Deriving new empirical relationships/physics from the ocean observations that can enhance model performance.	Targeted analysis of observations to deriveempirical coefficients that can be used in model physical schemes which parametrize mixing processes or air-sea fluxes. Analysis of observations to bring out new physical processes that have to be accounted in the numerical models Develop algorithms to introduce new model physics in numerical models
WP7: Regional Coupled Ocean-Atmosphere modeling.	**Regional coupled model** development for short to extended range forecast	Configuration of WRF/HWRF model for the Indian Ocean. Coupling WRF/HWRF with Indian Ocean configuration of MOM6 and WWIII. Fine-tune coupled ocean-wave-atmosphere modeling

		system
WP8: IT support for model porting, integration and pre- and post-processing.	**Computational Support**	Porting MOM6, FVCOM, ADCIRC, SWAN, WRF/HWRF and WAVEWATCH III in HPCs Optimize the model codes with respect to the HPC configuration/architecture/compilers/libraries/utilities Execution of models for different experiments Optimize the usages of HPC resource like processors, storage as well as transfer of files for HPC to local desktops and reverse Preparing the scripts for Pre-processing and postprocessing of data Pre-processing and post-processing of data Preparing scripts for integrating different modules of operational system Preparing user interfaces to analyze and disseminate model outputs and products Establishment of basic computational facilities

Potential users of different model configurations

Model	**Configuration**	**Purpose**	**Users/Uses**
MOM6	Global	Global Ocean Analysis	IMD/IITM/Academia/ Navy/Shipping agencies, sea level change projections etc.
	Regional	Indian Ocean analysis/forecasts	Academia/Navy/coast guard/shipping agencies/Off-shore industries,water quality forecasts, sea level change projections etc.
FVCOM	Coastal	Coastal forecasts	Coast Guard/fishermen/off-shore industries/tourism/water quality forecasts
ADCIRC+ SWAN	Regional	Tsunami/Storm Surge/Wave surge forecasts	Coastal population/ fishermen/IMD/Govt. Agencies for disaster management
Wavewatch III	Global/ Regional/ Coastal	Wave forecasts	Fishermen, off-shore industries, shipping agencies, Navy, Coast Guard, tourism industry etc.

In addition to the development of the numerical models and the evaluation/synthesis of model and observation data, it is important to groom teams to develop tailor-made applications using the forecasts/ analysis from the proposed modeling framework in accordance with the user demands. This includes oil spill trajectory predictions, the search and rescue aid tool, dispersion models for various applications (like pollutants, larves, etc.), water quality prediction, ecosystem model for higher trophic level prediction, swell surge forecast, GIS based coastal inundation estimates due to different natural disasters and global change etc.

6.0 Tentative schedule to complete the model configurations*

- Complete setup of WW III (unstructured grid) for global to coastal region (2021-2023)
- Configure a test-bed model (limited area) of MOM6 (2021)
- Configure full global configuration of MOM6 (2021-2023)
- Configure Indian Ocean configuration of high-resolution MOM6 (2022-2023)
- Nesting of High-resolution regional MOM6 with global MOM6 (2023-2024)
- Configure DA in full global MOM6 (2023-2025)
- Configure ecosystem model in global/regional MOM6 (2023-2024)
- Configure FVCOM (2021-2023)
- Configure ecosystem model in FVCOM(2023-2024)
- Complete setup of unstructured SWAN and couple with ADCIRC wherever required (2020-2023)
- Validations & documentation of end-to-end system (2025-2026)

*INCOIS will initiate preparatory activities for implementation of this unified modelling and forecasting framework as a mission-mode activity under the O-MASCOT. Activities and timelines of this roadmap beyond the current sanctioned period of the O-MASCOT project have been projected in the continuing programmes of INCOIS for 2021-26, and will be pursued subject to final approval of the EFCs by MoES.

7.0 Arrangements during transition phase shift to end.

The development of the new modeling framework and fine tuning the models to the specific requirements will take at least 3-5 years. At the same time, INCOIS has an obligation to serve the existing users with operational products. Also, INCOIS needs to meet the targets proposed to MoES. Most important among these are

- HYCOM analysis/forecasts for IMD’s HWRF-HYCOM setup for the cyclone prediction
- MOM4p0d based GODAS to IMD and IITM for seasonal and extended range forecasts
- PFZ forecast system for two coastal sectors (Niti Aayog monitored action item)
- Water quality forecasts for two coastal locations (Niti Aayog monitored action item)
- Sea level projections for the Indian coastline (Deep Ocean Mission objective)
- Operational products related to OSF/Tsunami/Storm surge (Ongoing service)

Hence, during the interim period, we may stop any further research and development activities in the models which we plan to discontinue in future, but continue to run the operational models as such until the new modeling framework is ready. At the same time, to meet the targets of providing PFZ forecasts and sea level projections, we may continue very focused, but very limited, development of products (like downscaling the climate sea level projections using MOM5 and assimilation of SST in ROMS). We may replace these products with the new modeling framework, when it is ready. A coarse-resolution MOM6 setup for a smaller region configured for the learning purpose can be used to experiment with the configuration of LETKF DA scheme in the MOM6.

8.0 Final Remarks

INCOIS will initiate preparatory activities for implementation of this unified modelling and forecasting framework as a mission-mode activity under the O-MASCOT. Activities and timelines of this roadmap beyond the current sanctioned period of the O-MASCOT project have been projected in the continuing programmes of INCOIS for 2021-26, and will be pursued subject to final approval of the EFCs by MoES. Even though there will be difficulties in the initial period of development and implementation phase of the new models, adaptation of the above framework will allow us to grow much faster be much more adaptive in the future with a morefocused approach in delivering more and more useful and operational products/services from the organisation. As we are adopting the models which are now emerging very fast with co-ordinated R&D efforts in the world, this will also keep us afloat in the global ocean modeling and operational ocean services scenario in the decades to come. Also, INCOIS will explore the possibility to adapt the dynamic core from a most suitable numerical model and add additional modules required to meet all the requirements of INCOIS so that, in future, INCOIS will soley depend only on this model to meet the operational needs.

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