Development of a customizable 3D numerical Hydrodynamics and Siltation tool

A Research Proposal
of
Indian Institute of Technology Madras, Chennai

Submitted to
Ministry of Shipping
Government of India

under

National Technology Centre for Ports, Waterways and Coasts (NTCPWC)

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1. **Title of Research / Development proposal** : Development of a customizable 3D numerical Hydrodynamics and Siltation tool
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2. **(a) Name of the Principal Investigator:** Prof. K. Murali

(b) Designation : Professor

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(e) Other Co- Principal Investigators: : None

(f) Other Co-Investigators : None

3 **(a) Proposed duration of the project:** 36 Months

(b) Proposed Budget : Rs. 67.328 Lakhs

(c) Proposed date of commencement of project / facilities: As soon as the project is sanctioned

4. **Total amount of grant proposed (Rs. in Lakhs):** **67.328 lakhs**

Budget Estimates

Budget heads	1st year	2nd year	3rd year	Total
1. Research Staff				
P.O. (Ph.D)	546000	546000	468000	**1560000**
P.A. (M.S)	468000	468000	421200	**1357200**
2. Specific Equipment	1800000	-	-	**1800000**
3. Boat hire charges	400000	400000	400000	**1200000**
3. Consumables	170000	170000	20000	**360000**
4. Contingency	200000	200000	200000	**600000**
5. TA /DA	300000	300000	300000	**900000**
6. Total	3884000	2084000	1809200	7777200
7. Overheads (15%)/ max 5 lakhs	776800	416800	361840	**1555440**
Grand total	4660800	2500800	2171040	9332640

5. **(a) Department of the institution where R&D project will be carried out.** Department of Ocean Engineering, IIT Madras.

(c) Details of financial support sought/obtained from other agencies Most field equipment are covered under capital cost of NTCPWC.

6. **(a) Specific Aim of the project :**

The present proposal aims to implement an integrated model for quantifying baroclinic and barotropic circulation in the shelf seas and provide a platform for obtaining sediment load. The following tasks are proposed.

- To incorporate various forcing factors such as inflows, tides, density variation and wind stress for simulating the hydrodynamics of the shallow water areas with baroclinicity.
- Explain the behaviour of baroclinic effects based on vertical mixing and apply proper turbulence closure methods.
- Develop a methodology to generate boundary forcing to regional circulation model that focus on shallow water regions.
- Develop new models for sediment load generation and mixing in the water column. Validate these models in the laboratories at department of Ocean Engineering, IIT Madras and also using field data from 3 typical sites along indian coast.
- Modeling sediment transport in the area of interest and analyze the erosional and depositional patterns by understanding the turbidity plumes.

(b) Summary of proposed Research / facilities and objectives — **Annexure 1**

(c) Key words — 3D circulation; Baroclinicity; Sediment load; Turbidity.

(d) Classification of the project — Basic and Applied Research; Facility Development and Hardware Development

7. **Background and Justification :** **Annexure 2**

8. **Indian & global Scenario on the envisaged Research :** **Annexure 3**

9. **Likely outcome/deliverables expected out of the proposed Research/work and Its relevance to NRB/Marine/Naval R&D / Applications :**

Reports, SCI publications and algorithm.

(i) A 3D circulation model including the effects of baroclinicity, tides, wind, temperature, salinity, sediment generation/ siltation in estuaries, waterways and coasts.

(ii) Capability to provide sediment concentration

		profiles in the water column. (iii) Capability to provide information on regions of clean water and turbid water.
10.	**(a) Approach (Details of approach to be adopted in the Execution of the project objectives listed in Item 6(a) will be achieved).**	**Annexure 4**
	(b) Bar chart/PERT chart indicating major milestones may please be attached	**Annexure 5**
11.	**Facilities available for carrying out the proposed R&D work in the applicant's Institution**	**Computing facilities: Virgo supercluster of IITM &** Under NTCPWC. **Shallow water basin & Wave flume:** Under NTCPWC. **Oceanographic equipment:** Under NTCPWC
12.	**Previous work done in this or related fields**	**Please see Annexure 6 for publications**

ANNEXURE 1

Summary of proposed research facilities and objectives

A regional 3D hydrodynamic model (ELCIRC) is implemented at IIT Madras covering Indian coast and the adjoining seas to study the tidal dynamics and the energetics including contributions of various constituents. Under the present proposal, it is intended to extend this model to include entire Indian coast including A & N islands and Lakhsdweep. The model will be validated with global data-assimilative model TPXO. The distribution of the semidiurnal amplitudes and the amphidromic points will be verified. Finally the distribution of tidal amplitudes along the coast will be verified. Boundary conditions of the model will be derived to be able to simulate the barotrophic and baroclinic circulation as desired. A specific focus will be laid on baroclinic circulation. This will allow the model to capture the vertical profiles of currents.

Concurrently, a sediment transport model will be developed to simulate the turbidity plumes as a result of combined tide, wave, wind and general circulation. Mere inclusion of the above effects, however, does not guarantee successful simulation of suspended sediments (and hence turbidity plumes). Hence, we propose to develop an empirical model that derive the sediment source strength as a result of wave action in the surf zone and fresh water in flow into the sea. Thus, the model will be capable of predicting short term water quality parameters. Such a model will play a crucial role in shallow water studies, i.e. optical characteristics; acoustical properties; optical communication; water quality; sediment fate etc.

In order to establish a correlation between sediment load and nearshore wave processes, laboratory and field experiments are planning. These experiments will focus on measurement of onshore-offshore currents, sediment generation and turbidity. The measurements will be carried out at 3 sites along Indian coast (north of Chennai; Mandovi Estuary and Gulf of Kutch, near Mundra) As part of this proposal, we also plan to develop and shallow water sled.

ANNEXURE 2

Background and justification

Prediction of the nearshore circulation and sediment transport is a complex and time consuming task. The nearshore circulation primarily has two components, the intra-annual variability and the tide induced variability. These are commonly known as general circulation and tidal circulation. Traditionally, the role of tidal circulation has been consistently ignored by most investigators due to the difficulties in modeling the tide induced circulation. The usual approach was to use the thermal gradients and wind as input, and model the circulation of ocean basins.

The above approach is fine as long as circulation in the basin as a whole is looked at. As there is enormous data available pertaining to SST, wind and salinity, and as the large scale circulation has got a number of areas of application, basin level circulation modeling has been usual trend in the literature. However, this approach is insufficient and inaccurate for shallow water circulation in the shelf. Based on our previous studies (Sajumon and Murali, 2015; Murali et al., 2002; Chen et. al., 2002 and Chen et al., 2005), it has been shown that tidal components plays the major role in hydrodynamics of shallow straits. The region between shoreline and 50m water depth is an active region which highly complex in terms of sediment motion, nutrient mixing, evaporation and baroclinic over turning. This region would also have many localized turbulent circulations centered around vertical vortex lines. There is fresh water input at many locations. Hence, the tidal forcing should be necessarily included for modeling the shallow water circulation and related ocean environment. Furthermore circulation in the coastal area is often mainly composed of two parts; the barotropic and baroclinic contributions. The barotropic component is generally due to astronomically driven surface tidal gradients while the baroclinic component is the internal disturbances generated due to the interaction between the stratified fluid and the bottom topography. Tidal forcing by the sun and moon acts as a body force on the ocean, and it responds by accelerating as a barotropic flow.

Many codes using different approaches exist in literature for modeling of 3D circulation including effects of baroclinicity. Thus, selection of an appropriate approach is very important in addressing the objectives mentioned. Here, the Eulerian-Lagrangian Circulation model (ELCIRC) is used to account for the baroclinicity. It is an unstructured grid model designed for the effective simulation of 3D baroclinic circulation across river-to-ocean scales. At IIT Madras, we have been working with ELCIRC for the past several years and presently developed and improved version of it (ELCIRC-IITM). This improved version includes a specific meshing tool to produce orthogonalized grids which has minimal computational errors and hence stability and conservation over time. The code has been validated with field measurements of water levels and velocity (3D). The improved version also has basic sediment transport capability.

Thus, we are in a right position to carry on with the proposed research. The proposed work aims to equip ourselves with basin scale and nearshore circulation around India. The nearshore circulation capability will feed-into turbidity and sediment transport modeling which will be correlated to OCM imageries. Thus a framework will be created to continuous and real time monitoring of coastal water quality for civilian and defense purposes. The present project will also pave way for extending the circulation model to understand interactions of Antarctica ice and bottom boundary circulation of southern ocean with the oceans surrounding India, thereby paving way for comprehensive climate impact assessment.

The model studies will be complemented by laboratory and field investigations The measurements will be carried out at 3 sites along Indian coast (north of Chennai; Mandovi Estuary and Gulf of Kutch, near Mundra). These investigations will focus on developing a correlation between sediment load in to water column due to nearshore wave and circulation processes and interaction.

ANNEXURE 3
Indian & Global scenario on the envisaged research

There is a critical lack of nearshore modeling expertise in India. The main reason for this appears to be lack of data availability and interest in understanding nearshore processes / requirements. Traditionally, most ocean modeling in India focused on general circulation which in turn is driven by availability of SST and Salinity data. These data were further augmented by wind data. IIT Madras have been involved in several coastal and port projects. Hence, there is an obvious interest in nearshore dynamics and its effects on coastal hydrodynamics and sediment regimes. Zhai et al., (2007) carried out one of the earliest observations of the dynamical response of a coastal embayment to wind, tide and buoyancy forcing with modern 3D hydrodynamics codes. They had shown that the circulation has been mainly governed by the first 5 tidal species and wind forcing. This was followed by a research by variability associated with the first EOF played an important role in the heat budget of the bay, exchanging heat (and also salt) with the neighbouring inner Scotian Shelf. and Fernando et al.,

Studies have shown that 25-30% global barotropic tidal energy is lost in the deep ocean (Munk and Wunsch 1998; Egbert and Ray, 2000, 2001). A wide variety of analyses of altimetry data now suggest that 70%–75% of the dissipation does indeed occur in shallow areas. Although, the tidal dissipation of the global oceans has been quantified approximately, the regional features of the dissipation and the tidal flux distribution is not well addressed. This is mainly due to modeling difficulties and lack of data pertaining to shallow waters.

Pertaining to the Indian ocean basins including Bay of Bengal and Arabian Sea, which is the interest of this study, very few studies have been reported in the Bay of Bengal to understand the regional features of tides. Sindhu (2012) simulated the major diurnal and semidiurnal tidal constituents and generated the co-tidal and co-range charts for the Bay of Bengal, in order to produce the tidal forcing for a surge prediction model. A 2D vertically integrated model was used for this purpose with the five major tidal constituents M2, S2, N2, K1 and O1. The tidal analysis mainly focused on the identification of the characteristic features in the distribution of the major tidal constituents in the Bay of Bengal, especially in shallow regions such as head bay, Gulf of Martaba and Malacca. Kantha et al., (1997) used the TOPEX/POSEIDON (T/P) altimetry data and estimated the barotropic tidal energy of the M_2 constituent to be approximately to 50PJ (1PJ=10^{16} J). Currents from a high resolution ($1/5^0$) barotropic model have been used to estimate both the energy and dissipation rate in M_2, S_2 and K_1 baroclinic tides. The model results suggested that about 360 GW tidal energy is dissipated in M_2 baroclinic tides alone, and 520 GW (1 GW=10^9 W) is dissipated in all first mode baroclinic tides. Zu et al. (2008) used the (T/P) altimetry data to study the tide and the tidal energy in the South China Sea (SCS) using a barotropic model using the OTIS (Oregon State University Tidal Inversion Software: Egbert et al.,1994; Egbert and

Erofeeva, 2002) and the study revealed that the M_2 amplitude decreases, while the K1 amplitude increases when the tidal wave propagated from the western Pacific to the SCS through the Luzon Strait (LS), where the maximum tidal energy dissipation was observed. Hu et al. (2009) simulated fifteen tidal constituents individually in the East Asian seas using a $1/12^0$ two-dimensional barotropic model with accurate bottom topography. The tide gauge data around Taiwan is assimilated into the model in order to have better accuracy and the tidal energetics derived from the model suggested that the barotropic tidal energy in the seas around Taiwan is primarily supported by O_1, K_1 and M_2. Unnikrishnan (2010) studied the tidal propagation off the central west coast of India with modified bathymetry derived by Sindhu et al. (2007), and concluded that the semidiurnal constituent M_2 is amplified considerably on the wide shelf, while the diurnal constituent K_1 has only marginal amplification. The currents in the study region were mainly driven by tides. Li et al. (2010) made an approximate quantification of the M_2 tidal energy flux in the Berring Sea (30.43 GW) and the other constituents N_2 and S_2 have only 10% flux magnitude compared to M_2. Ding et al. (2012) analyzed the tides and the tidal energetics in the Indonesian Seas using a 3D finite volume coastal ocean model and revealed some important conclusions regarding the characteristics of the tidal energy distribution in the Indian and the Pacific Oceans. The energy transport of the tidal constituents suggests that the Indian Ocean is dominated by semidiurnal energy. However, there is no indication of detailed investigations in the shallow water and it sediment regimes.

The present work aims to address the issues of time-accurate modeling of tides around indian sub continent. Obtaining the elevations as well currents in the shallow shelf seas is of primary interest. The PI has recently published a detailed work on modeling of tides in the shallow regions of Indian regional sea. This was achieved through hydrodynamics modeling of tides using 3D baroclynic equations. The baroclinicity is included as this will allow in the future to move towards a unified shallow and deep water model where baroclinic effects could be included. A well known open source circulation model, ELCIRC, was adopted for the computations after customizing for the indian ocean region. Since nearshore flow features is one of the main interests, extra care has been taken to model the nearshore features in bathymetry - also providing fine grid resolutions of up to few 100 meters. Extensive validation of the simulated results is carried out by comparing them with the observed elevation and velocities of tide induced flow. Further, the simulations were extended for extracting both dynamics and energetics of the tidal motion in one of the most ecologically sensitive coastal waters of southern part of India, the Gulf of Mannar and Palk Bay. Under the present project this implementation will further be extended up to Melacca Straits on the east, East coast of Africa on the west and 10deg. South.

ANNEXURE 4

(APPROACH)

A regional model covering southern indian coastlines and northern indian ocean has been implemented by the PI recently. Using this as launch pad, we propose to extend this to model complex hydrodynamic and sediment dynamic computations in the estuaries, ports and waterways with appropriate boundary conditions, validation of the same and extending the model capabilities and customization will be carried out under this study.

- To start with, it is envisaged to extend the model domain to Hooghly estuary. Validation will be carried out with extensive field data collected by IITM along with KoPT.
- Implementing the corresponding boundary conditions for barotrophic and baroclinic forcings will be taken up and validation will be carried out with available data.
- Experiments will be conducted in the field and in the lab to correlate the sediment generation mechanism from shallow water due to wave and current action. The measurements will be carried out at 2 sites along Indian coast (Hooghly Estuary and Gulf of Kutch).
- Sediment generation and transport in the regional circulation model will be implemented and validated with data from field experiments.

ANNEXURE 5

Major milestones	Year 1				Year 2				Year 3			
	Q1	Q2	Q3	Q4	Q1	Q2	Q3	Q4	Q1	Q2	Q3	Q4
Appointment of Staff	x											
Equipment procurement	x	X	x									
Literature study	x	X	x	x								
Model implementation & validation		x	x	x								
Field and Lab tests		x	x	x	x	x	x					
Model extension & validation				x	x	x	x	x				
Shallow water hydrodynamic - sediment dynamics							x	x	x	X		
Publications & Documentation							x	x	x	X	x	X
Report Preparation											x	X

ANNEXURE 6 (a)

Publication of articles in this related areas (only SCI journals):

1. Murali.K, Jing Lou and Kurichi Kumar.(2002). "An Unstructured model Simulations for Singapore Strait". *Maritime and Port Journal*, Singapore, 2002.
2. Ming Chen, K. Murali, B.C.Khoo. and Jing Lou. (2002). "Three dimensional circulation modelling in Strait of Singapore". *Maritime and Port Journal*, Singapore, 2002.
3. Ming Chen, K. Murali, B.C.Khoo, Jing Lou and Kurichi Kumar. (2005). "Circulation modelling in the Strait of Singapore". *Journal of Coastal Research,* 21(5), pp.960-972.
4. Manasa Ranjan Behera, K. Murali, S.A. Sannasiraj and V. Sundar (2008), Explicit FE modelling of Indian Ocean Tsunami using unstructured mesh**,** *International Journal of Ecology and Development*, Special Issue on Costal Engineering, 10(s08), pp -.
5. Manasa Ranjan Behera, K. Murali and V. Sundar (2010), Identification of Suitable Grid Size for Accurate Computation of Run-Up Height, *International Journal of Ocean and Climate Systems*, Vol.1(3 and 4), pp223-237.
6. Manasa Ranjan Behera, K. Murali and V. Sundar (2010), Effects of tidal currents at amphidromes on the characteristics of N-wave type tsunami, *Proceedings of the Institution of Mechanical Engineers, Part M, Journal of Engineering for the Maritime Environment*, Vol. 225, pp 43-59.
7. Scaria S., K. Murali and P.Shanmugam, (2015). " Numerical analysis of tidal dynamics in the region around Gulf of Mannar and Palk Strait", *Ocean Dynamics,* In PRess.

ANNEXURE 6 (b)

<u>Publication of articles in other areas (only SCI journals):</u>

1. Mani.J.S, Murali.K and Chitra.K. (1997). 'Prediction of Shoreline Behaviour for Madras, India – A Numerical Approach', *Ocean Engineering*, Vol.24(10), pp.967-984.
2. Sudharsan, N.M., Murali,K. and Kurichi Kumar, (2003), "Preliminary Investigations on Non-linear Fluid Structure Interaction of an Offshore Structure", *Journal of Mechanical Engineering Science*, *Proceedings of the I MECH E, Part C,* Vol. 217, pp. 759 – 765.
3. Rajendra M. Patrikar, Murali K, Li Er Ping. (2004). "Thermal distribution calculations for block level placement in embedded systems". *Microelectronics Reliability.* Vol. 44(1), pp 129-134.
4. Sudharsan N.M.; Ajaykumar R.; Murali K.; Kumar K. (2004). “A comparative study of dynamic mesh updating methods used in the simulation of fluid-structure interaction problems with a non-linear free surface”, *Journal of Mechanical Engineering Science*, *Proceedings of the I MECH E, Part C,* 1 March 2004, Professional Engineering Publishing, Vol. 218, no. 3, pp. 283-300(18).
5. Sudharsan,N.M., Ajaykumar, R.,Murali, K. and Kurichi Kumar, (2004),"Transient sloshing response of a liquid in an elastic container" *Journal of Computational Methods in Sciences and Engineering (in-press).*
6. Sudharsan,N.M., K. Murali and K. Kumar, (2004), "Finite Element Analysis of non-linear Fluid Structure Interaction in Hydrodynamics using mixed Lagrangian-Eulerian Method", *International Journal of Computational Engineering Science, World Scientific, Vol. 5 No. 2 (June 2004).*
7. Jagadeesh.P and Murali.K, (2005), “Application of Low-Re Turbulence Models for Flow Simulations Past Underwater Vehicles Hull Forms”, *Journal of Naval Architecture and Marine Engineering, 1(2005), pp.41-54.*
8. Jagadeesh. P and K.Murali (2006) “Investigations on Alternative Turbulence Closure Models for Axisymmetric Underwater Vehicles”, *The Jl. of Ocean Tech.,* 1(2), pp 36-57*.*
9. Behera, M. R., and Murali, K. (2007) “Semi-empirical model for initial displacement of salt water wedge in a bar-blocked estuary”, *ASCE, Journal of Waterway, Port, Coastal, & Ocean Engineering*, 133(4), pp 264-267.
10. Behera, M. R., and Murali, K. (2007) “Investigations into salt wedge dynamics at a bar blocked estuary using front tracking approach”, *Journal of Hydro-Environment Res.*, 1(1), pp 1-8.
11. Jagadeesh P. and K. Murali (2010), RANS predictions of free surface effects on axisymmetric underwater body, *Engineering Applications of Computational Fluid Mechanics* Vol. 4, No. 2, pp. 301–313.
12. Nithiarasu P, R.L.T. Bevan and Murali K, (2012), "An artificial compressibility based fractional step method for solving time dependent incompressible flow equations. Temporal accuracy and similarity with a monolithic method", *Computational Mechanics*, vol. xx, pp.xx. (Published online, 01 May 2012).