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TOWARDS A COASTAL OCEAN PREDICTION SYSTEM FOR THE GULF OF BACBO

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Abstract

The Tonkin Bay waters include the shallow area along the west and north coast, the estuarine transition regions, as well as waters of the western South China Sea. It is therefore essential that any coastal ocean prediction (COP) system can account for the extreme physical environments encountered in these waters..

The system of the MDEC model had been applied to simulate the hydrodynamics, suspended matter and environmental components included oil in the Tonkin Bay and coastal area The simulated results can help to explain the oil pollution case appeared in the Vietnamese coastal during winter season 2007. The developed MDEC modeling system is opened up the applications in monitoring and forecasting coastal and marine environment.

1. Introduction

Predicting the behaviour of the flow in the oceans is a challenge. It is however widely recognized to be of great social and economic significance. The increased utilization of coastal regions, problems of pollution and over-fishing are widely acknowledged. Consequently the demand for coastal ocean prediction (COP) systems (integrated circulation, modeling and observation systems) is becoming as acutely felt as demand that exists for weather forecasting systems.

The coastal ocean is here defined to include the 200 nautical mile Exclusive Economic Zone (EEZ) as determined by the UN Convention on the Law of the se (UNCLOS), plus estuaries. The EEZ generally covers the continental margin; i.e., continental shelf, slope, and rise, where water depth, and its strong variations, exert a controlling influence on oceanic processes and the bio-production of living marine resources is high.

While the circulation of the coastal ocean has much in common with that of the open ocean; such as, the strong dynamical influence of Earth's rotation and density stratification, there are a number of unique factors, too. The importance of shallow water depth and steep bottom topographic variations were mentioned above; in addition, the coastline itself, and its irregularities, have a strong influence on the circulation. Furthermore, the costal ocean is more responsive to atmospheric synoptic scale forcing than the open ocean; it is often under the influence of buoyancy forcing from major river discharges or distributed coastal sources; and tidal currents, wind waves, and swell effects are generally stronger.

The coastal ocean serves as a transition zone between continental and open ocean regimes. Materials from the continents destined for the deep sea must traverse the coastal ocean via physical, chemical, or biological transport processes, while, at the same time, the predominant coastal ocean and offshore flows are generally parallel to the coast. Very often the transport from the open the open ocean onto the shelves via upwelling is also important, especially for bio-production.

COP is a broad term encompassing a wide range of ocean forecasting problems. It includes such diverse fields as sediment transport and COP. While two-dimensional storm surge models still from basis for many operational forecasting models, the new generation of coastal ocean prediction systems increasingly rely on three-dimensional primitive equation models. The challenge ahead lies in developing the numerical techniques that can deal with these complex regions, together with an understanding of the physical processes that must be resolved in a given COP domain. These processes typically have vast spatial and temporal scales and intelligent choices need to made to reduce the system to a manageable forecasting problem. While the long-term objective is to have a more general forecasting system; here, the focus is on physical and numerical issues that these systems must already address.

The Tonkin Bay waters include the shallow area along the west and north coast, the estuarine transition regions, as well as waters of the western South China Sea. It is therefore essential that any COP system can account for the extreme physical environments encountered in these waters. The Tonkin Bay waters, in particular, highlight many of challenges that need to be met in the development of COP systems.

2. Coastal ocean prediction

Tidal prediction, which is essential for safe navigation in shoal waters, was the earliest predictive capacity in oceanography. Wind wave and swell forecasts achieved a useful level during Word War II, however, there does not generally exist a routine predictive capacity today due to the complexity of shallow water wave dynamics, which necessitate observing system and computational resources that are not presently available. Storm surge modeling has traditionally dominated operational oceanography. In recent decades, storm surge prediction has allowed forecasts of coastal inundation by marine storm; however, these forecasts are not always sufficiently accurate due mainly to inadequacies of the forecasted atmospheric forcing; other limiting factors include uncertainties in the surface stress and bottom stress under storm conditions. Spontaneously, over the past few years, there has emerged an incipient operational coastal ocean circulation capacity in several countries due to combination of increased scientific understanding; improved computational, telecommunications, observational, and modeling technologies; and growing social demand. Yet to emerge are operational coastal ecosystem, water quality, sediment transport, etc. prediction systems.

The growing environmental pressure on coastal regions has, however, lead to a demand for COP systems that can meet many of the applications and users. For example, those concerned with offshore structures; e.g., oil rigs, need to know the wind-wave and current forces to be expected for the safe design (in simulation and hindcast modes) and safe operation (in nowcast and forecast modes) of those structures. In contract, those concerned with oil spill mitigation and clean-up need to know the space-time trajectories that a spill is likely to follow based on winds and currents; those concerned search-and-rescue operations have very similar needs. Fishermen have another set of concerns; they need to know the location of oceanic fronts and upwelling zones, the strength of the thermocline, and depth of the mixed layer. Hence, their information needs are somewhat similar to those of naval forces involved in pro-and-anti-submarine warfare: they need to know the location in space and time of ocean thermal structure in order to predict the performance of sonar systems. Those concerned with dumping negatively buoyant waste materials in the coastal ocean need to know the bottom currents (and the turbulent mixing they generate), especially their potential for resuspending unconsolidated material, as well as advective and turbulent diffusive conditions in the water column. Shipping interests are concerned about safe navigation, especially when entering and living port – actually, a day or more advance. For them, hour-by-hour knowledge of sea level, and currents, and even density, a crucial as their technology and economics have led to larger vessels with deeper drafts and narrower margins for error. Growing classes of users of coastal prediction information are the planners and policy makers concerned with the response of the coastal ocean to climate and global change (e.g., coastal flooding and shoreline erosion due to rising sea level and harmful algal blooms and hypoxic and anoxic conditions due to eutrophication from river runoff of agricultural and municipal effluents. The fate of contaminants from Red River system and the oil spill pollution was already causing concern in Vietnamese coastal areas.

Three-dimensional models

Coastal ocean models must be capable of handling the combined effects of irregular coastlines, highly variable and steep topography, large density gradients, and complex time depending. The choice of either the vertical co-ordinate system or the advection algorithm can influence the suitability of a numerical model for a regional COP. The model capability to resolve bottom boundary layers is very important in sediment transport application. However, the ability to handle surface and bottom boundary layer interactions, particularly in shallow coastal regions is more restrictive. The numerical treatment of the advection terms is important in regions with large density gradients.

In addition, one of the major problems facing limited-area modeling is the specification of the open boundary conditions. The open boundary conditions must allow disturbances to propagate freely out of the model domain, with minimal reflections. However, they also need to allow the large external scale forcing to enter the domain of interest.

3. The MDEC COP system

While a number of ocean models have been explored for their suitability to handle the extreme conditions met in this region, the MDEC model [1,2,3] currently forms the basis of the COP system. The MDEC model is developed from initially GHER- University of Liege model. It is a three-dimensional, hydrostatic, primitive equation model that uses an Arakawa C-grid in the horizontal and sigma-ordinates in the vertical. It was chosen because it has free-surface and advanced turbulence closure scheme. While the former property is important for the simulation of tides and surges, and the latter feature is particularly important in order to simulate boundary layers. Since atmospheric forcing is so important, it is essential to accurately resolve the surface boundary layer. For the shallow Tonkin Bay area, the resolution of bottom boundary layer in the frequently wavy conditions is also crucial.

For the development of a COP system, the model needs to be eddy-resolving, which places rather severe restriction on the horizontal resolution.

In the MDEC COP system, a fate and transport model was developed for the SPM and oil pollution and coupled with 3D thermo-hydrodynamic model. In practice, the Euler approach is traditional in hydrodynamics and the Lagrange approach is used in studying the fate and suspended matter spreading trajectories. In the future, the Euler approach will become more and more popular due to the demand of combining the dynamic equations of polluted substances transportation with the thermal hydrodynamic model. Using of similar techniques as in thermo-hydrodynamics allows us to enhance the modeling capability of water qualities as well as the precision of the environment studies in general. The integration of the dynamic principles and the experimental data opens up the possibility of application of the model to several marine environment problems.

Based on the study of the dynamic principles of interactions of oil phases and the environment compound, we can build the dynamic model of oil compound as well as the marine environment [4,5]. There are four phases in the marine environment: oil slick, emulsion, particulate and dissolved oil. Among those, the oil slick only exists on the sea surface and the there remaining phases exist in the water column. In the sediment, there are only two phases: the dissolved and particulate oil (Fig.1)

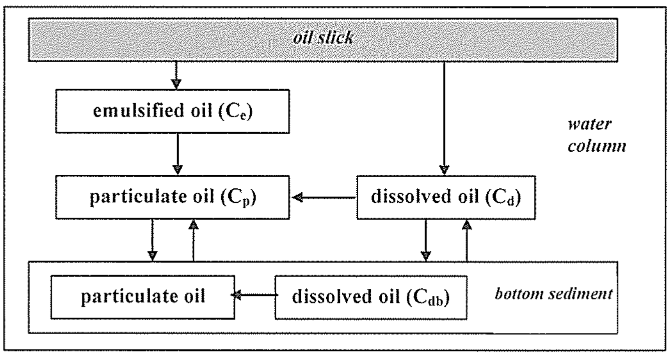

Fig.1. Dynamic diagram of the oil phases in marine environment.

4. Application of the MDEC COP model for the Gulf of Bacbo

The system of the MDEC model had been applied to simulate the hydrodynamics, suspended matter and environmental components included oil in the Tonkin Bay and coastal area. The initial oil mass is supposed about 1,000 tons spill out in the region near south-west of Hainan Islands. The simulated fields of the water circulation and water temperature show mostly well for as very complex coastal and estuarine condition as combined river- air-sea interaction. Fig. 2 show the surface water circulation and temperature fields for February and April, that is well conformed with the climatology of observed sea surface current.

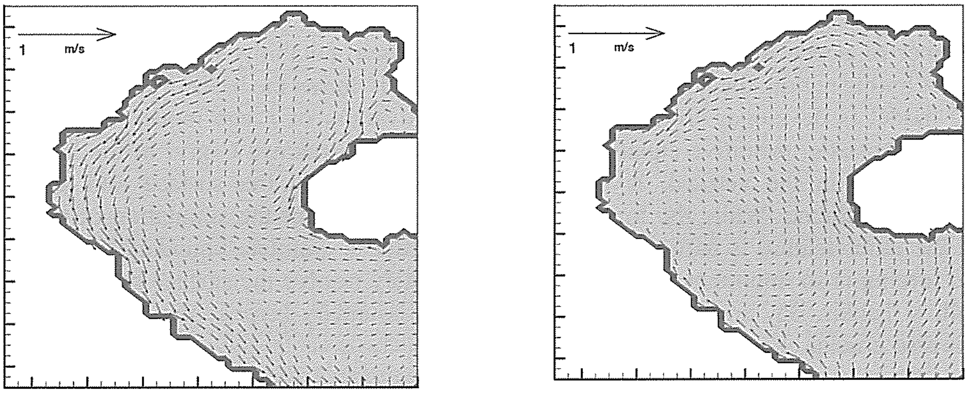

Figure 2a. Simulated surface water circulation the February and April

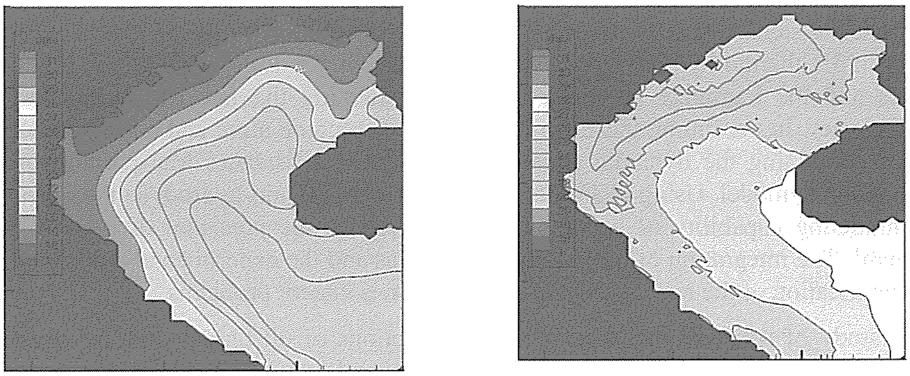

Figure 2b. Simulated surface water temperature in the February and April

The obtained results for the spreading of oil slick (figure 3) show that the model has been successfully simulate in time and shape of the oil spill as in the classical models as well as in reality [6]. In the climatologic conditions, the surface oil slick will be disappeared during 30 days; the oil slick thickness is decreased from 10 mm to less than 0.1 mm after this period.

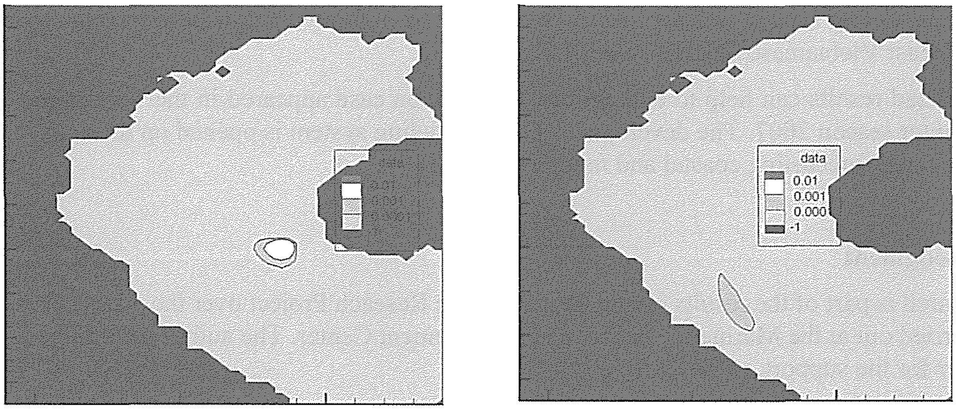

Figure 3. Simulated oil spill slick thickness (m) after 1 day and 30 days

Another oil spill phase: oil in emulsion conserves and spreads longer than oil slick and could attained the south-western coast and north part of the Gulf after 2-3 months (fig.4).

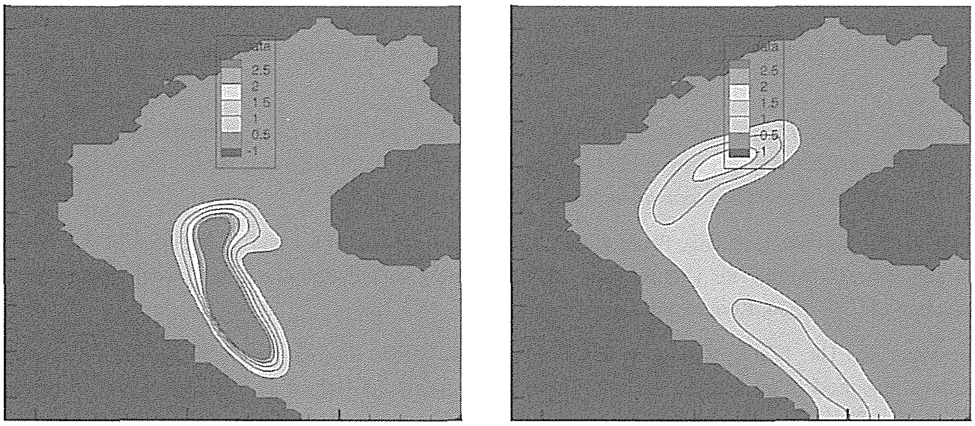

Figure 4. Simulated oil emulsion (g-oil/m3) after 30 day and 60 days

In another hand, the concentration of particulate oil in bottom sediment will be accumulated and transported with the same direction with the delay about 1-2 moths relative to emulsion phase (Fig. 5).

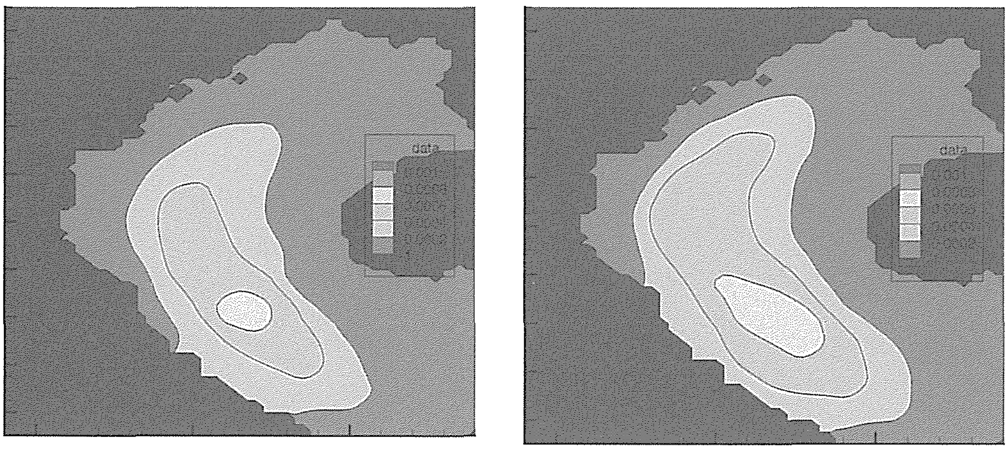

Figure 5. Simulated patrticulate oil in sediment (g-oil/kg-sediment) after 90days and 120 days

The same modeling system was applied to investigate the hydrodynamic-environmental regimes for the South-East Vietnamese Coastal area [3].

The simulated results can help to explain the oil pollution case appeared in the Vietnamese coastal during winter season 2007. The developed MDEC modeling system is opened up the applications in monitoring and forecasting coastal and marine environment.

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