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Efficient Non-Hydrostatic Modeling of Rotational, Turbulent, Dispersive, and Variable-Density Flows in the Vicinity of River Mouths and Inlets

Patrick Joseph Lynett
Department of Civil Engineering
Texas A&M University
College Station, TX
phone: (979) 862-3627 fax: (979) 862-8162 email: plynett@tamu.edu

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LONG-TERM GOALS

The long-range goal of this project is to develop a physics framework, and an associated numerical tool, which provides relatively rapid, phase-resolving predictions of wavy environments in the presence of strong currents and vertical stratification. The benefit of this approach, as contrasted with existing models, is that here we are able to more completely represent the nonlinear wave field, without using coarse statistical approximations, and can include the non-hydrostatic physics introduced by these nearshore wind waves.

OBJECTIVES

The scientific objectives of this project are founded on the modeling of currents and coherent turbulent structures generated by tidal or river flow coupled directly, via the same equations, with weakly dispersive wind waves. Integrated with the hydrodynamic model will be a transport module, permitting estimation of the evolution/dispersion of scalar tracers and Lagrangian drifters, in both the depth-averaged sense and with full 3D transport modeling. Finally, modification of the governing physics will include spatial variations in fluid density, in both horizontal and vertical directions, such that fresh and salt water mixing might be captured. Combining this models ability to simulate turbulence and transport in shallow flows with its capacity to include weakly dispersive wind waves, there exists the potential to simulate a wide range of complex and nonlinear processes with a single, practical numerical approach. This project is part of the River Mouth and Inlet DRI, and will be used to both guide the field experiment and interpret the measured data.

APPROACH

The numerical efforts undertaken here implement established aspects of Boussinesq-type modeling, developed by the PI and other researchers. These aspects include wind wave breaking (e.g. Kennedy et al, 2000; Lynett, 2006), accurate moving boundary schemes for shoreline motion (Lynett et al., 2000), and a MPI-based parallellization (Sitanggang & Lynett, 2005). Within this model basis, the project attempts to include physical processes relevant to the hydrodynamic environment near a river mouth or a tidal inlet. The PI and students will work through the theoretical obstacles of including

these physics in the Boussinesq-type framework, and then implement in a numerical model. Once this comprehensive model is developed and tested against established experimental data, it will be used to simulate numerous possible wave and current conditions at New River Inlet. These numerical simulation results are expected to help the field teams to best place measurement equipment, as well as provide them with some expectations on the range and scale of phenomena that might be observed at New River.

WORK COMPLETED

This is a new project in FY10. In this first year of the project we have developed a Boussinesq-type formulation that permits the explicit inclusion of small-scale, random turbulent fluctuations. Inclusion of these effects has been demonstrated to be very important for transport and mixing. This work is "in review" for the journal Physics of Fluids. In addition, the depth-integrated hydrodynamic model has been coupled with a 3D scalar transport model. The goal of this coupling was to permit the modeling of near-field and/or depth-dependent mixing due to combined waves and currents. The results of this effort are currently "in review" for Advances in Water Resources.

RESULTS

A depth-integrated model including subgrid scale mixing effects for turbulent transport by long waves and currents has been developed. A fully-nonlinear, depth-integrated set of equations for weakly dispersive and rotational flow are derived by the long wave perturbation approach. The same approach is applied to derive a depth-integrated scalar transport model. The proposed equations are solved by a fourth-order accurate finite volume method (FVM). The depth-integrated flow and transport models have been applied to typical problems which have different mixing mechanisms. Several important conclusions are obtained from the simulations: (i) From simulation of a mixing layer generated by internal transverse shear, it is revealed that the dispersive stress implemented with a stochastic backscatter model (BSM) plays an important role for energy transfer in a shallow mixing layer; (ii) The proposed transport model coupled with the depth-integrated flow model can predict the passive scalar transport physically - that is, based on the turbulent intensity - without relying on a coarse empirical constant; (iii) For near field transport simulations, the inherent limitation of the two-dimensional horizontal model to capture vertical structure is recognized; (iv) If the main mechanism of flow instability originates from relatively large-scale bottom topography features, then the effects of the dispersive stresses (i.e. BSM) are less important. In practice, this new approach will permit simulations of very complex turbulent and rotational flows where both nearshore wind waves and currents are important.

An example of the application of this model is given in Figure 1. This is a simulation of 2m, 10-s waves approaching New River Inlet, NC. The image on the top, Figure 1a), shows a snapshot of the ocean surface elevation, approximately 60 minutes into the simulation. The models ability to reasonably recreate a directional, nearshore wave field is evident. The image on the bottom, Figure 1b), gives the instantaneous vertical vorticity at the water surface. From this image, there is clearly a significant level of small-scale variability and rotation, while the waves also create a large-scale circulation at the head of the ebb shoal (blue arc). From this type of detailed simulation, the field study teams should be better prepared for the phenomena they might observe.

IMPACT/APPLICATIONS

This project has the potential to develop a depth-integrated nearshore hydrodynamic model which explicitly includes a number of currently neglected physical forcings. In particular, this will make the model uniquely applicable near inlets and river mouths where wind waves are present.

RELATED PROJECTS

This effort is one of a large number of projects that make up the River Mouths and Inlets DRI.

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PUBLICATIONS

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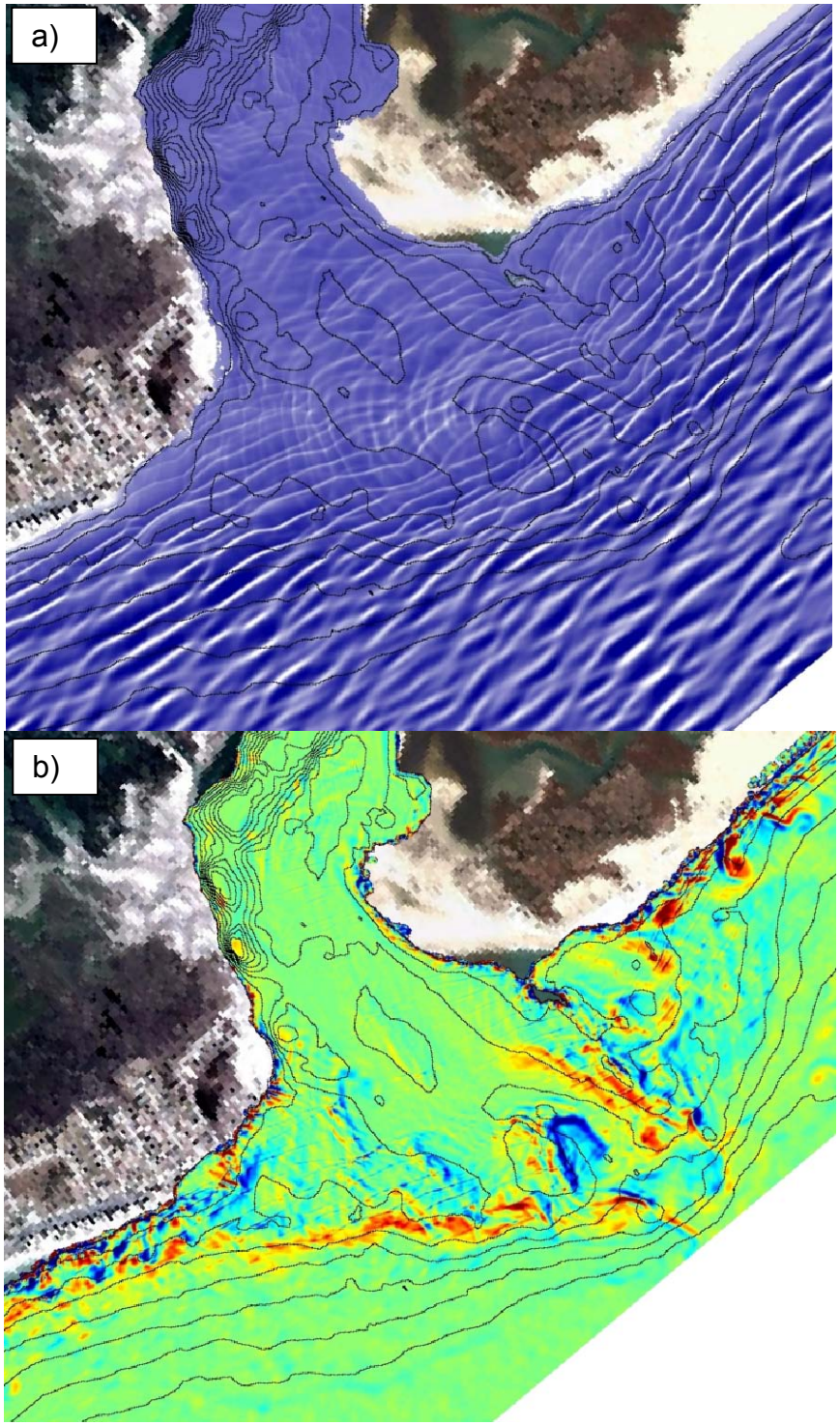

Figure 1. Snapshots from a wave-only simulation of New River Inlet, NC. Top plot (a), shows the water surface elevation. Note that the depth contours are given by the black lines, where the contour interval is 1 m, and the deepest contour is 7 m. The lower image (b) shows the instantaneous vertical vorticity, where the blue colors indicate clock-wise rotation and the red counter-clockwise rotation. The topography overlay on both images is from Google Earth.