Development and Verification of a Comprehensive Community Model for Physical Processes in the Nearshore Ocean

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LONG-TERM GOAL

Our goal is to develop a comprehensive, verified community model that predicts nearshore hydrodynamics, sediment transport, and seabed morphology changes given offshore wave conditions and initial bathymetry.

OBJECTIVES

The basic scientific objective is to synthesize understanding of physical processes in the nearshore ocean by developing a model for

- waves and resulting radiation stresses and mass fluxes over evolving coastal bathymetry and currents
- wave-induced circulation
- sediment transport and morphological evolution

Additional objectives include developing techniques to assimilate observations into model predictions, and to test model components and the full community model with field observations.

APPROACH

Our approach is to develop a tightly-coupled system of individual model components, or modules. We are utilizing a framework where wave processes are distinguished from wave-averaged processes by means of a suitable time average. The resulting set of modules and their functions are:

1. wave module - calculation of second- and third-moment wave properties, including frequency-directional spectra, radiation stresses, and wave skewness and asymmetry

2. circulation module - calculation of wave-driven circulation and turbulence levels

3. seabed module - calculation of local sediment fluxes and seabed changes resulting from flux divergences, and characterization of bed geometry

A model backbone will allow interaction and feedback between the individual modules, as well as provide an interface to users. Candidate models to be used within each module are being investigated and tested. The model backbone will be constructed as an open architecture with a documented set of required inputs and outputs for each component, allowing users to provide alternative formulations for each module.

Wave modules based on energy balances and on frequency domain Boussinesq or mild-slope equations are being investigated. Phase resolving formulations will allow detailed time series of waves to be simulated, and stochastic approaches will allow waves over large nearshore regions to be modeled. Breaking wave dissipation will be included to model waves propagating across the surf zone.

Circulation will be modeled with SHORECIRC and the Princeton Ocean Model (POM). SHORECIRC solves the short-wave averaged equations including the 3-dimensional structure of mean and infragravity band currents using forcing and mass flux calculations provided by the wave module. A model for turbulence generated by wave breaking, the bottom boundary layer, and mean flows will be included in the SHORECIRC circulation module. POM is a finite-difference approximation to the hydrostatic primitive equations with a free surface, and includes equations for continuity, momentum, temperature, and salinity. The Mellor-Yamada level 2.5 turbulence closure is used. Forcing by breaking waves and mass flux is parameterized.

The seabed module will model the local flux of sediment and the evolution of seafloor sedimentology and morphology. Field observations are being used to develop models for sediment flux driven by near-bottom velocities. Conservation of mass allows sediment flux calculations to be used to predict changes in large-scale nearshore bathymetry. The effects of bedforms such as ripples and megaripples will be incorporated into the modules.

Model components, and eventually the full community model, will be tested by comparison with field observations. Waves, currents, sea floor morphology and bathymetric evolution observed on the Outer Banks of North Carolina and on the Southern California coast are being used to test model components. Observations from future field experiments near complicated nearshore and inner-shelf bathymetry will be reduced to the same format as existing data for additional model testing. Techniques to assimilate observations of nearshore waves and circulation into model predictions are also being investigated.

WORK COMPLETED

Two meetings have been held to organize activities and review results. Working groups have been formed in the areas of

(1) surface wave dynamics, (2) wave-induced circulation and turbulence , (3) sediment transport and seabed morphology, and (4) verification and data assimilation.

Groups (1)-(3) are pursuing the development and testing of individual modules with the goal of advancing the science in each, as well as defining how each module will interact most effectively with the other model components. Group (4) is testing and calibrating existing models, and assembling a WWW site for field data that can be used by the NOPP partners to test individual modules.

The nonlinear spectral parabolic wave model REF/DIF-SNL has been extended to accomodate a wider range of incident wave directions (Kaihatu, 2000) and has been tested with field data. Herbers *et al* (2000) have extended a stochastic version of the spectral Boussinesq formulation to include surfzone effects, and have tested the resulting model with field data with favorable effects.

The SHORECIRC model has been documented and released to project personnel in advance of a general public release (Svendsen et al, 2000). A reformulation of the model in terms of the the total depth-averaged Eulerian velocity has produced a much more stable numerical code, which is now being used to investigate the three dimensional structure of rip currents. Extensions of the model to incorporate random wave forcing (using REF/DIF S) and a curvilinear grid in horizontal coordinates are under development.

The Princeton Ocean Model (POM) has been adapted for applications to wave-averaged circulation by adding parameterized forcing represented by gradients in the radiation stress tensor. These forcing terms are partitioned appropriately as either surface stresses or as depth- independent body forces. Additional forcing related to rollers also is included. The effects of wave-induced mass flux are included through an appropriate boundary condition on the vertical velocity at the surface. Initial studies focus on alongshore-uniform flows with spatial variations in the cross-shore (x) and vertical (z) directions. Different turbulence closure models, including Mellor-Yamada and k- epsilon schemes, are being tested. Different boundary conditions for the turbulence quantities at the surface are also being tested following Craig and Banner (1994). An efficient wave-current bottom boundary layer sub-model that parameterizes the influence of the waves on the bottom stress (Styles and Glenn, 2000) has been embedded in POM. The model has been applied to studies of the circulation off Duck, NC and model results are being compared with velocity measurements from the DUCK94 field experiment.

Work on sediment transport modelling has concentrated on numerical prediction of bedload transport. Drake and Calantoni (2000) have extended a direct simulation of granular motion and fluid - grain interaction (Figure 1) to include the effect of bed slope and wave-induced velocity and pressure gradient time histories. Results from these simulations are being parameterized to provide improved wave-averaged transport formulations.

Results from previous field experiments have been collected and made available for model testing by means of a password protected web page located at http://science.whoi.edu/NOPP/NOPPmain/main.html. Data from the Duck 94/CoOP experiment and a surfzone deployment near the Scripps pier are presently online.

Work is continuing to determine the fluid motions that cause sand bar migration, to characterize

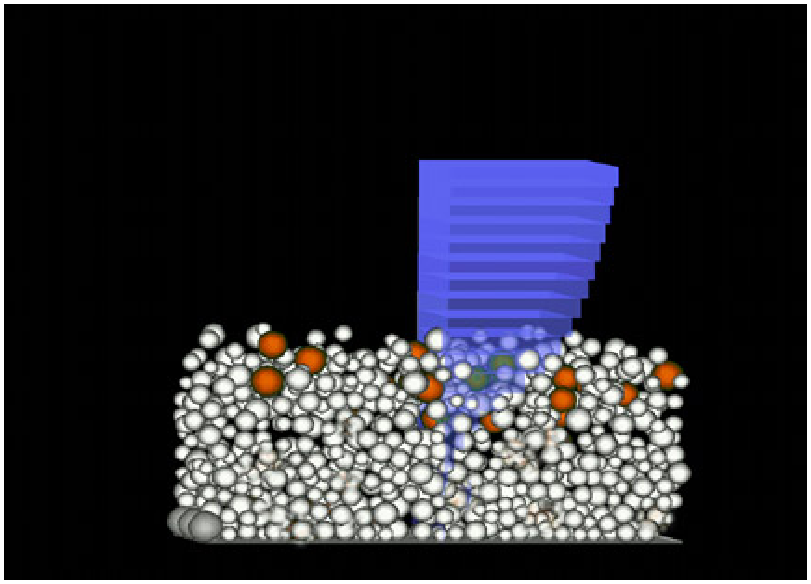

Figure 1: Discrete particle numerical simulation of bedload transport. Spheres are sediment grains and blue arrows are velocity vectors

shear and infragravity wave energy levels in field observations, and to obtain bottom drag coefficients based on inverse estimates from measured current data.

RESULTS

The deep water asymptote of the REFDIFSNL wave model has been tested against analytic solutions. It is shown (Kaihatu 2000) that permament form solutions of REFDIFSNL in deep water compare well against solutions from third-order Stokes wave theory.

Results obtained from the SHORECIRC model indicate that rip current dynamics are relatively insensitive to alongshore rip current spacing, and instead represent a balance between forcing and dissipation mechanisms that are localized close to the throat of the rip channel. The velocity, vorticity and streamline patterns for four different alongshore rip spacings are shown in Figure 2. The undertow component is removed from the velocity field to illustrate the residual flow pattern associated with the rip. The plots are for four relative channel spacings $L_B/L_c = 4, 6, 8, 12$, while the position of the bar relative to the shoreline is held fixed at $L_s/L_c = 2.5$. In part (c) and (d) the flow pattern near the rip is unaffected by the change in spacing, and panel (b) shows only a weak effect. Even for the closest rip spacing in (a) the flow near the rip is nearly unaffected though the circulation cells behind the bar are squeezed slightly at the side limits, which represent the symmetry lines to the neighboring rips.

The POM model applications to DUCK 94 conditions determine model solutions for (x,z) structure of the wave-averaged alongshore (v) and cross-shore (u) velocity fields. Reasonable agreement is found between the model and measured velocities (Figure 3). The effects of tidal elevation change on the circulation are investigated and show, in particular, variations in the strength of the undertow over the bar and in the trough with tidal height that are in general agreement with velocity measurements from the fixed array.

Investigation of the observed sand bar migration, waves, and currents suggests that coupling and

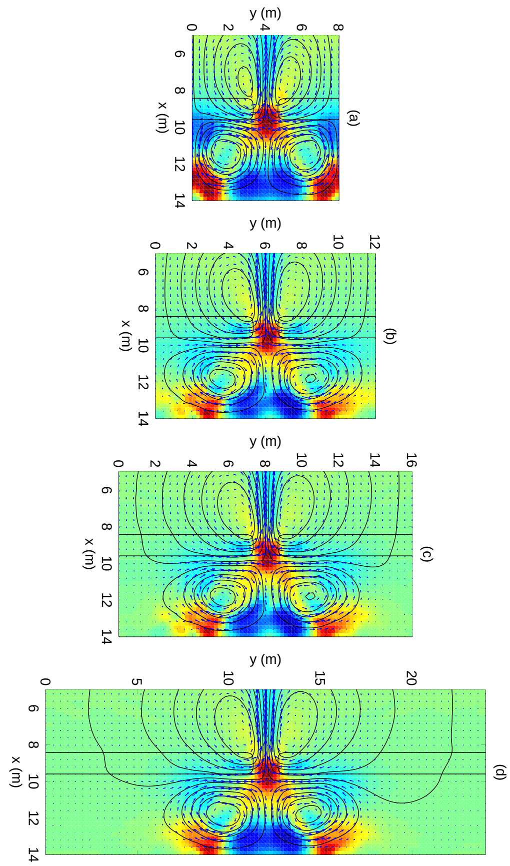

Figure 2: The mean circulation pattern for a laboratory-scale rip held in place by a channel in a longshore periodic bar. The progression from top to bottom shows the variation of rip current structure with increasing relative spacing between rip channels. Velocity vectors indicate the residual flow pattern after removing the undertow component. The color map indicates vorticity and solid curves indicate streamlines. The flow structure is localized around the rip channel and is not influenced by increasing spacing as the relative spacing becomes large.

feedback between morphology, shoaling waves, and wave orbital velocities and accelerations result in landward bar migration when mean currents are weak (Elgar et al, 2000). These results indicate that fluid acceleration, usually neglected in sediment transport models, may be an important component in sediment transport. This result is supported by the discrete particle simulations for the case of asymmetric broken waves, which also show the importance of fluid acceleration. Results of the discrete particle simulations (Drake and Calentoni, 2000) will be used to develop wave-averaged transport formulations for use in SHORECIRC and POM.

IMPACT/APPLICATION

The model system under development will provide a comprehensive predictive tool for nearshore processes, and will have a wide range of uses in the scientific community, as well as in DoD and civil planning and operations.

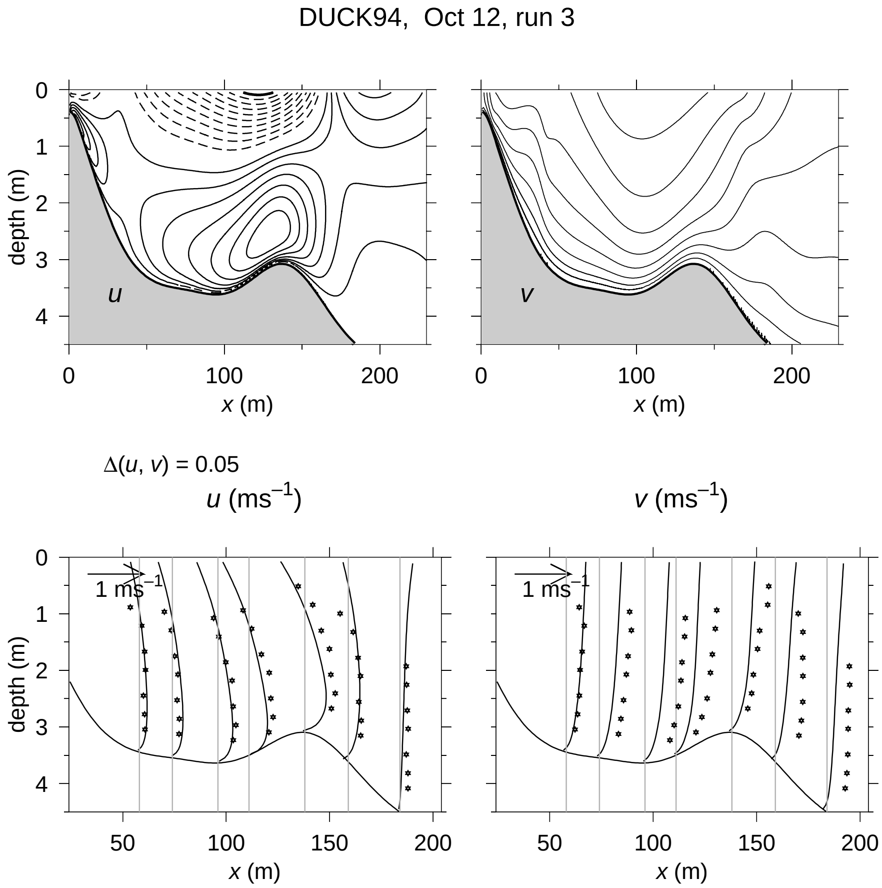

Figure 3: Top: Contours of cross-shore velocity u and alongshore velocity v from a simulation using the Princeton Ocean Model, , adapted for use in the nearshore and including a submodel parameterizing the wave-current interaction (Styles and Glenn, 2000). The contour interval is 0.05 ms^{-1} with dashed contours representing onshore flow. The alongshore velocities are to the south. Bottom: Vertical profiles of u and v at the locations of sled velocity measurements on Oct. 12, 1994 at Duck, NC (Garcez Faria et al. 1998; Garcez Faria et al. 2000). The solid lines are the model velocities and the bullets are the measurments. The model is forced with gradients of the radiation stress tensor calculated from measured wave heights and the effects of rollers are included.

RELATED PROJECTS

The investigators in the NOPP project have a range of individual projects with closely related science and modeling objectives. The NOPP model development effort benefits these other ongoing studies by increasing collaboration and exchange of results and data among the partners. The NOPP project allows results from individual investigations to be synthesized into a community-wide model for nearshore processes.

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