Nonlinear Time-Dependent Currents in the Surfzone

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LONG-TERM GOAL

The goals of this work are to develop better understanding and predictive capability for unsteady currents forced by breaking waves in the surfzone.

OBJECTIVES

The major tasks to be accomplished are:

(1) Examine rip current dynamics for different parameter ranges of wave height, bottom friction, incident wave angle, and beach bathymetry.
(2) Couple the wave field to the mean flow in physical-mathematical models for situations that produce alongshore-currents and rip-currents. As unsteady currents evolve the distribution of surface wave breaking and momentum input to the mean currents adjust. We will examine the influence of feedback from the time-mean currents on the radiation stress gradients that parameterize momentum forcing from the surface wave field.
(3) Investigate the influence of alongshore topographic variability (transverse bars) on alongshore currents over plane beaches (i.e., without alongshore-parallel sandbars).
(4) Simulate field conditions at Duck, N.C. using measured beach bathymetry and wave field conditions from the Delilah and Sandy Duck field experiments. This "best effort" model will include tides and coupled wave-current interactions.

APPROACH

The work involves theoretical development, numerical computations, and comparison with field and laboratory results. The primary experimental tools are shallow water equation models (Slinn et al, 1998) including parameterizations for wave forcing and bottom dissipation. Process studies are conducted for different key nearshore parameters (incident wave angle, wave height, bottom friction coefficient, beach bathymetry, etc.) to determine the effects on flow response.

WORK COMPLETED

We have revised a manuscript (Slinn and Allen, 1999, accepted for publication in JGR) on alongshore currents over barred beaches with alongshore non-uniformity. Key findings from that work indicate that alongshore currents respond strongly to topographic variability. The time averaged currents meander onshore and offshore approximately following contours of constant depth. Shear instabilities in the alongshore current develop at the wavelength of topographic perturbations more rapidly than at

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the wavelength of the fastest growing linearly unstable mode predicted for alongshore uniform beach profiles. In addition, for more turbulent alongshore currents, eddies preferentially break away from the mean current toward deeper water at locations of rip channels through the alongshore parallel sandbar.

The project has now been joined by Jie Yu (PhD, 1999, MIT, Civil Engineering). She is focusing on modifying the parameterization of the surface wave radiation stress forcing to include coupling with the time mean currents. We are applying this model first to the rip current system.

RESULTS

Including tides in the model is essential to accurately simulating field conditions. The water depth over a sandbar can change by approximately one meter over a six hour period due to tides, significantly adjusting the wave breaking pattern and the associated momentum input into the water column. Figure 1 shows vorticity fields from a numerical simulation of alongshore currents over a barred beach with tides included in the model (with an adjustable shoreline location). At periods of low tide, bottom friction increases over the sand bar because the water is shallower and the resulting flow is fairly uniform with wave-like disturbances. At periods of higher tides friction decreases and the currents over the bar generate significant eddy fields. Also at high tide the bar is farther from the shore line leaving more room for eddies to interact in the trough region.

An important parameter in the flow behavior over non-uniform beaches is the angle of wave incidence. Rip currents are generated through the radiation stress gradients produced by waves that approach the shore at small angles of incidence, $\theta_0 < 10^{\circ}$. Figure 2 shows steady and unsteady rip currents that develop for normally incident waves for barred beach topography with sinusoidal, 30 cm deep rip channels, located at $y_0 = 0$, 256, and 512 m. Here, the offshore wave-height is $H_0 = 0.7$ m, the peak wave period of $T_p = 8$ s, and results are shown for different values of the bottom friction μ (m/s). For the higher values of bottom friction steady circulation cells develop. The rip currents become progressively unsteady as μ is decreased below approximately 0.004 m/s.

Additional analysis indicates that the offshore transport of mass and momentum caused by the rip currents is a function of wave height, bottom friction, the beach bathymetry (depth, width, and spacing between rip channels). Maximum values of offshore fluxes often occur in intermediate ranges of these values. Small waves (or large bottom friction) generate weaker currents while larger waves (or small bottom friction) produce strongly nonlinear currents that quickly break down into eddies that often produce localized circulation shoreward of the sandbar. In intermediate ranges rip currents approximately 100 m wide with velocities of 50 cm/s provide the maximum efficiency at circulating water in and out of the surfzone.

Our experiments demonstrate that offshore wave angles $1^{\circ} < \theta_0 < 5^{\circ}$ produce patterns of circulation similar to the rip currents for $\theta_0 = 0$. These are often accompanied by a weak alongshore drift of eddies offshore of the sandbars. Between $5^{\circ} < \theta_0 < 15^{\circ}$ a rich combination of rip and alongshore currents can develop with the dominant behavior depending on the magnitude of other parameters (bottom friction, wave height, bathymetry). Above $\theta_0 = 15^{\circ}$ alongshore currents dominate with behavior that is tied closely to the details of the bathymetry.

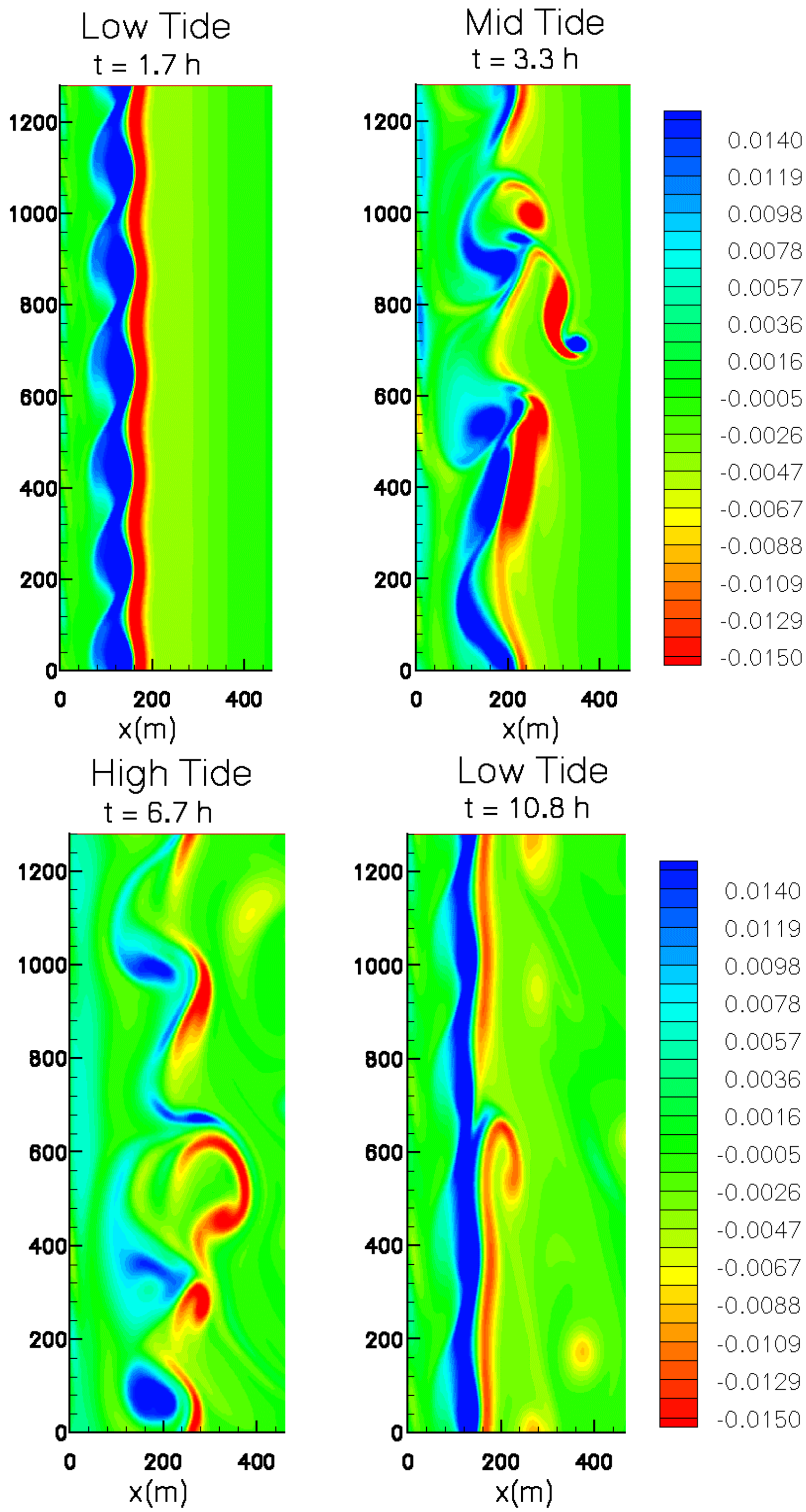

Figure 1: Instantaneous vorticity fields at different stages of a 11.5 hour tidal cycle over a barred beach. The angle of wave incidence is 20^o, the offshore wave height is 0.7 m, the bottom friction μ = 0.00087 m/s, the barred beach is uniform in the alongshore direction, and the tidal variation is 1 m.

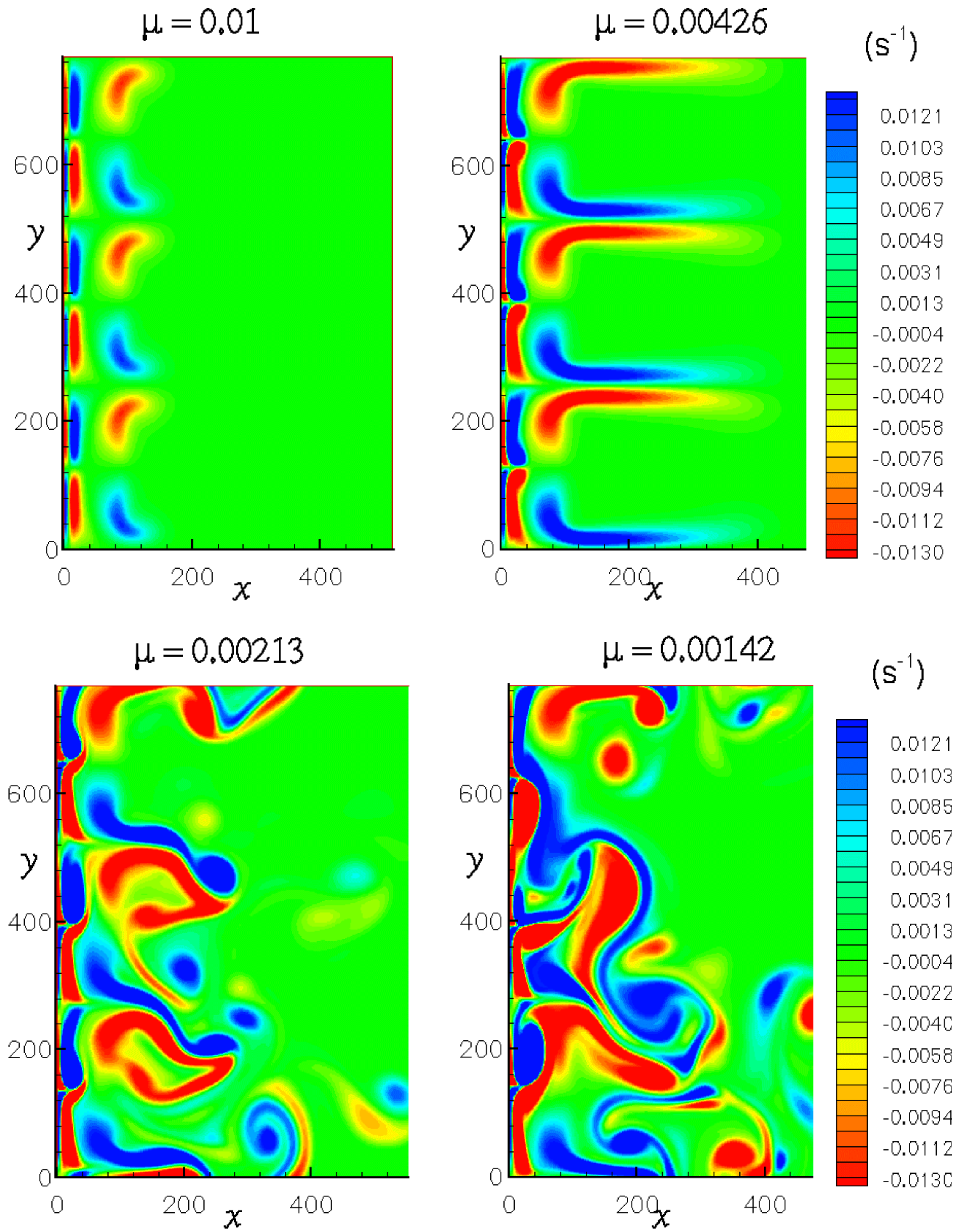

Figure 2: Instantaneous vorticity fields showing rip currents that develop for normal wave incidence with wave height of 0.7 m for different values of the bottom friction μ (m/s).

IMPACT/APPLICATION

Improved understanding of the near shore environment has potential benefits for society in several areas. These include shore protection against beach erosion, understanding the behavior of shoaling waves, keeping waterways open for shipping in harbors, ports, and inlets, safety for recreational beach users (e.g., from dangerous rip currents), and in defense of the country. We will have a strong indication that we understand and can quantify important near shore processes when predictive models can match field observations. For the scientific community, this is still a work in progress.

TRANSITIONS

Our two major transitions have been (1) focusing on rip currents rather than alongshore currents, and (2) including feedback between the mean currents and the radiation stress gradient model of the shoaling wave field.

RELATED PROJECTS

1. Tuba Ozkan Haller at the University of Michigan (ONR-YIP) is investigating coupling of mean currents and radiation stresses, using a formulation different from our approach, which will be valuable to confirm if each valid approach yields similar results.

2. A group of near shore researchers led by Jim Kirby at the University of Delaware (NOPP) are developing a near shore Community Model. We expect to benefit from and contribute our ideas to their modeling studies.

REFERENCES

Slinn, D. N., J. S. Allen, P. A. Newberger, and R. A. Holman, 1998: Nonlinear shear instabilities of alongshore currents over barred beaches, J. Geophys. Res., 103, 18,357-18,379.

PUBLICATIONS

Slinn, D. N., J. S. Allen, and R. A. Holman, 1999: Alongshore currents over variable beach topography, accepted for publication by J. Geophys. Res.