Nearshore Canyon Experiment

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Grant numbers: N00014-02-10145, N00014-02-10484, N00014-02-10758

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Grant number: N00014-02-1-0415
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LONG-TERM GOALS

The long-term goals are to understand the transformation of surface gravity waves propagating across the nearshore to the beach, the corresponding wave-driven circulation, and the associated evolution of surfzone morphology.

OBJECTIVES

The objective of the Nearshore Canyon Experiment (NCEX) is to understand the effect of complex continental-shelf bathymetry on surface gravity waves and on the breaking-wave-driven circulation onshore of the irregular bathymetry. A primary specific objective this year was to prepare for the observational phase of NCEX, including obtaining detailed bathymetric surveys of the canyons and nearshore area along several km of coastline, developing models for wave propagation across complex bathymetry and for breaking-wave driven circulation onshore of the canyons, and analyzing observations obtained in pilot studies. Additional objectives of our research are to test hypotheses for nearshore waves, currents, and morphological change with previously obtained observations.

APPROACH

Our approach is to test hypotheses by comparing model predictions with waves, currents, and morphological evolution observed on natural beaches.

WORK COMPLETED

The evolution of directionally spread waves across the shoaling region and surfzone was compared with stochastic Boussinesq wave model predictions (Herbers *et al.* 2003).

The role of fluid accelerations in onshore sand bar migration was investigated with Duck94 observations (Hoefel and Elgar 2003), and with a coupled Boussinesq wave and acceleration-based sediment transport model (Fernanda Hoefel thesis dissertation research).

Infragravity motions observed with 5 alongshore arrays of current meters and pressure gages deployed for 4 months during the SandyDuck experiment were analyzed (Sheremet *et al.* 2002, Noyes *in review*).

The performance of a surfzone drifter was evaluated with laboratory and field tests (Schmidt *et al.* 2003). The drifters are being used in studies of nearshore circulation (William Schmidt thesis dissertation research).

Spatial scales of nearshore turbulence and the corresponding drag coefficient were estimated from observations with a dense array of current meters (Trowbridge & Elgar 2003). The effects of seafloor roughness and wave breaking on the bottom drag coefficient were investigated (Feddersen *et al.* 2003) with Duck94 observations. Friction coefficients in the swash were estimated with observations from vertical stacks of current meters (Raubenheimer *et al. in review*).

The alongshore homogeneity of circulation observed during SandyDuck was investigated (Feddersen & Guza 2003).

The flow field near the nose of the buoyant coastal plume propagating along the North Carolina coast was investigated with field observations from the Duck94 experiment, and compared with a theoretical model and laboratory results (Lentz *et al.* 2003).

Field observations and numerical model results were used to investigate the formation of cusps on a natural beach (Coco *et al.* 2003).

The resonant Bragg reflection of ocean waves from a field of shore parallel sand bars was observed in Cape Cod Bay, near Truro, MA (Elgar *et al.* 2003).

An inverse model was compared with observations of nearshore circulation made during SandyDuck (Feddersen *et al. in review*).

Preparation for the Nearshore Canyon Experiment (NCEX) is nearly completed. Twenty-five surf-capable tripods have been constructed, 50 acoustic Doppler current meters and 50 pressure gages have been calibrated, and pre-deployment bathymetric surveys have been completed and distributed to NCEX PIs. Ten wireless, battery powered shorestations have been designed, constructed, and prepared for deployment. Office and equipment trailers, as well as generators and ancillary equipment have been delivered to the field site at Scripps. Wireless networking is being installed in the trailers, on the pier, and in laboratories to enable all NCEX investigators to exchange information. The planned deployment map (Figure 1) includes more than 100 instrument locations.

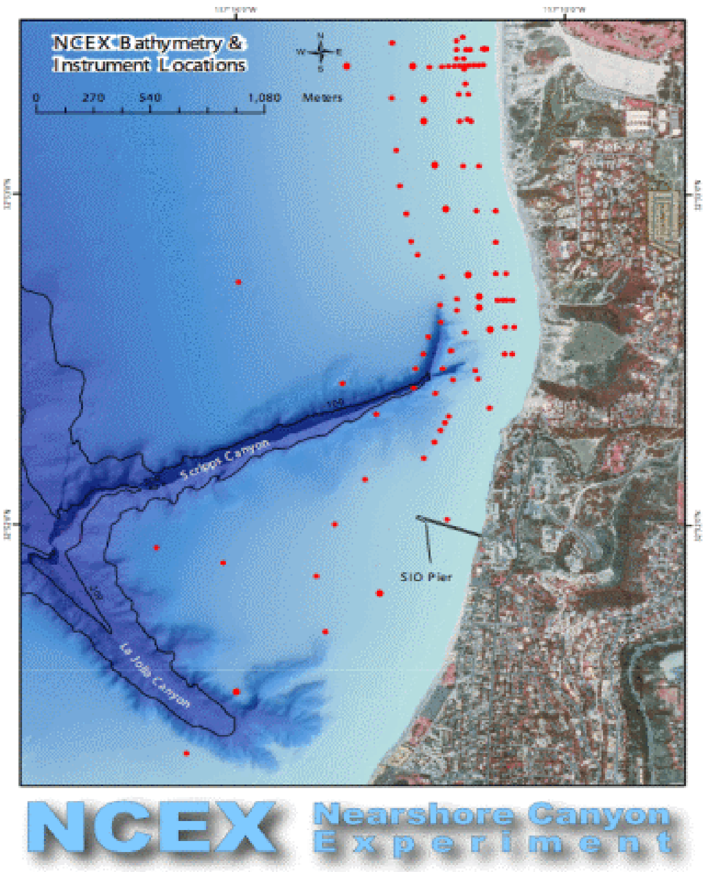

Figure 1. [Map of bathymetry (colors and curves show the two submarine canyons) and instrument locations (red circles) for the Nearshore Canyon Experiment. Deployment from shore, pier, and ship will begin in late September 2003. Data collection will continue until about 1 December 2003.]

RESULTS

Simultaneous observations of waves, currents, and morphology suggest that onshore migration of the sand bar is driven by asymmetrical, near-bottom fluid accelerations associated with pitched-forward shoaling waves. WHOI/MIT student Fernanda Hoefel has developed a numerical model for orbital-velocity acceleration driven bedload transport (Drake & Calantoni 2001) that has skill predicting the onshore bar migration observed at Duck, NC (Figure 2) (Hoefel & Elgar 2003).

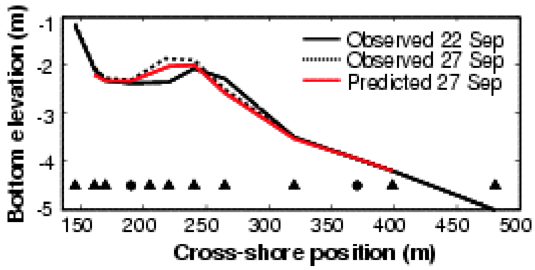

Figure 2. Elevation of the seafloor relative to mean sea level observed 22 Sep 1994 (black solid curve), observed 27 Sep (black dashed curve), and predicted by the acceleration-based transport model (red curve) versus cross-shore position. Cross-shore locations [10 sensors are distributed between 150 and 275 m from shore, and 4 sensors between 325 and 475 m from shore] of colocated pressure sensors, current meters, and altimeters are indicated with symbols. [Bottom elevation profiles show the observed 30 m onshore sandbar migration is predicted by the model.]

Results from investigations of offshore sandbar migration observed during storms and onshore migration observed when mean currents are weak suggest there is feedback between morphology and waves (Figure 3). Large waves in storms break on the sandbar, driving a strong offshore directed current (undertow) that is maximum just onshore of the bar crest (Figure 3a). The cross-shore changes (gradients) in the strength of the undertow result in erosion onshore, and deposition offshore of the sandbar crest, and thus offshore bar migration (Gallagher *et al.* 1998). The location of wave breaking and the maximum of the undertow move offshore with the sandbar, resulting in feedback between waves, currents, and morphological change that drives the bar offshore until conditions change, or until the depth at the bar crest becomes too large to induce wave breaking.

Small waves do not break on the bar, but develop pitched-forward shapes (Figure 3b). Water rapidly is accelerated toward the shore under the steep front face of the waves, and decelerates slowly under the gently sloping rear faces. Thus, the time series of acceleration is skewed, with larger onshore than offshore values (Figure 3b, rectangular panel). The cross-shore gradients in acceleration skewness (maximum on the bar crest) result in erosion offshore, and deposition onshore of the bar crest, and thus onshore bar migration. The location of the peak in acceleration skewness moves onshore with the sandbar, resulting in feedback between waves, currents, and morphological change that drives the bar onshore until conditions change, or until the depth at the bar crest becomes shallow enough to induce wave breaking.

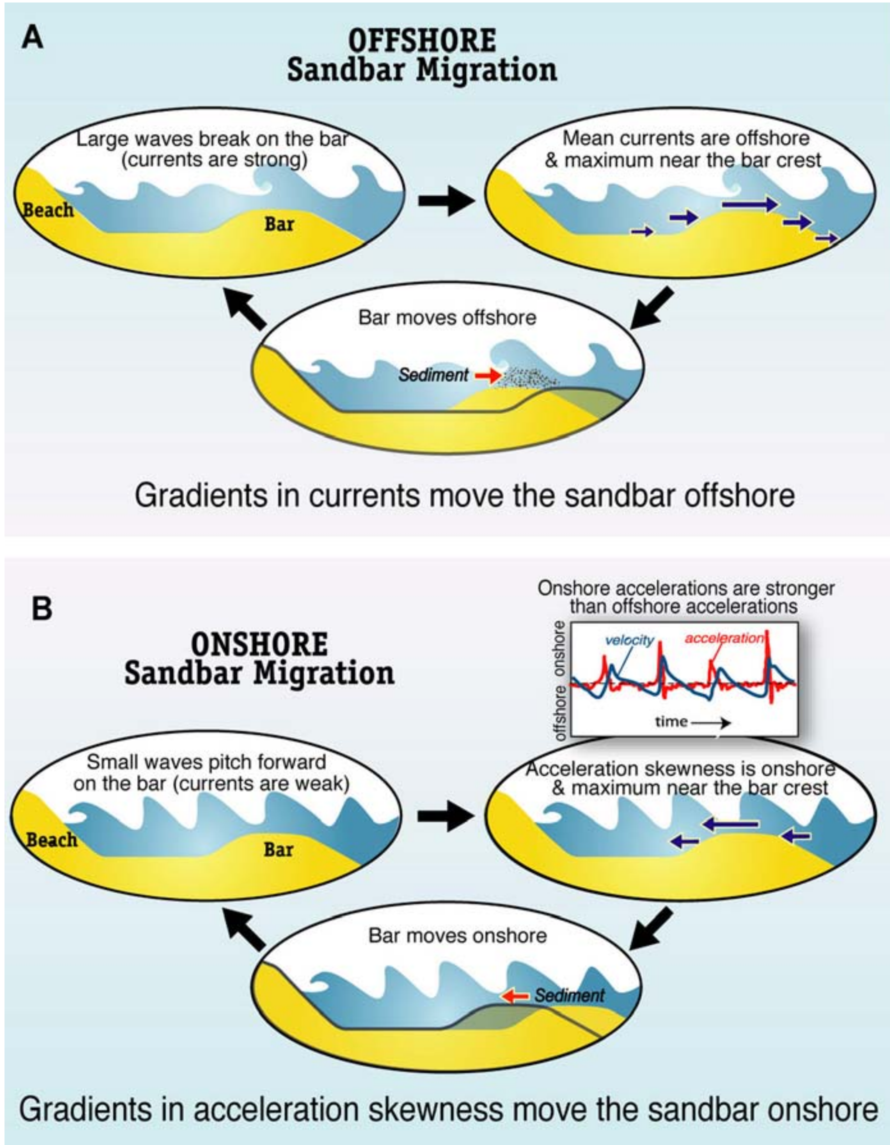

Figure 3. Schematic of the feedbacks that drive sandbar migration. (A) Large breaking waves produce strong undertow near the bar crest, resulting in offshore sediment transport and bar migration. (B) Small waves pitch forward on the bar crest, resulting in asymmetrical wave-orbital velocities that transport sediment and the sandbar shoreward. [The figure is described in the text.]

Observations made with arrays of sensors deployed in SandyDuck show that the evolution of the wave field is modeled accurately by the Boussinesq equations (Herbers *et al.* 2003).

Shear waves (instabilities of the breaking-wave-driven mean alongshore current) contribute to velocity fluctuations in the infragravity frequency band ($0.001 < f < 0.050$ Hz). Using 5 alongshore arrays of pressure gages and current meters deployed during SandyDuck, it was shown that in some cases the observed cross-shore structure of shear waves is similar to predictions based on linear stability theory. In other cases, shear wave energies are not consistent with this theory, suggesting the importance of neglected nonlinear effects (Noyes *et al. in review*).

The mean circulation observed during SandyDuck was shown to be alongshore homogeneous, demonstrating that simplified circulation dynamics are valid during the experiment (Feddersen & Guza 2003). In addition, inverse modeling of the circulation observed during SandyDuck allows independent estimation of the spatial variation of bottom friction and wave-breaking effects (Feddersen *et al. in review*).

A surfzone drifter that can measure near-surface flows was developed by SIO PhD student William Schmidt (Schmidt *et al.* 2003) (Figure 4). Laboratory and field tests demonstrate that the drifter follows near-surface particles that are not entrained in bores, and is not affected greatly by wind. Initial deployments showed slowly rotating eddies located near the surfzone edge of time-variable rip currents (Figure 5).

Figure 4. [Photograph of 6 surfzone drifters on the beach near the Scripps pier. The 50 cm tall drifters contain GPS, and transmit their position to shore in real time, and also record their trajectories internally.]

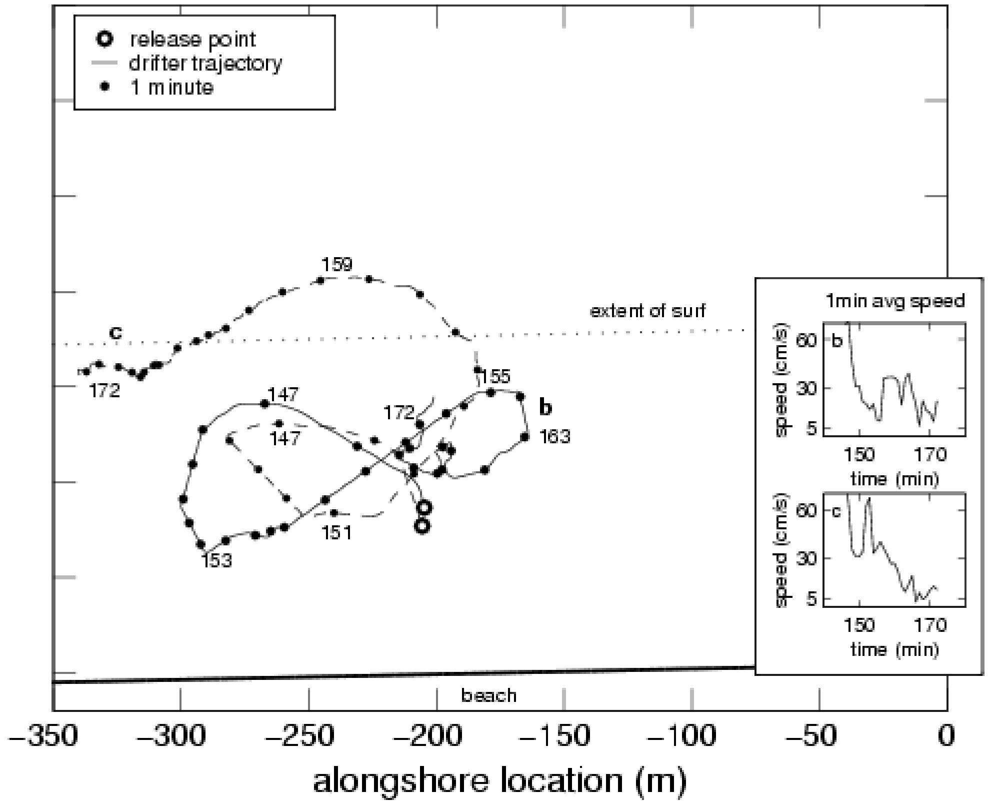

Figure 5. Trajectories of 2 drifters deployed in the surfzone. Time in minutes since release is indicated along the trajectories and the inset panel shows mean (1 min) speed versus time for the two drifters. [During the 30-min period, drifter b (solid curve) rotated with a figure-eight-shaped eddy-like motion within the surfzone, while drifter c (dashed curve) made one revolution and then exited the surfzone in a rip current.]

Observed drifter trajectories compare well with those predicted by a circulation model driven by offshore waves (Schmidt, thesis research.) The drifters will be deployed during NCEX to increase the coverage of *in situ* current meters, and to track water that crosses the surfzone to the inner shelf.

Several studies produced results about turbulence and bottom friction outside, within, and onshore of the surfzone. The spatial scales of stress-carrying turbulent eddies about 1 m above the seafloor in 4-5 m water depth (just seaward of the surfzone) are about 2 m for unstably stratified conditions, and reduce to about 1 m for stably stratified conditions (Trowbridge & Elgar 2003). Investigation of the bottom stress within and seaward of the surf zone over smooth and rough seafloors suggests breaking-wave-generated turbulence increases the bottom drag coefficient within the surf zone (Feddersen *et al.* 2003). Friction coefficients in the swash estimated with vertical stacks of current meters are consistent with previous laboratory results (Raubenheimer *et al. in review*).

Observations of waves and currents across a field of several shore-parallel sandbars in Cape Cod Bay, near Truro, MA are consistent with resonant Bragg reflection of ocean waves by the bars (Elgar *et al.* 2003). Waves transmitted through the bars were reflected strongly from the steep shoreline, and the observed cross-shore variations in the onshore- and offshore-directed energy fluxes are consistent with theory (Yu & Mei, 2000), including a 20% decay of the incident wave energy flux that is an order of magnitude greater than expected for wave-orbital velocity induced bottom friction.

IMPACT/APPLICATIONS

The field observations have been used to verify and improve models for nearshore and surfzone waves, circulation, and morphological change. The comparison of model predictions with observations has increased our ability to predict nearshore bathymetric change, including the migration of sandbars across the surfzone.

RELATED PROJECTS

The Duck94 and SandyDuck observations of nearshore waves, currents, and bathymetry are being used to test components of the NOPP nearshore community model.

The studies of nearshore morphology are in collaboration with an Army Research Office project to investigate onshore sediment transport and sandbar migration.

Surfzone drifters are being developed in collaboration with a Sea Grant project.

Observations of nearshore bedforms are being used as part of Mine Burial Program studies (with E. Gallagher).

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