Nearshore Canyon Experiment

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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 upcoming (Fall 2003) 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, analyzing observations obtained in a pilot study, and preparing for a second pilot study to be conducted in Fall 2002. 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

Boussinesq models for directionally spread breaking and nonbreaking waves (Herbers *et al*. 2002a,b) have been tested by comparison with field observations from Duck.

The role of fluid accelerations in onshore sand bar migration is being investigated with Duck94 observations (Elgar *et al*. 2001, 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 (Noyes *et al*. 2002, Sheremet *et al*. **in press**).

Mean longshore currents predicted by a steady one-dimensional model were compared with Duck94 and COAST3D (Egmond, Netherlands) observations (Ruessink *et al*. 2001).

The performance of a surfzone drifter was evaluated with laboratory and field tests (Schmidt *et al.*, submitted).

Spatial scales of nearshore turbulence and the corresponding drag coefficient were estimated from observations with a dense array of current meters (Trowbridge & Elgar, **in press**).

The alongshore homogeneity of circulation observed during SandyDuck was investigated (Feddersen and Guza, **in press**).

The effects of seafloor roughness and wave breaking on the bottom drag coefficient were investigated (Feddersen *et al.*, submitted).

The flow field near the nose of the buoyant coastal plume extending 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.*, submitted).

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

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.*, submitted).

RESULTS

Observations made with arrays of pressure sensors deployed in SandyDuck show that the evolution of the wave field is modeled accurately by the Boussinesq equations (Herbers *et al*. 2002a,b).

Simultaneous observations of waves, currents, and morphology suggest that onshore migration of the sand bar crest 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.

Shear waves (instabilities of the breaking-wave-driven mean alongshore current) and long gravity waves contribute to velocity fluctuations in the infragravity frequency band ($0.001 < f < 0.050$ Hz). Estimates of shear wave velocity fluctuations from three methods agree well (correlations >0.96), supporting the validity of their different underlying assumptions (Noyes *et al.* 2002). The magnitudes of shear wave velocity fluctuations and the local mean alongshore current are highly correlated.

Seaward of the surf zone, the shoreward energy flux of long gravity waves increases in the onshore direction owing to amplification by nonlinear interactions with groups of sea and swell. In the surf zone, phase coupling between long waves and groups of sea and swell decreases, as does the shoreward long wave energy flux, consistent with the cessation of nonlinear forcing and the increased importance of long wave dissipation. Seaward propagating long waves are not phase coupled to incident wave groups, and their energy levels suggest strong long wave reflection near the shoreline (Sheremet *et al.*, **in press**).

With weak alongshore variation of incident waves and bathymetry, breaking results in a mean alongshore-directed force within the surf zone that is balanced by the drag of the mean alongshore current on the seafloor. A model based on this balance agrees well with alongshore currents observed at Duck, NC and Egmond, Netherlands when the alongshore variability of the bathymetry was relatively weak. When the alongshore bathymetric variability increased, the model performance deteriorated (Ruessink *et al*. 2001).

The mean circulation observed during SandyDuck was shown to be alongshore homogeneous, demonstrating that simplified circulation dynamics are valid during the experiment (Feddersen and Guza, **in press**).

A surfzone drifter that can measure near-surface flows was developed (Schmidt *et al.*, submitted). 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.

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, **in press**).

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*. submitted).

Fresh water from Chesapeake Bay forms a buoyant plume that flows south along the coast of North Carolina. During five events when wind and surface gravity wave forcing were weak, the buoyant current 90 km south of Chesapeake Bay was less than 5 km wide, 5-10 m thick, and propagated alongshore at ~50 cm/s. The density decreased 2-3 kg m^{-3} over a few hundred meters at the nose of the current, which was located about 1 km offshore in ~8 m of water. Water up to 4 km ahead of the advancing nose was displaced southward and offshore. The southward alongshore current increased abruptly to ~50 cm/s at the nose, and continued to increase to a maximum of ~70 cm/s about 1 km behind the nose. The observed flow structure is qualitatively similar to recent theoretical predictions and laboratory measurements of buoyant gravity currents propagating along a sloping bottom (Lentz *et al.*, submitted).

Aspects of field observations of cusp formation on the beach near Duck, NC are similar to those predicted by a numerical model that incorporates self-organization between fluid velocities and sediment motion (Coco *et al.*, submitted).

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. 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.

Extensive surveys have provided bathymetric data for use in NCEX (Figure 1). The abrupt canyon topography results in strong alongshore changes in wave height and direction, as shown by the aerial photograph in Figure 1. North of Scripps Submarine Canyon, the waves are much larger than onshore of La Jolla Canyon, a few km to the south. In between the canyons, there are other areas of strong wave focusing (eg, large waves) and shadowing (eg, small waves) (Figure 1). Spectral refraction models predict strong alongshore gradients in wave height and direction (curves in Figure 2), that are consistent with observations (symbols in Figure 2) obtained in a pilot test.

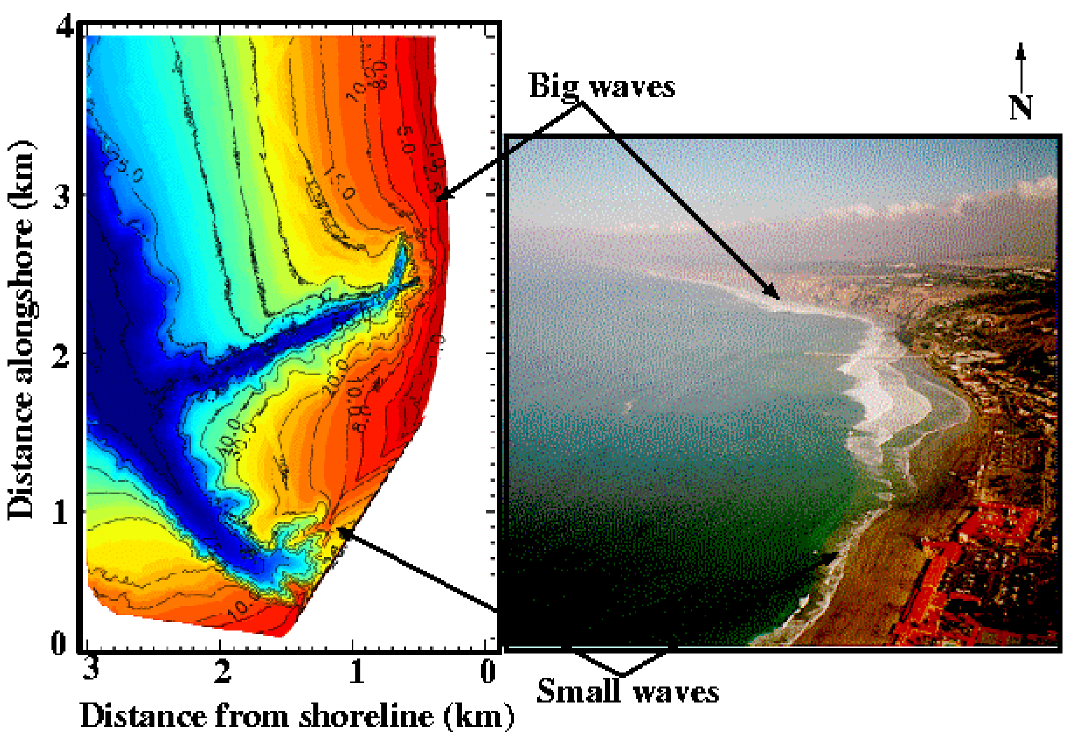

Figure 1. Map of the bathymetry in the NCEX study area, including Scripps and La Jolla Canyons. The canyons produce strong alongcoast changes in wave height, which can be seen in the aerial photograph on the right. There are large waves (indicated by the wide surfzone, the white areas near the shoreline) onshore of the head of Scripps Canyon and near the Scripps pier (near alongshore coordinate 2 km), and small waves (eg, almost no surf zone) between Scripps Canyon and Scripps pier, and also near the head of La Jolla Canyon, at the southern edge of the photograph.

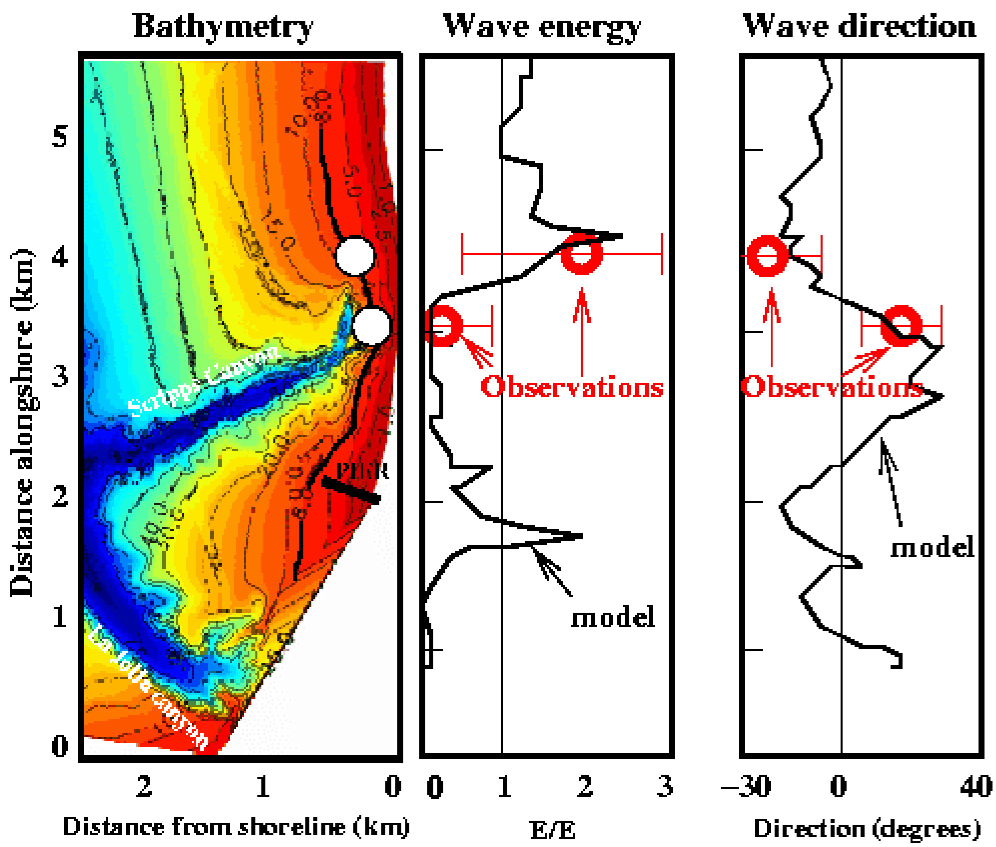

Figure 2. Model-data comparisons of wave height and direction. (left) Canyon bathymetry. Color contours range from deep (blue) to shallow (red) water. The two white circles near the head of Scripps Canyon are locations of pressure gage - current meter pairs deployed for 40 days in 8-m water depth. (center) Wave energy (relative to energy offshore) and (right) wave direction (relative to shore normal). The curves are model predictions for 17 s waves arriving from the northwest, and the red symbols are the mean of the observations (bars are ±1 standard deviation). [The map shows the steep canyon bathymetry. The model predicts strong alongshore gradients in wave energy, with energy levels ranging from less than 10% to more than 200% of the offshore values. The observations of wave energy and direction at locations with strong focusing and defocusing are similar to the model predictions.]

IMPACT/APPLICATIONS

An application of the field observations is to verify and improve models for nearshore and surfzone waves, circulation, and morphological change. An impact of comparison of model predictions with observations is that mean alongshore currents on bathymetrically simple beaches can be predicted accurately given the bathymetry and incident wave conditions. Morphological models tested with the Duck field observations may result in more skillful predictions of sandbar migration during and between storms.

TRANSITIONS

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 Raubenheimer and Gallagher).

REFERENCES

Coco, Giovanni, T.K. Burnet, B.T. Werner, and S. Elgar, Test of self-organization in beach cusp formation, *J. Geophys. Res.*, submitted.

Drake, T.G. and J. Calantoni, Discrete particle model for sheet flow sediment transport in the nearshore, *J. Geophys. Res.* **106**, 19,859-19,868, 2001.

Elgar, S., E. Gallagher, and R.T. Guza, Nearshore sand bar migration, *J. Geophys. Res*. **106**, 11,623-11,627, 2001.

Elgar, S., B. Raubenheimer, T.H.C. Herbers, Bragg reflection of ocean waves from sandbars, *Nature*, submitted.

Feddersen, F., E. Gallagher, R.T. Guza, and S. Elgar, The drag coefficient, bottom roughness, and wave-breaking in the nearshore, *Coastal Engr*., submitted.

Feddersen, F., and R.T. Guza, Observations of Nearshore Circulation: Alongshore Uniformity, *J. Geophys. Res*., **in press**.

Herbers, T.H.C., S. Elgar, N. A. Sarap, and R. T. Guza, Nonlinear dispersion of surface gravity waves in shallow water, *J. Phys. Oceanog*., **32**, 1181-1193, 2002a.

Herbers, T.H.C., Mark Orzech, S. Elgar, and R.T. Guza, Shoaling transformation of wave frequency-directional spectra, *J. Geophys. Res*., **in press**, 2000b.

Lentz, S., S. Elgar, and R.T. Guza, Observations of the flow field near the nose of a buoyant coastal current, *J. Phys. Oceanog*., submitted.

Noyes, T.J., R.T. Guza, S. Elgar, and T.H.C. Herbers, Comparison of methods for estimating nearshore shear wave variance, *J. Atms. Ocean Technol*., **19**, 136-143, 2002.

Ruessink, B.G., J.R. Miles, F. Feddersen, R.T. Guza, and S. Elgar, Modeling the alongshore current on barred beaches, *J. Geophys. Res*., **106**, 22,451-22463, 2001.

Sheremet, A., R.T. Guza, S. Elgar, and T.H.C. Herbers, Observations of nearshore infragravity waves: Part 1: Seaward and shoreward propagating components, *J. Geophys. Res.*, **in press**.

Trowbridge, J. and S. Elgar, Spatial scales of stress-carrying nearshore turbulence, *J. Phys. Oceanog*., **in press**.

Yu, J. and Mei, C.C. Do longshore bars shelter the shore? *J. Fluid Mech*. **404**, 251-268, 2000.

PUBLICATIONS

Chandran, V., S. Elgar, and A. Nguyen, Detection of mines in acoustic images using higher-order spectral features, *IEEE J. Oceanic Engineering*, **in press**.

Coco, Giovanni, T.K. Burnet, B.T. Werner, and S. Elgar, Test of self-organization in beach cusp formation, *J. Geophys. Res*., submitted.

Elgar, S., E. Gallagher, and R.T. Guza, Nearshore sand bar migration, *J. Geophys. Res*. **106**, 11,623-11,627, 2001.

Elgar, S., B. Raubenheimer, T.H.C. Herbers, Bragg Reflection of Ocean Waves from Sandbars, *Nature*, submitted.

Feddersen, F., E. Gallagher, R.T. Guza, and S. Elgar, The drag coefficient, bottom roughness, and wave-breaking in the nearshore, *Coastal Engr*., submitted.

Herbers, T.H.C., S. Elgar, N. A. Sarap, and R. T. Guza, Nonlinear dispersion of surface gravity waves in shallow water, *J. Phys. Oceanog*., **32**, 1181-1193, 2002a.

Herbers, T.H.C., Mark Orzech, S. Elgar, and R.T. Guza, Shoaling transformation of wave frequency-directional spectra, *J. Geophys. Res*., **in press**, 2000b.

Lentz, S., S. Elgar, and R.T. Guza, Observations of the flow field near the nose of a buoyant coastal current, *J. Phys. Oceanog*., submitted.

Noyes, T.J., R.T. Guza, S. Elgar, and T.H.C. Herbers, Comparison of methods for estimating nearshore shear wave variance, *J. Atms. Ocean Technol*., **19**, 136-143, 2002.

Ruessink, B.G., J.R.Miles, F. Feddersen, R.T. Guza, and S. Elgar, Modeling the alongshore current on barred beaches, *J. Geophys. Res*., **106**, 22,451-22463, 2001.

Schmidt, W.E., B.T. Woodward, K.S. Millikan, R.T. Guza, B. Raubenheimer, and S. Elgar, A GPS-tracked surfzone drifter, *J. Atmos. and Ocean. Tech.*, submitted.

Sheremet, A., R.T. Guza, S. Elgar, and T.H.C. Herbers, Observations of nearshore infragravity waves: Part 1: Seaward and shoreward propagating components, *J. Geophys*. *Res*., **in press**.

Trowbridge, J. and S. Elgar, Spatial scales of stress-carrying nearshore turbulence, *J. Phys. Oceanog*., **in press**.