Surface Wave Processes on the Continental Shelf and Beach

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LONG-TERM GOALS

There is a growing need for surface wave information on the continental shelf and beach to estimate sea state, and to provide input for models of currents, sediment transport, radar backscatter and aerosol generation. While surface wave spectra in the open ocean evolve slowly over distances of O(100-1000 km), wave properties on the continental shelf and beach are highly variable (typical length scales of 0.1-10 km) owing to a variety of topographic effects (e.g., shoaling, refraction, scattering) and strongly enhanced nonlinear interactions and dissipation. The long-term goal of this research is to develop a better understanding of the physical processes that affect the generation, propagation and dissipation of surface waves in shallow coastal waters, and improve the accuracy of models that predict the transformation of wave properties across the shelf and beach.

OBJECTIVES

- predict accurately the nonlinear shoaling transformation of ocean surface waves on beaches including the excitation of infragravity motions

- evaluate models for wave dissipation by bottom friction

- determine the scattering effects of resonant wave-wave and wave-bottom interactions on the evolution of wind sea and swell spectra on the continental shelf

- improve the representation of source terms in operational wave prediction models

- determine the importance of wave reflection and trapping by steep submarine topography

APPROACH

A combination of theory, analytical and numerical models, and field experiments is used to investigate the physical processes that affect surface wave properties on the continental shelf and beach. The transformation of wave spectra is predicted with models that include the effects of refraction, scattering by wave-wave and wave-bottom interactions, and parameterizations of bottom friction, and wave breaking. Extensive field data sets were collected in recent ONR experiments off North Carolina (DUCK94, SandyDuck, SHOWEX), California (NCEX), and the Florida Gulf coast (SAX04/Ripples) to test these models in a range of coastal environments. Analysis techniques applied to the measurements include various inverse methods to extract directional and wavenumber properties from

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14. ABSTRACT **There is a growing need for surface wave information on the continental shelf and beach to estimate sea state, and to provide input for models of currents, sediment transport, radar backscatter and aerosol generation. While surface wave spectra in the open ocean evolve slowly over distances of O(100-1000 km), wave properties on the continental shelf and beach are highly variable (typical length scales of 0.1-10 km) owing to a variety of topographic effects (e.g., shoaling, refraction, scattering) and strongly enhanced nonlinear interactions and dissipation. The long-term goal of this research is to develop a better understanding of the physical processes that affect the generation, propagation and dissipation of surface waves in shallow coastal waters, and improve the accuracy of models that predict the transformation of wave properties across the shelf and beach.**			
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array cross-spectra, bispectral and trispectral analysis to detect nonlinear coupling, as well as standard statistical methods to determine empirical relationships between observed variables.

WORK COMPLETED

During FY05 I continued the analysis of observations collected in the Nearshore Canyon Experiment (NCEX) which took place during the fall of 2003 near La Jolla, California where two submarine canyons control the nearshore environment. The main objectives of this experiment (a collaboration with William O'Reilly and Robert Guza at SIO and Steve Elgar and Steve Lentz at WHOI) are to understand the effects of complex bathymetry on nearshore wave transformation and the associated circulation, and to test the robustness of state of the art wave and circulation models in regions with steep topography. The data analysis is well underway. Graduate student Jim Thomson (advisor Steve Elgar) showed that infragravity waves are strongly reflected by La Jolla Canyon in agreement with theory (Thomson et al., 2005). Graduate student Rudy Magne (advisor Fabrice Ardhuin) investigated the effects of the canyons on swell propagation with numerical models for wave propagation and scattering by steep topography (Magne et al, submitted). A preliminary example of model-data comparisons is presented below.

During FY05 I also continued to contribute to collaborations using the SandyDuck and SHOWEX data sets. Steve Henderson showed that directional broadening of waves in the surf zone can be explained as the result of wave scattering by random shear instabilities in the surf zone (Henderson et al., in press). Jim Noyes compared observations of shear instabilities to nonlinear model simulations (Noyes et al., 2005). Whereas the observed propagation speeds of shear waves are in good agreement with model predictions, the observed spectra are notably broader than the predicted spectra. Fabrice Ardhuin compared observations of fetch-limited wind waves on the continental shelf to predictions of third-generation wave prediction models including full computations of the Boltzmann integral of nonlinear wave-wave interactions (Ardhuin et al., submitted). These comparisons highlight some deficiencies of wave growth and dissipation parameterizations in mixed swell-sea conditions.

In the fall of 2004 I participated in the SAX04/Ripples Experiment on the Florida Gulf Coast. In collaboration with Bill O'Reilly and Fabrice Ardhuin, I deployed an array of 8 bottom pressure recorders, 4 acoustic Doppler current meters and a directional wave buoy on the continental shelf extending from Ft. Walton Beach (where the main SAX04 experiments took place) to Apalachee Bay. The main objective of our study is to evaluate the attenuation of waves by bottom friction. Concurrent surveys of sediment characteristic and ripples were conducted by Peter Traykovski and Dan Hanes. During the experiment several hurricanes (Frances, Ivan, Jeanne) passed close to the experiment site. In particular, category 4 Hurricane Ivan provided an interesting data set with a maximum significant wave height of 12 m offshore of Ft. Walton Beach. Unfortunately, instrument tripods were lost at 3 out of 9 instrumented sites as a result of these extreme wave conditions. Preliminary analysis of the observations at the remaining sites indicates strong dissipation of waves propagating across the continental shelf. At Ft. Walton Beach where the shelf is about 50 km wide, the spectral levels at the dominant swell peak decrease by about a factor 3 between sites 7 (85 m depth) and 9 (19 m depth) (lower left panel of Figure 1). Interestingly, at frequencies below the peak frequency an increase in energy levels is observed, suggesting a nonlinear energy transfer from the spectral peak to lower frequencies. The observed decay of the swell peak is even stronger in Apalachee Bay where the shelf is about 200 km wide. At site 5 (12 m depth) the swell peak has virtually disappeared and the spectrum is dominated by higher-frequency, locally generated waves (lower right panel of Figure 1).

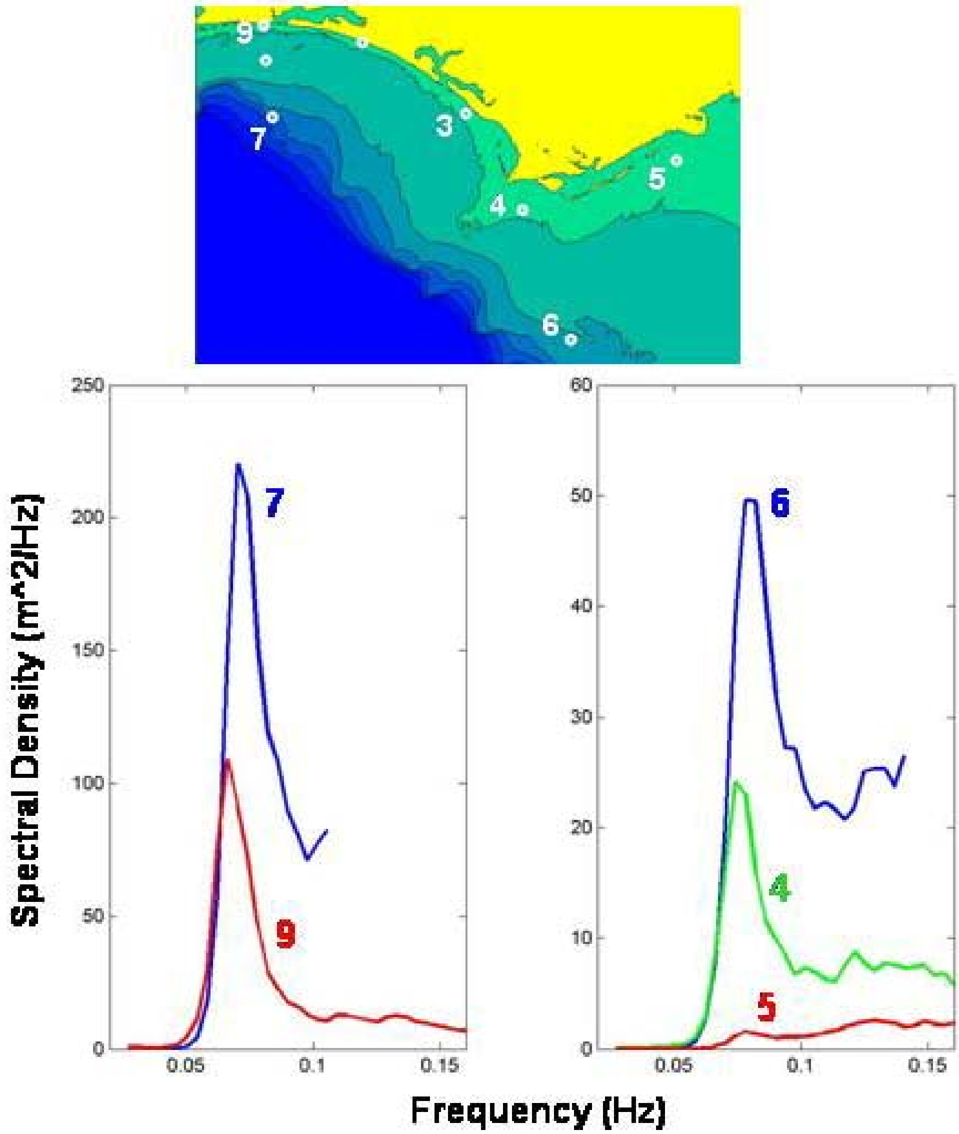

Figure 1. Surface height spectra observed at 5 locations on the Florida panhandle shelf during the passage of Hurricane Ivan. The upper panel shows the locations (white circles) of bottom pressure recorders. Observations on the relatively narrow shelf near Ft. Walton Beach (sites 7 and 9) are compared in the lower left panel. Observations on the wider shelf of Apalachee Bay (sites 4-6) are compared in the lower right panel.

RESULTS

Graduate student Rudy Magne examined the transformation of swell over a submarine canyon using a model for surface gravity waves over steep 3-dimensional topography (Athanassoulis and Belibassakis, 1999; Belibassakis et al., 2001) and observations from the NCEX experiment (Magne et al., submitted). The coupled-mode model NTUA5 solves the full linear potential flow problem using an expansion of the velocity potential in propagating and evanescent modes. A preliminary comparison of model results with NCEX observations is shown in Figure 2. Significant wave heights observed at six Datawell Directional Waverider buoys are compared to predictions of the NTUA5 model, as well as various Mild Slope Equation models (MSE and MMSE) and the more widely used parabolic refraction-diffraction (Ref-dif) and spectral refraction approximations. The NTUA5 and MSE/MMSE results are similar and in excellent agreement with the observations. The simpler refraction and Ref-dif approximations also capture the observed dramatic variations in wave height although the refraction model underpredicts the low wave heights behind the canyon whereas Ref-dif predictions are biased high. Ray paths shown in Figure 2 indicate that the large reduction in wave height across the canyon is the result of refractive trapping of waves by the offshore canyon rim. Although rays do not cross the canyon at swell frequencies, some 'tunneling' of energy takes place owing to the narrow width of the canyon (Thomson et al., 2005), and this effect appears to be well described by both the coupled-mode and mild slope equation models.

Graduate student Tim Janssen developed a new spectral model for nonlinear surface gravity waves propagating over 3-dimensional topography (Janssen et al., in press). In this model, the bottom topography is approximated with an alongshore uniform shelf with a small 3-dimensional perturbation. A new treatment of the second-order bound waves accounts for their transition from non-resonant forcing in deep water to resonant forcing in shallow water. The complete model is uniformly valid from deep to shallow water and accounts for nonlinear quartet and triad wave-wave interactions as well as refraction and diffraction effects induced by the topography. The validity of the approximations was tested through comparisons with published laboratory result in deep and shallow water. An example comparison of model predictions with laboratory observations of harmonic generation over a submerged shoal (Luth et al., 1994) is shown in Figure 3. In this test a monochromatic wave train (period 2.86 s) propagates over a steep trapezoidal-shaped shoal. Strong nonlinear triad interactions in shallow water on the crest of the shoal result in pronounced harmonic evolution, initially steepening the waves, followed by frequency-doubling behind the shoal. The numerical model predictions are in excellent agreement with the laboratory observations, supporting the validity of the approximation in shallow water.

IMPACT/APPLICATIONS

Abrupt shelf bathymetry can cause dramatic alongshore variations in waves, resulting in beaches with large waves located only a few hundred meters away from beaches with small waves. These along-coast changes in wave height and direction can force complicated circulation patterns, including alongshore flows that reverse direction across the surf zone and along the shoreline, and strong offshore-directed rip currents that may be an important mechanism for transport of water, sediment, and pollution between the surf zone and inner shelf. The NCEX experiment has produced the first comprehensive data set of these processes that will be used extensively to validate and advance nearshore prediction models.

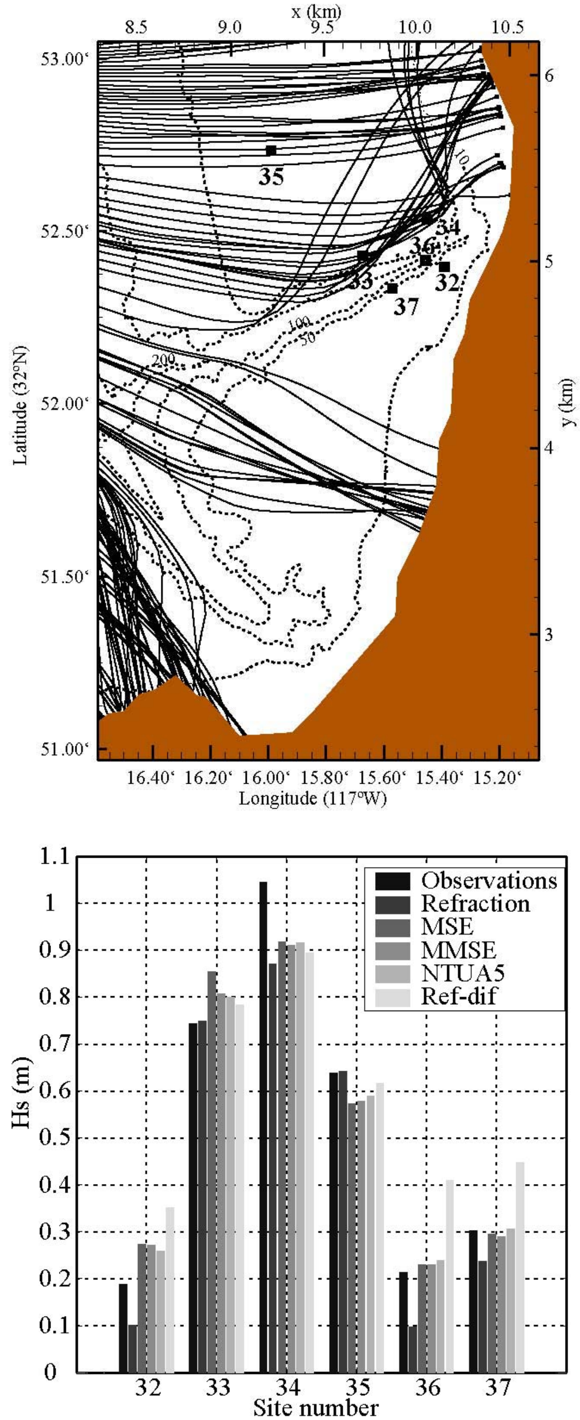

Figure 2. Comparison of observations of swell transformation over Scripps Canyon on November 30, 2003, to predictions of various models. Upper panel: Locations of directional wave buoys deployed during NCEX. Rays computed for the dominant swell period (15 s) and direction (272 deg.) illustrate the strong refraction effects. Dotted lines indicate depth contours in m. Lower panel: comparison of observed and predicted significant wave heights. (from Magne et al., submitted)

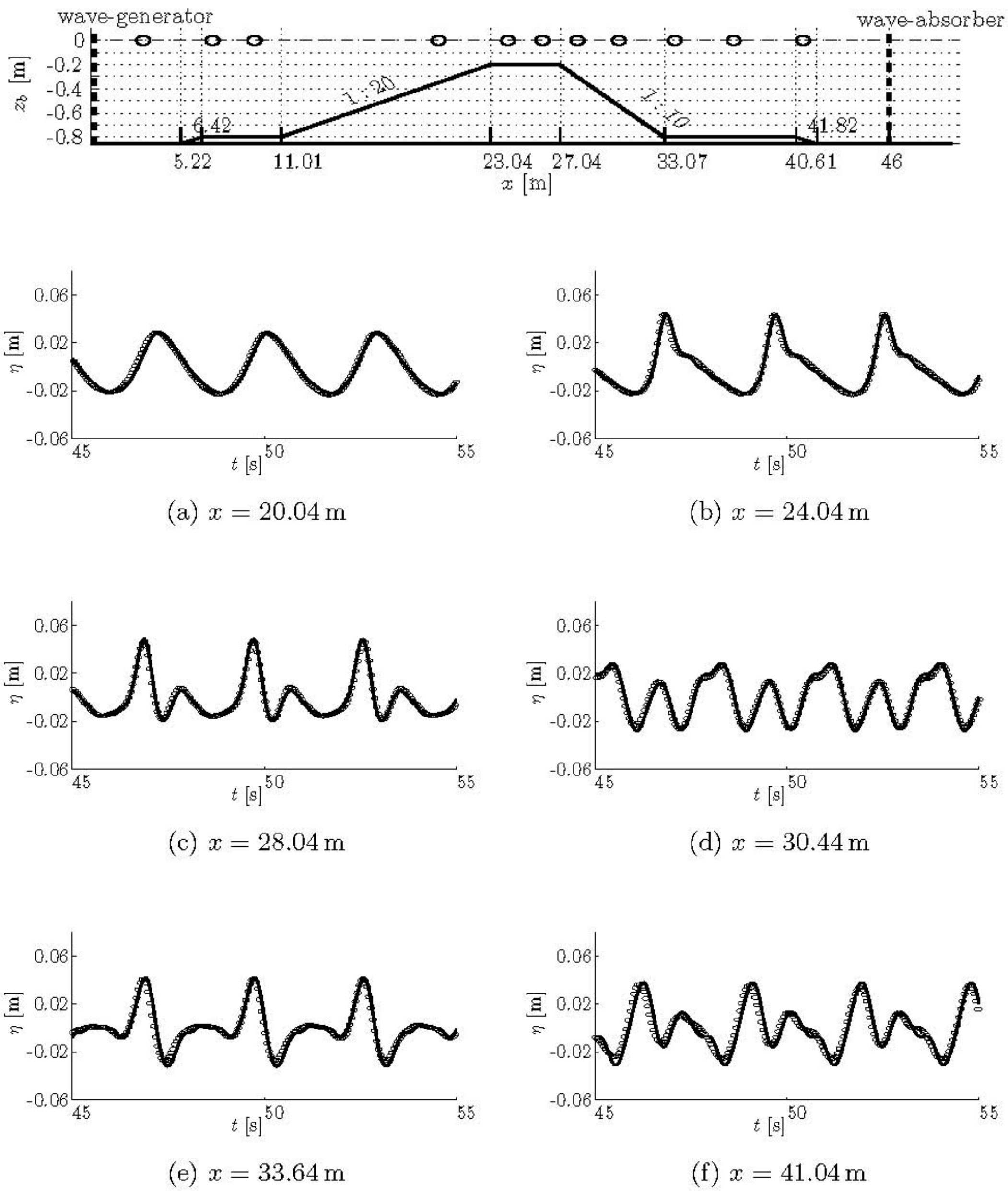

Figure 3. Validation of numerical model results for wave propagation over a submerged shoal with laboratory observations by Luth et al. (1994). The upper panel shows a schematic of the laboratory set up with the bottom profile (solid line) and wave gauge positions (circles). The monochromatic incident waves have a period of 2.86 s and amplitude 0.02 m. Observed (circles) and predicted (solid line) time series are compared at 6 locations. (from Janssen et al., in press)

RELATED PROJECTS

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