Surface Wave Processes on the Continental Shelf and Beach

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LONG-TERM GOALS

Wind waves and swell dominate the hydrodynamic and sediment transport processes on many continental shelves and beaches, affect underwater acoustics, and play an important role in remote sensing applications. Wave prediction in coastal environments is a challenging task because waves are affected by many processes, including scattering by sea floor topography, strong nonlinear interactions, wave breaking, and friction in the bottom boundary layer. Several of these processes are poorly understood and existing wave prediction models rely on parameterizations and empirical validation. The long term goals of this research are to obtain a better understanding of the physical processes that affect ocean surface waves in the coastal environment and develop accurate wave prediction models.

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 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

We use a combination of theory, numerical models, and field experiments 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

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inverse methods to extract directional and wavenumber properties from array cross-spectra, higher-order spectral analysis to detect nonlinear coupling, as well as standard statistical methods to determine empirical relationships between observed variables.

WORK COMPLETED

During FY06 I continued to contribute to the analysis of observations collected in the Nearshore Canyon Experiment (NCEX) which took place during the fall of 2003 near the La Jolla and Scripps submarine canyons on the southern California coast. 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. Jim Thomson used NCEX observations in his recently completed Ph.D. dissertation (MIT-WHOI Joint Program, advisor Steve Elgar) to investigate the generation and propagation of infragravity waves. His work shows that infragravity waves are strongly reflected by La Jolla Canyon in agreement with theory (Thomson et al., 2005) and that the nonlinear generation of these waves is sensitive to variations in the beach profile shape. The latter effect convincingly explains the strong modulation of infragravity waves by tides observed in previous studies (Thomson et al., 2006). Rudy Magne also used NCEX observations in his Ph.D. dissertation (University of Toulon, advisors Fabrice Ardhuin and Vincent Rey) focused on the scattering of swell by sea floor topography (Magne et al, in press). Some results of this work are described below.

During FY06 I also contributed to analyses of 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., 2006). 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., in press). These comparisons highlight some deficiencies of wave growth and dissipation parameterizations in mixed swell-sea conditions.

We are currently analyzing data from the SAX04 Experiment that was conducted during the fall of 2004 on the Florida Gulf Coast in the first phase of the Ripples DRI program. In collaboration with William O'Reilly and Robert Guza (SIO) we deployed an array of bottom pressure recorders, acoustic Doppler current meters and a surface-following 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 characteristics 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. In collaboration with Fabrice Ardhuin we completed a high resolution hindcast of hurricane Ivan using a third generation wave prediction model. Preparations are underway for the second phase MVCO Experiment (Co-PI's Robert Guza and William O'Reilly, SIO) that will take place offshore of Martha's Vineyard in the fall of 2007.

RESULTS

Rudy Magne examined the transformation of swell over a submarine canyon using a model for surface gravity waves over steep three-dimensional topography (Athanassoulis and Belibassakis, 1999; Belibassakis et al., 2001) and observations from the NCEX experiment (Magne et al., in press). The coupled-mode model NTUA5 solves the full linear potential flow problem using an expansion of the velocity potential in propagating and evanescent modes. An example comparison of model results with NCEX observations is shown in Figure 1. Significant wave heights observed with Datawell Directional Waverider buoys offshore and inshore of the Scripps Canyon are compared with predictions of the NTUA5 model, as well as various combined refraction-diffraction models (MSE, MMSE, REF/DIF1) and the commonly used spectral refraction approximation. The NTUA5 and refraction-diffraction model results are similar and in good agreement with the observations. The simpler refraction approximation also captures the observed dramatic variations in wave height but under-predicts the low wave heights behind the canyon. Ray paths shown in Figure 1 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 refraction-diffraction models.

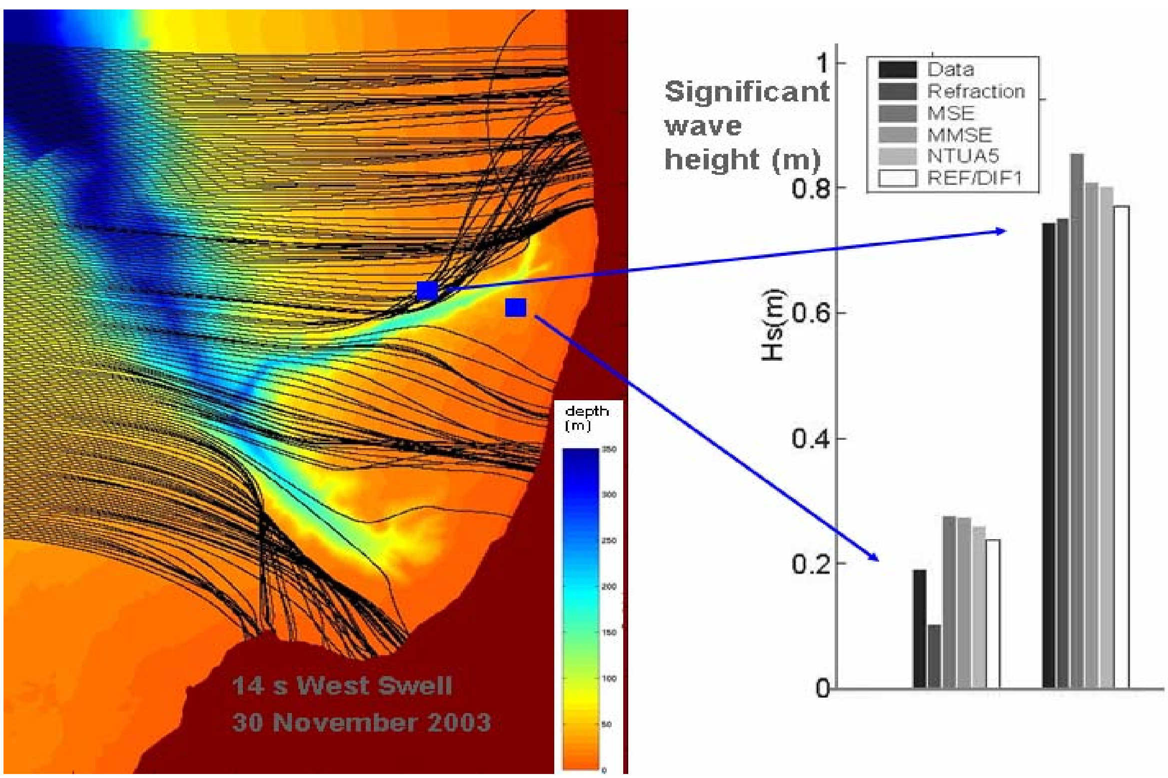

Figure 1. Comparison of observations of swell transformation over Scripps Canyon on November 30, 2003, to predictions of various models. Left panel: Rays computed for the dominant 14 second period swell from the west illustrate the strong refraction effects. Right panel: comparison of observed and predicted significant wave heights at two buoys located offshore and inshore of the Scripps canyon. (from Magne et al., in press)

Postgraduate researcher Tim Janssen developed a new spectral model for nonlinear surface gravity waves propagating over three-dimensional topography (Janssen et al., 2006). In this model, the bottom topography is approximated with an alongshore uniform shelf with a small three-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. Model predictions of the nonlinear evolution of wave groups in uniform depth are compared with laboratory measurements by Shemer et al. (2001) in Figure 2. In this test initially symmetric wave groups generated in a wave flume develop a pronounced asymmetry with larger waves at the front of the group and smaller waves in the rear. The model results are in excellent agreement with the observations, demonstrating the correct representation of third-order (quartet) nonlinear wave-wave interactions in the model. Over longer distances on a sloping bottom these interactions cause interesting effects (Figure 2, lower panel): in relatively deep water the groups become unstable forming isolated ‘freak’ waves (e.g., Janssen, 2003), but as the wave groups continue to shoal this process reverses and the waves become more uniform in height. While the basic physics of nonlinear wave-wave interactions are fairly well established, their effects on natural broadband wave fields are not well understood. We will extend these phase resolving simulations to realistic directionally spread wave fields propagating across a continental shelf and compare model results with records of large amplitude waves observed during hurricanes and severe storms in the DUCK94, SHOWEX and SAX04 experiments.

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.

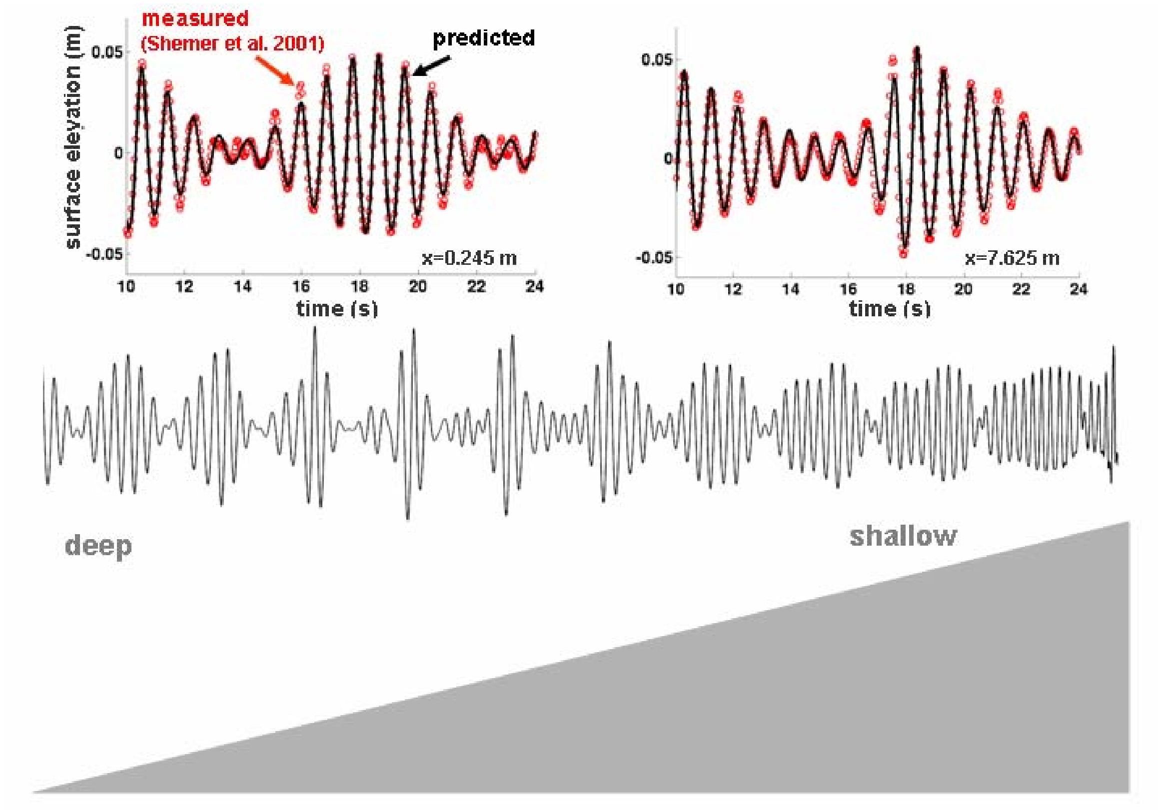

Figure 2. Upper panels: model validation using laboratory measurements of nonlinear wave groups by Shemer et al. (2001). Left: time series of the initially symmetric wave groups. Right: time series of the same wave groups after they have evolved in uniform depth through strong nonlinear interactions. Bottom panel: prediction of nonlinear wave groups propagating from deep to shallow water. (from Janssen et al., 2006)

RELATED PROJECTS

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