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 across the continental shelf is predicted with models based on a spectral energy balance that include the effects of refraction, scattering by resonant interactions (e.g., wave-bottom triads and wave-wave quartets), and bottom friction. A different approach is used near the shore where near-resonant wave-wave triad interactions cause a rapid transfer of energy to harmonic components and lower-frequency infragravity waves. A new model is developed, based on a stochastic closure of Boussinesq theory, that predicts the nonlinear shoaling transformation of a random, directional wave field across a beach. Extensive field data are used to verify predictions of topographic and nonlinear effects, and to estimate the energy losses owing to bottom friction and wave breaking. The data sets include measurements from arrays of pressure sensors, current meters, and directional buoys deployed in a series of experiments (DUCK94, SandyDuck, SHOWEX) on a wide shelf with a relatively straight beach along the North Carolina coast. A new experiment (NCEX) is planned on the southern California coast to study wave transformation over a steep, irregular shelf. Analysis techniques applied to the measurements include various inverse methods to extract directional and wavenumber properties from 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

The evolution and local properties of surface waves in shallow water were investigated with data from the SandyDuck experiment (Herbers et al., 2002a,b). Large deviations (as much as 20-30%) from the linear gravity wave dispersion relation observed in high energy conditions were shown to be in good agreement with theoretical predictions of amplitude dispersion based on Boussinesq theory. Predictions of a stochastic Boussinesq model for the nonlinear transformation of wave spectra over a gently sloping beach (Herbers and Burton, 1997) agree well with field and laboratory observations. Outside the surf zone the model predicts the observed spectral evolution, including energy transfers to harmonic components traveling in the direction of the dominant waves, and the cross-interactions of waves traveling in different directions that transfer energy to components with the vector sum wavenumber. The sea surface elevation skewness and asymmetry, third-order moments believed to be important for sediment transport, also are predicted well. A simple parameterization of surf zone wave breaking was calibrated with observations that span a wide range of conditions. Work is in progress (in collaboration with Steve Elgar and graduate student Fernanda Hoefel) to couple the wave model with models for wave-driven currents and sediment transport to predict beach profile evolution.

During FY02 several field tests were conducted in Monterey Bay and La Jolla Bay (in collaboration with Steve Elgar and Bill O'Reilly) to evaluate self-contained pressure-velocity (PUV) sensors that will be used in the Nearshore Canyon Experiment (NCEX). Three different instruments were tested: the FSI 3D-Wave (equipped with an acoustic travel time meter), and the Sontek Triton and Nortek Vector (both use acoustic Doppler current meters). Analysis of pressure-velocity transfer functions and intercomparisons with a co-located Datawell Directional Waverider buoy generally show good agreement for all three instruments. A light mooring system using a fiberglass tripod for easy deployment and maintenance also performed well during these tests. The test results demonstrate the feasibility of obtaining accurate pressure and velocity measurements with the large array of instruments that will be deployed in NCEX. Preparations are underway for a pilot experiment at Scripps in October to obtain preliminary observations of wave variability across the steep canyon walls. Fabrice Ardhuin and graduate student Rudy Magne have compared different theories for wave reflection from idealized steep topography. Work is in progress to determine theoretical reflection coefficients for the Scripps canyon using a multi-step approximation (Rey, 1992).

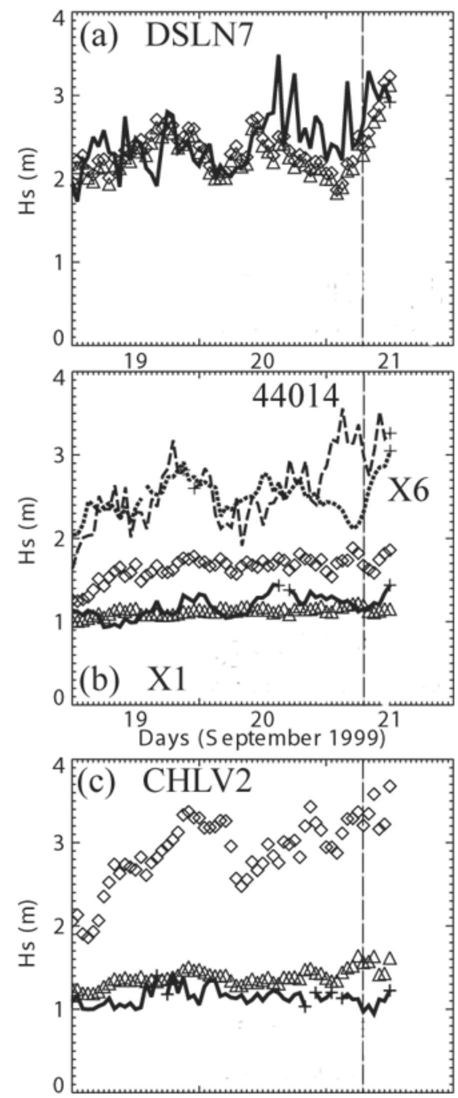

Figure 1. Observed (solid) and predicted (diamonds: without bottom friction, triangles with bottom friction) significant wave heights near the U.S. East Coast during the arrival of large swell from Hurricane Gert. From top to bottom results are shown at Cape Hatteras (where the shelf is narrowest), Duck, and Chesapeake Bay (where the shelf is widest). Included in panel b are offshore wave heights observed near the shelf break (dashed curves). The variable decay is represented well by the bottom friction parameterization adopted from Tolman (1994). Predictions for the entire shelf during the morning of September 21 (vertical dashed line) are shown in Figure 2. (from Ardhuin et al., 2002c)

RESULTS

A cross-shelf transect of six Datawell Directional Waverider buoys and a high-resolution coherent array of five bottom pressure sensors were deployed on the North Carolina continental shelf during September-December 1999 as part of the SHOWEX Experiment (in collaboration with Bill O'Reilly). Additional wave data was available from the National Data Buoy Center and the Army Corps of

Engineers Field Research Facility. Unique observations of wave evolution across the shelf were collected, including energetic seas during the passage of Hurricanes Floyd and Irene, and long period swells from Hurricanes Gert and Jose. Supporting measurements of seabed characteristics (collected in collaboration with Tom Drake and Jesse McNinch) include sediment samples and side-scan sonar surveys of wave-induced sand ripples. Former graduate student Fabrice Ardhuin used these data sets in conjunction with the spectral wave prediction model CREST (Ardhuin et al., 2001) to examine swell damping across the shelf. Dissipation of wave energy by bottom friction was represented in the energy balance with a source term given by Tolman (1994), based on models and laboratory measurements of the drag induced by wave-formed sand ripples (Grant and Madsen, 1979; Madsen et al., 1990). Predicted strong damping of energetic swell across the shelf is in good agreement with the observed swell decay (Figures 1,2). Widespread sand ripples observed in side scan sonar images of the sea floor support the hypothesis that the damping is caused by enhanced bottom friction over rough bed forms (Ardhuin et al., 2002a).

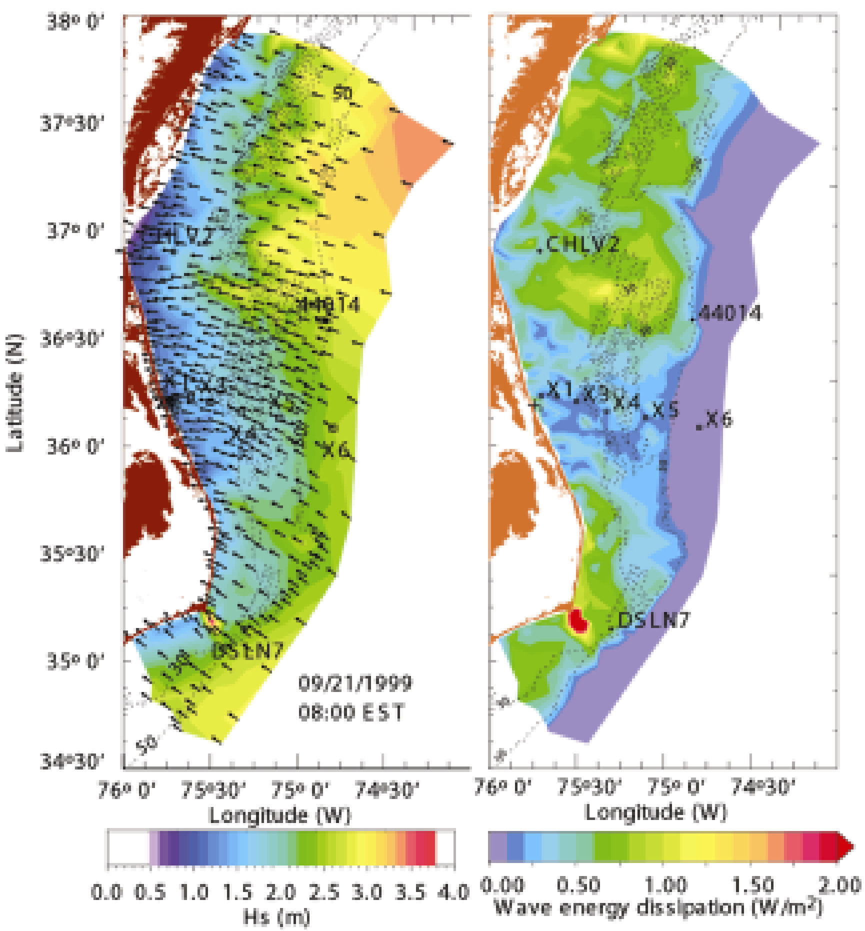

Figure 2. Left panel: Predicted significant wave heights (colors) and mean propagation directions (arrows) on the shelf during the arrival of Hurricane Gert swell. The 30- and 50-m isobaths are indicated with dotted curves. Right panel: predicted energy dissipation rates resulting from bottom friction. Note the predicted strong dissipation over a shallow shoal area located east of station CHLV2 that explains the observed strong swell decay near the mouth of Chesapeake Bay (lower panel of Figure 1). (from Ardhuin et al., 2002c)

IMPACT/APPLICATIONS

Results of this research confirm the critical importance of rough bed-forms in swell transformation across a wide continental shelf. Analysis of swell decay shows that as much as 80% of the incident wave energy flux can be dissipated on the shelf and the variable dissipation rates appear consistent with existing movable bed roughness models. This dramatic sheltering of a coastline with a wide, sandy shelf has important implications for nearshore hydrodynamics and sediment transport.

TRANSITIONS

Parameterizations of bottom friction were evaluated in hindcasts of all swell events that occurred during the DUCK94 and SHOWEX experiments (Ardhuin et al., 2002d). Results of this study, including tuned coefficients that optimize the overall hindcast skill, will be made available for implementation in operational wave prediction models.

RELATED PROJECTS

Results of this research are adapted and implemented in a comprehensive nearshore community model that is being developed under sponsorship of the National Oceanographic Partnership Program (NOPP) (Lead-PI: J. T. Kirby).

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