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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 seafloor 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 calibration to represent them. 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 improved wave prediction capability.

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OBJECTIVES

- Predict the nonlinear shoaling transformation of waves on beaches including the excitation of infragravity motions.

- Observe the seafloor damping effects on ocean surface waves in sandy and muddy coastal environments.

- Model the effects of a fluid-mud layer on wind wave evolution.

- Improve the representation of source terms in operational wave prediction models.

- Advance deterministic and stochastic modeling capability for nonlinear wave evolution over complex seafloor topography.

APPROACH

By combining theoretical advances with numerical models and field observations, we investigate the physical processes that affect ocean surface waves on continental shelves and beaches. 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 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. New experiments were conducted during FY08 on the sandy Martha's Vineyard shelf and the muddy Louisiana shelf. Analysis techniques applied to the measurements include various 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. The modeling efforts include deterministic and stochastic models that incorporate quadratic and cubic nonlinearity and wide angle diffraction effects, suitable for application to energetic wave environments with complex seafloor topography.

WORK COMPLETED

During FY08 we continued to analyze some of the older data sets in collaboration with Jim Thomson, Steve Elgar, and Britt Raubenheimer at WHOI and Rudy Magne and Fabrice Ardhuin at the French Naval Oceanographic Center, Brest.

Jim Thomson investigated the generation and propagation of infragravity waves near submarine canyons using data from the NCEX Experiment. His work showed that infragravity waves nonlinearly excited in the surf zone are strongly affected by refraction and reflections over the canyons in agreement with geometrical optics (Thomson et al., 2007).

Rudy Magne examined the transformation of swell over a submarine canyon using a linear theory for the potential flow problem including evanescent modes. Comparisons of model results and observations from the NCEX experiment show that refractive trapping of waves by the offshore canyon rim effectively blocks the arrival of long period swell on the adjacent beach (Magne et al., 2007).

Fabrice Ardhuin compared SandyDuck and SHOWEX 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., 2007). These comparisons highlight some deficiencies of wave growth and dissipation parameterizations in mixed swell-sea conditions.

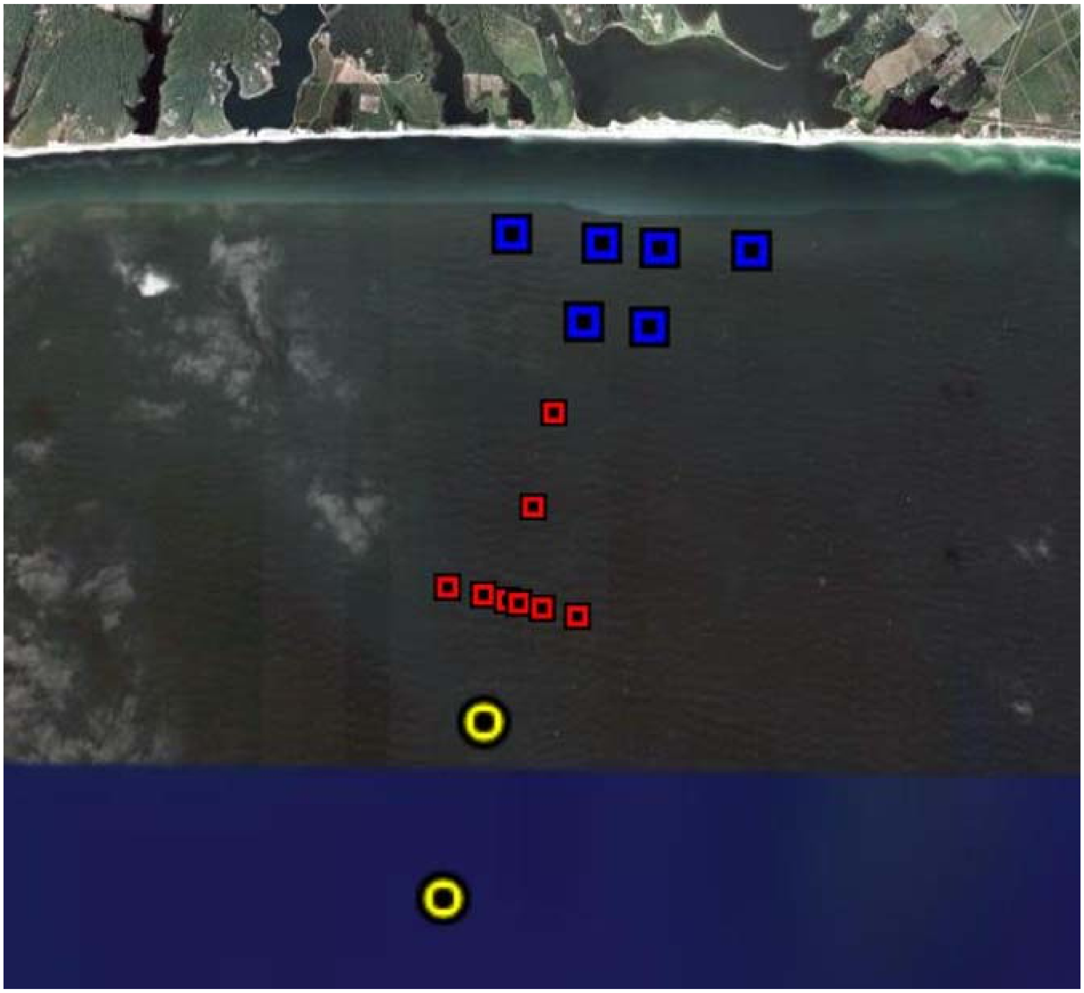

Figure 1. Array plan Martha's Vineyard Experiment. Detailed measurements of surface wave evolution across the inner shelf were collected during September and October of 2007. The array spans about 5 km from 24- to 8-m depth.

The Martha's Vineyard Experiment, focused on seafloor ripples excited by the orbital motion of ocean surface waves, took place during the fall of 2007. We deployed an array of wave measuring instruments (Figure 1) to observe in detail the wave evolution across the inner continental shelf and provide the hydrodynamic forcing conditions for collaborative studies of the coupled wave-morphology dynamics. The array spans a 5 km distance from 8- to 24-m depth, including the dynamic inner shelf region. Two Datawell Directional Waverider buoys were deployed along the deeper part of the transect in 24 and 20 m depth. In the middle of the transect an 8-element coherent array of bottom pressure transducers was deployed in 18-15 m depth to provide detailed measurements of the two-dimensional wave group structure. At the shallow end of the transect six bottom tripods with an acoustic Doppler velocimeter and an acoustic Doppler profiler (each also containing a pressure transducer) provide near-bed velocity measurements and surface wave directional spectra. The tripods were deployed along the 10- and 12-m isobaths in fine and coarse sediment patches to study the effect of the heterogeneous sediment environment on the wave-seafloor interactions. The sensor locations were coordinated with the deployment of other tripods by Peter Traykovski (WHOI), Alex Hay (Dalhousie Univ.), and Chris Sherwood (USGS) that were equipped with a variety of seafloor mapping instruments in addition to surface wave sensors.

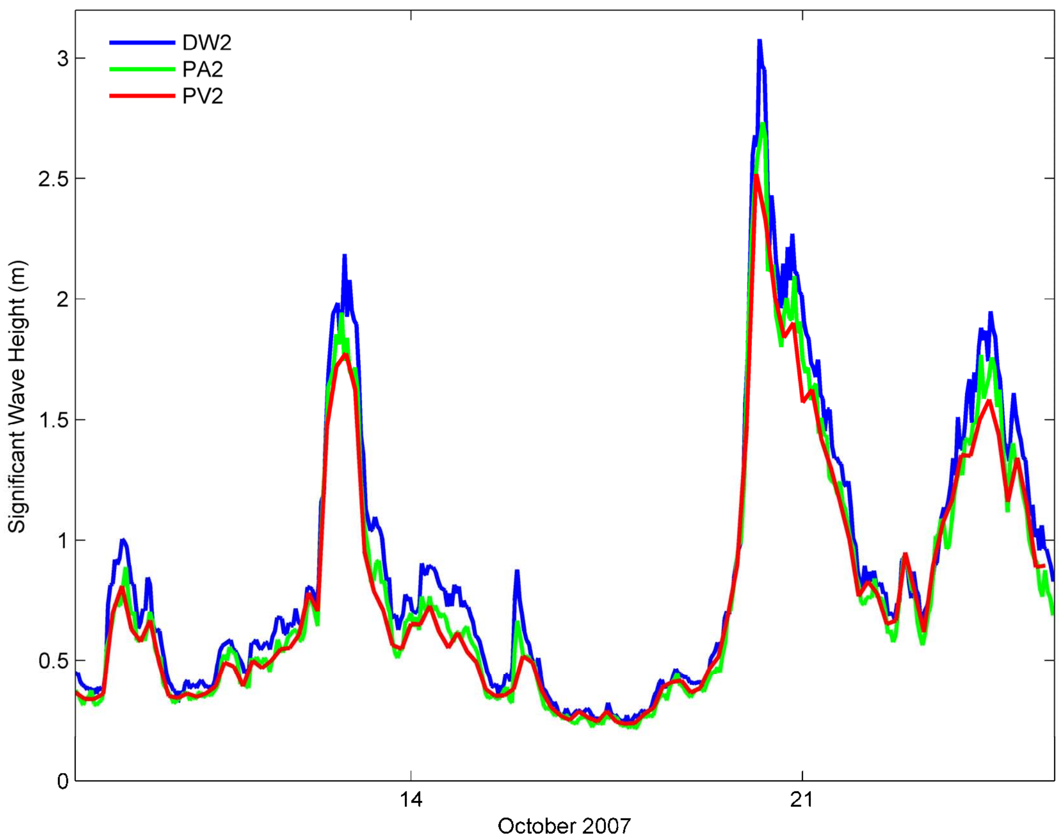

Figure 2. Observed wave evolution across the Martha's Vineyard inner shelf. Time series of significant wave heights are shown at three stations (see Figure 1) for a selected period with multiple energetic wave events. The attenuation of wave heights over a distance of only five kilometers suggests significant damping by bottom friction.

The observed wave evolution across the inner shelf is illustrated in Figure 2 with example time series of significant wave heights measured at the offshore buoy (blue), a mid-transect pressure gauge (green) and an inshore pressure-velocity tripod (red).   During energetic events with predominantly onshore wave propagation directions (not shown) the observed wave heights at the shallowest sites are consistently smaller by about 15-25 % than those observed at the deepest site, suggesting appreciable bottom friction effects over this relatively short (about five kilometers) distance. Quantitative estimates of dissipation rates will be made based on the array observations and a two-dimensional wave propagation model that accounts for shoaling and refraction effects. These estimates together with seafloor roughness measurements collected by other investigators will be used to test parameterizations of bottom friction. The Martha's Vineyard data set will also will be used to test new models for nonlinear wave evolution in variable depth (Janssen et al., 2007; Janssen and Herbers, 2008)

RESULTS

It is well known that the presence of mud deposits on the continental shelf can cause dramatic damping of ocean surface waves, but quantitative field observations are scarce. We recently participated in a comprehensive field experiment on the wide and muddy shelf of Western Louisiana to investigate the interaction of wind-generated ocean surface waves with a muddy seafloor. We deployed an extensive array of instruments (Figure 3) during February-March, 2008, that included two directional waverider buoys, six bottom tripods equipped with a pressure-velocity sensor and a current profiler, and six bottom tripods equipped with a pressure sensor.

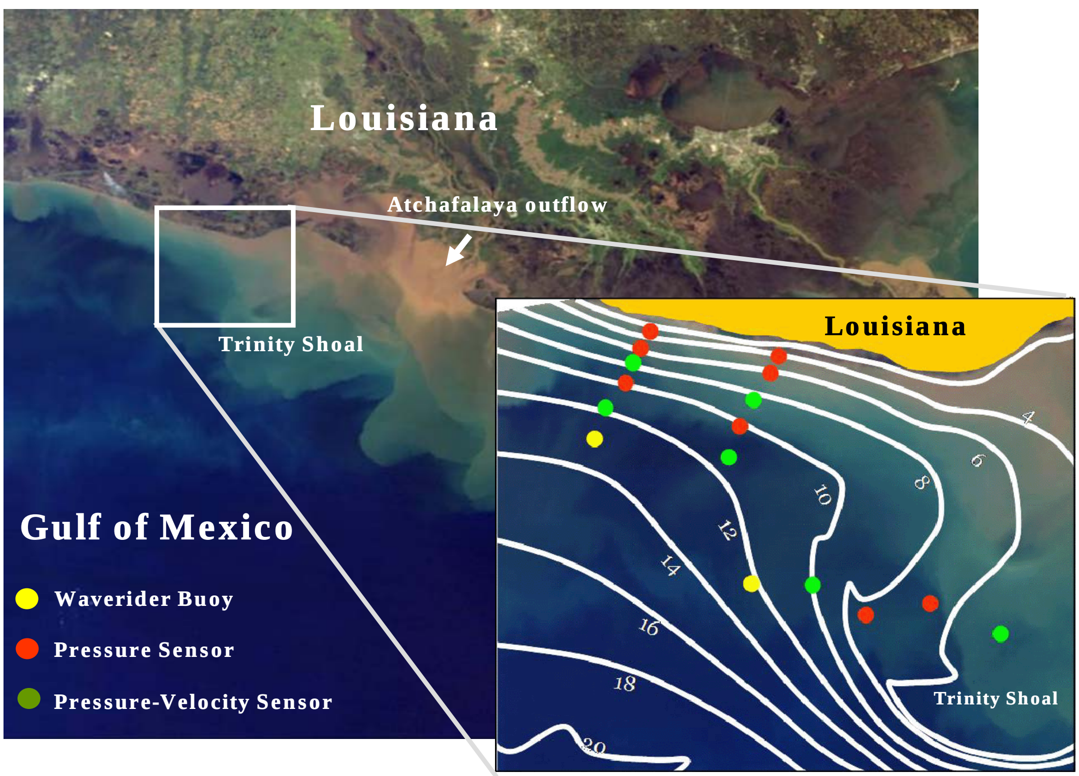

Figure 3.Field site and array plan of the Louisiana Mud Experiment. Mud deposits from the Atchafalaya River are evident in the satellite image. White lines indicate depth contours in m.

The two-dimensional array consisted of two cross-shore transects and an alongshore transect spanning a 40 by 25 km area in depths ranging from 13 to 4 m. The dataset includes numerous local wind sea events with wave directions predominantly from the south (i.e. onshore propagation). Box cores were collected at all instrument sites to characterize the surficial sediment properties (Garcia-Garcia et al., 2008).

Preliminary analysis generally shows a consistent decay of waves from the deeper to the shallower instruments (e.g. Figures 4 and 5), similar to earlier observations (Sheremet and Stone, 2003; Elgar and Raubenheimer, 2008). The wave spectra evolution (Figure 5) shows strong decay (as much as an order of magnitude) of high-frequency wind sea spectral levels and weaker decay at the lower swell frequencies. These observations suggest that the dissipation is not the result of a direct wave-bottom interaction (which would affect only longer-wavelength waves), but possibly the result of heavy sediment suspension over the entire water column affecting the hydrodynamics of short wavelength waves (Sheremet and Stone, 2003). The observed decay was strongest at the shallowest site of the central transect (e.g. Figure 5) where box cores showed fresh mud deposits (Garcia-Garcia et al., 2008) and a visibly murky sea surface was observed during the experiment cruises.

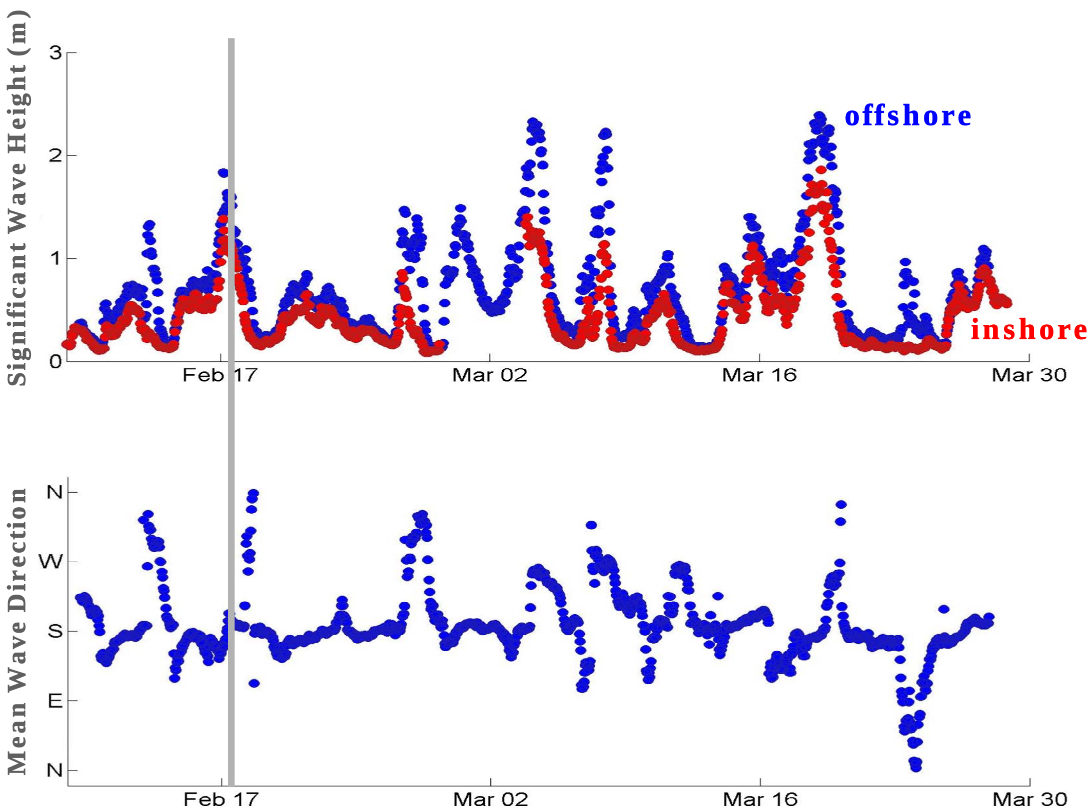

Figure 4. Wave conditions along the western transect during the Louisiana Mud Experiment. Blue and red dots indicate estimates from the offshore directional waverider buoy and the inshore bottom pressure sensor, respectively. The vertical line indicates a wave event examined in more detail in Figure 5.

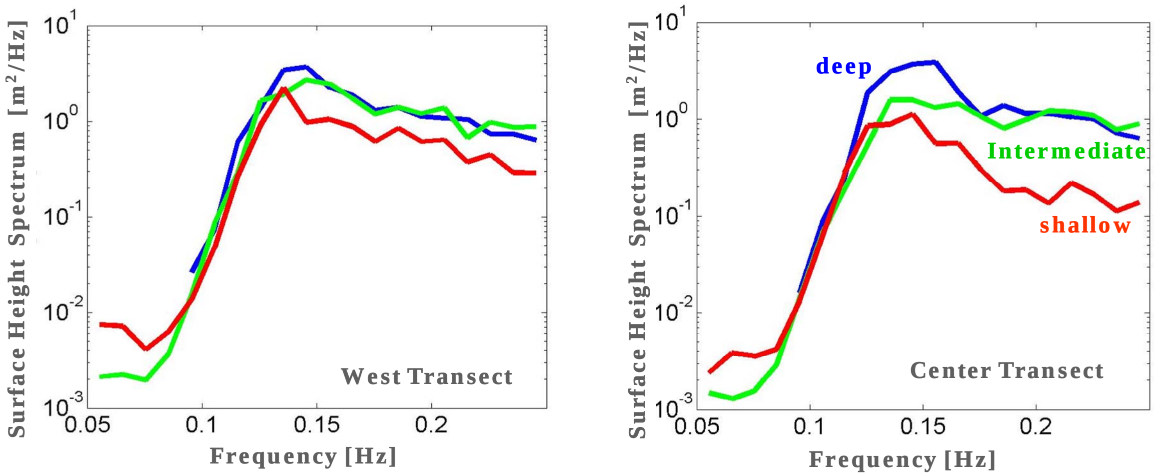

Figure 5. Evolution of surface height spectra on February 17 along the western transect (left panel) and the central transect (right panel). Blue, green and red curves indicate estimates from sites at the offshore end, the middle and the nearshore end of the transect, respectively.

IMPACT/APPLICATIONS

Existing spectral wave prediction models contain crude, largely untested parameterizations of seafloor damping effects. We have conducted new field experiments on sandy and muddy continental shelves that provide the much needed comprehensive data sets for improving these parameterizations. We are developing new deterministic and stochastic wave evolution models that incorporate diffraction and quadratic and cubic nonlinear effects for more accurate predictions in complex coastal environments.

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