Nearshore Processes

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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 FY99 objectives were to obtain and analyze field observations on natural beaches in order to develop and test hypotheses about the

- transformation of surface waves across the shoaling region and surf zone

- generation and spatial variation of wave-driven setup and near-bottom circulation

- evolution of the nearshore bathymetry in response to waves and circulation

Additional objectives include providing data supporting other SandyDuck studies of wave transformation, circulation, sediment transport, and acoustic properties, and continued development of instrumentation for nearshore observations.

APPROACH

Our approach is to test hypotheses by comparing model predictions with field observations. Waves, currents, and bathymetry were observed on a natural beach during the SandyDuck field experiment on the North Carolina coast. Pressure gages, current meters, and sonar altimeters were deployed for about 4 months on a grid extending 400 m from the shoreline to about 5 m water depth and spanning 200 m alongshore (Figure 1).

In collaboration with T. Herbers, Boussinesq models for the evolution of directionally spread breaking and nonbreaking waves are being developed and tested by comparison with the array observations. The SandyDuck observations are also being used to test models for wave-breaking induced setup and the corresponding offshore directed undertow (with Britt Raubenheimer), mean circulation and bottom stress (with Falk Feddersen), shear waves (with student Jim Noyes), infragravity waves (with postdoc Alex Sheremet), the evolution of the sand bar-scale morphology (with Edith Gallagher), and effects of the pier and associated bathymetry on waves (with O'Reilly, Raubenheimer, and Herbers).

Our approach to surf zone instrument development utilizes bench tests, field deployments, and comparisons of observations with theory.

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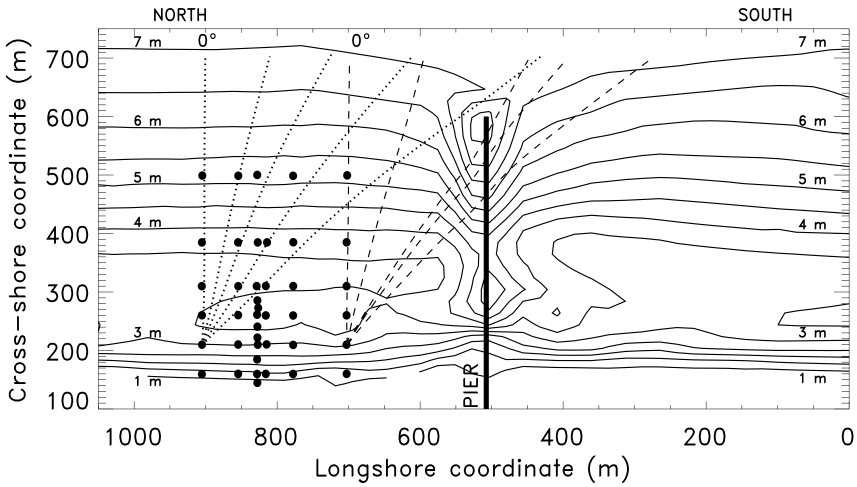

Figure 1: Sensor array (circles) and nearshore bathymetry (depth contours relative to mean sea level in 0.5 m steps). A bidirectional current meter, pressure gage, and sonar altimeter were colocated at most locations. The broken curves are wave rays (eg, wave energy propagation paths) for shoreward propagating $f = 0.15$ Hz waves with incident angles (in 5 m depth) from $0°$ to $-40°$ in steps of $-10°$. Waves approaching the beach obliquely from the south pass under the pier before reaching instrumented locations near the shoreline and immediately downwave of the pier.

WORK COMPLETED

Preliminary data processing of the SandyDuck observations is complete, and maps of nearshore wave heights and directions, bathymetry, mean flows, and setup every 3 hours for the entire experiment have been produced. Time series from all instruments have passed stringent quality control to remove bad data (eg, malfunctioning sensors, instruments exposed at low tide, noisy sonar returns in the bubbly, sediment laden inner surf zone).

Breaking complicates wave evolution, but the nonlinear triad interactions included in Boussinesq models appear to be important throughout the shoaling region and the surf zone. One-dimensional Boussinesq shoaling wave models have been compared with observations made on the cross-shore transect of the Duck94 pilot experiment (Chen et al. 1997, Norheim et al. 1998, Herbers et al. 2000). The directional spread of energy was shown to increase as waves broke over a sand bar, in contrast to the directional narrowing predicted by linear refraction theory (Herbers et al. 1999). Observations made with compact pressure sensor arrays (SandyDuck) show that nonlinear amplitude dispersion can alter the phase speeds of sea and swell by as much as 25%, consistent with Boussinesq theory predictions (Herbers et al. submitted).

Comparison of the bottom drag of the mean longshore current with the forcing by wind and breaking waves shows that currents within the surf zone primarily are wave-driven and that the alongshore bottom stress is represented well by a quadratic bottom drag law. The drag coefficient in the surf zone is about 3 times larger than seawards of the surf zone, possibly owing to the effect of breaking wave turbulence on the vertical mixing of momentum (Feddersen et al. 1998). Parameterizations of the nonlinear velocity term in the quadratic bottom stress formulation were investigated with both Duck94 and SandyDuck observations. Several nonlinear parameterizations were shown to be more accurate than linear parameterizations, and are adequate for many modeling purposes (Feddersen et al. 2000).

Concurrent observations of waves, wind and currents across the inner 16 km of the North Carolina shelf were used to determine for the first time the cross-shelf variation of the dominant terms in the cross-shelf and alongshelf momentum balances between the shoreline and midshelf (Lentz et al. 1999). Wave-driven setdown was dynamically significant on the inner shelf, so the cross-shore momentum balance there is not geostrophic.

RESULTS

The Duck pier pilings and associated bathymetry produce alongshore gradients in wave height and direction within our SandyDuck array. When incident waves approached the beach obliquely from the south (see the rays in Figure 1), wave energy observed near the shoreline 200 m downwave of the pier was as much as 50% lower than observed 400 m downwave, and waves close to the pier were more normally incident than farther downwave. Alongshore gradients were much smaller 400 m offshore of the shoreline, upwave of the pier, and with nearly normally incident waves (Figure 2), confirming that the gradients are associated with wave propagation under the pier. A spectral refraction model for waves propagating over the measured bathymetry, which includes a depression under the pier (Figure 1), accurately predicts the observations 400 m downwave of the pier, but overpredicts energy near the pier. Model predictions that include partial absorption of wave energy by the pier pilings reproduce the observed alongshore gradients, suggesting piling-induced dissipation may be important (Elgar et al. submitted).

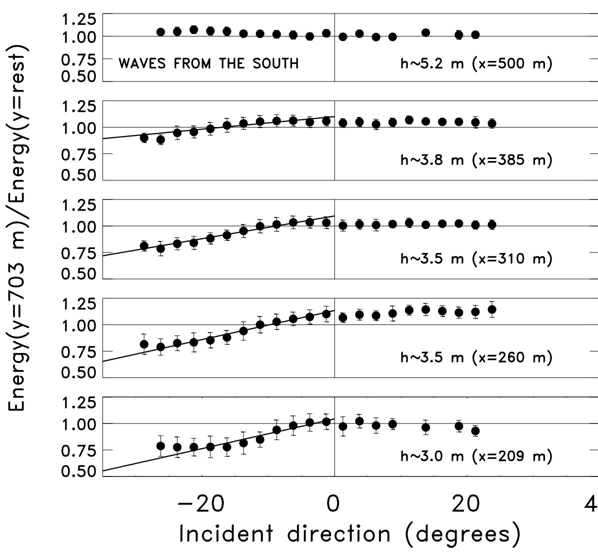

Figure 2: The ratio of sea-surface elevation energy observed nearest the pier (alongshore coordinate $y = 703$ m) to the energy averaged over the rest of the array at the same depth ($775 \leq y \leq 905$ m) versus average direction of the incident waves (measured at depth $h = 5.2$ m). Mean and standard deviations for each $2.5°$-wide directional bin are shown as circles and bars, respectively. Solid lines are least squares fits to directions less than $0°$ (waves from the south). Alongshore variations increase from offshore ($h \approx 5.2$ m, top) to onshore ($h \approx 3.0$ m, bottom) and with increasing southerly propagation direction.

It is difficult to measure velocities in the surf and swash zones. Widely used electro-magnetic current meters (EMCM) do not function well when alternately covered and uncovered by water, are inaccurate at elevations above the bed less than about 30 cm, and are subject to offset drift and biofouling. Field tests near the Scripps pier suggest that acoustic current

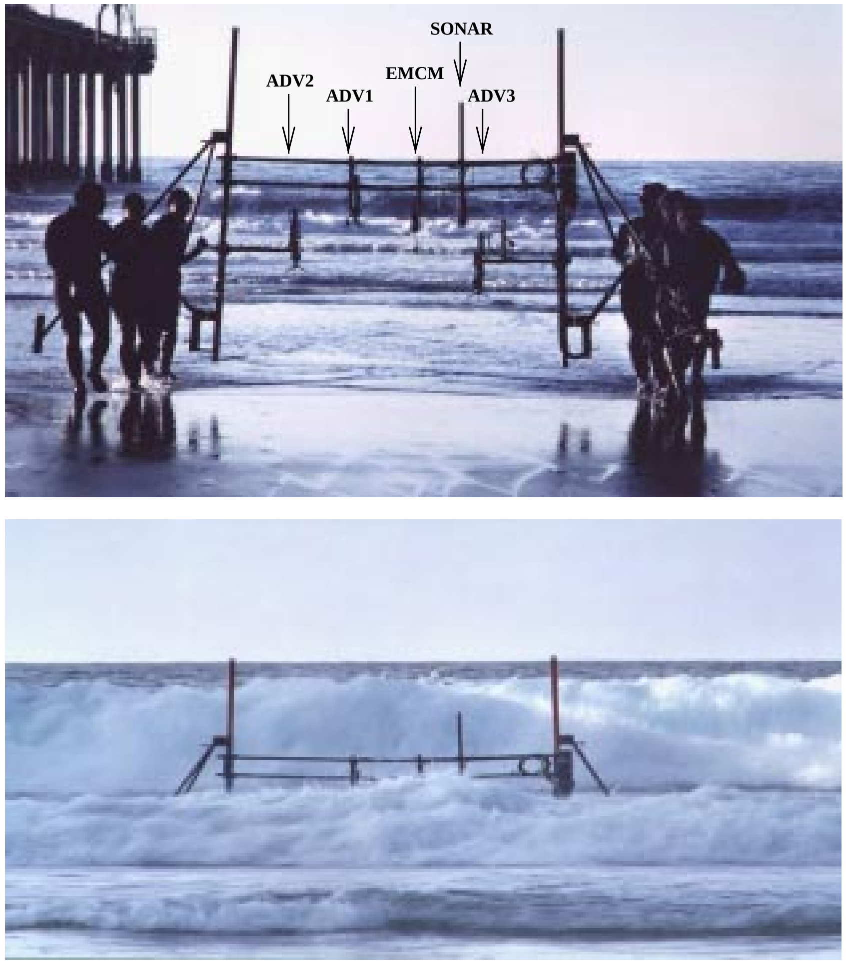

Figure 3. (Upper) Mounting frame and instruments (arrows indicate the current meters and sonar altimeter). The pressure gage was mounted near the right-hand frame leg. (Lower) The instruments about to be covered by a wall of foam as a breaking wave passes. Wave forces bent the upper cross–bars about 30 cm out of line, resulting in the nonparallel vertical pipes (upper panel), but the instruments survived.

(ADV) meters perform well in the surf zone, even during energetic wave conditions when their performance might be degraded by high concentrations of bubbles and sediment. Three vertically stacked ADV, one EMCM, a pressure gage, and a sonar altimeter (to determine changes in bed elevation) (Figure 3a) were deployed in the surf zone for 3 weeks. Surf zone wave heights ranged from 25 to 175 cm. When waves were energetic, the instruments were in surf with high suspended sediment and bubble concentrations (Figure 3b), and strong vertical velocities. Comparison of velocity with pressure energy density spectra indicate that all the current meters (located 43, 62, and 101 cm above the seafloor) accurately measure wave orbital velocities (Figure 4). The ADV sensors have more stable electronics, less susceptibility to biofouling, and better performance with intermittent submersion than EMCMs, and thus are an attractive alternative for surf zone observations.

IMPACT/APPLICATIONS

The SandyDuck observations will be used to verify and improve wave, circulation, and morphological change models of interest to oceanographers and engineers. In addition, the

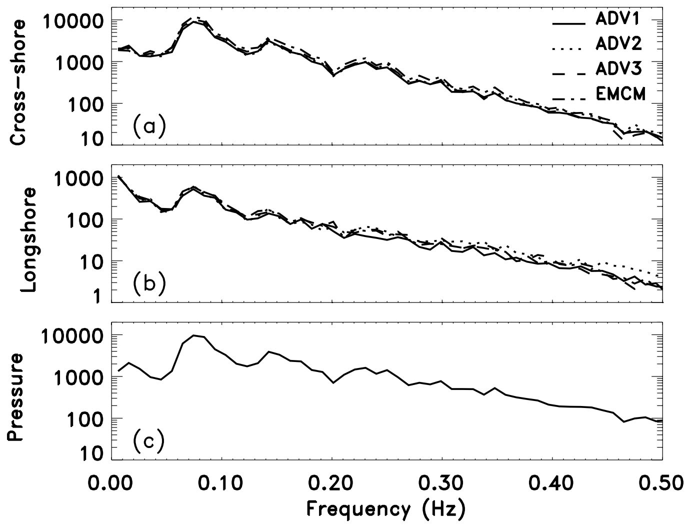

Figure 4. Energy density spectra (60 degrees of freedom) calculated from (a) cross- and (b) alongshore velocity observed for one hour with acoustic (ADV) and electro-magnetic (EMCM) current meters in the surf zone. Velocity spectra have been converted to equivalent bottom pressure with linear theory. (c) Bottom pressure spectra. The sum of converted cross- and alongshore velocity spectra are within a few percent of the bottom pressure spectra, suggesting the current meters are accurate. Instrument locations are shown in Figure 3. The significant wave height was about 1.5 m.

spatially and temporally extensive observations provide the opportunity to discover new phenomena not included in present models.

TRANSITIONS

The sonar altimeters developed under this program are being utilized by other scientists, including altimeters mounted on the CRAB (Thornton, Gallagher), on a movable instrument sled (Thornton, Stanton), on the FRF's Sensor Insertion System (Miller, Resio), and as part of the European COAST3D experiments (on the WESP (Gallagher) and on a fixed platform (Miles)).

RELATED PROJECTS

The observations of nearshore waves, currents, and bathymetry compliment collaborative (with Herbers and O'Reilly) investigations of wave propagation across the continental shelf.

We also are collaborating with other SandyDuck investigators, including using our measurements of waves, currents, and bathymetry in studies of bottom roughness (hydraulic drag) (Thornton, Drake), wave breaking (Lippmann), the vertical distribution of currents (Thornton, Hathaway), circulation (J. Smith, Trizna, Kirby), the determination of bathymetry from wave data (P. Smith, Holland), acoustical properties (Hay, Heitmeyer), wave-breaking induced bubbles (Su), nearshore bedforms (Hay, Thornton, Gallagher), sediment transport (Miller, Resio), video estimation of surfzone currents (Holland), and swash processes (Holland, Sallenger).

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