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 objectives in FY97-98 are to obtain comprehensive field observations on a bathymetrically complex natural beach to develop, test, and improve models describing the

- transformation of surface waves across the nearshore and surfzone

- breaking wave-driven setup and near-bottom circulation

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

An additional objective is to provide data supporting other SandyDuck studies of wave transformation, sediment transport, and acoustic properties.

APPROACH

The evolution of waves, currents, and bathymetry on a natural beach is being observed during the SandyDuck field experiment on the North Carolina coast. Pressure gages, current meters, and sonar altimeters have been deployed on a two-dimensional grid extending 370 m from near the shoreline to about 5 m water depth and spanning 200 m along the coast (figure 1). The grid is large enough to sample significant bathymetric inhomogeneities and their effects on wave evolution and circulation. The spatially extensive instrument arrays will allow quantitative investigations of sea and swell, edge waves, shear waves, alongshore inhomogeneous circulation, and changing morphology.

In collaboration with T. Herbers, a Boussinesq model for the nonlinear evolution of nonbreaking, directionally spread waves will be tested by comparison with the array observations. The model will be initialized with wave directional spectra estimated from pressure sensor array data

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acquired in 8-m water depth (not shown), and model predictions will be compared with wave observations at shallower depths (figure 1).

Breaking substantially complicates wave evolution. Field measurement-based algorithms for estimating breaking location and significant wave height in the surfzone are used widely in practical applications. However, the effect of breaking on wave propagation directions is unknown. In collaboration with T. Herbers and W. O'Reilly, models for directionally spread waves will be initialized with measurements in 5 m depth, and predictions of total wave energy, mean propagation direction, directional spread, and radiation stresses will be compared with surfzone observations.

A cross-shore transect of buried (to avoid flow-induced pressures) Paros pressure gages provides estimates of the wave-breaking induced setup. In collaboration with B. Raubenheimer, the observations will be compared with models for setup and with the corresponding offshore directed near-bottom flows (undertow).

Graduate student F. Feddersen is comparing the observed breaking wave-forced circulation with predictions of a shallow water equation-based model that incorporates the physics of bathymetrically controlled surfzone flow, including longshore pressure gradients and the nonlinearity believed to cause rip currents. Instead of relying on problematic (on a natural beach) periodic boundary conditions or longshore boundary conditions requiring an unrealistically large number of observations, nonlinear inverse modeling and data assimilation will be used. The assimilation of observed currents includes the effects (on the modeled flow field) of large-scale, longshore variations in the bathymetry (or wave field) that are outside the instrumented area and not modeled explicitly.

Observed currents and sediment characteristics will be used to drive a 2D energetics-type morphological evolution model that is under development. Predictions of bar-scale morphological evolution will be compared with observations made with the array of altimeters (figure 1b), supplemented by spatially dense surveys made daily with an amphibious vehicle.

WORK COMPLETED

The array was deployed in July 1997 and data have been acquired nearly continuously for more than 2.5 months (Aug – mid-Oct 1997). Data collection is planned until early Nov. Data return is greater than 97%. Significant processing is performed in near-realtime, and maps of nearshore wave heights and directions, bathymetry, mean flows, and setup every 3 hours for 75 days have been produced (figures 1 and 2, discussed below, correspond to a single 3-hour period).

One-dimensional Boussinesq shoaling wave models have been compared with observations made on the cross-shore transect of the Duck94 pilot experiment (Elgar et al. 1997, Chen et al. 1997, Norheim et al. 1997). The momentum balance described by the shallow water equations was verified by comparison with mean longshore currents observed along the Duck94 transect (Fedderson et al. 1997). A 1D morphological evolution model was shown to predict the offshore sandbar migration observed in Duck94 (Gallagher et al. 1997).

RESULTS

Nearshore waves and circulation driven by a moderate storm (150 cm significant wave height in 5 m depth) are shown in figures 1 and 2. The waves were obliquely incident on the shoreline (figure 1a). Wave breaking was weak and the wave height remained approximately constant in water depths greater than 3 m (figures 1a and 2a). Strong, wave-driven mean longshore currents (> 130 cm/sec) were observed in the narrow surfzone near the shoreline (figure 1c). There was little alongshore variation in bathymetry (figure 1b), wave directions (figure 1a), or mean currents (figure 1c). Breaking related changes in the wave radiation stress are approximately balanced by wave setup (figure 2b) that drives strong offshore directed mean currents (figure 2c). Preliminary analysis suggests that, in this case, alongshore gradients in the bathymetry and wave field are not important in either the mean longshore or mean cross-shore momentum balances. It is anticipated, based on previous experience at this site, that the bathymetry will become irregular as storms become more intense and frequent.

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 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 (E.B. Thornton, E. Gallagher), on a movable instrument sled (Thornton, Stanton), and on the FRF's Sensor Insertion System (C. Miller, D. Resio). Field tested models for surfzone waves have been adapted by the operational Navy (eg, the SURF model).

RELATED PROJECTS

The observations of nearshore waves, currents, and bathymetry compliment collaborative (with Herbers and O'Reilly) investigations of wave propagation across the inner (Waves in the Ocean BAA) and entire (Shallow Water Waves DRI) 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), the determination of bathymetry from wave data (P. Smith, T. Holland), acoustical properties (Hay, Heitmeyer, Livingston), wave-breaking induced bubbles (Su), nearshore bedforms (Hay, Thornton, Gallagher), sediment transport (Miller, Resio), video estimation of surfzone currents (Holman), and swash processes (Holland, Sallanger).

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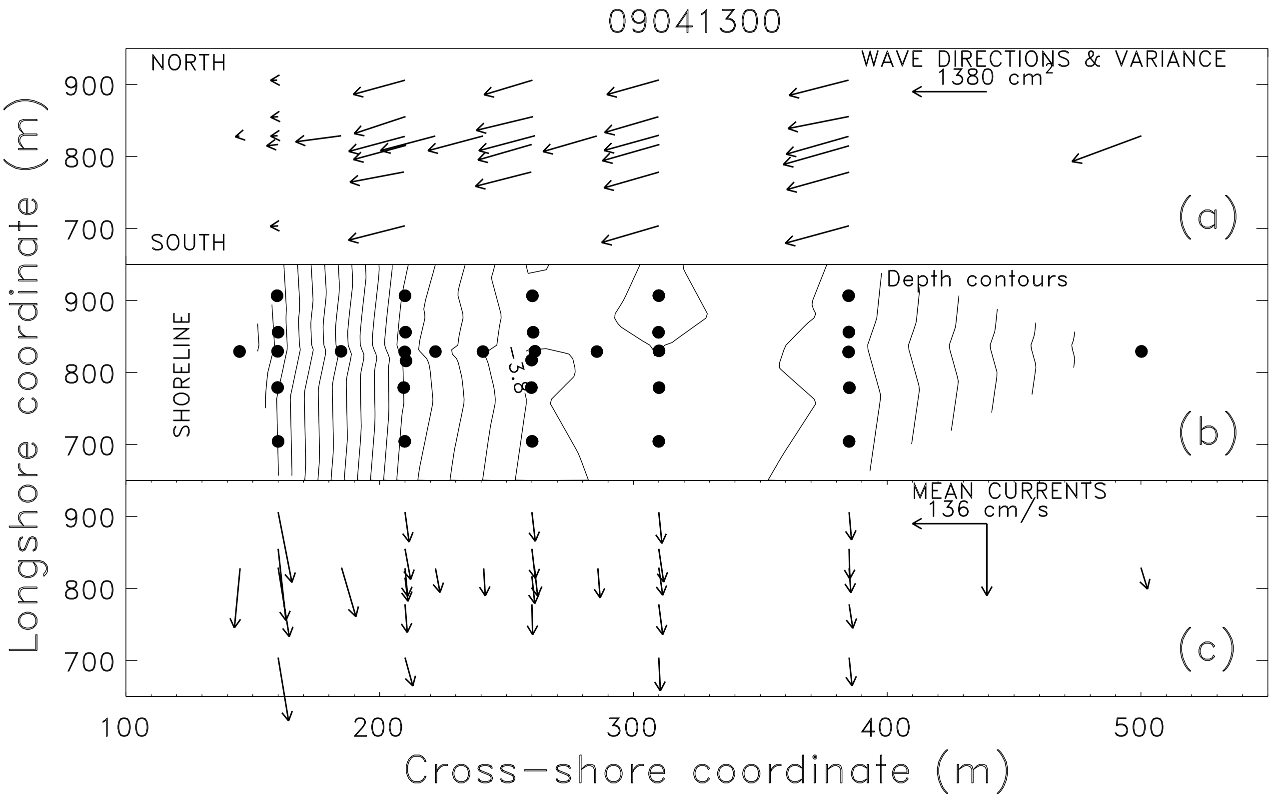

Figure 1: Summary of observations obtained with our SandyDuck array during a stormy 3 hr-period (1300-1600 hrs, 4 Sep 1997). Each panel shows a plan view of the instrumented region with north toward the top and the shoreline to the left. (a) Wave propagation direction (indicated by the arrow direction) and wave variance (proportional to the arrow length) estimated with data from a biaxial current meter and pressure sensor located at the base of each arrow. (b) Depth contours (20 cm intervals) based on sonar altimeters (filled circles). A cross-shore profile of water depth is shown in figure 2c. (c) Mean (3-hr average) currents (direction and magnitude are indicated by the arrow direction and length, respectively). The longest vector corresponds to about 136 cm/s.

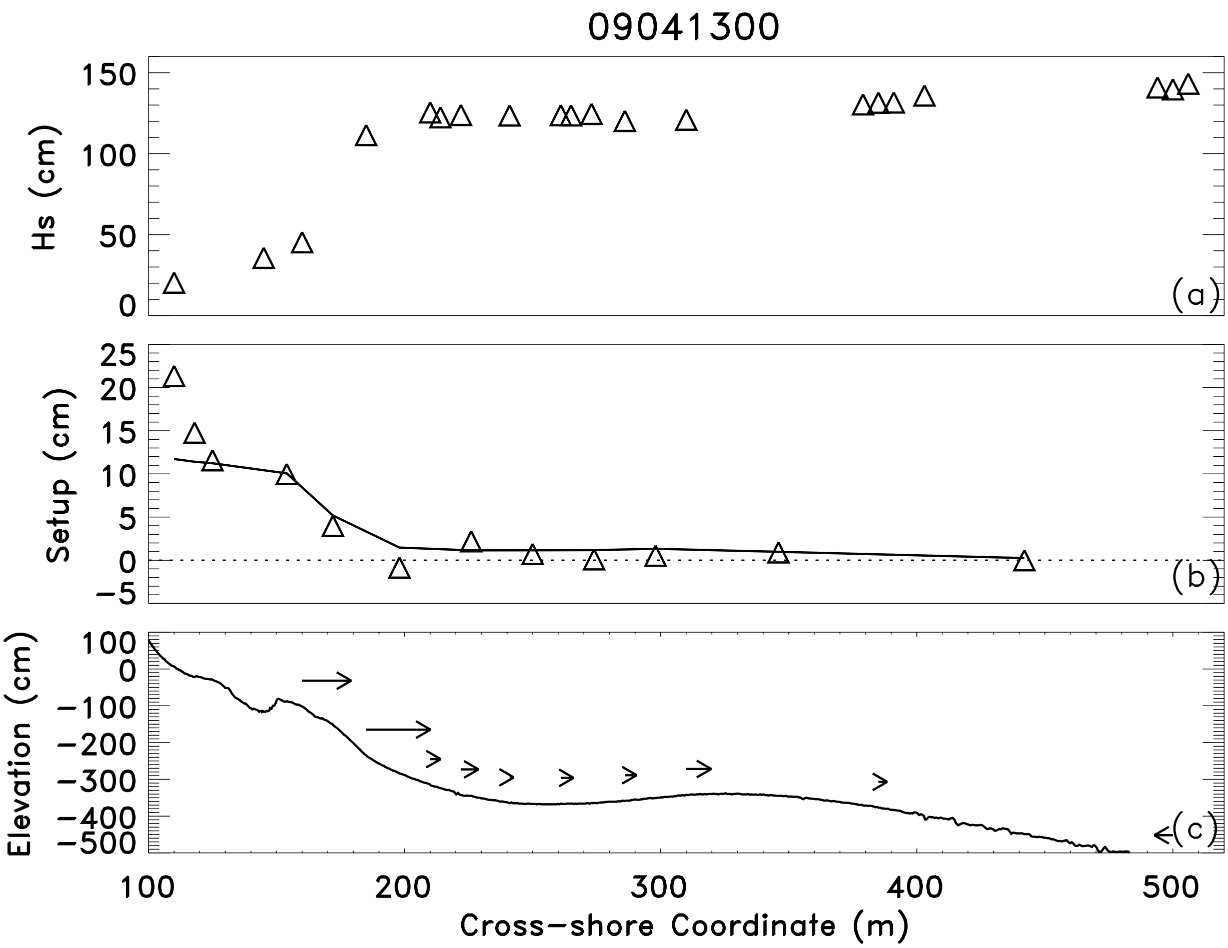

Figure 2: Observed (a) significant wave height H_s, (b) super-elevation (eg, setup) of the mean sea surface (solid line corresponds to a theoretical prediction), and (c) water depth (solid line) and near-bottom cross-shore currents (the base of each arrow corresponds to a flow meter location and the longest vector corresponds to about 30 cm/sec) versus cross-shore distance. The observations were obtained along the central transect near longshore coordinate 827 m (figure 1) between 1300 and 1600 hrs, 4 Sep 1997.