Modeling Swashzone Fluid Velocities

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LONG-TERM GOALS

The long-term goal is to develop and verify models for fluid and sediment processes in the swash zone.

OBJECTIVES

The CY99 objectives were to:

- evaluate an existing model of wave runup velocities.
- extend the model to include a turbulent bottom boundary layer.

APPROACH

An existing model (Kobayashi et al, 1989), known as Rbreak, based on the depth-averaged nonlinear shallow water equations with quadratic bottom friction is being tested by comparing predictions with observations of swashzone fluid velocities collected during the SandyDuck experiment (Fall 1997) conducted near Duck, NC. Cross-shore, alongshore, and vertical velocities were measured with a acoustic current meter at a 2 Hz sample rate for 8 hours. The sampling volume of the current meter ranged from 5 to 15 cm above the sand bed. Owing to changing tidal levels, the cross-shore locations of the observations spanned the swashzone region. The range of measurement positions allows the model accuracy to be examined as a function of sensor elevation above the bed and cross-shore location within the swash zone.

The effect of the bottom boundary layer is being examined by incorporating a boundary layer parameterization in the nonlinear shallow water equation model. Empirical parameters in the formulations are estimated by requiring that the model velocities outside the boundary layer agree at least qualitatively with the observations. Furthermore, the inclusion of the boundary layer must have little effect on the predicted runup excursions (which are predicted well by Rbreak). Using a plausible range of model parameters, comparisons of predictions by models with and without the bottom boundary layer parameterization will be used to estimate the importance of the boundary layer to the bottom shear stress and the cross-shore structure of the flow field.

WORK COMPLETED

Data processing and quality control of runup fluid velocity observations is complete, and comparisons of observations with Rbreak predictions have been conducted for the entire data set.

Quality control of the velocity observations was performed using the correlation of sequential backscatter pulses within the sampling interval, and the ratio of the received acoustic signal strength to background noise. Based on the manufactures' recommended minimum correlations and comparisons of observed surfzone velocities with sea-surface

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elevations, measurements with average (for the 3 measurement axes) correlations greater than 42% and signal to noise ratios greater than 35 dB were considered high quality. Velocity measurements with correlations or signal to noise ratios below the minimum acceptable levels were set equal to 0.0 cm/s.

Rbreak is initialized at the model seaward boundary with observations from a pressure sensor and current meter (Figure 1a) colocated about 60 m offshore of the swash zone (in about 1.5 m water depth). The still water depth was determined from the beach profile and the observed pressure time series every 17 min. The initial 17 min of each approximately 170-min-long predicted time series were discarded to eliminate transients owing to the initial condition of no wave motion. To synchronize the predictions with the velocity and video runup observations (recorded on different data acquisition systems), the measurement start times were adjusted until the phase difference between overlapping time series was minimized.

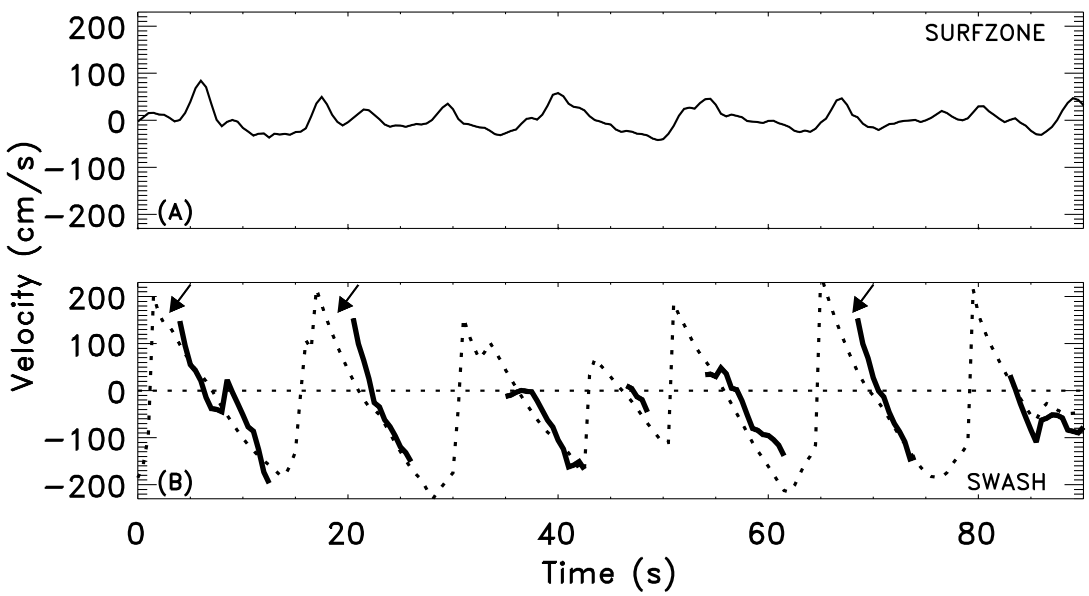

Figure 1: (a) Observed surfzone velocities (1.5 m water depth) and (b) observed (solid curve) and predicted (dotted curve) wave runup velocities. Runup velocity observations were made nominally 5 cm above the bed and are not shown when the sensor (located 10 cm above the bed) was out of the water or when data quality was poor (possibly owing to suspended sediment or air bubbles). Arrows indicate underprediction of observed decelerations.

The nonlinear shallow water equation model has been extended to include the bottom boundary layer. Following Packwood (1980) and Elfrink and Fredsoe (1993), the influence of the bottom boundary layer is included by accounting for the displacement and momentum thickness owing to the vertical structure of the cross-shore flow, which is assumed to be logarithmic (eg, Fredsoe, 1984).

RESULTS

Cross-shore runup velocities measured during low wave-energy conditions are predicted qualitatively well by the numerical model Rbreak (Figure 1b). Similar to previous results, the predicted maximum uprush and downrush velocities occur at the beginning and end of the runup, respectively. Near the intersection of still water level and the beach, the predicted velocity fluctuations are skewed (maximum uprush velocities are larger than downrush velocities and uprush periods are shorter than downrush periods). Model simulations suggest that the skewness increases from negative to positive values shoreward across the swash zone.

Although the model predictions are qualitatively accurate, the observed uprush decelerations ($\Delta U/\Delta t$, where U is the velocity and t is time, between the maximum uprush velocity and flow reversal ($U = 0$)) of runups with maximum predicted uprush velocities $Umax$ greater than 100 cm/s are about 60% larger than the predicted decelerations (Figures 1b and 2). The differences between the observed and predicted velocity time series may result in significant differences in sediment transport (not shown). The transport estimated with an energetics model (Bailard, 1981) driven with the observed velocities is small, consistent with the lack of swashzone morphological evolution during the experiment. In contrast, the transport driven with the Rbreak-predicted velocities (for times when predictions and observations overlap) results in erosion rates of up to 5 cm/hr between the sensors and the maximum runup location (where transport is assumed to be zero).

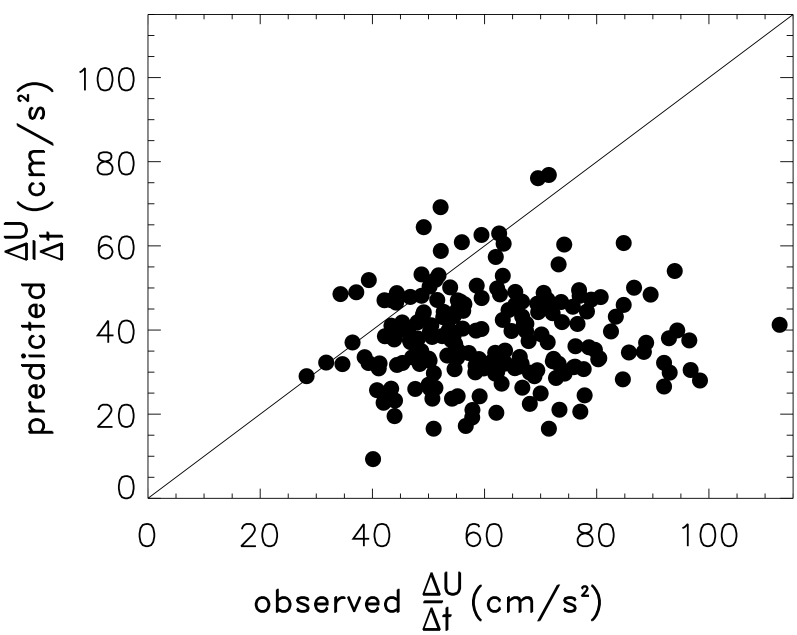

Figure 2: Predicted versus observed uprush deceleration ($\Delta U/\Delta t$) for $100 < Umax \leq 320$ cm/s. The geometric mean ($\pm$ 99% confidence interval) of the ratios of the observed to the predicted deceleration is 1.62$\pm$0.02.

Preliminary comparisons of velocities predicted by Rbreak with those predicted by the extended model suggest that Rbreak-underprediction of uprush decelerations (Figures 1b and 2) may be at least partly owing to neglect of the boundary layer velocity structure (Figure 3). The importance of the boundary layer to the runup velocities is predicted to be largest near the offshore edge of the swashzone.

IMPACT/APPLICATIONS

The bottom boundary layer may be particularly important in the swashzone where its thickness is not small relative to the water depth. The boundary layer parameterizations evaluated here may provide a basis for revising other time-domain models of swashzone

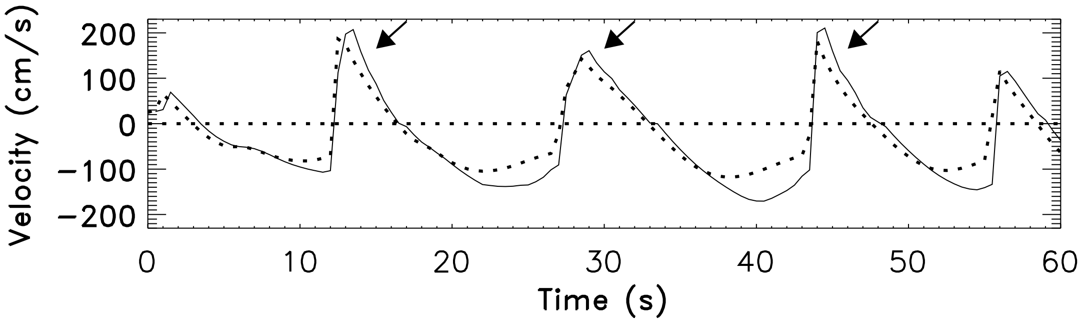

Figure 3: Wave runup velocities predicted by models with (solid curve) and without (dotted curve) the bottom boundary layer extension. Including the boundary layer parameterization results in larger predicted uprush decelerations (indicated by arrows) and downrush velocities.

velocities that assume quadratic bottom stresses.

TRANSITIONS

RELATED PROJECTS

The effects of infiltration on runup are being investigated (supported by NSF), and may be included in future swash zone investigations if shown to be important. Future simulations with a model including both infiltration and boundary layer dynamics will be useful to examine swashzone processes on coarse-grained beaches having high permeability and large bed roughness.

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