Next Generation Modeling for Deep Water Wave Breaking and Langmuir Circulation

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LONG-TERM GOALS

The goals of this work are to develop better understanding and predictive capability for (1) deep water wave breaking (2) the transfer of momentum from waves into the water column and (3) the interaction between irrotational waves and vorticity in the surface shear layer.

OBJECTIVES

We are presently focused on addressing three key aspects of open ocean wave breaking:

- What are the net vertical distributions and flux rates of momentum transfer, vorticity, turbulence intensities, and kinetic energy dissipation from the breaking waves into the mean water column?
- As multiple random waves of different wavelength superpose to create localized steepness sufficient to induce white capping or mixing events, what are the proportions of wave energy and momentum from different wave components that are dissipated and transferred into the water column?
- How well do the current generation of Langmuir circulation parameterizations perform for the effects of waves on mean surface layer dynamics for different degrees of wave non-linearity and percent area of white capping in open water?

APPROACH

The work involves theoretical development, numerical computations, and comparison with laboratory measurements. The primary experimental tools are three-dimensional volume of fluid models (Truchas and Sola3D). We are working on including improved sub-grid closure models based on the Large Eddy Simulation (LES) approach for the unresolved effects of small-scale turbulence and surface gravity waves not represented in the model.

WORK COMPLETED

We have (1) Begun to calibrate our models against historical wave data sets; (2) Formulated model physics and algorithms for wave initial conditions that will lead to wave breaking and implementing an appropriate LES sub-grid stress model in a domain with a moving free-surface; (3) Performed preliminary computations and laboratory experiments.

RESULTS

In preparation for laboratory data on deep water wave breaking (Donelan and Haus), we have begun to calibrate our 3-D Volume of Fluid models using the historical data sets of Visser (1991) for depth limited wave breaking. Figure 1 shows the model predictions for wave amplitude for a obliquely incident wave on a shoal. The turbulence and small scale waves generated during wave breaking propagate offshore against the incident wave field and create a complex pattern of wave superpositions. Using this data set we are able to calibrate the modeled momentum transfer from the waves into the water column by comparing the strength of the forced mean alongshore currents against the laboratory data. In this model a steady incident wave train is forced at the offshore boundary with a 15^{o} angle of incidence.

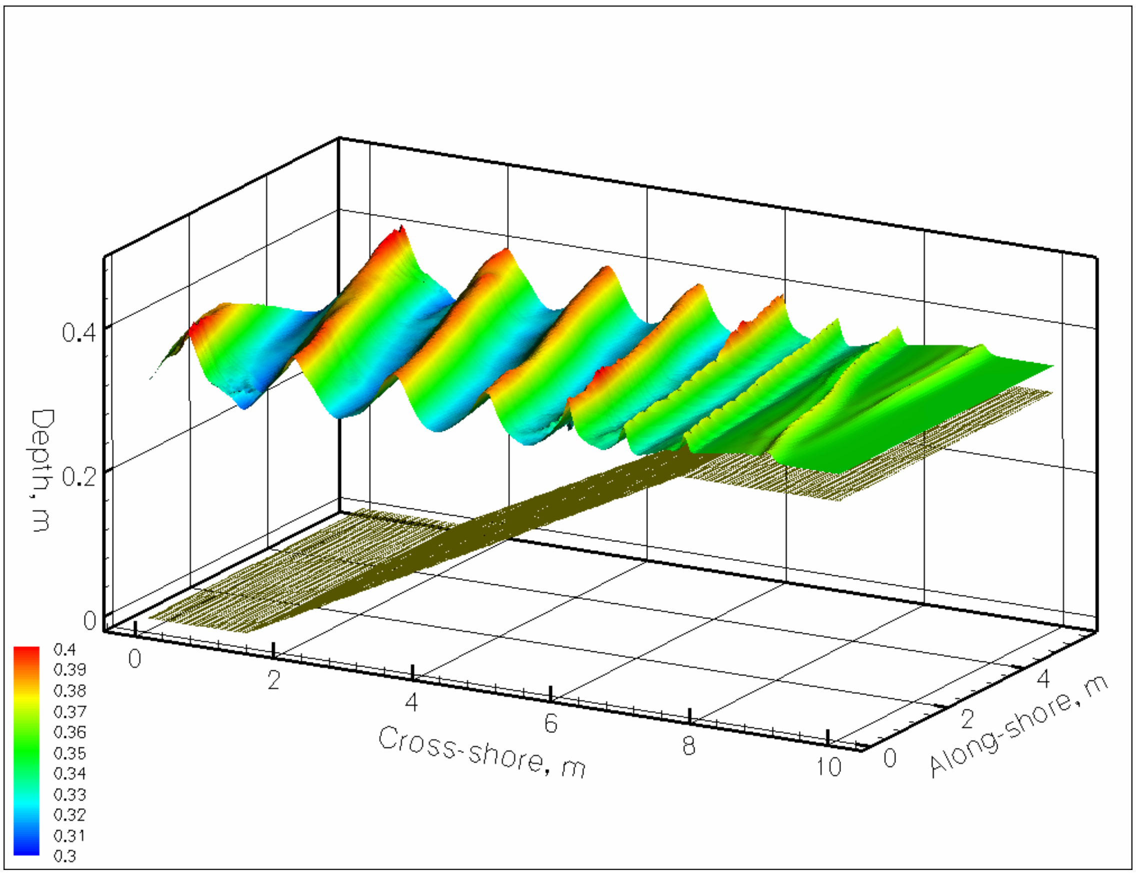

Figure 1: Wave height field predictions using the 3D Volume of Fluid model compared to the historical Visser (1991) data set (his Case 4) for obliquely incident waves on a slope.

Figure 2 shows the *u-w* projections of velocity vectors onto the center *x-z* plane under the shoaling waves from the three-dimensional simulation. When the wave induced current velocities under the wave crest exceed the wave phase velocity the wave begins to steepen rapidly leading to breaking. In these simulations we use a 10 meter horizontal domain with 10 cm horizontal and 2 cm vertical resolution. The offshore wavelength is approximately 2 meters and decreases as the waves shoal.

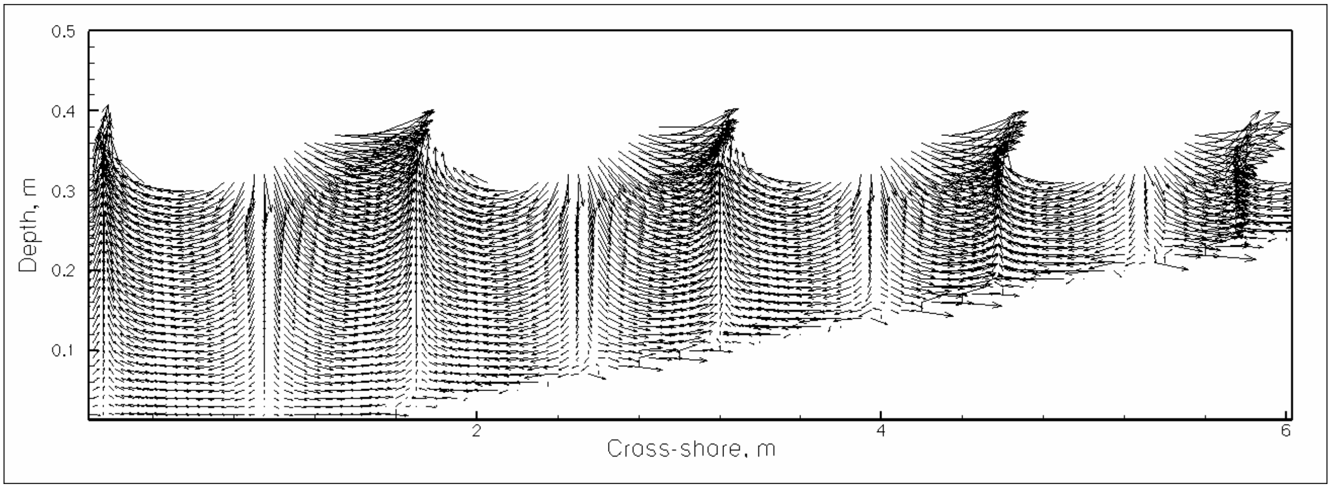

Figure 2: A cross section of the projection of the 3D velocity vectors onto the x-z center plane of the wave field shows the model resolution and the velocity field under the wave.

A comparison between the measured and modeled wave heights as a function of cross-shore location for Visser's Case #4 for the shoaling surging breakers in the surf zone is shown in Figure 3. The model somewhat under predicts the increase in wave height prior to breaking, but captures the location of wave breaking and subsequent decrease fairly accurately. We note that no tuning of model coefficients for wave breaking parameterizations is done to facilitate this agreement. When the wave steepness becomes sufficiently large, the wave potential energy is transferred to kinetic energy and the wave falls apart. Small-scale turbulent motions are produced and the wave momentum is transferred into the mean water column. We utilize a no-slip boundary condition at the sea bed and a no-stress condition at the free-surface.

Figure 4 shows a video image from our laboratory partner conducting new wave breaking experiments of deep water wave breaking that we are attempting to model. The computational advantage of the deep water experiments is that the overall domain is smaller than the shoaling wave problem that we have been examining in preliminary studies, allowing more resolution of fine scale structures. We are presently engaged in setting up our models to simulate the deep water breaking problem. The model requires a number of simultaneous enhancements that need to be tested. We are working on implementing our algorithms on a large parallel computing system. We are attempting to formulate a wave sub grid parameterization to account for surface waves that cannot be resolved by the VOF grid in a manner similar in principle to what Large Eddy Simulations do for unresolved turbulent structures. For example, when resolved waves interact and break, smaller wavelength features are formed. Some of these waves have wavelengths smaller than our grid resolution and therefore would be smoothed by the spline fitting method in the VOF model. Laboratory data will also provide estimates of the surface wave spectra resulting from the breaking events, which could possibly be used to formulate a wave sub grid parameterization along the lines of current turbulence sub grid scale models.

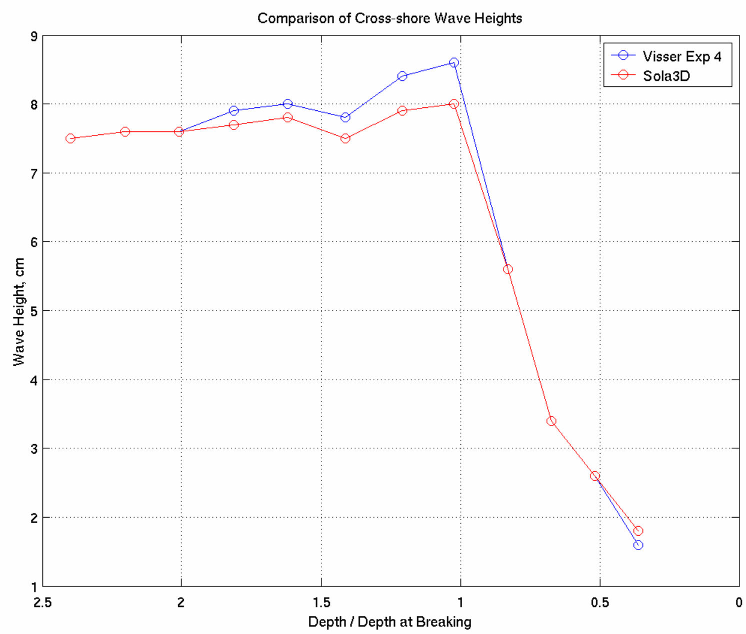

Figure 3: Comparison of the wave heights between the laboratory data and the CFD model for the Visser experiment #4 showing good agreement in cross-shore wave properties.

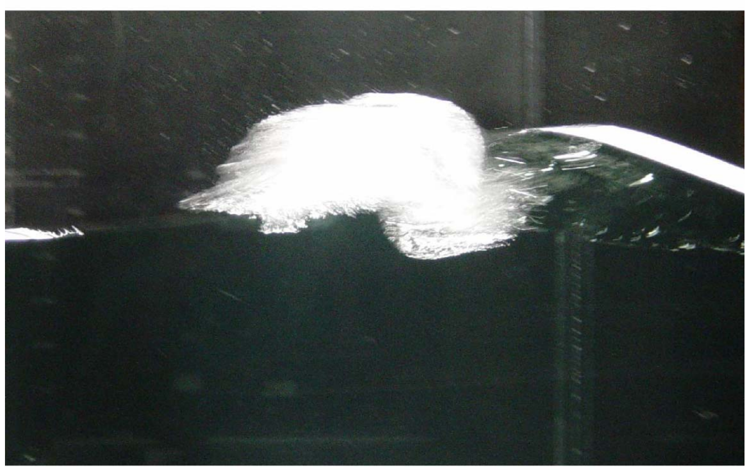

Figure 4. Bubble cloud image from laboratory experiments of Donelan and Haus (our partners on the project) of a coalescing plunging breaker generated by the programmable wavemaker using a Gaussian pulse with center frequency of 1.0 seconds. Approximate size of the image is 1.2 m x 0.7 m. Exposure time was 1/30 s.

IMPACT/APPLICATIONS

Our model includes a moving free surface and resolves individual wave events. This is an advance over most open ocean models that consider the air-sea interface in a time-averaged sense. In our approach we should be able to evaluate the impact of simpler parameterizations for the ocean surface in larger scale ocean models.

TRANSITIONS

The project is a new start in FY03, we are following our initial plan of work.

RELATED PROJECTS

The ONR CBLAST initiative is conducting field studies of air-sea interaction including momentum input from breaking waves under various wind conditions.

REFERENCES

Visser, P.J., 1991. “Laboratory measurements of uniform longshore currents.” *Coastal Engineering*, 15: 563-593.