Field Testing Model Predictions of Foam Coverage and Bubble Content in the Surf Zone

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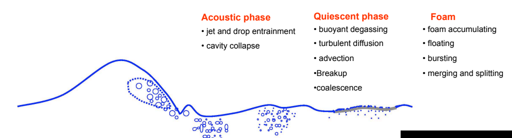
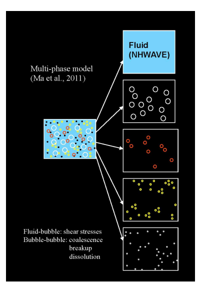
1. Introduction

Field-scale modeling of surfzone bubbles and foam coverage is challenging in terms of the computational intensity of multi-phase bubble models based on Navier-Stokes/ VOF formulation. In this study, we developed the NHWAVE-bubble package, which includes a 3D non-hydrostatic wave model NHWAVE (Ma et al., 2012), a multi-phase bubble model and a foam model. The model is applied in a field scale domain at FRF, Duck, NC where optical data in either visible band (ARGUS) or infrared band were collected during 2010 Surf Zone Optics experiments. The decay of image brightness or intensity following the passage of wave crests is presumably tied to both decay of bubble populations and foam coverage after passage of a broken wave crest. Infrared imagery is likely to provide more detailed information which could separate active breaking from passive foam decay on the surface. Model results are compared with the measurements with an attention to distinguishing between active generation and passive decay of the foam signature on the water surface.

2. Modeling generation and evolution of surfzone bubbles and foam



Direct numerical simulations of the acoustic phase and quiescent phase of breaking wave-induced air bubbles is computational unaffordable in a surfzone-scale computational domain. In this study, we have used air bubble entrainment formulas in a two-fluid model (Shi et al., 2010) and a multi-phase model (Ma et al., 2011) to predict air bubble evolution in the quiescent phase in a breaking wave event. The breaking wave-induced entrainment is formulated by connecting the shear production (Shi et al., 2010) or the kinetic energy dissipation (Ma et al., 2011) at the air-water interface, and the bubble number intensity with a certain bubble size spectra observed in laboratory experiments.



The foam layer on the water surface is modeled using a shallow water formulation based on a balance of drag forces due to wind and water column motion (Shi et al., 2000). Foam mass conservation includes source and sink terms representing outgassing of the water column, direct foam generation due to surface agitation, and erosion due to bubble bursting.

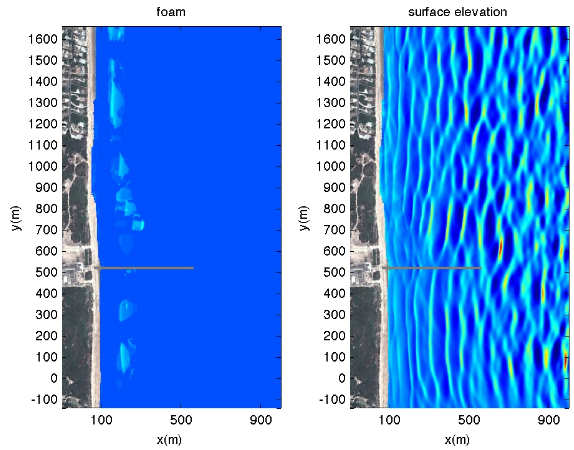


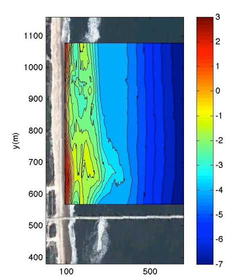
Figure 1.Modeled foam thickness (left, random unit) and wave surface elevation from Case 1.

3. Coupled hydrodynamic, bubbles and foam model

NHWAVE uses a surface and bottom following sigma coordinate system, making it more applicable to 3D modeling of nearshore waves and circulation in a large-scale field domain. It has been extended to include a multiphase description of polydisperse bubble populations following the approach applied in a 3D VOF model by Ma et al. (2012). The foam layer model is one-way coupled with NHWAVE and the multiphase bubble model in the model package.

4. Field scale tests

Field-scale model testing is based on an extensive history of imagery obtained at the USACE FRF at Duck, NC, including ARGUS imagery in the visible band and IR band imagery collected during the 2010 Surf Zone Optics Experiment (SZO).



The left figure shows the bathymetry measured during SZO. A rip channel is observed around y=850 m, which affects wave breaking locations and nearshore circulation.

The model is set up in a 1000 x 1800 m domain (full domain shown in Figure 1) with a uniform grid size of 2m. Two wave conditions are modeled.

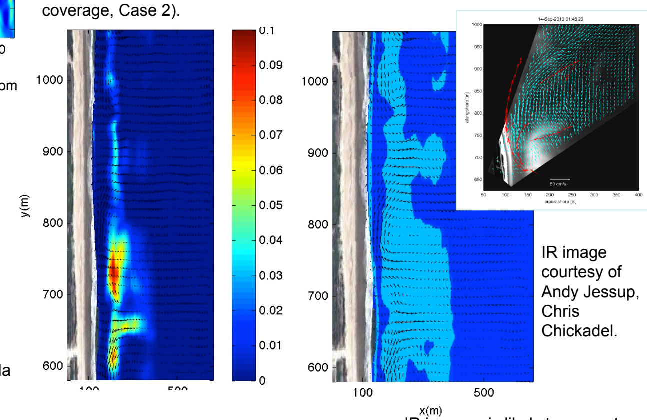
Case 1: Hs = 1 m , T = 10 s, in the full domain.

Case 2: Hs = 2 m, T = 10 s, in a 800 x 512 m domain (left figure).

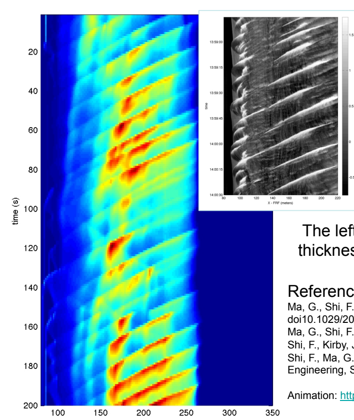
No wind is included in both cases.

ARGUS image (right) shows intermittent patches of breaking offshore as well as more complete breaking wave and foam coverage over a shore parallel bar and at the shoreline. Visible band imagery gives a complete representation of the spatial and temporal extent of these combined bubble and foam effects, but does not intrinsically separate them in a useable way. In contrast, the model with a similar wave condition predicted air content (void fraction) and foam coverage (below left: void fraction at water surface, below middle: foam coverage, Case 2).

IR-based PIV surface velocity map (below right) reveals a significant rip current between 850-900 m which is also predicted by the numerical model.



IR image courtesy of Andy Jessup, Chris Chickadel.



IR imagery is likely to separate active breaking from passive foam in terms of more rapidly cooling on passive foam. Time stack of nearshore water surface in infrared band (figure in BW) shows active breaking events as high intensity (white spots), with relative cool surface foam shown as low intensity, black "cool" spots.

The left figure shows the time stack of foam thickness from the model (Case 2).

References

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Animation: http://www.coastal.udel.edu/~fyshi/frf_big_smwv.gif