Comments on “Bubbles Produced by Breaking Waves in Fresh and Salt Water”

EDWARD C. MONAHAN

Department of Marine Sciences, University of Connecticut at Avery Point, Groton, Connecticut

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In a recent note in this journal Wu (2000) concluded that more air is entrained by a breaking wave in saltwater than in freshwater and that there is little difference in the sizes of the bubbles produced as a consequence of these breaking events in salt- and freshwater.

Our earlier work on these questions, as reported in our papers cited by Wu, and in particular our more recent work with which Wu is apparently unfamiliar, leads us to just the opposite findings from those set forth in Wu’s (2000) note.

Wu, in discussing the findings of Monahan and Zietlow (1969) failed to report that we found in a set of simple pouring experiments “relatively more bubbles with radii below 500 [micrometers] for sea water” than for freshwater. With the passage of years, and the replacement of limited resolution film cameras with small video cameras (“bubble microscopes”) our more recent experiments involving “tipping bucket” simulations of breaking waves have confirmed that the concentration of bubbles with radii between 180 \( \mu m \) and 5 mm in saltwater, or even “brackish” water with a salinity of 20½, is considerably more than one order of magnitude greater than in freshwater [see, e.g., Monahan et al. (1994) and Wang and Monahan (1995)], for otherwise identical simulations. And these recent experiments have confirmed that the typical radius of the bubbles produced by a pouring event in freshwater is many times the typical radius of the bubbles generated with the same pouring geometry in saltwater. Wang and Monahan (1995) found that the mean bubble radius in the freshwater pouring experiment was 2480 \( \mu m \), that when the experiment was repeated with water of salinity of just 6½, the mean bubble radius was reduced to 1132 \( \mu m \), and that when the salinity was increased to 20½, the mean bubble radius shrunk to only 320 \( \mu m \). These findings as to the great disparity in bubble size between salt- and freshwater should not come as a surprise, given the elegant, albeit qualitative, laboratory documentation of this phenomenon presented in two convincing papers by Scott (1975a,b) a quarter century ago.

Controlled “tipping trough” field experiments in which the sound produced by breaking waves in fresh- and saltwater were recorded have yielded quite different acoustic spectra for the same “tipping trough” event in the two liquids (Carey et al. 1993). The differences observed in the higher-frequency sound levels between the fresh- and saltwater tipping trough experiments are consistent with the differences in the bubble spectra measured in these two liquids.

Contrary to Wu’s (2000) inference that more air is entrained in a breaking wave in saltwater than in a similar breaking wave in freshwater, we have found (Monahan et al. 1994; Wang and Monahan 1995) that the peak void fractions are remarkably similar just beneath the water surface in the bubble plumes produced in “tipping bucket” simulations of breaking waves in salt- and freshwater.

Wu (2000) accurately reported our conclusion (Monahan and Zietlow 1969), based on laboratory whitecap simulations, that freshwater whitecaps decay more rapidly than saltwater ones. Now whitecaps, the surface manifestations of subsurface bubble plumes, only persist as long as bubbles continue to rise to the surface within the plume to replace the bubbles that burst on the surface (see, e.g., Monahan and Lu 1990). Our explanation of why freshwater whitecaps decay more rapidly than saltwater ones has been, and continues to be, that the characteristically larger bubbles found in the plumes beneath freshwater whitecaps rise more rapidly than the smaller bubbles in the plumes beneath saltwater whitecaps, and thus the freshwater plumes are exhausted faster than the saltwater ones. It follows that, if one has, for a particular set of meteorological conditions, the same number of breaking waves per second per unit area of an ocean as one has per unit area of a large lake, then the instantaneous fraction of the ocean covered by whitecaps will be significantly greater than the fraction of the lake covered by such surface signatures of bubble plumes, simply as a con-
sequence of the longer lifetimes of the saltwater whitecaps (Monahan 1971). Thus, one need not conclude, from a comparison of our whitecap data collected on the Great Lakes (Monahan, 1969) with our whitecap data obtained at sea (Monahan 1971), that more air is entrained per breaking wave in the seawater case, as Wu (2000) has done.

While we agree with Wu (2000) that further studies need be conducted to improve our understanding of the generation of bubble clouds during wave breaking, we do not feel that he has "[t]aken together all available results" in arriving at the conclusions put forth in his recent note.

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REFERENCES


