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The effects of wave scale, non-linearity, spectral bandwidth and direct wind shear stress on air entrainment and bubble size distributions in laboratory breaking waves

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Bubble plumes within the two-phase flow generated by sufficiently energetic surface breaking waves (whitecaps) enhance the exchange of gas, mass and heat between the atmosphere and ocean. The bubbles formed inside whitecaps range in size from order tens of microns to centimetres, and accurate measurements of the space- and time-evolving bubble size distribution is central to achieving a better understanding of air-sea gas exchange and aerosol production flux.

In the present study, we describe the measurements of time- and space-evolving bubble size distribution in 2-D laboratory breaking waves. The bubbles were measured with high resolution digital images using a range of novel image processing and object detection techniques. A wide range of breaking waves were considered by altering the underlying scale, nonlinearity and spectral bandwidth of the dispersively-focused wave groups. The experiments were initially conducted in the absence of wind, and again under influence of direct wind shear stress. A variety of wind speeds were examined to replicate the effects of varying wave age on the breaking process, air entrainment and resulting bubble size distribution.

Our experimental results demonstrate that underlying wave scale, non-linearity, spectral bandwidth and wind speed (wave age) all have a measurable influence on the evolution of the two-phase flow and bubble size distributions within the breaking waves studied here, highlighting the complexity of the air entrainment over the breaking process. The relative magnitude and importance of these influences will be discussed in detail in this work. For instance, compared to breaking waves without wind stress, wave in the presence of wind tend to break at lower wave steepness, resulting in a reduction of total air entrainment and significantly different spatial distribution of bubbles.