# High-fidelity observations and modeling of wave breaking dissipation and bubble plumes

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**Abstract**

Combining high-fidelity numerical modeling and field observations, we examine wave-breaking-induced energy dissipation and bubble plumes over a wide range of sea state conditions, including storms with sustained winds up to 22 m/s and significant wave heights up to 10 m. We use a polydisperse two-fluid LES/VOF model (Derakhti & Kirby, 2014) to simulate bubble entrainment and turbulent bubbly flow in short-crested deep water wave breaking events. Bubble contributions to dissipation and momentum transfer between the water and air phases are considered. Using the numerical model results, we examine the statistical characteristics of wave breaking and associated turbulent dissipation rates in a field of intermittent events. We show that convergence of statistics occurs for signals that have minimum length of approximately 1000–3000 wave periods with randomly spaced observations in time and space relative to 3D breaking events. We further show important effects of obscuration of velocity measurements due to entrained bubbles on the estimated turbulent dissipation rates. Observations are recently collected in the North Pacific Ocean and include arrays of surface following SWIFT buoys as well as shipboard winds and optical video systems. Two types of SWIFT buoys are concurrently used with uplooking and downlooking Acoustic Doppler Current Profilers to measure turbulence and image bubble plumes with echograms in a wave-following reference frame. This vertical reference is used throughout the analysis, with important distinctions from the more common mean-sea-level reference frame. Combining the data from both types of SWIFT buoys, we obtain turbulence dissipation rate profiles that extend from sea surface to 3 m depth. The echograms extend to 30 m depth range and indicate bubble plumes reach more than 10 m beneath the surface, with residence time of several wave periods. The volume of bubble plumes is estimated by combining active whitecap coverage and plume depth measurements. Dependencies of the observations on wave age, bulk and spectral steepness, and wind accelerations are explored. Finally, we show that bubble plume statistics are closely linked to wave breaking dissipation, such that one may scale the other.

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