Bubbles and Surf Zone Oceanography

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Abstract: Breaking waves in the surf zone entrain high-density bubble clouds which can be transported offshore via rip currents and turbulent diffusion. The presence of the bubbles presents a complex problem for acousticians interested in the propagation of natural and man-made sound in very shallow water. To investigate the acoustical properties of this area, a multi-investigator experiment was performed near the Scripps Pier, March 1-12, 1997 (Scripps Pier Experiment).

A broadband acoustic technique which measures sound speed and attenuation was deployed in a four-channel configuration in water of 6 m depth. Each channel of the system allows the determination of the bubble size distribution at a discrete depth via inversion of the measured sound speed and attenuation. Analysis of the data shows high concentrations of bubbles advecting offshore via rip currents, resulting in frequency-dependent attenuations ranging from O(1) - O(100) dB/m. Vertical gradients were observed in the bubble concentrations.

ACOUSTIC BUBBLE MEASUREMENTS

The presence of bubbles in the ocean is known to significantly scatter, absorb, and disperse incident sound waves. Our ability to accurately predict the effect of bubbles on the acoustical properties makes sound a powerful tool for bubble measurement. An acoustic bubble-measurement technique has been developed which simultaneously measures sound speed and attenuation using broadband pulse propagation across a fixed pathlength (1). The data can be inverted using both a resonant approximation (2,3) or a finite-element method which considers the off-resonant contribution of bubbles (4). The hardware allows a continuous ping-rate of a few Hz, permitting inversions for the bubble field with similar temporal resolution. The acoustic technique has been tested beneath breaking waves generated in the laboratory and found to give close agreement with independent optical measurements of the bubble field. A vertical array of four of the broadband modules was fixed to the seafloor through a semi-compliant base located approximately 120 m offshore of the surfline, 10 m north of the Scripps Pier. The NRL Delta Frame was located 10-15 m inshore of the vertical array of broadband modules.

PRESENCE OF BUBBLES IN RIP CURRENTS

Rip currents, visible from the surface as plumes of sediments and bubbles, were observed to pass through the measurement site during the afternoons of 3/7 and 3/8. The presence of the rip currents coincided with the larger swell (H1/3 -1m) and low tides (-0.41 m) present these afternoons. A twenty minute record of the offshore component of the water motion, measured at the vertical array using an electromagnetic current meter on the afternoon of 3/8, is shown in figure 1a. The orbital velocities of the surface gravity waves have been filtered from the time series using a low-pass filter with a cut off frequency of 0.03 Hz. The 43 kHz attenuation, measured during the same time period with the broadband technique, is shown in figures 1b. The data, obtained at a 1.1m depth, show an increase in attenuation due to bubbles being carried through the measurement site by the offshore flow.

FIGURE 1. a) Time series of the offshore component of the water velocity near the array of broadband modules and b) the 43 kHz attenuation measured at a depth of 1.1m during this time period.
An example of the frequency-dependent attenuation for the event starting near \( t = 1000 \) seconds (refer to figure 1b), measured at the 1.1 m depth, is shown in figure 2a. The attenuation averaged over the 200 seconds of the event duration (lower line) as well as the maximum attenuations that occurred during the event (upper line) are shown. The large differences between the peak and mean attenuations emphasize the variability in the bubble densities. The curves show large attenuations present in the 30-80 kHz band.

Figure 2b is an example of the bubble size distribution measured at three different depths for the same event. The size distributions were found to follow a power law of approximately \( r^{-3} \) for the larger radii, with a break in the slope occurring near radii of 100 \( \mu \text{m} \). The void fractions of these bubbles advecting from the surfzone were found to range from \( \Omega(10^{-6}-10^{-5}) \). Scaling the bubble size distribution by the volume contribution (figure 2c), shows that bubbles with a radius of approximately 100 \( \mu \text{m} \) (corresponding to the break in the slope of the size distribution) contribute most to the total void fraction. This peak in the volume contribution curves is found to shift towards smaller radii with depth, a shift that cannot be explained by Boyle's law. A simple turbulent-transport model of bubbles advecting offshore demonstrates that the depth dependence of the volume contribution peak is dependent on the level of turbulent mixing inside the rip current. Behavior of the peak of the volume contribution curves has acoustical importance as the resonant frequency of these bubbles corresponds to the frequency of maximum attenuation.

The bubble size distributions measured in the rip-current events that occurred on the afternoons of 3/7 and 3/8 will be presented. The role of transport and turbulent mixing processes in modifying the bubble size distributions and their relevance to the acoustical properties that depend on these bubbles will be discussed.

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REFERENCES