

# **High Frequency Acoustical Propagation and Scattering in Coastal Waters**

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## **LONG-TERM GOALS**

To learn about the physical processes controlling the propagation of high frequency acoustical signals; in particular to understand the relationship between the presences of bubble distributions, surface gravity waves and turbulence on sound propagation.

A second long-term goal is to model these processes to improve our understanding and to enhance the predictive capabilities.

## **OBJECTIVES**

Our objectives are (1) to develop improved measurement approaches, to carry out high frequency propagation experiments in environments with dense bubble distributions; (2) to develop, model and use innovative measurement approaches applicable to these environments; and (3) to interpret the results in terms of appropriate scattering models.

## **APPROACH**

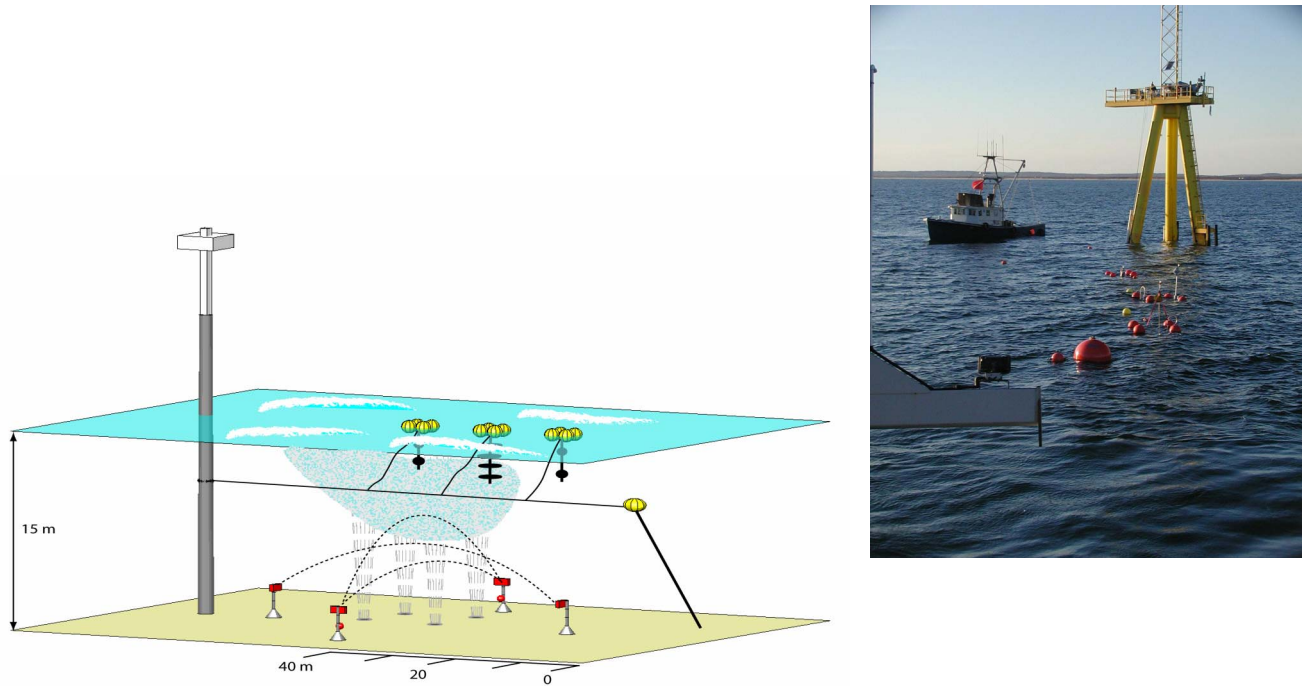
Our approach to high frequency propagation near the ocean surface in the presence of bubbles includes observational and model analysis of the relative contribution of specular and volume scatter.

Based on significant experience and insight from earlier studies in the surf zone, and higher wind state conditions in shallow and deep waters, a major experiment at Martha's Vineyard took place in October and November 2002. This was a joint effort between us, G Deane from Scripps Institution of Oceanography and J Preisig from Woods Hole Oceanographic Institution. Our sensors consisted of four vertical range gated sonars (50 & 120kHz) pointing upwards from the sea floor and four 100kHz sidescan transducers mounted in a bistatic configuration with acoustic path lengths of approximately 40 m (Fig. 1 & 2). A bottom mounted 300kHz ADCP measured the advection

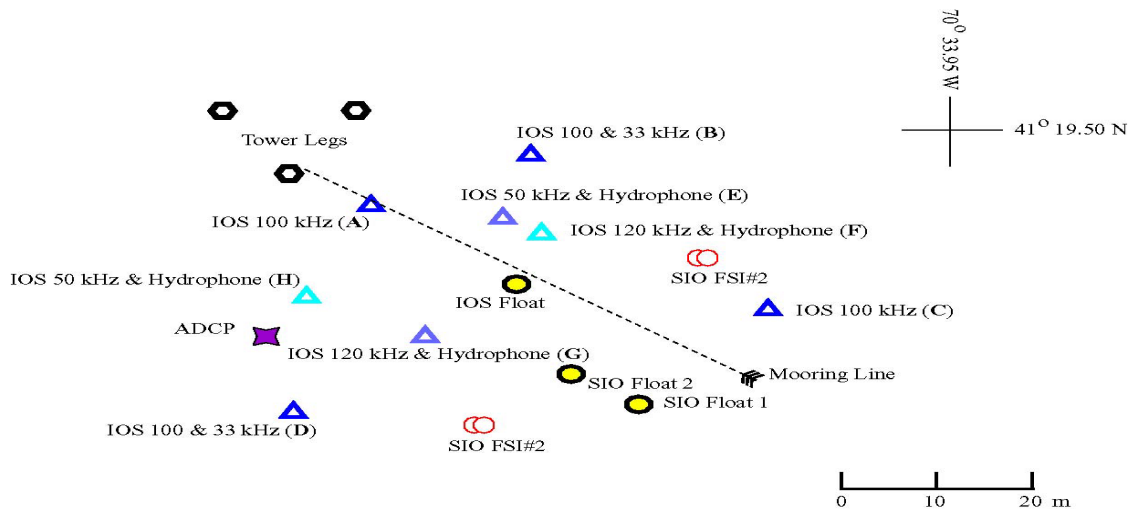
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rates in the experimental area in addition to vertical coherent flows such as Langmuir circulation. An array of four broadband hydrophones (20Hz-25kHz) measured the ambient noise field, predominantly originating from breaking waves.

The bubble, turbulence and temperature fields near the ocean surface were sampled near the center of the acoustic transmission paths from a wave following float tethered to a horizontal mooring attached at one end to the tower. Bubble size distributions were obtained with an acoustical resonator (Farmer, Vagle & Booth, 1998). From the top of the tower, G. Deane obtained video images of the surface wave and breaking wave fields in the vicinity of our instrumentation. These data will be crucial in interpreting the observations.



***Figure 1. Three dimensional artistic layout and photograph of sensors deployed in the Martha's Vineyard Coastal Observatory (MVCO) acoustical communications experiment October-November 2002.***



**Figure 2. Birds eye view of actual sensor deployments during the first part of the Martha's Vineyard experiment (November 4-November 9).**

As part of this effort we are also developing acoustic propagation and scattering models applicable to these environments in which the acoustic models are directly coupled to time evolving hydrodynamic models of the bubble distribution. Propagation in bubble clouds advected by currents is modeled using a bubble size distribution that evolves under the combined influence of turbulence, buoyancy effects and bubble dissolution.

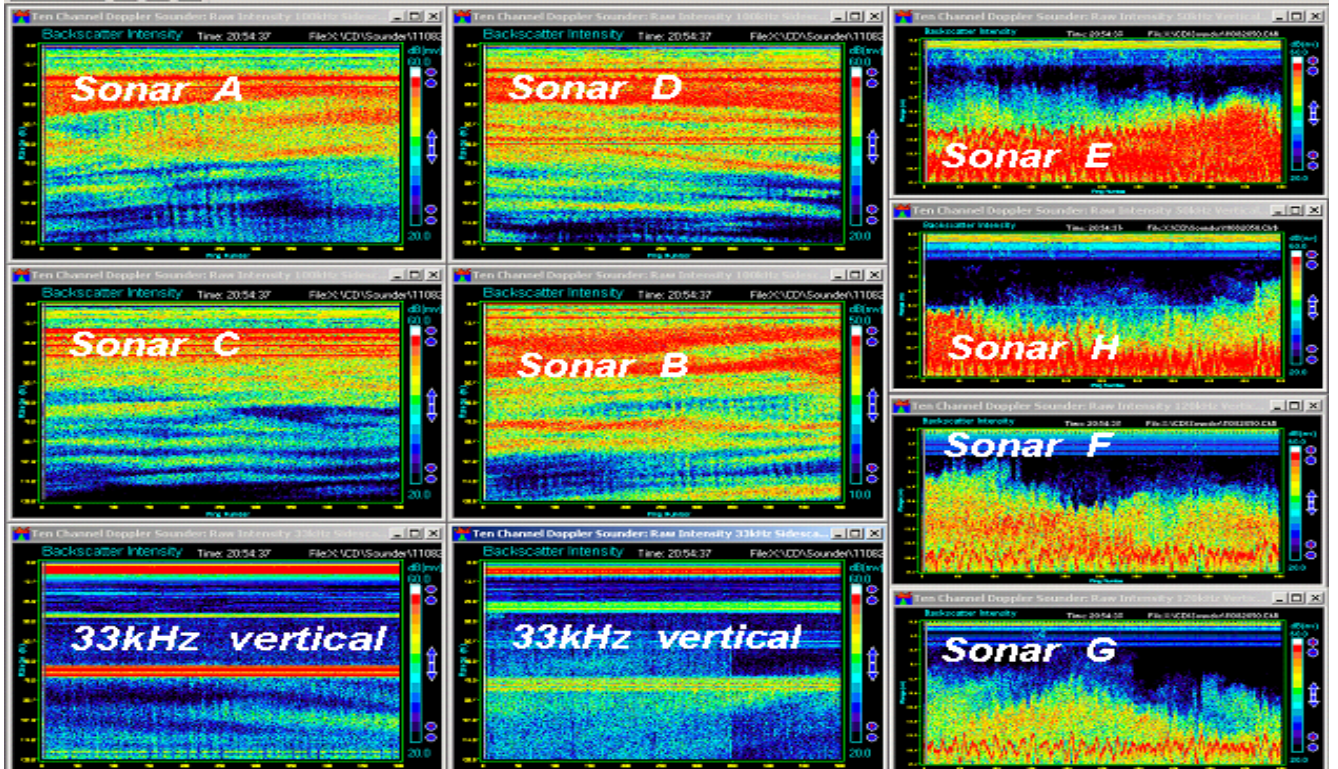
## WORK COMPLETED

Part I of the MVCO experiment was executed over the period of November 4-November 9 with instrumentation layout as originally planned (Fig. 2). Unfortunately, parts of our systems and J. Preisig's (WHOI) acoustical propagation instrumentation were not yet deployed and operating when the strap connecting the horizontal mooring to the tower severed in a storm. The result was complete system failure on all instruments attached to the horizontal mooring. In addition the failure also ripped all the cables in a conduit on one of the tower legs, resulting in loss of data from our bottom mounted sonar systems.

The instrumentation was recovered and a limited number of acoustical sensors were redeployed for a reduced experiment during the period from November 21 to December 5. The surface following floats on the horizontal mooring and a number of bottom mounted sensors could not be made operational again during the experimental period.

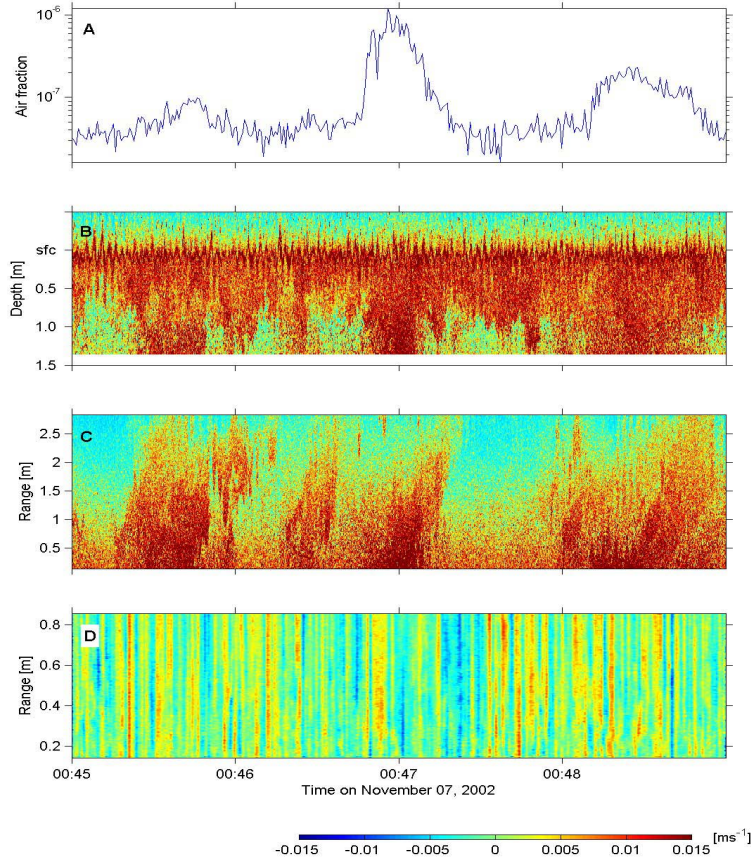
Even though the experiment was significantly affected by the unfortunate accident there is still a large data set available for important and significant data analysis and interpretation. The large data sets from the two experimental periods have now been cleaned up and organized for analysis. A two-minute example of the range gated backscatter intensity from the ten Doppler sonars shown in Fig. 2 is displayed in Fig. 3. The horizontal range for the six horizontal sonars (A-D and B33kHz and D33kHz) is 120 m and the depth range of the four vertical sonars (E-H) is 17 m with the distance from the sea floor depicted downwards in the figure. The wholly refracted received signals can be seen in the

sidescan images at a back scatter range of approximately 20 m which correspond to path lengths of approximately 40 m for the forward propagating signals.



**Figure 3. Backscatter images for the 10 sonars used in the MVCO experiment. The letter correspond to the sonars shown in Fig. 2. Red indicates high**

An example of the data from the surface following float is shown in Figure 4. This figure shows a four-minute record of total air-fraction from the bubble size distributions (A), upward-looking 2 MHz backscatter data from one of the three dopbeam sonars(B), horizontal 2 MHz backscatter intensity at a depth of 0.84 m, perpendicular to the dominant wave direction (C) and the velocity field observed at this depth with contour levels as shown on the bottom scale. Residual wave orbital speeds are clearly seen in the figure but also temporal and range dependent variability associated with enhanced turbulence levels.



**Figure 4.** *Air-fraction calculated from resonator bubble size distributions showing the increased levels associated with breaking waves at 00:46:40 and shortly after 00:48 (A). Also shown are the vertical 2 MHz backscatter intensity from an upward pointing dopbeam sonar (B) where the bubble plumes associated with the breaking waves are clearly seen. The corresponding backscatter intensity and Doppler speeds from a second dopbeam sonar mounted at a depth of 0.84 m are shown in (C) and (D) respectively.*

## RESULTS

The result of the accident late on November 8, which caused total system failure, was that one of the main objectives of the experiment, namely to obtain environmental measurements at the specular points of J. Preisig's acoustical arrays, was not met. Nevertheless, the data that were obtained before the break and the data from the limited experiment following the break will be able to give insight into a number of important scientific problems associated with high-frequency acoustical propagation.

The observations are allowing a number of scientific topics to be addressed using the present dataset:

1. Surface scatter variability. Interpretation of the 100kHz sidescan sonar measurements in terms of stochastic and deterministic wave breaking properties as measured with tower-mounted camera.

2. Investigating the direct path propagation of 33 and 100kHz pulses through bubble clouds as the wind and therefore the bubble density increases. The variability in the received signals can be interpreted in terms of observed backscatter and estimated bubble size distributions from the surface following float resonator data.
3. The surface following float data plus the tower mounted camera data will allow investigation of the variation of bubble population in breaking waves and comparison with available models.
4. Reconciliation of ambient noise measurements from the bottom mounted four -hydrophone array with J. Preisig's larger scale array and the camera observations.
5. The limited reciprocal transmission data should be sufficient to attempt investigation of fine structure vector/scalar variability and its gravity wave modulation. This also includes comparisons of Doppler backscatter measurements with path integrated reciprocal transmissions.

## **IMPACT/APPLICATIONS**

Hydrodynamic considerations of the surface wave field, the bubbles and the turbulence are critical to the development of robust acoustical propagation models (Vagle, Farmer & Deane, 2001; Farmer, Deane & Vagle, 2001). Even though the data set obtained during the MVCO experiment is limited it will result in insight into important aspects of shallow water sound propagation and lay the foundation for future experiments and modeling efforts.

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