Analysis of Delta-Frame Tomography Data from the Scripps Pier Bubble Experiment

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LONG-TERM GOAL

Our long term goal is to better understand the effect of nearshore bubble clouds on acoustics. Properties of interest include the temporal and spatial scales of the clouds, as well as the size distribution and density of the bubbles. Related properties are sound speed and attenuation, and their effect on acoustical propagation and scattering.

OBJECTIVES

The objective of the present effort is to analyze data taken during the 1997 Scripps Pier Shallow Water Bubbles Experiment.

APPROACH

We have developed a tomography algorithm to process data and produce quantitative images of the bubble attenuation field. The measurements were made using the Delta Frame designed and constructed at the Naval Research Laboratory, Stennis Space Center (NRL-SSC). The outer frame was in the shape of a triangle with each leg approximately 10 m long. Acoustic sources were installed at two vertices of the triangle. Distributed around the outer frame were eight receivers. Over the course of the experiment, the acoustic travel time and attenuation were measured along each of the resulting 16 horizontal rays paths. The transmission sequences were repeated at one-second intervals at eight different frequencies between 40 and 250 kHz. Combining the measurements taken at a particular frequency gives a snap-shot of the small scale features of the bubble cloud at that time.

The tomography problem is formulated as a constrained least-squares inversion. The method is appropriate for reconstructing a cross-section of a diffuse region that can be interpreted as a realization of a random process. An attractive feature of the algorithm is that most of the computationally expensive work can be done prior to processing any data. This makes it practical to produce a video showing the bubble field evolving in time. Moreover, there is the potential to do nearly real-time imaging in future applications.

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WORK COMPLETED

The tomography algorithm was implemented and tested. Simulations showed that features in the bubble cloud greater than two meters in size could be recovered for the Delta Frame configuration as implemented. For individual transmission sequences, images of the attenuation field were generated for each of the eight transmission sequences. A five minute section of data taken during the fifth deployment of the Delta Frame was analyzed in detail. This was a period of high activity when other investigators were also making measurements. A video of this section was produced. Results were presented at two Acoustical Society meetings [1,2].

Because of dispersion in bubbly water, the group velocity is not equal to the phase velocity. Sometimes the group velocity is larger than the speed of sound in bubble-free water; this is known as anomolous dispersion. This occurs frequently in a region around 50 kHz. A translation of a theorem in optics due to Sommerfeld to acoustics states that no part of the acoustic signal goes faster than the group velocity in bubble-free water; in the case of anomolous dispersion, the group velocity does not describe the propagation of a pulse. We have computed pulse propagation in bubbly water for both normal and anomolous dispersion.

RESULTS

Figure 1 shows the attenuation field spatially averaged over the interior of the Delta Frame plotted versus frequency for a particular transmission sequence. The peak average attenuation occurs at 59 kHz. This spatial average was used to rescale the attenuation images produced at each frequency. The resulting rescaled images were similar indicating that in this instance the bubble size distribution is nearly homogeneous; the small bubbles responding to higher acoustic frequencies are not located in a different region than the large bubbles resonating at low frequencies.

Figure 2 shows the spatially averaged attenuation field at 146 and 244 kHz plotted versus time. For the two minutes of highest attenuation, the 146 kHz time series was correlated with pressure sensor measurements of the local wave height [P. Dahl, personal communication]. The result showed strong negative correlation; attenuation maxima correspond to wave troughs while attenuation minima correspond to wave crests. A video of this section was produced [2] and will be made available for viewing at our web site.

Some data of D. Farmer and S. Vagle from the Scripps pier experiment shows normal dispersion at 100 kHz and anomolous dispersion at 110kHz. Figure 3 shows pulse propagation at these two frequencies. For both cases, the effect of Sommerfeld's theorem is clear. For normal dispersion, aside from small precursors and a tail, the received pulse is similar to the transmitted pulse, delayed by the group velocity. For anomolous dispersion, the received pulse has little resemblence to the transmitted pulse; one cannot easily define a pulse velocity.

IMPACT/APPLICATIONS

These results may be transitioned to better predict MCM sonar system performance in the near shore environment.

RELATED PROJECTS

Researchers from several institutions were involved in the complete experiment. These include: NRL-SSC [J. W. Caruthers, R. Goodman, S. Stanic], the Institute of Ocean Sciences [D. Farmer, S. Vagle], the Scripps Institution of Oceanography [W. K. Melville, E. Terrill] and APL-UW [P. Dahl, J. Nystuen].

REFERENCES/PUBLICATIONS

[1] D. Rouseff, F. S. Henyey, J. W. Caruthers and S. J. Stanic, "Tomographic reconstruction of shallow-water bubble fields observed in the Scripps Pier bubble experiment," *J. Acoust. Soc. Am.* **102**(5), Pt. 2, 3063, (1997).

[2] D. Rouseff and F. S. Henyey, "Tomographic reconstruction of evolving bubble fields in the Scripps Pier bubble experiment," *J. Acoust. Soc. Am.* **103**(5), Pt. 2, 2829, (1998).

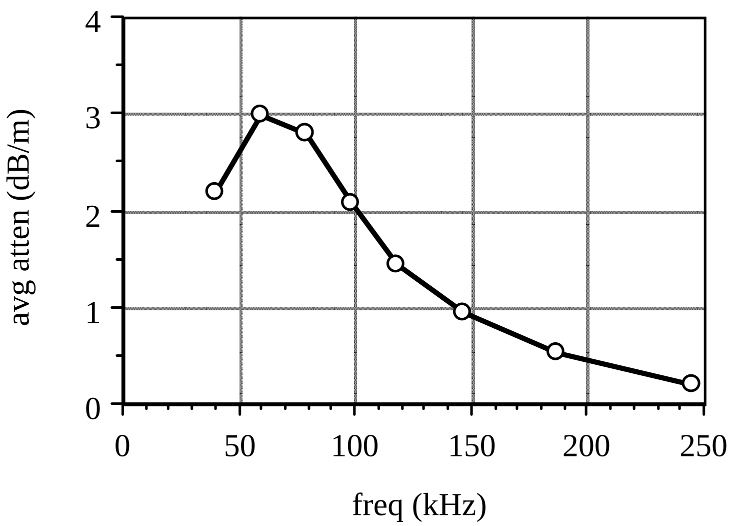

Figure 1. Attenuation averaged over delta frame plotted versus frequency. Results are for Sequence 2823 of Run 7.

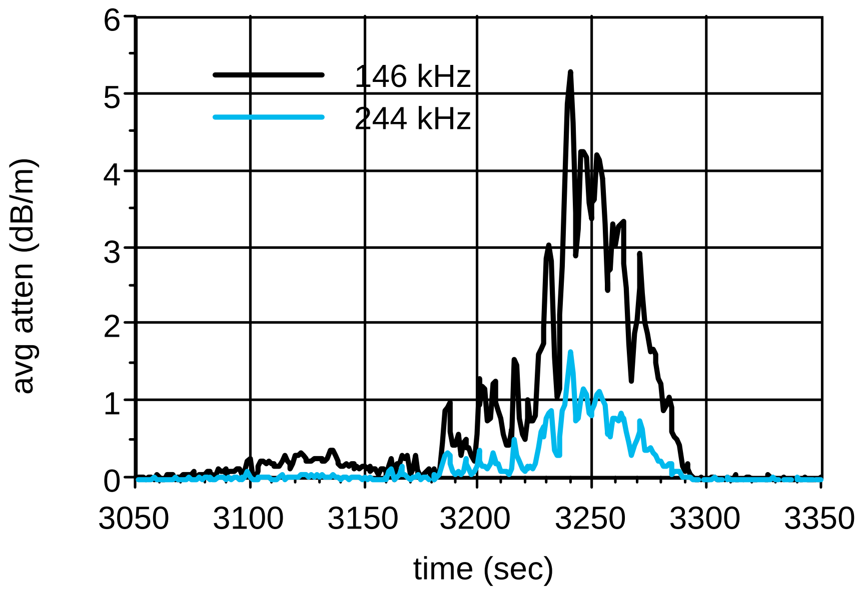

***Figure 2. Five minute sequence of attenuation averaged over area of Delta Frame. Time relative to start of Run 5*.**

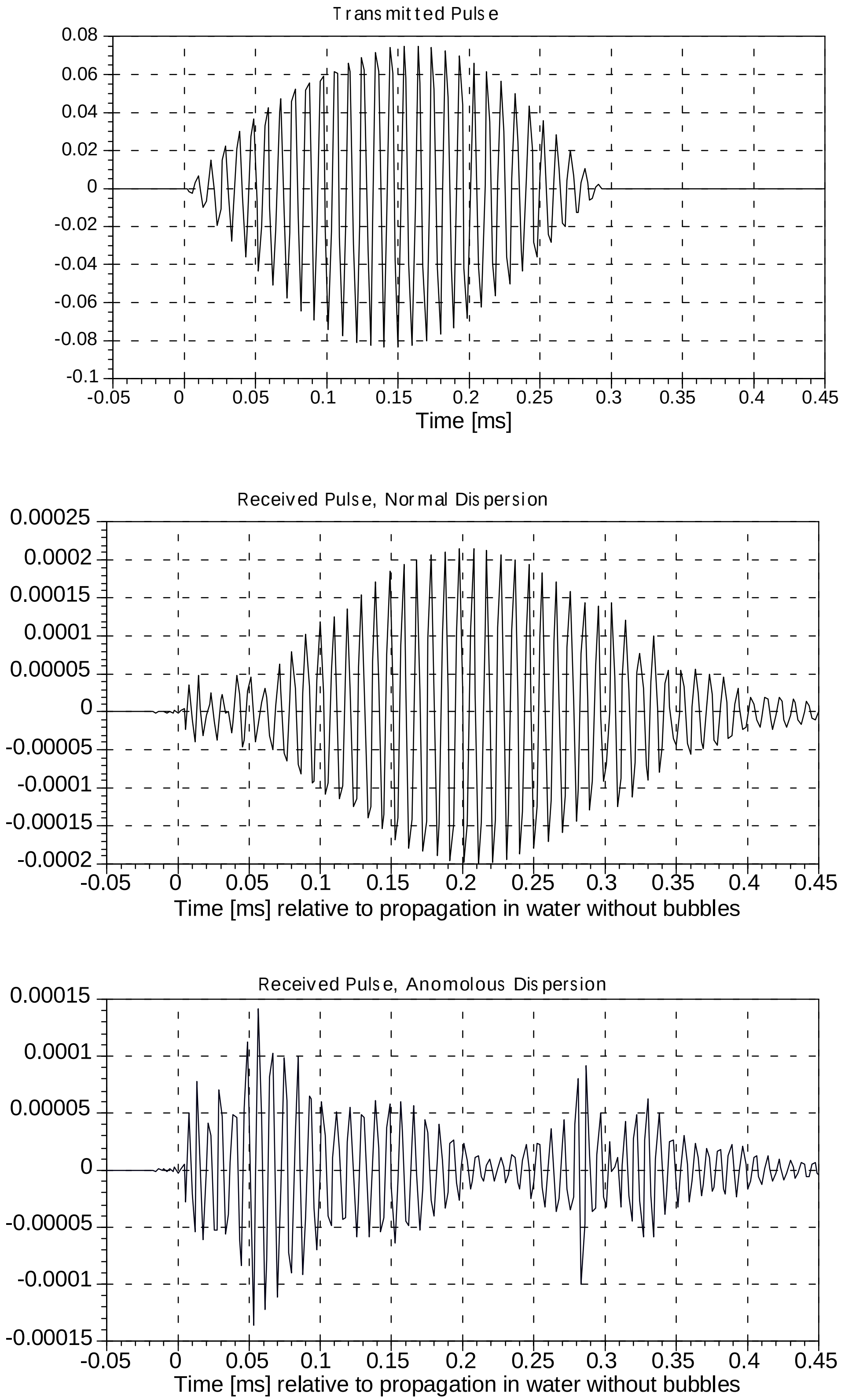

Figure 3 Pulse propagation in a bubbly medium. Bubble size distribution from data by Farmer and Vagle.