

Environmental Acoustics and Intensity Vector Acoustics with Emphasis on Shallow Water Effects and the Sea Surface

Peter H. Dahl

Applied Physics Laboratory

University of Washington

Seattle, Washington 98105

phone: (206) 543-2667 fax: (206) 543-6785 email: dahl@apl.washington.edu

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LONG-TERM GOALS

To understand and predict key properties of the signal intensity vector field in forward propagation with emphasis on mid-frequency, shallow water propagation. Because of enabling technologies involving MEMS and bio-inspired transduction, tomorrow's navy will depend on and utilize acoustic vector field properties (velocity, acceleration, intensity) much more than today's. Advancement in Navy relevant capabilities will be in part realized through a better understanding of the environmental and acquisition geometry dependence (source depth, range, etc.) of the vector field in a shallow water environment.

OBJECTIVES

The primary technical objective this year was analyze and model measurements of pressure spatial coherence, and pressure-velocity coherence, and complex vector intensity from Shallow Water 06 (SW06) experiment off the coast of New Jersey (2006) and from the Trans-Acoustic Variability Experiment (TAVEX) in Korean waters (2008), both of which the PI was involved in. Since data from both experiments was taken with using a vertical line array, a particular focus is the vertical component of active and reactive intensity.

APPROACH

Key individuals are doctoral graduate student David Dall'Osto (APL-UW and UW Mechanical Engineering supported by OA Graduate Traineeship Award) who worked on PE simulations of the vector field, and on SW06 data analysis and William Plant (APL-UW) who worked on simulation of rough surfaces at both large and small scale.

The technical approach can be demonstrated with Fig. 1 showing a sound speed profile (left) derived from the Woods Hole Oceanographic Institution's SW54 mooring [1], which was located approximately 750 m from the center of APL-UW acoustic measurements. A candidate ray fan for the sound speed profile (right) illustrates how sound might undergo focusing for a shallow receiver (circle) and remain generally unfocussed for a deeper receiver (square) at this range of 200 m. The circle and square in fact represent nominal positions of the APL-UW line array and points where the

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vertical component of complex intensity can be computed. We are interested in measuring and understanding properties of vector intensity under these conditions.

Our approach to computing complex instantaneous intensity is outlined in [2]. Reactive intensity, or the imaginary part of complex intensity, is commonly viewed as an effect limited to the vicinity of a source (or within a few wavelengths.) However, within waveguide reactive intensity can be observed far from the source, and our interest here is how the reactive intensity vector measured far from the source relates to focusing and defocusing. From [3,4] the vertical component of reactive intensity is:

$$Q_z = -\frac{\nabla_z |p|^2}{\rho 4\omega} \quad [1]$$

Where $|p|^2$ is pressure magnitude squared and ω and ρ are angular frequency and density. Thus, owing to being closer to a focusing caustic region, for a receiver within the circle of Fig 1 we expect to observe a non-zero Q_z the sign for which indicates whether the receiver is above or below a high-pressure region. Similarly, within the square of Fig. 1 we expect Q_z to be nearly zero as the field is much smoother here and sufficiently distant from the caustic. In fact, because the sound speed profile is changing with time due, in part, to the passage of non-linear internal solitary wave packets [5], we anticipate a change in sign of Q_z for a receiver in the upper circled area.

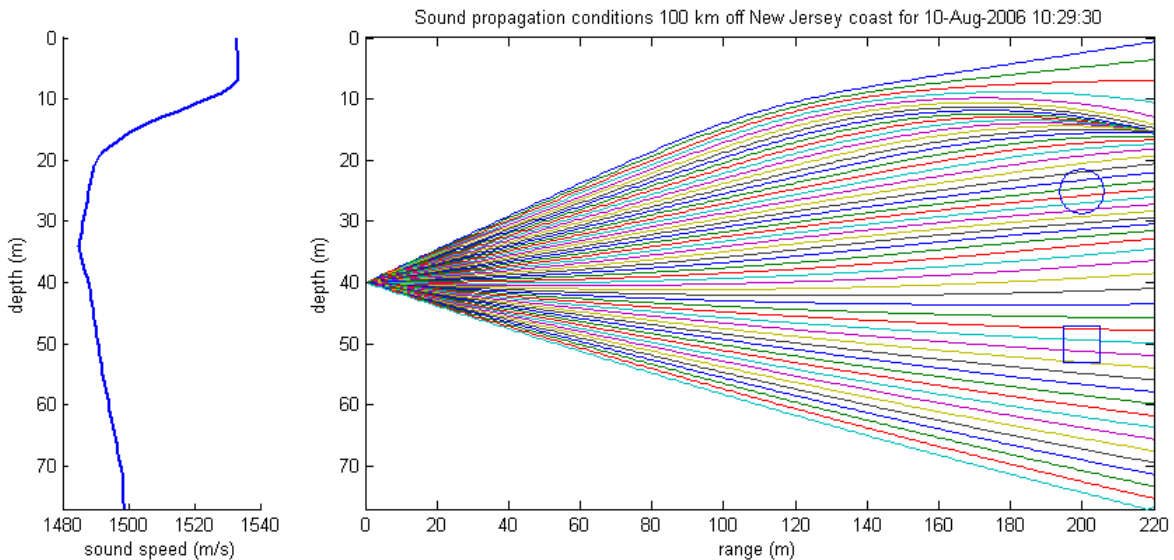


Figure 1. Sound speed (left) and ray fan (right) for conditions during SW06. The circle and square show two receiver positions where the vertical component of active and reactive intensity are studied.

WORK COMPLETED

A simulation capability was developed to accurately compute vector acoustic fields, and vector intensity fields in an underwater waveguide through modification of the RAM parabolic wave equation (PE) code [6]. Figure 2 shows complex instantaneous intensity computed with PE equation for conditions shown in Fig. 1. The time period is reduced time (with propagation delay removed) and period ~ 3 - 5 ms is associated with direct arrivals as would be indicated by the rays in Fig 1. Active vertical intensity (top) for a spatially separated arrivals can be directly related to the propagation angle. In this color-scheme, red active intensity indicates a downward traveling wave and blue active intensity indicates an upward traveling wave. Reactive vertical intensity (bottom) is directly related to gradients in the pressure magnitude field. The degree of focusing or interference is indicated by the magnitude of reactive vertical intensity, the sign indicates the direction of a pressure magnitude maxima. In this color-scheme, red reactive intensity indicates a maximum above the receiver, blue reactive intensity indicates below the receiver.

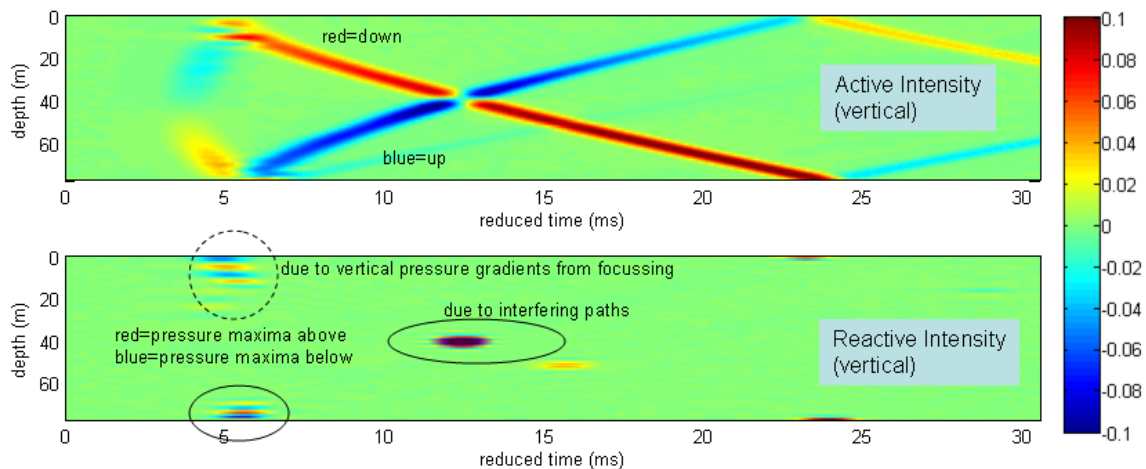


Figure 2. Complex instantaneous intensity computed with PE equation for conditions shown in Fig. 1. The time period ~ 3 - 5 ms (arbitrary reference) is associated with direct arrivals as would be indicated by the rays in Fig 1. Active vertical intensity (top) for a spatially separated arrivals can be directly related to the propagation angle. In this color-scheme, red active intensity indicates a downward traveling wave and blue active intensity indicates an upward traveling wave. Reactive vertical intensity (bottom) is directly related to gradients in the pressure magnitude field. The degree of focusing or interference is indicated by the magnitude of reactive vertical intensity, the sign indicates the direction of a pressure magnitude maxima. In this color-scheme, red reactive intensity indicates a maxima above receiver, blue reactive intensity indicates a maxima below the receiver.

RESULTS

Figure 3 is another view of the kind of PE data shown in Fig 2, however plotted here to represent something closer to actual measurements made during SW06. Shown left to right are the vertical components of active intensity, reactive intensity, and scalar intensity which is essentially pressure magnitude squared. The upper set of three figures represents a receiver located within the circle in Fig. 1 (25 m receiver depth) and the lower for the square in Fig. 1 (50 m receiver depth). Although the PE data in Fig. 2 is free of errors for all time segments, shown in Fig. 3 are only results from the first-arriving, direct path. This is because vertical intensity properties from only this first-arriving path can be reliably estimated from our SW06 field observations owing to errors in estimating spatial gradients using finite difference approximation. (The first-arriving path is close enough to broad side to reduce such errors to an acceptable level.)

In Fig. 3, “ping number” represents a different sound speed profile used for the PE simulation obtained from WHOI mooring SW54 [1], but sequential in time. That is, Figs. 1 and 2 are based on one profile, where as Fig. 3 shows the result of 10 different profiles. The key points of Fig. 3 are as follows:

1. Active intensity (left column) remains nominally steady for all the profiles going upward (blue) for the upper receiver and downward (red) for lower receiver.
2. Scalar intensity (right column) containing no information on direction, but remains very steady for all profiles.
3. For the case of the 25 m depth receiver, reactive intensity (center column) tends to be very responsive to small changes in the sound profile that shift the location of pressure maxima. There is even a sign switch during the course of these 10 sequentially estimated sound speed profiles each separated by 30 s. In contrast, for the case of the 50 m depth the pressure field is smooth and reactive intensity remains near zero for all times.

Figure 4 shows results from SW06 measured at center frequency ~ 1 kHz. Here we have used the finite difference approximation to obtain an estimate of vertical particle velocity which is subsequently used to estimate vertical components of active and reactive intensity.

Our intention is not to view Fig. 3 as a prediction of Fig. 4, rather the two figures combined demonstrate:

1. active and reactive intensity can be both observed and modeled,
2. there are situations where the active component (including scalar intensity) remains relatively steady where as the reactive component may either be negligible or take on significant values, the sign of which may vary.
3. In this latter case, pressure and particle velocity are no longer exactly in phase and assumptions dependent on plane-wave propagation may no longer be correct.

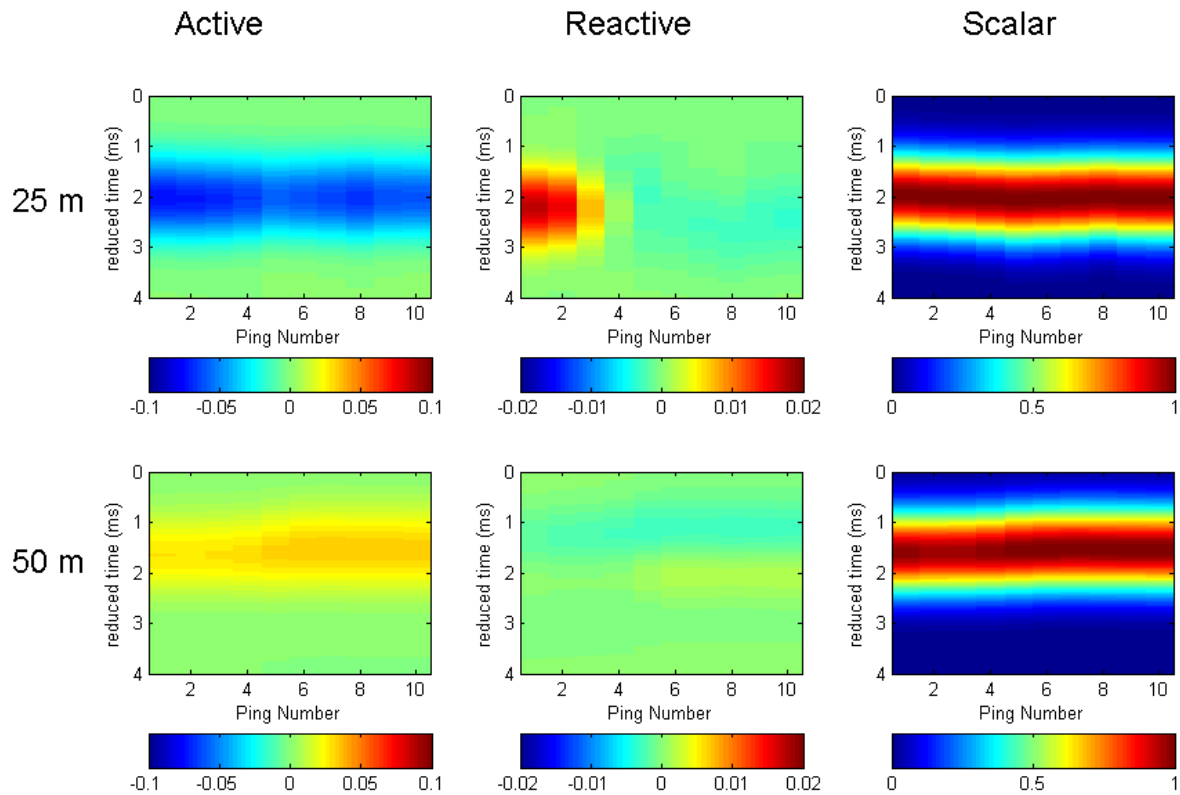


Figure 3 Another view of the kind of PE data shown in Fig 2. Upper row shows the vertical components of active, reactive intensity, and scalar intensity for receiver depth 25 m, limited to the first-arriving, direct path, and plotted as a function of “ping number”. Each “ping” is based on a different sound speed profile. The lower row gives the same information for a receiver depth 50 m. Color code for active and reactive intensity is the same as in Fig 2, i.e., blue active intensity in top row, left column indicates downward propagation whereas red active intensity in bottom row, left column indicates upward propagation. Scalar intensity code is indicated by its separate color bar.

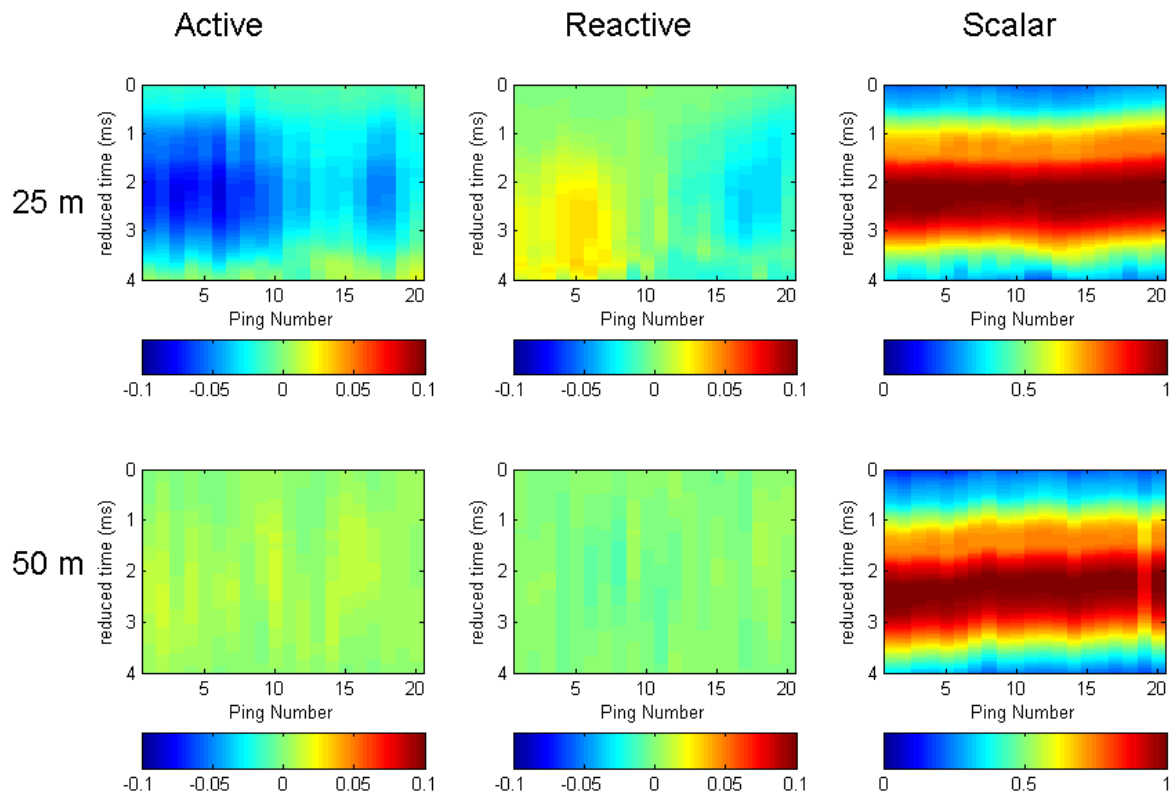


Figure 4. *Measurements of vector intensity that are comparable to those shown in Fig. 3, made 10 Aug 2006 as part of the Shallow Water O6 experiment. Upper row shows the vertical components of active, reactive intensity, and scalar intensity measured for receiver depth 25 m, limited to the first-arriving, direct path. Data are plotted here as a function of true ping number each of which is separated by ~30 sec. The lower row gives the same information for a receiver depth 50 m. Color code for active and reactive intensity is the same as in Fig 2, i.e., blue active intensity in top row, left column indicates downward propagation whereas orange-yellow active intensity in bottom row, left column indicates upward propagation. Scalar intensity code is indicated by its separate color bar.*

IMPACT/APPLICATIONS

The knowledge base gained from these objectives applies directly to vector sensing technologies, prediction of bottom and sea-surface reverberation, and model development for shallow water acoustics that focuses on both scalar and vector quantities.

RELATED PROJECTS

The PI is also advising PhD student Mr. Jeffrey Daniels, from the Acoustics Research Detachment (Bayview ID) Carderock Division, who has received an ILIR grant from ONR to study new vector sensing technologies at the University of Washington.

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