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

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LONG-TERM GOALS

To understand and predict key properties of the signal intensity vector field (Umov vector) as it propagates away from an active sound source, with emphasis is 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 objectives this year were to: (1) Complete acoustic and sea surface wave modeling relating to the influence of sea surface directional waves on propagation measurements from the Shallow Water 06 (SW06) experiment off the coast of New Jersey and complete the analysis of the vector property known as circularity also using data from SW06. (2) Undertake the Targets and Reverberation Experiment (TREX13) off the coast of Florida.   Here a new vector sensor from China was used in the first full-scale field test, following controlled laboratory testing from the previous year.
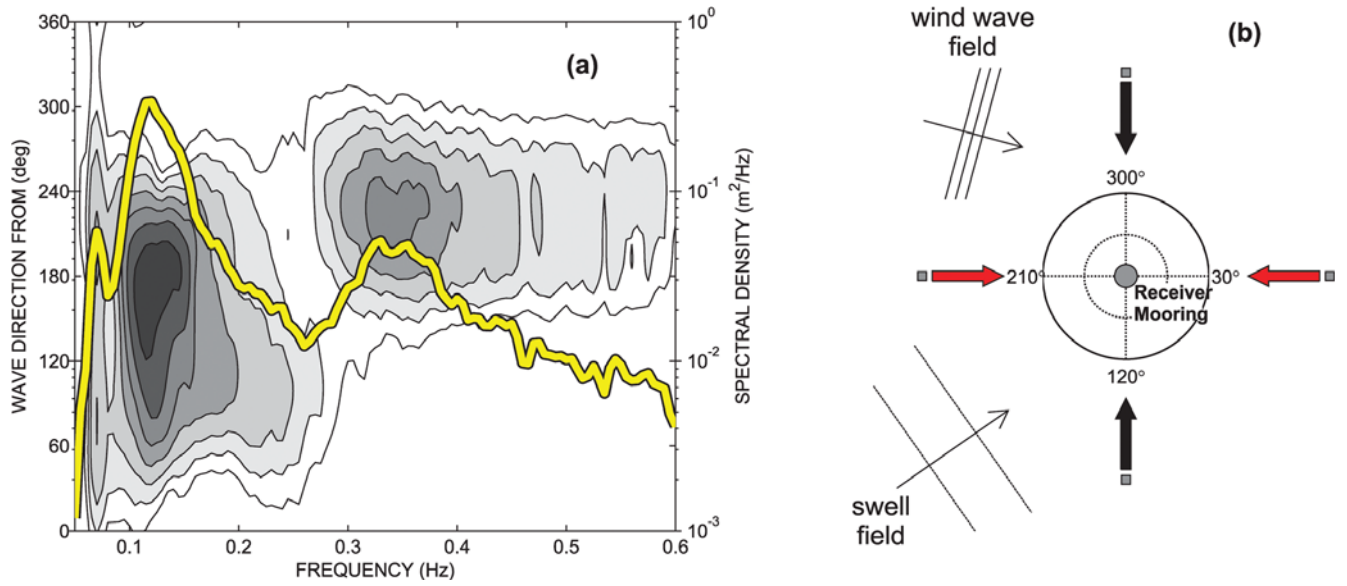
These objectives share a common thread: towards understanding the environmental influences on the intensity vector field in shallow water sound propagation.

APPROACH

Key individuals are doctoral graduate student David Dall'Osto (APL-UW and UW Mechanical Engineering), who was supported by the OA Graduate Traineeship Award and who completed his Ph.D. studies in June 2013, and William Plant (APL-UW) who worked on the modeling of sea surface directional waves.

Completion of the first objective greatly informed our planning for the TREX13 endeavor.   For example, our studies on elliptical particle motion and related circularity as published in [1] influenced the source transmission geometry that we used in TREX13. Furthermore, Fig. 1, from our publication [2], shows the measurement arrangement from SW06 with respect to the directional wave spectrum. Key findings of that work (summarized below) highlight the role of the directional wave spectrum as an influence on acoustic propagation in shallow water propagation and thus a similar geometry was used in TREX13.

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Figure 1. Geometry of 2006 SWO6 experiment studied this year that greatly informed our thinking for the 2013 TREX experiment (see publication [1].) (a) Time average, 10 August 2006, 0830–1500 UTC, of the non-directional frequency spectrum (yellow line) and the equivalent time-averaged directional frequency spectrum (b) Acoustic source stations (four small squares), each 200 m from the MORAY receiver representing positions of the source vessel, R/V Knorr. The source was deployed from the stern, hence, for example, heading 300° establishing propagation in the direction indicated by the black arrow pointing down, heading 210° establishing propagation in the direction towards the right.

WORK COMPLETED

Results of completion of the first objective are given by publications [1] and [2] with brief summary on this work provided in the Results section.

For 2013 TREX13 work, we incorporated a field measurement geometry (Fig. 2) in our experimental design that was motivated by that shown in Fig. 1. Specifically, a primary goal of TREX13 concerned the measurement and interpretation of shallow water, mid-frequency reverberation, and measurements were made along a primary look angle (129° line in Fig. 2) that was aligned with the shoreline of the experimental site off Panama City, FL. Our team made related propagation measurements both parallel, and perpendicular to this primary reverberation track, to study the role of directional waves on both reverberation and related propagation.

These measurements were recorded on receiving station (known as MORAY) consisting of a combined pressure and vector sensor (4 channels), a 7-element vertical line array and a 4-elment horizontal line array of pressure sensors (Fig. 3.). The combined set of vector sensors and array elements established a set of 15 channels that were coherently recorded.

Directional wave measurements were made using one wave buoy at the TREX13 reverberation source location (near the research vessel R/V *Sharp*) and one buoy located 5 km distant along bearing 129° (near the

research vessel R/V *Smith*). A time series (Fig. 4) of the waveheight from these two buoys during a period of simultaneous buoy-operation shows that the wave conditions at these two positions were consistent. A website has been set up to disseminate this wave data (and other environmental data) to TREX13 researchers which will be used in acoustic modeling.
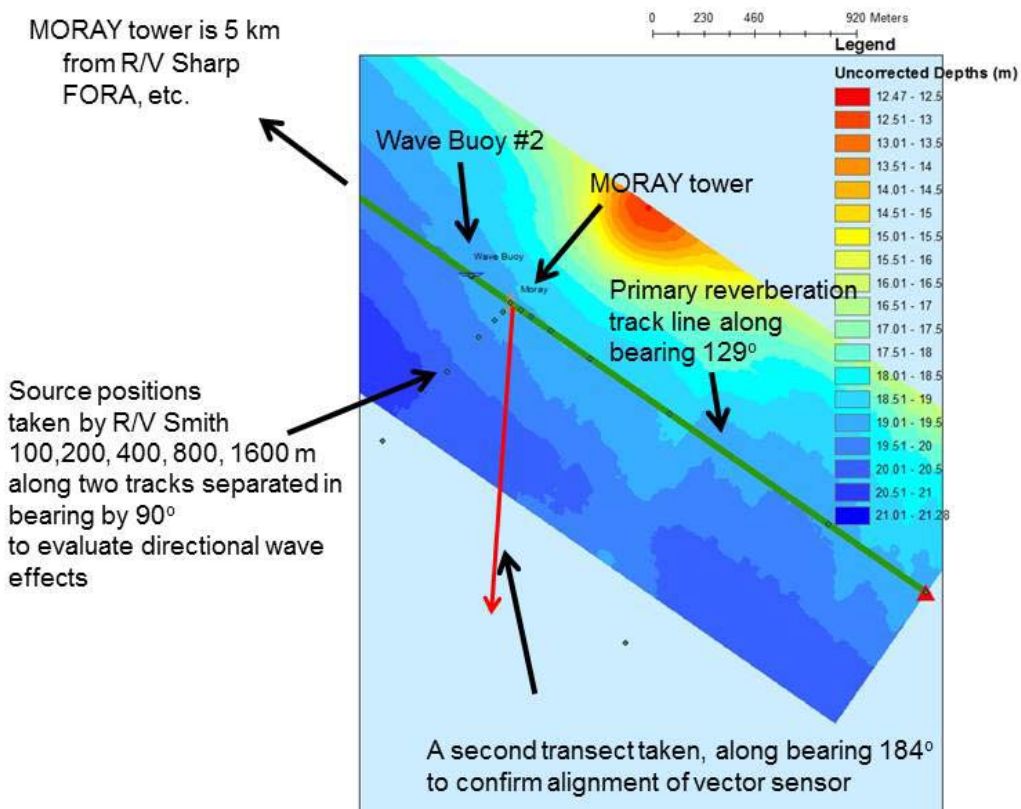
Figure 2. Geometry of the MORAY-based measurement from TREX13. The MORAY tower was positioned at the end of the reverberation track that follows an alongshore bearing of 129°.
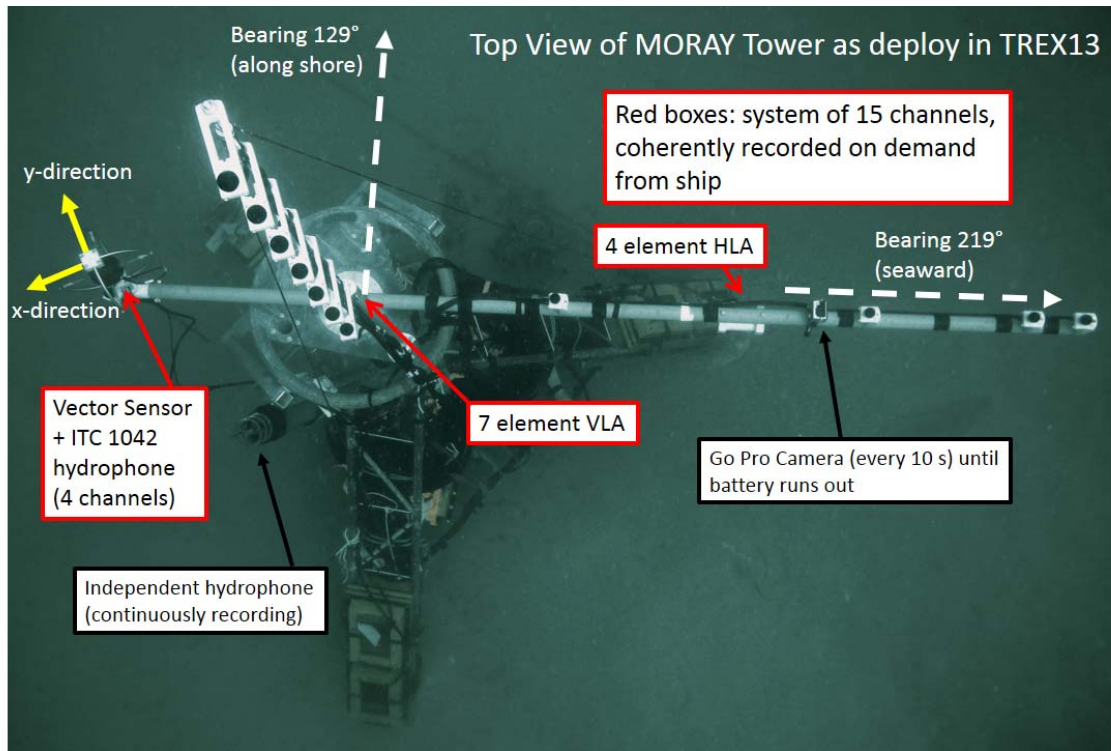
Figure 3.   Dive photograph of the MORAY tower made just prior to its recovery from the TREX13 experiment, with its key elements identified.   The neutrally buoyant VHS-100 vector sensor is shown on the left suspended within its framework.
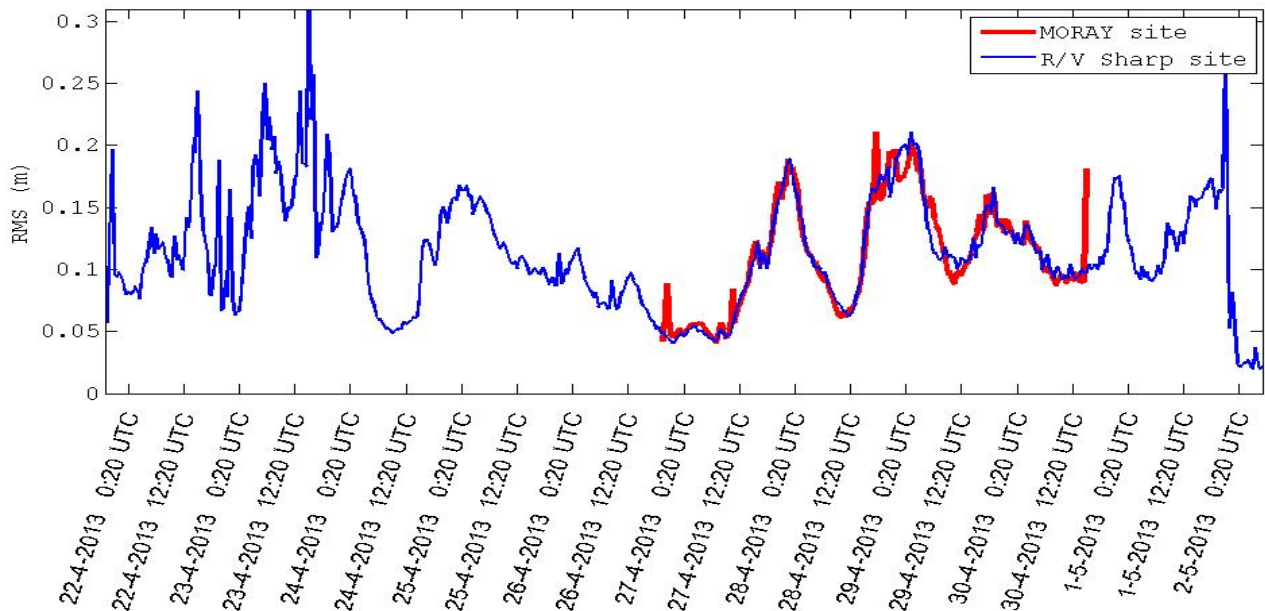
Figure 4.   Time series of the RMS waveheight as measured with a directional wave buoy positioned near the R/V Sharp (blue) and near the R/V Smith (red) located approximately 5 km away along bearing of 129°.

RESULTS

The TREX13 experimental work is relatively recent, and data are currently undergoing further analysis. Figure 5, however, provides a quick look of acoustic particle velocity and intensity vector measurements made with the vector sensor.
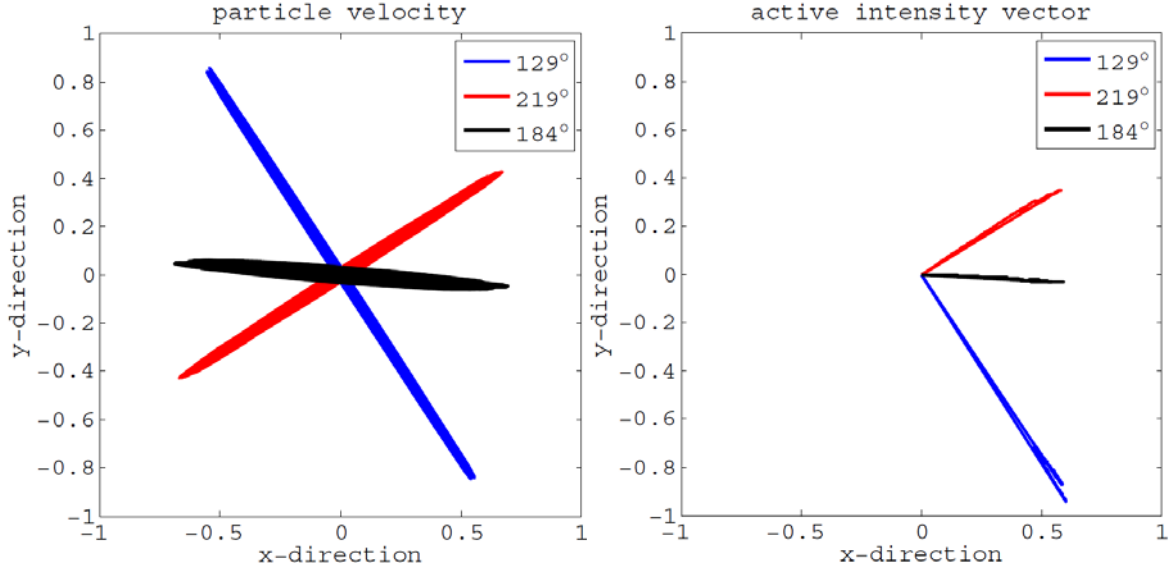
Figure 5.   (Left) Acoustic particle velocity in the horizontal (x-y) plane made with the Vector Sensor along three source-receiver bearings. Notice that measurements with source at bearing 184° show nearly zero particle velocity in the y-direction. (Right) The active intensity vector in the horizontal plane corresponding to the particle velocity estimates shown on the left.

The velocity data has an ambiguity in the source direction, given that it travels back and forth along the line as shown in Fig. 5 (left side). This can be resolved by measurement of the active intensity vector which is possible by combining the 3-channel vector sensor measurements of particle velocity with the fourth channel consisting of the ITC-1042 hydrophone placed within the frame of the vector sensor. Figure 5 (right side) shows the horizontal components of active intensity (all paths are scaled by the same constant). The active intensity points unambiguously away the source, resolving this uncertainty. The vector sensor shown in Fig 3 forms part of a 15-channel coherently sampled data system (red boxes in Fig. 3) consisting of a vertical line array, horizontal line array, and combined vector sensor, with this data to be subject of vigorous analysis in the coming months.

Significant results concerning acoustic particle velocity and the role of directional waves in propagation were also completed and published this fiscal year [1,2]. As the particle velocity work [1] is related to that shown in Fig. 5, we shall emphasize the latter here, which concerns results of an experiment to measure vertical spatial coherence from acoustic paths interacting once with the sea surface. Measurements were made over four source–receiver bearing angles separated by 90°, during which sea surface conditions remained stable and characterized by a root-mean-square wave height of 0.17 m and a mixture of swell and wind waves.

Among the findings of the work in [2] arrived at both observationally and with two modeling approaches is that vertical spatial coherence is significantly reduced when the scattering direction was such that it was

approximately perpendicular to wave crests associated with the wind wave field, compared with a scattering direction characterized by being approximately parallel to these crests.

IMPACT/APPLICATIONS

Our work on the effects of the directional wave spectrum [2] has shown how directional waves can have a direct impact on reverberation in shallow water, e.g., lower coherence indicates larger vertical angular width, which in turn can influence both propagation loss (through mode stripping) and reverberation from the sea bed. Thus, these findings are likely to enter into the predictions of mid-frequency (1-10 kHz) reverberation in shallow water, where two-way propagation and reverberation effects can differ depending on the scattering (look) angle of the sonar system. We will be testing this idea further using the simultaneous field measurements of reverberation and sea surface directional waves made during TREX13 in spring 2013.

Our studies in vector acoustics as summarized in [1] lead to potential applications involving the detection sources in shallow water where match field approaches have performed poorly. These studies have also found application in the interpretation of the underwater noise from underwater explosions and impact pile driving [4].

RELATED PROJECTS

The TREX13 experiment was carried out in cooperation with colleagues D.J Tang, Todd Hefner (TREX13 co-chief scientists), and Kevin Williams, all of APL-UW, and William Hodgkiss of SIO-MPL.

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.

PUBLICATIONS

[1] D.R. Dall'Osto and P. H. Dahl, Elliptical acoustic particle motion in underwater waveguides, J. Acoust. Soc. Am., 134 (1), 109-118, July 2013. [published, refereed]

[2] P. H. Dahl, W. J. Plant and D.R. Dall'Osto, Vertical coherence and forward scattering from the sea surface and the relation to the directional wave spectrum, J. Acoust. Soc. Am., 134 (3), 1843-1853, Sept. 2013. [published, refereed]

[3] D. R. Dall'Osto, Properties of the Acoustic Vector Field in Underwater Waveguides, Ph.D. thesis, Dept. Mechanical Engineering, University of Washington, Seattle, June 2013. [published, non-refereed]

[4] P. H. Dahl and P. G. Reinhall, Beam forming of the underwater sound field from impact pile driving, J. Acoust. Soc. Am., Express Letters, 134 (1) 1-6, July 2013. [published, refereed]