Ocean Acoustics Turbulence Study

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LONG-TERM GOAL

The long-term goal is to measure in situ the three-dimensional wave number spectrum of ocean turbulence using high frequency broadband acoustic scatter.

OBJECTIVES

The aim of this effort is to develop tools and techniques to quantify acoustic scattering from scalar turbulence. This includes: verification of the theory used to describe the acoustic scatter; estimation of the three-dimensional spectral density (3dsd) of thermally generated turbulence from the acoustic scatter; comparison of the acoustic estimate to a classical turbulence model; description of the acoustic scatter from saline variability; and initiation of classification techniques of high frequency acoustic scattering sources.

APPROACH

The problem of describing the acoustic scatter from medium variability is approached through application of far-field weak scattering theory. For the case of thermally generated turbulence, the dominant scattering mechanism is sound speed variability. When salinity becomes important, both sound speed and density variability are necessary to properly describe the scattering process. Interestingly at backscatter, a unit change in salinity (1 psu, through the sound speed and density) has nearly the same potential scattering strength as a unit change in temperature (1 degree C, through the sound speed).

Validation of the theoretical description of the acoustic scatter is ideally accomplished through an independent measurement of the scattering field. The time and spatial scales involved with the plume make at present a ground truth determination unobtainable. However, as a consequence of the far-field weak scattering theory the Bragg scattering condition can be used to indirectly verify the theory describing the acoustic scatter. One caveat of this technique is that the wave front curvature of the Bragg wave front (the resulting sampling wave front) throughout the entire scattering volume must be negligible. For a single beam generated using a circular aperture as is the case here, this is best determined by the radius of the Bragg wave front at the volume being less than the Fresnel radius.

The Bragg scattering condition relates the transform variable of the scattering process, also called the Bragg wave number, to the incident acoustic wave number and the scattering angle. Since the receive acoustic scatter is related to the spatial spectrum of the scattering field at the Bragg wave number,

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multi-static measurements are used to compare the estimated spectra for data collected at nearby scattering angles. This technique requires the use of broadband incident signals such that data collected at nearby scattering angles will have regions of overlapping wave number spectra. The agreement between the spectra in regions of overlapping wave numbers indirectly validates the theoretical framework.

For the case of the thermal plume, ping to ping coherent Doppler information is used to estimate the mean broadband velocity of the scattering field. Combining this with mixing length theory, assuming isotropic turbulence, the turbulent kinetic energy dissipation rate is estimated from the acoustic scatter. To compare the acoustic scatter to a classical turbulence model knowledge of the dissipation rate of thermal variance is also required. A band limited calculation from the acoustic scatter appeared to underestimate this quantity as expected. Using Taylor's hypothesis applied to data from a stationary temperature probe located above the scattering volume resulted in an estimate of the thermal variance that yielded a close relationship between the acoustically measured turbulent field and the classical turbulence model prediction.

The total receive high frequency acoustic scatter observed in the ocean is usually the sum of several different sources of scattering. One means of attempting to systematically classify the source of scattering is through the technique of wavelet dictionary analysis and the search for the best basis. Additionally, for the case of scattering from turbulence compared to suspended matter or small scale biologics, the scattering isotropy is used to classify the source of scattering, since small particles usually have a more isotropic scattering pattern than turbulence which favors the forward direction.

WORK COMPLETED

The laboratory work completed this year consisted of measuring the acoustic scatter from three different scattering mechanisms. All three utilized essentially the same high frequency broadband multi-static scattering configurations. (1) A thermally generated buoyant plume was used as the scattering field for the classical turbulence model comparison with the estimate from the acoustic scatter. (2) For the classification analysis of acoustic scatter generated using different scattering sources, the data collected from the thermal plume was used to compare with data obtained by generating a plume-like scattering field consisting of 200 micron diameter glass beads. This was done such that the acoustic data from both sources had similar spatial and temporal variability as well as similar signal to noise ratios. (3) The negatively buoyant saline plume data were collected using a salt-water reservoir and gravity fed into a fresh-water tank to generate the scattering field.

RESULTS

The acoustic estimate of the three-dimensional spectral density (the spectrum of temperature variance) is simply related to the measured acoustic scattering cross section. The classical turbulence model requires estimating the spectral subrange boundaries, determined by the turbulent kinetic energy dissipation rate, which combined with mixing length theory is known through the rms velocity fluctuations. For the thermally generated buoyant plume, the rms velocity fluctuations were calculated using a mean coherent broadband acoustic Doppler technique resulting in a value of 2.8 mm/s, thus a turbulent kinetic energy dissipation rate of 2.3e-6 W/kg. Also necessary to the model is the dissipation rate of thermal variance. This is calculated in two ways, first from the acoustic scatter itself however, since this a band limited calculation it is expected to underestimate the true value, and second by using the temperature from a point sensor located above the scattering volume and assuming uniform vertical advection of the plume. These two techniques resulted in values of 0.013 $^oC^2/s$ and 0.15 $^oC^2/s$ respectively for the dissipation rate of the thermal variance.

Figure 1 shows the 3dsd as a function of the Bragg wave number for the thermally generated buoyant plume. The top (bottom) curve is the 3dsd for the dissipation rate of the thermal variance determined by using Taylor's hypothesis (the acoustic scatter). Each curve has the same spectral subrange boundaries depicted from left to right by the broken line segments, the inertial-convective, Batchelor, and viscous-diffusive subranges. The data points represent the acoustic estimate of the 3dsd from a three channel simultaneous multi-static measurement. The data points in the upper left region are from a pair of 300 kHz center frequency transducers at a scattering angle of 40^o. The remaining points are from 500 kHz transducers at 80 and 160^o scattering angles. The good agreement between the acoustic estimate and classical model using Taylor's hypothesis is quite remarkable. This suggests that high frequency acoustic scatter can be used to make quantitative measurements of thermally generated turbulence.

The classification work using the wavelet analysis technique was conducted by Quyen Huynh of CSS. The data was generated with the purpose of making the classification as difficult as possible. For the two classes of acoustic scatter, individual pings were parsed from each data set to train the classifier. The classification used uncorrelated pings from those used to train the classifier. The results yielded 82% correct classification. The author used scattering isotropy as a criterion to classify the scattering from the glass beads and the thermal plume using the multi-static data sets and obtained 84% correct classification. This may lead to a syntheses of wavelet analysis and scattering isotropy, combining statistical and physical information to obtain improved results.

The acoustic scatter generated by using a negatively buoyant saline plume in fresh water is described using the far-field weak scattering theory. Use of the common Bragg wave number spectrum comparison is made to verify the theory used to describe the problem. Figure 2 shows this comparison for a turbulent saline plume from data collected using a 3 channel broadband multi-static scattering measurement. Salinity fluctuations can be a significant contributor to the acoustic scatter, and its unique angular dependence suggests the possibility of separating contributions to the total receive acoustic scatter from temperature and salinity driven scattering mechanisms through multi-static measurements.

IMPACT/APPLICATION

When the far-field weak scattering condition is satisfied and wave front curvature is negligible, the acoustic scatter from medium variability can be used to accurately represent quantitative information on the scattering field.

RELATED PROJECTS

The classification analysis is related to the Integrated Approach to Target Recognition project at CSS run by Quyen Huynh.

REFERENCES

N. Intrator, Q. Huynh, and G. Dobeck, "Feature extraction from acoustic backscattered signals using wavelet dictionaries", Proceedings of the SPIE's 1997 Symposium, Orlando Florida.

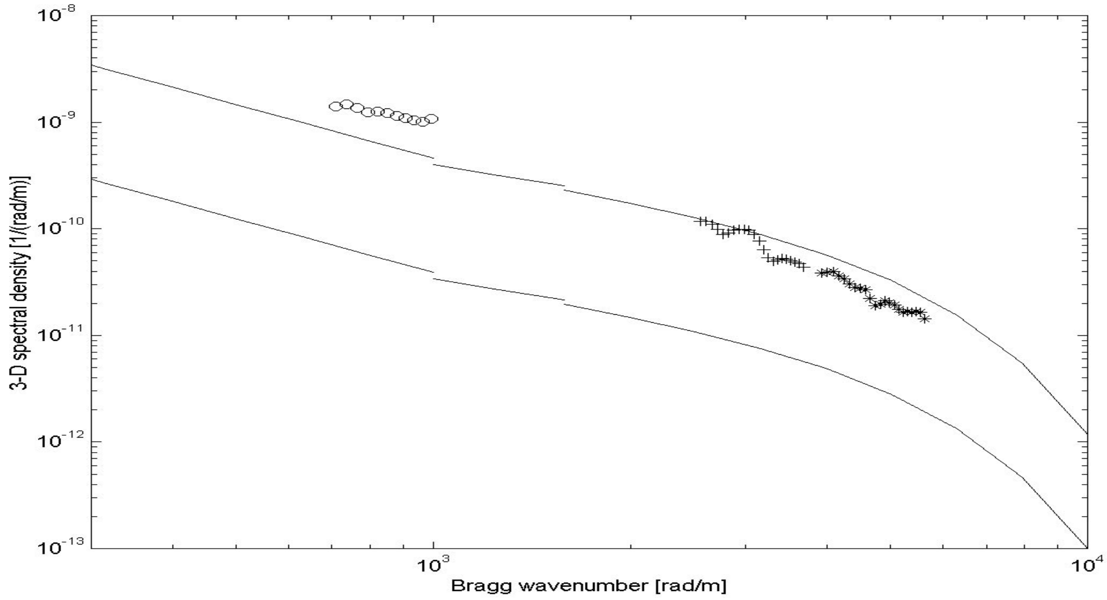

Figure 1. Three-dimensional spectral density from thermally generated buoyant turbulent plume, classical turbulence model and acoustic scatter results. Symbols "o", "+", and "*" represent broadband acoustic scatter data collected at 40, 80, and 160^o respectively, measured from the forward direction.

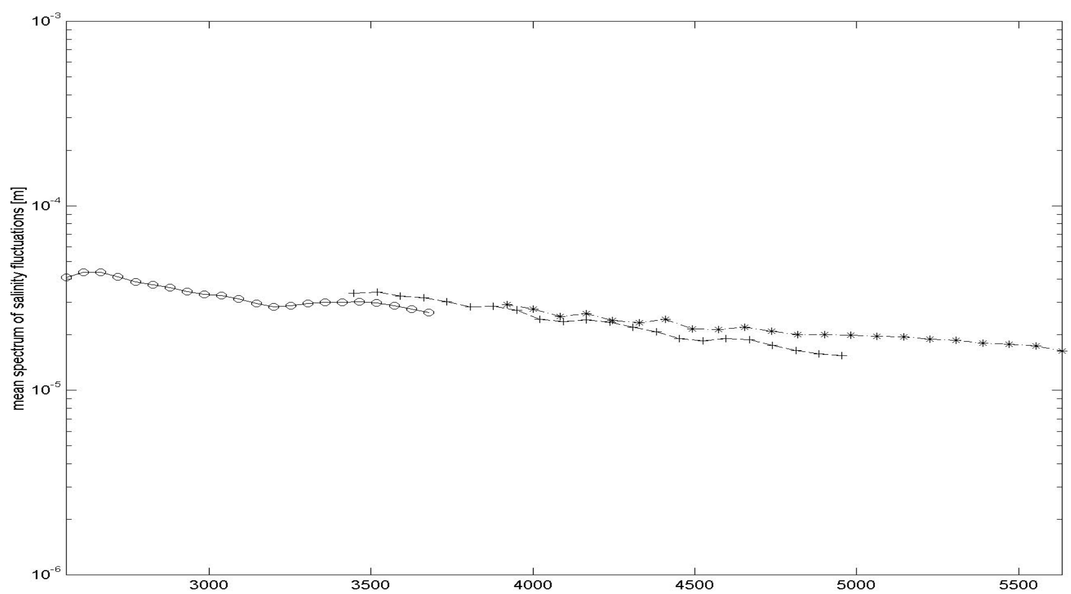

Figure 2. Mean common Bragg wave number spectrum comparison for a negatively buoyant saline plume. Symbols "o", "+", and "*" represent broadband acoustic scatter data collected at 80, 120, and 160^o scattering angles, respectively.