Co-Located Measurements of Turbulence and Acoustic Scattering

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LONG-TERM GOALS

The long-term goal of this program are to quantify the relationship between acoustic scattering and stratified turbulence, and to use the combination of turbulence and acoustic measurements to better understand and quantify stratified turbulence.

OBJECTIVES

In this effort we are obtaining co-located measurements of turbulence and acoustic backscatter in a highly stratified estuary in order to test the hypothesis that the intensity of acoustic energy is directly related to the intensity of salinity microstructure. We are also investigating the mechanisms of stratified turbulence and testing turbulence closure.

APPROACH

The Mobile Array for Stratified Turbulence (MAST) was developed at WHOI and deployed from the WHOI coastal research vessel, the R/V Tioga (Fig. 1). The MAST is 8" in diameter, 10 m long, with 8 sensor locations with adjustable depths, and is designed to make measurements in 0.3-2 m/s flow. The MAST provides a unique means of measuring turbulent velocities and scalar fluxes in shallow, stratified environments. The turbulence sensor suite at each depth includes acoustic Doppler velocimeters (ADVs- sampling at 25 Hz), micro-conductivity sensors (SBE-7 sampling at 300 Hz), CTD measurements (RBR sampling at 6 Hz), in addition to an altimeter and an inertial measurement systems for supporting measurements of platform motion. This instrument platform provides continuous measurements at multiple vertical locations through the water column, producing continuous temporal resolution of the turbulent processes. This advanced turbulence-resolving platform provides critical support for the acoustics measurements as well as providing unprecedented measurements of turbulent stress, buoyancy flux, mixing efficiency and turbulence length scales in stratified, estuarine flows. Two types of measurements were performed: anchor-station and along-river transects. The advantage of the anchored measurements is that the velocities relative to the MAST are relatively low, allowing higher effective spatial resolution of eddies (based on Taylor's "frozen turbulence" hypothesis). This is not an issue for the quantification of conductivity variance due to the rapid sampling rate of the micro-conductivity sensors, but the direct estimation of stress via direct eddy correlation is more effective with a stationary vessel. The advantage of a moving vessel is the ability to resolve the spatial evolution of instabilities, which is typically more pronounced than the local,

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temporal evolution. In this mode the dissipation of TKE and scalar variance are readily measured; however the Reynolds stress cannot be precisely quantified due to relatively high relative velocities (typically 1.5-2 m/s).

Two broadband acoustic scattering instruments are used to measure scattering from turbulence-induced microstructure: a commercial system from Edgetech spanning the frequency range from 120 kHz to 600 kHz, and a WHOI broadband system (developed with funding from the ONR MMB program) spanning the frequency range from 120 kHz to 1.25 MHz. The development of the WHOI broadband system leveraging heavily upon a compact Doppler sonar board developed by E. Terray, T. Austin and P. Traykovski with NSF and ONR funds. This board has been adapted to enable the measurement of broadband acoustic backscattering, has been interfaced with a number of octave-bandwidth transducers, and the software and hardware capabilities of the system have been enhanced.

In addition to these turbulence and acoustics instruments, almost continuous CTD casts were performed during the November 2008 experiment, and a 1.2 MHz RDI ADCP was used to measure depth-resolved mean fluid velocities. A conventional free-fall microstructure probe was also deployed, which provides shear and conductivity spectra as functions of the vertical coordinate. The microstructure profiler provides estimates of the vertical overturning scale as well as estimates of the small-scale anisotropy using two orthogonally mounted shear probes. For the upcoming experiment, continuous water sampling will be added at various depths in order to quantify the abundance of zooplankton and suspended sediments.

WORK COMPLETED

Measurements of acoustics and turbulence were conducted in the Connecticut River in November, 2008. The data were analyzed, and results were presented at the ONR Physical Oceanography Meeting in June 2009 in Chicago.

RESULTS

The measurements of stratified turbulence conducted during the last funding cycle of this project provide compelling evidence for the effectiveness of this combination of broad-band acoustics and turbulence measurements for revealing new phenomena related to stratified turbulence. The measurements were obtained in a stratified shear layer, in which a topographic transition produced a persistent zone of energetic shear instabilities (Fig. 2). The turbulence measurements revealed elevated rates of dissipation of turbulent kinetic energy in the unstable regions, as have been documented in earlier studies. What was unique about these measurements was the ability to determine *where within the developing instabilities the turbulence occurred*, based on the continuous measurements of conductivity microstructure at multiple levels within the Kelvin-Helmholtz billow (Fig. 3). With this ability to localize the distribution of turbulent mixing, we were surprised to discover that the maximum turbulence does not occur in the statically unstable cores of the billows, as indicated in Direct Numerical Simulation (DNS) studies of shear instability as well as laboratory studies, but rather these measurements clearly indicate that the intense turbulence and mixing occur along the strongly sheared braids that extend diagonally between the cores. This result was hypothesized by Corcos and Sherman (1976) for high Reynolds number, but the idea received little further attention, in large part because DNS is incapable of attaining the Reynolds numbers required to develop turbulence in the braid. Smyth (2003) recently re-examined the Corcos and Sherman hypothesis and confirmed the occurrence of secondary instability within the braids for Re>2000, although his simulations did not produce fully developed turbulence in the braids. However our new observations greatly exceed the Reynolds number (and Prandtl number) that can be achieved with the most advanced DNS calculations, bringing us into a regime that is structurally different, in fundamental ways, from the low to moderate Re regime that has been well characterized in DNS and laboratory measurements.

This new finding (which is described in a manuscript to be submitted to *Geophysical Researh Letters*) has potentially important implications for mixing efficiency, as noted by Smyth (2003) in his analysis, as well as in the phenomenology of the growth and breakdown of instabilities. Perhaps more importantly, the marked difference between these field measurements at high Re and "conventional wisdom" based on low-Re analysis emphasizes the great value of highly resolved "experiments" at the scales relevant to ocean mixing processes.

IMPACT/APPLICATIONS

This research will lead to much more effective use of acoustics in the interpretation of turbulent processes, as well as improved discrimination of the role of turbulence in generating acoustic backscatter. The study is also leading to a significant advance in our understanding of high Reynolds number stratified turbulence, with potential impact on turbulence closure parameterizations for stratified shear flows.

RELATED PROJECTS

None

REFERENCES

Corcos, G.M. and Sherman, F. S. 1976. "Vorticity concentration and the dynamics of unstable free shear layers," *J. Fluid Mech.*, 73, 241-264.

Smyth, W.D., 2003. "Secondary Kelvin-Helmholtz instability in weakly stratified shear flow," *J. Fluid Mech.*, 497, 67-98.

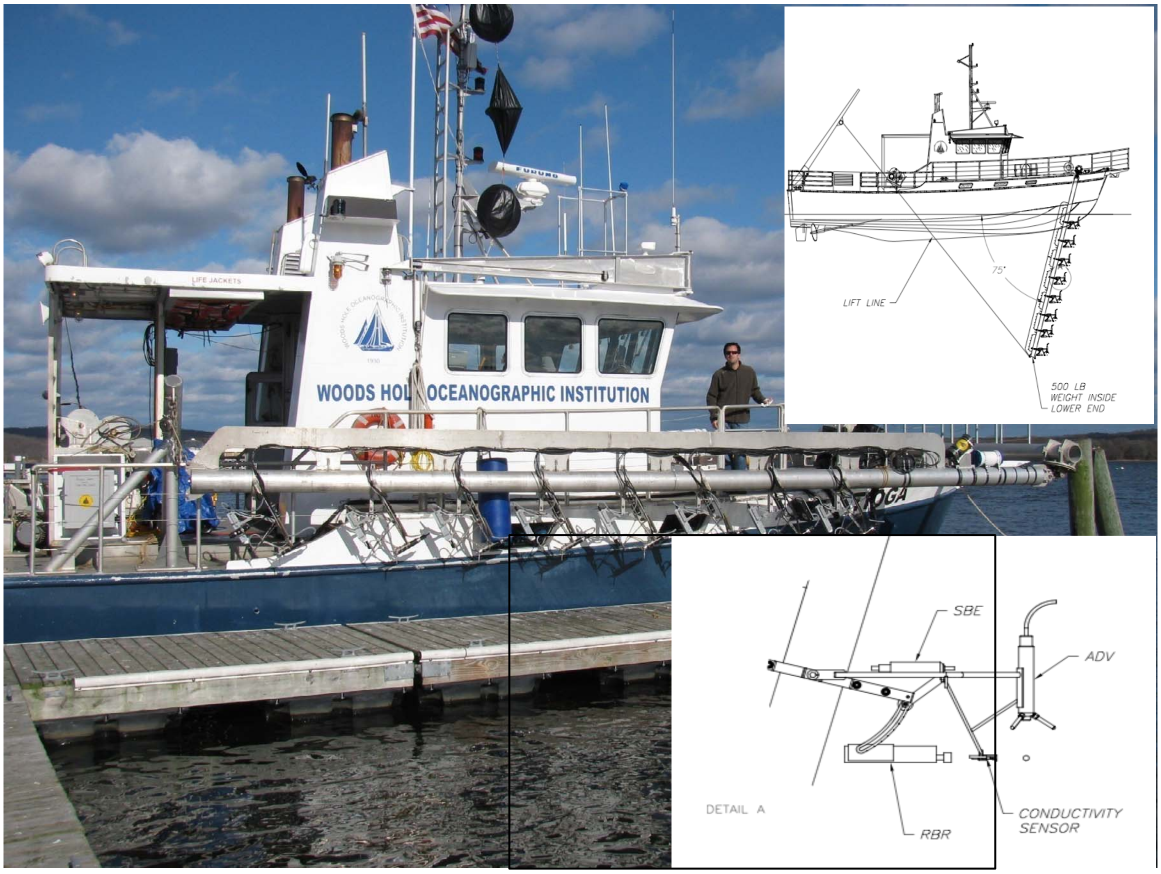

Figure 1. The Measurement Array for Stratified Turbulence (MAST) mounted on the R/V Tioga in the Connecticut River. Insets show the deployment configuration and the detail of the sensor configuration.

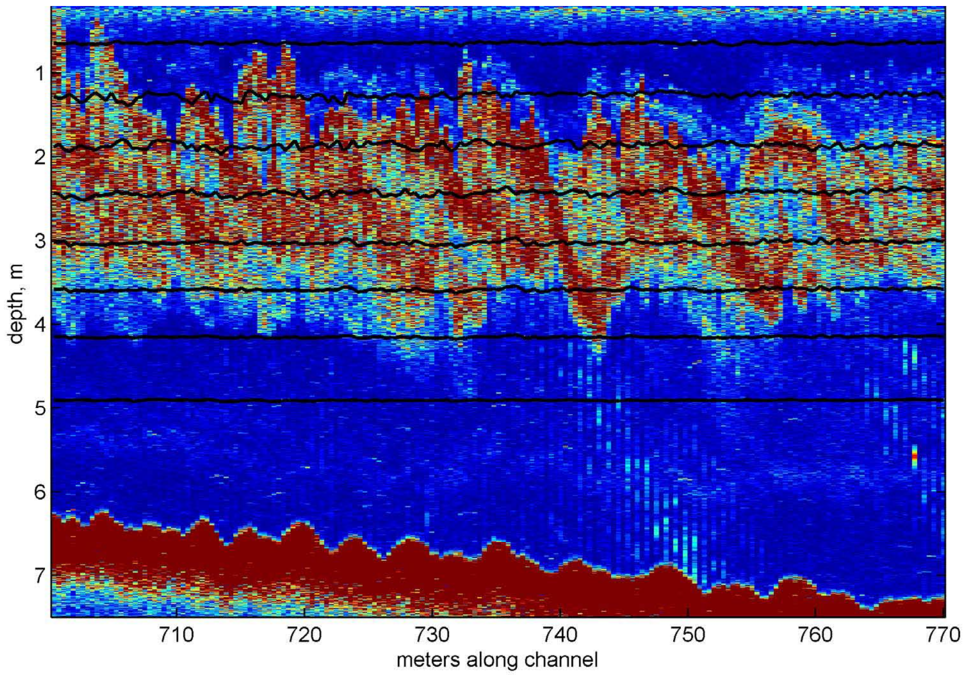

Figure 2. Echo sounding image of shear instabilities in the Connecticut River, showing the distinctive braid structure.

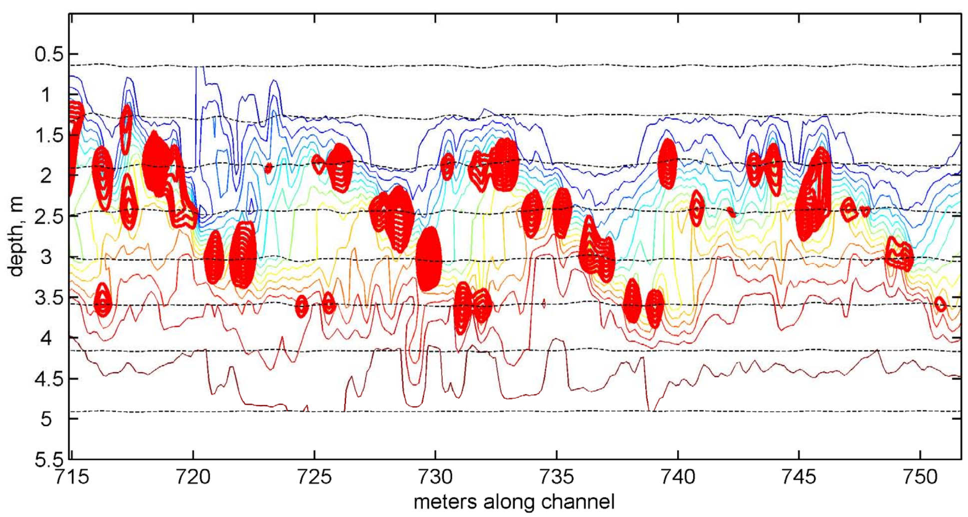

Figure 3. Contours of salinity (colors) with contours of high-frequency salinity variance (red) superimposed, for the same set of shear instabilities shown in Fig. 2. The high variance occurs on the braids, not the cores, indicating that the mixing occurs within the braids, in contrast to low-Reynolds number conditions.