UUV-BASED STUDIES OF TURBULENCE AND MIXING IN SHALLOW WATER

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LONG-TERM GOAL

The overall goal of the research is to utilize turbulence measurements obtained from Autonomous Underwater Vehicle (AUV) based sensors to investigate the role of vertical mixing processes on the horizontal structure of hydrographic and optical properties in shallow water.

SCIENTIFIC OBJECTIVES

The specific scientific questions addressed are:

°Is the estuarine and shelf pycnocline and ocean surface layer a region of enhanced mixing, and what is the effective diffusivity?

°What is the horizontal spatial scale of pycnocline and ocean surface layer mixing events?

°How do boundary layer turbulence, internal waves, Langmuir eddies, and shallow water fronts contribute to pycnocline mixing?

APPROACH

In general, the approach is to measure the horizontal variation of turbulence, hydrographic parameters, and optical parameters using an autonomous and self-propelled UUV, with instrumentation housed in a projecting sting and oceanography payload section. Horizontal profiles and yo-yos are taken over a variety of depths from near-surface to within a safe operating depth of the bottom. This work is done in close cooperation with Rolf Lueck of the University of Victoria.

The steps to be taken to meet the scientific objectives are:

(1) Obtain high quality UUV-based turbulence measurements in Narragansett Bay, i.e., establish the viability of an AUV as a platform for coastal turbulence data. Horizontal profiles of the rate of dissipation of kinetic energy (ε) are made using established techniques. In addition, an estimate of the vertical flux of heat ($w'T'$) is made, as well as an attempt to estimate the vertical flux of horizontal momentum. Simultaneous UUV-based measurements of standard

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hydrographic parameters (temperature, salinity, dissolved oxygen) and optical properties (i.e. optical absorption and attenuation) are also made.

(2) Study mixing in the context of process oriented scientific studies in the logistically benign environment of Narragansett Bay or the nearby continental shelf. Expand measurements of mixing to include summer thermocline studies, Langmuir eddys, and mixing and spatial property gradients around a tidal front in Narragansett Bay. The measurements are placed into the context of large scale features using a bottom mounted ADCP and CTD-O_2 surveys. We utilize piggyback opportunities to reduce ship and acoustic range operations. The character of the larger scale features are examined with bottom mounted ADCP and CTD-O_2 surveys. Piggyback opportunities will be sought in order to reduce ship and acoustic range operations costs.

WORK COMPLETED

Horizontal profiles of coastal turbulence have been obtained from a large, stable, autonomous underwater vehicle (AUV). Field trials in Narragansett Bay resulted in obtaining turbulence in the mid-water pycnocline, in the ocean surface layer, and in a frontal region; also, a yo-yoed section was obtained.

RESULTS

Results indicate that the large NUWC vehicle, the LDUUV (0.7 m diameter, 7.6 m length), exhibited the proper stability for measurement of the microstructure of velocity, and hence the dissipation of kinetic energy, to characterize mixing in the coastal environment. Horizontal profiles of turbulence were obtained enabling near-synoptic horizontal mapping in a variety of coastal process studies. The instrumentation included two piezo-ceramic shear probes sampling orthogonal to the vehicle's direction of motion, an ultra-fast thermistor, and three orthogonal accelerometers, all mounted on a sting. Turbulence was characterized in the mid-water pycnocline, in the ocean surface layer, and in an estuarine frontal zone. Noise reduction in the shear signal was significantly reduced by removing the coherent portion of the spectrum associated with acceleration.

A comparison of the corrected spectra with the Naysmuth universal spectra (Oakey, 1982) shows a good agreement in spectral level and shape. For the frontal zone, time series of noise corrected velocity shear and temperature microstructure show enhanced levels on the boundaries of the front. For the complete dataset (Fig. 1), dissipation rate averages for the mixed layer, pycnocline, yo-yo between these levels, and the frontal zone were of order 10^{-6}-10^{-8} W/kg consistent with measurements in similar regimes from conventional platforms such as the results of Peters (1997) in an estuary, and Huang (1997) in a tidal channel. The dissipation rates and their variations with depth (in the yo-yo'd section) agree well with estimates of the locally measured rate of working by wind and bottom friction. Preliminary heat flux estimates utilizing the fluctuating temperature and vertical velocity data indicate that the large AUV is significantly stable for these calculations. Thus, an AUV can be utilized to characterize mixing, in addition to hydrography and optics, along continuous horizontal and yo-yoed paths.

Figure 1. Time series of dissipation rate, temperature gradient, Richardson number (the minus symbol indicates an unstable density profile), depth and temperature for Narragansett Bay.

IMPACT/IMPLICATION

The UUV-based measurements enable stable, non-obtrusive investigations of small-scale physical processes in the coastal regime over spatial scales and operability regimes that would not be possible with conventional methods. The much greater length of the LDUUV (7.6 m) compared to a typical towed vehicle (1.8 m), the absence of any connection to a surface ship, and its pitch and roll stability (~1°) contribute an order of magnitude improvement in the low-wavenumber resolution of the cospectrum of vertical velocity and temperature.

Also, this research is relevant to the following Science and Technology Requirements Guidance Undersea Battlespace requirements:

• Environmental Assessment: provide an organic, deployable suite of sensors (including unmanned underwater vehicles (UUVs)) to covertly and overtly sample the environment, and to communicate in real-time, *in situ* oceanographic information.

• Provide for detailed environmental physics-based understanding of the littoral environment to aid in: sensor design, sensor and weapon models, nonacoustic submarine and mine detection, oceanographic intelligence, improvement of special operations forces (SOF) sensors to covertly image in any environment (e.g., dark and turbid waters).

TRANSITIONS

In the context of the ONR funded National Ocean Partnership Program combined ocean/observation systems, the turbulence measurement system is being integrated into the small, logistically simpler REMUS vehicle. Mixing will be studied in the context of process oriented scientific studies in the environment of the LEO-15 site in the MAB, and the LOOPS site in Mass. Bay. The measurements of mixing will include upwelling zones, fronts, and the benthic and ocean surface boundary layer, estuarine/continental shelf interactions, and their bio-optical consequences. Results will be compared with numerical model predictions.

RELATED PRODUCTS

(1) Comparison of turbulence and optical datasets - with P. Donaghay (University of R. I.)

(2) Comparison of coastal turbulence datasets - with R. Lueck (University of Victoria)

(3) Model comparison and turbulence closure scheme testing - with Dale Haidvogel and Scott Glenn (Rutgers University) in the LOOPS NOPP study.

(4) Model/data system interaction for nowcasting and forecasting with Alan Robinson, Harvard University.

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