# Coastal and Near Surface Mixing

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Award #: N00014-93-1-0362

## Long-term Goals

My long-term goals are to increase our understand of the role of turbulence and mixing on the circulation of the ocean and the transport of heat, salt, and other important scalars.

## Scientific Objectives

I wish to establish whether the horizontal distribution of heat flux and dissipation rate are related to the distribution of Langmuir cells, as indicated by the density of bubble clouds, and to what extent, if any, the flux of heat and the intensity of mixing are enhanced by Langmuir circulation. Langmuir cells are wind and wave induced flows in the surface mixing layer and consist of counter rotating horizontal vortices with a typical spacing of 10 to 100 m and a length of several hundred meters. They essential form a quasi-coherent structure that has large ($O(0.1\ \mathrm{m\ s^{-1}})$) vertical velocity at the convergence zone between vortex pairs and, therefore, may enhance the rate of vertical exchange with the atmosphere.

## Scientific Approach

We are using a unique towed vehicle that carries both conventional turbulence sensors and acoustic transducers. Turbulent vertical velocity fluctuations and the rate of dissipation of kinetic energy are measured with shear probes, while temperature fluctuations as small as $10^{-5}$ °C are measured with an FP-07 thermistor. The vertical flux of heat is estimated from the covariance of the turbulent vertical velocity and temperature. The rate of dissipation is estimated from the variance of the horizontal gradient of vertical velocity. Sonars (two athwartship direct side-scans, one forward directed side-scan and a vertical echo sounder) mounted on the towed vehicle are used to map out the distribution of turbulence with respect to bubble clouds (hence, Langmuir cells) in the near surface zone. A paravane deflects the tow line by about 40 m away from the side of the ship and out of its wake.

The acoustic instrumentation was supplied by D. Farmer (IOS) and installed on the vehicle with considerable help from his research group. F. Wolk (Uvic) has been responsible for computing the motion of the vehicle and for estimating the vertical flux of heat and the rate of dissipation. S. Holgate (UVic) is examining the relationship between mixing layer shear, Richardson number and dissipation rate.

# Report Documentation Page

*Form Approved*
*OMB No. 0704-0188*



| 1. REPORT DATE | 2. REPORT TYPE | 3. DATES COVERED |
|---|---|---|
| **30 SEP 1997** | | **00-00-1997 to 00-00-1997** |

4. TITLE AND SUBTITLE
**Coastal and Near Surface Mixing**

5a. CONTRACT NUMBER
5b. GRANT NUMBER
5c. PROGRAM ELEMENT NUMBER

6. AUTHOR(S)

5d. PROJECT NUMBER
5e. TASK NUMBER
5f. WORK UNIT NUMBER

7. PERFORMING ORGANIZATION NAME(S) AND ADDRESS(ES)
**University of Victoria,School of Earth and Ocean Sciences,PO Box 1700,Victoria, B.C. V8W 2Y2,**

8. PERFORMING ORGANIZATION REPORT NUMBER

9. SPONSORING/MONITORING AGENCY NAME(S) AND ADDRESS(ES)

10. SPONSOR/MONITOR'S ACRONYM(S)

11. SPONSOR/MONITOR'S REPORT NUMBER(S)

12. DISTRIBUTION/AVAILABILITY STATEMENT
**Approved for public release; distribution unlimited**

13. SUPPLEMENTARY NOTES

14. ABSTRACT

15. SUBJECT TERMS

| 16. SECURITY CLASSIFICATION OF: | | | 17. LIMITATION OF ABSTRACT | 18. NUMBER OF PAGES | 19a. NAME OF RESPONSIBLE PERSON |
|---|---|---|---|---|---|
| a. REPORT | b. ABSTRACT | c. THIS PAGE | | | |
| **unclassified** | **unclassified** | **unclassified** | **Same as Report (SAR)** | **5** | |

**Standard Form 298 (Rev. 8-98)**
Prescribed by ANSI Std Z39-18

**Work Completed**

For the data collected in Monterey Bay during the MBL Experiment of April 1995, we have completed the complicated task of using the measured 6 degrees of motion of the towed vehicle to correct the velocity sensed by the shear probes. The orbital velocity induced by waves has also been removed from the measured signals by using the measured pressure and its rate of change. We have completed the estimation of the vertical flux of heat and the rate of dissipation. The vertical profiles of velocity collected with an ADCP on the *R/V Wecoma* have been processed and made available to all researchers on our ftp site (george.seos.uvic.ca).

**Results**

At a depth of 12 m and in the frequency range of wave motions (≈0.1 Hz), the variance of vertical velocity sensed by the shear probes is about 10 times larger than the turbulence within the mixing layer (Fig. 1, left panel). The cospectrum of vertical velocity (*w*) and temperature fluctuations (*T*) is significantly changed by correcting the measured velocity (Fig. 1, right panel) — spurious counter-gradient fluxes below 0.1 Hz are eliminated as are some anomalous features in the quadrature spectrum. The cospectrum spans from 2 to 30 m wavelength and peaks at 10 m wavelength. The buoyancy wavelength is 7 m indicated that the bulk of the flux is carried by eddies that are damped by stratification. Our cospectra are fully resolved and we have improved the range of resolved wavenumbers by a factor of 10 compared to Fleury and Lueck (1993). Thus, it is now feasible to make direct oceanic heat flux measurements with a horizontal profiler.

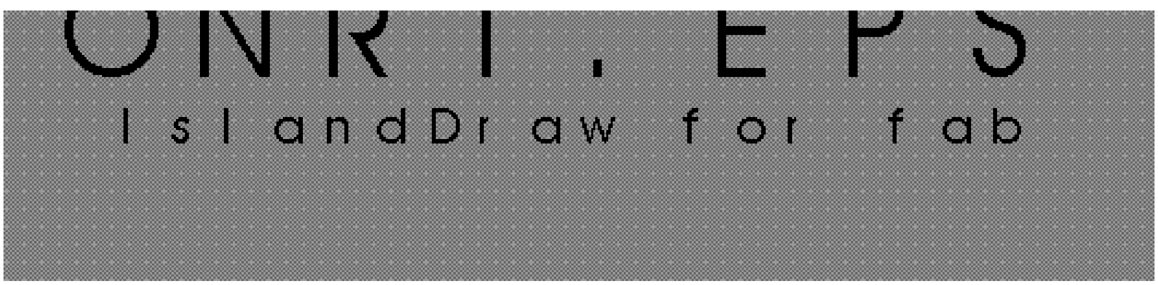


**Figure 1**. Variations of temperature, its fluctuations and the rate of dissipation along a night-time tow track at 12 m depth in Monterey Bay. Elevated temperature fluctuations were usually found on the warm and stable side of thermal fronts (MBL097-099) adjacent to ragions of neutral stability (MBL096 and MBL100). The time axis is in minutes and represents 12 km of towing.

Tows taken at 12 m depth were categorized according to stratification as neutral, stable and convective. In the neutral regime, the small positive temperature stratification was canceled by a salinity gradient, while in the convective regime the surface layer was completely mixed down to 40 m in both temperature and salinity. In all cases, the

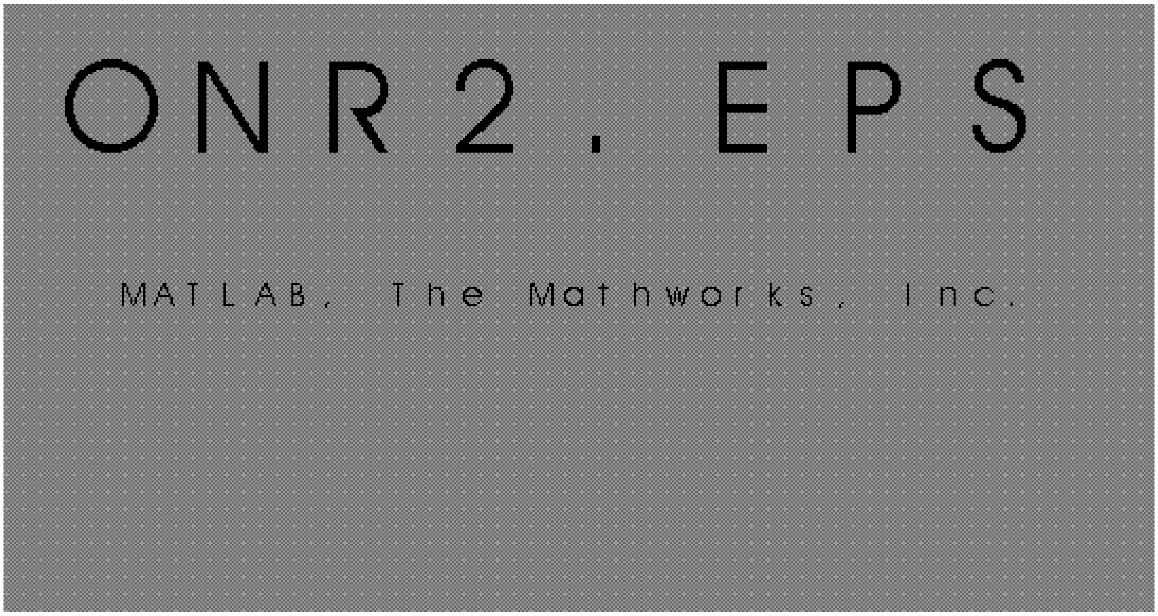


**Figure 2**. Left panel: Typical spectra of vertical velocity fluctuations (thick solid line), velocity reported by the shear probe (thin line), and the velocity of the probe through the water (dotted line). Co- and quadrature-spectra of vertical velocity and temperature after (thick line) and before (thin line) motion correction.


**Figure 3**. Cospectra (solid line) and quadrature spectra (dashed line) from (a) stable, (b) neutral and (**c**) convective regions showing that these spectra are fully resolved. The spectra are plotted in units of W $m^{-2}$.

upper 5 m were slightly super-adiabatic. The largest temperature variability was found in the stable regions and the rate of dissipation there was 10 times larger than in either the neutral or the convective regions (Fig. 2). In all case, the surface was loosing heat to the atmosphere. The heat flux was down ward in both the stable and the neutral regions (Fig. 3) but upward in the convective region. The mixing efficiency $\Gamma$ was 0.5 in the stable regime placing it between the classic value of 0.2 and 0.7 found in the thermocline (Moum 1996) and in a frontal regions (Gargett and Moum 1995), respectively. The bubble cloud distributions were similar in all three regions, thus, the large-scale horizontal variations of dissipation rate and heat flux are not attributable to Langmuir cells. At shorter scales and at 12 m depth, we found no correlation between bubble cloud distribution and either temperature fluctuations, heat flux nor the rate of dissipation.

**Impact/Application**

The direct and unambiguous measurement of the vertical flux of heat and other scalars is now fairly routine for atmospheric boundary layer studies but this technique has been used with only limited success in the ocean (except for sensors attached to the bottom or the underside of ice). The successful application of motion correction to the measurement of vertical velocity from a towed vehicle now make it possible to use this direct technique on a variety of platforms such autonomous vehicles, submarines, and moorings.

The poor correlation between bubble clouds and other physical parameters may be a consequence of the limited penetration of the Langmuir cells and future measurements will have to be taken closer to the surface than 12 m.

**Transitions**

The electronic systems developed for the towed vehicle are now being utilized in Autonomous Underwater Vehicles (AUV) by E. Levine at the Naval Undersea Warfare Centre and our general instrumentation technique has been adapted to AUV measurements by M. Dhanak at Florida Atlantic University. Our signal enhancement technology is being exploited by D. Farmer at the Institute for Ocean Sciences for near surface temperature measurements and is being incorporated into a commercial tide gauge manufactured by ASL Environmental Sciences.

**Related Projects**

1. Hide Yamazaki of the Tokyo University of Fisheries and I are investigating shear instability and internal-wave breaking events near the bottom of the mixing layer in the MBL Experiment using a thermistor chain attached to our towed vehicle.

2. Ed Levine of the Naval Undersea Warfare Center and I are utilizing the small autonomous vehicles *REMUS* to study mixing processes very near the surface. We expect these vehicle to be more flexible than towed ones and be able to get much closer to the surface than our current technique.

3. Our heat flux and dissipation measurements are being compared to stress and flux measurements taken by Jim Edson of WHOI.

4. We are working closely with D. Farmer at the Institute of Ocean Sciences to continue using acoustic transducers on our towed vehicle to study the role of Langmuir cells in near surface mixing and wee are comparing acoustic techniques for turbulence measurements against shear probes.

**References**


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