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14. ABSTRACT

The primary objective was to assess mixing levels over a coastal regime, Monterey Bay, extending the scope of previous measurements that have been restricted to single lines or small domains. Secondarily, we sought to obtain enough data to compare mixing intensity, known to be high, with measurements on the New England shelf, which were low.

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Assessing the Effects of Diapycnal Mixing in a Coastal Regime (AESOP)

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LONG-TERM GOALS

To identify the major processes producing mixing in the upper ocean and to understand their dynamics sufficiently well to permit accurate parameterization of mixing for use in numerical models.

OBJECTIVES

The primary objective was to assess mixing levels over a coastal regime, Monterey Bay, extending the scope of previous measurements that have been restricted to single lines or small domains. Secondarily, we sought to obtain enough data to compare mixing intensity, known to be high, with measurements on the New England shelf, which were low.

APPROACH

After placing a 300 kHz ADCP on the bottom of, microstructure profiles were collected along lines 5-10 km long, passing back and forth for at least a 12.4-hour cycle of the semidiurnal (M_2) tide (Fig. 1). Nineteen groups of profiles were collected using the Modular Microstructure Profiler (MMP), and six groups were done with the Advanced Microstructure Profiler (AMP).

WORK COMPLETED

MMP group 2, the first set of runs in the bay, revealed startling vertical lines of intense turbulent dissipation (Fig. 2) coinciding with a vertically coherent velocity reversal. Lengthy analysis after the cruise demonstrated that this and similar observations were produced by aggregations of fish, presumably anchovies. To figure this out, I worked with John Horne (UW and NOAA fisheries), the results appearing as *Gregg and Horne* (2009).

Some aggregations filled the 80-m water column and extended 100-200 m along the track. Figure 3 shows several examples, including that shown in the raw data in Figure 2. Dissipation rates were often $10^{-6} - 10^{-5}$ W kg^{-1}, several decades larger than those in background mixing patches. Cumulatively, aggregations roughly doubled the average dissipation rate near the bottom-mounted ADCP (Fig. 3). This, however, had little effect on diapycnal diffusivity, K_ρ, owing to very low mixing efficiency, $\gamma_{\rm mix}$ in the aggregations, manifested by overturning (Thorpe) scales much smaller than expected from Ozmidov scales computed using observed dissipation rates, ϵ, and stratification, N^2. Low efficiency was confirmed by comparing temperature gradient variance, χ_T, with ϵ to compute $\gamma_{\rm mix} = \kappa_T C N^2/\epsilon$, where κ_T is the molecular diffusivity of heat in water and C is the Cox number obtained from χ_T.

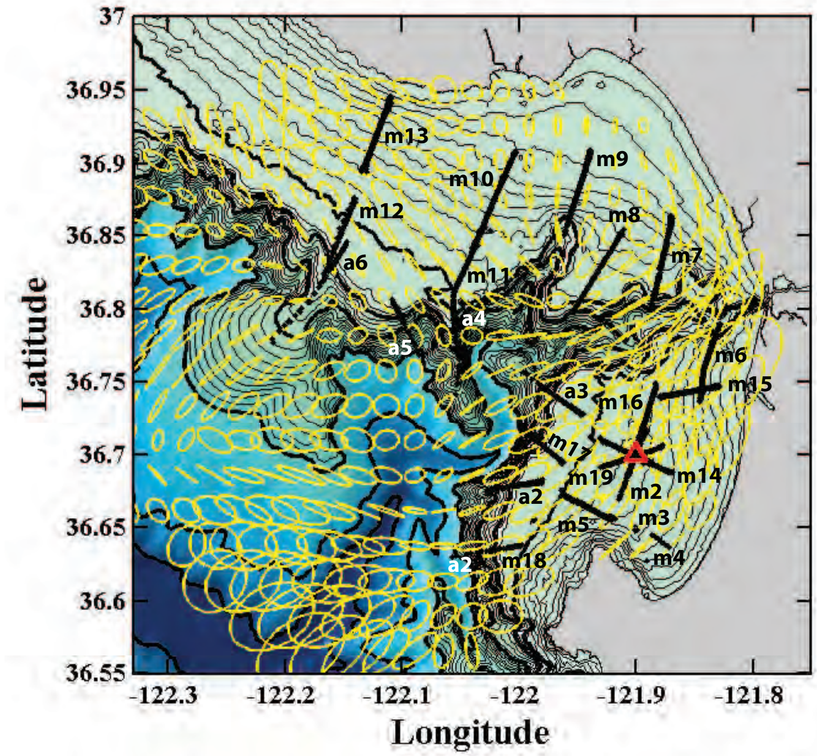

Figure 1: Bathymetry of Monterey Bay overlaid with tidal ellipses observed with CODAR (*Rosenfeld et al.*, 2009). Black lines are composed of dots, one for each AMP and MMP profile taken in the bay. The red triangle marks the location of the Workhorse 300 kHz ADCP mounted on the bottom. Black lines are locations of microstructure profiles, labeled with 'm' for those taken with MMPs and with 'a' for those using the AMPs.

In aggregation, γ_{mix} averaged 0.0022 compared with 0.23 outside them. In summary, the observed aggregations increased dissipation 100-fold, but their low mixing efficiency reduced K_ρ by about the same amount.

ONGOING WORK

Although funding has ended on this project, analysis is continuing and is expected to result in several more papers. Currently, work is focusing on background mixing near the bottom-mounted ADCP. Removing profiles that sampled aggregations focuses on the persistent mixing in horizontal layers evident in Figure 2 at 20-30 m before (left) the aggregation and at 50-60 m afterward. Flow and shear maxima persisted at these depths during the 12.4-hour group of profiles, shown by the group averages in Figure 5. $S^2 \approx N^2$ in the upper dissipation zone and $S^2 \approx 2N^2$ in the lower zone. In spite of the differences in shear and stratification, ϵ in both zones peaked at 6×10^{-8} W kg^{-1}. Corresponding peak diffusivities were 0.01 and 0.002 m^2 s^{-1} in upper and lower zones. In between, ϵ dropped to noise levels, with $K_\rho = 10^{-6}$ W kg^{-1}.

The persistent shear appears to have been produced by internal standing modes. In addition to their signature in velocity, the accompanying strain played a major role in controlling turbulent production. Examining spatial and temporal evolution of the section, termed a sub, whose average was in the previous figure, inreasing strain, i.e., expanding isopycnals, turned on the upper turbulence half way the section, while decreasing strain, compressing isopycnals, shut off the lower turbulence (Fig. 6).

The next paper will examine these and other observations over the Workhorse, focusing on links between internal wave modes and mixing. Subsequent investigations will consider shoaling solitons found on the north side of the bay and changes in regime over the upper continental slope, where shelf conditions give way to those more characteristic of deep water. Finally, one paper will summarize all of the work on internal waves and mixing in the bay.

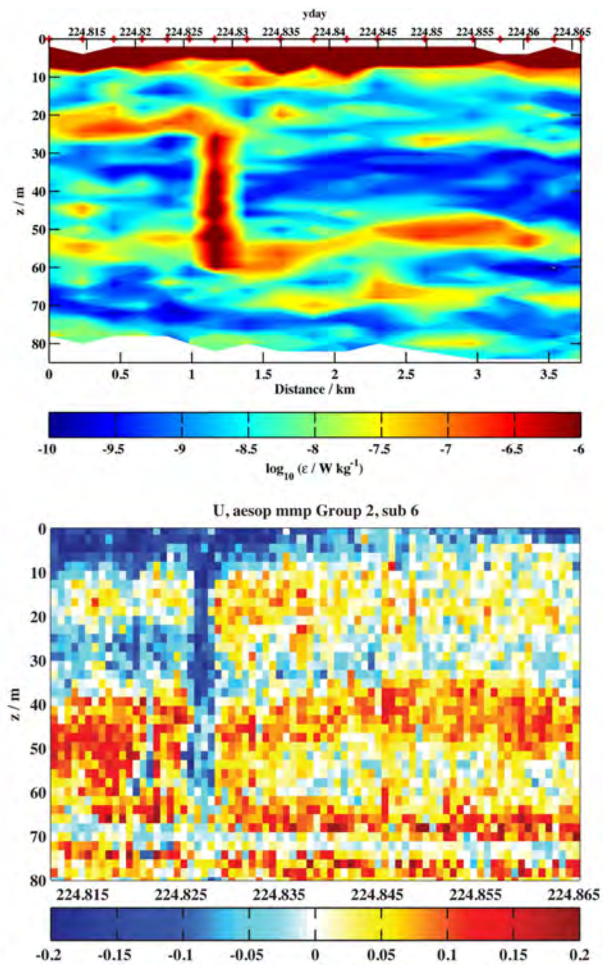

Figure 2: Logarithm of the turbulent dissipation rate (upper panel) and east/west velocity observed with the R/V *Revelle* hydrographic ship sonar (lower panel) during MMP Group 2, Sub 6 (*Gregg and Horne*, 2009). Top axis, upper panel is time in decimal year day, and the red crosses are times profiles began. Bottom axis, distance along the track from the first profile. The color bar below the lower panel is velocity in m s^{-1}, and the bottom axis is year day. Distance on this plot began at the first drop location.

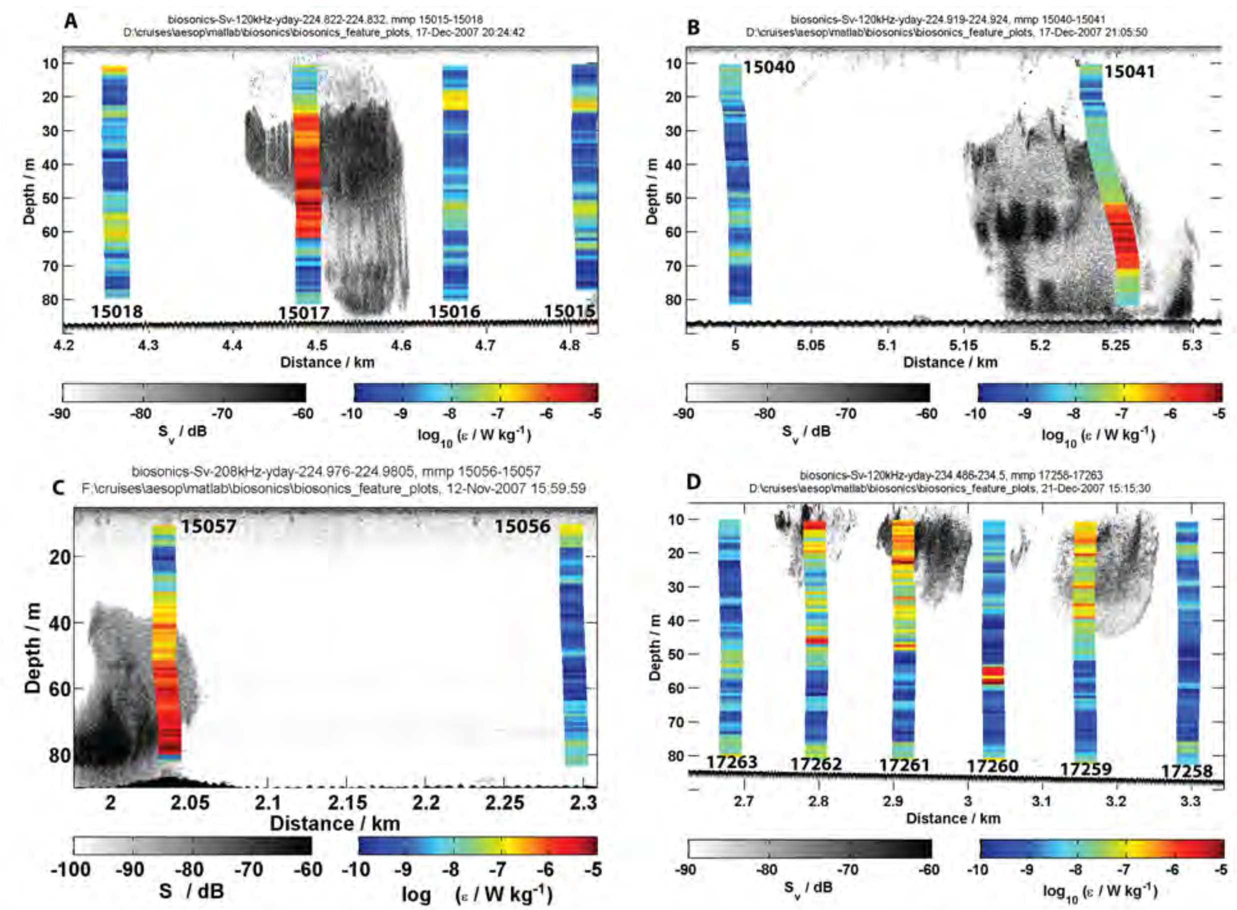

Figure 3: Four examples of turbulence in fish aggregations. Volume backcattering strength, S_v (dB re 1 m^{-1}) at 120 kHz in grayscale overlaid with $\log_{10}(\epsilon/\mathrm{W\,kg^{-1}})$ in color from MMP profiles (*Gregg and Horne*, 2009).. Distances in these plots are relative to fixed waypoints for MMP groups, and the profiles are sequential designators of MMP profiles. The upper left plot shows the same fish aggregation as in the previous figure.

References

Gregg, M., and J. Horne (2009), Turbulence, acoustic backscatter and pelagic nekton in Monterey Bay, *J. Phys. Oceanogr.*, *39*(5), 1097–1114.

Rosenfeld, L., I. Shulman, M. Cook, J. Paduan, and L. Shulman (2009), Methodology for a regional tidal model evaluation, with application to central California, *Deep-Sea Res II*, *56*, 199–218.

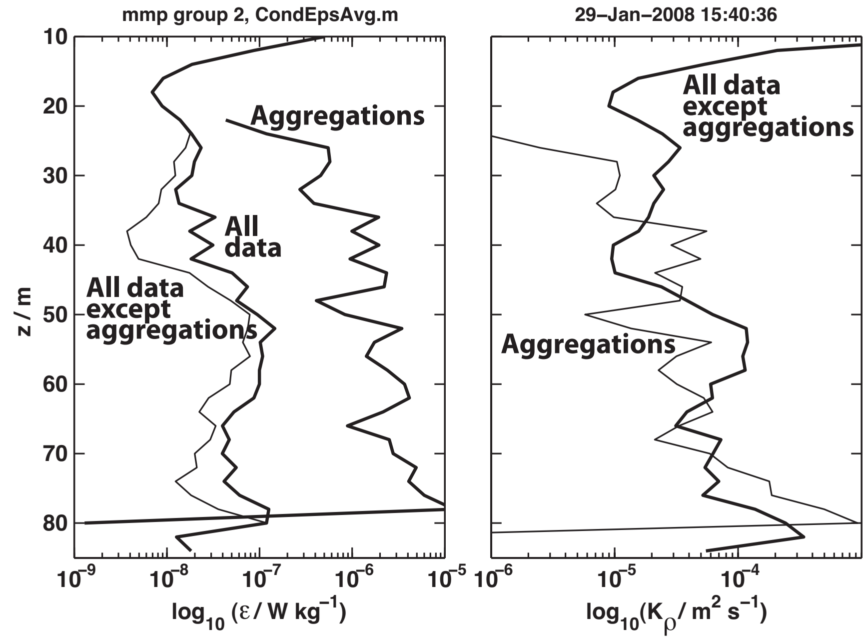

Figure 4: Left) Averages of a) the 142 dissipation profiles comprising Group 2, b) the three profiles in large, intense fish aggregations, and c) the 139 profiles not in large aggregations. Right) Average K_ρ of the 139 profiles not in large aggregations using $\gamma_{\rm mix} = 0.2$ and for the three profiles in aggregations using $gamma_{\rm mix} = 0.0022$, the average efficiency found in aggregations. Although ϵ in aggregations averages 100 times that outside, the lower efficiency compensates, resulting in no significant difference in K_ρ inside and outside of the aggregations.

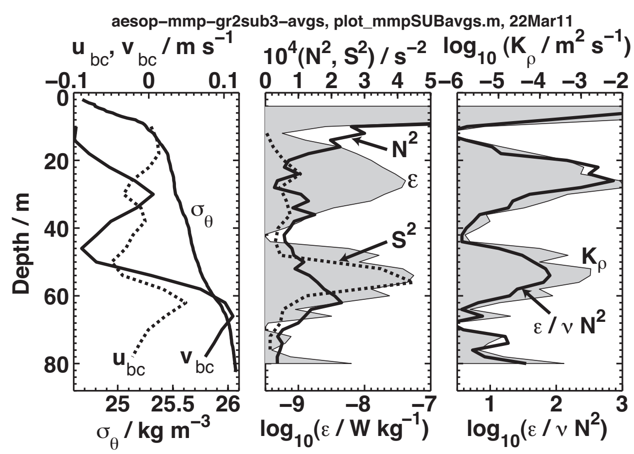

Figure 5: Averages of MMP group 2 sub 3, showing two 30-m-thick zones of strong, persistent turbulence. In the upper dissipative region $S^2 \approx N^2$, but in the lower $S^2 \approx 2N^2$. In spite of the differences in shear and stratification, ϵ in both zones peaked at 6×10^{-8} W kg^{-1}.

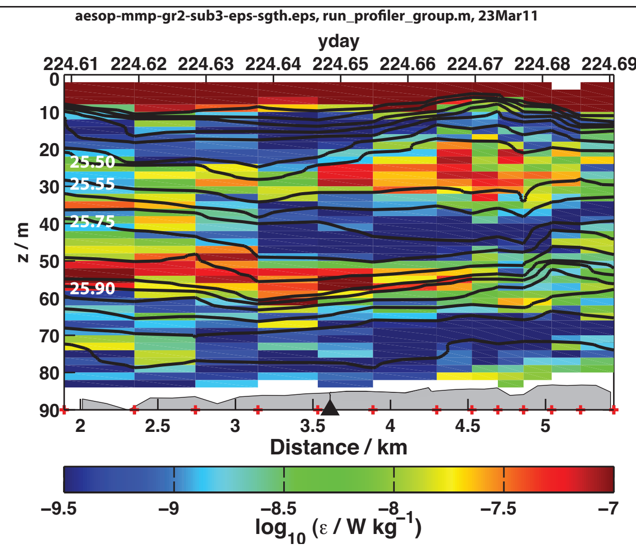

Figure 6: Dissipation rate for MMP group 2 sub 3. The upper region of strong turbulence was turned on by increasing strain (isopycnal expansion) during the second half of the observations , as the lower region was being turned off by decreasing strain (isopycnal compression).