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Detection of Oceanic Microprocesses by Towed Profiling Sensors

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SUMMARY Vertical diffusion of ocean properties such as temperature cr dissolved species is usually determined by relatively intense, small scale mixing events, widely separated in space and time, driven by and imbedded in oceanic features such as internal wave fields with length scales several orders of magnitude larger. A towed ocean profiling system is described which is intended to provide a variety of small scale measurements over an appropriately wide bandwidth in space and time. Small scale conductivity fluctuations seem to be particularly valuable as signatures of oceanic mixing events.

1 INTRODUCTION

Vertical diffusion of heat, mass and momentum in the ocean occurs by complex processes involving wave, shear and turbulent motion. Inadequate field measurements of these motions and their effects on the temperature, salinity and density fields have severely limited progress in understanding or parameterizing the phenomena.

A variety of difficulties beset field measurements of oceanic mixing and diffusive processes. Signal levels are extremely low, noise levels are high, platforms are expensive and an extremely wide bandwidth in space and time must be covered to encompass all the relevant factors. Turbulent mixing is poorly understood even when the scalar property is dynamically passive, let alone with strong stratification in the same or opposite directions by two properties with different molecular diffusivity, as is the case for temperature and salinity in the ocean.

Measurements have been attempted by towed bodies (Nasmyth (1970), Gargett (1976), Williams and Gibson (1974), Schedvin et al. (1977), Belyaev et al. (1975a, b)), submarines (Grant et al. (1968)) and vertical dropsondes (Cox et al. (1969), Gregg (1975, 1976a, 1977), Gregg and Cox (1971), Gregg et al. (1973) and Osborn and Cox (1972)). The picture which seems to emerge is that below the surface layer, the turbulence is extremely weak and patchy. Although towed and dropped sensor packages have not been properly intercompared by simultaneous measurements in the same ocean region, a systematic difference in indicated temperature and velocity fluctuation levels seems to exist, with higher levels resulting from towed measurements. For example, Belyaev (1975a, b) and Williams and Gibson (1974) find dissipation rates of about 10^{-2} to 10^{-1} cm^2/sec^3 for velocity and 10^{-5} to 10^{-6} $°C^2/sec$ for temperature in the equatorial undercurrents of the Atlantic and Pacific using towed instruments, while Gregg (1976b) and Osborn (private communication) report values of 10^{-4} to 10^{-5} cm^2/sec^3 and 10^{-9} to 10^{-10} $°C^2/sec$ using vertically dropped sensor packages. This extreme difference in ranges is within the wide range of possible values in this region of the ocean, and as will be discussed in following section, it is not clear at this time which, if either, set of values is more representative of the actual average values. Although noise in towed measurements may provide part of the explanation, as pointed out by Gregg (1976b), estimation of average values becomes more difficult when the process is highly variable in magnitude and distributed in patches of unknown geometry.

2 OCEANIC TURBULENCE

Compared to the atmosphere, vertical diffusion in the ocean is weak. However, compared to molecular diffusion alone it is still quite strong and generally depends crucially on the presence of oceanic turbulence.

Solar heating of surface waters produces strong stable stratification in the ocean, which limits the size of vertical turbulence to scales less than the buoyancy length $L_R = (\epsilon/N^3)^{1/2}$, where ϵ is the viscous dissipation rate of the turbulence and N is the local mean Väisälä frequency $\left(-\frac{g}{\bar{\rho}}\frac{\partial\bar{\rho}}{\partial z}\right)^{1/2}$ averaged over vertical scales larger than L_R. When L_R becomes smaller than the Kolmogoroff scale $L_K = (\nu^3/\epsilon)^{1/4}$, where ν is the kinematic viscosity, turbulence is no longer possible. Since buoyancy extracts energy at the largest scales and radiates it away from a turbulent region as internal waves, stratified turbulence dies away more rapidly than turbulence in constant density fluid once its source of energy is removed.

Turbulent mixing in a stratified medium is also different than in a neutrally buoyant fluid, since large scale fluctuations in temperature or salinity variability produced by stratified turbulence have no mechanism corresponding to internal wave radiation for damping, and will simply be left "frozen" in the fluid as turbulent (temperature, salinity) fossils until relatively slow gravitational or molecular diffusive mechanisms destroy their geometrical identity. Experimental evidence and theoretical analysis of such turbulent "fossils" is in a preliminary stage (see Turner (1973), Figure 10.2, p 315).

Figure 1 is a schematic diagram of the major sources and possible geometrical distribution of oceanic active and fossil turbulence. As indicated, only the upper layers will generally be continuously active, with fossil, active and non-turbulent patches distributed in all permutations and combinations below.

It is clear from Figure 1 that sampling a particular horizontal layer for an average dissipation rate (for example) requires intersection of a representative number of patches. Even with a horizontally towed sensor package, an assumption must be made as to whether patches encountered are more nearly one, two or three dimensional (sheets, strips or blobs) in order to apply the appropriate weighting factor in estimating the average.

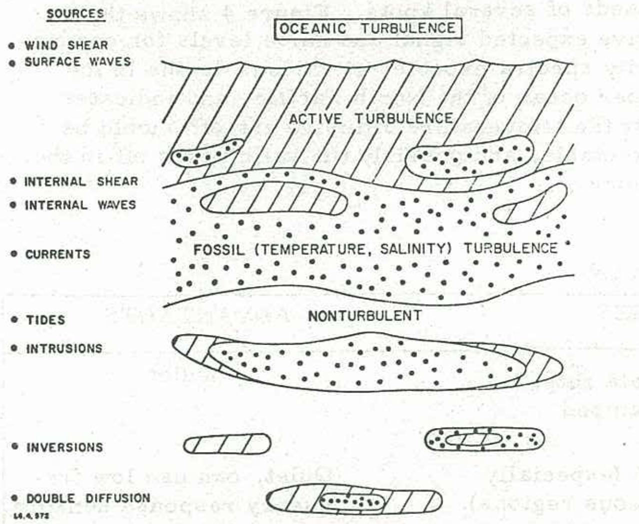

Figure 1 Sources and distribution of oceanic turbulence

This sampling problem is illustrated in Figure 2. ϵ is a physical parameter sampled in the horizontal direction x, with values of ϵ_p in patches of thickness x_p, and ϵ_o in background regions of width x_o. If the patches are like sheets (one-dimensional) the average $\bar{\epsilon}_1$ for the layer is

$$\bar{\epsilon}_1 = \left(\frac{x_p \epsilon_p}{x_p + x_o}\right) + \left(\frac{x_o \epsilon_o}{x_p + x_o}\right) \tag{1}$$

However, if the patches are like cylinders (two-dimensional) or blobs (three-dimensional) the average should be estimated by

$$\bar{\epsilon}_2 = \left(\frac{x_p^2}{x_p^2 + x_o^2}\right)\epsilon_p + \left(\frac{x_o^2}{x_p^2 + x_o^2}\right)\epsilon_o \tag{2}$$

and

$$\bar{\epsilon}_3 = \left(\frac{x_p^3}{x_p^3 + x_o^3}\right)\epsilon_p + \left(\frac{x_o^3}{x_p^3 + x_o^3}\right)\epsilon_o \tag{3}$$

respectively.

As shown in Figure 2, the true mean value $\bar{\epsilon}$ may differ by orders of magnitude from the background value ϵ_o, depending on the patch geometry and the relative intensity ϵ_p/ϵ_o inside and out. Estimation of $\bar{\epsilon}$ from a single vertical or horizontal cut through a layer is clearly questionable without some evidence of the scales required to achieve homogeneity.

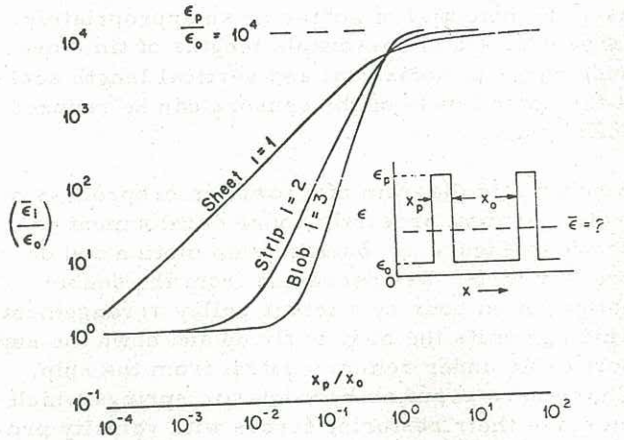

Figure 2 Effect of Patch Geometry and Intensity on Average Estimates

Dissipation rates may vary by 3-5 orders of magnitude between adjacent layers or at the same depth within a few meters (Schedvin et al., 1977). Bias in the estimate of the average may occur by several mechanisms. Sensors must have sufficient dynamic range to cover both ϵ_p and ϵ_o. Thermistor frequency response of the vertical dropsonde requires correction beyond wavelengths of about 20 cycles/meter according to Gregg (1977). This corresponds to the peak of a temperture spectrum mixed by turbulence with viscous dissipation rates of about 10^{-4} cm^2/sec^3 which is about the smallest value which can be sensed by present turbulent velocity sensors on towed bodies. The analogy with blind men attempting to describe an elephant is apparent: towed signals might be dominated by noise in the background water between patches most likely encountered by vertical drops, and dropsonde signals may be beyond the frequency response of the instruments in the rare circumstances when they encounter a patch. Peaks in temperature spectra reported by Gregg (1971 to 1977) show only two records with peak dissipation wavenumbers significantly larger than $(0.4 \pm 0.2)(N/D)^{1/2}$, which is the range expected for fossil temperature turbulence fluctuations (of temperature) strained by small scale internal waves (Schedvin et al, 1977). Although hardly a representative sample, this would suggest that only 10-20 meters of the 4-5 kilometers of vertical records collected are actively turbulent, a volume fraction of 5×10^{-3}, 3×10^{-5} or 10^{-7} depending on whether the patches are sheet, strip or blob-like, respectively. Belyaev et al. (1975a, b) report a wide range of patchiness geometries from about 5,000 km of tow data.

3 MEASUREMENT PLATFORMS

Table I compares advantages and disadvantages three platforms used to detect oceanic microstructure. The first measurements were made using a manned submarine (Grant et al., 1968) and showed the great difficulties to be expected in measurements of such weak and patchy phenomena. A wide variety of dropsondes have been employed with adequate signal to noise and less cost, but as indicated, they may severely undersample the phenomena and may not be inexpensive when ship time is considered.

Towed bodies with high frequency response sensors have the potential of achieving an appropriately large data set in reasonable lengths of time over a wide range of horizontal and vertical length scales, if the noise levels of the sensors can be reduced sufficiently.

A schematic diagram of a towed microprocess detection system presently under development is shown in Figure 3. Surface ship motion and depressor forces are decoupled from the double hulled towed body by a tether pulley arrangement which permits the body to fly up and down the support cable under remote control from the ship. The tethers serve as hydroelastic springs which increase their restoring forces with velocity proportional to the drag forces on the "fish" which they must overcome. Up to 10^6 bits/second of information may be transmitted through the tethers and support cable to the deck unit for recording or computer analysis. Table II shows some of the most important sensors used on the fish to detect velocity, temperature and conductivity fluctuations.

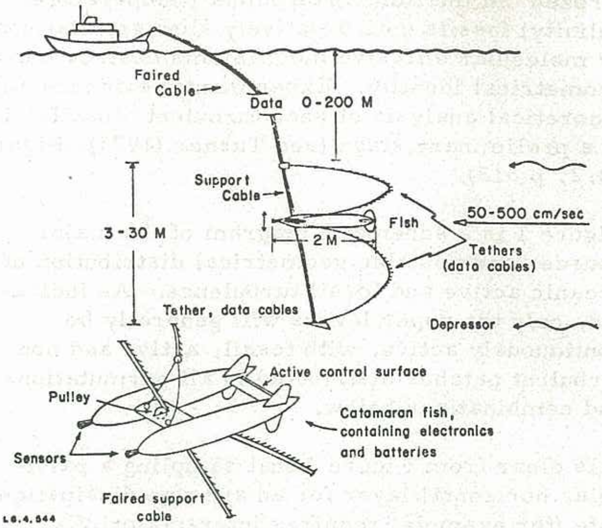

Figure 3 Schematic of towing arrangement

The most important sensor is the small scale conductivity probe, since it has sufficiently high frequency response (5000 Hz) and low noise to permit detection of conductivity fluctuations to diffusive scales (see Gibson et al., 1974) at tow speeds of several knots. Figure 4 shows the relative expected signal and noise levels for conductivity spectra expected at various depths in the upper ocean of the North Pacific, and indicates that the temperature diffusive cut-off should be detectable, and possibly the salinity cut off in the halocline.

TABLE I
SENSOR PLATFORMS

PLATFORM	DISADVANTAGES	ADVANTAGES
Submarines (manned, unmanned)	Expensive, limited data rate, electronic space cramped	Quiet
Dropsondes	Slow, may undersample (especially horizontally inhomogeneous regions), limited data rate and storage	Quiet, can use low frequency response sensors, can go deep
Towed	Noisy if not decoupled from ship motion and depressor forces, requires high frequency response sensors at high speeds	High data rate, inexpensive, samples wide band space-time, real time processing, display, control; flexible sensor and topside electronic systems

TABLE II
TOWED SENSORS

PARAMETER	SENSOR	PURPOSE
Velocity	Ducted current meter Hot film anemometer	Mean speed Turbulence detection
Temperature	Platinum resistance Thermistor	Accurate mean (0.01°C) High frequency (25 Hz)
Conductivity	Centimeter - 4 electrode Millimeter - 4 electrode	Accurate mean (0.01 ‰) High frequency (5000 Hz)

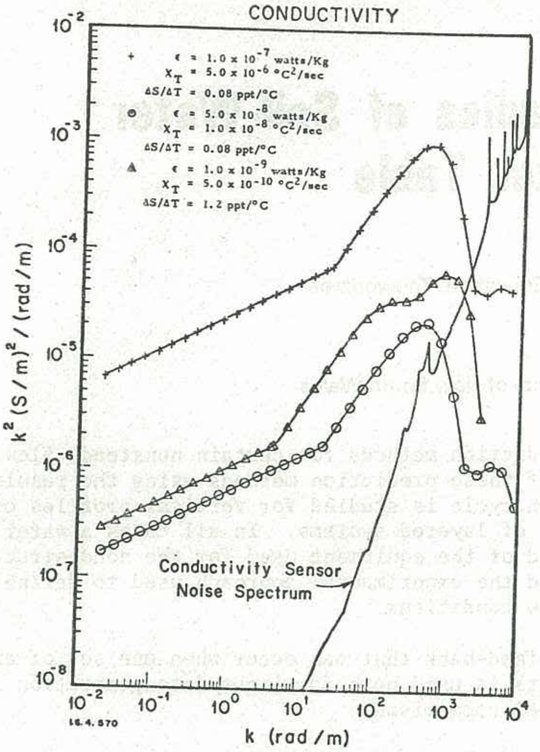

Figure 4 Conductivity $k^2\Phi_c$ spectra - signal vs noise

4 CONCLUSIONS

Appropriate platforms, sensor systems and fluid mechanical understanding of vertical diffusive processes in the upper ocean are in an early stage of development. Available information strongly suggests a complex, patchy, intermittent array of coupled non-linear processes distributed over scales from many kilometers to a few millimeters which must be sampled rapidly and with wide dynamic range. A towed profiling system with small, high frequency response sensors appears to offer the only hope of adequately measuring such phenomena.

5 ACKNOWLEDGMENTS

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