Finestructure Studies

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LONG-TERM GOALS

The long term goal of this project is to contribute to our knowledge of finescale internal waves and quasi-permanent finestructure, and to define their impact on larger scales.

OBJECTIVES

The objective of this study is to better understand the processes which govern the spatial and temporal evolution of both internal wave and quasi-permanent finestructure. This includes interactions between finescale internal waves, interactions between internal waves and quasi-permanent finestructure, turbulent production and isopycnal dispersion processes.

APPROACH

The approach is foremost to obtain, define and interpret finescale phenomena in oceanographic data, and secondarily to develop simple analytic and numerical representations to explain those phenomena.

WORK COMPLETED

Work efforts are currently focused upon the preparation of manuscripts for publication. Listed below is the status of the various manuscripts being prepared as part of this grant.

Internal Wave Modeling and Prediction

Polzin, K. L. Idealized Solutions for the Energy Balance of the Finescale Internal Wave field. *Journal of Physical Oceanography*, submitted.

Polzin, K. L. Notes on the Oceanic Internal Wave Spectrum. *Journal of Physical Oceanography*, submitted.

Polzin, K. L. Momentum Conservation and Equilibration of Finescale Internal Wave Spectra. *Journal of Physical Oceanography*, submitted.

Polzin, K. L. An Abyssal Recipe, in preparation

Polzin, K. L. Idealized Solutions for the Background Oceanic Internal Wave Spectrum, in preparation

Polzin, K. L. A Rough Recipe for the Energy Balance of the Internal Tide, in preparation.

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The long term goal of this project is to contribute to our knowledge of finescale internal waves and quasi-permanent finestructure, and to define their impact on larger scales.

15. SUBJECT TERMS

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Polzin, K. L. A Rough Recipe for the Energy Balance of Quasi-Stationary Internal Lee Waves, in preparation.

Quasi-Permanent Finestructure

Polzin, K. L., E. Kunze, J. M. Toole and R. W. Schmitt, 2002. The partition of finescale energy into internal waves and geostrophic motions. *Journal of Physical Oceanography*, in press.

Polzin, K. L. and R. Ferrari. Isopycnal Dispersion in NATRE. *Journal of Physical Oceanography*, submitted.

Ferrari, R. and K. L. Polzin. Finescale Structure of the T−S Relation in the eastern North Atlantic, in preparation.

Twist

Polzin, K. L. A Fine- and Microstructure Section across the Continental Slope and Gulf Stream, in preparation.

Polzin, K. L. Subinertial Finestructure on the Continental Slope/Rise Transition, in preparation.

Polzin, K. L. Where do Topographic Rossby Waves go to Die?, in preparation.

Legg, S. and K. L. Polzin. Internal tides generated on a corrugated continental slope: Part 1: Cross slope barotropic barotropic forcing, in preparation.

RESULTS

Internal Wave Modeling and Prediction

This method defines a closure scheme for the spectral transport of energy associated with finescale internal wave interactions. A mixed spatial/spectral representation that does not invoke a wave packet formulation is used. Non-linearity is explicitly treated as a flux in the spectral domain. Momentum conservation is attained by transferring energy into an oppositely signed wave vector at a rate proportional to the energy transports. Dissipation is implicitly viewed as the end result of nonlinear transfers to high wavenumber.

A specific formulation was given to these transfers which can be described as a relaxation to equilibrium power laws and a backscattering process. The closure scheme incorporates a quadratic dependence of the high-wavenumber transport on buoyancy frequency and spectral level in the vertical wavenumber and frequency domains, and interaction timescales which decrease with increasing wave frequency. This specific formulation was used in a numerical scheme to assess the spatial evolution of an anisotropic wavefield. The predicted patterns of relaxation and vertical anisotropy are in reasonable agreement with finescale observations above rough bathymetry. Simple analytic solutions have been examined.

Quasi-Permanent Finestructure

In a prior analysis of vertical profile data (Polzin, 1996), we had determined that

- horizontal kinetic energy / available potential energy ratios for mid-latitude data approached values between 1.5 and 2.0 at high wavenumber, in contrast to low wavenumber values ranging over 4−10.

- S^2 and N^2 variability are increasingly correlated with decreasing vertical scale.

These signatures are consistent with a relative increase of low aspect ratio quasi-permanent finestructure at small vertical scales. The correlation is interpreted as a product of the interaction between waves and finestructure. Quasi-permanent finestructure spectra were inferred with the use of a quasi-permanent density finestructure model for the observed correlation between S^2 and N^2. The quasi-permanent finestructure spectra were corroborated and refined with the use of concurrent current meter records. A parametric representation of the quasi-permanent finestructure spectrum was proposed.

The efficiency of internal waves and quasi-permanent finestructure in dispersing parcels along isopycnals varies greatly. Dispersion arises because spatial variations in the velocity field create persistent differential displacements of Lagrangian particles. A key feature of turbulence is persistent straining and relative separation in a Lagrangian reference frame. The decomposition of the finescale velocity and density fields into waves and quasi-permanent finestructure discussed above permits us to investigate isopycnal stirring associated with vortical modes. This stirring is treated here as a relative dispersion problem in the context of 2-D turbulence. Lateral diffusivities attain values of the order of 1 $m^2 s^{-1}$ after an initial transient of 5−10 days. After two weeks time an initial spot of tracer is predicted to have evolved into a convoluted web having an rms width of 2−4 km. These estimates agree with observations of the evolution of an anthropogenic tracer in NATRE.

The T−S relation at Mediterranean Water levels (about 1000-m depth) exhibits a large degree of variability. A surprising feature about the T−S finestructure observations at this level is a lack of horizontal coherence. It is difficult to relate features in one T−S profile with features in neighboring profiles at an 8-km grid spacing. Even at a 1.8-km grid spacing, the lack of coherence is alarming. This lack of coherence is evident as a 0.2-psu cloud when T−S diagrams for nearby stations are overplotted. In contrast, at shallower levels characterized by North Atlantic Central Water, the T−S relation is much tighter. The large amount of T−S variability at the Mediterranean Water level and the lack of horizontal coherence is consistent with compensated T−S finestructure being stirred as a passive tracer by the mesoscale eddy field. The eddy field is stirring large scale isopycnal gradients in salinity associated with the Mediterranean Tongue. The isopycnal gradients are much weaker at North Atlantic Central Water levels. This interpretation of eddy stirring producing compensated finestructure is supported by the temperature variance budget for the eastern North Atlantic (Figure 1).

Twist

The TWIST (Turbulence and Waves above Irregular, Sloping Topography) field program was conceived under the hypothesis that the finescale wavefield above topographic roughness would have the horizontal scale of that roughness superimposed upon it. We strongly suspected enhanced fine- and

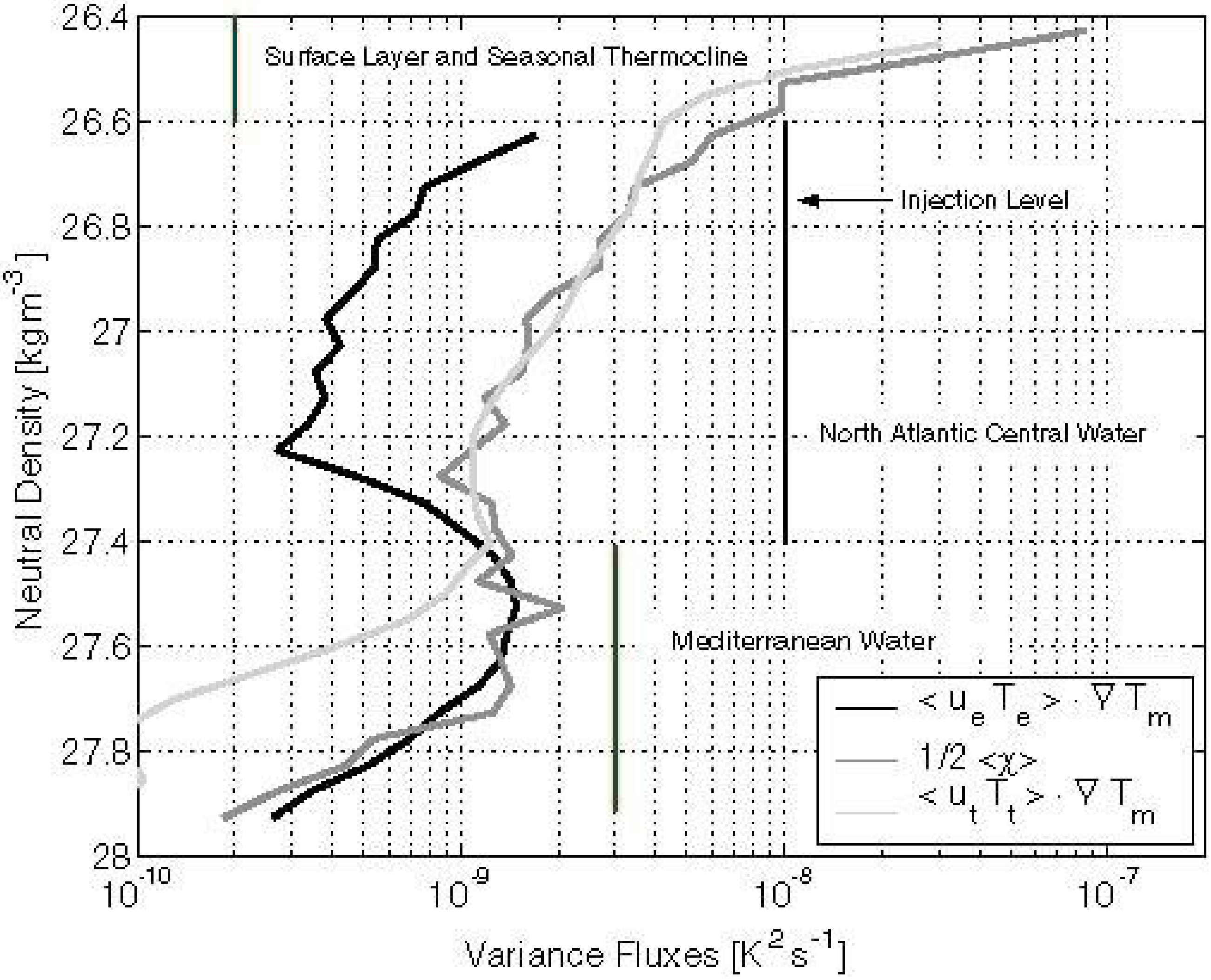

Figure 1. The temperature variance budget as a function of density surfaces for the NATRE region, in the eastern North Atlantic on the southern edge of the Mediterranean Salt Tongue. The black line represents the cascade of temperature variance by eddy stirring of the mean isopycnal temperature gradient. The dark gray line is the cascade of temperature variance by turbulent motions acting on the mean diapycnal gradient. The light gray line is the dissipation of temperature variance by molecular processes, as measured by microstructure probes. Water mass designations and the level of the SF_6 injection appear to the right and upper left. At the North Atlantic Central Water level, temperature gradient variance is largely associated with processes such as internal wave breaking and double diffusion. At the Mediterranean Water level, eddy stirring significantly contributes to the production of temperature gradient variance.

microstructure would be present on the Continental Slope just north of Cape Hatterras as this region exhibits a combination of substantial flows and topographic roughness superimposed upon the Slope.

These data reveal that turbulent mixing is greatly enhanced above rough bathymetry on the continental slope. Vertical profiles of turbulent diffusivity indicate a bottom enhancement there. At the moored array, the turbulent diffusivity ($K_\rho = 0.25\ \varepsilon/N^2$, with ε the rate of dissipation of turbulent kinetic energy and N the buoyancy frequency) in the bottom 200 m is more than two orders of magnitude larger (20×10^{-4} m^2 s^{-1}) than that estimated for the upper 100 m of the water column. Farther offshore, the turbulent diffusivity decreases. Within the Gulf Stream, vertical mixing is weak ($K_\rho \leftarrow 10^{-5}$ m^2 s^{-1}) and approximately independent of depth, despite the fact that the oceanic velocities within the Gulf Stream are typically much larger than on the continental slope. The key to mixing in this experiment, as with our previous investigations of tidal mixing, is the presence of rough bathymetry. Beneath the Gulf Stream, the ocean bottom is well-sedimented and quite smooth. The weak signal within the thermocline on the warm side of the Gulf Stream front may be associated with near-inertial internal wave trapping in the negative relative vorticity pool of the velocity jet.

The turbulent mixing on the continental slope is associated with subinertial fluctuations having periods of 1–2 days, vertical wavelengths of 100–300 m, horizontal wavelengths of 10–15 km, and peak-to-peak amplitudes of 0.1 m s^{-1}. Preliminary analysis suggests that these fluctuations represent topographic waves which are the by-product of baroclinic instability of the larger-scale flow. The energetics of this system is under study.

The moored array data documents a mode 3 (approximately) internal tide that does not appear to be propagating offshore. With Sonya Legg, the problem of wave scattering from a sloping boundary with superimposed topographic corrugations has been investigated. For internal waves propagating in the offshore sense, there is a tendency for wave energy to be scattered back towards shallow water. Preliminary analysis suggests the mode-3 internal tide evident in the data is a product of the internal tide generated at the shelf break being back scattered by bathymetric features superimposed upon the continental rise.

IMPACT/APPLICATIONS

We anticipate that this work will form the basis for future representations of internal wave processes and finescale isopycnal dispersion in predictive numerical models.

TRANSITIONS

Existing predictive numerical models do not represent finescale phenomena. The predictive ability of these models depends upon the parameterization of such phenomena. The descriptions of finestructure and physical understanding provided by our simple representations will help improve their skill.

RELATED PROJECTS

E. Kunze participated in the TWIST field program which initiated this grant. S. Legg has obtained ONR funding for numerical studies of internal wave processes in the littoral zone. We are working closely with Dr. Legg. M. Sundermeyer is working on numerical simulations of isopycnal stirring associated with vortical modes. A collaboration with Y. Lvov on internal wave modeling has been initiated. Finally, the insight gained as part of this grant will have a direct impact on the interpretation of HRP and tracer data acquired during the Brazil Basin Experiment (NSF grants to J. Ledwell, J. Toole and R. Schmitt) and the interpretation of finestructure in WOCE data (NSF grant with E. Kunze).

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