parameter regimes and identify essential physical processes instrumental in maintaining different types of low-frequency variability.

These results are used to study predictable climate modes that can be detected at the ocean's surface in an optimal way, by distinguishing between surface signatures of the model's oscillatory solutions.

OS41S-12 1135h

A new approach to parameterising geostrophic eddies

Susan T Adcock[1] (+44 118 987 5123 ext 7901; susan@met.rdg.ac.uk)

David P Marshall[1] (davidm@met.rdg.ac.uk)

[1]Deptartment of Meteorology, University of Reading PO Box 243 UNITED KINGDOM, Reading RG6 6BB, United Kingdom

We revisit the problem of parameterising geostrophic eddies from the perspective of geostrophic turbulence theory. A key aspect is that energy cascades to larger spatial scales and is approximately conserved, whereas potential enstrophy cascades to smaller spatial scales where it is dissipated. Results are presented from an eddy-resolving, one-and-a-half layer model of abyssal recirculations. Using these results, we develop a new parameterisation that successfully reproduces aspects of the eddy-resolving integrations.

Extensions of these calculations to multiple layers will be presented, in particular focussing on which properties are conserved and dissipated, with an emphasis on interior layers that are not directly in contact with the upper or lower boundaries.

OS41T HC: 316 B Thursday 0830h

Mixing and Doubly Diffusive Processes

***Presiding:* F G Jacobitz,** University of California**; B R Ruddick,** Department of Oceanography

OS41T-01 0830h

Differential Diffusion of T and S in Bi-stable Conditions

Ann E. Gargett[1] (757-683-6009; gargett@ccpo.odu.edu)

William J. Merryfield[2] (250-363-6402; Bill.Merryfield@ec.gc.ca)

Greg Holloway[3] (250-363-6746; hollowayg@pac.dfo-mpo.gc.ca)

[1]Center for Coastal Physical Oceanography, Old Dominion University, Norfolk, VA 23529-0276, United States

[2]Canadian Centre for Climate Modelling and Analysis, University of Victoria P.O. Box 1700, Victoria, BC V8W 2Y2, Canada

[3]Institute of Ocean Sciences, P.O. Box 6000, Sidney, BC V8L 4B2, Canada

Double diffusive phenomena resulting from the factor of 100 difference in the molecular diffusivities for T and S are widely known and studied. Less well recognized is the potential for preferential diffusion of T relative to S in conditions where both mean gradients are stabilizing, conditions common in estuarine and coastal environments. This phenomenon, termed differential diffusion, has been explored in a series of fully three-dimensional direct numerical simulations of decaying turbulence, using molecular coefficients consistent with T in seawater, and a "salt" scalar S which is 10 times less diffusive than T. The simulations exhibit differential diffusion, in the expected sense of larger flux of T than of S : the maximum flux differential is of order 20%, and is associated with the largest observed mixing efficiency. Since T and S made equal contributions to the mean density gradient in the simulations, the observed flux differences imply that T has a larger turbulent diffusivity than S. Although the physical scale range of the simulations is restricted by computer limitations, available comparisons with oceanographic data, including values of turbulence Re and temperature Cox numbers, as well as velocity and scalar spectral shapes, all suggest that the numerical results are indistinguishable from direct observations of sporadic turbulence in the stratified ocean interior. Since these simulations will underestimate the degree of differential diffusion between T and true salt (with molecular diffusivity 100 times less than T), we conclude that the sporadic turbulence characteristic of stratified ocean water columns will normally exhibit significant differential diffusion, in the sense of a vertical diffusivity of T exceeding that of salt. Equal turbulent diffusivities of T and S is a basic tenent of our beliefs about the effects of "ordinary" turbulence in the stratified interior of the ocean, underlying both the "theory" used to derive density flux (diffusivity) from measurement of T microstructure, and the alternate method using observations of the vertical diffusion of a dye (which generally has the molecular diffusivity of neither T nor S). Acceptance of the reality of differential diffusion thus impacts much of what we "know" about the magnitude of turbulent fluxes in stratified regions of the ocean. Accounting for differential diffusion may be particularly important in settings, such as high latitude oceans and estuaries, where density structure is dominated by salinity.

OS41T-02 0845h

Laboratory Experiments on Continually Forced 2D Turbulence

Mathew G Wells[1] (+31 40 2474285; m.g.wells@tue.nl)

Herman Clercx[1]

Gert Jan van Heijst[1]

[1]Eindhoven University of Technology, Department of Applied Physics P.O. Box 513, Eindhoven 5600 MB, Netherlands

There has been much recent interest in the advection of tracers by 2D turbulence in geophysical flows. While there is a large body of literature on decaying 2D turbulence or forced 2D turbulence in unbounded domains, there have been very few studies of forced turbulence in bounded domains. In this study we present new experimental results from a continuously forced quasi 2D turbulent field.

The experiments are performed in a square Perspex tank filled with water. The flow is made quasi 2D by a steady background rotation. The rotation rate of the tank has a small ($< 8\%$) sinusoidal perturbation which leads to the periodic formation of eddies in the corners of the tank. When the oscillation period of the perturbation is greater than an eddy roll-up time-scale, dipole structures are observed to form. The dipoles can migrate away from the walls, and the interior of the tank is continually filled with vortexs. From experimental visualizations the length scale of the vortexs appears to be largely controlled by the initial formation mechanism and large scale structures are not observed to form at large times. Thus the experiments provide a simple way of creating a continuously forced 2D turbulent field. The resulting structures are in contrast with most previous laboratory experiments on 2D turbulence which have investigated decaying turbulence and have observed the formations of large scale structure. In these experiments, decaying turbulence had been produced by a variety of methods such as the decaying turbulence in the wake of a comb of rods (Massen et al 1999), organization of vortices in thin conducting liquids (Cardoso et al 1994) or in rotating systems where there are sudden changes in angular rotation rate (Konijnenberg et al 1998).

Results of dye visualizations, particle tracking experiments and a direct numerical simulation will be presented and discussed in terms of their oceanographic application.

URL: http://www.fluid.tue.nl/users/mathew/

OS41T-03 0900h

Vertical Mixing and Transports Through a Stratified Shear Layer

H.J.S. Fernando[1] (480-965-5602; j.fernando@asu.edu)

Eric J. Strang[1] (480-965-3671; estrang@phx.telusa.com)

[1]Environmental Fluid Dynamics Program, Department of Mechanical and Aerospace Engineering, Arizona State University, Tempe, AZ 85287-9809, United States

A stratified shear layer was generated in the laboratory by driving a turbulent mixed layer over a quiescent, deep dense layer. As a result, a density was formed between the upper and lower layers. This density interface was embedded in a velocity shear layer. Detailed velocity, density, and average local Richardson number Ri measurements were made through the stratified shear layer, from which the fluxes of momentum and density through the interface as well as energetics of the stratified shear layer were evaluated as a function of Ri. The quantities measured included the flux Richardson number, the dissipation flux coefficient, and the eddy diffusivities of momentum and density averaged across the shear layer. The results were compared with various deep and coastal oceanic data as well as common oceanic eddy diffusivity and flux parameterization schemes.

OS41T-04 0915h

Shear Diffusion in Plumes

Stefan G Llewellyn Smith (1-858-822-3475; sgls@mae.ucsd.edu)

Department of Mechanical and Aerospace Engineering, UCSD, A-0411 9500 Gilman Drive, La Jolla, CA 92093-0411, United States

The hot fluid issuing from hydrothermal vents supports communities comprising animals that can only survive close to the vents. Vent activity appears to be ephemeral with a time scale of decades, and the only way for stationary benthic species to survive on evolutionary time scales is to colonize other active vent habitats. Kim, Mullineaux & Helfrich (1994) have measured larval abundances near hydrothermal vents and have combined these measurements with standard plume models to provide estimates of vertical larva fluxes. The larvae entrained into the plume are transported a considerable distance vertically into regions of faster horizontal motion which may lead to dispersal into habitats unreachable by larvae in near-bottom flows.

We investigate the dispersion of particles disperse inside a plume is modelled. The particles are viewed as a passive tracer that is advected by the velocity field of a line or axisymmetric plume. This velocity field is different from the usual Poiseuille flow of shear dispersion. Nevertheless, shear dispersion occurs and we develop a convection-diffusion equation is developed for the particle density. The effect of entrainment is discussed.

OS41T-05 0930h

Experiments on Differential Diffusion in a Diffusively-Stable, Turbulent Flow

Patrick Ryan Jackson[1] (217-333-6183; prjackso@uiuc.edu)

Chris R. Rehmann[1] (217-333-9077; rehmann@uiuc.edu)

[1]University of Illinois at Urbana-Champaign, 2527 Hydrosystems Laboratory 205 N. Mathews Ave., Urbana, IL 61801, United States

If temperature and salinity are mixed at different rates, the mixing efficiencies in flows with the same relative stratification strength can vary if the contributions of temperature and salinity to the density differ. We performed laboratory experiments to evaluate the conditions under which differential diffusion of heat and salt occurs and its effect on the mixing efficiency. A linearly stratified system that is stably stratified with both heat and salt is stirred with horizontally-oscillating vertical rods. This configuration isolates effects of molecular diffusivity by ensuring that both scalars experience the same stratification and turbulence strengths. Eddy diffusivities are equal for $\epsilon_a/\nu N^2 > 300$, where ϵ_a is an average dissipation, and the eddy diffusivity of heat exceeds that of salt for lower values. The effect of differential diffusion on the mixing efficiency was evaluated by allowing the initial density ratio $\alpha\Delta T/\beta\Delta S$ to vary. For weak stratification, the efficiency does not depend on density ratio, but for strong stratification, the efficiency increases with increasing density ratio.

OS41T-06 1005h

Measuring Intrusive Heat Flux Across a Front

Barry R Ruddick[1] ((902) 494-2505; barry.ruddick@dal.ca)

Neil Oakey[2] ((902) 426-3147; OakeyN@mar.dfo-mpo.gc.ca)

[1]Department of Oceanography, Dalhousie University, Halifax, NS B3H4J1, Canada

[2]Bedford Institute of Oceanography, P.O. Box 1006, Dartmouth, NS B2Y 4A2, Canada

The lateral heat flux <uT> across intrusive thermohaline fronts is nearly impossible to measure directly because the intrusion velocities are small, O(1 mm/s). These velocities are almost completely masked by instrument errors and by internal wave velocities. We present a model that relates the intrusive-scale motions to the thermal microstructure, resulting in a simple parameterization for the cross-frontal heat flux. This model, a combination of Joyces intrusion model and the microstructure model of Osborne and Cox, shows that the cross-frontal heat flux results in intrusive-scale temperature variance, which must be erased by diapycnal mixing, and then dissipated by molecular heat conduction. The specific intrusive driving mechanism doesnt matter to this method.

The method is tested using hydrographic and microstructure observations from Meddy "Sharon. Three sets of hydrographic observations over a one-year period showed inward erosion of the Meddy by thermohaline intrusions, and consequent decrease in radius of the

salinity front, the velocity structure, and other aspects of the Meddy structure. The outward flux associated with this detrainment is used to calculate the total rate of microstructure dissipation demanded by the model.

Partway through the year, the microstructure dissipation was surveyed. This was found to be most intense in the intrusive frontal zone, and to a lesser degree, just above and below the Meddy core. The volume integrated thermal dissipation rate was estimated from these observations, and agreed with that demanded by the model to better than 10%. We conclude that this method and model can be used in other less well-constrained situations to estimate the cross-frontal intrusive heat flux.

OS41T-07 1020h

Critical Internal Wave Reflection, High-Frequency Internal Waves, and Turbulence in Mono Lake and Lake Tahoe, California

Erika McPhee-Shaw[1] (1-805-893-2363; eemcphee@icess.ucsb.edu)

William Shaw[1] (1-805-893-5501; wshaw@icess.ucsb.edu)

Sally MacIntyre[1] (1-805-893-3951; sally@icess.ucsb.edu)

[1]Institute for Computational Earth Systems Science University of California Santa Barbara, 6832 Ellison Hall, Santa Barbara, CA 93106, United States

The internal wave field was measured with an array of temperature moorings located over varying topographic slope angles in Mono Lake, CA and Lake Tahoe, CA. We present observations of the spectral distribution, and spatial and temporal variability of high-frequency internal waves. In particular we focus on waves in the frequency band critical for local bottom slopes, and on waves at higher frequencies, approaching N. Internal wave breaking near the critical frequency for sloping topography is hypothesized to be one of the important mechanisms by which energy is lost from the internal wave field to turbulent dissipation near boundaries. Because high-frequency internal waves can be a signature of shear instabilities, the energy at the near-N frequencies also may be related to turbulent dissipation. The low-frequency, basin-scale internal waves in Mono Lake appear to be directly forced by the wind. The spectral energy density from the total time series in each lake falls off as ω^{-2}, however over smaller time blocks, occasional anomalies from the G-M spectrum appear at intermediate and high frequencies. These peaks occur on specific density surfaces and are not distributed throughout the water column. We investigate the relationship between such events and phase of the basin-scale waves and wind strength. Spectra at varying depths are examined for evidence of critical-frequency energy enhancement over four sites with different bottom slope angles. Preliminary results suggest that critical reflection may not be a dominant mechanism for turbulent dissipation in Mono Lake. Microstructure profiles concurrent with some of our temperature measurements are used to ascertain whether a direct relationship can be made between turbulent dissipation and internal wave energy in the near-critical or near-N frequency bands.

OS41T-08 1035h

Flow Structure and Turbulence Distributions in the Coastal Ocean from PIV Data

William A M Nimmo Smith[1] (alexns@jhu.edu)

Luksa Luznik[1] (lluznik@titan.me.jhu.edu)

Weihong Zhu[1] (wzhu@titan.me.jhu.edu)

Joseph Katz[1] (katz@jhu.edu)

Thomas R Osborn[1] (osborn@jhu.edu)

[1]Dept. Mechanical Engineering, The Johns Hopkins University, Latrobe Hall, 3400 N. Charles St., Baltimore, MD 21218, United States

Particle Image Velocimetry (PIV) allows measurements of the instantaneous distribution of two velocity components within a sample plane. This technique overcomes the inability to separate the unsteady flows associated with turbulence from those induced by surface waves in the coastal ocean, which adversely affects the data obtained using point measurement techniques. The availability of instantaneous spatial distributions of velocity enable us to calculate spatial turbulence spectra and structure functions. To estimate the Reynolds shear stress, we calculate the covariance of velocity components, cov(Δu,Δw), as a function of separation between measurement points, r. Trowbridge (JAOT, **15**, 290) shows that, provided the separation is larger than the characteristic turbulence scale and smaller than the surface wavelength, cov(Δu,Δw) is equal to twice the Reynolds shear stress and insensitive to slight misalignments of the velocity components. In our system the sample area varies between 0.3x0.3 - 0.5x0.5m, each containing 63x63, 2-D velocity vectors, spaced 0.5-0.8cm apart, respectively. Two such sample areas positioned on the same vertical plane and separated horizontally by 1m have been used for calculating the distribution of cov(Δu,Δw) up to r=1.5 m. The data shows, as expected, that cov(Δu,Δw) increases with r at small separations and then reaches asymptotically a constant value at scales of about 1m. The spacing required to reach a plateau increases with distance from the bottom. When the covariance reaches this plateau and the length scale is still substantially smaller than the wavelength of surface waves (~100m in our measurements), we cover the relevant turbulent length scales and the data is still free of wave contamination. We have used this method for measuring the distributions of shear stresses in the bottom boundary layer of the coastal ocean.

To obtain the data, a submersible PIV system was deployed at two locations close to the LEO-15 site in regions with depths of 12 and 20m. The PIV and auxiliary instruments were mounted on adjustable seabed platforms, which enabled us to orient the sample areas with the flow and perform measurements at any desired elevation, from very close to the bottom up to 10m above the bed. Specific details of the system are presented in another abstract (Katz et al.). Data were collected at different elevations and under different mean flow and wave conditions for periods in excess of 20min each, and at rates of up to 3.3Hz. The PIV data are augmented and compared to simultaneous measurements of turbulence using an airfoil probe and of surface waves using a pressure transducer. CTD and ADCP are used for profiling the entire water column.

The results include vertical distributions of mean velocity, dissipation rate and shear stress under different mean current and wave conditions. The dissipation rates are estimated from the turbulence spectra. There is clear evidence that a log layer exists only when the amplitude of the wave induced motion is significantly smaller than the mean flow. Distributions of vorticity enable us to identify and follow the transport and development of large scale eddy structures within the sample areas. Conditional sampling enables us to correlate between the characteristics of the turbulence and the phase of the wave induced flows. The analysis is performed at different ratios of mean flow to amplitude of wave induced motion, including cases with zero mean flow.

Funded in part by NSF and in part by ONR.

OS41T-09 1050h

Anisotropy and Reynolds Number Effects in Turbulent Stratified Shear Flow

Frank G. Jacobitz ((909) 787-2927; jacobitz@engr.ucr.edu)

University of California, Department of Mechanical Engineering, Riverside, CA 92521-0425, United States

Shear and stratification are ubiquitous features of turbulent flow in the ocean. A prototypical example of this flow with uniform shear and stratification has been studied extensively in the past decade using direct numerical simulations. The numerical simulations provide great detail of the flow. For example, all components of the viscous dissipation rate can be computed from the numerical data. Due to the presence of shear and stratification, the overall dissipation is distributed unevenly over its components. It was found that the contribution of the vertical gradient of the downstream velocity component increases from about 20% for unstratified flow with $Ri = 0$ to about 30% for weakly stratified flow with $Ri = 0.1$ and to about 50% for strongly stratified flow with $Ri = 1$.

In field experiments, generally only a limited number of these components can be measured. Therefore, numerical simulations can help to estimate the overall value of the dissipation rate from the measured components. However, the Reynolds number of the direct numerical simulations is relatively low compared to oceanic flow and great care has to be taken in an application of the numerical results to oceanic flow. This contribution discusses Reynolds number effects on the Reynolds stress anisotropy, buoyancy flux, and dissipation rate components. It was found that Reynolds number effects on Reynolds stress anisotropy and buoyancy flux are limited to very low values of the Reynolds number but that they persist to larger values of the Reynolds number for dissipation rate components.

The direct numerical simulations are performed on a parallel computer and the computational domain has up to $512 \times 256 \times 256$ grid points. The spatial discretization is accomplished by a spectral collocation method and the time advance uses a fourth-order Runge-Kutta scheme.

This study is supported with computer time by the National Partnership for Advanced Computational Infrastructure (NPACI).

OS42A HC: Hall III Thursday 1330h

Molecular Ecology of Carbon and Nitrogen Cycles in Ocean Margins II

Presiding: **F Wilkerson,** San Francisco State University**; J Paul,** University of South Florida

OS42A-92 1330h POSTER

Bacterial life strategies in an oligotrophic riverine environment: Microcolony formation versus living 'single'.

Denis Mavrocordatos (41-1-823-5409; denis.mavrocordatos@eawag.ch)

Edith Kaiser[1] (41-1-823-5096; edith.kaiser@eawag.ch)

Konrad Egli (41-1-823-5201; konrad.egli@eawag.ch)

[1]Edith Kaiser, EAWAG, Ueberlandstr. 133, Duebendorf 8600, Switzerland

The activity and the different life strategies of heterotrophic riverine bacteria as well as their major bacterial groups had been investigated in the highly pristine and oligotrophic River Tagliamento (Italy). Attached bacteria showed low abundance but very high biomass production. An opposite activity was observed for free-living cells from the water column. Temperature and low nutrient and DOC concentrations seem to overall control the activity pattern. From our samples eubacteria generally dominated the bacterial community living in the water column (70%) as well as attached on the substrate (100%). Eubacteria were comprised by >67% of alpha-, beta-proteobacteria and cytophaga. Mostly alpha-proteobacteria appeared to form microcolonies in the oxygenated hyporheic zone. Additionally, Atomic Force Microscopy of bacteria in water under controlled pH clearly demonstrated that coccoid-shaped cells develop large exopolymers to randomly colonize the surface of the carbonaceous substrate. Patches of biofilms could also be observed. According to our results, we propose that in competition for scarce resources, cells exhibit an active exchange between free-living and attached phases.

OS42A-93 1330h POSTER

Uptake of Selected DOM Components by Bacterial Groups in the Delaware Estuary

Rex R Malmstrom[1] (302-645-4030; rexrm@udel.edu)

Matthew T Cottrell[1] (cottrell@udel.edu)

David L Kirchman[1] (kirchman@udel.edu)

[1]College of Marine Studies University of Delaware, 700 Pilottown Rd, Lewes, DE 19958, United States

Assemblages of aquatic heterotrophic bacteria display a high degree of phylogenetic and metabolic diversity, though the link between phylogeny and metabolic activity remains unclear. This link can be investigated using a combination of microautoradiography and fluorescence in situ hybridization (Micro-FISH). Previous investigations using Micro-FISH observed certain phylogenetic groups dominate the uptake of specific components of the DOM pool. The dominance of a phylogenetic group, however, may vary in an environment such as the Delaware estuary where large shifts in the abundance of certain phylogenetic groups occur. In an investigation of the Delaware estuary with both FISH and Micro-FISH, large changes in the bacterial community composition were observed along the salinity gradient. Beta Proteobacteria and Cytophaga-Flavobacteria were the most abundant groups in the fresh waters, while the alpha Proteobacteria and Cytophaga-Flavobacteria were the most abundant in the saline waters. Similar to previous studies, preliminary Micro-FISH data suggest that Cytophaga-Flavobacteria dominated the degradation of protein in saline waters. Acetate was utilized primarily by the alpha Proteobacteria in saline waters, while the beta Proteobacteria and Cytophaga-Flavobacteria were the main acetate degraders in fresh waters. These data indicate that as the community composition changes along the salinity gradient, different phylogenetic groups dominate the degradation of the same compound.