180213 Tuesday PS21A

- **PS21A** Recent Advancements in Stratified Turbulent Mixing I

- *Oregon Convention Center*

- *- A107-A109*
    - This session will explore recent developments in understanding mixing in stratified turbulent shear flows and its role in ocean circulation. The significance of mixing to the ocean energy cycle has long been recognized. While pioneering work developed a basic understanding of turbulence generated by shear instabilities and its efficiency in overcoming stable stratification, significant advancements have been made in recent years. A new framework based on the concept of Available Potential Energy has shed light on the role of mixing in the ocean energy cycle and its efficiency in flows driven either by shear or convective overturning, both characteristic of intermittent ocean turbulence. Meanwhile, new mechanisms for the development of shear instabilities are being discovered through numerical modeling and observations. In addition, meta-analyses of increasingly resolved DNS and ocean microstructure are leading to improved mixing parameterizations for use in ocean models and interpreting observational data. The talks in this session will span theory, experiments, modeling, and observational approaches to discuss recent advancements, new techniques and outstanding questions in turbulent mixing. We encourage submissions focusing on mixing across a range of ocean scales and settings, including global, coastal and estuarine, and its influence on biogeochemical processes.

Primary Chair

- Brian L White
  - *University of North Carolina at Chapel Hill*

Co-Chairs

- Stephen G Monismith
  - *Stanford University*
- Jeffrey R Koseff
  - *Stanford University*

- 08:00 AM**PS21A-01** On the Prediction of Diapycnal Mixing in Stably Stratified Turbulence***Subhas Karan Venayagamoorthy***, *Colorado State University, Department of Civil and Environmental Engineering, Fort Collins, CO, United States*
- The understanding and quantitative prediction of diapycnal (irreversible) mixing of density and momentum in stably stratified flows remains an important ongoing challenge. This is not surprising given the complexity introduced into most geophysical flows by factors such as density stratification, complex topography and a host of physical phenomena associated with such flows. From a practical perspective, there is a critical need to obtain accurate prediction of turbulent heat and momentum fluxes using indirect measurements in the field. Indirect methods for estimating mixing rates typically rely on the inference of two key quantities namely: (i) the rate of dissipation of turbulent kinetic energy ε and (ii) the mixing efficiency R_f, which is a measure of the amount of turbulent kinetic energy that is irreversibly converted into background potential energy, respectively. This talk will bring to focus some traditional (indirect) methods used to infer diapycnal mixing rates in stably stratified turbulence and highlight some new insights that may provide a basis for more robust and unifying prediction of turbulent mixing.
- doi: 10.1063/1.4868142,doi: 10.1063/1.4813809,DOI: 10.1175/JPO-D-14-0128.1
- ## Plain Language Summary
- The understanding and quantitative prediction of diapycnal (irreversible) mixing of density and momentum in stably stratified flows remains an important ongoing challenge. This is not surprising given the complexity introduced into most geophysical flows by factors such as density stratification, complex topography and a host of physical phenomena associated with such flows. From a practical perspective, there is a critical need to obtain accurate prediction of turbulent heat and momentum fluxes using indirect measurements in the field. Indirect methods for estimating mixing rates typically rely on the inference of two key quantities namely: (i) the rate of dissipation of turbulent kinetic energy and (ii) the mixing efficiency, which is a measure of the amount of turbulent kinetic energy that is irreversibly converted into background potential energy, respectively. This talk will bring to focus some traditional (indirect) methods used to infer diapycnal mixing rates in stably stratified turbulence and highlight some new insights that may provide a basis for more robust and unifying prediction of turbulent mixing.

- 08:15 AM**PS21A-02** Energetics of Mixing at Geophysical Scales***Alberto D Scotti**, University of North Carolina at Chapel Hill, Marine Sciences, Chapel Hill, NC, United States, Pierre-Yves Passaggia, UNC, Marine Science, Chapel Hill, NC, United States and Brian L White, University of North Carolina at Chapel Hill, Chapel Hill, NC, United States*
- Energetics arguments have been central to understand the role of mixing in the ocean, both in the bulk, as well as when applied to isolated mixing events. In a stratified incompressible flows there are two reservoirs of energy, the kinetic and potential energy. The standard expression $E_{¥rm p}=¥rho gZ$ for the potential energy is not convex, and thus, within an energetic framework based on this definition, turbulent fluctuations have zero potential energy, a rather unsatisfactorily state of affairs.
The solution is to modify the definition of potential energy to include only the portion that is effectively available. This introduces the concept of Available Potential Energy (APE). Within the oceanographic community, the idea of APE has been strongly influenced by Lorenz's approach published in a seminal 1955 paper, which used a reference state depending only on the buoyancy distribution of fluid. Within the atmospheric community, there have been attempts to define more general reference states, which include large-scale constraints imposed by rotation (Codoban and Shepherd, 2003). In this talk, we consider a general framework for Available Energy which shows that
Lorenz's definition, as developed by Winters et al. (1995), and Codoban and Shepherd's definition are special cases of a more general theory of AE which apply when the joint distribution of buoyancy and potential vorticity satisfy particular conditions. Within this new framework, resting states may possess a non-zero velocity component. This generalization of the APE theory opens new perspectives for distinguishing between thermally and mechanically driven systems, their energy budgets and the role of diapycnal mixing in large scale rotating flows.
- 08:30 AM**PS21A-03** Goldilocks Mixing in Wave-Induced Stratified Turbulence***Colm-cille Patrick Caulfield**[1], Ali Mashayek[2], Gunnar Voet[2] and Matthew H Alford[2], (1)University of Cambridge, BP Institute/Department of Applied Mathematics and Theoretical Physics, Cambridge, United Kingdom, (2)Scripps Institution of Oceanography, La Jolla, CA, United States*

- Turbulence induced by breaking waves is an abundant feature in nature occurring over a wide range of scales. Shear-induced turbulence, in particular, leads to `efficient' mixing of important properties such as temperature, salinity, nutrients, and chemical and biochemical tracers in the ocean and atmosphere. The complex nature of stratified turbulence, in particular its inherent spatio-temporal intermittency, has kept our understanding of its mixing properties largely dependent on observations and computations, both of which have serious limitations. Here we show that recent advances in ocean observations and computational resources have put us in a position to gain new insight into the nature of transient (but still highly significant) wave-induced turbulent mixing. Our primary finding is that the (generic) existence of natural transient `overturns' associated with the break down into turbulence of waves of different kinds has two key features. First, such overturns act so as to optimize the efficiency of turbulent mixing, defined as the percentage of energy available to turbulence which contributes to irreversible mixing. Second, this optimization of the mixing efficiency typically occurs for overturns when the turbulence is most energetic, thus leading in combination to substantially enhanced vertical transport of buoyancy. We show that this optimal absolute amount of mixing associated with the combined simultaneous effect of highly efficient and highly vigorous mixing manifests itself in direct numerical simulations, in a seemingly diverse range of historic oceanic datasets, as well as in more recent observations of overturn-based mixing in the Samoan Passage, an important choke-point as far as the ocean meridional overturning circulation is concerned. Therefore, there is an emerging amount of evidence that such mixing optimization is a generic feature of overturn-induced stratified turbulence.
- 08:45 AM**PS21A-04** Mixing Efficiency in the Ocean***Michael Charles Gregg**, Mercer Island, United States, Eric A. D'Asaro, University of Washington, Applied Physics Laboratory, Seattle, WA, United States, James J. Riley, University of Washington, Mechanical Engineering, WA, United States and Eric Kunze, Northwest Research Associates, Redmond, WA, United States*
- Mixing efficiency is the ratio of the net change in potential energy
  to the energy expended in producing the mixing.
  Parameterizations of
  efficiency and of related mixing coefficients are needed to estimate diapycnal diffusivity

from measurements of the turbulent dissipation rate.
Comparing diffusivities from microstructure profiling
with those inferred from the thickening rate of four simultaneous tracer releases
has verified, within observational accuracy,
0.2 as the mixing coefficient over a 30-fold range of diapycnal diffusivities.
Although some mixing coefficients can be estimated from pycnocline measurements,
at present mixing efficiency must be obtained
from channel flows, laboratory experiments and numerical simulations.
Reviewing the different approaches demonstrates that estimates and
parameterizations for mixing efficiency and coefficients are not converging beyond
the at-sea comparisons with tracer releases,
leading to recommendations for a community approach to address
this important issue.

- **Plain Language Summary**
- Owing to intense controversy about mixing efficiency, different ways of estimating it,
- observational and numerical, are reviewed and evaluated, leading us to conclude
- that present approaches are not converging. We recommend steps to improve the situation.
- 09:00 AM**PS21A-05** Buoyancy Fluxes in Stratified Flows: Observations and Parameterizations*Jeffrey R Koseff[1], **Stephen G Monismith**[1], Ryan K Walter[2], Kristen A Davis[3], Clifton Brock Woodson[4], Geno R Pawlak[5], Michael E Squibb[1] and Jamie Dunckley[6], (1)Stanford University, Stanford, CA, United States, (2)California Polytechnic State University, Physics Department, San Luis Obispo, CA, United States, (3)University of California Irvine, Civil and Environmental Engineering Department, Irvine, CA, United States, (4)Stanford University, Palo Alto, CA, United States, (5)University of California San Diego, La Jolla, CA, United States, (6)EPRI, United States*
- We present a synthesis of observations of turbulent buoyancy fluxes, *B*, made at five sites where flows and turbulence are primarily associated with internal waves, both breaking and non-breaking. In four cases, *B* was calculated from the covariance of velocity and density whereas in the fifth case, it was inferred from the rate of temperature variance dissipation. Overall, we find that the flux Richardson number, Ri_f, depends on what we believe should be called the Gibson number (also

known as the buoyancy Reynolds number), $Gi = \varepsilon/\nu N^2$: when $Gi < 100$, $Ri_f \approx 0.27$, and when $Gi > 100$ $Ri_f \approx 2.7\ Gi^{-0.5}$, in agreement with the functional relationship found originally using direct numerical simulation (DNS). Our observations do not match well other DNS-derived models that parameterize Ri_f in terms of the gradient Richardson number, *Ri,* or the turbulence Froude numbers, Fr_k and Fr_t. Similarly, $Ri_f(Gi)$ is found to be the same for all the covariance data sets, despite the fact that these 4 flows produce turbulence that falls in different regimes defined by several pairs chosen from the 5 non-dimensional numbers that the Buckingham Pi theorem shows may affect Ri_f . Comparison will also be made to measurements made using microstructure profilers as compiled in the Scripps Microstructure Data Archive.

- 09:15 AM**PS21A-06** Diapycnal Mixing on Continental Shelves***Nicole L Jones***[1], *Cynthia Bluteau*[2], *Gregory N Ivey*[3], *Jeffrey W Book*[4], *Tamara Lillian Schlosser*[5], *Matthew Rayson*[6] *and Andrew Zhulberti*[5], *(1)University of Western Australia, Crawley, WA, Australia, (2)Institut des Sciences de la Mer de Rimouski, Rimouski, QC, Canada, (3)University Western Australia, School of Civil, Environmental and Mining Engineering and UWA Oceans Institute, Crawley, Australia, (4)U.S. Naval Research Laboratory, Stennis Space Center, MS, United States, (5)University of Western Australia, School of Civil, Environmental and Mining Engineering and UWA Oceans Institute, Crawley, Australia, (6)The University of Western Australia, School of Civil, Environmental and Mining Engineering and UWA Oceans Institute, Crawley, Australia*
- Diapycnal mixing on continental shelves is important both to the transport of scalars and the regional circulation. Here we focus on moored observations of mixing from three contrasting shelf locations around Australia: each with varying strength of stratification, bathymetry and tide and wind forcing. The instrumentation observed both vertical temperature and velocity structure as well as turbulence quantities at point locations, allowing diapycnal diffusivity to be estimated via two contrasting methods. A new method allowed estimation of diapycnal diffusivity from more typical through water column moorings via the Ellison length scale and the mean vertical shear, producing long (approximately 2 months) time series of through water column mixing estimates. Whereas collocated acoustic Doppler velocimeters and fast-response thermistors provided point estimates of the diffusivity throughout

the measurement period. The observed diffusivity spanned six orders of magnitude and the median value was over four orders of magnitude greater than molecular diffusion. The highest values of diapycnal diffusivity were event driven, for example, during the occurrence of nonlinear internal wave packets on the Australian Northwest Shelf when the stratification weakened and there were comparatively large turbulent overturns. The diffusivity was often larger at the mid-water column compared with the near-bed, due to changes in the stratification and shear. Our direct estimates of diffusivity demonstrate that using the Osborn model with a constant mixing efficiency can both vastly over-predict and under-predict the diffusivity. Our diffusivity estimates can be used to improve predictions of processes such as the transport of nutrients, sediment and pollutants.

- 09:30 AM**PS21A-07** Observed variations in turbulent mixing efficiency in the deep ocean***Takashi Ijichi*** *and Toshiyuki Hibiya, The University of Tokyo, Department of Earth and Planetary Science, Graduate School of Science, Tokyo, Japan*
- Recent progress in direct numerical simulations (DNS) of stratified turbulent flows has led to increasing attention to the applicability of the constant mixing coefficient Γ in the Osborn’s turbulent diffusivity model, Γ = 0.2, which has been widely used to evaluate turbulent diffusivities in the ocean. Motivated by lack of observational estimates of Γ particularly in the deep ocean, this study examines variations of Γ using deep microstructure profiles obtained in various regions such as the Izu-Ogasawara Ridge, the Aleutian Ridge, and the Southern Ocean. It is shown that Γ is not constant but significantly varies with the ratio of the Ozmidov scale to the Thorpe scale R_{OT} in a fashion similar to that obtained by previous DNS studies. Efficient mixing events with Γ ~ 1 and R_{OT} ~ 0.1 are frequently observed in the deep ocean, while moderate mixing events with Γ ~ 0.1 and R_{OT} ~ 1 tend to be observed in the upper ocean. Furthermore, the observed negative relationship between Γ and R_{OT} is consistent with a simple scaling $\Gamma \sim R_{OT}^{-4/3}$ that can be derived from classical turbulence theories. In contrast, the observed results exhibit no definite relationships between Γ and the buoyancy Reynolds number Re_b, although Re_b has long been thought to be another key parameter controlling Γ.

- 09:45 AM**PS21A-08** Richardson number dependence of turbulent stratified mixing at high Gibson numbers.***Pierre-Yves Passaggia***[1]*, Brian L White*[2] *and Alberto D*

Scotti[1], (1)University of North Carolina at Chapel Hill, Marine Sciences, Chapel Hill, NC, United States, (2)University of North Carolina at Chapel Hill, Chapel Hill, NC, United States

- Turbulent mixing is a critical component of the ocean energy budget, contributes to the closure of the Meridional Overturning Circulation, and is an important driver of coastal processes. However, despite decades of research, we still lack a precise understanding of how mixing in a stratified environment depends on the environmental conditions that drive it. We propose a new experiment that allows for performing shear-driven stratified turbulent experiments at high buoyancy Reynolds (i.e. Gibson) numbers while varying the bulk Richardson number. The present setup consists of a 36 m (long) x 1.2 m (high) x 0.75 m (wide) stratified recirculating tank where a shear profile is created by injecting dense salty water through a slit. The jet coming out from the slit forces a linear type profile that mixes a stratified density profile, triggering instabilities, turbulence and mixing.
- We use combined measurements of particle image velocimetry (PIV), laser induced fluorescence (LIF), acoustic doppler velocimetry (ADV), hot wire anemometry (CTA) and conductivity measurements (CTD), to investigate the dependence of mixing efficiency together with the statistics of the gradient Richardson number. Vertical profiles of velocity and density are gathered using the ADV and high-frequency CTD measurements and are compared with combined PIV and double emission LIF. The measurements of dissipation are also compared between the CTA and the PIV where the results span a line in the Gibson-number Richardson parameter space. These experiments provide the first quantitative study linking mixing efficiency and Richardson numbers at high Gibson numbers in the range $Ri_b¥approx[0.1,4]$. The energetics of the flow are further analyzed comparing the flux Richardson method with the local energetics (Scotti & White, JFM, 2014) obtained from the combined PIV and LIF.
- **PS23A** Recent Advancements in Stratified Turbulent Mixing II
    - *Oregon Convention Center*
    - *- A107-A109*

- 02:00 PM**PS23A-01** Rapid temporal evolution of shear instabilities revealed with multi-beam sonar***W Rockwell Geyer***[1]*, Andone C Lavery*[2] *and EeShann Bhatt*[2]*, (1)Woods Hole Oceanographic Institution, Applied Ocean Physics and Engineering, Woods Hole, MA, United States, (2)Woods Hole Oceanographic Institution, AOP&E, Woods Hole, MA, United States*
- A multi-beam echo sounder was used to image the structure of shear instabilities in a highly stratified estuary. The resulting images resolve the temporal variation and spatial structure of shear instabilities as they evolve within the stratified shear layer of the estuary. The novel capability from the use of the multi-beam is the unambiguous, simultaneous resolution of temporal evolution and spatial structure. The characteristic signature of the development of instabilities was the bifurcation of the interface into two braids, which would separate at the crest of a pre-existing internal wave. The braids usually exhibited secondary instabilities that rapidly evolved and collapsed within the lifetime of the primary braids. The lifetime of the instabilities was remarkably short, on the order of 5-8 seconds or 2 to 3 shear timescales (du/dz ~0.5 s^{-1}). The rapid evolution is not explained by low gradient Richardson numbers— the mean value of Ri was close to the stability threshold of 0.25 but instantaneous estimates were highly variable due to perturbations by internal waves and the shear instabilities themselves. The rapid evolution of the shear instabilities may be explained by continual, finite-amplitude perturbation of the flow by bottom topography under near-critical Froude number conditions. A word of warning: these instabilities look and behave considerably differently from those typically observed in the laboratory or Direct Numerical Simulation.
- 02:15 PM**PS23A-02** Stratified Shear Instability in a Field of Pre-Existing Turbulence***Alexis Kaminski*** *and William Smyth, Oregon State University, Corvallis, OR, United States*
- In the stably-stratified ocean interior, turbulent mixing of heat and momentum occurs in discrete events driven by vertical variations of the horizontal velocity. Typically, these events have been modelled by assuming an initially laminar stratified shear flow which develops wavelike instabilities, becomes fully turbulent, and then relaminarizes into a stable state. However, in the real ocean there is always some level of turbulence left over from previous events, and it is not yet understood how this turbulence impacts the evolution of future mixing events. Here,

we perform a series of direct numerical simulations of turbulent events developing in stratified shear layers that are already at least weakly turbulent by varying the amplitude of the initial perturbations. We investigate the effect of the pre-existing turbulence on the subsequent development of the shear instability and the transition to a fully turbulent shear layer. The resulting mixing of the mean velocity and buoyancy fields for different initial amplitudes is examined and quantified in terms of overall energetics and mixing efficiency.

- 02:30 PM**PS23A-03** Marginally unstable shear flows in the upper equatorial oceans***William Smyth**, Oregon State University, Corvallis, OR, United States, Hieu T Pham, University of California San Diego, Mechanical and Aerospace Engineering, La Jolla, CA, United States, Jim Moum, Oregon State University, College of Earth Ocean & Atmospheric Sciences, Corvalis, OR, United States and Sutanu Sarkar, Univ California at San Diego, La Jolla, CA, United States*
- In certain cases, stratified turbulence with strongly forced mean shear exists in a state of marginal instability. This state is characterized by a mean flow that fluctuates around the stability boundary in parameter space (e.g., Richardson number = ¼). Persistent forcing drives the mean flow towards the unstable state, while sporadic bursts of turbulence relieve the instability. Each turbulent burst originates as a Kelvin-Helmholtz-like shear instability, forming billows that roll up and break. I will show evidence for this scenario in the upper equatorial oceans and discuss implications for our future understanding of geophysical turbulence.
- 02:45 PM**PS23A-04** Distinctions in Turbulence Between Atlantic and Pacific Equatorial Cold Tongues: Inferences from Several Years of Moored Mixing Measurements***Jim N. Moum**[1], Emily Shroyer[2], Jonathan D Nash[2], Sally J Warner[3], Johannes Becherer[4], Peter Brandt[5] and Bernard Bourles[6], (1)Oregon State University, COAS, Corvallis, OR, United States, (2)Oregon State Univ, Corvallis, OR, United States, (3)Oregon State Univeristy, COAS, Corvallis, OR, United States, (4)Oregon State University, College of Earth, Ocean, and Atmospheric Sciences, Corvallis, OR, United States, (5)GEOMAR, Kiel, Germany, (6)Centre IRD de Brest, Plouzané, France*
- Mixing meters (χpods) have been deployed on equatorial moorings in the cold tongues of the Pacific (as part of the TAO array) since 2005 and the Atlantic (PIRATA array) since 2014. While data are not continuous due to instrument failures and mooring losses, a significant record has been obtained. This record

permits a look at similarities and differences between locations. It is also long enough to infer spectral peaks from multiple, continuous year-long records.

- A 2-slide summary of ongoing and forward-looking χpod improvements will be presented.

- 03:00 PM**PS23A-05** Enhanced Dissipation of Near-Inertial Waves in Mesoscale Vertical Vorticity and Shear***Thomas Bayes Sanford***[1]*, Barry Binbing Ma*[2]*, Matthew H Alford*[3]*, Oliver M Sun*[4]*, Andrew Lucas*[3]*and Robert Pinkel*[5]*, (1)Univ Washington, Applied Physics Lab, Seattle, WA, United States, (2)Applied Physics Laboratory University of Washington, Seattle, United States, (3)Scripps Institution of Oceanography, La Jolla, CA, United States, (4)Naval Undersea Warfare Center, United States, (5)Univ California San Diego, La Jolla, CA, United States*
-

A pair of EM-APEX floats were deployed in the Sargasso Sea in a surface intensified anticyclonic eddy, which strongly influenced propagation and stability of near-inertial internal waves. As the floats profiled along concentric paths, the velocity and density structures of the eddy and internal waves were observed continuously to a depth > 300 m. The most prominent feature of the observations is the enhanced near-inertial wave (NIW) interaction with the mesoscale vertical vorticity and shear. Vertical vorticity vs. depth was computed by the Kelvin circulation theorem on contours along and between the floats. Vertical shear was computed directly from the float profiles. The combination of the eddy's vertical vorticity and vertical shear reduced the minimum frequency of the NIW (σ_{min}, *Whitt and Thomas* 2013) by 0.29f at the surface and 0.1f at 140 m, where f is the local Coriolis frequency. The effect of σ_{min} increasing with depth meant that a wave packet, which initially had an intrinsic frequency $\omega_i > \sigma_{min}$, could reach a level where $\omega_i » \sigma_{min}$. At this point the vertical group velocity (c_g) tended to zero, while the KE density (E) became large, consistent with continuity of vertical energy flux (c_gE). This condition led to the NIW packet becoming unstable and breaking. The parameterized KE dissipation rate based on N and shear was 4 x 10^{-8} m^2 s^{-3}, a large value for the thermocline. Without a local energy source, the turbulent energy of 4 x 10^{-4} m^2 s^{-2} would have been largely dissipated in less than one day. However, the turbulence remained for the weeklong observation period. The vertical

gradient of the energy flux was comparable to the dissipation rate and sufficient to maintain the turbulence. The observations confirmed the important roles that both ambient vertical vorticity and shear (i.e., sloping isopycnals) play in the propagation, evolution and dissipation of NIWs in the ocean.

Whitt, D. B., and L. N. Thomas, 2013: Near-inertial waves in strongly baroclinic currents. *J. Phys. Oceanogr.*, **43**, 706–725.

03:15 PM**PS23A-06** Evolution of Turbulent Processes Affecting Oceanic Near Surface Stratification in Response to a Storm***Natasha Sarah Lucas***[1], *Alan L Grant*[2], *Tom Philip Rippeth*[3], *Jeff Polton*[4], *Matthew Palmer*[4], *Mark Inall*[5], *Liam Brannigan*[6], *Stephen E Belcher*[7] *and Tim Boyd*[8], *(1)Bangor University, School of Ocean Sciences, Menai Bridge, United Kingdom, (2)University of Reading, Reading, RG6, United Kingdom, (3)Bangor University, School of Ocean Sciences, Bangor, Wales, United Kingdom, (4)National Oceanography Center, Liverpool, United Kingdom, (5)Scottish Association for Marine Science, Argyll, United Kingdom, (6)Stockholm University, MISU, Sweden, (7)Univ Reading, Reading, United Kingdom, (8)Scottish Association for Marine Science (SAMS), United Kingdom*

Here we present high resolution measurements of the rate of dissipation of turbulent kinetic energy obtained as part of the Ocean Surface Mixing and Submesoscale Interaction Study (OSMOSIS). The measurements were made using an ocean microstructure gilder together with measurements of the temperature and salinity of the water column and vertical current structure using a shipborne ADCP. The measurements were made in the NE Atlantic, in the run-up to, and during, a storm.

During the storm winds speeds reached ~20 m s^{-1} and significant wave heights reached ~6 m. Observations of the currents show that the inertial oscillations are excited in the mixed layer at the onset of the storm, with the layer in which inertial oscillations occur deepening as the storm progresses. These oscillations produced shear at the base of the ocean surface boundary layer (OSBL), which generated turbulence. The presence of turbulence was evident in the periodic variation in the dissipation rate at the base of the OSBL.

A simple bulk model of the OSBL is developed. The model assumes that deepening of the OSBL is due to entrainment by a combination of Langmuir and convective turbulence. A parameterization of shear production at the base of the OBSL is used to estimate the dissipation rate from the model. The parametrization was developed using results from large-eddy simulation (LES).

The rate at which the OSBL deepens in the model agrees with the observed deepening, suggesting that the dominant process is entrainment. The estimates of shear production from the parametrization are consistent with the observed dissipation rates at the base of the OSBL. The model provides an example of the use of LES in designing parametrizations of turbulent processes which could be used to improve parametrizations in global ocean models.

- 03:30 PM**PS23A-07** Observations of Microstructure in the Loop Current Using Slocum Gliders***Christian Nygren**[1], Steven Francis DiMarco[2], Zhankun Wang[3], Binbin Wang[1] and Kurt L Polzin[4], (1)Texas A&M University College Station, College Station, TX, United States, (2)Texas A & M University, College Station, TX, United States, (3)Texas A&M University, College Station, TX, United States, (4)WHOI, Woods Hole, MA, United States*
-

The Loop Current and its associated Loop Current Eddies are major drivers for many dynamic processes within the Gulf of Mexico and have far reaching effects on the ecological community structure of the Gulf and the operations of numerous commercial industries that drive the economies the Southern States. Here, we present data collected from a Rockland MicroRider outfitted for use on a Teledyne Webb Research Slocum Glider, and standard hydrographic data from the surface to 1000 meters depth as it was flown both along and across Loop Current Fronts in the eastern Gulf of Mexico west of the West Florida Shelf during the Summer/Fall of 2017. Of particular interest were locations where it was believed the Loop Current would interact with bathymetry that was steep or highly variable over length scales that could produce current funneling, steep isopycnals, and elevated velocities along the sea floor.

Rates of dissipation calculated across the fronts are compared to background rates both inside and outside the Loop Current at multiple depths. Early Data suggests that different water masses may have distinct dissipation rates that can be double or triple that of rates in deeper waters, and the boundaries between them can have rates ten to fifty times higher than background. With this, we look to describe background rates as they change with depth and identify mechanisms and impacts of increased mixing, including interaction with bathymetry and those associated with the active tropical weather season. Further, comparisons between dissipation rates as calculated from both Microrider and Slocum Glider data demonstrate whether elevated mixing can be identified and estimated in non-sheer based data and to what degree.

- 03:45 PM**PS23A-08** Winter stratification and turbulent mixing in Base Mine Lake***Sarah Chang**, Edmund W Tedford, Greg Lawrence and Jason Olsthoorn, University of British Columbia, Civil Engineering, Vancouver, BC, Canada*
    - The winter 2015 behaviour of Base Mine Lake was reviewed. High-frequency moored temperature and turbidity sensors were placed throughout the water column. At the time of ice-on, the lake was uniform in temperature, with warm, fine tailings present beneath the water column; an additional temperature sensor was located below the interface, within the tailings.
    - Heat is transferred from this material to the water column via advective flux and conduction, inducing warming at depth. Where the water column is below the temperature of maximum density, reverse stratification and stability develops. At depths where temperatures are above the temperature of maximum density, mixing dominated by natural convection occurs.
    - In contrast to the relatively slow and steady mixing at depth, in the upper water column, turbulent flows associated with falling plumes of saline water excluded during ice formation were observed to significantly reduce stratification. Thermal stratification is observed in this region throughout the winter due to the cooling of the near-surface water, but the mixing due to salt exclusion causes it to be marginal and frequently unstable, with cooler packets of water regularly observed below warm ones.
    - The heat flux into the system was estimated, and a simple model of the system was developed. The magnitude of mixing and stability in the upper and lower regions of the lake were estimated and compared over the duration of the winter.
  - **PS24A** Recent Advancements in Stratified Turbulent Mixing III Posters
- *Oregon Convention Center*
- *- Poster Hall*

- **PS24A-2212** On Energy and Mixing in the Thermocline***William K Dewar****, Florida State Univ, Tallahassee, FL, United States and James C McWilliams, UCLA, Los Angeles, CA, United States*
-

A method for computing the rate at which turbulent mixing builds potential energy in the ocean is described. The traditional approach has focused on the rate of change of the background potential energy associated with an adiabatically leveled state. The leveling depends upon a somewhat arbitrary choice of domain size and suffers from a few conceptual issues. The method recommended here is, strictly speaking, also non-local but is based on a specific choice of domain. It is also tightly confined to mixing zones turbulence and addresses the conceptual issues surrounding the classical technique. It can be shown that the resultant kinetic energy equation relates irreversible kinetic energy loss to the dual reservoirs of dissipation and potential energy gain, leading to a natural definition of mixing efficiency and turbulent diffusivity. The equation differs from the classical formula by a quantity that can be locally sign indefinite, but returns a positive definite value upon integration over a mixing region. Applications to Kelvin Helmholtz instability argue an integrated efficiency of ~0.15 for a Prandtl number of 1, and of ~0.08 for a Prandtl number of 10. The larger is comparable to the classical value of 0.2 used frequently by the mixing community, and smaller than that found in some recent simulations. Possible explanations for the latter result are offered.

PS24A-2213

Energy transfer and turbulence in oscillatory baroclinic boundary flows***Pranav Suresh Puthan***[1]*, Masoud Jalali*[2]*, Vamsi Krishna Chalamalla*[2,3] *and Sutanu Sarkar*[4]*, (1)University of California San Diego, La Jolla Shores, CA, United States, (2)University of California San Diego, La Jolla, CA, United States, (3)University of North Carolina at Chapel Hill, Chapel Hill, NC, United States, (4)Univ California at San Diego, La Jolla, CA, United States*

Convective overturns in a stratified boundary flow lead to near-bottom turbulence. In the present study, we use large eddy simulation (LES) to examine the evolution of a patch of unstably stratified fluid over a sloping bottom. The flow evolution involves energy exchange between four major energy reservoirs, namely the mean and turbulent counterparts of kinetic energy (KE) and available potential energy (APE). In the presence of a sloping bottom, the energy transfer is dominated by an oscillatory exchange between mean APE and mean KE with frequency of 2Nsin**β**, where N is the buoyancy frequency and **β** is the slope angle with the horizontal. Some energy is also transferred to turbulence. In the absence of a slope, energy transfer occurs from mean APE to turbulent KE and turbulent APE. The significance and applicability of Thorpe-scale estimation of the turbulent dissipation rate from convective overturns is also analyzed in each case.

PS24A-2214 Stratified and Unstratified Mixing: A Large-Eddy Simulation investigation***Ashley Brereton****, National Oceanography Centre, Liverpool, United Kingdom, Jeff Polton, National Oceanography Center, Liverpool, United Kingdom and Andres E Tejada-Martinez, University of South Florida, United States*

Regional scale ocean models are underpinned by turbulence closure schemes. These schemes govern the flux of momentum and scalars across vertical co-ordinates. These schemes do considerably well when reproducing fluxes associated with well-mixed water columns, but they are not as effective when density stratification is present. This a problem, as important phenomenon are associated with diapycnal fluxes, such as phytoplankton blooms induced by nutrient fluxes at the pycnocline and the carbon cycle.

A fully 3D high-resolution modelling approach known as Large-eddy simulation (LES) is utilised. This technique directly resolves the turbulent flow that ocean models attempt to parameterise. We derive a new methodology that is both user-friendly and intuitive. In this formulation, the mean flow is supplied as an input and the model calculates the turbulent field associated. This approach is validated against traditional LES methods and the skill is assessed by comparison to observations of energy dissipation rate from a barotropic tide. Finally, an idealised test case for a pycnocline is simulated and we assess the skill of popular turbulent closure schemes in comparison to the LES.

PS24A-2215 Initializing DNS Turbulence Models to Represent Naturally Occurring Turbulence***Vashkar Bernard Palma****, University of Massachusetts Dartmouth, New Bedford, MA, United States, Daniel G MacDonald, U Mass/Dartmouth-Est&Ocean Sci, Fairhaven, MA, United States and Mehdi Raessi, University of Massachusetts Dartmouth, Mechanical Engineering, North Dartmouth, MA, United States*

Direct Numerical Simulation (DNS) has been employed with success in a variety of oceanographic applications, particularly for investigating the internal dynamics of Kelvin

Helmholz (KH) billows. These studies have yielded an impressive array of information regarding interactions (including pairing) of adjacent KH billows, the generation of secondary instabilities, and the evolution of local mixing efficiencies, among other topics. An alternative focus of DNS models is to mimic naturally occurring turbulence at laboratory or weakly forced geophysical scales, in order to broaden the parameter space of available measurements to enable the development of enhanced closure techniques. To do this, it is necessary to demonstrate the mean values of turbulent quantities (e.g., production, buoyancy flux, and dissipation) are consistent with measurements of similarly parameterized flows. Modeled turbulence evolution in a stratified shear flow is determined not only by the strengths of the background shear and stratification, but also by the initial and boundary conditions used to define the, and focus our analysis on two parameters: the intensity of background "noise" which is used to stimulate the turbulent field, and the length of the domain in the streamwise direction. Variation of the domain length is shown to have profound implications not only for the number of billows formed, but also for the nature of their interactions, and for the intensity of the resulting mean turbulence. Results indicate that the ratio of domain length to a theoretical KH wavelength, , where h is the thickness of the shear layer and Ri_B represents the bulk Richardson number, is a critical parameter in evaluating the effect of variable domain lengths. Results of simulations with varying initial noise amplitudes are used to identify the impact of initial noise on final turbulence parameters and identify ideal initialization noise levels.

PS24A-2216 Sensitivity of Vortex Pairing and Mixing to Initial Conditions in Stratified Shear Flows***Wenjing Dong**, New York University, New York, NY, United States, Edmund W Tedford, Univ. of California, Santa Barbara, CA, United States, Mona Rahmani, UBC, Vancouver, BC, Canada and Gregory A Lawrence, Univ British Columbia, Vancouver, BC, Canada*

Kelvin-Helmholtz (KH) instabilities are an important source of mixing in oceans, lakes and the atmosphere. The process of vortex pairing can increase the amount of mixing. The effects of initial conditions on vortex pairing and mixing are studied by running Direct Numerical Simulations with a variety of initial perturbations. It is shown that when the subharmonic component of the perturbation is out of phase relative to the KH mode, vortex pairing is delayed or even eliminated. The amount of mixing in the simulations where the subharmonic mode is out of phase is approximately half of that in the simulations where the subharmonic mode is in phase. The time of pairing is also found to be sensitive to the phase of the subharmonic mode. A slight change of the phase can change time of pairing significantly when the subharmonic mode is close to being out of phase.

PS24A-2217 Does Scale Matter? Bridging the Gap Between Field and Laboratory Observations of Turbulence***Daniel G MacDonald***[1], *Mehdi Raessi*[2] *and Anneliese K Schmidt*[1], *(1)University of Massachusetts Dartmouth, Civil and Environmental Engineering, North Dartmouth, MA, United States, (2)University of Massachusetts Dartmouth, Mechanical Engineering, North Dartmouth, MA, United States*

The generation of turbulence in pure shear-stratified environments is known to be driven by interfacial instabilities within the stratified shear layer, typically resulting in coherent overturning structures such as Kelvin-Helmholz billows (particularly for near-critical values of the gradient Richardson number) that subsequently decay to turbulence. Efforts to parameterize these processes using bulk flow variables have resulted in a variety of approaches, where non-dimensional forms of turbulent intensity, including the entrainment ratio, E, and a non-dimensional turbulent buoyancy flux, ξ, are typically assumed to be functions of a local bulk Richardson number, Ri_B. However, recent comparisons of laboratory data with data collected from the coastal ocean, including several supercritical river plume environments, indicates that geophysical turbulence (expressed either as E or ξ) falls several orders of magnitude below similarly generated laboratory turbulence at consistent values of Ri_B, suggesting that scale may play a critical role in the generation of turbulence. The goals of the current study are to bring together field and laboratory turbulence observations, along with DNS turbulence simulations, to bridge the gap across a wide range of scales, as represented by the Reynolds number, Re, and a broad range of Ri_B. Collectively, this data will be used to test a variety of predictive parameterizations. A power law approach, utilizing both Re and Ri_B shows some initial promise, and a weak to moderate inverse dependence of turbulent intensity on Re. The utility of other approaches, including available energy analyses utilizing the difference between shear and buoyancy time scales, are also explored. An enhanced understanding of the role of scale in the generation of shear-stratified turbulence will facilitate the use of laboratory data or direct numerical simulation (DNS) output to inform dynamics at geophysical scales, and may improve turbulence closure schemes for ocean models.

PS24A-2219 The Role of Intermittency in Internal Wave Driven Lateral Mixing***Cimarron J Wortham***, *NorthWest Research Associates, Boulder, CO, United States, Marie-Pascale Lelong, Northwest Research Associates, Redmond, WA, United States,* *Jeffrey J Early, NorthWest Research Associates, Redmond, WA, United States, Eric L Kunze, NorthWest Research Associates Redmond, Redmond, WA, United States and Miles A Sundermeyer, School Marine Sci. & Tech., New Bedford, MA, United States*

Lateral mixing is a fundamental process in the ocean, and helps determine the formation of water-masses and distribution of chemical tracers and nutrients in the ocean. Several tracer release experiments have observed submesoscale (~1-10 km) isopycnal diffusivities of order 1 m^2 s^{-1} across a variety of dynamical regimes and mesoscale field strengths. This near-constant submesoscale diffusivity suggests a role for internal waves in driving isopycnal mixing at submesoscales. However, the observed isopycnal diffusivities are up to an order of magnitude larger than traditional internal-wave shear dispersion predictions. The intermittency of turbulent mixing presents a possible resolution.

The role of intermittency in internal wave-driven lateral mixing is studied in a three-dimensional, nonlinear, Boussinesq numerical model. We use a one-way nested model, with open boundary conditions consistent with the Garrett-Munk (GM) internal wave spectrum at scales larger than the domain. Nonlinear dynamics maintain a GM internal wave field in the interior. The boundary forcing allows us to include the impact of waves larger than the model domain, resulting in a more realistic internal wave spectrum. Both diapycnally-mixing passive tracers and non-diffusive Lagrangian particles are used to quantify the diapycnal and isopycnal diffusivities, and the role intermittency. We will describe the model formulation as well as the impact of intermittency on isopycnal diffusivity.

PS24A-2220 Geostrophic Turbulence Observed in Eddy Vertical Structure Variability***Jacob Steinberg**, University of Washington, Oceanography, Seattle, WA, United States and Charles Eriksen, University of Washington, Seattle, WA, United States*

Key predictions of geostrophic turbulence theory compare well with vertical wavenumber spectra of potential and kinetic energy inferred from full depth temperature and salinity profiles collected by Deepglider autonomous underwater vehicles. Hundreds of full depth profiles collected at the Bermuda Atlantic Time Series Station (BATS) and along 26N offshore the Bahamas were used to compare with predictions of energy and enstrophy cascades over separate wavenumber bands within the submesoscale range. Isopycnal vertical displacements resulting from geostrophic motions, including transient eddies, are

related to horizontal motions that drive stirring in the inertial range. Observations reveal deep vertical displacements O(200m) which produce an unequal energy partition with potential dominating kinetic energy above the second baroclinic mode. Examination of profiles from hydrographic stations including BATS, Papa, station ALOHA, and newly deployed Deep Argo floats display spatial and seasonal variability in energy spectra. The structure and variability of density profiles reveal stirring processes that set energy and tracer distribution to be consistent with quasi-geostrophic motions. Spectra contain the predicted k^{-3} slope of the enstrophy cascade with the exception of profiles made in less energetic regions where internal wave variability dominates.

PS24A-2221 Mobile Bay river plume mixing in the inner shelf***Sabrina Marie Parra**, US Naval Research Laboratory, Washington, DC, United States, Jeffrey W Book, U.S. Naval Research Laboratory, Stennis Space Center, MS, United States, Sally J Warner, Oregon State Univeristy, COAS, Corvallis, OR, United States and Jim Moum, Oregon State University, College of Earth Ocean & Atmospheric Sciences, Corvalis, OR, United States*

The microtidal region (0.5 m spring tides) of the inner shelf outside Mobile Bay presented a complex circulation pattern driven by the pulsed river discharge and winds. Currents, salinity, temperature, and turbulence profiles were measured for up to three weeks in April 2016 at six moorings outside Mobile Bay. Currents varied between locations and with depth. During neap and spring tides the currents were reliably >0.4 and <0.4 m/s, respectively. The outflow from Mobile Bay generated a complex density circulation, where two to three layers were normally present. Multiple density layers included a thicker brackish middle layer (5-10 m thickness), and a salty bottom layer (5-10 m thickness), with a thin (~1-3 m) freshwater surface layer found intermittently. The multilayer currents were strongest at neap tides (>0.5 m/s) and toward deeper waters, concurrent with the strongest stratification. The possible flow drivers considered include tides, winds, inertial oscillations, waves, and stratification. Turbulent kinetic energy production and dissipation were calculated with multiple methods using data from bottom-mounted, upward-looking acoustic Doppler current profilers sampling at 1 Hz, and using data from line-moored chi-pod turbulent temperature microstructure instruments sampling at 100 Hz. This work explores different forcing mechanisms involved in modulating the circulation and turbulence in a multi-layered pulsed-river inner shelf region in the Gulf of Mexico.

- **PS24A-2222** The Effect of Background Salinity Gradient on Langmuir Turbulence*Yalin Fan[1], Ewa Jarosz[2], **Zhitao Yu**[3], William Erick Rogers[4], Tommy G Jensen[1], Peter P Sullivan[5] and Junhong Liang[6], (1)Naval Research Laboratory, Stennis Space Center, MS, United States, (2)John C. Stennis Space Center, Stennis Space Center, MS, United States, (3)US Naval Research Laboratory, Washington, DC, United States, (4)U. S. Naval Research Laboratory, Stennis Space Center, United States, (5)National Center for Atmospheric Research, Mesoscale Microscale Meteorology, Boulder, CO, United States, (6)Louisiana State University, Department of Oceanography and Coastal Sciences, Baton Rouge, LA, United States*
-

Langmuir circulation (LC) is believed to be one of the leading order causes of turbulent mixing in the upper ocean. It is important for momentum and heat exchange across the mixed layer (ML) and directly impact the dynamics and thermodynamics in the upper ocean and lower atmosphere including the vertical distributions of chemical, biological, optical, and acoustic properties. Based on Craik and Leibovich (1976) theory, large eddy simulation (LES) models have been developed to simulate LC in the upper ocean, yielding new insights that could not be obtained from field observations and turbulent closure models. Due its high computational cost, LES models are usually limited to small domain sizes and cannot resolve large-scale flows. Furthermore, most LES models used in the LC simulations use periodic boundary conditions in the horizontal direction, which assumes the physical properties (i.e. temperature and salinity) and expected flow patterns in the area of interest are of a periodically repeating nature so that the limited small LES domain is representative for the larger area. Using periodic boundary condition can significantly reduce computational effort in problems, and it is a good assumption for isotropic shear turbulence. However, LC is anisotropic (McWilliams et al 1997) and was observed to be modulated by crosswind tidal currents (Kukulka et al 2011). Using symmetrical domains, idealized LES studies also indicate LC could interact with oceanic fronts (Hamlington et al 2014) and standing internal waves (Chini and Leibovich, 2005).

The present study expands our previous LES modeling investigations of Langmuir turbulence to the real ocean conditions with large scale environmental motion due to strong horizontal density gradient. Large scale gradient forcing is introduced to the NCAR LES model through scale separation analysis. The model is applied to a field observation in the Gulf of Mexico in July, 2016 when the measurement site was impacted by large fresh water inflow due to flooding from the Mississippi river. Model results indicate that the strong salinity gradient can reduce the mean flow in the ML, align Langmuir cells with the pressure gradient direction and inhibit turbulence in the planetary boundary layer.

PS24A-2223 Large-eddy Simulation of the Effects of Different Stokes Drift Estimations on the Turbulence in the Upper Ocean***Ying Qiu*** *and Shuang Li, Ocean College, Zhejiang University, Institute of Physical Oceanography, Zhoushan, China*

Stokes drift is a significant source term of vertical mixing in the upper ocean .The Stokes-Vortex force generated by the interaction between the wind-driven mean flow and the Stokes drift, which substantially enhances the turbulence effect in the mixing layer, induces the formation of Langmuir circulation.Based on the modified Large-Eddy-Simulation (LES) model , Four stokes drift approximation formulas and the Stokes drift velocity profile evaluated by the wave spectrum are applied to the numerical experiments for comparison. Results show that different stokes drifting profiles can lead to the distinctions of Langmuir production terms.The vertical turbulence intensity changes with various wind speed. There exists difference between the turbulence intensity which obtained by using different approximation approaches.When U_{10}=10m/s,the maximum value of vertical turbulence intensity among these experiments present noticeable deviation. The ratio of the value can reach to 2.12 which becomes larger as the wind speed increases.The profiles of mean TKE and the TKE flux show significant discrepancy .The maximum value of magnitude of shear production appears at different depths in the mixed layer.This research shows that the Stokes drift velocity profile required for Langmuir turbulence solutions in the LES model can be an important influential factor to the results of turbulence characteristics.

PS24A-2224 Storm-driven Turbulent Stratified Mixing from Underwater Gliders***Jeff R Carpenter****, Larissa Schultze and Lucas Merckelbach, Helmholtz-Zentrum Geesthacht, Institute of Coastal Research, Geesthacht, Germany*

Storm Bertha passed over the North Sea in mid-August 2014, bringing with it gale-force winds that completely mixed the strongly stratified water column. Unique observations of this storm-driven mixing event were made possible with an underwater ocean glider equipped with microstructure sensors for the quantification of the dissipation rate of turbulent kinetic energy. We present a first look into the turbulent mixing of the North Sea thermocline that resulted during the storm. To our knowledge this is the first such data set capturing stratified ocean turbulence measurements during a shelf sea storm. Combining the glider observations with a nearby bottom-mounted Acoustic Doppler Current Profiler (ADCP) we are able to quantify currents, stratification, and turbulence. The results show that the thermocline reaches a state of marginal shear stability during times of strong wind forcing. This is found to be the primary mechanism responsible for mixing the stratification. During these times of marginal stability we observe that the thermocline transitions to a fully turbulent state of primarily energetic stratified turbulence, opposed to pre-storm conditions that are mainly characterised by laminar and weakly turbulent conditions. The significant alterations caused by the storm impact the distribution of chlorophyll-a, causing increases in the surface mixed layer. In addition, estimates suggest that the increase in turbulent thermocline fluxes during the storm are significant fractions of seasonal budgets.

PS24A-2225 Analysis of Turbulence in the Weddell Sea: Observations and Modeling***Aditya Narayanan*** *and Murali K, Indian Institute of Technology Madras, Ocean Engineering, Chennai, India*

Downslope flows of negatively buoyant water that form in the marginal seas around the Antarctic contribute to the formation of bottom water currents. Downslope flows are known to play an important role in the energy transport in the polar seas, thereby affecting the stability and melt rate of ice sheets and as a consequence, also affect the rate of sea level rise. An accurate energy closure is necessary for the correct modeling of global climate. High Salinity Surface Water (HSSW) form in the polynyas in the western and southern regions of the Weddell sea. This HSSW being negatively buoyant descend and collect in the depression of the marginal sea and eventually overflow over the sill. The overflowing water may diffuse at some intermediate depth if it undergoes sufficient entrainment with ambient waters and becomes neutrally buoyant. However, some of the overflow water may eventually reach greater depths. 2-equation turbulence modeling of the bottom mixing due to unstable stratification of the water column in the vertical is presented here. CTD data from the Weddell Sea is fed into the model which then computes the turbulence parameters. It proposed to capture some of the important physical phenomena associated with such downslope flows such as entrainment, bottom friction, thermobaricity, cabbeling and viscous Ekman drainage. Model output will be compared with physical observations of the vertical CTD profiles and microstructure data of the Weddell sea. The study is aimed towards an improved understanding of downslope flows by looking at important individual physical processes, as such understanding is required to improve the parameterization of these flows in climate and ocean general circulation models.

Plain Language Summary

In polar seas, the surface waters become cold and highly saline and thereby highly dense, while warmer and lighter waters may be found at intermediate depths. This sets up a vertical overturning of water. Some of the cold and dense waters that descend flow along the continental slope where the bottom roughness and other mechanisms cause them to become turbulent, that is, the flow becomes highly disturbed resulting in a lot of mixing. The amount of disturbance and the amount of mixing is studied by computationally modeling the flow and comparing with field measurements.

PS24A-2226 Turbulent mixing induced by Cold Water Intrusion over the southwestern East Sea***Seongbong Seo***[1], *Young-Gyu Park*[2], *Chanhyung Jeon*[3], *Hong Sik Min*[4], *Dong Guk Kim*[4] *and Jae-Hun Park*[5], *(1)KIOST Korea Institute of Ocean Science and Technology, Ocean Circulation and Climate Research Center, Ansan, South Korea, (2)KIOST Korea Institute of Ocean Science and Technology, Ansan, South Korea, (3)Inha University, Department of Marine Science and Biological Engineering, Incheon, South Korea, (4)KIOST, Ocean Circulation and Climate Research Center, Ansan, South Korea, (5)Inha University, Department of Ocean Sciences, Incheon, South Korea*

Along the southeastern coast of Korea (southwestern part of the East Sea) the warm and salty Tsushima Warm Currents flows northeastward. During summer a southwestward cold water intrusion from the East Sea occurs along the bottom below the warm current. Thus, a strong shear and consequently strong turbulent mixing are expected along the boundary between the warm water and cold water. To quantify the mixing hydrographic surveys using a free falling microstructure profiler (VMP-500) and CTD were conducted. Enhanced dissipation of energy was indeed observed along the interface located between 15°C to 20°C layers. Along the bottom there was another layer with enhanced energy dissipation. These high energy dissipations resulted in high vertical diffusivities. The layers of high vertical mixing slanted upward toward the coast could supply nutrient to the surface layer to support high productivity along the Korean coast.

PS24A-2227 Penetrative convection in the bottom nepheloid layer of a lake***Edmund W Tedford***[1], *Greg Lawrence*[1], *Roger Pieters*[2], *Sarah Chang*[1], *Jason Olsthoorn*[1] *and Tomy Doda*[3], *(1)University of British Columbia, Civil Engineering, Vancouver, BC, Canada, (2)University of British Columbia, Vancouver, BC, Canada, (3)ETH Swiss Federal Institute of Technology Zurich, Zurich, Switzerland*

Base Mine Lake has a near-bottom nepheloid layer that exhibits seasonal variations in turbidity and temperature. During fall turnover when the layer is thermally unstable (warm compared to the overlying water) suspended solids are transported upward resulting in increasing turbidity throughout most of the water column. We conducted a field study and laboratory experiments aimed at understanding this upward transport.

In the field we profiled a transparent Niskin bottle in combination with a high frequency temperature sensor and a turbidity sensor. Moored instrumentation captured the temporal variability of temperature and turbidity. The turbulence kinetic energy due to wind and convective cooling at the depth of the nepheloid layer were estimated using similarity scaling. The similarity scaling indicated wind is the dominant source of turbulence particularly as the water cools to the temperature of maximum density. Complimentary near bottom turbulence data were collected with an Acoustic Doppler Velocimeter with an inertial motion unit.

In the laboratory investigation, the water was initially uniform in temperature with a stationary nepheloid layer at the bottom. Cooling was imposed at the free surface and subsequent changes in turbidity and temperature were captured with sensors at the top and bottom of the water column and images are recorded with a camera. In two separate sets of experiments, one forced with melting ice and the other with cool air, convection resulted in complete mixing of the nepheloid layer and overlying water.

PS24A-2228 A Simplified Mixing Model of a Shallow Lake***Jason Olsthoorn**, Edmund W Tedford and Greg Lawrence, University of British Columbia, Civil Engineering, Vancouver, BC, Canada*

The seasonal variation in the stratification of a dimictic lake has been shown to significantly affect the transport of suspended particulates within the water column. This is particularly important in a shallow body of water where significant sediment resuspension can have a profound effect on the water quality. Recent field measurements within a lake (pit lake) have demonstrated how the annual temperature variation within the lake correlates with turbidity, which is here used as a proxy for the amount of suspended particulates. These results demonstrate the intrinsic dependence of turbidity on turbulent convection. In addition, the particular lake used in this study is rapidly increasing in depth (~1 m/year). Here, we present a simple turbulent diffusion model to predict the seasonal variation of turbidity in this context. Such a model highlights the key dynamical features that affect the particulate transport. The model is then compared with the field data for both spatial (vertically averaged) and temporal agreement. Further, we highlight the impact of lake depth on the distribution of turbidity.

- **PS24A-2229** The effect of mixing processes on epilimnetic and hypolimnetic turbidity***Greg Lawrence***[1], *Edmund W Tedford*[2], *Roger Pieters*[3] *and Jason Olsthoorn*[1], *(1)University of British Columbia, Civil Engineering, Vancouver, BC, Canada, (2)Univ. of California, Santa Barbara, CA, United States, (3)University of British Columbia, Vancouver, BC, Canada*
    - Base Mine Lake is a 10 m deep lake overlying fine tailings from an oil sands mining operation. During summer the lake becomes strongly thermally stratified with an epilimnion extending to approximately mid-depth. We examine three years of data and analyse the near exponential decay of turbidity in both the epilimnion and hypolimnion, and deviations from this decay. Particle settling competes with diurnal mixing and internal seiching. After the second summer flocculants were added to the lake resulting in reduced turbidity, increased primary productivity, and modified response to mixing processes during the third summer.