

Lateral Mixing

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LONG-TERM GOALS

I seek to understand the processes controlling lateral mixing in the ocean, particularly at the submesoscale, i.e. 100m-20km.

OBJECTIVES

Existing high resolution regional models typically resolve the mean vertical structure of the upper ocean boundary layer. Physically-based parameterizations of vertical fluxes make it possible to account for subgrid mixing at length scales smaller than the layer depth, but no specialized parameterization is used to represent the dynamics of horizontal mixing below the $O(1)km$ - $O(10)km$ resolution scale. We aim to determine the physical limitations of subgrid parameterization on these scales. These projects address the following questions:

- What physics govern horizontal and vertical mixing in the presence of horizontal variability on the 1-10 km scale?
- What is the relative importance of horizontal and vertical mixing in determining the structure of the boundary layer?
- What physics should be included to improve parameterizations?

APPROACH

During AESOP, Lee and D'Asaro pioneered an innovative approach to measuring submesoscale structure in strong fronts. An adaptive measurement program employed acoustically-tracked, neutrally buoyant Lagrangian floats and a towed, undulating profiler to investigate the relative importance of vertical and horizontal mixing in governing boundary layer structure in the presence of $O(1)$ km scale horizontal variability. Remotely sensed sea surface temperature and ocean color, combined with rapid, high-resolution towed surveys and model results guide float deployments to key locations within fronts. Synoptic, high-resolution surveys followed Lagrangian float drifts to characterize three-dimensional variability within the span of a model grid point. Acoustic tracking allowed towed surveys to follow floats and geolocated all observational assets for later analysis. Measurements characterized boundary layer turbulence and facilitated detailed separation of vertical and horizontal processes.

These measurements were specifically designed to allow direct comparison with Large Eddy Simulations and thus have direct application to assessing regional model subgrid parameterizations.

The 2012 experiment work involved two global class vessels, the *R.V. Knorr* and *R.V. Atlantis*, each carrying a towed/profiling CTD package for making km-scale temperature, salinity, density and velocity surveys. Two Lagrangian floats, designed to accurately track the three-dimensional motion of water parcels were tracked by a Trackpoint-II system installed on the *R.V. Knorr*. The deep mixed layers and high quality of the WHOI mounting system allowed unusually good tracking, often exceeding ranges of 5 km. Each float measured temperature and salinity at its top and bottom (1.4 m separation) and high frequency velocity relative to the float. The float provided a central point for each of 4 intensive surveys at the North Wall. In each, the float was deployed close to the front, the *R.V. Knorr* surveyed on a 5-km-scale around the float, while the *R.V. Atlantis* surveyed on a 10-20-km-scale. Up to 4 gliders were deployed nearby and also navigated to stay near the float. On some surveys, multiple surface drifters were deployed. On three of the four surveys, dye was injected near the float and its evolution mapped by the two-ship surveys.

This project funds D'Asaro's role in the analysis of the 2011 and 2012 Lateral Mixing experiment and, with Craig Lee's project, supports Andrey Shcherbina's analysis work on this same data.

WORK COMPLETED

A LATMIX 2011 overview paper was published in BAMS.

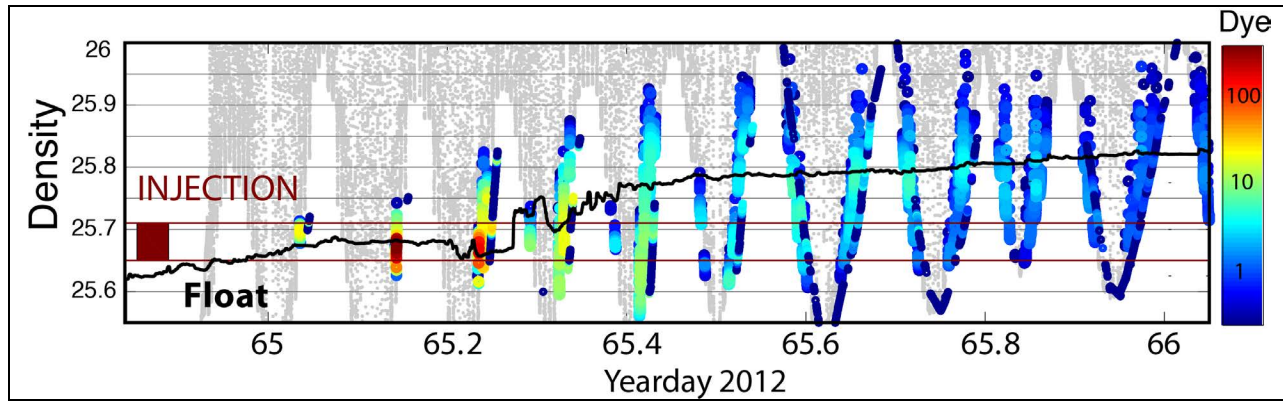
An analysis lead by Leif Thomas at Stanford and focussing on the North Wall and the associated mixing processes has been resubmitted to JPO after review.

An analysis lead by Jody Kymak at U. Victoria and focusing on stirring of streamers from the Gulf Stream has been submitted to Nature Geosciences.

Internal APL funding has been arranged to fund a Postdoc to work on further analysis of the mixing dynamics within the North Wall front.

RESULTS

The combination of dye and a Lagrangian float deployed in the 'north wall' frontal zone of the Gulf Stream created a particularly powerful combination for evaluating mixing processes here. The most dramatic results are shown in the Figure. Dye injected in the southern part of the frontal zone, spreads across the front in about a day, mixing with a broad range of density classes as it crosses the float. On average, the dye becomes denser. The float shows the same result, tracking the increasing density of the dye patch. These results qualitatively verify a major prediction of symmetric instability theory: that mixing resulting from symmetric instability will make the mixed layer denser. This provides additional evidence that symmetric instability is a major factor in creating mixing at fronts and in thus limiting the thickness of fronts. Ongoing modelling efforts with Leif Thomas and John Taylor aim to model and parameterize this mixing.



Time and cross-stream evolution of a dye patch injected into the ‘north wall’ front of the Gulf Stream during Latmix 2012. Vertical axis is density, which varies across the front with denser water to the north. Colors show the dye concentration; gray marks show location of measurements with no dye. Brown lines show the range of densities of the dye at injection. Black line shows the density of the Lagrangian float near which the dye was injected. Over 24 hours, the dye spreads across the entire frontal zone, getting denser through mixing. The float also gets denser and at nearly the same rate.

IMPACT/APPLICATIONS

The LATMIX studies show the complexity of submesoscale phenomena at fronts, but also show strong agreement with models and theory, suggesting that rapid progress is likely. Our results indicate that these theories can yield parameterizations of the submesoscale for use in larger scale models.

PUBLICATIONS

Shcherbina, Andrey Y., et al., 2015: The LatMix Summer Campaign: Submesoscale Stirring in the Upper Ocean. *Bull. Amer. Meteor. Soc.*, **96**, 1257–1279.

doi: <http://dx.doi.org/10.1175/BAMS-D-14-00015.1>

Klymak, Jody M., R. Kipp Shearman, Jonathan Gula, Craig M. Lee, Eric A. D’Asaro, Leif N. Thomas, Ramsey Harcourt, Andrey Shcherbina, Miles A. Sundermeyer, Jeroen Molemaker, and James C. McWilliams, 2015, Submesoscale streamers exchange water on the north wall of the Gulf Stream, *Nature Geosciences*, submitted

Thomas, Leif N., John R. Taylor, Eric A. D’Asaro, Craig M. Lee, Jody M. Klymak, Andrey Shcherbina, 2015, Symmetric instability, inertial oscillations, and turbulence at the Gulf Stream front, *J. Phys. Ocean.*, in revision