Lateral Mixing

Eric A. D'Asaro
APL/UW
1013 NE 40th Str
Seattle, WA 98105
phone: (206) 685-2982 fax: (206) 543-6785 email: dasaro@apl.washington.edu

Award Number: N00014-09-1-0172
http://apl.uw.edu/dasaro

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 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. This project paid for the preparation of two Lagrangian floats, designed to accurately track the three-dimensional motion of water parcels. A Trackpoint-II system was installed on the *R.V. Knorr* and used to acoustically track the float; 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.

An additional experimental effort surveyed the more homogeneous region south of the Gulf Stream. Here, deep mixed layers and the continual lateral injection of potential vorticity and scalars is predicted to create an intense 'submesoscale soup' of high small-scale variance. The combination of small scales and the expected high-frequency near-inertial oscillations presents a particularly challenging sampling problem. We overcame this by driving the two ships 1-km apart along a set of lines through the region, thereby getting km-scale simultaneous spatial differences in the cross-track direction and nearly simultaneous spatial differences on km-scale in the long-track direction

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

During February and March 2012, the LATMIX-II experimental program focused on measuring submesoscale structures within the North Wall of the Gulf Stream in winter (Fig. 1). This location combined all of the major elements thought to contribute to strong submesoscale activity. Strong lateral gradients were caused by the convergence of subtropical water carried northward by the Gulf Stream with subpolar water carried southward along the east coast of North America. Strong meteorological forcing occurred in February and March with the climatological winds blowing along the front, a condition that promotes Ekman transport of the cold heavy water over the warm lighter water and thereby causes intense submesoscale activity. Deep mixed layers, occurring at the end of the winter season, increase the potential energy associated with the lateral gradients, thereby increasing the intensity of submesoscale motions.

One major analysis, led by Andrey Shcherbina, has focused on the 'Submesoscale Soup' region. A GRL paper describing this work is in press.

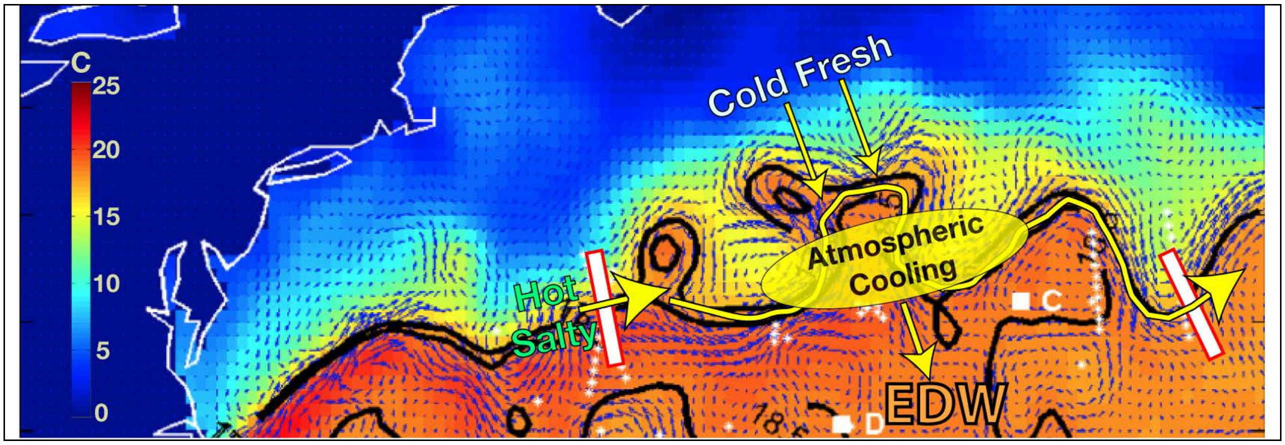

Figure 1. The setting of the 2012 LATMIX experiment in the North Wall of the Gulf Stream. Hot, salty subtropical water, carried northward by the Gulf Stream, is cooled by the atmosphere and potentially mixed with cold-fresh water from the subarctic Atlantic. One of the focuses of this experiment was to understand the intensity and mechanisms of mixing at the North Wall and its role in forming "Eighteen Degree Water" (EDW) in this region.

A second analysis has focused on the North Wall and the associated mixing processes (Fig. 1). Preliminary results were presented at the 33rd CNLS Conference on Ocean Turbulence.

RESULTS

Analysis of the submesocale soup region south of the Gulf Stream (Fig. 2) shows a remarkable correspondence between our observations (black) and the results of a 500m resolution ROMS simulation by J. McWilliams and J. Molemaker. In the mixed layer (panels a-c), these show a vertical vorticity distribution strongly skewed toward cyclonic vorticity, with a more symmettric distribution of divergence. Below the mixed layer (panels d-f), the observed distributions are symmettric in both model and data, but the model underestimates the variance because it does not properly simulate the internal wavefield. The excellent agreement between model and data confirms the presence of submesoscale variability in the upper ocean and our ability to model it. The lack of similar strong submesoscales in the summertime, LATMIX-I measurements, confirms the theoretical prediction of a strong seasonal cycle with mixed layer depth being a key controlling factor.

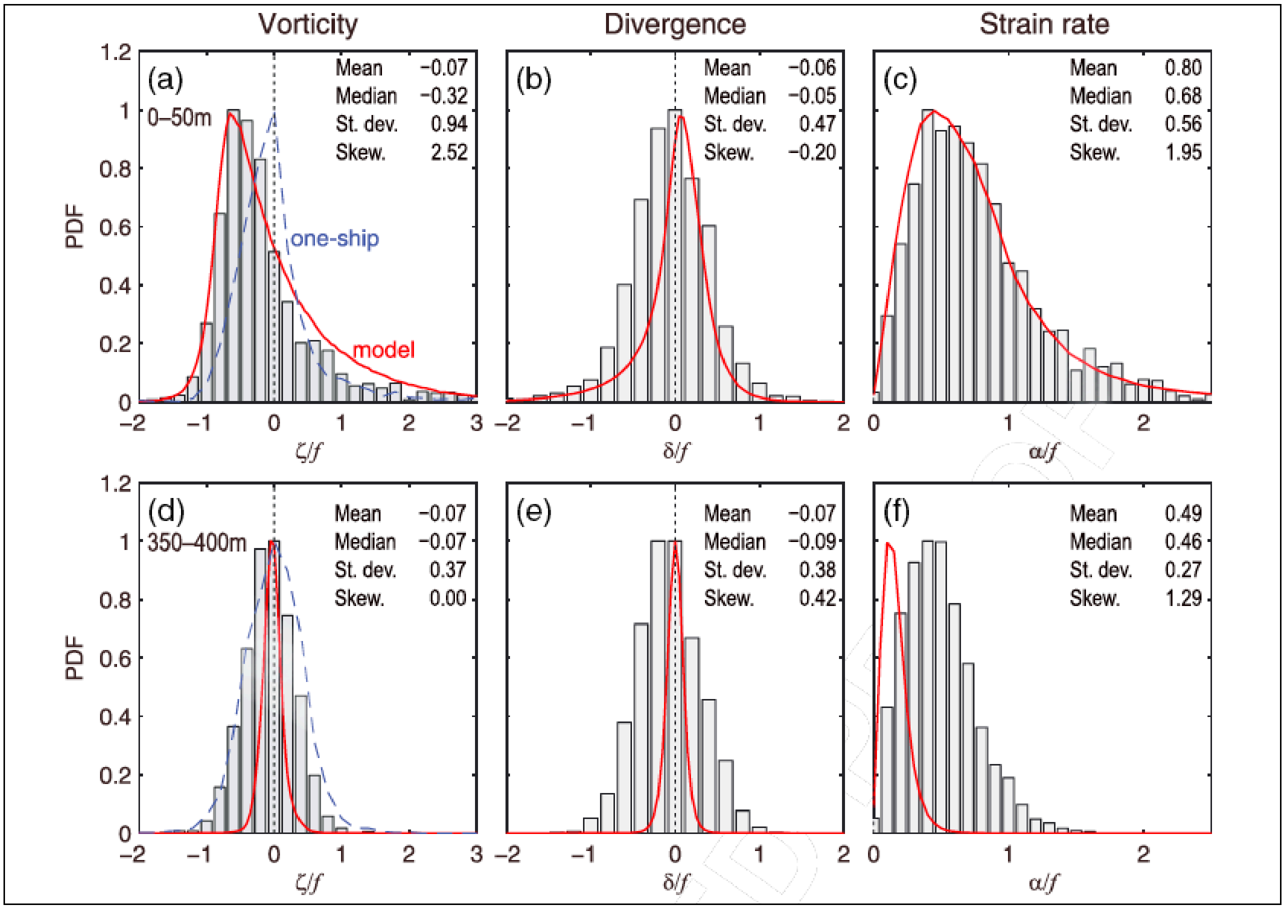

Figure 2. Histograms of normalized (a, d) vorticity, (b, e) divergence, and (c, f) strain rate in the mixed layer (0–50 m, 300 kHz ADCP, top row) and upper pycnocline (350–400m, 75 kHz ADCP, bottom row). Red curves show corresponding distributions produced in a 0.5 km numerical model. Blue dashed curves in Figures 2a and 2d show one-ship LatMix vorticity distributions. All distributions are scaled by their maximum value. Parameters of observation-based distributions are shown on the insets.

Surveys of the North Wall of the Gulf Stream clearly show negative potential vorticity in a stratified boundary layer, the signatures of symmetric instability at the front. Analysis of the float and dye data show both the float and the dye getting heavier with time due to mixing. The rate (Fig. 3) scales with the Ekman flux, as suggested by theories of symmetric instability. This suggests that the Ekman flux impinging on the Gulf Stream (Fig. 1) is mostly absorbed by mixing at the front. This is consistent with budget calculations on the formation of EDW in this region, which require an input of fresh water from the north.

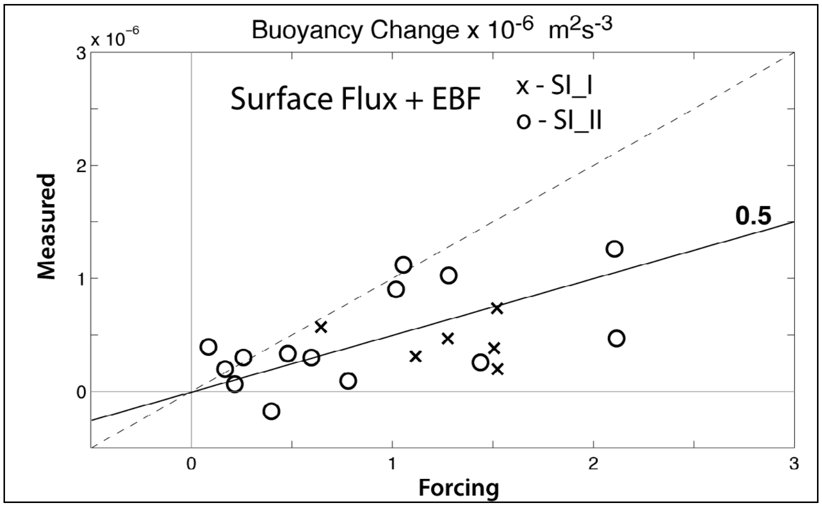

Fig. 3. Change in buoyancy following the Lagrangian float in the North Wall of the Gulf Stream scales with the sum of the surface buoyancy flux and the Ekman buoyancy flux. This implies that the diapycnal motion of the boundary layer, due to cross-frontal mixing, is comparable to that needed to absorb the cross-frontal Ekman transport.

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, A., E. A. D'Asaro, C. M. Lee, J. M. Klymak, M. J. Molemaker, and J. C. McWilliams (2013), Statistics of vertical vorticity, divergence, and strain in a developed submesoscale turbulence field, *Geophys Res Lett,* in press, DOI: 10.1002/grl.50919.