Using Dye to Study Lateral Mixing in the Ocean: 100 m to 1 km

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LONG-TERM GOALS

The long-term goals of this research are to understand submesoscale processes causing horizontal dispersion of momentum and scalar quantities. We are interested in these processes in the open ocean as well as their role in mixing the coastal ocean.

OBJECTIVES

The specific objectives of the proposed research are to:

- Participate with Lateral Mixing DRI investigators in conducting a coordinated observational program in 2011 and 2012,
- Conduct dye release experiments in 2011 in conjunction with the observations planned with the other investigators to address the DRI hypotheses, and
- Analyze experimental data and report results in Lateral Mixing workshops, national scientific meetings and publications.

APPROACH

In addition to the PI, this project relies heavily upon the efforts of two Research Associates in our college: Stephen Pierce and Brandy Kuebel Cervantes.

The approach for each of the three specific objectives is given below.

Experiments: 2011 & 2012. A central component of the Lateral Mixing DRI was the spring experiment that occurred in June 2011. This field program required extensive planning as it involved three ships for a three week period. A system was developed to have core observations made by each ship available to the other vessels in near real-time. This information was also needed to determine how to modify the sampling plan while the experiment was underway. Our group also played a minor role in the 2012 experiment: Steve Pierce participated on the R/V Atlantis to help with ADCP measurements and glider operations.

Dye releases: 2011. Our contribution to the 2011 field program was to participate in the dye release experiments from the R/V Cape Hatteras. Each experiment started with an injection of dye under Jim

Ledwell's direction. Both fluorescein and rhodamine dyes were used at different times depending on the objective. Two types of systems were used to map the dye patches: an Acrobat system (M. Sundermeyer, U Mass Dartmouth), which has an active wing to fly up and down as it is towed, and a Moving Vessel Profiler (MVP) (M. Levine), which profiles vertically using an active winch system. The logistical challenge is to sample fast enough to map the patch sufficiently well while the dye is being advected and diffused. The ship's underway ADCP is used to measure the horizontal velocity field so the effect of advection can be estimated to aid in guiding the survey track.

Analysis of 2011 experiment. The analysis of the rich data set obtained in the 2011 experiment continues. The experiment was conducted by a coordinated team of investigators and hence the analysis requires an organized effort. Toward that goal there have been all-hands meetings/workshops in Portland, OR in January 2012 and Woods Hole, MA in June 2012. Another meeting is planned for January 2013 at Stanford University.

Our group is taking the lead on the following analysis efforts:

* Fluorescein surveys – with contributions from M. Sundermeyer, D. Birch, J. Ledwell and E. D'Asaro. This analysis will involve the 7 fluorescein experiments which consist of sampling of the dye immediately after injection. Since the dye has not had time to diffuse into a large patch, the sampling was a challenge. An innovative analysis method is being tried in order to estimate the horizontal dispersion from these incomplete dye surveys.

* Streamline mapping technique – We are exploring a new method of streamline mapping using shipboard ADCP. This product will be useful for our dye mapping and analysis.

* T, S, and internal waves – This less-defined topic is meant to explore the statistical properties of the ocean variability on the small scales of the dye patch. The intent here is to learn about the mechanisms responsible for the lateral diffusion. We intend to contribute and collaborate with others doing similar analyses at larger scales.

Our group is also contributing to the following analysis efforts:

* Rhodamine surveys – lead by M. Sundermeyer, D. Birch, and J. Ledwell. We will contribute the MVP surveys that were done immediately after these 2 injections and participate in the joint analysis.

* LIDAR observations – lead by B. Concannon, J. Ledwell, G. Terray and M. Sundermeyer. The aircraft LIDAR was able to sample a number of the fluorescein patches relatively soon after injection. Our coincident *in situ* observations and subsequent analysis of the dye and TS structure will help ground-truth and interpret the LIDAR maps.

WORK COMPLETED

The main accomplishments this year include:

* MVP profiler processing. The impulse response of the fluorometer was estimated from profiles through very thin dye streaks. Using an exponential shape of the this response, we assumed that the observed thicker layers of dye could be modeled as a convolution of this response with the "actual" (unmeasured) dye layer. Actual dye profiles were then estimated by deconvolving the impulse response with the observed profiles.

* Transect analysis. We have developed software to be able to look in detail at various sections of data as a function of 3-dimensions and time. Estimation of the role of horizontal advection plays an important role in this analysis.

* Theoretical study. To help understand the fluorescein dye releases, we have explored the expected dye dispersion for idealized diffusivities. We are developing a methodology to help us interpret these undersampled dye patches in the context of solutions to theoretical advection-diffusion equations.

* Presentation of results. An oral presentation was made at the Ocean Sciences meeting in Salt Lake City, Utah, in February 2012 in a science session focused on lateral dispersion.

RESULTS

The profile data has been corrected for instrument response for temperature, conductivity, and fluorescein. Maps have been constructed showing the dye in absolute horizontal coordinates and in a coordinate system accounting for horizontal advection (Figure 1).

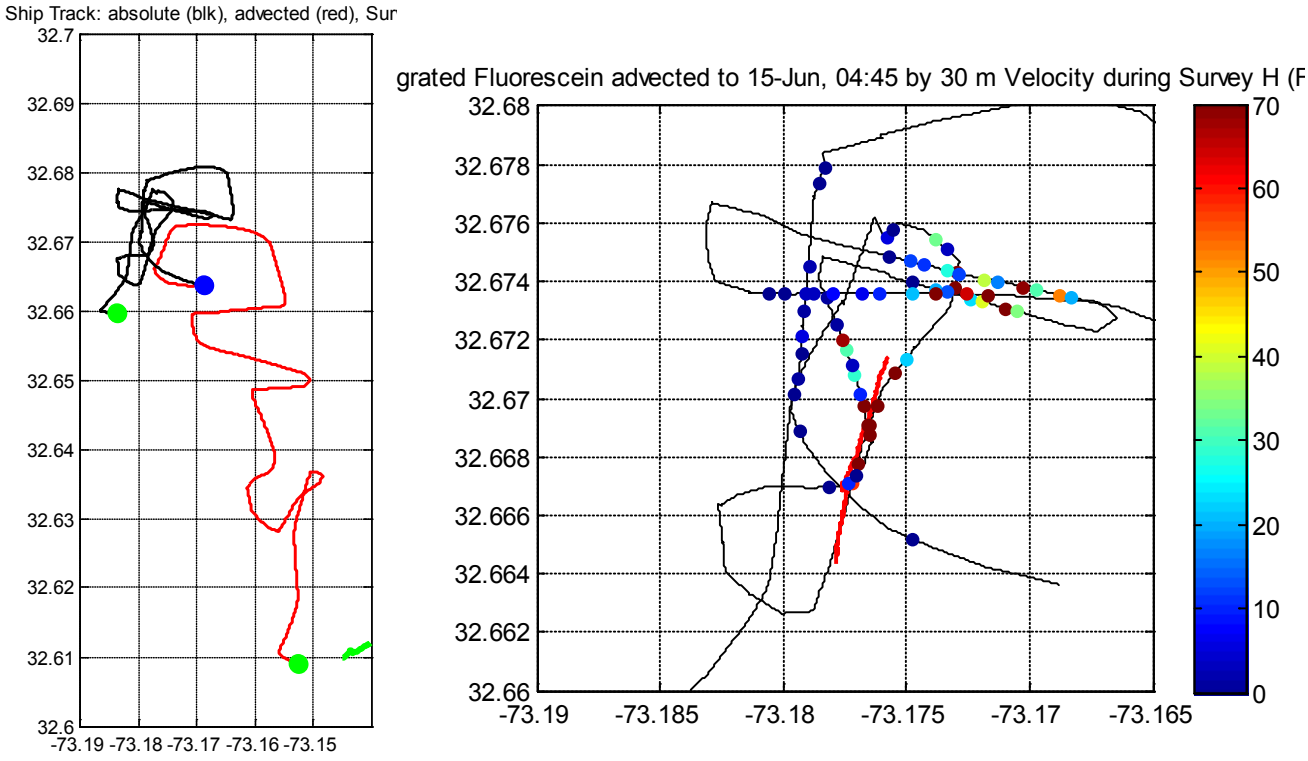

Figure 1. An example of fluorescein dye tracking made during the 15 June injection. The left panel shows the ship track in absolute coordinates (red) starting from the green dot and ending at the blue dot. The same track is also plotted in advected coordinates (black). The right panel shows the same track in advected coordinates (black) with dots indicating vertically integrated dye. The red line indicates the location of the injected streak of dye in advected coordinates. The absence of dots implies the absence of dye.

The map of the dye shown in Figure 1 can be overlaid with the dye patch as surveyed by aircraft LIDAR (Figure 2). The dye measured in situ by the profiler appears to have significant correspondence with the LIDAR image especially if one considers the uncertainty in the advective scheme. A more quantitative comparison is underway.

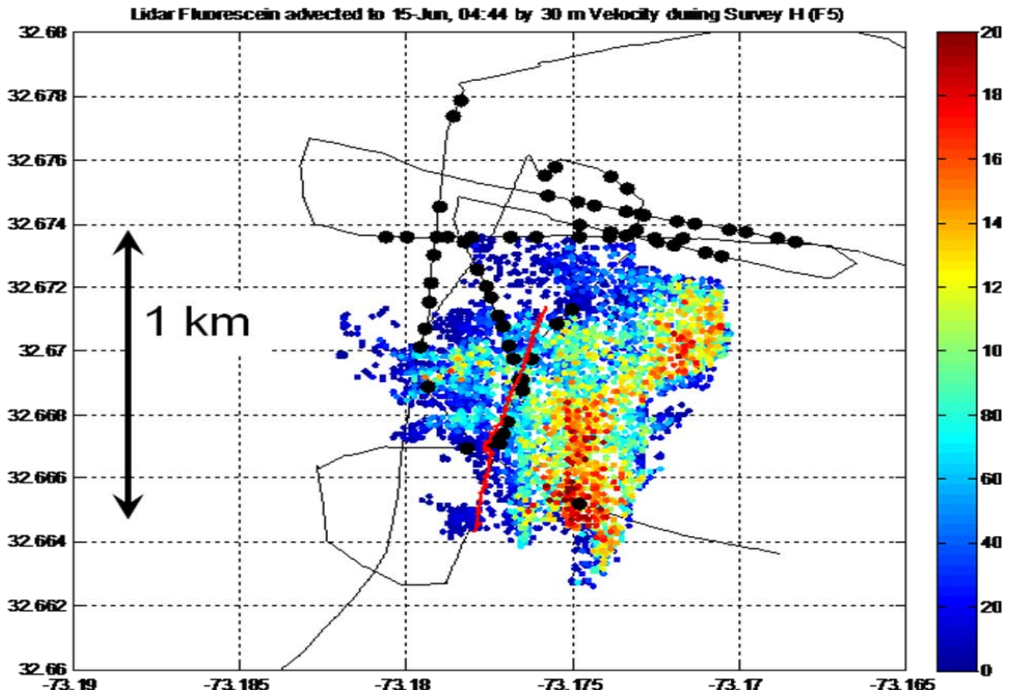

Figure 2. The ship track and location of profiles where dye was found (as in Figure 1) are plotted in black. Dot color indicates dye con-centrations found in the LIDAR image. The red line is the predicted position of the initial dye streak in advected co-ordinates.

IMPACT/APPLICATIONS

The experience gained with the MVP and Acrobat systems during the spring Lateral Mixing experiment and the development of processing techniques to correct the data will improve our ability to contribute to future research initiatives where dye tracking is an important component.

RELATED PROJECTS

The observation and modeling of the coastal ocean off Oregon continues to be of great interest at OSU. Ultimately, an improved understanding of the lateral mixing process will help in our ability to accurately model coastal circulation.

Relating to the coastal ocean, I am currently involved in making continuous observations from a mooring at a site 10 miles off Newport, Oregon (NH-10). Near-real time data are being collected and distributed on the web (http://www.nanoos.org/nvs/nvs.php). This effort is funded by NOAA, through the Northwest Association of Networked Ocean Observing Systems, and by NSF, through the Center for Coastal Margin Observation & Prediction (CMOP) (www.stccmop.org).

I am also involved in CMOP (as Co-Director) with a major goal of improving our understanding of the river to ocean system. Submesoscale lateral processes are important in trying to understand horizontal dispersion and mixing of the river plume with the coastal ocean. We have had the opportunity to conduct several short dye release experiments in the Columbia River plume, learning much about tracking dye in a very energetic environment.