Lidar for Lateral Mixing (LATMIX)

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Award Number: N0001412WX21031(FY12)
N0001411WX21010(FY11)
http://www.smast.umassd.edu/mixing/lidar_ONR_NSF.php

LONG-TERM GOALS

Our long-term goal is to better understand lateral mixing processes in the ocean on scales of 10 m to 10 km, i.e., the "submesoscale". We aim to understand the underlying mechanisms and forcing, as well as the temporal, spatial, and scale variability of such mixing. The research will contribute to fundamental knowledge of ocean dynamics at these scales, and to efforts to properly parameterize sub-grid scale mixing and stirring in numerical models. Ultimately our research will also enhance modeling and understanding of upper ocean ecosystems, since the flow of nutrients and plankton depends on stirring and mixing at these scales.

OBJECTIVES

One objective of our work is to determine the extent to which shear dispersion – the interaction of vertical mixing with vertical shear – can explain lateral dispersion at scales of 10 m to 10 km. A second objective is to determine whether slow but persistent vortices enhance the stirring attributable to shear dispersion. We also share the overall objectives of the Lateral Mixing DRI to try to determine the extent to which submesoscale stirring is driven by a cascade of energy down (in wavelength) from the mesoscale versus a propagation of energy upwards from small mixing events (e.g. via generation of vortices). A key technical goal of our work is to develop the use of airborne LIDAR surveys of evolving dye experiments as a tool for studying submesoscale lateral dispersion.

This annual report marks the end of year 3 of a 5 year study as part of the "Scalable Lateral Mixing and Coherent Turbulence" (a.k.a., LatMix) DRI. The main effort of the present work is a collaboration between J. Ledwell and E. Terray (WHOI), M. Sundermeyer (UMass Dartmouth), and B. Concannon (NAVAIR).

This project is being performed jointly with a collaborative NSF grant to J. Ledwell, E. Terray, and M. Sundermeyer (see "Related Projects" below). ONR is providing support for the airborne LIDAR operations and for some of the field operations and analysis.

APPROACH

Our approach is to release dye patches on an isopycnal surface in the seasonal pycnocline, and to survey their evolution for periods of 1 to 6 days. Drogues released with the dye not only help with tracking but also give valuable measurements of the shear/strain field on the outer scale of the patches. Lagrangian floats released with the dye patches give measurements of shear and strain following the patch (D'Asaro). The dye patches are sampled not only with towed instruments from ships (Sundermeyer; Levine) but also, as mentioned above, with airborne LIDAR (Concannon, Terray, and Sundermeyer). Because of the scope of the DRI of which our work is a part, the hydrographic and dynamic setting of the dye dispersion studies have been well measured with profiling towed bodies from two other ships (Lee and Klymak), with a swarm of EM-APEX floats (Sanford, Shcherbina), and a flotilla of gliders (Shearmann), as well as with satellite remote sensing (Harcourt) and ultimately with numerical models (Mahedevan, McWilliams, Molemaker, Ozgokmen, Tandon). Members of the DRI field team have also studied fine structure and microstructure with a heavily instrumented AUV (Goodman) and a heavily instrumented towed system (Kunze). Theory will be applied to our observations by all of the DRI PI's and their students and post-docs, but especially by Ferrari, Smith, Thomas, and McWilliams.

WORK COMPLETED

This section is lidar specific; refer to Ledwell (WHOI) and Sundermeyer (UMD) reports for a broader scope.

FY 08-10
After the LATMIX kick-off meeting the lidar system modification design effort was initiated. During this period the lidar telescope was redesigned to separate the green and blue return signals and record them simultaneously. The redesign included insertion of a beam-splitting device, insertion of logarithmic amplifiers in the electronic signal path, software changes to control two receivers and software changes to record two waveform channels. Due to Navy project funding shifts, the lidar system was de-installed form the Twin Otter and installed in a Navy P3. The physical install occurred in July of 2010 but due to unforeseen flight certification issues, the lidar system was not cleared for operation until the following spring.

Figure 1 (l) Drawing of telescope redesign to record simultaneous backscatter and fluorescence signals; (c) interior picture of system install on P3, (r) belly window visible, lidar telescope and scanner are located above window, under floor of P3.

FY11

During the spring of 2011, system flight certification, Navy test plan and system de-bug were completed. In June a system shakedown flight and 4 successful dye mapping flights occurred. WHOI participants, E. Terray and C. Sellers, were on-site at Patuxent River to receive the lidar data for preliminary analysis. The field experiment was conducted roughly 465 km (250 nmi) SW of Cape Hatteras, 785 km (425 nmi) from Patuxent River, MD. Four successful dye mapping flights, three Flourescein and one Rhodamine, were achieved. In total over 100 flight passes sampled the water volume and evolving dye patch in both low strain and moderate strain conditions.

A sample of the lidar return signals, blue backscatter and green Flourescein dye fluorescence, are shown in Figure 2 on the left. For this strong fluorescence return, absorption of the blue laser signal is evident in the sudden change in amplitude at the depth of the dye patch. A preliminary map of the geo-registered dye returns from a single pass is shown in Figure 2 on the right. A still concentrated core is evident and more diffused dye concentrations are shown to the East and West of the core. Extremely weak but still detectable dye returns are not shown in this preliminary map. Decimated data sets of lidar sampling time and location were generated so that in-situ and lidar measurements can be coordinated and compared. Analysis to detect weak dye returns, invert the lidar signal to dye concentration and advect each flight pass's dye hits is an ongoing effort between NAVAIR, WHOI and UMD.

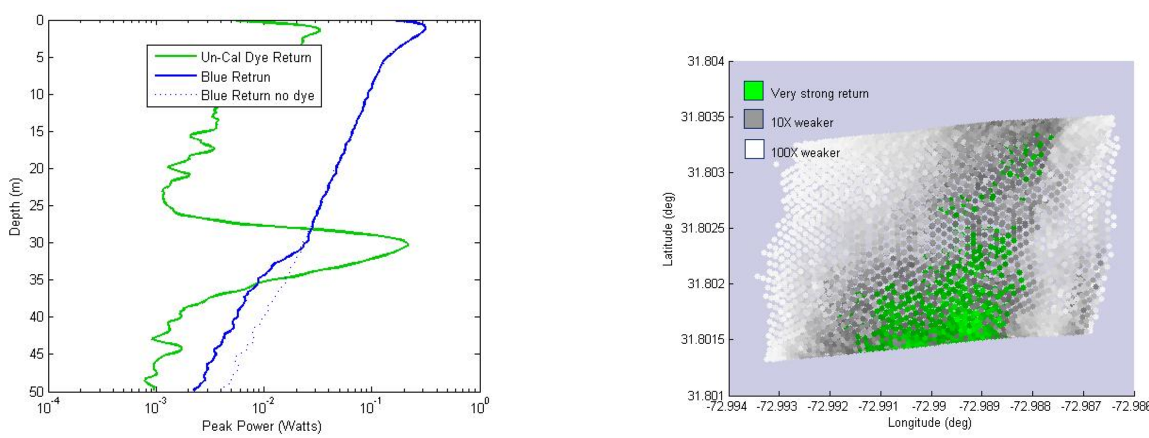

Figure 2 To the left, an example of the dye return signal (green) and lidar backscattered return signal (blue), sampling water with (solid) and without dye (dotted). To the right, geo-registered lidar dye returns from a single flight pass, the dye return strength varies from the central core to the edges of the streak by several orders of magnitude, indicating similar dye concentration variations.

FY12

During the first half FY12 NAVAIR continued to develop the processing software and analyze the lidar data collected during the June 2011 experiment. Initial efforts were focused on bringing the processing software to a robust state so that it could be shared among the collaborators (Terray, Sundermeyer). The result of the processing software can be seen in Figure 3, calibrated, advected, lidar dye returns rendered into a plan view of the dye sheet several hours after initial dye tracer injection. This map is composed of several flight passes, as see in the image on the right; each pass captured a 200 meter swath. In this figure the core of the dye streak is visible running North to South and the prevailing shear is disposing the dye to the West. Interesting fine scale structure can be seen in the intensity variation streaks to the West. The stability of the small scale features were confirmed on short time scales (10 minutes) by comparing multiple flight passes.

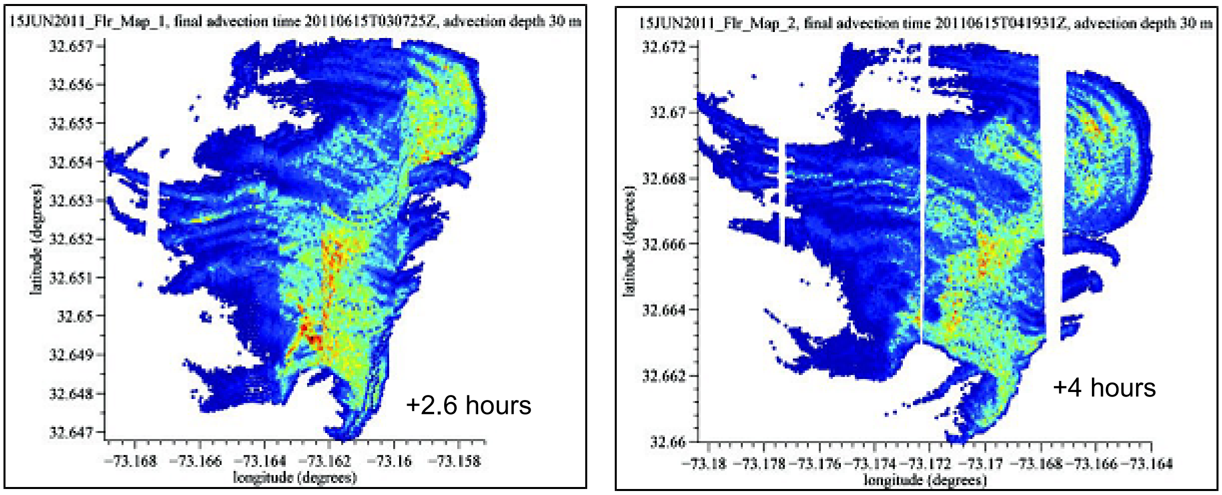

Figure 3 June 15, 2011 Flourescein composite plan view of peak lidar dye return signal 2.6 hours (left) and 4 hours (right) after initial dye tracer injection. Dye core is readily visible, North-South bright band, and small scale streaks are show shearing to the west.

During the second half of FY12 we focused on invention from lidar return signal to dye concentration. Initial efforts focused on utilizing both the absorption detected in the elastic backscatter channel and the Flourescein dye fluorescence, as described in Terray et al. Initial results, generated by M. Sundermeyer, are depicted in Figure 4. This plan view shows the dye injection line (Green), lidar spot locations (small blue dots) and dye concentration as measured by the lidar (colored large dots). This initial effort underestimates the dye concentration when compared to in-situ measurements and is currently under investigation. However, the plus two hour lidar measured dye concentration results do show structures similar to original dye injection streak (kink at south end) and have enough fidelity to show that fine scale structure, on the 10's of metros, exists and persists. Giving more weight to the inversion of the lidar fluorescence channel in the 2011 data, which has a larger dynamic range than the elastic backscatter channel, is in processes and should prove more robust.

For any inversion method, comparison with in-situ measurements is important. The lidar system overflew the R/V Hatteras while in-situ measurements (MVP - Levine) were in progress. The lidar system returns from the ship are clear indicators of co-location of the two sampling methods. Further, a profiling float (Lagrangian - D'Asaro) was sampling the dye during the course of the entire experiment. The float was affixed with retro-reflecting tape so that when the lidar system overflew, a strong reflection front he float could be detected in the lidar elastic backscatter channel. Initial searches have detected several liar float returns. In Figure 6 the geographical closest lidar dye return shots are plotted for near simultaneous sample times (+/- 15 seconds) for both MVP and LG Float measurements. It is clear that, for this portion of the June 15 flight, there are several co-located, near simultaneous   lidar and in-situ dye measurements. These data points will be used to calibrate the lidar inversion process.

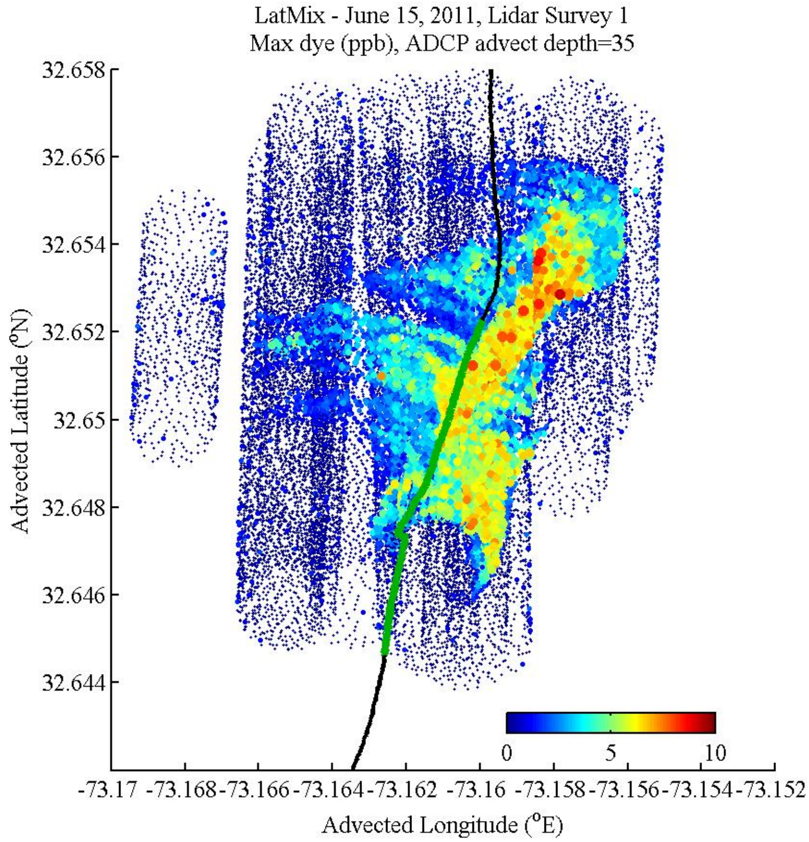

Figure 4 maximum dye concentrations (ppb), derived from lidar measurements is depicted with lidar sample location (small dark blue dots), R/V Hatteras ship track (black line) and dye injection streak (green line). North-South dye core is readily visible two hours after injection as well as smaller scale tendrils to the west.

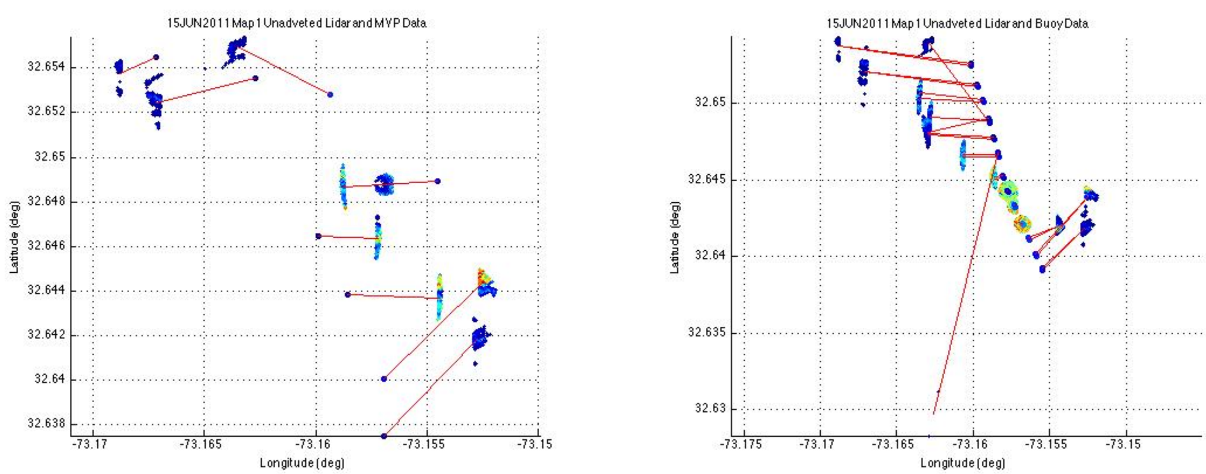

Figure 5 Coincident lidar and in-situ sampling of the Flourescein dye sheet for June 15, MVP fluorometer (left) and Lagrangian float fluorometer (right). Circularly grouped lidar samples show co-located, simultaneous measurements.

During FY 12 two LATMIX working group meetings were held, the first in Portland, OR during January of 2012 and the second in Woods Hole, Ma during June of 2012. The lidar data collection efforts funded under the LATMIX DRI were presented at the AGU Ocean Sciences conference in Salt Lake City, UT during Feb 2012, titled, "Lidar Studies of Small-Scale Lateral Dispersion in the Ocean".

RESULTS

To date, analysis pertaining to the understanding of lateral mixing processes in the ocean on scales of 10 m to 10 km is not complete. However, it is clear that the capability to measure processes on the scales of 10 meters in the horizontal and 1 m in the vertical with >3 decades of signal dynamic range for sustained periods of time will play an important role in this analysis.

IMPACT/APPLICATIONS

The results of this investigation will help determine the importance of submesoscale measurements in modeling and understanding of lateral mixing processes in the ocean. Lidar system measurements could provide even finer scale measurements if warranted.

RELATED PROJECTS

The above work and findings represent a joint effort on the part of LatMix DRI PIs Ledwell and Terray (WHOI) and Sundermeyer (UMass Dartmouth) under ONR grants N00014-09-1-0175 and N00014-09-1-0194, respectively.

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