Lateral Coherence and Mixing in the Coastal Ocean: Adaptive Sampling using Gliders

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Award #: N00014-09-1-0379

LONG-TERM GOALS

Lateral mixing is driven through the interplay between finescale isopycnal stirring (shear + strain) and small-scale diapycnal turbulence. We seek to understand this interplay within highly anisotropic coherent structures, such as fronts, jets, eddies and filaments, which likely control lateral dispersion in both coastal and open ocean. These structures evolve yet are often persistent on O (3 day) timescales, so are ideally suited to be adaptively sampled by autonomous gliders that actively report both turbulent and finescale statistics.

OBJECTIVES

As part of a coordinated effort to quantify the meso- through micro-scale processes driving lateral dispersion, we plan to deploy 4 AUV gliders to perform intensive, adaptive surveys. Newly-enhanced to measure turbulent mixing, water-column currents and dye concentration, these OSU autonomous gliders will capture the interplay between shear, strain, and turbulence over a wide range of scales. In conjunction with ship-based dye release experiments, adaptive glider sampling will substantially increase the synoptic coverage of the dye surveys, providing a more complete description of the spread and dispersion of the dye. Microstructure sensors will allow for the quantification of small-scale mixing and its dynamical feedback to meso and sub-mesoscale flows. ADCP imaging of water-column velocity will (i) characterize the features driving fluid dispersion, (ii) help build better turbulence parameterizations in anisotropic environments, and (iii) will provide enhanced tracking capabilities for lateral coherence calculations. The scarcity of synoptic observations in the past has made it impossible to detangle the lateral and vertical processes. Adaptive sampling with multiple gliders in multiple locations for extended durations will provide the detailed statistics necessary for the community to make progress.

APPROACH

We plan to deploy four newly-enhanced, autonomous gliders to measure the lateral coherence and evolution of dynamically significant properties. These properties include velocity (U), velocity shear (dU/dz), stratification (N2), temperature (T), salinity (S), temperature variance dissipation rate (χ), turbulence dissipation rate (ε), turbulence diffusivity (K_T), biological fluorescence, and, in cooperation with a dye release experiment, dye concentration.

OSU enhanced gliders are ideal sampling platforms for multiple reasons:

- Because they incorporate acoustic Doppler current profilers (ADCPs) with bottom-tracking capabilities, these gliders will be tracked while below the surface, permitting continuous spatial coherence computations on horizontal scales spanning O (10 m – 10 km). Gliders will also be equipped with a six component gyro package (3 linear and 3 rotational rate sensors) which will provide enhanced navigational capabilities at water depths where bottom-tracking is unavailable. All navigational data will be post-processed in a full LADCP-type inversion (i.e., Visbeck, 2002, Nash et al 2007) that utilizes all ADCP, gyro, and GPS data to provide both water-column velocity and vehicle location/speed.
- Because all data are logged and reported back on a regular basis, all data (including velocity and turbulence data) will be incorporated into the adaptive sampling that will be necessary to track laterally coherent features. This will be the first use of turbulence data for guidance of autonomous vehicles using adaptive sampling
- Because each enhanced glider possesses measurement capabilities similar to that obtained during a single shipboard microstructure operation (albeit slower), a fleet of 4 enhanced gliders operating independently will both (1) sample more mixing/dispersion "events" from a statistical perspective, and (2) provide simultaneous observations at multiple locations – necessary for coherence calculations. The strength of this measurement is in addressing the interactions between isopycnal stirring via measurement of lateral coherence of dynamically significant aspects of the flow field and diapycnal mixing via direct turbulence measurements.

WORK COMPLETED

Tests were conducted in June 2009 (internal pod) over Stonewall Bank on Oregon's continental shelf with the two existing microstructure gliders. These were coordinated with Chameleon turbulence profiling. An engineering test cruise was completed in July 2010, in which the glider successfully flew a fixed pattern relative to a moving drifter.

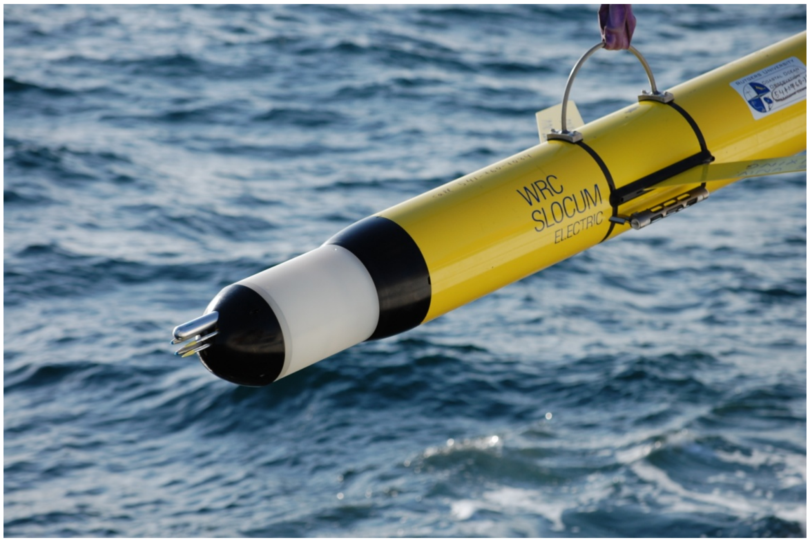

Figure 1 – Photograph of Webb glider with internal turbulence pod.

LatMix 1 Main Field Experiment

In June 2011 we conducted the first main field experiment. Two gliders (350 m Webb Slocum) were equipped with CTD (SBE 41), single wavelength backscatter, chlorophyll, and rhodamine fluorescence (WETLabs FLBBRH), fluorescein fluorescence (FLUR), and 600 kHz phased array DVL (RDI) – gliders john (unit 185) and june (unit 186). Two gliders (200 m Webb Slocum) were equipped with CTD (SBE 41) and homemade microstructure package with two thermistors, two shear probes and a six port pressure sensor 'gust probe' – gliders doug (unit 93) and russ (unit 91). A fifth glider (1000 m UW Seaglider) was equipped with CTD (SBE 41), dissolved oxygen (SBE 43), single wavelength backscatter, chlorophyll and colored dissolved organic matter fluorescence (WETLabs FLNTU) and photosynthetic active radiation (Satlantic) sensor – glider sg158.

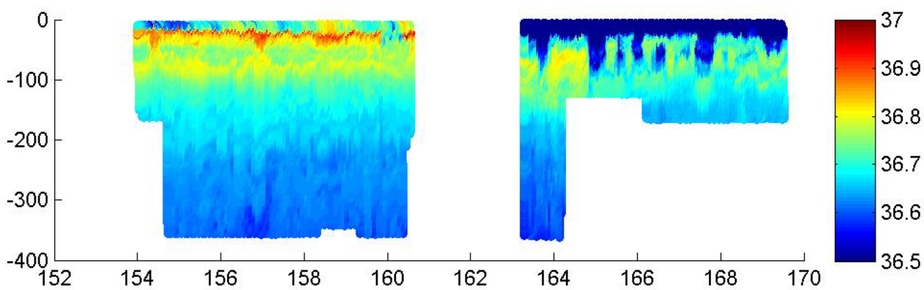

Figure (2): Salinity observations from glider john during both deployments (x-axis day of year, y-axis depth in meters). At site 1 there was an abundance of submesoscale structure near the pycnocline, characterized by local maxima that may or may not show a connection to the surface. At site 2, salinity was fresher by 0.3 and structures typified by salinity minima extending vertically down from the surface layer.

The glider observation showed submesoscale structure in the salinity field at the pycnocline consistent with features seen in the MVP observations. The features appeared as local maxima in the salinity field sometimes connecting up to the surface layer. Observations below 100 m also showed submesoscale structure in the salinity field, but less intense than the pycnocline variability.

We have completed the processing of glider CTD and optic observations. ADCP velocity observations are nearing completion as part of Chris Ordonez Master's thesis. Microstructure data processing for temperature microstructure is complete and nearing completion for shear microstructure.

LatMix 2 Main Field Experiment

In February and March of 2012, we conducted the second main field experiment. LatMix 2 was carried out in the Gulf Stream during extreme wind forcing conditions. Utilizing two global class RVs, we sampled the region around a lagrangian float drifting along the north wall of the Gulf Stream (Figure 3).

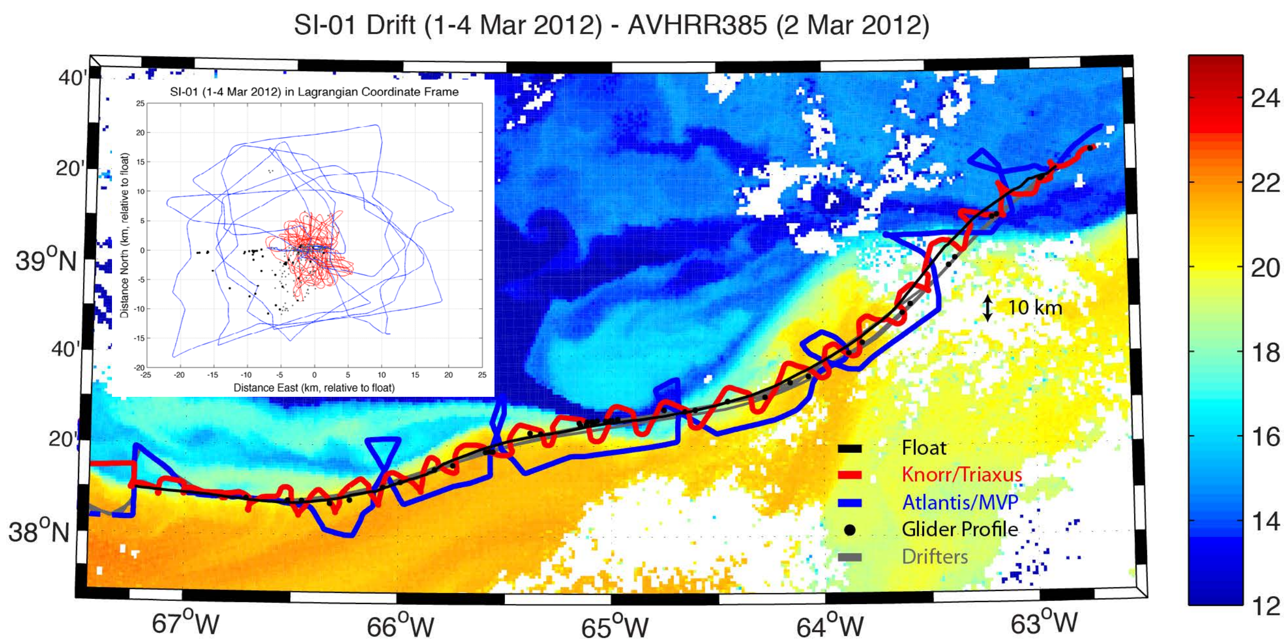

Figure 3: Survey tracks from the first symmetric instability experiment during LatMix 2 in geographic coordinates, superimposed on a SST image from the mid-point of the survey. And the survey tracks in the coordinate system moving with the lagrangian float (inset).

We deployed the same set of 4 gliders as deployed in LatMix 1. Sadly, glider june was lost some time on 07 Mar 2012 during intense winds and large seas.

Processing of glider CTD and optical data is complete. Glider-based ADCP data reduction is nearing completion and is part of Chris Ordonez Master's thesis. Microstructure data processing has just begun.

RESULTS

The gliders successfully flew fixed survey patterns relative to moving drifters in both LatMix 1 and LatMix 2 field efforts, including the low energy (20 cm/s), medium energy (70 cm/s) and high energy (2 m/s; Gulf Stream) field sites. Successful glider-based ADCP observations were collected during both experiments and we're developing an algorithm for processing the ADCP data into full depth profiles of absolute velocity, using techniques borrowed from LADCP data processing. Glider-based microstructure analysis is progressing.

During LatMix 1 observations of temperature microstructure indicated relatively weak mixing at the first site (The Big Nothing) and increased mixing at the Filament site (approximately a factor of 5). Turbulence on the flanks of the filament were approximately 10 times larger than turbulence outside the filament. We are investigating the possibility that enhance turbulence is related to frontal dynamics, either a super positioning of thermal wind shear and internal wave (near-inertial) shear or other frontal processes (such as symmetric instability).

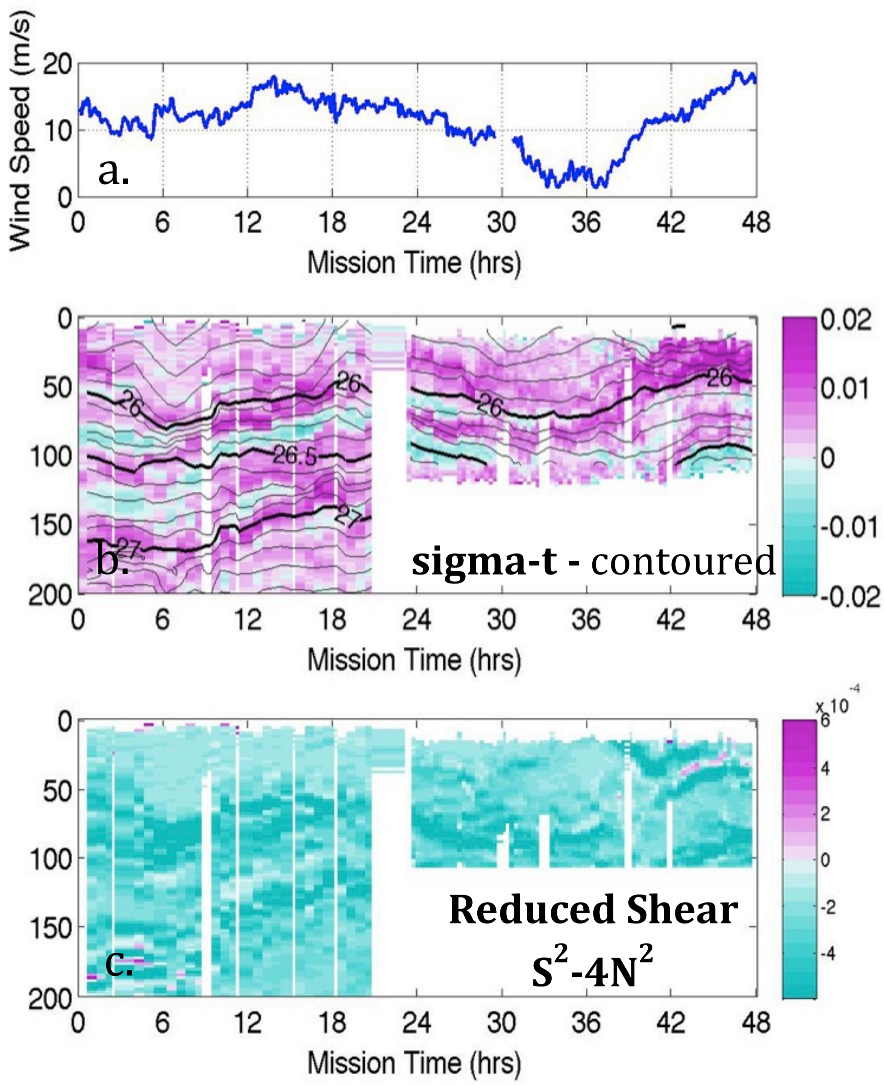

Figure 5: Results from the first symmetric instability experiment 01-03 Mar during LatMix 2. a) wind speed, b) glider-based observations of the shear and density, and c) calculation of the reduced shear.

The gliders we deployed for 48 hours during which winds were greater than 10 m/s for over a day, then there was a lull, followed by rapidly intensify winds. The ADCP glider observed coherent structures in the shear field. And comparing the stratification (N^2) to the shear-squared, indicates the potential for turbulent mixing, during the rapidly intensifying winds (MT 36 – 48) when values of the reduced shear are greater than zero. However, these regions are below the surface mixed layer in a region of average stratification, a possible signature of symmetric instability. We are in the process of comparing these measurements to the turbulent microstructure to search for mixing events.

IMPACT/APPLICATIONS

Gliders offer a means of making two very valuable types of relatively autonomous measurements in the ocean. The first is the type of repeated routine observation that permits establishment of a climatology from which significant deviations can be identified and addressed. The second is the observation of extreme events (such as hurricanes) that cannot be made from ships. We have established standards of ocean turbulence measurements and have extended our ship-based vertical and horizontal profiling packages to moored mixing measurements. It has been a natural evolution to use this expertise to integrate new sensors into gliders that will both begin to define climatologies of mixing in coastal waters and lead to turbulence measurements in events such as hurricanes for which we have limited or no observation.

PUBLICATIONS

Shearman, R.K., J.D. Nash, P.J. Wiles, J.N. Moum, J.A. Barth, and S. Glenn, 2012. Glider observations of pycnocline mixing over the Mid-Atlantic Bight induced by Tropical Storm Hanna, in prep

C. E. Ordonez, R. K. Shearman, J. A. Barth, P. Welch, A. Erofeev and Z. Kurokawa, “Obtaining Absolute Water Velocity Profiles from Glider-mounted Acoustic Doppler Current Profilers,” Marine Technology Society Oceans 2012 – Yeosu, 21-24 May 2012, ISBN: 978-1-4577-2089-5.