

## **Turbulence and Prey Field Properties of Gulf Stream Frontal Eddies on the Shelf Break**

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### **Abstract**

Our study was aimed at characterizing turbulence and mixing levels in a region subject to Gulf Stream frontal eddies. We deployed a newly developed turbulence-measuring glider into Onslow Bay, in the Cape Lookout region of the Mid-Atlantic Bight off North Carolina. The system provided turbulence data of excellent quality for just over 80 hours, and temperature and salinity data for 6 days, over a 50 km section of Onslow Bay. Turbulence levels were modulated over a 24-hr period, most likely associated with the diurnal nature of the local tides. Mixing levels were correlated to the stratification, which was estuarine in nature, with cool-fresh water defining the upper layer and warm-salty water defining a lower layer. After 7 days, the glider experienced a problem, jettisoned its emergency ballast, and drifted at the surface for 3 days subject to gale force winds related to tropical storm Ida. In addition to the excellent science data, the mission proved the feasibility of the new instrument system, and gave us valuable experience operating in difficult conditions.

### **Introduction**

Numerous studies have suggested that the feeding efficiencies of zooplankton and fish are enhanced in regions of active turbulence. Larger predators can exploit these turbulent patches, as their prey is often congregated at these locations. Thus, regions of enhanced turbulence are often associated with sites of heightened biological activity. Top marine predators, such as beaked whales, dolphins, and porpoises, are particularly adept at targeting prey in such regions. Studies aimed at understanding the behaviors of these high-trophic level animals are often tied to surveys of their prey field, consisting of the mid-trophic level nekton that feed on zooplankton. It is through an upward trophic level cascade that the turbulence properties of the ocean influence the behaviors of marine predators.

One environment well suited for turbulent enhancement of the marine predator prey field is Gulf Stream frontal eddies on the Mid-Atlantic Bight. The circulation associated with such eddies favors both the flux of nutrients into the euphotic zone of the continental shelf, as well as turbulence production by enhanced thermohaline and shear fine-structure. Colleagues at the Duke Marine Lab have been surveying the marine mammal activities southwest of Cape Lookout, and find that the presence of frontal eddies significantly influences animal behaviors. It is hypothesized that these behavioral changes are the result of changes in the prey field, triggered by the influence of turbulence being supported by frontal eddy processes.

Turbulence describes the class of processes acting in a fluid that leads to the general disorder of physical properties. This includes the flow itself, as the orderly flow of currents must eventually breakdown into the whirls of chaotic motion that eventually dissipate energy, and lead to mixing of properties like temperature. In the ocean, turbulent mixing has long been known to influence the physics of both coastal- and basin-scale systems, generally through the influence of vertical mixing on the distribution of buoyancy. The feedback of turbulence acting on biology has also been noted, particularly in its ability to impact zooplankton (e.g. Rothschild and Osborn 1988; Sunby and Fossom 1990; Davis et al. 1991). These studies have been well supported by observational work, indicating that zooplankton prefer to feed in turbulent patches, where their

frequencies of encounter with prey are enhanced. It is perhaps a more recent observation that the feeding behaviors of higher trophic level animals also are influenced by the propagation of this effect up the food chain.



Figure 1. The turbulence SLOCUM glider. The *microrider* package, built by *Rockland Scientific*, can be seen along the top of the glider. The specialized probes for measuring microstructure are visible protruding past the nose of the instrument. These include the sensors for measuring turbulent parameters for shear (energy) and temperature (thermal variance).

Of interest here are the marine mammal predators of the Mid-Atlantic Bight. A study underway along the Cape Lookout region of the N. Carolina shelfbreak suggests that the physical forcing by Gulf Stream frontal eddies (GSFEs) is influencing the prey field of local marine mammal predators. The role of such eddies in stimulating biological activity is not a new finding (e.g., Yoder et al. 1981; y and McGillivray 1985). However, most previous studies have focused on the “nutrient pump” aspect of GSFEs in supporting blooms on the shelf. The potential influence of small-scale turbulent patches on biology has not been assessed.

## Fieldwork

We used the newly developed (at the time) turbulence glider system (Fig. 1), which was built for the PI through the cooperation of *Teledyne Webb Research* (Falmouth, MA) and *Rockland Scientific* (Victoria, BC). These groups had not previously worked together, but were willing to cooperate for this particular instrument system.

The turbulence SLOCUM glider was ideal for the project, as it is the only profiling turbulence system capable of collecting upper-ocean (to 200-m depth) microstructure (shear and temperature) over a multi-day mission, without the need of a station-keeping vessel. The microstructure records are then used to compute dissipation rates of turbulent mixing for energy and thermal variance, which in turn can be used with the SLOCUM’s CTD data to estimate turbulence diffusivities (a.k.a. “mixing rates”) using long established methods (Osborn 1980). Like all gliders, the system can be deployed and recovered from a small boat, and then operated from shore, using only a small team. The glider is suitable for documenting both the hydrographic structure of the GSFE properties, as well as measuring the microscale patches of turbulence occurring due to finescale variations of the eddy and coastal driven flows.

The worksite was the region south of Cape Lookout, NC, in Onslow Bay (Fig. 2). We worked with our colleague, Dr. Doug Nowacek at the Duke Marine Lab. He provided us access to the lab’s 40-ft vessel *Cetus* for the deployment, which was done on 5 November 2009, for a planned 10-day mission. This date was chosen after a previous set of dates in October failed due

to tropical storm activity along the S. Atlantic coast. Remote sensing imagery (SST, compiled by Rutgers) seemed to show the beginnings of a Gulf Stream Frontal Eddy. It was hoped that after 1 week, the glider would reach the front.

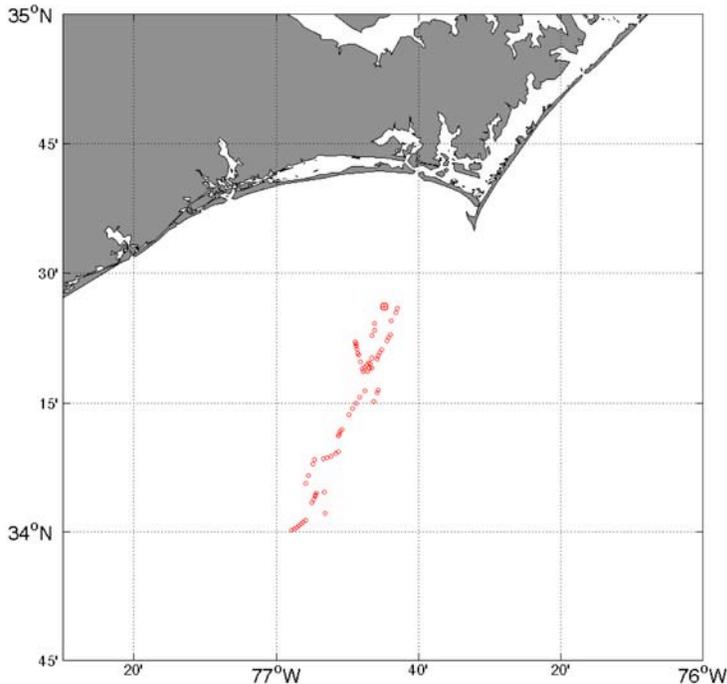


Figure 2. Map showing the glider mission in Onslow Bay, 5-11 November 2009. Positions of the glider are shown at approximately 3 hr intervals. The mission start point (shown has a circle with cross) was at the northern end of the position record. The glider generally maintained a south-southwest trajectory to 34 N. Cape Lookout is the prominent coastal headland to the north.

November 15, Ken Decoteau arranged to recover the unit on the marlin fisher *Sensation* operating out of Beaufort. The glider was recovered that morning. There was clear evidence that the glider had struck something hard, as some of the turbulence probes were bent. However, no conclusive statement could be made concerning the nature of the incident that prevented the glider from surfacing.

### Data

CTD data from the glider show the estuarine nature of the stratification along the near-shore segment of the mission segment (Fig. 3). Cool, Fresh waters from the Trent and Neuse Rivers flows out of the Morehead/Beaufort inlets, and defines the surface layer of Onslow Bay out to about the 30-m isobath. Seaward of the 30-m isobath, temperature is stratified in the usual oceanic way, with warm water overlying cooler water. Offshore salinity is well mixed to the bottom. In all, just over 1200 full-depth CTD profiles were collected in 6 days of continuous sampling, which gives a profile at about 10 minute intervals.

The glider was deployed along the 20-m isobath, as a site about 20 km from the Duke Marine Lab. The glider ran well for the first 5 days of the mission. Turbulence data was collected for 80 hours until the disk filled with 4 GB of data. Glider CTD and navigation data continued to be collected until mid-day on November 11, over a 50 km section reaching to the 35-m isobath. On November 11, a problem occurred that caused the glider to abort its mission and drop it emergency ballast weight. The incident appears to have been caused when some undetermined event caused the glider to be stuck underwater for more than 12 hours. Fishing gear is one possibility. Following this incident, the glider drifted east on the surface, subject to gale force winds due to the remnant of tropical storm Ida. Given the heightened seas associated with the storm, the Duke Marine Lab vessel was not suitable for recovering the glider. On

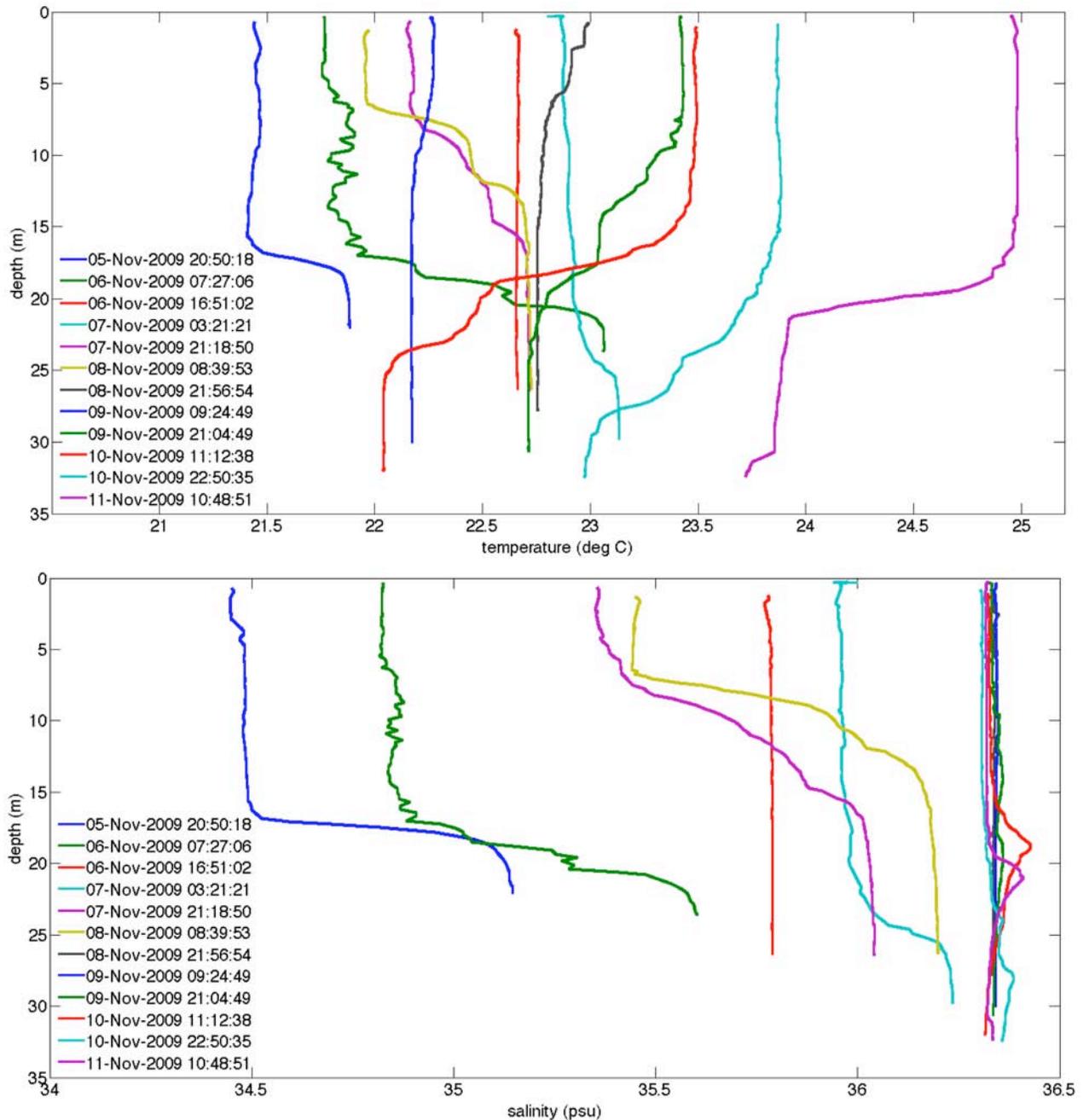


Figure 3. Temperature (top) and salinity (bottom) profiles for the period between 5 – 11 November 2009. 11 representative profiles are shown from the more than 1200 collected. Onshore to offshore records proceed from left (cooler fresher water) to right (warmer saltier water) in each panel, representing date from the 20-m to 35-m isobaths.

Turbulence data show enhanced microstructure in the near surface layer, the bottom boundary layer, and at density (thermal or haline) interfaces in the profiles (Fig. 4). Measurements of microstructure were used to compute the dissipation rates for kinetic energy and thermal variance using standard analysis procedures. Here, we focus on the turbulent kinetic energy dissipation rate,  $\varepsilon$  (Osborn, 1980).

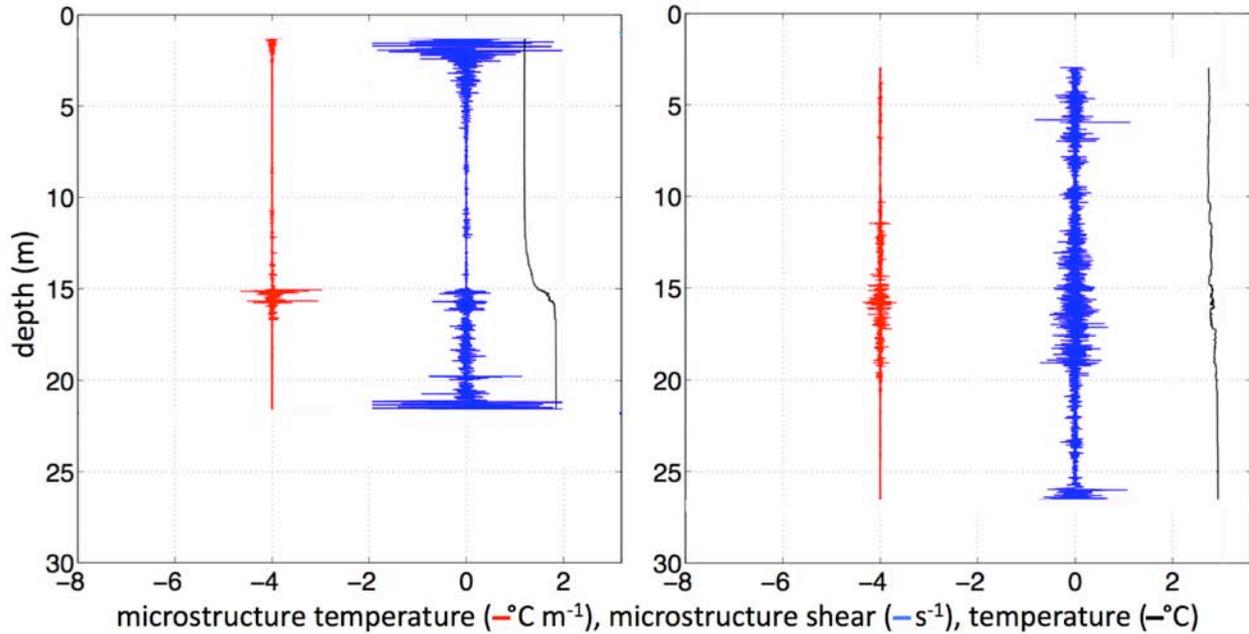


Figure 4. Microstructure data from a representative on-shore (left) and off-shore (profile), showing characteristic temperature and shear turbulence records. Micro-structure temperature (black) and gradient data (red) are offset by -20 and -4, respectively.

Figure 5 shows the evolution of thermal stratification and turbulent dissipation rate for an 80-hour period as the glider transited from the 20 to 30-m isobath. The dissipation rate fluctuates between  $\varepsilon = 1 \times 10^{-9}$  W/kg and  $\varepsilon = 1 \times 10^{-6}$  W/kg as the temperature structure oscillates between estuarine and well-mixed conditions. The modulations of both dissipation rate and temperature seem to occur on a roughly 24-hr cycle.

Figure 6 shows a record of the local tides for the 3-week period centered around the observations. As shown by all components of the barotropic tide, the signal is overwhelming diurnal in nature. While the model predicted tidal flow seems on the weak side, only  $\sim 1$  cm/s, we speculate that these are considerable underestimates, as the glider's behavior suggested considerable strong tidal flows were at play.

## Conclusions

The goal of the project was to provide data on the turbulence and mixing environment of a Gulf Stream Frontal Eddy. This goal was never met, due to several factors: 1) the glider stopped collecting turbulence data on the 4<sup>th</sup> day, when its data card became full ahead of schedule, 2) the glider aborted its mission on the 6<sup>th</sup> day due to an undetermined incident, and thus never got far enough offshore to reach the Gulf Stream front.

However, we believe we have obtained the first microstructure data set from Onslow Bay, and we been the first to show that turbulence and mixing levels fluctuate with the diurnal signal of tide. This finding will be of value to anyone interested in understanding how properties in the Bay are influenced by mixing levels.

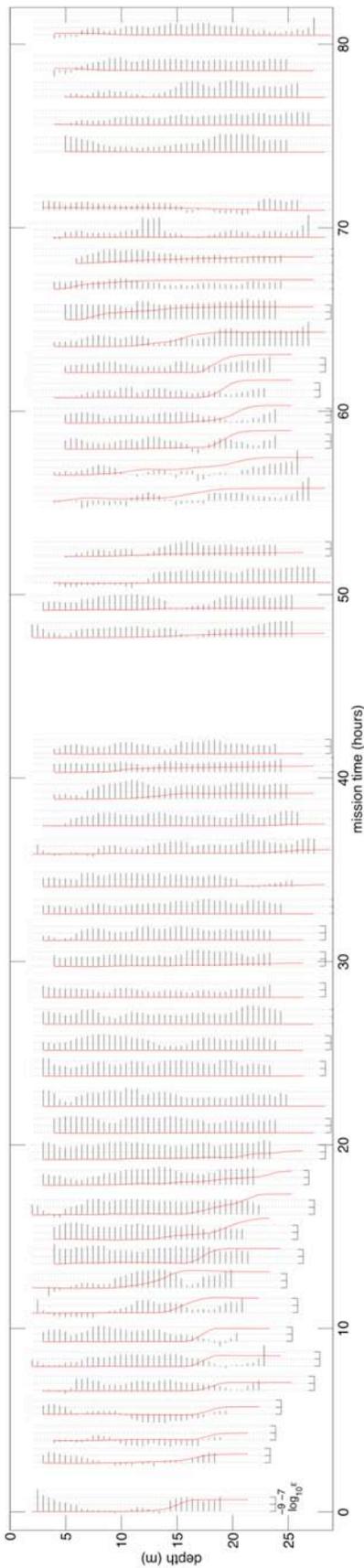


Figure 5. Timeseries of turbulent kinetic energy dissipation rate (black stick plots), and temperature structure (red profiles). Every 10<sup>th</sup> profile is shown of the 520 collected. Gaps in the record reflect periods when the glider was at the surface transmitting data to shore. Dissipation rates are plotted on a logarithmic axis, with ticks at 10<sup>-9</sup>, 10<sup>-8</sup>, and 10<sup>-7</sup> W/kg. Only the relative temperature profile is shown at each time.

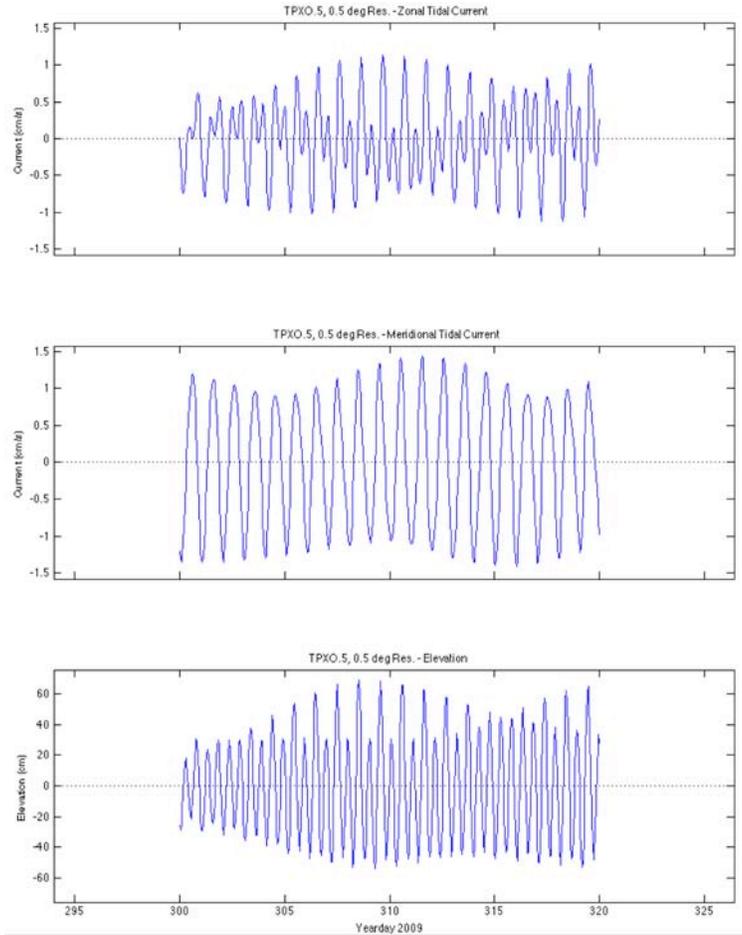


Figure 6. TPXO tidal model estimates of tides in Onslow Bay, over the date range from year days 300 (10/27) to 320 (11/16). Both components of the flow (zonal, upper, and meridional, middle panel) and tidal height (lower panel) show a strong diurnal signal.

## **Outcomes**

This project was our first scientific deployment of the turbulence glider, and despite the technical issues associated with the glider encountering a problem, was a success. The data collected were of excellent quality, the experience gained running the system under challenging circumstances proved helpful in preparing us for future work. Since this project, the glider has been used in two ONR programs. In addition, ONR has sponsored our glider work in the Vietnam DRI, and NSF has sponsored the use of this glider in the upcoming SPURS program. In all cases, data from the Onslow Bay mission was used to illustrate the science capabilities of our instrumentation.

This project also opens the door to a follow-up study in the Cape Lookout region, involving our glider, with some of the newly acquired gliders at the Duke Marine Lab equipped with acoustic sensors for monitoring marine mammal behaviors. This project will possibly be proposed to ONR in the coming year.

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