Monitoring the Gulf Stream and shelf environment in the South Atlantic Bight through integrated autonomous underwater glider observations and data assimilative ocean model predictions

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Abstract- Gliders are the state-of-the-art autonomous underwater vehicles (AUV) that can operate unattended for roughly a month-long period in the ocean. Given a forward horizontal speed of 0.25 ms^{-1}, gliders can cover ~ 25 km per day. They trace sawtooth profiles in the ocean by changing buoyancy, observing subsurface temperature, conductivity, and other water properties versus depth, and at the surface, fix position via Global Positioning System. Onshore team monitor and direct glider trajectories using two-way Iridium satellite communications, which permit near real-time delivery of observations and re-direction of mission/adaptive sampling. NCSU Ocean Observing and Modeling Group group has been running glider surveys in the South Atlantic Bight on a seasonal basis. Active research are being carried out to assimilate glider data along with other coastal ocean observations (satellite SST and SSH, mooring time series, HF Radar surface currents) into high resolution regional ocean model using advanced variational data assimilation schemes, providing a new look at along-shelf and cross-shelf exchanges associated with Gulf Stream dynamics.

Keywords-*Glider, data assimilative ocean models, Gulf Stream, South Atlantic Bight*

I. Introduction

Shelf circulation and water properties in the South Atlantic Bight (SAB) are affected by a variety of processes and characteristics that are unique to the region (i.e., broad and shallow shelf, influence of strong boundary currents, strong tidal forcing, distributed river input, passage of powerful tropical storms and hurricanes). Interactions with the Gulf Stream in particular, play a crucial role controlling stratification and circulation dynamics on the shelf, and provide an efficient mechanism for cross-shelf transport. Those processes have wide ranges of spatial and temporal scales and are not easily observed with traditional technology, which has led to a historic lack of information on density stratification and horizontal and vertical structure of biologically relevant variables. The paucity of observations is enhanced in winter and during storm conditions, when shipboard measurements are difficult to obtain.

At North Carolina State University, the Ocean Observing and Modeling Group (OOMG) has been using glider technology to survey SAB shelf environment. Gliders are considered an essential part of coastal observing systems, with multiple interfaces with other data and model streams. Taking advantage of buoyancy and attitude to "fly", gliders collect physical and biological data for up to 4-5 weeks, proving to be very useful tools in other observing systems throughout the U.S. [1, 2]. Glider surveys provide a near real-time inflow of 3-D observations of temperature, salinity, density, chlorophyll, leading to an unprecedented understanding of shelf and shelf-edge processes, including the investigation of cross-shelf transport pathways for Gulf Stream derived waters, and allow for the integration of glider data into circulation and ecosystem modeling efforts.

II. Results

Density fields are critical for initialization, validation, and assimilation into circulation models, which can be coupled to biological and geochemical modules to model ecosystem function on a regional scale [4, 5, 6]. Measurements of biological parameters in tandem with physical properties on a regional scale at the proposed frequency provide an opportunity to extend the capabilities of regional ocean circulation and marine ecosystem models.

Since 2011, OOMG has been operating slocum glider surveys to measure the SAB hydrographic conditions. Figure 1 show a two-week glider survey off the North Carolina coast. The glider made 4 repeated cross-shelf transects between September 1 and 13. In addition of revealing strong cross-shelf gradients in temperature, salinity and density fields between inner- and mid-shelf areas. Glider data also clearly elucidate strong time dependence in the shelf hydrography, such as pronounced temperature diurnal change, near-coast salinity decrease due to large rain fall and river runoff.

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OOMG glider survey in 2012 (Figure 2) was performed over 30 days in a larger shelf context covering Georgia, South Carolina and North Carolina shelf seas. After released off Georgia coast, the glider was directed to move offshore to ~ 200 m isobath first. It then moved to the north/northeast in approximately parallel direction of the shelfbreak before moving onshore to survey the mid-shelf areas. The last leg of this glider survey repeated the same transect of 2011 survey off North Carolina coast. Over a month time frame, this successful deployment surveyed both shelf water and Gulf Stream water, providing direct observations of strong temporal and spatial heterogeneity in the ocean density.

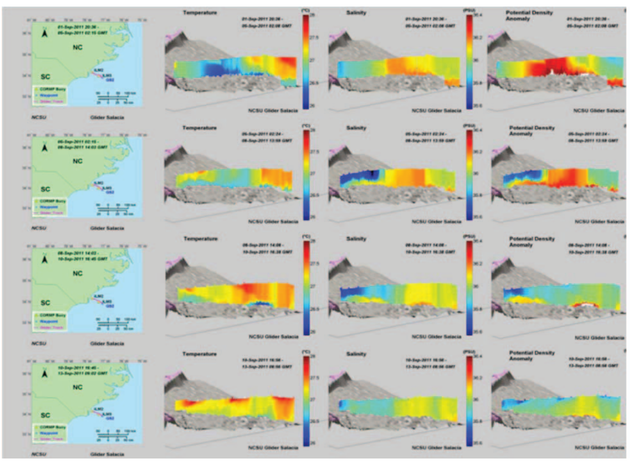

Figure 1. OOMG glider survey during September 1-13, 2011. From left to right are the glider transects, observed temperature, salinity, and density fields. Four repeated transect (from top to bottom) were measured, showing strong temporal and spatial variability in the shelf hydrography.

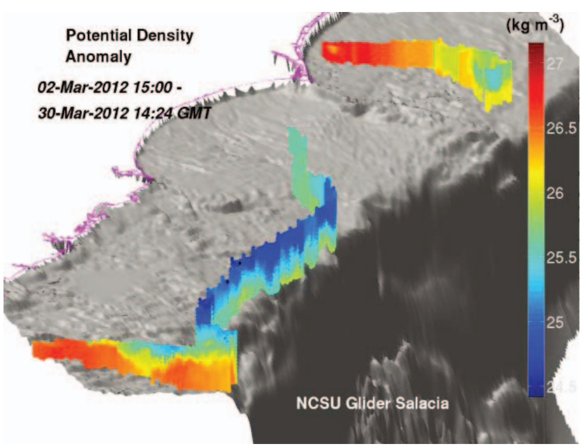

Figure 2. Ocean density field observed by OOMG glider survey during March 2-30, 2012.

Figure 3 shows another cross-shelf survey of North Carolina in September 2013. The time glider was guided to move further offshore, allowing more sampling of Gulf Stream. Strong density contrast between the shelf water and Gulf Stream was observed. We note that all of these glider surveys were highly cost-effective, and provided unprecedentedly detailed hydrography observations than any traditional ship survey is capable of doing.

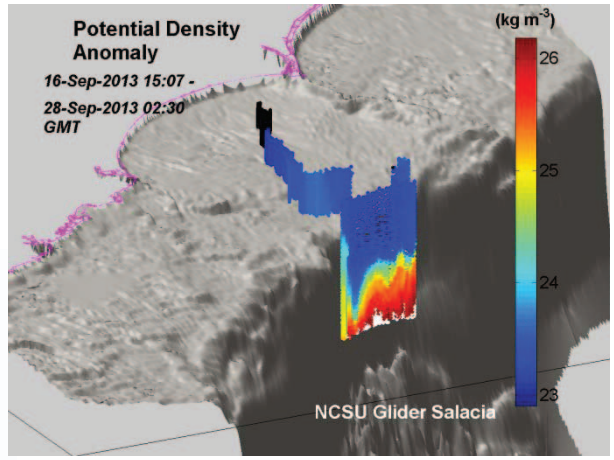

Figure 3. Ocean density field observed by OOMG glider survey during September 16-28, 2013.

In addition to the glider program, OOMG has also developed a high resolution regional ocean model that can assimilate subsurface glider observations, remote sensing ocean surface information (i.e., satellite observed sea surface temperature, sea surface height), and other coastal ocean buoy measurements.

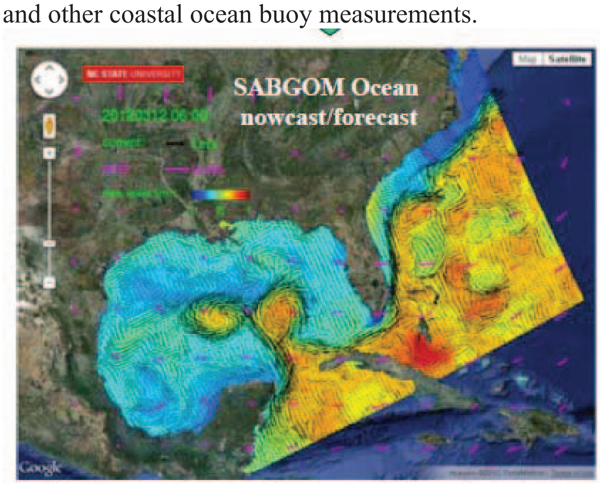

Figure 4. The footprint of OOMG SABGOM ocean nowcast/forecast model. Shown in color shading is the model predicted sea surface height field. Black vectors represent model simulated surface velocity field on March 12, 2012.

The model domain (Figure 4) covers the entire SAB and its upstream Gulf of Mexico areas (hereafter SABGOM), allowing upstream transport variations and the Loop Current/Florida Current/Gulf Stream dynamics to be properly represented. This model was implemented based on the Regional Ocean Modeling System (ROMS) [7]. Spatial resolution of the SABGOM ROMS is 5 km. The model has 36 vertical layers weighted to better resolve surface and bottom boundary layers. For open boundary conditions, the SABGOM ROMS is nested inside the operational 1/12º global data assimilative HYCOM NCODA analysis, superimposed by tidal harmonics from ADCIRC western Atlantic tidal database. Surface forcing conditions are obtained from NCEP NARR. Major rivers in the region are considered in model simulation with daily runoff data taken from USGS river gauges. Since May 2008, the model launches every day to provide daily SABGOM circulation nowcast and 3-day forecast. It has also been successfully used in the hindcast mode to investigate strong upwelling that occurred in SAB in summer 2003 [3] and hurricane Ivan in 2004 [6].

SABGOM ROMS applies four-dimensional variational assimilation (4DVAR), which uses observations to correct model initial and boundary conditions as well as surface forcing while maintaining the dynamical balance of the system. An appeal of this "strong constraint" methodology is that the resulting fields can be fed into the same analysis of term balances used to diagnose the free-run model. ROMS 4DVAR has been successfully applied in several coastal areas, such as the Inter-American seas [8], California Current System [9], and most recently by OOMG in studying Gulf Stream warm core eddy impact on the Mid-Atlantic Bight shelf circulation [10]. The data assimilative simulations created with 4DVAR provide an improved hydrodynamic context for data interpretation and dynamical analysis.

The resulting four-dimensional physical fields can facilitate several lines of inquiry into processes occurring during the passage of Gulf Stream eddies along the SAB shelfbreak. For example, the residual differences between simulated and observed properties can provide guidance as to the most important deficiencies of the model itself. As such, we can analyze those residuals, identify any coherent patterns, and undertake model improvements as warranted. Because our gliders are mobile and can be easily adjusted spatially as needed, we have the unique opportunity to use the model to optimize the observational design, so that its utility for hypothesis testing is maximized.

III. Summary

Through an integrated glider based shelf observation and data assimilative modeling efforts, we are in the process of: 1) establishing a regional glider observatory sampling the shelf of South Atlantic Bight; 2) providing regional 4-D information about temperature, salinity and density structure, oxygen /chl-a concentrations and using those observations to investigate hydrography and circulation dynamics in the region, including the identification of cross-shelf pathways between the shelf edge and the nearshore zone in the SAB. In doing so, we efficiently deliver information to coastal stakeholders in a timely and effective fashion; and build a base of regional ocean observing system.

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