A NATIONAL GLIDER NETWORK FOR SUSTAINED OBSERVATION OF THE COASTAL OCEAN

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Abstract

A national glider network is essential to provide baseline ocean observations to connect the coastal and global ocean, and to address such issues as natural climate variability, ecosystem health, and water quality. The development of gliders is briefly reviewed. Requirements for a national network are presented, and the capabilities of gliders are shown to be suited for the task. The needs of a data management system tuned to gliders are outlined. Planning is underway for a workshop to produce a strategy for a glider network. A document from this workshop will be completed during 2012.

Key words: underwater gliders, observational network, data management, assimilating models

1. INTRODUCTION

Sustained subsurface observations in the coastal ocean, and the adjacent boundary currents are essential to address climate variability, ecosystem management, and water quality. Boundary currents that are important drivers of natural climate variability pass through the coastal ocean, such as the Gulf Stream on the US east coast. Interannual climate variability caused by El Niño has profound effects on the ecosystem of the on US coasts, especially in the Pacific. The Loop Current, and its associated eddies, dominates circulation in the Gulf of Mexico, influencing dispersion of pollutants. Addressing these issues often reduces to questions of the source of water reaching the coastal ocean, and the destination of water leaving. With the goal of observing and predicting the sources and destinations of waters in the coastal ocean, here defined as the US Exclusive Economic Zone (within 200 miles of shore), we propose a plan using underwater gliders.

Gliders are buoyancy driven vehicles that profile vertically by changing volume, and glide horizontally on wings [*Rudnick et al.*, 2004]. Glider technology is a direct descendant from profiling floats of the kind that make up the Argo network [*Roemmich et al.*, 2004]. In fact, Stommel's [1989] first imagining of gliders was highly informed by the capabilities of profiling floats of the era. The first underwater gliders were developed in parallel by three teams funded by the Office of Naval Research beginning in the late 1990's. Parallel efforts were encouraged to foster a diversity of approaches that would be both competitive and cooperative. The three glider models in most widespread use today are a result of this process: Slocum [*Webb et al.*, 2001], Seaglider [*Eriksen et al.*, 2001], and Spray [*Sherman et al.*, 2001]. While each of these models is unique in its own way, the principle of operation is largely the same, so in the remainder of the article we consider the technology of underwater gliders without regard to the individual model or manufacturer.

The notion of a coordinated network of underwater gliders has existed from the earliest days of development. In 2003, at the Autonomous and Lagrangian Platforms and Sensors (ALPS) workshop [*Rudnick and Perry*, 2003; *Perry and Rudnick*, 2003], a vision was presented for a network in the California Current System [*Eriksen*, 2003]. This idea was influenced by the growth of the Argo network, which at the time of the ALPS workshop had 900 floats, on its way to its current size of about 3500 floats. The community has been headed towards a glider network for at least a decade, and the time has arrived to make concrete steps for its establishment.

2. TECHNICAL AND USER REQUIREMENTS

The central goal is to observe long-term, large scale changes along the US coast with sufficient resolution to quantify along and across shore fluxes of mass, heat, salt, and biogeochemical variables. Gliders will allow oceanic variables to be measured across a range of temporal and spatial scales to complement other observational networks, such as high frequency radar.

Observations by a national glider network will provide baseline context needed for a multitude of end users.

Experience gained through year round operations by several institutions provide a solid perspective on the costs involved and the technical infrastructure needed for a national glider network. By incorporating lessons learned over the past decade, regional glider support groups will be able to initiate operations with reduced effort. In fact, the existence of a national network may provide further efficiencies with regards to certain aspects of the glider deployments, such as the data management and quality assurance needs. This should allow the regional operations to focus more effort on the scientific objectives of importance for each region.

To achieve these objectives, the coastal ocean scales of variability must be considered. Many coastal processes are anisotropic in that across-shore length scales are shorter than along-shore scales, so the observing system should reflect this. Dominant processes in the across-shore direction include upwelling and the formation of fronts, which are known to have scales shorter than 10 km. Coastally trapped waves are a ubiquitous alongshore signal with wavelengths of order a few hundred kilometers. Eddies and fronts that are prevalent along the coast and at the edges of continental shelves are often persistent for time scales on the order of weeks. Stratification and upwelling

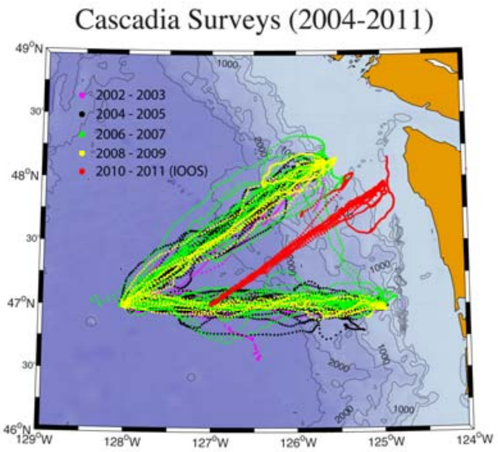

Figure 1: Washington Coast (Cascadia) glider missions, beginning with developmental deployments (2002) and extending to the recent (2010-2011) IOOS deployments. A total of 25 distinct deployments, with a maximum of 6-month endurance, collected 7338 profiles and occupied 141 sections across the Cascadia shelf. Gliders typically required 2 weeks to traverse a section. Each dot marks a profile, with colors indicating different time periods. Red dots mark IOOS-supported sampling.

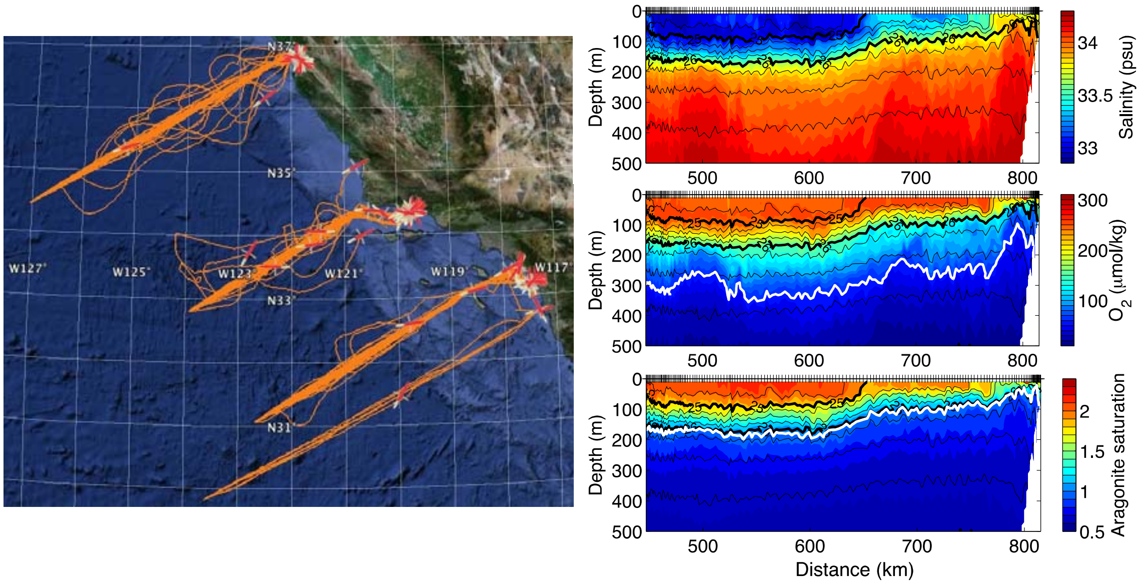

Figure 2. Glider tracks in the Southern California glider network from 2005 to present (left). Over 6000 glider-days and 120,000 km cumulative track length have been completed to date. A section occupied from 17 April to 9 May 2012 offshore of Pt. Conception (right). Panels show salinity, dissolved oxygen, and aragonite saturation calculated from a proxy relationship by Alin et al. [2012]. Black lines are isopycnals. The white line in the dissolved oxygen panel marks the hypoxic level of 60 µmol kg^{-1}, while the white line in the aragonite panel marks the value 1. Upwelling is apparent near shore as isopycnals bend upward. This upwelling brings hypoxic and corrosive water near the surface. Aragonite saturation less than one may be harmful to organisms that form shells.

vary on an annual cycle. This combination of requirements argues for an along-shore sequence of highly resolved sections oriented in the across-shore direction, each repeated roughly every few weeks throughout the year, as in Figure 1.

Measurements collected by a network of gliders will resolve the relevant oceanic processes, providing the context critical for addressing societal issues impacted by the coastal ocean. Increasing ocean acidification poses a threat to organisms that form shells. Baseline observations, as provided by a glider network, are essential to monitor changes (Figure 2). Hypoxic conditions are spreading throughout the nation's coastal oceans, caused by both anthropogenic input and natural variability. Harmful algal bloom evolution and migration depends on circulation not only for transport of the bloom itself, but also for the delivery of bloom-maintaining nutrients from the deep waters and the estuaries. Efforts to monitor events, such as the Deepwater Horizon oil spill, benefit from the use of ocean circulation models constrained by glider-based observations. During Deep Water Horizon, this allowed researchers to successfully locate subsurface plumes whose existence had not been predicted using other methods. Improved characterization of the upper ocean heat budget will contribute to advances in understanding and prediction of tropical storms. Gliders can provide these measurements in the most demanding of operating conditions (Figure 3). The proposed national glider network would provide measurements for a wide range of operation and science activities, exploiting the persistence and access provided by gliders to collect observations that would be impractical to obtain through other means.

3. STATE OF THE OBSERVING SYSTEM AND TECHNOLOGY

Autonomous underwater gliders developed, over the last several years and now operated routinely, offer sustained fine resolution observations of the coastal ocean. In typical deep water coastal use gliders profile from the surface to 500-1000 m, taking 3-6 h to complete a cycle from the surface to depth and back. During the cycle the gliders travel 3-6 km in the horizontal for a speed of about 1 km/h. Deployments of 3-6 months are routine, during which time the

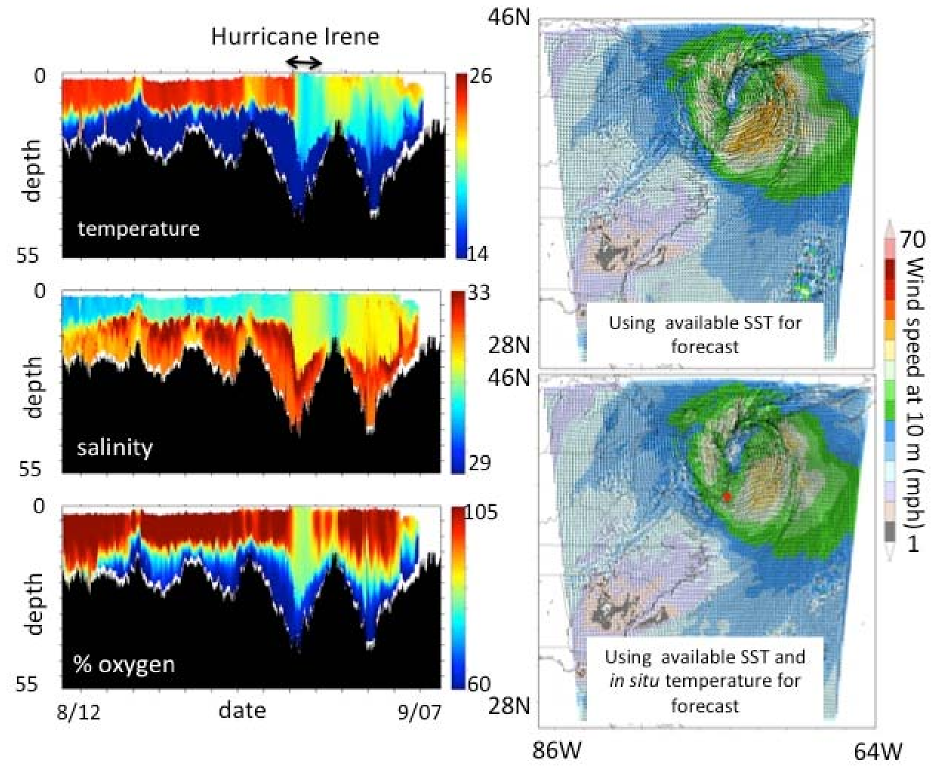

Figure 3: Glider data collected offshore New Jersey during the passage of the Hurricane Irene in August 2011. The columns on the left show glider data exhibiting an extremely stratified continental shelf prior to the storm. The hurricane leads to the entrainment of cold bottom water to the surface. The impact of the decreased temperatures is shown in two simulations of Hurricane Irene wind speed. The upper panel shows the simulation utilizing the warm temperatures provided by satellite before the storm arrival. The bottom panel shows a simulation incorporating the declines in upper ocean temperatures measured by the glider (location was within the red circle in bottom panel). The simulations using the lower surface temperatures show decreased storm intensity and slightly altered storm track, which was closer to the actual storm track.

gliders' survey tracks typically extend well over 2000 km. Gliders can sense the bottom to enable operations in shallow water such as on continental shelves. The increased energy demands resulting from more frequent buoyancy adjustments restricts shallow-water deployments to shorter time spans, typically measured in weeks rather than months. During a few minutes on the surface, gliders obtain location by GPS and communicate through the Iridium satellite phone system. Sensors on gliders can vary greatly depending on the desired research. Some of the more commonly used measure such physical variables as pressure, temperature, salinity, and current, biological variables relevant to the abundance of phytoplankton and zooplankton, and ecologically important chemical variables such as dissolved oxygen and nitrate. As pH sensors mature, gliders will provide excellent platforms for monitoring ocean acidification. Gliders may be deployed and recovered from a wide range of platforms, including small boats and chartered fishing vessels.

4. INTEGRATION WITHIN IOOS, MODELING, AND DMAC

Gliders transmit the measurements they collect to shore in real time, so a national distribution and archiving scheme is essential. At present, glider data is received by servers and distributed in a variety of formats and through several protocols. Establishing a standards-based approach to serve glider data at a national level will simplify the distribution process for glider operators and data users alike. The creation of a standard format for glider data will make exchange more efficient. Standardizing procedures for quality control must be a priority. Archiving this data in a national repository will ensure its continued availability to all users.

Among the primary users of glider data are ocean modellers. Glider data has proven essential to constrain assimilating models of coastal circulation. Just as the combination of Argo floats and satellite data are the primary input for models of global circulation, gliders and remote sensing will be the important data sources for predictions of the coastal ocean. A complete observing and predicting system for the coastal ocean is the ultimate outcome.

5. THE WAY FORWARD FOR THE NEXT TEN YEARS

A national network of glider observations should include about 7-10 gliders deployed at all times on lines along the US coasts including the Great Lakes. The capability to sustain such lines has been demonstrated for several years, for example off Southern California and the Pacific Northwest. This national network of 20-30 gliders is practical, not only operationally, but also financially. Based on typical 3-5 month missions, experience suggests that a glider line can be maintained locally for about $150K/year, with one glider in the water and one being refurbished in the lab at all times. Extensive operation in shallow water (e.g. over the shelves) would reduce mission endurance to 1-2 months, raising operating costs to roughly $250K/year. Thus, operational costs would be roughly $3M per year for a network focused on the slope, increasing to approximately $7.5M per year if operational and scientific needs demand that a significant fraction of the measurements be made over the shallow shelves. With two gliders required for each line, and the cost of a new glider about $150K, capital costs are $6M-$9M. There is no question that a national glider network is practical and affordable.

5.1. Workshop

The first step towards creating a glider network is to develop a plan. A workshop is being held August 1-3, 2012 at Scripps Institution of Oceanography. The workshop will address:

- The compelling rationale for a national glider network
- The capabilities of gliders currently being used for sustained deployments
- The requirements of a national network
- Guidelines for glider operations in a network
- Data standards and management protocols appropriate for a network.
- Uses of glider data, including data assimilative modeling

Potential Partners include:
- NOAA
- NSF
- ONR

5.2. Glider operations

Following are the components through which glider expertise will be expanded throughout the US coasts, and gliders will be deployed.

- Develop operating guidelines and lessons learned to assist regions who are adding gliders into their observing systems
- Develop network that incorporates gliders currently operated by RA partners
- Establish drivers for glider operations, including national and regional specific missions.

- Create implementation plan to augment current gliders

Potential Partners include:

- Regional Associations
- Academic institutions
- Federal glider operators

5.3 Data management

While observations are, by necessity, distributed, data archiving and distributions will be centralized. The essential parts of a system tuned to glider data will include the following.

- Data standards
- Quality Assurance /Quality Control Process
- Data architecture for archiving and sharing data
- Visualization tools

Potential Partners include:

- Regional Associations
- Federal data archives
- OOI

6. CONCLUSIONS

In summary:

- A glider network will provide data to address problems on long time and space scales along the nation's coast
- Underwater glider technology is ready for expanded deployment.
- Requirements for data management are relatively straightforward based on experience to date
- Glider data is especially suited for assimilation into models of coastal circulation
- A plan is being developed, with a workshop scheduled for August 2012.

The rationale for a national glider network seems clear. The needed capabilities are well within the reach of the current generation of glider technology. Required now are the will and the resources to make the network a reality.

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