Toward a U.S. IOOS® Underwater Glider Network Plan:

Part of a comprehensive subsurface observing system

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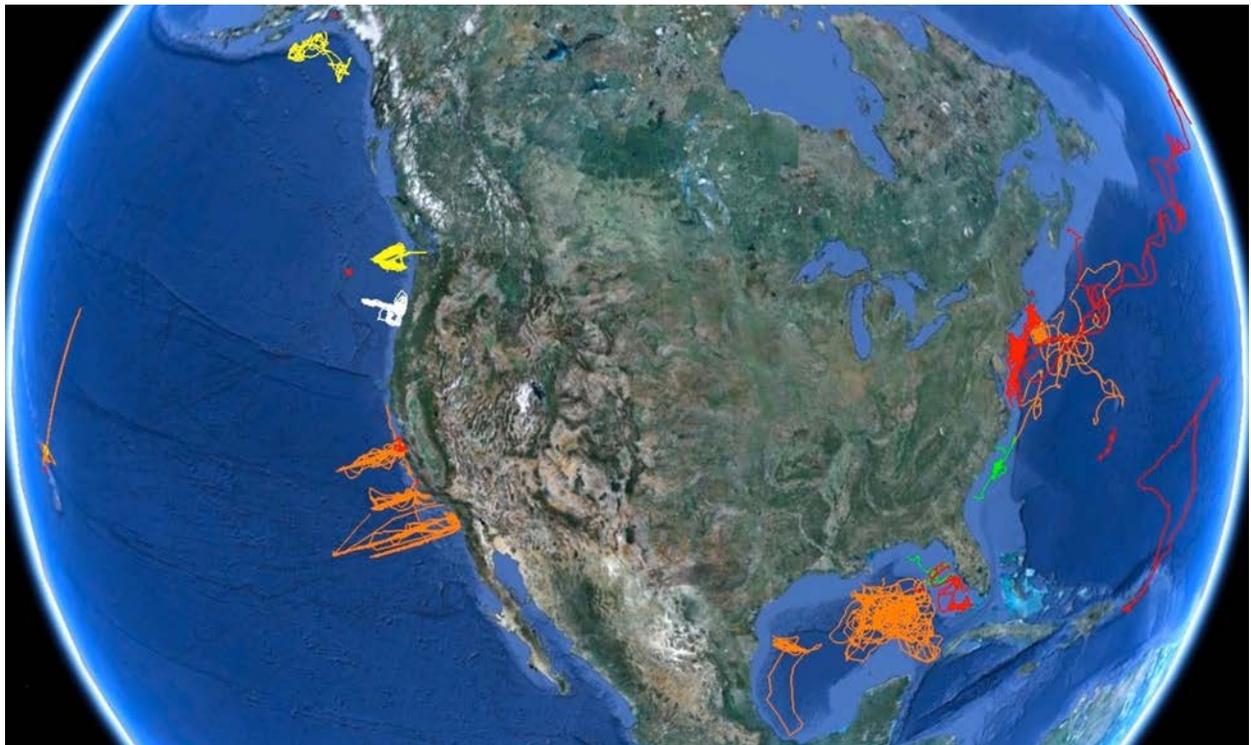
Glider tracks along the U.S. coast since 2002.

Document Approval

U.S. IOOS Program Office Approval

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Executive Summary

There is a critical need to link the terrestrial and ocean systems over time and space scales to address episodic (days) and climatic (years) scale problems facing the scientific and management communities. One element of a strategy to address this need is a sustained sampling protocol that includes the three dimensional ocean from the coasts to the deep ocean. This protocol must include adaptive sampling capabilities to sample episodic events as well as routine and sustained sampling of transects in order to monitor long term changes in the subsurface ocean. These sampling capabilities along the coastal regions of the United States and the Great Lakes would provide critical information to address numerous critical drivers spanning ecosystem and water quality forecasting, hurricane prediction, response to extreme events and man-made disasters, address climate change, and a number of other applications discussed in this report. These drivers identified in numerous national and international reports (JSOST 2007, NOP IP 2013) as well as at a community meeting of glider operators (see Appendix D) comprise the motivation of this report.

This white paper is focused on using the underwater glider as part of a larger comprehensive three dimensional ocean, coastal and Great Lakes observing system. This paper outlines the structure to develop an initial network that includes maintaining existing glider lines, acquiring additional glider lines to fill high priority identified gaps, and improving data management, product development, and data/product delivery. We recognize that there are other autonomous surface and underwater vehicles and we expect they will complement glider capabilities, but this paper focuses on underwater gliders because of the level of maturity of the technology and the community of operators. Tagging of marine animals and fish are also emerging as another capability, and an animal telemetry strategy is also being developed. Both of these efforts are being overseen by the Interagency Ocean Observing Committee (IOOC) and the U.S. Integrated Ocean Observing System (IOOS®) Program Office within NOAA to ensure consistency.

The efforts of the Office of Naval Research, University of Washington, Scripps Institute of Oceanography, Rutgers University and Teledyne Web Research are acknowledged for their early work in gliders that laid the foundation for the United States to be talking about having a network. Today, funding for civilian gliders is provided by National Science Foundation, National Aeronautics and Space Administration, National Oceanic and Atmospheric Administration (NOAA), Environmental Protection Agency, and the U.S. IOOS Program Office. A majority of the gliders are operated by IOOS Regional Associations (RAs) and academic institutions. The High Frequency Radar network evolved similarly and provides an example of the benefits in operational efficiency and in information delivery that were achieved when the network became centrally coordinated as part of IOOS. This paper reflects similar concepts.

In writing this plan a number of questions were raised that merit further discussion. This plan identifies the need for a national steering team to continue the discussion. The questions focus on two main issues (1) should the plan only focus on long endurance lines as opposed to campaigns that support event driven issues and (2) the exact locations of the glider lines. In the end we wrote the plan outlining both long endurance lines as well as the campaigns for event driven issues because the of the versatility of the glider as a platform. But in doing this we are

not suggesting that gliders can or should be used in every circumstance. Further, the identification of the glider lines are a suggested lay out based on efforts that have already been funded and will be refined in the future.

Over the past 6 years, regional glider operators have completed 33,400 glider days, funded by several federal, state, and local agencies private foundations, and industry. The resulting infrastructure provides a solid framework for a nationwide, operational, glider network; however, many of these assets were obtained via grants and contracts that do not provide ongoing funding for sustained operations and maintenance or data management. With the goal of better modeling and understanding of the dynamic properties of the subsurface Great Lakes and coastal ocean, here defined as the U.S. Exclusive Economic Zone (within 200 nautical miles of shore), this plan describes a way to maximize the benefit of existing investments by providing a mechanism for sustained operation and delivery of these subsurface profile data in a consistent manner to users around the country. The plan also identifies highest priority data gaps that must be filled to achieve a national subsurface sustained monitoring capability that can characterize the coastal waters so that information can meet many of the needs of diverse stakeholders in each region.

The Glider Network is designed to function as a distributed system, with some centralized data management functions that apply consistent data standards and best practices to achieve integration, among various glider observing assets. As the lead federal agency for U.S. IOOS, NOAA will lead the overall plan and coordinate requirements and efforts to ensure consistency between national and regional needs and to align with the national Data Management and Communication objectives.

The plan outlines how IOOS will coordinate data from local and regional efforts across the glider community to deliver a collaborative approach for the design, implementation, and management of the Glider Network, including staffing and training requirements, cost, hardware and server requirements, as well as data management principles. The U.S. IOOS Program Office will collaborate with other NOAA programs, the Inter-agency Subcommittee on Unmanned Systems and the IOOC to identify specific product requirements.

The cost estimate to implement this plan, including operations and maintenance (O&M), acquisition and deployment of new gliders to fill priority data gaps, and acquisition of additional replacement gliders to minimize down time is provided. The capital costs are estimated at $9M-$12M, however some of the costs are already covered by existing programs. The operational costs should not exceed $6-8M per year.

The Glider Network requires active participation at the federal and regional levels, with distributed expertise in the regions to operate and maintain the gliders. Data management and operational data delivery would be the responsibility of IOOS with support from the RAs. Technical workshops and a proposed Glider Network Steering Group and Data Team will continue to refine the network and data management requirements over time working with IOOS to ensure the guidelines included in this plan are updated accordingly. Additionally the development of a national glider community will be linked to evolving educational programs focused on developing the glider workforce of the future.

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1. Rationale

1.1. Why Gliders

Numerous national efforts have developed national ocean policy objectives (JSOST, 2007; NOP IP 2013; ICOOS Act 2009) and all emphasize the need to enable the stewardship of the ocean, protecting life and property, promoting sustainable economic vitality and increasing fundamental scientific understanding. These needs argue for expanded and sustained ocean observations. Specifically, the National Ocean Policy Implementation plan calls for, "a national sub-surface ocean observation and monitoring plan that will address use of new autonomous underwater vehicle technologies and sustained monitoring and operational observations in the water column to support decision-making." Maintaining healthy ecosystems requires knowledge of the ocean environment, which includes but is not limited to the effects of natural climate variability, local and nonpoint human influences, water quality, and the presence of harmful species. Safe and efficient marine operations benefit from observation and prediction of currents, salinity and temperature profiles of the water columns. All the issues above are dependent on the knowing the three dimensional structure of the ocean over time.

Historically ocean observations have been accomplished using fixed-point moorings and sampling conducted from ships. While moorings have proven to be extremely effective in collecting time series measurements they cannot effectively resolve the spatial variability. Ships will always be central tools for mapping the ocean interior however their expense and limited ability to maintain a sustained presence is an issue. While satellites are effective in mapping the variability in the surface ocean, they provide insufficient information on the vertical structure of the ocean. This is problematic as the vertical variability is often orders of magnitude more variable than the horizontal surface variability and represents the primary observational gap for oceanography. Overcoming these sampling gaps is one of the fundamental challenges facing the community and numerous studies have documented that the mesoscale variability of coastal systems will require mapping approaches not possible using traditional technologies (See Appendix A for peer reviewed literature demonstrating science utility).

New autonomous technologies have matured over the last decade and now offer the potential to fill these observational gaps to map the subsurface feature in the ocean. Autonomous technologies range from propeller and buoyancy platforms to autonomous surface platforms to animal tagging. Each of these different platforms samples different time/space domains and all in a different state of demonstrated readiness.

Autonomous underwater gliders developed over the last several years, and now operated routinely, offer sustained fine resolution observations of the coastal ocean. In typical use gliders profile from the surface to depth (up to 1000m) repeatedly at horizontal speeds of 0.7 to 1 km/h. Deployments of up to 6 months are routine, during which time the gliders survey track can extend well over 2000 km. During a few minutes on the surface, gliders obtain location by GPS and communicate through the Iridium satellite phone system. Sensors on gliders measure such physical variables as pressure, noise (background, ambient, ships, marine mammal calls, etc.), 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. And in the past decade their use has steadily increased as the systems have become more versatile and reliable, to the point now that much of the work they do can be called routine.

Here, we propose an Integrated Ocean Observing System[1] (IOOS®) Underwater Glider Network (here forward, Glider Network) as an efficient approach to providing sustained sub-surface ocean observations. We believe such a network will become an integral component of IOOS. We focus on underwater gliders (here after gliders) for several reasons. Gliders have demonstrated an operational maturity by many in the marine community (see Appendix A), collect subsurface data for sustained periods (months) of time, operate safely in heavily trafficked coastal waters, provide data during extreme weather events, operate in the strong coastal currents present within U.S. EEZ waters, and can be cost effective enough to be scalable on a national level given projected budgets. As other technologies, such as the Wave Glider®, propeller driven AUVs, animal tagging and telemetry mature and refine their operation toward this mission, it is envisioned they could be added to expand the capabilities of the proposed Glider Network.

1.2 Why a Network

Today's national High Frequency (HF) radar network evolved from a collection of technology development projects into a coherent network that covers a significant percent of the US coastline. The HF radar current network is centrally managed by the U.S. IOOS Program Office but still retains the local expertise and diverse funding sources that originated the network. It delivers a consistent national capability and supports regionally specific enhancements based on local needs. A network of underwater gliders that operates with a similar model is within reach and worth pursuing.

Given their importance to marine fisheries, weather, climate, shipping, recreation, energy production and other activities, the Great Lakes, coastal oceans and adjacent ocean boundary currents need to be regularly monitored. Ocean processes that influence these activities, whether they are changes in ocean temperature from El Nino/La Nina cycles on the west coast, stronger than average penetration of cold, high-latitude water along the northern east coast, or large hurricanes in the Gulf of Mexico, span entire coasts. Accurately assessing the full water column impact of these large-scale events is best done with a network of coordinated underwater glider sampling. Such a network can assess the geographic scale, timing and severity of these coast-wide events. The data from the Network can feed models to predict these events as they propagate along the coast. There are numerous examples of the connection of oceanographic processes across great distances along the coast, including advection of harmful algal blooms or pollutants by coastal currents, and changes in thermocline and nutricline depth carrying equatorial signals north along west coast of the United States. Local sampling, whether by coastal moorings, small boats or targeted glider deployments, can then be placed within this large-scale context provided by the Glider Network.

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[1] Within this document "IOOS" refers to the whole IOOS enterprise, not a specific entity. The term "U.S. IOOS Program Office" refers to the program office in NOAA.

Boundary currents are an important driver of climate and carry oceanic waters along the coast that become the source waters for coastal ocean processes. In the deep ocean, the Argo program's profiling floats provide a wealth of subsurface information (Roemmich et al., 2010). But the Argo float target density of one float per 3°x3° square is insufficient to observe boundary currents. By actively steering and being capable of moving at a half a knot or more, underwater gliders can provide the needed resolution in boundary currents. A glider network sampling the nation's coastal oceans and adjacent boundary currents is necessary to complement the successful global, deep-water network of floats. In essence a glider network will tie the global Argo observations to the coastal ocean. Such a network has the potential to transform the observation and understanding of boundary currents, and will serve as part of the IOOS contribution to the global ocean observing system.

Important benefits of an underwater glider network are consistent operational and data processing standards and quality control procedures, and timely data dissemination and archiving. Consistent operational standards include insuring that the sensor suites on each glider in the network are providing data on priority ocean variables. Agreed upon and consistent data processing and quality control procedures will make glider network data most useful to the end users and will allow local glider sampling to be part of such a network. Efficient and timely data dissemination will allow ingestion of glider network data, data that is on entire-coast and boundary-current scale, into operational ocean circulation and ecosystem models. Consistent data formats and centralized access and archiving procedures will allow Glider Network data to contribute to the steady stream of oceanographic data now delivered by other ocean sampling platforms.

1.3 Gliders in Modeling
Data assimilative models use the physical dynamics of a body of water, external influences, along with observations to develop hindcasts and forecasts of conditions. Models suffer from gaps in observations which can improve the forecasts. The Glider Network will serve an important role in the ocean modeling subsystem for several reasons. The unique sampling capabilities of gliders provide data over sufficient spatial scales to enable ocean numerical model parameterization, data assimilation, and model validation. The Glider Network will supply time series of subsurface physical, chemical and bio-optical ocean properties with extended spatial coverage. Through data assimilation, they will be invaluable for keeping regional and local IOOS numerical circulation and biophysical models on track [*Matthews et al*., 2012, *Todd et al*. 2011b, *Gangopadhyay et al*. 2012]. Given a verified modeling and glider observing system, adjustments in the system can be made through Observing System Simulation Experiments (OSSE). An improved glider observing system will ultimately enable improved model predictions. This feedback loop between glider observations and models is the foundation for a successful, modern marine forecasting system. As modeling systems are being developed throughout all the IOOS Regional Associations (RA), the Glider Network could enable the overall national capacity.

Models will also be employed to improve the scientific value of the glider observations collected by optimizing vehicle navigation based on geographic or scientific constraints. In the 2006 Adaptive Sampling and Prediction (ASAP) experiment, the Glider Coordinated Control System (GCCS) was used to optimize spacing between multiple vehicles sampling off Monterey Bay (Paley et al., 2008). More recently, an improved and expanded version of the GCCS, the Glider

Environmental Network Information Operating System (GENIOS), was used in an experiment off South Carolina to control two gliders operating in quasi-stationary profiler and transect missions nearly continuously for over 4 months, with a 75% reduction in glider path error through the integration of real-time predictions from ocean models and feedback control algorithms. Similar feedback controls have also been demonstrated that glider data can be used to adaptively adjust and improve other sampling systems such a satellites (Schofield et al. 2010). Models will also extend the value of the glider measurements in space. Through dynamic interpolation, that is ensuring that the glider observations are consistent with dynamical balances in the ocean, they can be extended in space to fill out a larger three-dimensional (3-D) volume. This allows for better use of the glider data plus model fields to create products like subsurface volumes of low-oxygen water or particle trajectories for use in Search and Rescue (see 3.5).

1.4 Applications of Glider Technology

The benefit of improvements to our modeling and prediction capabilities can be seen in a multitude of applications. The better we understand the entire system of the ocean and its connectivity, the better context we have for understanding specific events or processes that reside within any boundary current, shelf region, or estuary. Following, we provide several examples that highlight specific issues that have benefited from subsurface data provided by gliders and how these issues will benefit from a network. These include:

- **Emergency Response,** for example, the dispersion of oil by currents in the Gulf of Mexico and for hurricane landfall;
- **Climate Variability,** including El Niño/La Niña in the California Current System and the Gulf Stream along the U.S. east coast;
- **Hurricane Intensity Forecasting**, relevant for the east coast, Gulf of Mexico and American territories; improving response to hurricanes
- **Harmful Algal Blooms** throughout U.S. coastal waters;
- **Low dissolved oxygen in bottom water.** All coasts.

1.4.1 Emergency Response

Perhaps the most impressive community effort involving gliders was in response to the 2010 Deepwater Horizon oil spill in the Gulf of Mexico (Figure 1). A voluntary consortium of federal, industry, and academic partners provided several gliders to the effort. The gliders produced subsurface observations of temperature, salinity, and velocity in support of efforts to determine where oil was likely to be taken by currents. Data were made available in real time to modeling centers throughout the country, and were provided to a central data base for all interested parties to access freely. Using fluorometers, the gliders also acted as sentries for subsurface plumes of hydrocarbons. Spurred by an immediate need for ocean observations, the nation responded by coordinating its assets and their use for a national purpose thereby demonstrating the potential value of a more formalized plan and means for coordination. The goal is to progress from the ad hoc network temporarily assembled in 2010, to a sustained glider network along all the nation's coasts. With such a network, in addition to our sustained monitoring, we would be prepared for the next comparable emergency, whatever it may be.
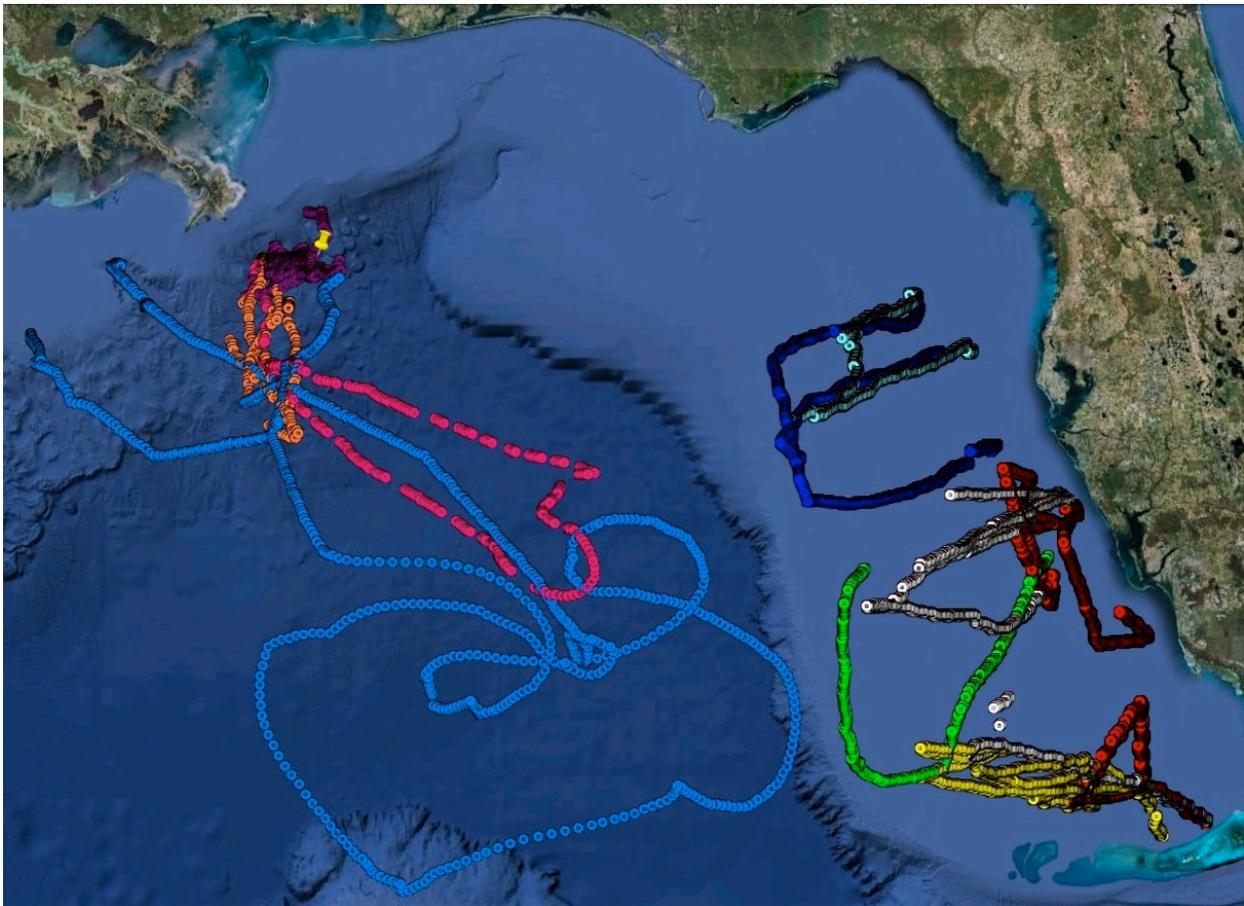
Figure 1. Glider tracks during the response to the 2010 oil spill in the Gulf of Mexico. Gliders were deployed by a voluntary consortium of federal, industry, and academic partners. Observations spanned the shallow continental shelf and deep ocean.

1.4.2 Climate Variability

Gliders are particularly effective for observing climate variability in the coastal ocean, here defined as the Exclusive Economic Zone (EEZ) within 200 nautical miles (322 km) of shore. The regional effects of large-scale climate variability, as by El Niño and the North Atlantic Oscillation, are of great societal importance. Such effects include changes in precipitation on land, and in commercially important species in the ocean. For example, sustained glider missions, supported by the National Oceanic and Atmospheric Administration (NOAA) Ocean Climate Observation Program and U.S. IOOS Program Office, have been observing physical and biological variables relevant to climate effects on the ecosystem of the California Current System (Davis et al, 2008). These sustained observations (Todd et al, 2011) have produced a simple index of climate variability based on temperature at 50 m depth (Figure 2). The glider observations are run along a few of the same lines as those occupied quarterly by the California Cooperative Oceanic Fisheries Investigations (CalCOFI). Thus, the gliders augment the 60-year ongoing shipboard program, and support the goal of fisheries management.
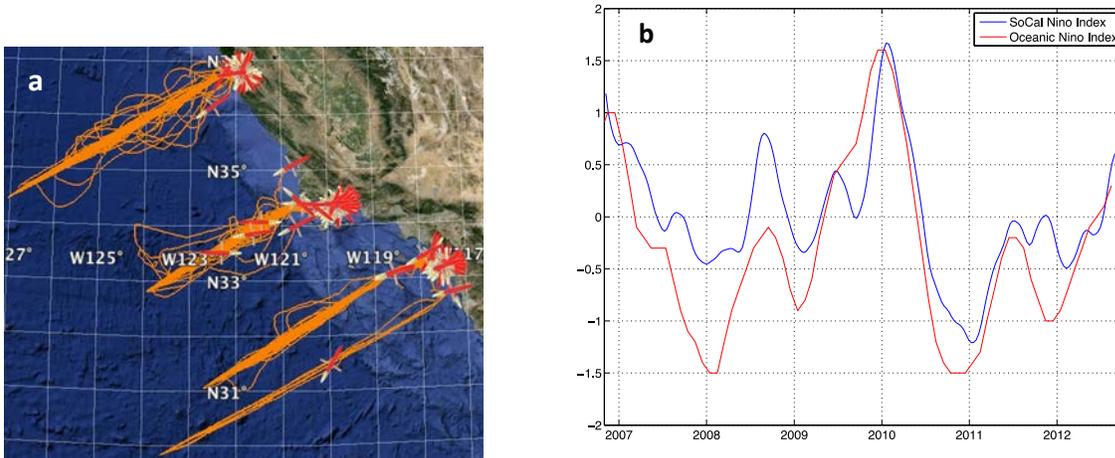
Figure 2. (a) Glider lines continuously occupied off California since 2006. (b)Two indices of climate variability. The glider-derived SoCal Niño Index (blue), the temperature at 50 m depth averaged over the inshore 200 km along CalCOFI line 90 (the central line in (a)) off Dana Point, California. The Oceanic Niño Index (red), surface temperature in the Niño 3.4 region of the equator. The two indices are clearly correlated, indicating the remarkable connection between the west coast of the U.S. and the equator.

The boundary currents on the western sides of ocean basins are drivers of climate variability through their transport of heat, whose observation is a key gap in the current global observing system (Send et al., 2010). Understanding the dynamics of the Gulf Stream along the U.S. east coast, the most powerful current in the North Atlantic, with undeniable influence on the ocean and atmosphere, is extremely important to quantifying the effects of the ocean and atmosphere on climate variability. The Gulf Stream was an early target of glider observations, with the first crossing from Woods Hole, MA to Bermuda in 2004 (Oceanus). In 2009, the crossing of the Atlantic by the glider Scarlet Knight, took advantage of Gulf Stream currents (Figure 12). Gliders can be used effectively in dynamic environments to sample where other non-directed systems cannot be sustained. Permanent glider lines in a coordinated Glider Network would make possible baseline monitoring of the Gulf Stream to monitor baseline natural climate variability.

1.4.3 Applicability of glider data for hurricane events

Hurricanes, cyclones, and typhoons are some of the most destructive and deadly weather phenomena on Earth, and have killed more people than any other natural catastrophe (Keim et al. 2006). Forecasting approaches have successfully reduced hurricane track forecast errors by factors of 2-3 over the last two decades, allowing communities sufficient time to proactively prepare for the storms and evacuate prior to their arrival. Despite the progress in predicting hurricane tracks, the predictive skill for hurricane intensity forecasts has remained "flat" over the last twenty years (Pasch, Blake 2012). The Mid-Atlantic Bight of North America was recently struck by hurricanes Irene and Sandy which devastated dense population centers and communities spread over a dozen neighboring states. Gliders were launched into both hurricanes to collect and deliver data back to shore before, during, and after the storms.

Glider temperature collected during Irene (Figure 3) indicates that on August 27, the Mid Atlantic shelf was near its peak summer stratification, with a thin 10 m thick layer of warm surface water near 22C-24C, and a thicker layer of bottom "Cold Pool" water near 8C-10C. The summer thermocline was typically sharp, with the transition from warm surface waters to bottom

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Cold Pool waters occurring in a few meters. As Irene approached, mixing within each of the surface and bottom layers made each layer more uniform and tightened the thermocline. On August 28, between 0000 GMT and 1200 GMT, as the front side of Irene passed over the location of the glider, the thermocline broadened (from less than 5 m to over 15 m) and deepened (from 10 m to 28 m), and the surface layer cooled (from 24C to 18C). After 1200 GMT, as the backside of the hurricane passed over the glider, the deeper thermocline remained near 25 m. The drop in the surface ocean temperatures were confirmed by satellite-derived Sea Surface Temperature (SST) maps of the Mid-Atlantic Bight just after Irene passed that showed cooling was widespread across the Mid-Atlantic Bight. The satellite SST product showed surface temperatures dropped to as low as 14C on the shelf.

The impact of the rapidly cooling SST on the Weather Research Forecast (WRF) is being assessed in several hindcast sensitivity studies of Hurricane Irene and the results illustrate the significant impact of the cooler water. The glider data indicates that the cooling occurred ahead of the eye as the high winds of the outer wind bands approached. Thus the eye of the hurricane passed over cool water as it propagated northward. Figure 4 compares the WRF forecasts for wind speed using the warm SST and cooler temperatures observed by glider and post-storm SST imagery. At the time of landfall, the hurricane intensity was over-predicted using the warm SST maps, which was consistent with the federal forecasts for Irene. The resulting WRF forecast using the cooler temperatures was lower by 5-10 knots and matched the observed intensity of Hurricane Irene (Figure 4).
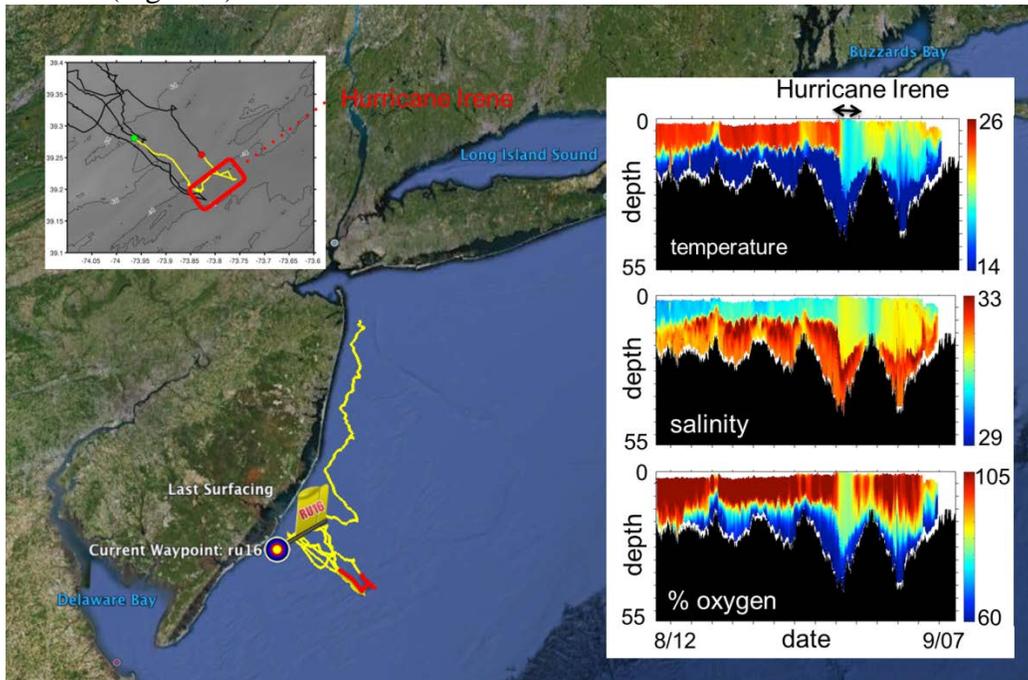

Figure 3. Glider track for deployment during Hurricane Irene. The red section represents when Irene passed through. Glider results used to hindcast the storm showed improved input for hurricane intensity. The RMS error in knots for the warm water forecast was 7.13 while the RMS error for the cold water hindcast was 3.61. The official NHC forecast RMS error was 9.43 kts.
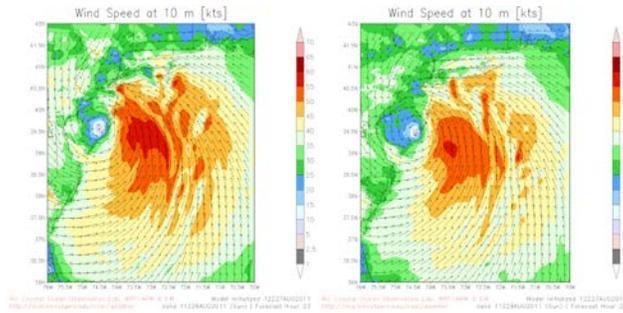
Figure 4. Weather Research Forecast (WRF) atmospheric hindcasts of Hurricane Irene with different ocean boundary conditions. (a) Using the warm SST observed prior to the arrival of Irene's clouds throughout the run. (b) Using to the cold SST associated with the observed cooling by the glider data extrapolated over the observed cooling from satellite before and after the storm. Results suggest that a spatial network of gliders would be required to assist weather forecasting efforts in the future.

1.4.4 Harmful Algal Blooms

Gliders offer three dimensional sampling for monitoring HABs. Off the coast of central and southwest Florida, glider transects have been made in and around *Karenia brevis* blooms. The gliders are equipped either with a red tide detection system capable of identification of high concentration bloom conditions, or equipped with a sensor suite including fluorometers, dissolved oxygen sensors, and passive acoustic recorders. An example of these efforts to help understand the onset and evolution of a bloom is found in Figure 4. Panel A shows the tracks of two gliders overlain on a normalized fluorescence line height (nFLH) MODIS satellite image used to predict the bloom's area. Temperature (panel B) and chlorophyll fluorescence (panel C) sections show the vertical structure of these properties along the offshore glider track, with a strong thermocline and an active bottom layer that only emerges at the surface nearshore, where stratification disappears at the nFLH image's bloom boundary. The glider data helps to identify upwelling from the bottom Ekman layer. Such multidisciplinary collaborations utilizing gliders, traditional cell counts, satellite imagery, drifters, moorings, and predictive circulation models are providing new insights to bloom evolution from onset to termination. Gliders deployed routinely across shelf transects will allow researchers access to subsurface variables year round. This will improve the context of the three dimensional scales and evolution of bloom events.
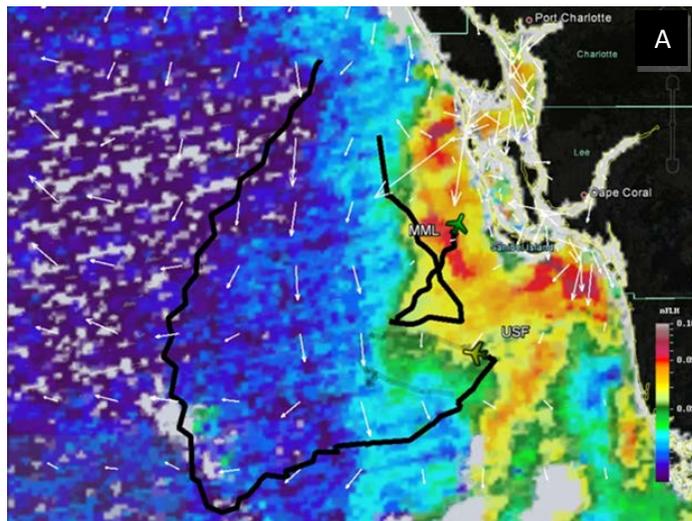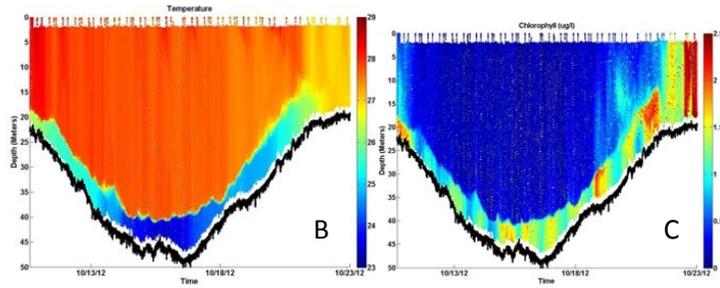
Figure 5. A. Tracks from two gliders tasked with mapping the three-dimensional ocean properties around a *K. brevis* HAB (red tide) off the south west coast of Florida in the Fall of 2012. The background MODIS image shows the normalized fluorescence line height (nFLH), overlaid with surface current velocity vectors from numerical circulation models. **B, C.** Temperature (left bottom panel) and chlorophyll fluorescence (right bottom panel) collected by the offshore glider as it progressed around and into the bloom area. Data demonstrates upwelling in the offshore region, with water column mixing occurring at the bloom boundary shown in the satellite image.

1.4.5 Bottom Water Hypoxia/Anoxia

While low Dissolved Oxygen (DO) concentrations are not uncommon in the coastal ocean, what is less understood is how the location and size of these low DO regions vary and what impact that variability has on ecosystem health. For many coastal regions in the U.S. EEZ water this is a primary environmental concern for water quality managers and fisheries managers. Low dissolved oxygen waters are found below the surface layer of the ocean so cannot be characterized by surface measurements alone. Alternative sampling strategies are needed to continuously map these low DO areas in a way that quantifies this variability. Gliders have been used to sample dissolved oxygen in U.S. coastal waters, including since 2006 off central Oregon and off New Jersey in 2011 and 2012. All the New Jersey glider missions were completed in accordance with the operating procedures described in the Quality Assurance Project Plan (QAPP) so that data quality would meet the liability requirements of the Environmental Protection Agency (EPA) and the New Jersey Department of Environmental Protection (NJDEP). This provides a demonstration of how Glider Network could provide a unique national water quality monitoring capability.
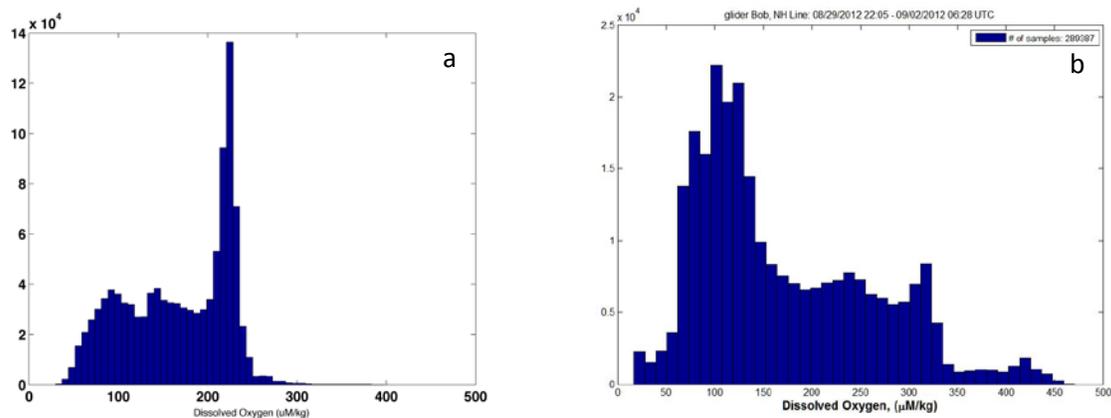

Figure 6. Histograms of dissolved oxygen for glider deployments off the coast of (a) New Jersey and (b) central Oregon, both during September 2012. Dissolved oxygen values below 87µM/kg (66 µM/kg) are considered hypoxic and values below ~130.5µM/kg are of concern to water quality managers.

Consistent with previous discrete sampling off New Jersey, gliders observed DO concentrations below ~163.5µM/kg (Figure 6a). These lower concentrations were limited to the bottom layer. Off Oregon, near-bottom DO concentrations are frequently observed well below the hypoxia threshold (~66µM/kg) (Figure 6b, Pierce et al., 2012; Adams et al., 2013). The unique sampling provided by gliders shows that subsurface DO concentrations off both coasts are highly variable in the vertical, horizontal, and through time. The scales of variability are on the order of a few to tens of kilometers horizontally and 3-4 days in time. While there are persistent patterns in the dissolved oxygen fields off our coasts, rapid changes can occur with varied responses across the region. Since the gliders report subsurface oxygen values in near real-time, the monitoring data can inform the response of resource and water quality managers (e.g., those at NJDEP and EPA) to these low-oxygen events. The glider-based approach is now feeding back to the sampling strategies of the EPA and NJDEP, which has found that gliders can provide spatial maps much more cost effectively then ship based sampling.

1.5 International Consensus

The potential use of gliders for ocean research was discussed at the OceanObs'99 conference in San Raphael, France, "… In terms of specific need, the Conference noted that gliders (self-steered profiling floats) offered a potential effective solution for repeated sampling through narrow, swift boundary currents. …" and "… Technological advances help us improve cost-effectiveness, sampling, and distribution."

Ten years later, the use of glider technology was promoted during the OceanObs'09 conference in Venice, Italy. (Testor et al. 2010) emphasized that gliders can help optimize the global ocean observing system. They also argued that combining glider deployments with ships, moorings, floats and satellites would enhance the capacity for observing the ocean by filling gaps left by the other observing systems. The OceanObs'09 Conference Statement noted, "There is potential for their [glider's] role in deep ocean observations and in taking observations under sea ice." This could fill critical gaps in Alaskan waters.

At the same conference, (Meldrum et al. 2010) described key variables needed by the ocean and climate forecasting community that are challenging to measure, including biological variables, where presently installed sensors rely on optical measurements that tend to experience bio-fouling problems. Glider technology may be able to resolve some of the issues involved in measuring essential ocean variables like sea surface salinity, pCO_2, pH, nutrients, and phytoplankton biomass, health, and composition.

As noted in the OceanObs'09 Community White Paper, glider data help us better understand and characterize oceanic variability for physical and biogeochemical processes at many scales. "The assimilation of glider data in global or regional/coastal numerical models can significantly reduce the uncertainties of our ocean state estimates (physical and biogeochemical) and there is now a general agreement that gliders can make us enter into a new era in oceanography."

The Implementation Plan for the Global Observing System for Climate in Support of the (UNFCCC, 2010) states: "Promote and facilitate research and development (new improved technologies in particular), in support of the global ocean observing system for climate." Areas

requiring research and technology development involve making improvements in ocean platforms, including increased capabilities for Argo floats, and improved glider and mooring technology.

The United States have been the leaders in the development of gliders; however the rest of the international community has embraced this technology and is coordinating their efforts. This is quickly closing the expertise lead that the United States had. For example, the international community has developed the EGO glider network (http://www.ego-network.org/dokuwiki/doku.php), which has provided an effective forum largely utilized by European countries to leverage expertise, build a growing glider community, and coordinate large regional efforts. Currently the United States does not have a similar community and does not effectively coordinate for the technology development. The proposed Glider Network would provide a means to ensure that United States maintains leadership in this technology by building a community that would enable significant technical advancement by leveraging of a national effort. Additionally, the U.S. glider DAC will make an effort to coordinate data efforts with the other (multi-) national DACs, both in dissemination and in exchanging information on user needs and quality control techniques.

1.6 Requirements for subsurface data
Requirements for water column profile data and improved ocean observing capabilities have been emphasized in national and international reports, including the National Ocean Policy Implementation Plan (2013), the Integrated Coastal and Ocean Observation System Act of 2009, the Ocean Research Priorities Plan and Implementation Strategy (2013), and Ocean Obs (2009). There are further requirements for biological and acoustic monitoring identified in the Endangered Species Act, the Marine Mammal Protection Act and for completion of stock assessments. During the 2011 Glider Strategy Workshop, participants assembled operational and scientific requirements for the network based on professional experience. These can be found in Appendix D. Finally, NOAA has specifically identified program requirements found in Table 1 for temperature, salinity, dissolved oxygen, chlorophyll concentration, phytoplankton abundance, stock assessment and survey observations. These observing capabilities can satisfy requirements for numerous NOAA programs identified through the Consolidated Observations Requirement List (CORL).

Observation Requirement	Requiring Program(s)	Horizontal Resolution	Measurement Accuracy	Sampling Interval	Data Latency
Sea Surface Temperature	NMFS, NESDIS, NOS	1 Km	.01°	hours	hours
Temperature Profiles	NOS, NWS, OAR	1 Km	.01°	hours	hours
Sea Surface Salinity	OAR	1 Km	.01 psu	hours	hours
Salinity Profiles	NMFS, NOS, OAR	1 Km	.01 psu	hours	hours
Dissolved Oxygen	NCCOS	5 Km	0.1 mg/l	hours	hours
Dissolved Oxygen Profiles	ONMS	22 sentinel sites	0.2 mg/l	1 day	undefined
Chlorophyll Concentration	NCCOS	1Km	30%	Daily	undefined
Chlorophyll Concentration Profiles	ONMS	14 sanctuary units	5%	1 day	undefined
HAB, phytoplankton abundance	NCCOS	1 Km	Undefined	Seasonal (summer/ spring)	Undefined
CalCOFI Surveys	NMFS	Undefined	Undefined	1 yr	Undefined
Stock Assessments, Various	NMFS	Place-based	Undefined	1 yr	Undefined

Table 1. Requirements identified by numerous programs from NOAA's Consolidated Observation Requirements List which can be met using underwater gliders. CORL Database query as of November 7, 2013

2. Glider Technology

Throughout society, the use of robots for work too difficult or costly for humans to do has increased dramatically in recent decades. In the marine environment, the use of unmanned systems has provided researchers with new methods of collecting information about our oceans. Technological advancements have taken oceanographic robots to a truly operational level, as demonstrated by the thousands of drifting profilers of the Argo program. Unsurprisingly, these advancements have resulted in a diverse multitude of impressive platforms capable of a wide variety of capabilities. From profiling floats to autonomous propeller driven submarines to wave gliding surface vehicles to seafloor crawling rovers, the successes of the past decade are providing unique opportunities. As with any technology developed, each of these systems is engineered to operate with a specific set of capabilities, often geared toward a specific mission or set of missions. One such platform, the autonomous underwater glider, is tailored to efficiently collect water column data, from the surface to the bottom or its depth limitation, over moderate temporal and spatial scales with minimal time investment by the operator. And over the past

decade, they have reliably demonstrated that capability with thousands of deployments by many users.

Autonomous underwater gliders have been in development by a number of research groups for over two decades. This has resulted in several successful versions with robust track records. They all use changes in buoyancy to profile vertically and glide horizontally on wings (Figure 7). With minimal energy they cycle repeatedly, directing themselves with attitude adjustments and control surfaces. The movement is slow but efficient, so that they can stay deployed for weeks to months at a time. This sawtooth progression provides the user with data from the surface to depth, 24 hours a day, regardless of sea states, nearly wherever the user wants to send it. They periodically surface to communicate with their pilots via satellite communications, allowing for real time analysis and mission redirection. They can carry sensor packages that measure a multitude of water state and other biological variables essential to the understanding of oceanic processes and biology. Glider deployments can be expected to last for weeks to months, covering 100s to 1000s of km.
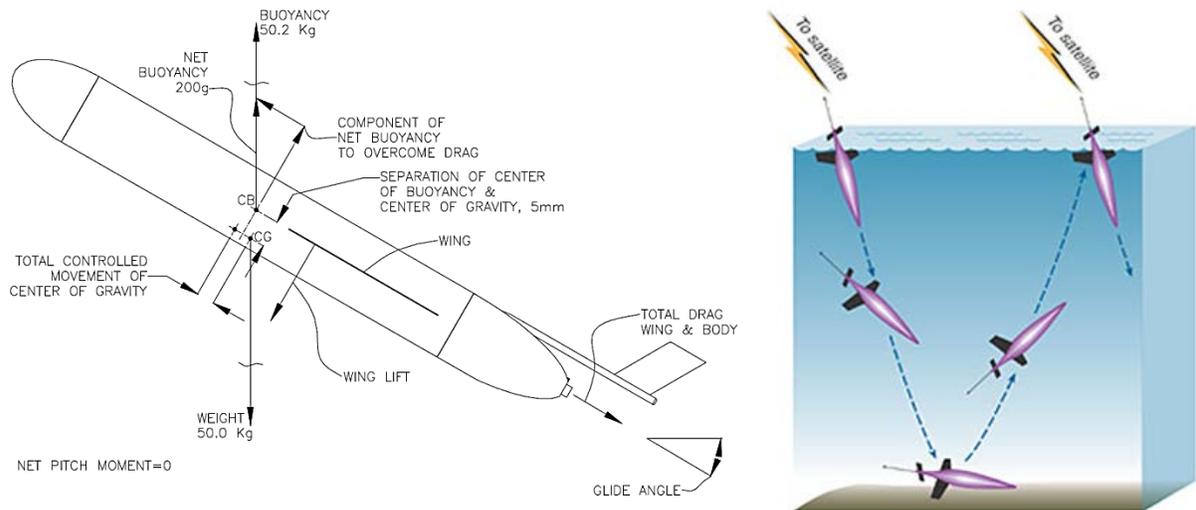
Figure 7. Typical glider operation.

To date, three versions of autonomous underwater gliders have demonstrated persistent observations in an operational capacity: Spray, Seaglider, and Slocum (Figure 8). All three have displayed robust reliability, and fulfill the mission outlined above. Collectively, over 500 of the three glider versions have been manufactured and used. It is plausible and perhaps even expected that in the future other manufacturers of similar platforms or different platforms capable of similar missions may demonstrate even greater efficiencies and reliability in collecting similar data sets. But the track records of these three build confidence that the missions described in this plan are realistic.
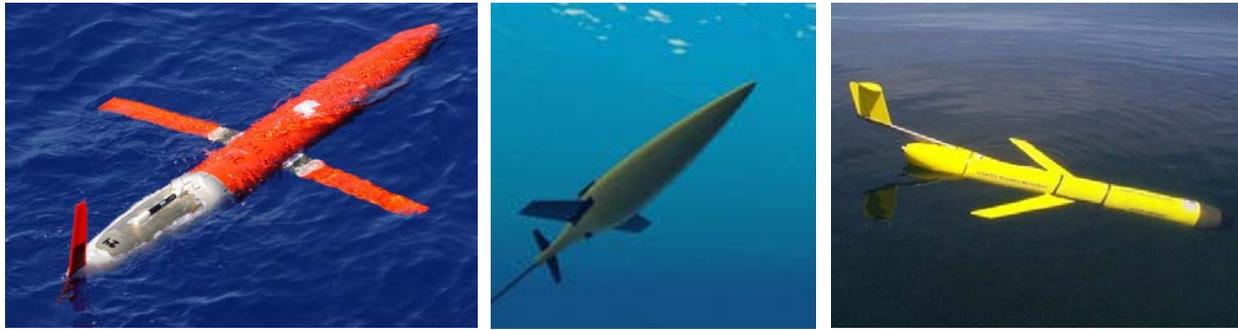
Figure 8. Spray, Seaglider, and Slocum Autonomous Underwater Gliders

These three glider types are very similar in most physical and operational aspects. They weigh 52-60kg and measure 0.2-0.3m x 1.5-2.5m, making them all deployable from small vessels with minimal equipment (Figure 9). They operate using a combination of buoyancy adjustment and center of gravity manipulation to profile at rates of 0.15 - 0.3 m/s and transit from waypoint to waypoint at 15-25 km/day. This method of propulsion is extremely efficient; but, presents limitations in navigating some density differences and currents. They operate to depths of 1000 m and as shallow as 10 m, depending on the buoyancy engine used. Deployment durations are reasonably similar at up to 6 months, heavily dependent on mission objectives, sensor loads, operating depth, ocean stratification, communication needs, and area of operations. The operational models are similar, with each glider profiling underwater for a period of 2-10 hours, then surfacing. These surfacings allow the gliders to receive commands, transmit data collected, and obtain positions, within minutes using two-way Iridium satellite communications while

Figure 9. Deployment of Slocum Glider from
fishing charter vessel

deployed. This allows the gliders to typically spend over 90% of their time submerged, out of harm's way, collecting subsurface data.

Beyond the gliders themselves, infrastructure and operational investments are modest. An experienced operator typically completes deployment preparation in several days. Such

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preparation includes battery replacement / recharging, re-ballasting, hardware evaluation, calibration, and mission software programming. Additionally, modest maintenance and sensor calibrations are typically done annually to ensure reliability. Deployment and recovery are often accomplished using small vessels such as Rigid-Hulled Inflatable Boats (RHIBs) or charter boats with a minimal crew of 2-3 operators. Once a glider is performing its mission, manpower needs can be reduced to periodic checks on glider performance, perhaps more if the mission objectives dictate. Each operator for communicating with gliders usually maintains a shore-based communications server. Once established, these servers can be run with minimal maintenance. In all, an operational team of 3 full time experienced members is capable of maintaining and deploying a fleet of approximately 10 gliders.

As with any platform, gliders have been optimized for the measurement of certain scientific variables, most notably the physical properties of salinity and temperature. In addition, by the nature of their operation, they provide water velocity averaged over their dive depth and the distance traveled between surfacings. A wide variety of other variables have been measured using gliders. Fluorometers, dissolved oxygen sensors, and various optical and acoustic sensors are all in common use. The sensors used and their configurations can have an impact on the mission duration due to power consumption and possible fouling impacts. However, power management and the use anti-biofouling techniques has enabled many multiple month deployments with diverse sensor packages.

Lastly, the reliability of these systems, perhaps their most important quality, is best demonstrated by the successful track records of a number of institutions. Glider lines have been maintained off of Southern California, the Pacific Northwest, and the Mid-Atlantic Bight for years. The groups running these lines have accumulated thousands of glider days (Table1). One group reports only 7 gliders lost in over 6000 glider days, mostly due to pushing the operational and technical capabilities of the gliders. Another institution has steadily increased its operations to the point of averaging over 10 gliders deployed year round (Figure 10). These models for success can be utilized within a Glider Network to help build programs in regions where more modest deployment operations have been started and where new groups would like to help fill in the gaps. Despite the need to optimize operations for specific regions with different biofouling, anthropogenic hazards, and environmental conditions, the costs, infrastructure needs, and effort levels for a specific number of missions per year should not vary greatly.
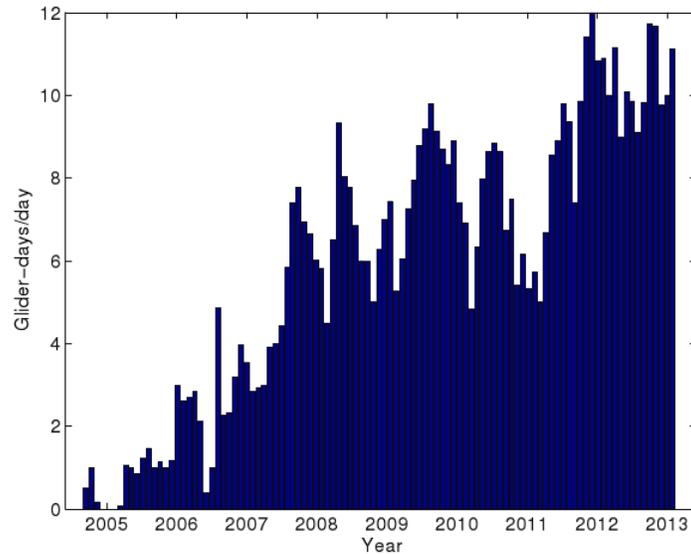
Figure 10. Spray glider operations since 2004. The average number of gliders in the water in 30-day bins is shown. Since late 2004 glider operations have grown to average 10 gliders in the water since 2011. Fluctuations in glider operations are due to short term projects beginning and ending. The long-term growth in operations is the increase in sustained missions of the sort that will comprise a Glider Network.

Based on the above, it is reasonable to plan for reliable and repeatable operations conducted by a community of glider operators around the country with the purpose of providing sustained subsurface ocean observations.

Summary of Glider Days for 2008-2012			
Year	Glider-days of data collected annually by glider operators. (Glider-day = 1 glider in the water collecting data for 1 day)	Glider-days completed outside of the EEZ	Glider-days supported by IOOS
2008	4013	890	349
2009	4744	1132	337
2010	4973	1329	990
2011	5740	1663	772
2012	6292	1793	715
2008 – 2012 Totals	**25762**	**6807**	**3163**

Table 2: Glider Days provided with support from Federal Agencies including NSF, ONR, NOAA, EPA, state and local governments and private foundations

3. Network Description

3.1 Network Components
The Glider Network will be structured as a federation of glider operators, bound together by a Network Steering Group (NSG), the Glider Program Manager (GPM), who will provide

guidance, long-term planning and administrative support, and by shared Network resources. Network components include:

- **Glider Operators (**see Section 3.3.1**)**, located at academic institutions, federal laboratories, state, local and private organizations associated with the various RAs. Capabilities will range from small teams that handle local logistics and piloting to larger operators with the capacity for technical development, hardware and software support. Glider operators will use support from the Glider Network and the U.S. IOOS Program Office to implement network elements designated by the TSG. Glider operators may also conduct observing activities driven and supported by the RAs that contribute to the Glider Network.
- A **Network Steering Group** (NSG, see Section 5.1) will set long-term direction, provide operational guidance and provide decision-making for the overarching Glider Network. The TSG will work closely with the RAs to develop and periodically update Network plans.
- The **Glider Program Manager** (GPM, see Sections 3.2.2, 5.1) will serve as the Network's primary point of contact, provide administrative support and coordinate overarching planning, resource management and funding activity.
- A **Data Assembly Center** (DAC, see Section 4) will aggregate and distribute Glider Network data, and derive a limited set of products. Real-time data will be provided by **Glider Operators**, to the DAC for dissemination to the Global Telecommunications System by the **National Data Buoy Center** (**NDBC**) and to the public via the DAC web services. The **National Oceanographic Data Center (NODC)** will serve as the long-term archive and repository for glider data, assigning Digital Object Identifiers (DOI) and ensuring access through a variety of web services. In the future, the DAC, along with the TSG, will explore ways to integrate the delayed mode processing and quality control into the data management framework.
- **Resources** (gliders, personnel, facilities) funded by the Glider Network, managed and operated by **Glider Operators**, the **GPM** or the **DAC.**

3.2 Observing Activities

The Glider Network will focus on the long-term, continuous occupation of key 'Baseline' sections distributed across the coastal U.S. Baseline sections will be selected by the NSG, in consultation with the RAs, with the explicit goals of quantifying climate variability, characterizing large-scale circulation, biogeochemistry and providing observations to improve the utility of operational nowcast/forecast models. These sections derive value from consistent, long-term occupation, and are thus intended to be stable, rather than responsive. Changes will be undertaken only after careful consideration and solely at the direction of the NSG. To achieve an optimal balance between sustainability and scope, the Baseline will be restricted to roughly 30 sections. This could be augmented by additional, regionally-targeted sections selected and supported by the IOOS RAs. Maintaining the network of Baseline sections represents the Glider Network's primary task and highest priority.

The lightweight logistics and mobility of gliders provides an inherent flexibility that can be exploited by the Glider Network to provide focused observations of seasonal and/or semi-regularly recurring events, such as hypoxia, phytoplankton blooms or storm runoff. Likewise, the

existence of an IOOS national glider fleet and the underlying operational infrastructure provides the capability to mount a coordinated, rapid response to unexpected events, such as oil spills, hurricanes and other natural disasters. At the discretion of the NSG, Glider Network assets, drawn from the reserve gliders held by the various regional operators, may be tasked for limited-duration, targeted surveys, or to respond to urgent national needs. The IOOS RAs and NSG will nominate targets, with scope and tasking determined by the NSG.

3.3 Resource Requirements for Sustained Network Operations
The intent is to lay out a notional structure that is based on the successful High Frequency Radar network. Sustained, consistent operations and timely delivery of high-quality data will require stable resource allocation to support Glider Network glider operators, the Glider Program Manager and the Data Assembly Center.

3.3.1 Glider Operators
Currently, the expertise to operate gliders lies outside of the Federal Agencies. The operation centers are within academic institutions that are associated with IOOS RAs. Glider operations utilize the IOOS infrastructure. Glider Network operations will be initiated by a federation of existing glider operators- skilled teams that already pursue a broad mix of science and technology development efforts, with the expectation that the pool of operators will grow and more will join Network operations. By engaging established teams, the Glider Network gains access to a broad range of advanced capabilities (personnel and infrastructure) without incurring the costs of building dedicated Glider Network teams supported exclusively by IOOS. To engage glider operators and exploit the efficiencies provided by this federation of experienced teams, the Glider Network must provide financial support to acquire hardware sufficient to meet the Network's operational needs and supply ongoing funding to support day-to-day operations. A minimum of two gliders will be required to support each baseline section, with the proposed Glider Network of 30 sections thus requiring 60 vehicles. New gliders cost roughly $150K apiece, resulting in a capital cost of $9M, less savings gained from the IOOS gliders already held and operated by the RAs. Experience indicates that operational costs (e.g. maintenance, piloting, deployments and recoveries, telecommunications, data management, QA/QC, shipping, batteries and other supplies) of roughly $150K per glider section per year, assuming deep-water missions of 4-6 month duration, supported by local logistics. Shallow-water missions require more frequent servicing (1-2 months), resulting in higher operating costs of roughly $250K per glider section per year. Assuming a mix of 15 shallow-water and 15 deep-water Baseline Sections yields an annual operating cost of $6M. Additional funds must be budgeted to replace gliders lost due to malfunction, mishap, wear or obsolescence. A 10% replacement rate, or 6 gliders at a cost of $900K per year, provides a ten-year fleet replacement time, sufficient to sustain operations and stay abreast of new technological developments. Assuming that hardware could be drawn from the existing fleet, support for opportunistic sampling could be estimated at an additional 3 glider-years ($450K per year, estimated as deep-water missions) allocated to event-based sampling throughout the Network domain. Operations in remote areas are anticipated to be higher and will be refined as we gain experience in these areas.

3.3.2 Glider Program Manager

The Glider Program Manager should be a full-time position with responsibilities described in Section 5, below. Resource needs depend on the nature of this position. If the GPM is a FTE outside the federal government, located at a facility that can provide administrative support, annual cost might be estimated at $180K. Costs might change if the GPM were drawn from a federal agency, perhaps as part of their contribution to the Glider Network, or if the Network required a full project office. The full resource requirements can be found in Table 3.

Annual Resource Requirements	
Requirement	Cost
Glider Operations	~ $6.45 M
Glider Fleet Maintenance	~ $0.9 M
Data Assembly Center Personnel	$0.36 M
Glider Network Program Manager	$0.18 M
Annual Travel for 1 NSG Meeting	$0.002M
TOTAL	**$7.83 M**

Table 3: Annual resource requirements estimated from the operational experience of existing glider groups, with additional management and data handling costs. These figures assume continuous operation of 30 baseline sections and include ongoing maintenance of the glider fleet. This does not include the approximately $9M capital expense of hardware acquisition (gliders) required to initiate the Glider Network.

3.4 Network Coverage

The IOOS Glider Network should maintain continuous coverage of U.S. coastal waters, with coordinated Baseline sections optimized to capture large-scale variability spanning entire coastal regions and to maximize utility for operational models. Continual coverage allows the characterization of ocean variability on the important weather event scale (2-10 days), through the seasonal cycle, up to year-to-year changes (inter-annual), and, assuming sustained effort, to decadal scales.

Glider lines should extend from the coast, across the continental shelf and over the slope, except in island domains, with extent governed by specific science needs and operational considerations. Cross-shelf lines will characterize the strong cross-shelf water property gradients typical of the coastal ocean. Operational constraints that impact inshore extent include obstacles such as kelp beds, rough coastal features and strong freshwater plumes that can inhibit a glider's ability to surface. Glider profiles should cover as much of the water column as operationally feasible, for example gliders in shallow water typically profile within 2 m of the surface to 5-10 m off the bottom. The offshore boundary may be set by the desire to consistently characterize specific features (e.g. boundary currents such as the Gulf Stream, California Current and Gulf of Mexico Loop Current), but will extend to at least the 200 mile limit of the Exclusive Economic Zone. Additional considerations that may impact specification of Baseline Sections include the desire to optimize measurements for data assimilation into regional models and operational constraints such as strong currents or shallow bathymetry.

The IOOS Glider Network will accept glider data from operational gliders in U.S. coastal waters, including missions funded by RA and other entities including from gliders used for "one time" operations, for example, those used to survey an oil spill region or harmful algal bloom. The DAC will also ingest any other glider missions that are able to be shared from gliders operating outside coastal waters, or outside the network. The DAC is able to be used as a data resource beyond the limitations of Network coverage.

The Glider Network operators will also stay in close contact with glider network operators from around the globe to ensure lessons are shared and resources are leveraged to continue to improve the Glider Network. Examples of these are European Commission's Gliders for Research, Ocean Observation and Management (GROOM) and Australia's Integrated Marine Observing System (IMOS) National Facility for Ocean Gliders (ANFOG).

3.5 Resource Distribution

Experience gained through many years of glider operations, both within U.S. waters and in remote locations around the globe, underscores the efficiencies and advantages of light-weight, local logistics. Glider teams working locally, and in other regions where they have established long-term relationships with logistics providers and fellow researchers, can typically operate with greater efficiency and flexibility. Operational and scientific decision-making becomes more effective when informed by local knowledge. Local connections can identify cost-effective platforms for deployments and recoveries, secure workshop and storage facilities and provide great flexibility when trying to mount glider rescues. In some cases, local personnel can be trained to independently execute deployments, recoveries and rescues, providing an efficient, cost-effective alternative for staffing routine field operations. Local operations also allow for more effective use of narrow weather windows. The ability to exploit brief breaks in storm patterns can mean the difference between conducting continuous, year-round measurements and suffering large, weather-induced gaps. Similarly, glider piloting and data ingest require only modest infrastructure (reliable network access and basic computer resources). Experience thus argues for a Glider Network composed of a federation of local glider operators, each tasked with implementing glider missions within their region.

Although operations should remain distributed, other aspects of the Glider Network will benefit from centralization. Data assembly, quality control, and formatting capabilities at the DAC, as well as long-term preservation, stewardship, and access capabilities of NODC represent critical centralized Glider Network resources. Having streamlined data processing, QA/QC, archive, and data stewardship are some of the primary benefits to having a Glider Network. Glider refurbishment and troubleshooting of more complex problems may be another opportunity for central efficiency when performed by an experienced team. While the manufacturers can perform these tasks, it may prove more cost effective for an effort of this size to perform these tasks "in house". As the network builds out and matures, it might also establish protocols for sharing Glider Network assets between glider operators. This could allow more efficient use of available hardware, and would facilitate rapid response in times of national need. Lastly, the Glider Network operators and centralized resources together provide a wealth of opportunity for sharing methods for ensuring high data quality, cost efficiency, and performance metrics. This allows groups to stay in close contact with glider network operators from around the country and

around the globe to ensure lessons are shared and resources are leveraged to continue to improve the Glider Network, such as with GROOM and ANFOG.

3.6 Data and Information Products
The Glider Network will provide routine subsurface measurements of upper-ocean (0-1000 m) physical, chemical and bio-optical properties. As described in Chapter 4, uniform glider data format, access to glider data and associated metadata, and archiving of that data at NODC are key features of the IOOS Glider Network. The Network DAC will provide a centralized data of water properties from a single glider dive or cross-shelf sections of water properties. The IOOS Glider Network will maintain an up-to-date map of operational gliders in U.S. coastal dissemination and be capable of creating basic graphical displays of glider data, such as profiles waters, which will include direct links to glider data.

A centralized DAC does not replace the need for the IOOS RAs to display, serve glider data and use this data to produce particular products appropriate for that region. Examples include 0-500 m heat content in the California Current for tracking upper-ocean changes due to El Niño/La Niña cycles. Additional examples include subsurface distributions of hypoxic waters in coastal zones, that is, waters with dissolved oxygen concentration less than 1.43 ml/l.

3.7 Environmental Compliance
NOAA does not anticipate any significant adverse consequences on the quality of the human or natural environment during the implementation of the glider network plan. However, the U.S. IOOS Program Office will continue to assess glider impacts throughout the facility lifecycle as part of its routine processes. The gliders in the Network will comply with the IOOS Programmatic Environmental Assessment.

4. Data Management

The vision of a Glider Network involves cooperation between glider operators (including scientific PI's and operators), data managers, and end users. A critical component of this is a data management plan that provides the guidelines for the end-to-end process of getting data from the individual sensors to the archives, through a QA/QC process, and disseminated to users. There are several different user groups with a wide range of requirements resulting in different data models and transport mechanisms. In this section we describe the vision for a glider data system that addresses the needs of the glider network and fits within the DMAC guidelines of IOOS. We also identify and generally define roles that must be fulfilled. The implementation of this vision will be iterative and take different forms as constrained by resources and technology developments. It will also be in compliance with Executive Order 13642: Making Open and Machine Readable the New Default for Government Information.

While the sampling strategy of the glider network is initially focused on sustained lines within the U.S. EEZ, the data management strategy is applicable to all gliders regardless of funding source/sampling sensors/region/geography.

The data framework proposed here is an end-to-end system that manages glider data from collection through various levels of refinement to delivery to user groups. The flow through the glider data system is depicted in Figure 11. At the left of the figure are the glider operators. Glider operators employ on-site piloting (glider operator) and scientific planning (science PI) for their glider missions. The data are reported to a shoreside station. The data are received in a raw format and converted to engineering units if needed. Automated real-time QA/QC is applied, at the discretion of the operator, and the data are converted to netCDF (see documentation online at [github](#)[2]).

Next, the real time netCDF files are aggregated at a glider Data Assembly Center (DAC) which serves to collect individual data files from a glider operator and distribute the data through multiple channels. The DAC is the primary distribution point for real time glider data, and there are two mechanisms for distribution. Real time data are pushed by the DAC to the NDBC where they undergo a quality control assessment and are distributed on the World Meteorological Organization Global Telecommunications System (GTS). The GTS is only available to National Meteorological Centers so, for the public, the real time data are also available on the DAC data servers.

The DAC will also aggregate the real time per dive data files into collections or deployments. These aggregations will be served to the public via IOOS standard web services such as OPeNDAP, Sensor Observation Service and Web Map Services. It is through these services that the public will access glider data. The DAC may also serve some basic data products that are to be determined. This includes high-level users such as RA's or product developers as well as more informal or infrequent users. Finally, the DAC will have the responsibility for developing an archive agreement with the NOAA NODC to ensure that the glider data are properly archived.

There will be a need for glider data that is more refined, and complete than can typically be done in real time. This delayed mode data will be derived subject to the scientific guidance of the NSG (see Section 5.1) and interested principal investigators. These additional DAC responsibilities, addressed subject to available resources, may include but not be limited to:

- Serve delayed mode QA/QC data
- Smoothed or interpolated products such as section data for repeat transects
- Graphical summaries

To leverage existing infrastructure (e.g. office space, networks, servers) and reduce costs, DAC activities will be collocated with Glider Operators, the Glider Program Manager or an existing data facility. Regardless of physical location, the DAC will require stable support for the small team of programmer-analysts who will be responsible for developing and maintaining software for processing and disseminating glider data, and for applying delayed-mode quality control and correction to the Network's data stream. For a rough estimate, this plan budgets three Full Time Equivalents (FTE) with an annual salary of $60K per year, burdened at a multiplier of 2.0. This yields an annual DAC personnel cost of $360K (Table 3).

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[2] Documentation and examples of the real time netCDF file used in use by the IOOS Underwater Glider Network can be found at https://github.com/IOOSProfilingGliders/Real-Time-File-Format
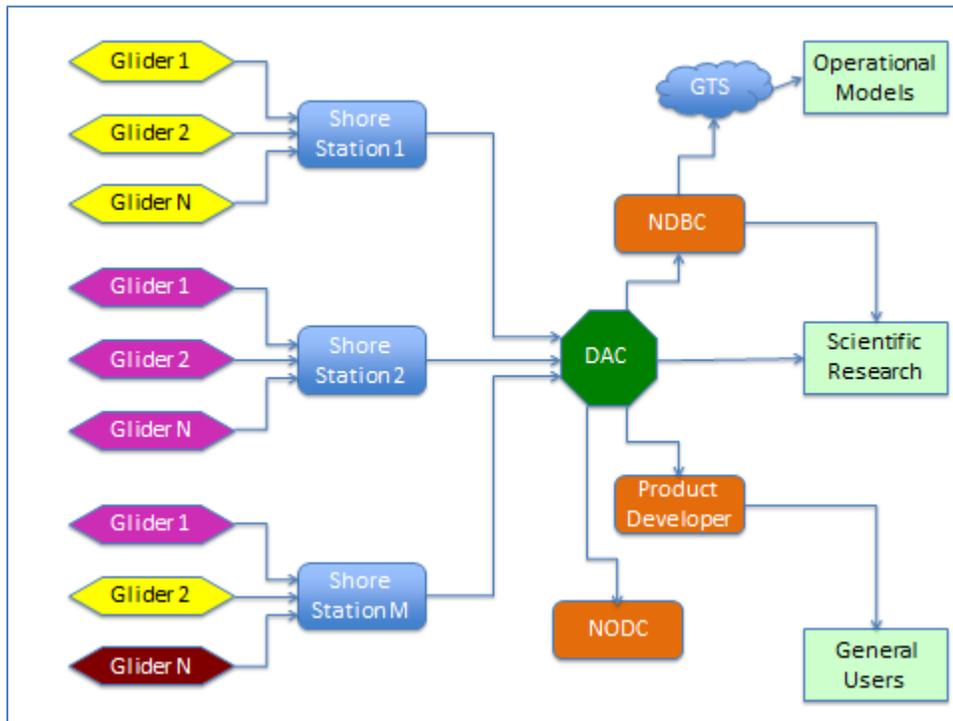
Figure 11: Data flow chart for glider data. Gliders send data to appropriate shore station, where it is in turn delivered to the DAC. From there, the DAC will deliver it to National Oceanographic Data Center for archival, National Data Buoy Center for transmission onto the Global Telecommunication System and to the rest of the world for the public to access. Different colored gliders represent different glider operators.

4.1 DAC Construction

Goals for the first phase of construction for the DAC include:

1. Specifying and creating a netCDF file content and format standard for the exchange of real time, per dive data;
2. Ingesting data from glider operators (providers will convert data to glider netCDF format);
3. The DAC will verify CF-1.6 and Attribute Convention for Dataset Discovery (ACDD) compliance of the netCDF files and report errors back to the individual providers where appropriate. The DAC will provide guidance to the providers on compliance;
4. Interfacing with the NODC and other data consumers (public, private, etc.) to provide access to the data sets;
5. Publishing the datasets using DMAC compliant web services (eg. THREDDS, ncISO, ncSOS, ERDDAP);
6. Supporting harvesting by IOOS Service Registry and Data Catalogs which includes liaising with NGDC (Registry) and ASA (Catalog) development teams;
7. Fully developing a data format description and user guide at the github site referenced above; and
8. Transmitting data to NDBC to be served on the GTS.

5. Governance

Governance of the Glider Network plan is essential to its success and is the responsibility of the IOOS. The network will be supported by multiple federal agencies and led by the U.S. IOOS Program Office in collaboration with the IOOS RAs. In this section we will outline roles and responsibilities for the network, how stakeholders will be engaged, and what metrics will be used to evaluate the network's performance.

5.1 Roles and Responsibilities

The Glider Network Program Manager (GPM) will be the overall coordinator for the glider network. The GPM will be responsible for planning and out year funding opportunities, liaising between the technical steering team, data team, program office, RA's and other agencies, and serving as the national and international point of contact. The GPM will coordinate with the IOOC to facilitate the cooperation and involvement of other agencies.

The responsibilities of the GPM are to:

1. Lead the development and update of overall glider network science and implementation plans, and provide leadership coordination in the annual budget planning process.
2. Prepare and maintain the annual operating plan (AOP) for implementing a year's objectives. The GPM seeks input from all IOOS RAs and federal agencies and presents the AOP to the U.S. IOOS Program Office Director.
3. Identify resource requirements and lead the development of funding pathways, in cooperation with partnering organizations, required for attaining the goals and related metrics established through the AOP.
4. Be responsible for the management of glider network activities and the proper alignment of all interagency glider network efforts with the AOP; (Major activities include, but are not limited to appraising scope of grants to RA's, evaluation and administration of awards, organizing science workshops, policy and budget updates).
5. Develop and track network performance metrics and report the results to the NSG and U.S. IOOS Program Office.
6. Represent the glider network to interagency and international bodies concerning ocean, coastal and marine glider observations and their applications in operational services.

To maintain a Glider Network, a NSG will be formed and supported by the U.S. IOOS Program Office. The NSG will be comprised of members from Federal agencies, the IOOS RAs, and academia. The U.S. IOOS GPM will serve as or designate a leader of the NSG. The members should have experience with underwater glider operations. The NSG members will serve on a rotational basis, with terms limited to two or three years. Its own charter members under its terms of reference will develop exact term lengths of the NSG. They will be tasked to meet annually and provide an annual report to the U.S. IOOS Program Office Director.

The NSG has the following responsibilities:

1. In conjunction with the GPM, define overarching Glider Network scientific and operational objectives that take into consideration federal, regional and other user needs. From this, develop the specifics of Glider Network operations.
2. Review and provide input to IOOS, partner agencies, and the academic community on scientific and technical directions.

3. Review the glider network AOP annually with each member providing recommendations to the GPM.
4. Review/evaluate the latest glider technologies and data management practices for incorporation into the network.
5. Assist GPM in reviewing proposals for new glider network operators.
6. Provide expert peer review for the glider network, as requested, on the progress of competitive projects through the award period and participates in quarterly reviews of the glider network effort.
7. This group will meet (virtually) at least quarterly and as necessary, including an annual meeting.
8. Facilitate development of glider operations best practices to assist newer operators as needed.
9. Provide input and guidance to the Data Team as needed.

A data team will also be formed to develop and maintain the DAC. The data team will be comprised of regional data managers, a NDBC representative, a NODC representative and DAC leadership. The members should have experience with underwater glider data and/or data management. The responsibilities of the Data Team are to:
1. Review and modify netCDF file content and format standard for the exchange of real time, per dive data as needed;
2. Develop processes for ingesting data from new and external glider operators
3. Coordinate with international partners to improve data exchange and formats
4. Assist in advancing data management, dissemination and access for gliders
5. Assist in execution of the Glider Network data plan as needed

Funding for glider operations will still come from multiple sources. There will be cases where a Federal, State or other agency/entity will directly fund glider missions and that will be accomplished through direct contact (e.g. EPA and NJDEP have funded MARACOOS gliders for special missions). Scientific research dollars will still go through a normal peer review process for dissemination. The intersection between the GPM and the NSG will be one of awareness and coordination such that the entire network structure can be used most effectively.

5.2 Stakeholder Engagement
Interaction with partners, especially during the initial start-up of the network, will be critical to the success of the Glider Network. Input from partners will be obtained through interactions at the annual NSG meeting, other presentations to the RA's, surveys, and workshops. Feedback will be used to refine the AOP for the network.

5.3 Performance Metrics
Performance metrics to gauge the performance of the build out of the Glider Network will be developed as the network is established. The intent of the glider network is to follow the standards set by other operational networks and data providers such as those in the national HF Radar network. The initial metric used will be that of Table 2, glider days. Ultimately, more specific metrics will be identified to demonstrate the use and application of glider data in product development and decision making to benefit the nation.

6. Education and Outreach and Communication

A robust education, outreach and communication plan is essential to developing the reach and impact of the Glider Network. The network in turn offers expanded education and outreach potential beyond that of individual glider missions with the likelihood of wide use of data relevant to multiple audiences. This component of the glider network will be executed through the existing education, outreach, and communication (EOC) groups existing within the RAs. The RA EOC groups can be used to expand the glider network and to inform the ocean community and the country of the significance and potential applications of glider technology. Additionally, Appendix B will discuss specific goals to reach various groups that could benefit from the Glider Network.

The Glider Network enables more robust EOC initiatives than those developed from individual glider missions. While individual missions inform a specific usually localized area, which may affect a small population, it is harder to garner mass interest in the data. A network of connected glider missions sampling on a larger scale with greater coverage can directly affect a much larger community. The Glider Network also provides an opportunity to coordinate and leverage resources with other glider operators, data users, the modeling community and other EOC programs to improve its reach and value. Appendix B will describe opportunities with both individual missions, such as the success of Rutgers Scarlet Knight mission, Figure 12, and coordinated glider lines of the network, which will be coordinated with the IOOS RAs.
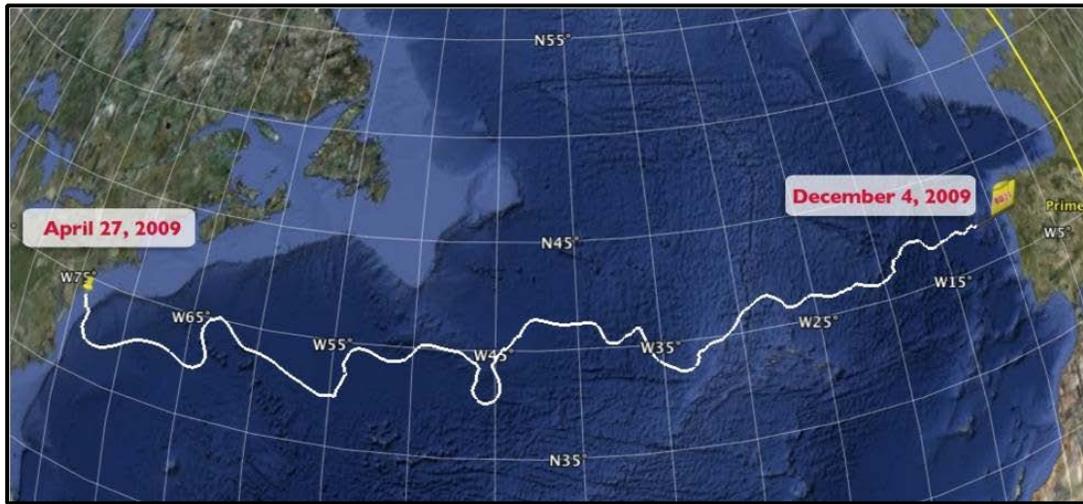
Figure 12. Crossing the Atlantic by the glider Scarlet Knight. This educational mission involved students and groups from Rutgers, Azores Islands, Norway, Puerto Rico, and the Canary Islands

EOC will enable many goals related to the Glider Network to be met, including:
1. Increasing understanding of the role of the Glider Network in an operational setting for operators;
2. Showcasing impacts of a Glider Network, including improved predictions for lives and livelihoods;
3. Improving educational reach for a large audience (i.e., enabling students and users across the globe to explore the ocean remotely via gliders by following glider tracks and analyzing glider

data as it is transmitted). The Glider Network can appeal to those studying everything from fisheries management, ocean circulation, ocean climate, weather extremes, and more;

4. Communicating to Congress and the user community (e.g., modelers, operational agencies, the public) the value of glider data to promote understanding of the present and future capabilities and applications of the Glider Network, and;

5. Promoting career paths related to technology, ocean observations, and ocean-related sciences. See Appendix B for expanded planning to execute the EOC piece of the Glider Network.

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Appendix B: Extended Education and Outreach Plan

B.1 Education and Outreach
Education and outreach represent two-way communication between a group and the public to establish and foster mutual understanding, promote public involvement, and influence behaviors, attitudes and actions with the goal of improving the foundations for stewardship. Instituting this interactive connection with external constituencies provides a reciprocal benefit that is essential to accomplishing the mission. Educating the public includes both formal and informal elements. Formal education is curriculum-based, provided by trained educators and tied to educational standards. Informal education happens outside of formal educational setting, in after-school programs, community-based organizations, museums, libraries, or at home. Informal education can also include the teaching elements beyond school students, and associated with area stakeholders, congress, and the general public. This can be similar to outreach which goes beyond general education and includes the ways glider teams collaborate with external groups in mutually beneficial partnerships that are grounded in scholarship and consistent with the role and mission of the glider and/or network team.

Communication and Marketing
Communication and marketing involves developing and enhancing tools to reach the public; describing the challenges, processes, and results of glider activities through stories and data visualizations on the web and in popular media, providing information to a range of audiences to enhance society's ability to understand, plan, and respond (if necessary). Marketing is essential to improve the awareness and visibility of glider products and describe why a glider network and the resultant data are essential to the user community.

B.2 Audiences
There are several types of audiences that would benefit from activities initiated under the education and outreach group and the communication and marketing group. These audiences include educators, students, scientists, operators, stakeholders, and the general public.

Educators and Students
Educators and students at the K-12, undergraduate, and graduate level can benefit from a Glider Network. Under this Plan, educational tools, programs, and opportunities for both teachers and students would be developed and made available. For the K-12 audience, partnering with NOAA's Adopt a Drifter Program to do an occasional Adopt a Glider event is possible so students can track their adopted glider as it completes its course. At the elementary and secondary level, a review of the data by teachers would enhance student interest and understanding, and provide a look into the "cool" technology of the present and future. In order to accomplish this, teachers will need to be trained through workshops and perhaps on-line webinars, like those provided through the National Science Teachers Association (NSTA) where large audiences of interested educators can be reached.

At more advanced levels, incorporating gliders into the curriculum could include providing access to real-time and delayed mode data and products for use in the classroom. Engaging undergraduate and graduate students to help maintain and operate the gliders as well as expand interest in the ocean sciences community will be essential to sustain glider operations in the

future. Students can learn to operate gliders, and get involved in developing and promoting the applications of a glider network through their research. Educators involved in the Glider Network can partner with Ocean Observatories Initiative (OOI) educators to produce tools and resources for secondary and university classes, so students can work with glider data in classrooms. A primary goal of these opportunities is to increase interest in the marine sciences, provide additional career options, and promote the use of alternate technologies for observations, among others. The hope is that undergraduates will pursue graduate studies, perhaps using gliders to conduct research, which will lead to improved research products and operations.

This education does not just apply to science students, but there are opportunities to leverage resources in other disciplines on campuses. For example, some science departments have coordinated with film classes to develop products for use in communicating about gliders. Engineering departments could work with Oceanography programs to encourage collaboration both in the classroom and for thesis and dissertation research.

Lastly, this program should include elements for educators to develop lesson plans through Regional Associations. Also, teachers who participate in the Teacher at Sea Program could be asked to develop lesson plans as part of their experience. These lessons can then be shared widely so others can benefit and the purpose of having a glider network can be promoted.

Scientists and Operators
The best way to ensure that a Glider Network is sustained is for scientists to work together to share tools, techniques, and strategies for using and operationalizing the network. Gathering a forum for discussion of the potential for glider use is essential. Reviewing successes achieved by other countries and how they gained that success will help build more quickly. Holding periodic meetings with the user community (e.g., modelers) to share data and uses, and determine future needs will provide the communication necessary to maximize the output from the network.

Education and communication among and between the scientists and users is essential. Creating a web page with links to glider resources, including descriptions, technology sites, education material, training opportunities, data access, and maps or portals showing glider lines will provide scientists and operators with the tools that they need to purchase and operate the gliders appropriately.

It would also be helpful to provide training programs for new glider operators and organizations with coordinated national training programs located at various regional glider hubs. Certificates could be made available for students, Navy operators, technicians, and others.

Stakeholders
In order to inform stakeholders of the real and potential value of the glider network, holding periodic meetings with decision makers, or producing online resources that can be delivered regularly, will educate the user community to understand and request glider observations.

Public
The public component of this plan includes Congress, other Federal and State ocean programs and public citizens at large. Better communication and understanding will lead to improved

funding support, coordination, collaboration and leveraging of resources. Additionally, better understanding about the ocean in general enables us to modify behaviors and protect lives and livelihoods. This includes enhancing society's ability to understand, plan and respond to major events. Methods to help achieve maximum communication and marketing can include development of a strong, targeted elevator speech about gliders, two-page fact sheets with attractive photos and simplified figures, and brochures that can deliver information quickly and in an appealing way. Creating meaningful graphics and visualizations that can be used in a variety of media (e.g., public presentations, web pages, and brochures) will promote the Plan effectively. In addition, taking advantage of every opportunity to meet with your representatives in Congress to discuss the need for support of these efforts will provide the communication and marketing necessary to lead to support of a sustained Glider Network.

Appendix C: Partners and Collaborations

While the U.S. IOOS Program Office and partners will initially lead this network, there will be several opportunities to expand or improve the network as it develops. In doing so, it is expected that the NSG and other IOOS members will work with others to either include more gliders and data streams into the network, to expand the visibility and capacity of the network and to broaden its role in sub-surface monitoring. The subsections below identify a number of the organizations and groups that may have a role in this network as it is developed.

Department of Defense (DOD): Currently gliders are becoming an active tool for the Navy. The Navy to that end has engaged in a large purchase of gliders. The gliders will provide critical data to improve the predictive skill of ocean model forecasts and adaptively carry a range of sensors in regions of high interest. Currently, the number of qualified operators will limit the full deployment of the available gliders; therefore the development of the national capacity in conjunction with teaching institutions will provide a means to fill those operational needs.

Department of Energy: There is a major push to develop offshore wind infrastructure. The offshore wind and sea breeze wind resource is a function of the ocean and the atmosphere. The ocean is chronically undersampled and spatial information on coastal ocean temperatures would fill a critical gap in improving modeling efforts for ocean wind and sea breeze resource.

Energy Companies: There is a major push to develop offshore wind infrastructure. The offshore wind and sea breeze wind resource is a function of the ocean and the atmosphere. The ocean is chronically undersampled and spatial information on coastal ocean temperatures would fill a critical gap in improving modeling efforts for ocean wind and sea breeze resource.

EPA: The gliders can provide a sustained capability to monitor water quality. Currently EPA's capability to sample coastal water quality is limited and gliders provide potentially a cost-effective means to provide a sustained presence and with a capability of carrying a range of sensors. As new water quality sensors increase, any proposed national glider backbone can continually enhanced to serve an increasing number of needs.

European Glider Operators (EGO): EGO provides a broad framework for Europe to develop a integrated system to monitor and manage their coastal waters. This will allow the individual countries to leverage and learn from their partners. A national network for gliders for the United States would provide a similar advantage.

Integrated Marine Observing Systems (IMOS): IMOS is Australia's integrated ocean and coastal observing system. It provides data with free and open access and a national array of observing systems to measure the marine environment around Australia. They provide a benchmark example and experience with a glider network and integrated approach to observing.

Interagency Working Group on Facilities and Infrastructure Subcommittee on Unmanned Systems (IWG- FI SUS): This group is tasked to advise, assist and make recommendations to the IWG-FI on policies, procedures and plans relating to unmanned system uses, upgrades and investments. One goal of the group is to develop a coordinated Federal effort and approach to

maximize the efficiency and capabilities of unmanned systems across the government. This network is one element of a coordinated sub-surface approach for unmanned systems. While initially, this plan will not include all unmanned systems, it will provide a significant opportunity for coordination.

National Science Foundation (NSF): Many individual NSF projects would benefit from the regional data provided by a Glider Network. This would greatly strengthen the individual projects increasing their scientific potential. The resulting improved understanding of the ocean resulting from these projects will be used to improve the evolving national glider backbone.

NOPP: The National Ocean Partnership Program (NOPP) provides an effective vehicle for interagency collaboration. The NOPP program may provide an effective mechanism to support sustained glider deployments given the dual use potential of the gliders to serve many needs simultaneously.

NOAA: NOAA has an Autonomous Underwater Vehicle (AUV) group that is looking for opportunities to improve NOAA's observing capabilities in challenging fiscal environment. AUV's have the potential to handle some of that tasking and the group is already interested in using the Glider Network as a resource to assist in handling some of its observing requirements.

Coastal storm and hurricane forecasting by National Centers for Environmental Prediction (NCEP) benefits from any in situ data. Gliders provide a regional data stream that can improve predictive skill in storm intensity and trajectory. Gliders provide a unique advantage in that the spatial configuration of the network can be adjusted adaptively based on storm dynamics.

Ocean Observatories Initiative: The NSF Ocean Observing Initiative (OOI) will be heavily dependent on gliders across the entire program. The Operations and Maintenance of OOI will follow the NSF Statute. OOI is the NSF contribution to IOOS. The NSF will address basic research and meet the NOP objectives provided by NSF. It complements the mission-based science addressed by this Network Plan.

Offshore Oil and Gas Companies: These companies are interested in using AUV technology to assist in their exploration and development and are interested in collaboration wherever possible.

State agencies: State agencies are often focused on developing effective mechanisms to monitor and manage their local waters. The data spans a wide range of issues spanning from fisheries, water quality and storm forecasting. Gliders have the ability to carry a range of sensors and thus individual states can adjust the sensor suites based upon their high priority issues. A national backbone of glider observations would allow the state's efforts to be embedded in a broader regional network.

U.S. Geological Survey (USGS): USGS has an ecosystems mission area, which provides "scientific understanding and technologies needed to support the sound management and conservation of our Nation's biological resources" and would benefit from glider network data.

Appendix D: Workshop

The National Glider Strategy Development Workshop was held at Scripps Institution of Oceanography, UCSD, La Jolla, CA, from August 1-3, 2012. It was organized both to frame priority requirements for broader coordination and collaboration of glider operations and to draft an outline for a national strategy. At the close of the workshop, authors were assigned sections of the outline to develop the first draft of the Network plan.

Attendees were:

Rich Arrieta, SPAWARSYSCEN-PACIFIC
Becky Baltes, U.S. IOOS
Jack Barth, NANOOS
Chris Beaverson, OAR (NOAA AUV Group)
Wendell Brown, MARACOOS
Francisco Chavez, CENCOOS
Bruce Cornuelle, SCCOOS
Jorge Corredor, CariCOOS
Mike Crowley, MARACOOS
David Demer, NOAA/SWFSC
Catherine Edwards, SECOORA
Scott Glen, MARACOOS
Stephen Harrison, San Diego Weather Forecast Office

Matt Howard, GCOOS
Craig Lee, NANOOS
Matthew James, GLOS
Chad Lembke, GCOOS/SECOORA
Dave McCarren, CNMOC
Jim O'Donnell, NERACOOS
Jim Potemra, PacIOOS
Brian Powell, PacIOOS
Dan Rudnick, SCCOOS
Tom Ryan, NODC
Diane Stanitski, OAR/CPO
Joe Swakos, NDBC
Rob Wahl, NAVO

The agenda, presentations and background documents for the workshop can all be found at http://www.ioos.noaa.gov/glider/strategy.

Among other valuable discussion, the group assembled a list of science and operational requirements for a glider network and defined it by region. The requirements are listed here.

Operational and Science Mission Requirements
Science Objectives:
Climate ecosystems and water quality are primary IOOS objectives (others are Marine Ops and Coastal Hazards)

Drivers for all regions:
1. Ocean Acidification
2. Connectivity between global and coastal
3. Decadal variability effects
4. Filling gaps in the observing system

West Coast Physical Drivers/Goals:
1. El Nino
2. Sub-artic influence (HI has HOT at Station Aloha and gliders)
3. PDO (Pacific Decadal Oscillations)
4. Linkage across the basin

5. Effect on ecosystems: Temp, Dissolved Oxygen, Salinity
6. Seasonal migration of fish happens during El Nino because of the changes in the water. Need to understand habitat shift with range (why and where they move)
7. Identify water sources: Where's it coming from and where is it going? Understand nutrients and where they are going.
8. Open ocean contributions and coastal ocean contributions. Important boundary currents could bound the glider network?
9. Large scale topographics as well as coastally trapped waves,
10. Alaska special case might be the ice covered areas.
11. HI special cases might be reef protected atolls. For HI, it might be more important to understand water quality (effects of rain) than climate level changes. Places like Palau will have to evacuate as coral reefs bleach and dissolve (or high temps or sea level rise)
12. Glider lines could be used to understand driver currents (N. Equatorial Current, etc...) It could potentially become like a Tao Array or augment Tao Array.

East Coast Physical Drivers:
1. Define evolving moving fisheries ecosystems, habitat definition, fisheries migration, 1000Km buoyancy currents, NAO (N. Atlantic Oscillation), shelf slope front scale (10Km), range of scales that drive operations, Gulf Stream, FL current, loop current affect East Coast even if initiated outside of the coast. Can't fully separate from Gulf of Mexico.
2. Gulf stream has different impacts N. and S. of Cape Hattaras and inside/outside East Coast. It is buffered by slope of coastline
3. In the Caribbean, repeat sections of CLIVAR line 22? (67W). Short term variability essential for hurricane impact forecasting. Eddies across the coast.
4. Ocean Acidification: hydrography lines can incorporate pH measurements
5. Long term: Upper ocean heat content
6. Short term: Upper ocean heat anomalies

Gulf Coast Physical Drivers:
1. Water quality
2. Gliders and circulation models were essential to success in DWH.
- It was an adhoc system and it could be so much better if infrastructure was in place
- Needs to be built into current ongoing monitoring effort b/c the one-time events get forgotten
3. Contribute to monitoring of local conditions during episodic climate or environmental events
4. Harmful Algal Blooms
5. Tsunami debris
6. Hurricanes
7. Oil spills

Operational Objectives:
1. Collaborative work leads to efficiencies
2. Data Management services to ease burden on group
- QA/QC services
3. Should NOAA be operating gliders for this mission or fund the glider network?
          - Participation not necessarily prescribed.
4. Enables technology refreshing plan/mechanism

- Research of new technologies: Initially outside of National Glider Plan (NGP). Eventually it folds in or at least we lay out the plan for how to advance technology
5. Newer glider users have much to gain from more seasoned users is essential. Also fresh faces bring new ideas.

Real-time Modeling Requirements:
1. Two kinds of modeling to consider; real-time and state estimates
2. Objectively map/ interpolate, long(er) term state-estimate
3. Determine how long to let instruments persist in the model
4. Modelers are certain users of glider data for assimilation and other purposes but may also be a 2-way interaction. Models can be used to help mission planning for gliders.
5. Models can forecast and models can be used to produce the products that the public users want.

Resulting Sampling Needs:
1. There are needs for both episodic sampling and some repeat sampling. Network should accommodate both.
2. Episodic events such as oil spill, large storm, etc…
3. May need to define the product better (ie. Data assim product, transects, …)
4. Variables: Temperature, Conductivity, Salt, Depth-average Velocity, Dissolved Oxygen, Backscatter

Stakeholders:
Modelers (secondary b/c they have their own stakeholders)
Scientists
Public – Fisherman, recreational users
Renewable energy companies
Dischargers (sewage companies)
Agencies- Fisheries service
           Water Quality forecasters
           USCG - SAR
           State Agencies
           NWS
           NHC
           National security

Appendix E: List of Acronyms

ANFOG: Australian National Facility for Ocean Gliders
AOP: Annual Operating Plan
ASA: Applied Science Associates
ASAP: Adaptive Sampling and Prediction
AUV: Autonomous Unmanned Vehicle
CalCOFI: California Cooperative Oceanic Fisheries Investigations
CEQ: Council on Environmental Quality
CONUS: Continental United States
CO-OPS: Center for Operational Oceanographic Products and Services
DAC: Data Assembly Center
DO: Dissolved Oxygen
DOE: Department of Energy
DOI: Digital Object Identifier
DMAC: Data Management and Communication
DOD: Department of Defense
EEZ: Exclusive Economic Zone
EGO: European Gliding Observatories
EOC: Education, Outreach and Communication
EPA: Environmental Protection Agency
FTE: Full Time Equivalent
ftp: File Transfer Protocol
GCCS: Glider Coordinated Control System
GCOOS: Gulf of Mexico Coastal Ocean Observing System
GENIOS: Glider Environmental Network Information Operating System
GLOS: Great Lakes Observing System
GMT: Greenwich Mean Time
GPM: Glider Program Manager
GPS: Global Positioning System
GTS: Global Telecommunications System
HAB: Harmful Algal Bloom
HFR: High Frequency Radar
ICOOS: Integrated Coastal Ocean Observing System
IMOS: Integrated Marine Observing Systems
IOOC: Interagency Ocean Observing Committee
IOOS: Integrated Ocean Observing System
IPO: IOOS Program Office
JSOST: Joint Subcommittee on Ocean Science and Technology
MARACOOS: Mid-Atlantic Regional Association Coastal Ocean Observing System
MODIS: Moderate Resolution Imaging Spectroradiometer
NANOOS: Northwest Association of Networked Ocean Observing Systems
NCCOS: National Centers for Coastal Ocean Science
NCEP: National Centers for Environmental Prediction
NDBC: National Data Buoy Center
NESDIS: National Environmental Satellite and Information Services
NetCDF: Network Common Data Form

nFLH: normalized Fluorescence Line Height
NGDC: National Geophysical Data Center
NHC: National Hurricane Center
NJDEP: New Jersey Department of Environmental Protection
NOAA: National Oceanic and Atmospheric Administration
NODC: National Oceanographic Data Center
NOP IP: National Ocean Policy Implementation Plan
NRC: National Research Council
NSF: National Science Foundation
NSG: Network Steering Group
NSTA: National Science Teachers Association
Glider Network: National Underwater Glider Network
NWS: National Weather Service
O&M: Operations and Maintenance
ONR: Office of Naval Research
OOI: Ocean Observatories Initiative
OPeNDAP: Open-source Project for a Network Data Access Protocol
OSSE: Observing System Simulation Experiments
OSTP: Office of Science and Technology Policy
PacIOOS: Pacific Islands Ocean Observing System
QA: Quality Assurance
QAPP: Quality Assurance Project Plan
QC: Quality Control
PI: Principle Investigator
RA: Regional Association
RCOOS: Regional Coastal Ocean Observing System
RHIB: Rigid Hull Inflatable Boat
RMS: Root Mean Square
SCCOOS: Southern California Coastal Ocean Observing System
SECOORA: Southeast Coastal Ocean Observing Regional Association
SOS: Sensor Observation Service
ssh: Secure Shell
SSS: Sea Surface Salinity
SST: Sea Surface Temperature
THREDDS: Thematic Realtime Environmental Distributed Data Services
UNFCCC: United Nations Framework Convention on Climate Change
U.S.: United States
USGS: United States Geological Survey
WMO: World Meteorological Organization
WMS: Web Map Services
WRF – Weather research forecast