Gliders as maturing technology: Using gliderpalooza as means to develop an integrated glider community

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***Abstract*— Underwater autonomous gliders have transitioned from exotic experimental systems to becoming a standard platform capable of collecting data over a critical range of spatial and temporal scales in the ocean. The data are proving to be extremely valuable for addressing a wide range of basic and applied research questions. These communities are growing from distributed research and/or education groups. It is crucial as systems continue to evolve that there is an effort to "harmonize" data products while preserving the diversity of approaches/science/experimentation. As the gliders have matured and new battery solutions provide additional energy, there is an increased focus on the integration of a wider range of sensors to be incorporated into gliders. Many of these new classes of sensors will be particularly effective for characterizing biological processes in the coastal ocean. As biological sensors generally provide proxy estimates of a parameter, developing robust quality control and assurance procedures is critical. These new sensors will be more power intensive thus requiring the development of planning tools for increasing energy efficiency during missions. Given the significant growth in the highly distributed glider community, efforts are now focusing on the development mission planning tools to allow for efficient operation of glider fleets. To further collaboration and standardization of the growing number of glider operators we have initiated a series of community efforts called glider paloozas. We had an exceptional turnout last year, encompassing 18 U.S. and Canadian partners, 28 gliders, 36 glider deployments, and spatial coverage from coastal regions of Newfoundland to the Gulf of Mexico and offshore to Bermuda. The coordinated effort focused on several research themes including continental shelf circulation, fish migrations, and storm activity. The main goals of last year's effort were to produce a seamless flow of real-time glider data into the Global Telecommunications System (GTS) via DMAC and into the regional ocean models and demonstrate the potential of a U.S. national glider network. This is in line with the goal to increase glider data accessibility from Federal and Academic oceanographic modeling communities, the U.S. Integrated Ocean Observing System (IOOS), and other federal funding agencies (i.e., NSF). In order to demonstrate the value and necessity of the planned U.S. national glider network and build on last years successes, we hope to continue these efforts and require that all glider data produced by Gliderpalooza 2015 participants be uploaded by the individual operators to the DAC 2.0 and into GTS.**

Keywords—gliders, coastal oceanography, gliderpalooza, IOOS

I. Introduction

Many basic and applied oceanographic research questions facing humanity require a better understanding of the physical, chemical, and biological interactions in coastal waters. These coastal regions are difficult to sample given numerous turbulent boundary layers and high frequency atmospheric/land forcing. Additionally there are numerous pressures associated with a growing human population, the associated anthropogenic environmental impacts are significant and are only expected to increase as coastal populations continue to grow. Understanding of the ocean's physical, chemical, and biological responses, particularly in the context of anthropogenic forcing (climate change, resource extraction and utilization, waste production and nutrient pollution), remains a difficult problem that limits our ability to predict and manage coastal waters. The data most relevant to understanding/supporting critical coastal processes (ocean productivity, water quality, fisheries, weather, climate, shipping, recreation, and energy production) spans a range of temporal (days to years) and spatial (meters to 1000's of kilometers) scales. These scales cannot be affordably resolved using traditional (ships, moorings) oceanographic sampling approaches alone. There is a greater need to combine monitoring efforts with adaptive sampling in time and space as many of the critical processes of are ephemeral. Autonomous underwater gliders (Davis et al 2003) are mobile platforms that can be steered adaptively from shore and have proven to be a robust that is being taken up by the oceanographic community (Schofield et al. 2015).

Gliders, as currently configured, were first detailed in Doug Webb' s lab book on 2/8/86 (Webb 1986). The concept matured during many backyard discussions with Henry Stommel who, in 1989, publicized his science fiction vision of the future of a smart fleet of instruments being coordinated by

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graduate students (Stommel 1989). These systems, a cousin to the Argo profiling float, were developed in parallel at several academic institutions and commercial companies through support from the Office of Naval Research in the United States. This progress has been mirrored in Europe, Asia, Australia and Africa They have now matured to the point that they are available for commercial purchase from several companies and there is a large growing community. Due to successes in the field, federal agencies in United States, Europe, Australia, and South Africa have begun to adopt gliders for a range of more applied and operational needs. The community is highly distributed and continues to grow. This evolution has stimulated the community to begin discussions about the potential for a national glider networks for several countries. One example is in the United States, glider community leaders working with NOAA's Integrated Ocean Observing System (IOOS) have been developing a draft national glider plan (http://www.ioos.noaa.gov/glider/strategy/glider_network_whitepaper_final.pdf).

While discussion about a potential national plan continues to evolve, there remains a need to continue to harmonize and accelerate collaboration among the growing glider community. As an example of this community-based coordination, a series of grass-roots regional ad-hoc experiments were conducted in 2013 and 2014. These efforts termed "gliderpalooza" represented coordinated individual experiments, funded by diverse federal and state sponsors, working together to provide regional data to modelers. The data supported their own local objectives while contributing to regional scale questions that could not be addressed by any one institution alone.

II. PATH FORWARD

A. Moving the glider technology forward

Increasing the utility of glider technology will be based on increasing a range of activities that include increasing the number of available sensors, coordination of communities of gliders, improved energy efficiency and standardizing quality assurance/control.

An ocean research platform is only as useful as the sensors it can carry. Historically the type of sensor has been limited by the size and energy consumption of the sensor. Fortunately, there is a revolution occurring in instrument miniaturization. Additionally, the increased availability of high-density energy lithium batteries has increased the power availability over traditional alkaline-based batteries. This has opened the door for the potential to integrate a new suite of sensors into gliders in the coming decade. Currently a wide range of physical, chemical, optical and acoustic sensors are being integrated into gliders.

As the number of sensors available for these platforms. As the sensor suite expands, we expect community efforts to shift from mainly hardware/software development to tools that allow for more effective operation of individual or fleets of vehicles. Coordinated fleets will be more common and efficient as it is likely that lifetime costs of gliders will be dominated by the cost of operating them, rather than the cost of purchasing the vehicles.

As the number of gliders sensors increase in oceanography, establishing solid quality assurance and quality control procedures for sensors and data collected from observatory platforms, including gliders, is essential (Fredericks et al. 2009). This includes the production of Standard Operating Procedures (SOPs), quality assurance procedures such as a Quality Assurance Project Plan (QAPP) and QARTOD (Quality Assurance in Real Time Oceanographic Data), validating data, applying quality control in real-time, and developing a data analysis/data management system for future glider monitoring. A QAPP has been successfully implemented for the glider-integrated CTD and monitoring dissolved oxygen using a glider optode (nepis.epa.gov/Exe/ZyPURL.cgi?Dockey=P100IVXI.txt). However, there are still several gliders sensors that do not have established QA/QC protocols. Many teams are actively working to fill the gaps and establish standard operating procedures (SOPs) for quality assurance as well as quality control of real-time glider data. These SOPs should be publicly available. Formal groups such as the MTS or IEEE can and should play a critical role in the facilitating discussion in developing community agreement on the appropriate procedures and QA/QC protocols.

Incorporation of any sensor into a glider results in an immediate new "sink" of power, which limits the lifetime of a mission. Therefore increasing energy efficiency is absolutely critical. Tools that allow for increased efficiency and assist in mission planning are becoming critical as the newer instrument suites tend to have high power requirements. With improvements such as the recent integration of the coulomb meter into the Slocum glider, measuring the discharge of the battery has become more accurate and critical to long duration glider operations. Knowing the rate at which energy is used and how much remains is vital to mission planning. However, the glider's coulomb meter only measures whole vehicle current. To perform more precise mission planning, the energy consumption of individual components (especially power intensive sensors) is necessary. To that end, we have developed a measurement infrastructure, which captures the currents drawn from distinct components of the Slocum Glider. The infrastructure has been deployed in test missions off the coast of New Jersey, and the data collected have been integrated into a Slocum Glider simulator. This measurement board and simulation framework can be used to assist in the planning and decision making of missions and shows possible tradeoffs, for instance, between mission duration, speed, and energy consumption. The simulation environment incorporates energy, speed, seafloor and ocean current models, and is used to predict the flight path, longevity and energy usage of a mission. The simulation environment has been validated against Teledyne Webb's Shoebox simulator and compared to a deployment on the continental shelf off of the coast of New Jersey. Results between the three compared well (Woithe et al. 2010). Mission planning tools such as this will become increasingly important for glider operations in the coming years as more sensors are integrated into the glider.

In situations where the desired sensor activation profile of "everything, everywhere, all the time" is not feasible for the entire duration of a mission, mission planning tools will be particularly crucial. Mission planning tools can help oceanographers to assess the potential tradeoffs between different sensing activities in terms of overall energy consumption and peak power requirements. Sensor activity planning and path planning need to be done together while leaving enough energy reserves to ensure a safe recovery of the glider at the end of a mission. In some cases, the effectiveness of sensing activities can be improved by using lower power sensors to trigger high power sensors only in situations where acquiring expensive sensing data is important. Such trigger chains have been recently proposed with promising results for triggering backscatter sensors of a Slocum glider while flying through a thermocline (Woithe et al. 2015). Simulation results and results from two glider deployments off the coast of New Jersey show energy savings between 34% and 82% without significant loss of scientific relevant data. Mission planning tools have to consider all aspects of sensor activation including the desired spatiotemporal resolution, tradeoffs between sensing activities and their energy/power demands, and the applicability and effectiveness of sensor trigger chains.

B. Moving the community forward

Forming an integrated community will require glider operators share, leverage off the respective experince of individual operators, and optmize/ standardize approaches. It should follow the example of the successful efforts of the ARGO community. To this end, coordinating activities through the MARACOOS community, a regional association of the US IOOS network, there was a concept to conduct a coordinated, but dispartely funded, regional glider experiment. This was to accomplished through a community coordinated event of individual principal investigator efforts which was called a gliderpalooza. The goals were to enable the individual glider missions to meet their specific mission goals but also provide a larger regional glider dataset that could serve a wider range of science and operational needs.

The first gliderpalooza was conducted in 2013. The initial group consisted four of the MARACOOS glider groups (Rutgers, University of Delaware, University of Massachusetts, and University of Maryland). Informal communication and subsequent word of mouth grew the community to eleven institutions (list in Table 1). Listed in Table are the partners, their science funding sources and distances each gliders traveled. In total, the effort resulted in over 7000 kilometers being surveyed through the ad-hoc community effort. The effort faciltated sensor sharing with the Ocean Tracking Network providing Vemco fish recievers to all participants. The effort also helped mature data flow. The community effort was facilitated with data flow through the national Glider Data Assembly Center (DAC). The data flow through the DAC is illustrated in Figure 1. Efforts were coordinated through weekly telecons/web-ex, the near real-time data collected by the gliders, and regional satallite-HF radar-model datastreams coodinated through the MARACOOS asset map (http://assets.maracoos.org/).

Table 1. The participants of the 2013 Gliderpalooza.

Gliderpalooza Gliders- 2013

	Group	Glider	Funding	Dist (km)
1	Dalhousie	OTN200	OTN	707
2		OTN201	OTN	575
3		OTN201	OTN	240
4	UMaine	Penobscot	Maine	737
5	WHOI	Saul	ONR	362
6	UMass	Blue	IOOS	482
7	Rutgers	RU28	EPA	697
8		RU22	IOOS	331
9		RU23	IOOS	411
10		RU23	IOOS	443
11	UDelaware	Otis	Private	299
12	VIMS	Amelia	VIMS	455
13	NC State	Salacia	NASA	430
14	Skidaway	Modena	Skidaway/SECOORA	237
15	T. Webb	Darwin	Teledyne	351
16	Navy	Navy1	Navy	500
			TOTALS:	7257

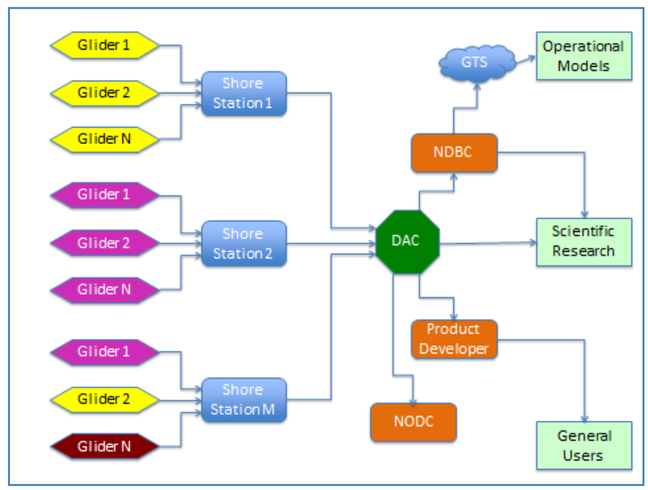

Figure 1. The data flow during the gliderpalooza efforts. During the first two years there was an effort of bringing larger proportions into the data systems illustrated above. The goal for the gliderpalooza in 2015 is to have all the members have their data flow through the NOAA DAC and onto the GTS.

We acknowledge the NOAA Integrated Ocean Observing System program and the Office of Naval Research.

The second gliderpalooza was conducted in 2014. This effort drew a much larger community response. The second gliderpalooza drew communities spanning from the Gulf Mexico to the Bermuda Biological Station (Figure 2). The second effort expanded to 18 partners spanning federal agencies and academic partners. The partners and the number of gliders deployed are presented in Table 2. Glider missions were coordiated through NOAA glider portal which provided a larger framework larger the regional MARACOOS domain. The effort was conducted through the late summer into the Autumn season. As before the effort represented a range of individually funded efforts.

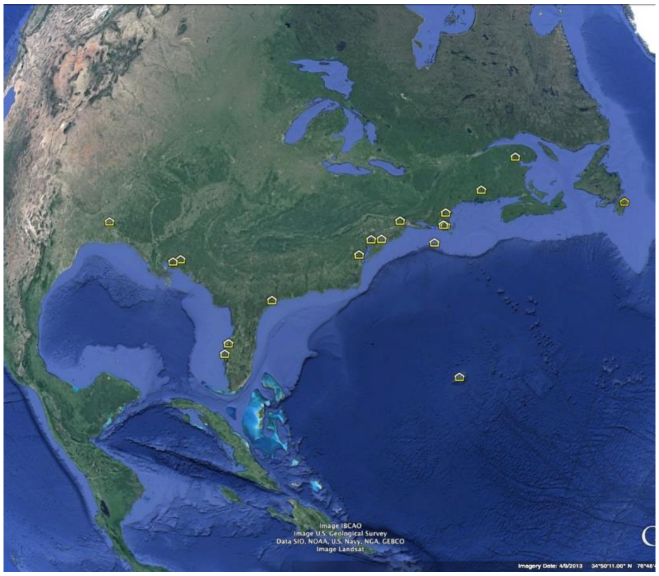

Figure 2. The yellow circles indicate the partners who partook in the 2014 gliderpalooza effort.

Table 2. The partners that were part of the 2014 gliderpalooza effort.

	Group	Gliders
1	Memorial University	3
2	Dalhousie (OTN)	2
3	Univ. of Maine	2
4	Woods Hole Inst.	5
5	Univ. of Mass. Dartmouth	1
6	Teledyne Webb	3
7	NSF OOI	3
8	Rutgers Univ.	4
9	Univ. of Delaware	1
10	Univ. of Maryland	1
11	VIMS	1
12	BIOS	1
13	Skidiaway Inst	1
14	Mote Marine Lab	1
15	Univ of S. Florida	1
16	US. Navy	2
17	Univ. of Southern Miss.	1
18	Texas A&M	3
	TOTAL:	**36**

The efforts have continued into 2015. There is a gliderpalooza planned for Fall in the Mid-Atlantic. It was however preceded by another complimentary community effort conducted in the Gulf of Mexico.

The Gulf of Mexico community coordinated a community event in the summer of 2015, which they called an AUV Jubilee. This effort was expanded beyond the gliderpalooza framework by expanding to a larger array of autonomous vehicles. The AUV Jubilee was an inaugural event to coordinate glider and other *in situ* ocean data operations in the Gulf of Mexico for the month of July 2015. The primary goal was to establish an open dialogue and collaboration with scientists across the Gulf, in order to acquire simultaneous ocean observations and leverage off of fellow participants to create a multifaceted and integrated data set. The AUV Jubilee was led by the University of Southern Mississippi's Ocean Weather Laboratory (http://www.usm.edu/marine/research-owx), which hosted a series of webinars to display real-time satellite ocean color and several ocean circulation models (HYCOM/NCOM), as well as maps of product uncertainty to allow the participating scientists to adaptively sample features of interest (e.g. eddies, river filaments, fronts, etc.). This data fusion tool enabled the display of up-to-date locations of various glider and ship/aerial operations while they were deployed, and facilitated near real-time data exchanges in order to further assist in decisions-making for adaptive sampling of ocean features. In addition to real-time operations, all participants were encouraged to submit data to the National Glider Data Assembly Center (NGDAC), so that the data

Table 3. The partners in the 2015 AUV Jubilee.

Institution	Platform
University of Southern Mississippi/CONCORDE	Ocean Weather Laboratory
Rutgers University/CONCORDE	Slocum
University of South Florida/MOTE Marine Lab	Slocum
Texas A&M	2 Slocums
Oregon State University/LADC-GEMM	Seaglider
Skidaway Institute of Oceanography/ University of Georgia/ECOGIG	Slocum
Gulf of Mexico Coastal Ocean Observing System (GCOOS)	GANDALF, data formatting, outreach
National Oceanic and Atmospheric Administration (NOAA)	Aerial LIDAR
Roffer's Ocean Fishing Forecasting Service, Inc.	Oceanographic Fishing Analysis
Florida Fish and Wildlife Research Institute	Vemco Mobile Tranceivers

could be available for assimilation into operational physical circulation models. The list of glider participants is shown in Table 3. The scope of the AUV Jubilee also included an educational outreach component, in which a competitively selected group of highly qualified teachers were brought in for an intensive one week program that included curriculum development, hands on oceanographic experience, and participation in real-time glider operations.

C. Conclusions

The glider community is rapidly growing as the technology has been demonstrated to be a transformative technology. As the platforms have matured, efforts are now focused on expanding the number of sensors, procedures to swarm fleets of gliders, improved/standardized data quality assurance/quality protocols, and extending duration of glider missions through improved energy efficiency. Just as important is the increasing number of open access community events that provide a means to collect valuable data and facilitate community exchange that will mature the community as a whole.

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