Gliderpalooza 2013 to Modelpalooza 2014: Joint U.S. & Canadian Ocean Glider Operations Supporting Multidisciplinary Scientific Research and Education

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Abstract— Gliderpalooza represented a grass-roots coordinated field demonstration of ocean observing technologies spanning the eastern seaboard of North America. The overarching goal was to coordinate disparate ocean research efforts, funded by disparate programs from a variety of agencies to demonstrate continental scale coordination of various ocean observing technologies to sample ecologically relevant scales.

The coordinated data from satellites, HF-Radar surface currents [1], moorings, drifters and models was focused on and around the distributed deployment of Slocum gliders. The seven science and technical goals were to:

1) provide a unique data set the modelers can use for years to come (real-time & hindcast),
2) provide a standardized dataset over ecological scales and information on fish/mammal migrations,
3) provide a 3-D snapshot of the MAB cold pool,
4) provide an extensive distributed instrumented network through the peak period of fall storms, demonstrating a community "surge" capacity,
5) provide one, of many demonstrations, of the potential U.S. national glider network,
6) proof of data flow throughput to the Global Telecommunications System (GTS) via DMAC and,
7) engage undergraduates in ocean observing efforts.

During the summer and fall of 2014, the Gliderpalooza team will once again work together, but with several additions to the group, the geographical scope will cover Texas to Newfoundland. There will be more than 30 glider deployments that will be assimilated by seven numerical ocean models. Acquisition of this massive data set of water column profiles will permit evaluation of the accuracy of the models, especially in the coastal zone. Additionally, new online educational tools developed through the NSF's Ocean Observatory Initiative (OOI) will be used to by students in the undergraduate classroom to analyze, compare and contrast the glider data in real-time during the fall 2014 semester.

Keywords — ocean glider, ocean modeling, data assimilation, physical oceanography, optics, mixing storm, cold pool, fish/mammal migrations, U.S. IOOS, MARACOOS.

I. Introduction

The research performed during Gliderpalooza grew out of the U.S. Integrated Ocean Observing System's (U.S. IOOS) Mid Atlantic Regional Association Coastal Ocean Observation System (MARACOOS) and Ocean Tracking Network's science priorities. Ten universities, one corporation and the US Navy worked together to perform 17 glider deployments along the eastern coast of the U.S. and Canada (Table 1 and Figure 1). Many of the deployment locations were determined by an ocean continuously well sampled by satellites, surface current data provided by the MARACOOS HF-Radar Regional Network [2] and drifters. Much of this data was assimilated into dynamical ocean models which were then used to direct the location of a handful of the deployments in the Mid-Atlantic bight. Upon completion of the project, full resolution data sets from almost all deployed gliders were shared amongst all researchers.

TABLE I. GLIDERPALOOZA GLIDER DEPLOYMENTS

#	Group	Glider	Deployed
1	**Dalhousie**	OTN200 (2)	10-Sep, 2-Dec
2		OTN201	16-Sep
3	**U. Maine**	Penobscot (2)	10-Sep, 15-Oct
4	**WHOI**	Saul	10-Sep
5	**U. Mass**	Blue	6-Sep
6	**Rutgers**	RU28	12-Sep
7	**U. Maryland**	RU22	22-Sep
8	**Rutgers**	RU23 (2)	10-Sep, 10-Oct
9	**U. Delaware**	Otis	12-Sep
10	**VIMS**	Stewart	10-Oct
11	**NC State**	Salacia	17-Sep
12	**Skidaway**	Modena	10-Sep
13	**T. Webb**	Darwin	11-Sep
14	**U.S. Navy**	Navy1	10-Oct

In late February of 2014, the Gliderpalooza team met in Honolulu during the Ocean Sciences meeting to plan research papers focusing on the seven program goals. This paper will summarize the seven science and logistical goals and elaborate on early results from initial data analysis performed during 2014. It will then discuss plans for Gliderpalooza 2 (aka Modelpalooza) which will occur during July-November 2015 but will now span from Texas north to Newfoundland and east to Bermuda.

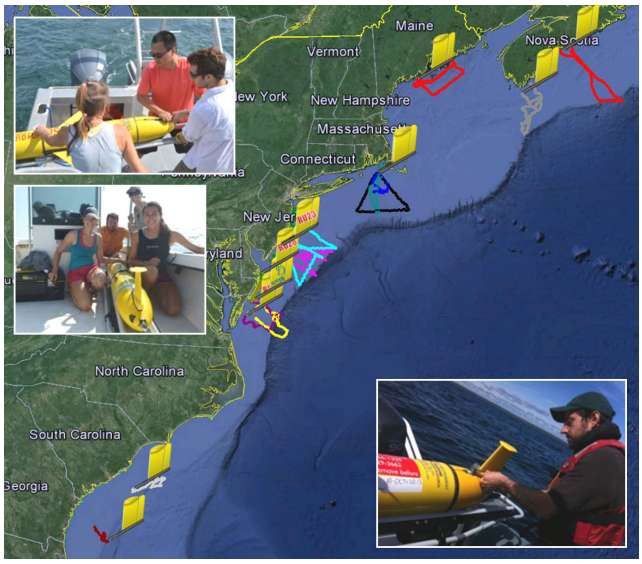


Fig. 1. Gliderpalooza deployments in summer and fall 2013.

II. Gliderpalooza Goals & Early Results

A. Goal 1: Provide a Unique Dataset for Ocean Modelers

A shelf wide subsurface perspective for the North American east coast was collected through a coordinated range of regional combined with coastal surveys. All gilders provided an extensive survey for the hydrographic and optical data as well as acoustically tracked animal locations. The database spans from the upstream condition of Canadian waters through the South Atlantic Bight. The database is enabling studies to improve data assimilative forecast models.

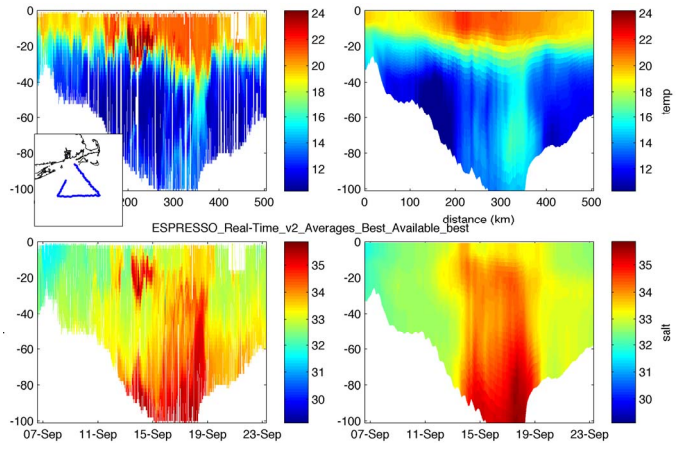


Fig. 2. Observed (left) and ROMS ESPRESSO model (right) temperature (top) and salinity (bottom) following glider BLUE. Inset shows the glider path south of Providence, RI (blue).

Moving forward, the goal is to support the improvement of the ensemble of ocean models through assimilation and validation. Figure 2 highlights a time series of temperature and salinity from a glider and compares it to the identical locations virtually sampled within the ROMS ESPRESSO model [3], [4].

B. Goal 2: Tracking Fish/Mammal Migrations

The glider survey was focused on collecting a broad environmental dataset to provide a map of the hydrography in which to interpret major migration patterns. The Ocean Tracking Network (OTN) is augmenting current capabilities to provide the foundation for a listening network. The collection of gliders provided a subsurface spatial snap shot of a Large Marine Ecosystem (LME) during the fall migration that was mined by scientists in both real-time and in hindcast mode as nine of the gliders were fitted with Vemco trackers. This effort is motivated as the region is home to some of the most migratory fish communities in the eastern United States and Canada. These data from multiple gliders are currently being combined by OTN. Species locations will be analyzed against the subsurface glider data as well as available satellite and CODAR assets and models of subsurface physical/biological parameters to provide a perspective of the northeast United States/Canada ecological domains.

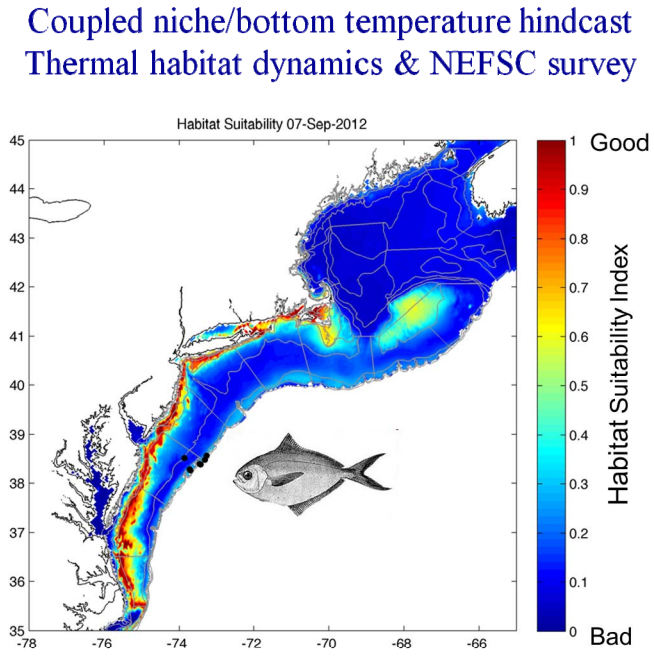


Fig. 3. A habitat sustainability model showing likelyhood of butterfish bycatch with likely areas shown in red. Block dots indicate in situ fishign surveys which tested the accuracy of this early model from 2012. Gliderpalooza data will help to improve these models in the future. Early funding for this work was from the NOAA NEFSC and Fisheries Habitat Program.

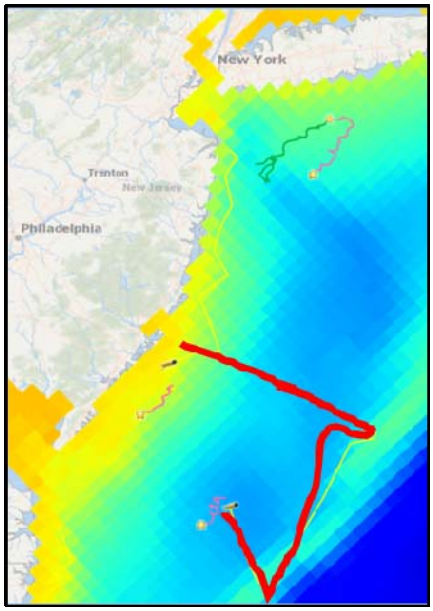
Sponsors of this work include NOAA's U.S. IOOS, Ocean Tracking Network Canada, N.J. Department of Environmental Protection, U.S. EPA, U. of Delaware, NASA, ONR, U. of Maine, College of William and Mary, U. of Georgia, Teledyne Webb, US NMFS, NSF Ocean Observatories Initiative and the U.S. Navy. Additional sponsors in 2014 will include Memorial University and Texas A&M U.

The data are also being used to improve fisheries bycatch models. Rutgers and NOAA's Northeast Fisheries Science Center (NEFSC) conducted in situ surveys in 2012 where forecast models were tested that predicted the butterfish bycatch amounts in the mid-Atlantic bight (Figure 2). Subsurface water column profile data, especially geographically distributed bottom temperatures, are key to these forecasting models, and the glider data sets will both aid in improving the models through assimilation and verifying the model's accuracy.

C. Goal 3: Mapping the Mid-Atlantic Cold Pool Water

During summer, a distinctive, bottom-trapped, cold water mass called the Cold Pool Water (CPW) resides as a swath over the mid to outer continental shelf throughout much of the Middle Atlantic Bight (MAB) [3]. This evolving CPW is important because it strongly influences the ecosystem, including several important fisheries. Thus there is a priority to better understand the relevant ocean processes and develop a CPW forecast capability.

Seven gliders crossed the area of Cold Pool during Gliderpalooza. The path of RU23 is show in red in figure 4 overlaid on a ROMS ESPRESSO modeled bottom temperature hindcast off of the New Jersey coast. Cold Pool water sits on the shelf between approximately 35m to 100m. Temperature and salinity glider transects are compared to a 2d version of this this model hindcast in figure 5.



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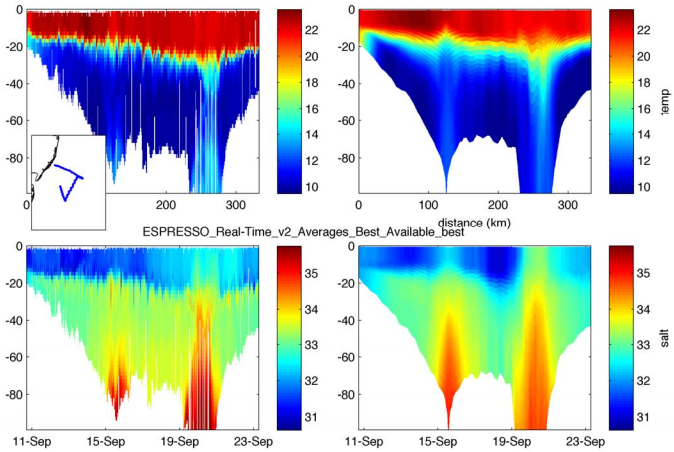

Fig. 5. RU23 glider temperature and salinity on the left are compared to modeled temperature and salinity on the right from ROMS ESPRESSO.

D. Goal 4: Analysis of Fall Mixing Storms

September is the peak month for tropical storm and hurricane landfall along the Eastern coast of North America. The regional array provided a comprehensive sampling of the continental shelves, which are the most undersampled with regards to subsurface temperatures. This subsurface temperature data is increasingly being viewed as valuable in potentially improving the ability to better predict hurricane intensity [6]. The 2013 Gliderpalooza dataset will serve as a baseline as it was a quiet tropical storm season. In 2014-2015, the Cooperative Institute for the North Atlantic Region (CINAR) is providing funding to support deployments of four storm gliders, rapid profile drifters and rapid deployable buoys into both tropical storms and winter Nor'easters. Storm gliders will be equipped with an acoustic Doppler current profiler, a full range of optical instruments, and accelerometers in addition to the standard CTD package. A preliminary in water test of these new storm gliders was performed during Hurricane Arthur in July, 2014 (figure 6).

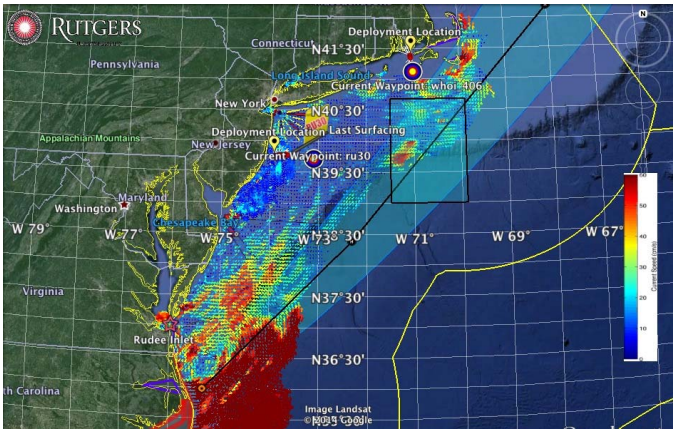

Fig. 6. Hurricane Arthur forecasted storm track from July 4, 2014. Locations of CINAR funded gliders RU30 and WHOI_406 are shown with target icons. HF-RADAR surface currents are shown, highlighting the counterclockwise circulation around the eye of Arthur just north of Cape Hatteras and the forecast track.

E. Goal 5: Demonstration of a National Glider Network

During the summer of 2012 a workshop funded by U.S. IOOS was held at Scripps Institute of Oceanography to discuss plans for a national glider network. As a result, multiple partners from federal agencies, IOOS Regional Associations (RAs) of coastal ocean observing systems, and universities were assembled to develop a National Glider Network Plan for a viable, sustainable, and reliable network that delivers timely monitoring and distribution of coastal subsurface glider data to federal, state, and local governments, as well as the general public. The plan is structured to develop an initial network that includes maintaining existing long term glider sampling lines, acquiring additional glider lines to fill high priority gaps, and improving data management, product development, and data/product delivery. The national plan was released in January 2014 and available at http://www.ioos.noaa.gov/glider/strategy/welcome.html.

Gliderpalooza enabled a first example of a multi-regional coherent effort to deploy, monitor and access glider data in real time through a central site at Rutgers University. The ultimate national goal is to attain funding for long term sustainability of deployments on all U.S. coasts (Figure 7).

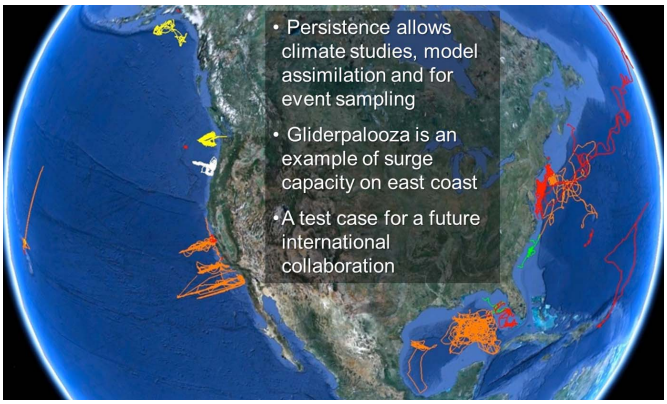

Fig. 7. U.S. glider deployments from 2000 through early 2013.

F. Goal 6: Data Throughput to the GTS

In 2013 IOOS secured funding to begin construction of a Data Management and Communications System (DMAC) specifically for glider data distribution. A successful goal of Gliderpalooza was to have real-time throughput of raw data from the gliders to Dockservers to the DMAC where it was converted to Climate and Forecast (CF) compliant NetCDF files and then sent to the National Data Buoy Center and finally to the Global Telecommunications System. This mission to make glider data available to modelers and forecasters worldwide will continue to expand outside the east coast region to the U.S. and eventually global throughput of glider data to NDBC and GTS.

Fig. 8. Schematic of glider data throughput from acquisition to the GTS.

G. Goal 7: Undergraduate Education

In addition to having undergraduate students assist with glider deployments and recoveries, the Gliderpalooza data were made available to undergraduate classrooms in real-time during the fall semester of 2013. During fall 2014, both real-time and archived glider data are going to be used by numerous Community and 4-Year college professors in the undergraduate classroom through cooperation with the NSF's Ocean Observatory Initiative's Education and Public Engagement team's (OOI EPE) newly developed online educational tools (Figure 9). This software can be used by undergraduate educators to build and share online lessons using ocean data from both the OOI and outside resources, including global glider deployments.

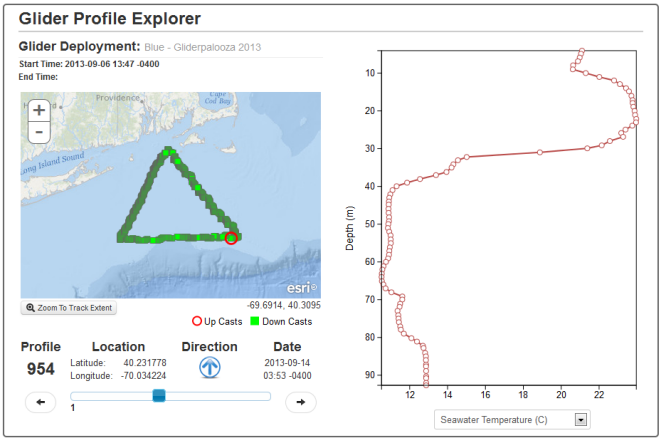

Fig. 9. Newly developed glider profile explorer tool that allows users to search and display glider profiles through the OOI EPE's website at: http://education.oceanobservatories.org/.

III. Next Steps: Gliderpalooza 2 – Modelpalooza!

The success of Gliderpalooza 2013 built on a collaborative community which was a great start, and one the team wishes to build on for the coming year. Gliderpalooza 2 will begin during the summer of 2014 but this time with a focus of using the real-time data for ocean model assimilation and validation in several models and, in turn, using model output to help drive sampling locations throughout the east coast, not just the mid-Atlantic bight. At least seven ocean models are going to be used for this effort (table 2). A new glider tool that will support comparison of the glider profiles to any of these ocean models is shown in figure 10.

The list of groups involved with glider deployments and models is expected to expand to include Memorial University of Newfoundland, Dalhousie University (Ocean Tracking Network), University of Maine, Woods Hole Oceanographic Institute, University of Massachusetts Dartmouth, Stevens Institute of Technology, Rutgers University, University of Delaware, University of Maryland, College of William and Mary, North Carolina State University, University of Georgia, Texas A&M University, the US Navy and the Bermuda Institute of Ocean Sciences.

TABLE II. MODELS TO BE USED FOR ASSIMILATION AND VALIDATION TESTING DURING GLIDERPALOOZA 2: MODELPALOOZA.

	Models	Affiliation
1	Regional Ocean Modeling System 1 (ROMS)	North Carolina State University
2	ROMS Experimental System for Predicting Shelf and Slope Optics (ROMS HOPS)	Rutgers University
3	Harvard Ocean Prediction System (HOPS)	University of Massachusetts Dartmouth
4	New York Harbor Ocean Prediction System (NYHOPS)	Stevens Institute of Technology
5	Real Time Ocean Forecast System (RTOFS)	NOAA National Centers for Environmental Prediction
6	MyOcean	European Union
7	Mercator Ocean	Europe (France)

In addition to the science and technical goals outlined in this paper, additional goals for Gliderpalooza 2 include; 1) Improved data flow of all gliders to the World Meteorological Organization's GTS, 2) Visualization of all data in the NOAA U.S. IOOS National Underwater Glider Network Map portal, 3) Data assimilation by four ocean models and validation testing of at least seven ocean models (hence the name Modelpalooza), 4) Using the ocean models to assist in planning glider sampling activities, 5) Building an active community blog, 5) Improving coordination between distributed teams, 6) Strengthening science working groups thereby accelerating the publishing of potential products/manuscripts/articles for the ocean science community and general public, and 7) Improving the existing web portal tools that link the community.

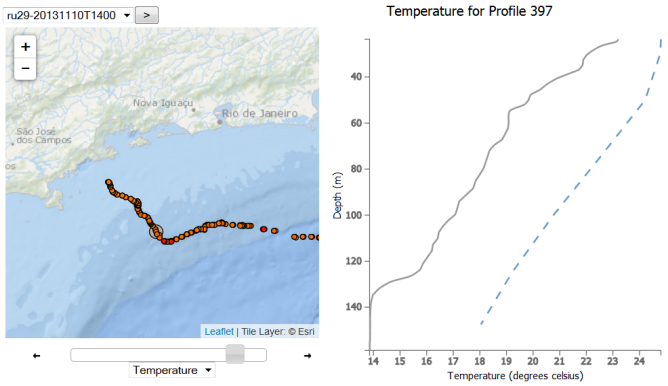

Fig. 10. Newly developed NSF OOI visualization tool that will enable researchers to compare glider profiles to model output. This example highlights a single profile from glider RU29 located just south of Rio de Janerio on the outer edge of the continental shelf (145 meters). The temperature data is compared to RTOFS and highlights that RTOFS is significantly warmer (~3C) throughout much of the water column. Development of this tool leveraged both NOAA US IOOS funds and NSF OOI funds.

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"Have fun, work hard, change the world" – Doug Webb

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