The Ocean is Our Classroom: A 4-Year Research Track for Undergraduate Exploration, Research and Discovery in Oceanography

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***Abstract*—Mitigating and adapting to climate change while the global human population continues its projected growth will be the dominant choice challenge confronting the present generation of undergraduates over their professional lifetimes. Today's students should be prepared to develop solutions that will involve the sea, but life-changing at-sea research experiences for undergraduates are limited. The rapid expansion of ocean observatories provides a solution. We have demonstrated in our own observatory how undergraduate student research can be enabled as a year-round activity during a student's full undergraduate career starting on day 1. What began as the Challenger Glider Mission has spread to other observatory technology and science activities both locally and in remote polar regions.**

Keywords — Ocean Observing; Undergraduate Education; Autonomous Underwater Gliders; Challenger Glider Mission.

I. INTRODUCTION

Present and future generations will be challenged by the impacts of climate change, including melting of land and sea ice, rising sea levels, ocean acidification and deoxygenation, and increasing extreme weather. This will be combined with the challenges of energy, food and water security as global populations continue to grow while natural and living marine resources are increasingly depleted. An improved multi-disciplinary understanding of the global ocean and its many large marine ecosystems, combined with the ability to observe their present and forecast their future state, is central to providing human society with mitigation and adaptation strategies. A growing constellation of ocean-viewing satellites, and the evolving suite of climate, global and regional scale ocean models, are key advances. Despite the international success of the Argo program, physical, biological and chemical ocean profiles are still among the most sought after datasets for the subsurface ocean, typically requiring expensive ship time countries can no longer afford. Long-duration autonomous underwater gliders, combined with compact sensors on marine mammals, reptiles and fish, can augment the Argo program with additional valuable data to enable discovery, promote scientific understanding, and ultimately improve our ability to forecast the ocean.

Today's undergraduate students will confront the dual challenges of a changing climate and a growing global population over their professional careers, not only the small percentage continuing to graduate school, but increasingly the broader distribution of students as future members of interdisciplinary teams seeking innovative solutions to societal issues within economic constraints. Even though the benefits of undergraduate research experiences are well known, hands-on oceanography remains limited by the availability of time at sea. The global proliferation of ocean observatories provide a means to overcome this issue, increasing undergraduate access to the sea via the Internet.

II. METHODS

At Rutgers, we have taken advantage of ocean observatories to provide undergraduates the opportunity to participate in a comprehensive oceanographic research program spanning their entire undergraduate career [1]. Based on the cognitive apprenticeship model, students progress through three levels of participation, frequently described in simple terms as "watch one, do one, teach one". As early as their first semester at Rutgers, interested students can participate in Oceanography House or one of several seminar courses taught by senior level faculty. The seminars introduce students to research opportunities the students may have never envisioned while they are still fulfilling general core course requirements. For those that have already chosen participation in ocean research as an undergraduate goal, Oceanography House provides hands on training in research skills that accelerates the student into the second level of participation, "do one". At the second level, students are

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taking many of their oceanographic core courses, including a hands-on Ocean Methods and Data Analysis course that includes the use of modern observational technologies on student-directed ½ day research cruises. Additionally, a more data analysis intensive course uses ocean observatory data on student led research. Typical classes of 50-70 students each semester are organized into research teams of 5-7 people led by a more senior student mentor. The semester long research of each group is presented at the end of each semester in a science symposium that features a high level invited speaker to inspire the students in their own future careers. In the final phase, students are taking their oceanography elective courses, and are acting as near-peer mentors to the younger students in the research course. The older students gain valuable mentorship experience including training in how to be a good mentor.

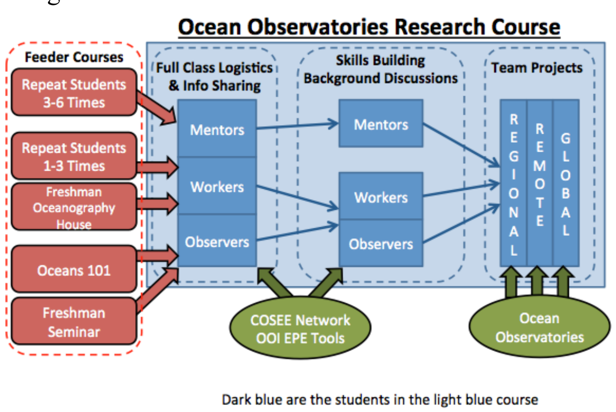

Figure 1: Ocean Observatories Research course that forms the core of the undergraduate research experience.

III. Results

The Challenger Glider Mission is the core field component for the above observatories research course. Student involvement in undergraduate research is enabled by multiple gliders on simultaneous basin-scale missions that over several years are revisiting the historic track of the H.M.S. Challenger, the first dedicated scientific circumnavigation and the beginning of modern oceanography. The scientific questions to be investigated focus on a quality assessment and interpretation of the ensemble of available global-scale ocean models. The mission has already begun with one global-class G2 Slocum Electric glider deployed in the North Atlantic (Silbo) and a second deployed in the South Atlantic (RU29). These two gliders have already completed over 1100 days at sea covering more 22,000 km. The goal is to match the 128,000 km distance covered by the H.M.S Challenger with glider tracks around all 5 ocean basins. The Slocum Electric Gliders Silbo and RU29 will be joined by the Slocum Thermal Glider Clark during the summer of 2015.

The immediate scientific goals are to assess the current capabilities of the existing international suite of global ocean forecast models, and assess the forecast impact on ocean conditions in the vicinity of the glider. The existing global ocean forecast models assimilate satellite sea surface height and temperature data as well as temperature/salinity profiles from the Argo network of over 3,000 drifters. Still, Observing System Simulation Experiments routinely indicate that additional profile data, especially profile data that crosses frontal features, are the most influential at reducing forecast uncertainty. Since the location of Argo drifters cannot be controlled after they are deployed, some regions are critically under sampled, and strong boundary currents are often unresolved. Moreover, even with the SST, altimeter and Argo data, the mesoscale eddy field, the dominant energetic structures for most of the global ocean, are not uniquely or completely resolved by the existing global observation network. Additional data provided by gliders can augment these structures where needed.

A current example is presented here. Glider RU29 recently began Leg 3 of a circumnavigation of the south Atlantic gyre (Fig. 2). Leg 1 ran from Cape Town, South Africa to Ascension Island in 2013. Leg 2 from Ascension to Ubatuba, Brazil in 2014. RU29 is now heading back to Cape Town in 2015 along one of two lines. The orange line is the direct great-circle route back to Cape Town. The red line includes the potential for a stop at the remote island of Tristan da Cunha. The white line is the actual track and current location of RU29, flying somewhere between the red and orange lines.

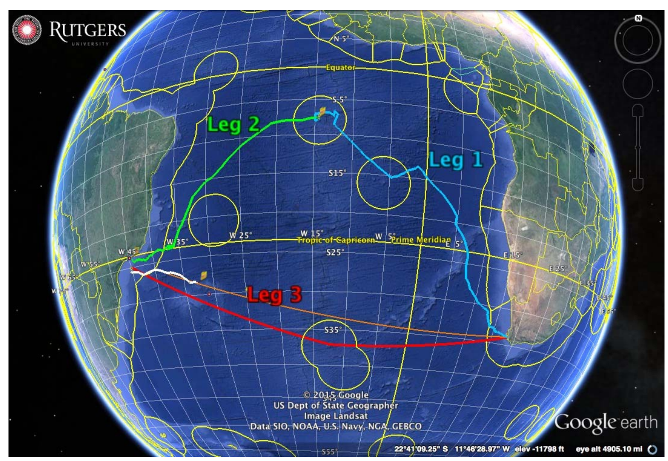

Figure 2: Glider RU29's circumnavigation of the South Atlantic Gyre, with Leg 1 (blue) begun in 2013, Leg 2 (green) in 2014, and potential Leg 3 lines, either directly across (orange) or with a stop in Tristan da Cunha (red). RU29's actual progress on Leg 3 in 2015 is shown in white.

Student-led comparisons between glider data and global ocean models along Legs 1 & 2 have already been reported at previous MTS meetings [2, 3]. Leg 3 is now in the navigation phase, where students must successfully pilot the glider across the basin and investigate interesting features along the way. Figure 4 zooms into the current location of the glider flying generally along the orange line directly towards Cape Town. The average current over the depth of the glider undulations as derived from the NOAA Real Time Ocean Forecast System (RTOFS) are plotted as the green vectors. If RU29 remains on this course along the orange line, RTOFS says it will soon encounter the southern side of a large clockwise rotating eddy (outlined in green) with its adverse currents.

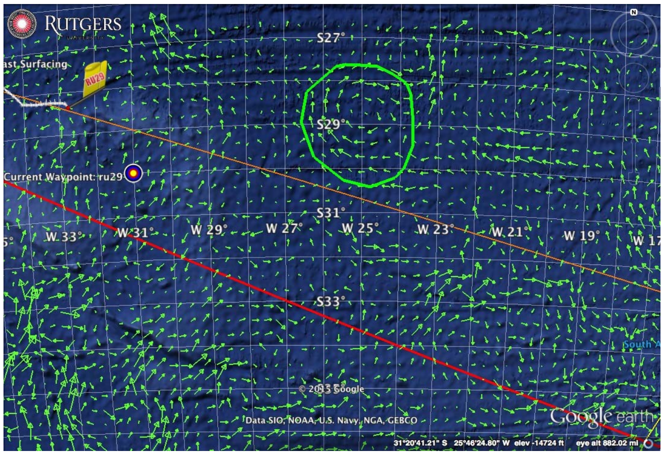

Figure 3: The U.S. RTOFS forecast depth average current field is shown in green. The large clockwise eddy along the orange track is circled with the green line.

However, if one examines the European Copernicus model for the same time period, the depth averaged currents (yellow) indicate a very different situation. Instead of a single clockwise eddy as found in RTOFS (green circle), there are two counterclockwise rotating eddies (yellow circles). The end result, a counter current near the orange direct path to Cape Town, but the reason is totally different. Even though both models are assimilating the same SST, Altimeter and Argo data, the end result on the energetic mesoscale is quite different.

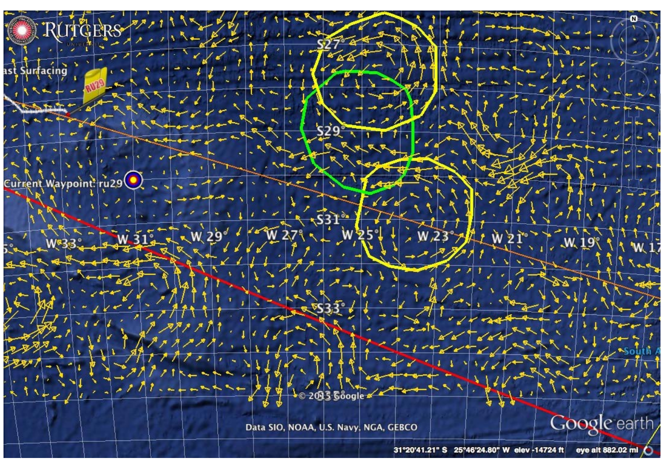

Figure 4: The European Copernicus forecast depth average current field is shown is yellow. The two counterclockwise eddies along the orange track are circled in yellow.

To investigate this, glider RU29 can be targeted to fly through the area of the greatest difference. While both structures produce a counter current to the west along the orange route, the structure between the two yellow eddies from Copernicus and across the middle of the green eddy from RTOFS will be very different. However, to get there, RU29 must first navigate through a field of seamounts (Figure 6), and then line up for a pass through the mesoscale eddies. Differences in the mesoscale eddy structure like this are common.

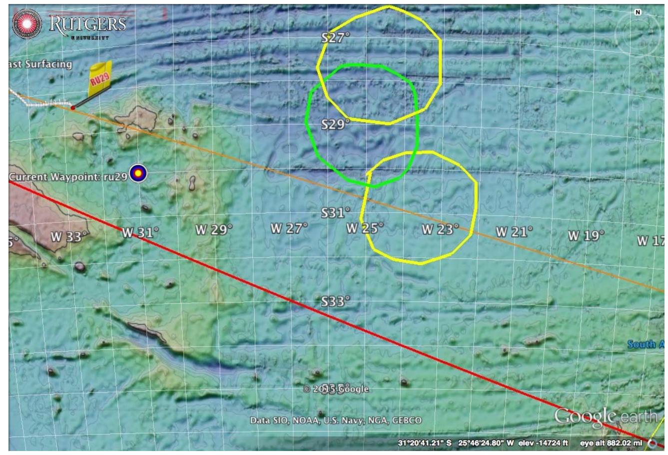

Figure 5: Bathymetry map showing the seamounts RU29 must initially navigate through before lining up for the survey of the differing mesoscale eddy field.

The growth in class size created a new demand for course research projects and intersession research internships. Research projects expanded to include the extensive observatory operated by the Mid Atlantic Regional Association Coastal Ocean Observing System (MARACOOS) as part of the U.S. Integrated Ocean Observing System (IOOS). Research participation ranged from technology improvements to the distributed glider network [4] and the extensive Mid-Atlantic High Frequency (HF) Radar network [5], to scientific applications of the data to homeland security [6.7], fisheries and offshore wind.

School-year research activities are augmented with more intensive hands-on undergraduate opportunities during class breaks. During the summer and winter intersessions, students can commit fulltime to hands-on research in ways not possible during the more class intensive semesters. The shorter winter break coincides with the southern hemisphere summer season. In the Southern Summer Research Institute, in collaboration with projects supported by the NSF Office of Polar Programs, undergraduates have the opportunity to participate in and contribute to research in Antarctica. Over the last 5 years, students have made significant contributions to research on polar research vessels and land based research stations. Students participating in the Northern Summer Research Institute are from Rutgers, the U.S. Naval Academy, and other universities around the country. They come to Rutgers each summer to work full time on team research projects that utilize ocean observatory data. Projects begun during the semester are often pursued in greater detail over the summer. Students are supported through a variety of mechanisms including university contributions, federal grants, and direct industry sponsorship. A major focal point of the Northern Summer Research Institute is the Challenger Glider Mission, where students work with researchers from around the world to validate global ocean models using basin-scale underwater glider missions. The Summer Research Institute uses the MTS/IEEE Oceans process to summarize and present results. Abstracts are submitted early in the summer, and results are documented in Proceedings papers submitted by the students at the end of the summer for presentation at the fall MTS/IEEE Oceans meeting. Over the last 3 years, 8 undergraduate student papers have been submitted to Oceans based on student research in the Summer Research Institute. Papers this year include optimizing glider flight parameters for long-duration missions, comparisons of basin-scale glider data with an ensemble of global ocean models, and the analysis of the first year of HF Radar data from the Western Antarctic Peninsula.

IV. DISCUSSION

We have found that augmenting the standard Marine Science course track with a concurrent research track increases student involvement, retention and diversity. The success of this approach can be assessed by tracking student involvement in the research course established in the fall of 2007. Pre-course levels of undergraduates working in the research lab were consistently at the level of 1 to 3 people per year for 10 years. The research course started with 7 students who began the mission to be the first group to fly an underwater glider across an ocean basin. After the Trans-Atlantic's mission success and publicity in 2009, the course peaked in 2012 with 70 students. Since then, student involvement has leveled off, consistently remaining near 50 students per semester as we continue to fly gliders across ocean basins as part of the Challenger Glider Mission.

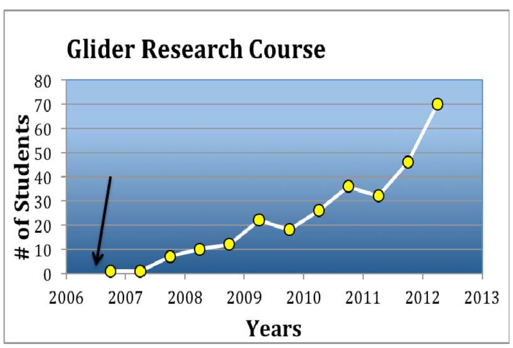

Figure 6: Student involvement in the Ocean Observatories Research course over time since the course was established in 2007.

As the number and diversity of ocean observatories grow worldwide, research courses like the one we teach at Rutgers can be put in place in more locations. One example will be the NSF Ocean Observatories Initiative (OOI). The OOI Education and Public Engagement (EPE) Implementing Organization has already built new software tools to enable undergraduate access to near real time data streams from the OOI. The tools are organized into a Concept Mapper that allows complex concepts to be deconstructed into more elemental components, Data Visualization tools launched from a web browser to reduce computer programming barriers to participation, and a Data Investigation Builder for teachers to produce custom guides for students.

V. ACKNOWLEDGEMENTS

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