Ocean Predictive Skill Assessments in the South Atlantic: Crowd-Sourcing of Student-Based Discovery

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Abstract— Autonomous Underwater Gliders have over a decade long history of successful regional deployments serving scientific, societal and security needs in application areas ranging from pole to pole and including the full range of water depths from shallow coastal seas to the deep ocean. Glider deployments covering the basin scale are much fewer, but are a growing capacity as demonstrated by the Woods Hole to Bermuda line that crosses the Gulf Stream, the Atlantic Crossing line that follows the Gulf Stream, and the basin circling flights now being conducted as part of the Challenger Glider Mission.

The next step in the evolution of the global Challenger mission is to enable an ensemble of modelers from different institutions and agencies to participate in a meaningful way. This process with be formalized in 2014 by leveraging the data management tools of the U.S. Integrated Ocean Observing System (IOOS) and the education tools of the U.S. National Science Foundation's (NSF) Ocean Observing Initiative (OOI). The Education Visualization (EV) tools developed by the OOI's Education and Public Engagement (EPE) Implementing Organization (IO) are currently being configured through the cyber OOI net to display real time OOI glider data with intuitive interactive browser-based tools, reducing the barriers for student participation in sea exploration and discovery. Through U.S. IOOS, forecast ocean data will be harvested from the ephemeral ocean snapshots produced by an ensemble of ocean models along the same glider tracks as Challenger. The parallel observed and forecast datasets, both evolving in real time, will be accessible through the same OOI EV tools, enabling student participation in a crowd-sourced ocean predictive skill experiment. The result will satisfy one of the important goals of the Challenger mission by enabling students to assess of the quality of the ensemble of available global scale ocean models.

Student research team projects that use the new model data comparison capabilities will be conducted during the summer of 2014. Students will compare an ensemble of the global ocean models along the high velocity transport pathways by gliders on basin-scale missions, such as one that traverses the northern side of the South Atlantic gyre along the Brazilian shelfbreak. The lasting impact of the Challenger mission will be a global fleet available to respond to events, an assessment of the ocean models along the fastest ocean transport pathways, and the establishment of a network of gliderports for global response.

Keywords — Ocean Forecasting; Autonomous Underwater Gliders; Challenger Glider Mission.

I. INTRODUCTION

Autonomous Underwater Gliders have been utilized by the scientific and defense communities for a multitude of different missions that cover all areas of the globe from the surface of the ocean to 1000 meters below. Recently, long scale endurance missions have started to become a focus. The Challenger Glider Mission is one such mission whose aim is to use gliders to explore five ocean basins covering 128,000 kilometers.

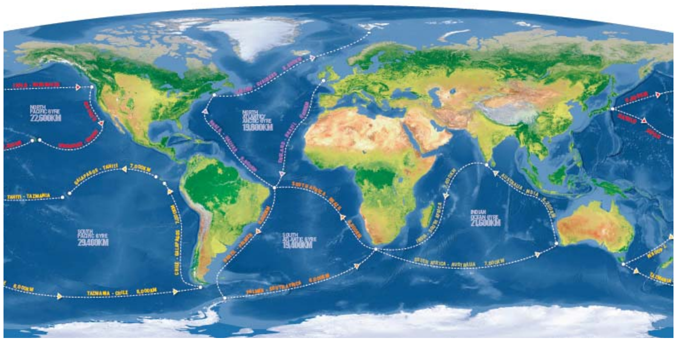

Figure 1: The projected paths of the Challenger Glider Mission.

Two of the gliders that are involved in this Challenger Glider Mission are Silbo and RU29. Silbo has not contributed significantly to the mission since the Dobson et al. [5] article where data from Silbo and RU29 were used to compare against the then current ocean models. As such, an extension on the analysis of the Silbo data is not needed. RU29, however, has stopped in the Ascension Islands and flown all the way to São Paulo, Brazil since the publication of the Dobson et al. [5] article.

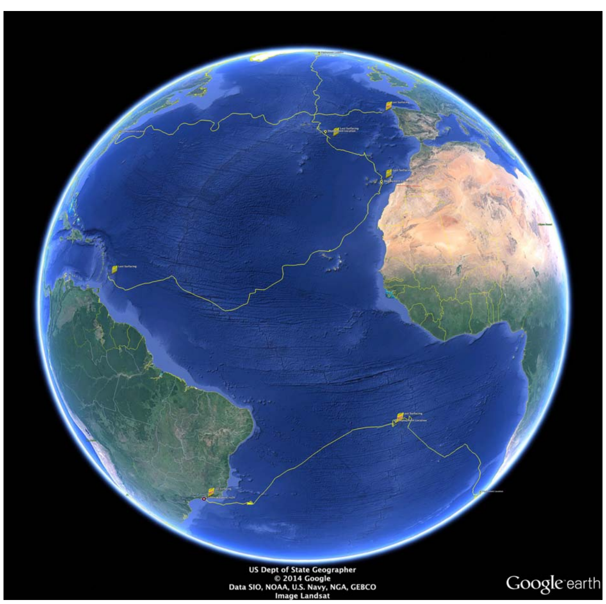

Figure 2: A map of the history of tracks covered by Rutgers Coastal Ocean Observation Lab's Challenger gliders. Basin scale missions, in collaboration with Teledyne Webb Research and Universidad de Las Palmas de Gran Canaria.

The data collected from the flight of RU29 from the Ascension Islands to São Paulo, Brazil can contribute significantly to our understanding of the accuracy of both the American RTOFS ocean model and the European MyOcean ocean model and expand upon the work done last year in the Dobson et al. [5] article. This flight completes the examination of the northern section of the South Atlantic gyre. While the ocean forecast models currently assimilate data from an Argo network of over 3000 drifters, assimilating glider data that crosses frontal features may be beneficial to increasing the forecast accuracy. Glider data can help to increase sampling resolution in areas not covered extensively by Argo drifters.

Figure 3: A photograph of RU29, an autonomous underwater glider that successfully crossed the Atlantic Ocean in 2014.Behind RU29, the Oceanographic Research Vessle Alpha Delphini, from the University of São Paulo

This study will report the results of student investigations comparing temperature, salinity, and depth-averaged currents between RU29 and the model forecasts. Preliminary student observations along RU29's flight indicate that the MyOcean model, while different from RU29 on a wider area, was closer to RU29 at points of discrepancy. The RTOFS model, however, had fewer areas of discrepancy, but the discrepancies that did exist were generally of a greater magnitude.

II. Methods

The two ocean forecasting models used in this paper are the MyOcean model and the RTOFS model. The MyOcean model is the result of collaboration between European countries such as the United Kingdom, France, Germany, and Denmark. The RTOFS model is created by the National Center for Environmental Prediction, a subgroup of the National Oceanic and Atmospheric Administration based in the United States.

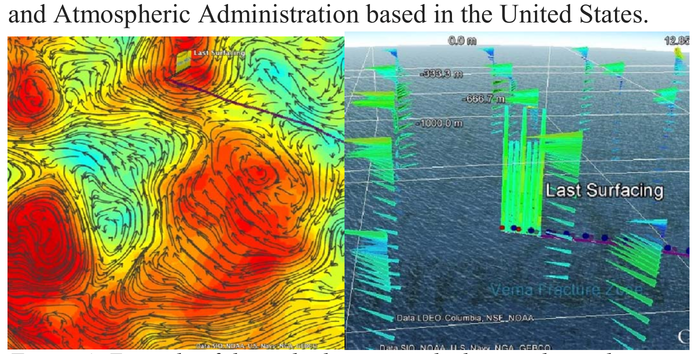

Figure 4: Example of the path planning tools that can be made using data from the ocean forecasting models RTOFS (left) and MyOcean (right) by Universidad de Las Palmas de Grab Canaria.

The sensor used by the G2 category of gliders is a SeaBird pumped Conductivity, Temperature and Depth (CTD) sensor. Temperature and Salinity data is recovered from the glider and thermal inertia from the conductivity sensor is corrected for using the process from Kerfoot et al. [3]. This data is compared to a section of the RTOFS model and the MyOcean model simulations along the path taken by the glider (Figure 5).

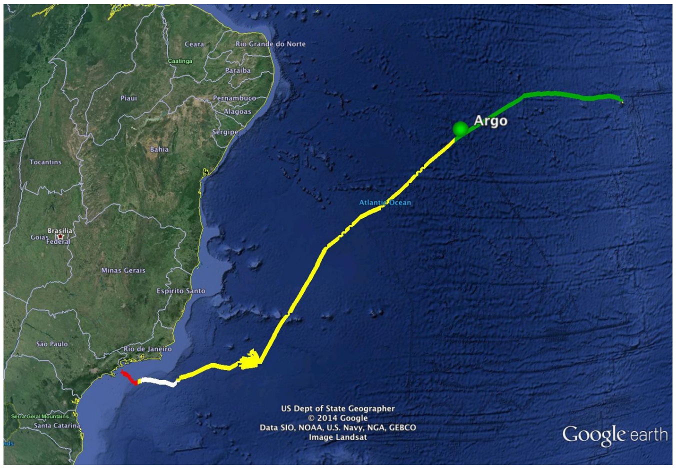

Figure 5: The portion of RU29's track that was used for comparison to the models, focusing on the green, white, and red sections. This track represents an east to west path along the northern side of the South Atlantic Gyre.

The comparisons made in this paper are a result of an analysis of temperature, salinity, and depth-averaged currents made by the models and RU29. MyOcean and RTOFS data was collected from respective Internet sources, while the glider data was collected by RU29 (Figure 3). A series of MATLAB scripts facilitated data processing and figure creation. By comparing the in-situ glider data to data obtained by the Argo Floats (Figures 7 & 9), we were able to confirm the quality of the glider temperature and salinity observations of the conditions of the water column. The most striking observation is of the temperature profiles, where the deep data from RU29, Argo, and RTOFS are similar, but MyOcean deep temperatures are about 1˚C higher.

The temperature and salinity data collected by RU29 was then compared to RTOFS and MyOcean (Figures 6 & 8). The figures were created by observing the difference between glider data and model predicted data. There was a general 1˚C difference between the MyOcean and RU29 temperature data (Figure 6b), whereas the discrepancies between the RTOFS and RU29 data were less widespread but more significant (Figure 6a). The most variation between the two models and RU29 exist within the first 300 meters of the water column, as shown in figures 6 and 8. Hence, the remainder of this paper will focus on analyses of depths above 300 meters.

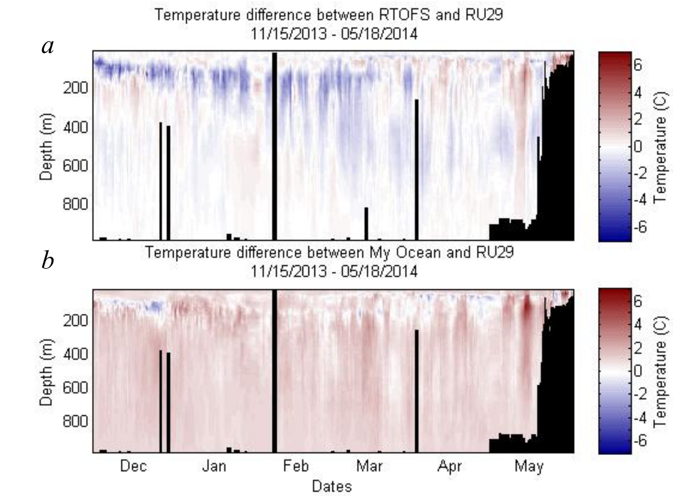

Figure 6: The difference in temperature between the RTOFS model with RU29 (a) and the MyOcean model with RU29 (b).

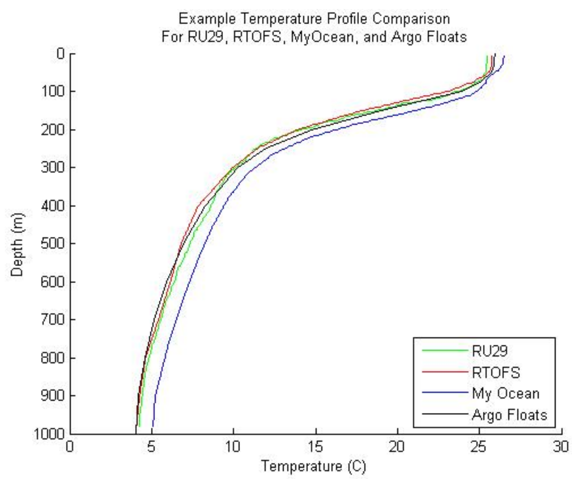

Figure 7: Temperature depth profile comparison between RU29, RTOFS, MyOcean, and Argo Float data at a sample point.

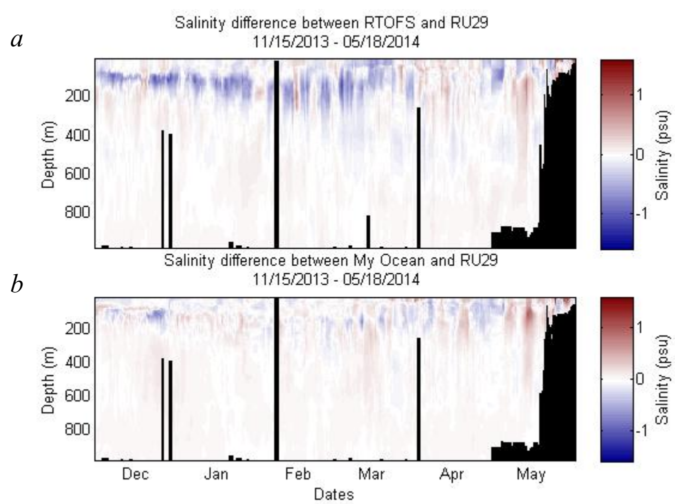

Figure 8: The difference in salinity between the RTOFS model with RU29 (a) and the MyOcean model with RU29 (b).

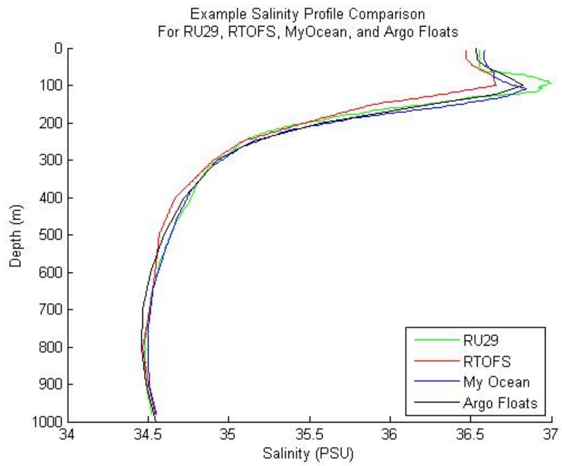

Figure 9: Salinity depth profile comparison between RU29, RTOFS, MyOcean, and Argo Float data at a sample point.

III. Results

RU29's mission from Ascension Island to São Paulo, Brazil lasted from November 15, 2013 to May 18, 2014. It traveled 4,420 km crossing the Atlantic on the northern part of the South Atlantic gyre. An analysis of temperature, salinity and currents was conducted on three areas of interest: a 1,262 km leg off the coast of Ascension Island, a 265km leg off the coast of Brazil, and a 179km leg on the Brazilian continental shelf (Figure 5).

A. Turtle Tracks

The first area of interest occurred from November 15, 2013 to December 30, 2013. This section will be referred to as "Turtle Tracks" and is denoted by the green section of the track in Figure 5. It is worth noting because the migration path of Green Sea Turtles between Ascension Island and Brazil runs along this path.

An analysis of temperature and salinity was conducted. There was not much disparity in temperature between the two models and RU29 (Figure 10). However a difference between RU29 and MyOcean exists at the surface and between 250 and 300 meters (Figures 10b &10c). The salinities of RTOFS and RU29 have larger differences than the salinities of RU29 and MyOcean. Most noticeable is the consistent subsurface salinity peak near 100 m visible in RU29 and MyOcean, but missing from RTOFS. Neither model accurately depicts the depth averaged current vectors measured by RU29 along this area of the track.

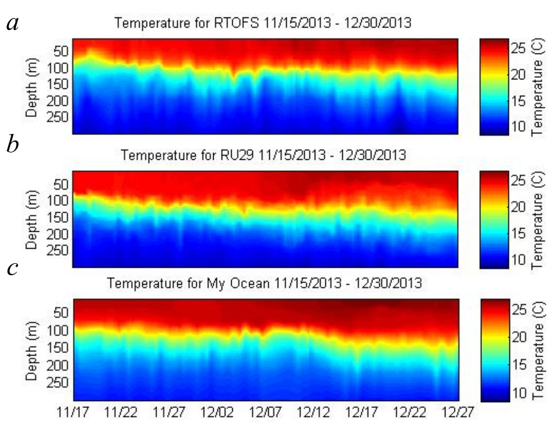

Figure 10: Temperature comparison between RTOFS (a), RU29 (b), and MyOcean (c) for the Turtle Tracks.

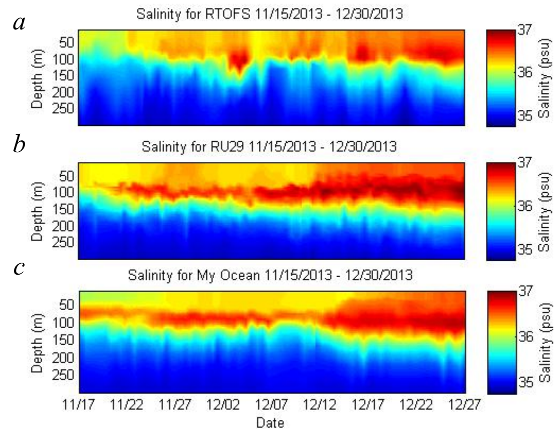

Figure 11: Temperature comparison between RTOFS (a), RU29 (b), and MyOcean (c) for the Turtle Tracks.

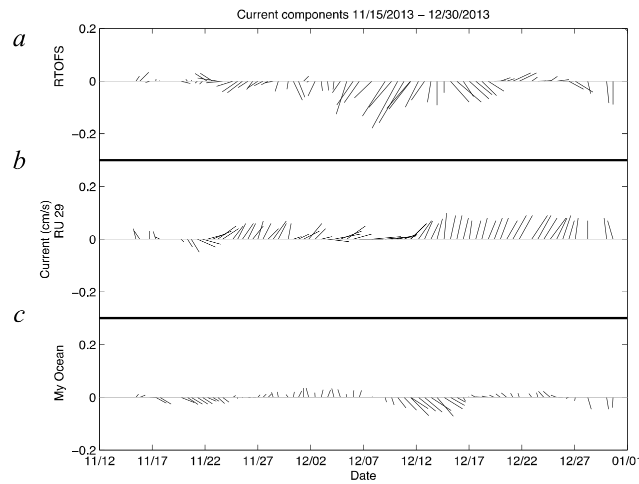

Figure 12: Current Vector comparison between RTOFS (a), RU29 (b), and MyOcean (c) for the Turtle Tracks.

B. Deep Eddy

The second area of interest occurred from April 26, 2014 to May 6, 2014. This section will be referred to as the "Deep Eddy" and is denoted by the white section of the track in Figure 5. It is worth noting because of the strong presence of an eddy. This is an area of strong meso-scale activity due to the Brazil Current[6] and the data collected with the glider can provide vertical and horizontal in-situ details that are not possible with other methods

There is evidence of a deep-water clockwise spinning eddy in the current plot of RU29 (Figure 15b), which is also seen in its temperature and salinity plots (Figure 13b & 14b). This eddy appears in the RTOFS current plot as well, with the same clockwise direction (Figure 15a). Although this eddy is present in the same spot as RU29 in both RTOFS' temperature and salinity plots, it manifests less gradually than the eddy shown in RU29's temperature and salinity plots (Figures 13a, 13b, 14a & 14b). MyOcean does not recognize the eddy structure at all (Figures 13c, 14c, & 15c).

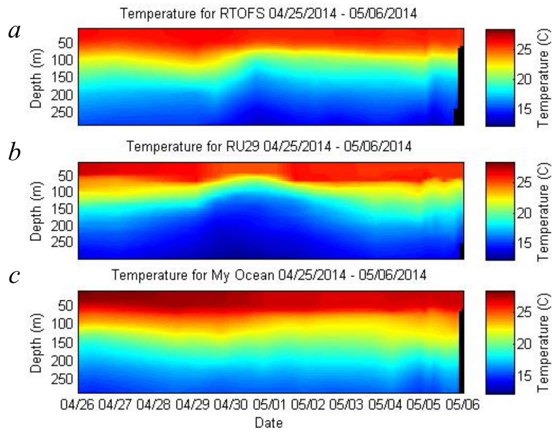

Figure 13: Temperature comparison between RTOFS (a), RU29 (b), and MyOcean (c) for the Deep Eddy.

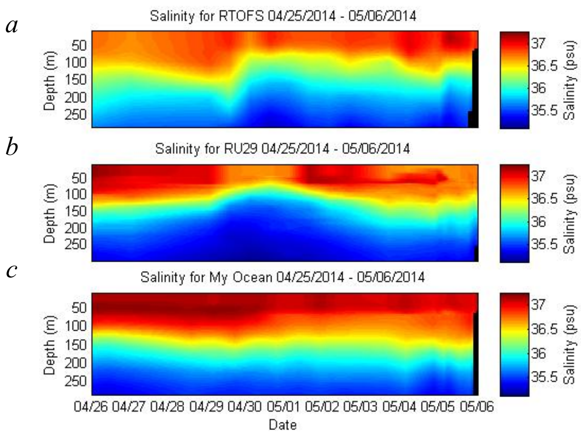

Figure 14: Salinity comparison between RTOFS (a), RU29 (b), and MyOcean (c) for the Deep Eddy.

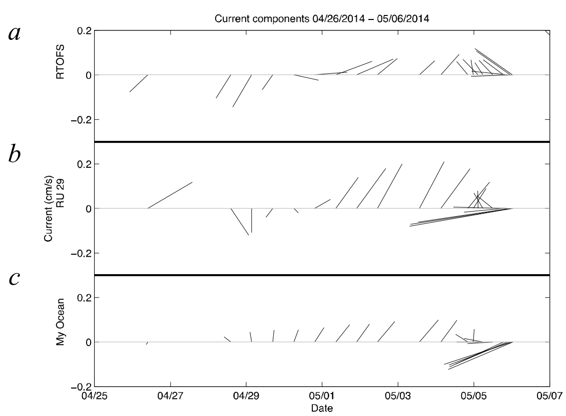

Figure 15: Current Vector comparison between RTOFS (a), RU29 (b), and MyOcean (c) for the Deep Eddy.

C. Continental Shelf and Cabo Frio Eddy

The third area of interest occurred from May 7, 2014 to May 18, 2014. This section will be referred to as "Continental Shelf and Cabo Frio Eddy" and is denoted by the red section of the track in Figure 5. It is worth noting because global models often have difficulty resolving features in shallow waters and the Cabo Frio Eddy is a well known eddy.

There is evidence of a shallow-water counter-clockwise spinning eddy in the current plot of RU29 (Figure 18b), which is also seen in its temperature and salinity plots (Figure 16b & 17b). This eddy appears in the MyOcean current plot as well, with the same counter-clockwise direction (Figure 18a). The eddy is present in the same spot as RU29 in the temperature and currents plots but the MyOcean model elongates the eddy (Figure 16b, 16c, 18b, & 18c). The MyOcean salinity plot also shows the eddy elongated, however, the eddy is shifted towards the coast. (Figure 17b &17c). RTOFS does not recognize the eddy structure at all (Figures 13c, 14c, & 15c).

On the continental shelf, possibly because MyOcean elongates the Cabo Frio eddy, the temperature and salinity it reports for the continental shelf are too warm and salty (Figures 16b, 16c, 17b, & 17c). While MyOcean is incorrect, it is not radically different from RU29, especially closest to the continent. RTOFS, however, reports noticeably warmer and saltier water in the very shallow waters (Figures 16a & 17a).

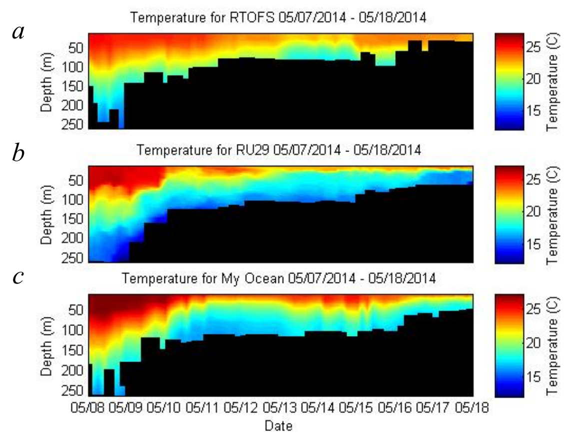

Figure 16: Temperature comparison between RTOFS (a), RU29 (b), and MyOcean (c) for the Continental Shelf and Cabo Frio Eddy.

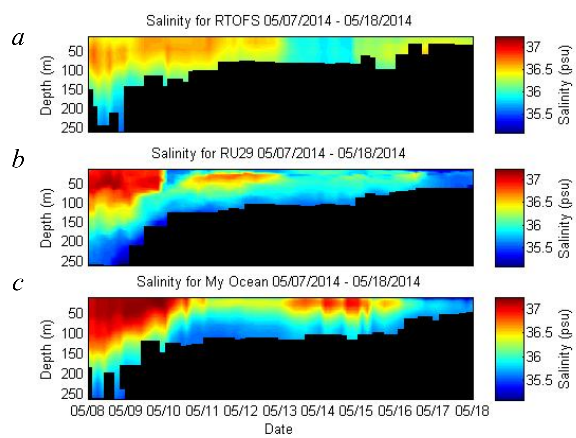

Figure 17: Salinity comparison between RTOFS (a), RU29 (b), and MyOcean (c) for the Continental Shelf and Cabo Frio Eddy.

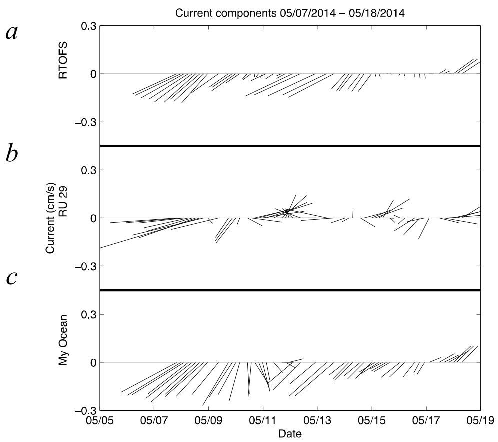

Figure 18: Current Vector comparison between RTOFS (a), RU29 (b), and MyOcean (c) for the Continental Shelf and Cabo Frio Eddy.

IV. Discussion

Two forecasting models, MyOcean and RTOFS have been studied in comparison to the glider RU29. The findings presented have lead to the conclusion that these two models have inconsistencies with in-situ glider data. Neither model can be considered superior as in certain areas, such as the “Deep Eddy”, the MyOcean model was lacking features in the ocean’s structure whereas the RTOFS model did not predict the existence of the Cabo Frio Eddy. Both the RTOFS model and the MyOcean model contain some important features that correspond with the glider data yet both also do not always reflect the structure apparent in the in-situ glider data.

Over the length of the RU29 Ascension Island to Brazil flight, the MyOcean model has a fairly consistent 1˚C to 2˚C difference in temperature from RU29, however there were not many places in either salinity or temperature that the MyOcean model differed notably from RU29. In comparison, the RTOFS model was fairly consistent with the RU29 data at lower depths but had very large discrepancies in magnitude at certain locations.

Ocean forecast models have become an indisputable tool for scientists and students, with the ability to resolve eddy structures and incorporate new data. They are easily accessible to researchers around the world. Such improvements to the models come from data taken from satellite and Argo floats that measure sea-surface temperature, sea surface height, and temperature/salinity profiles. In order to further improve the models, more data must be integrated from other sources. This will help advance forecast modeling in predicting features such as hurricane intensity.

Autonomous Underwater Gliders are able to contribute to the ocean forecast modeling because of their ability to traverse previously under-sampled regions of the ocean. It is crucial to the future of ocean modeling that glider-collected data be incorporated especially where areas of disagreement between the models occur.

V. Acknowledgements

The Challenger Glider Mission is growing global partnership of glider operators, scientists, educators and students coordinated by Rutgers University and endorsed by the Challenger Society. The results presented in this paper were initiated in a Rutgers research course and completed by three undergraduate summer interns (Rachael Sacatelli, Tobias Schofield, and Katherine Todoroff) supported by Teledyne Webb Research and four U.S. Naval Academy Interns (Angela Carandang, Alyson Eng, Ian Lowry, and Harrison Mather). Glider path planning and model/data comparison activities are led by Nilsen Strandskov (Rutgers) and Antonio Ramos (Universidad de Las Palma de Gran Canaria) with cyber infrastructure support provided by John Kerfoot (Rutgers). Glider operators include Chip Haldeman, Dave Aragon, Tina Haskin (Rutgers) and Ben Alsup (TWR). The RU29 deployment in South Africa was enabled by the University of Cape Town, The Nansen-Tutu Center, and the South African Marine Engineering & Robotics Centre at the Council for Scientific and Industrial Research (CSIR). The recovery and redeployment on Ascension Island was facilitated by the British Royal Navy, the U.S. Navy, and Ascension Island Fishing Charters (AIFC). The recovery and redeployment of RU29 in São Paulo, Brazil was enabled by University of São Paulo. RU29 mission support is provided by the U.S. Integrated Ocean Observing System, the U.S. Office of Naval Research – Global, and the G. Unger Vetlessen Foundation. Technology support provided by Teledyne Webb Research, Iridium and CLS America. Argo data was collected and made freely available by the International Argo Program and the national programs that contribute to it. (http://www.argo.ucsd.edu, http://argo.jcommops.org). The Argo Program is part of the Global Ocean Observing System.

VI. References

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