Upper ocean response to Hurricane Gonzalo (2014): Salinity effects revealed by targeted and sustained underwater glider observations

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Ocean Sciences Meeting, New Orleans, February 2016. Poster: A54C-2736

Abstract

- A network of underwater gliders was implemented in 2014 by NOAA/AOML as part of a multi-institutional project to carry out sustained and targeted upper-ocean observations to 1000m depth in the Caribbean Sea and Tropical North Atlantic Ocean in order to enhance our knowledge on the role that the ocean plays in the intensification of TCs, and to assess the impact of these observations on the TC intensity forecast.
- During Hurricane Gonzalo, for the first time gliders were used to obtain ocean observations at a fixed location during the passage of a Atlantic hurricane, and along a repeat section to assess upper-ocean changes and recovery after the hurricane. Hurricane Gonzalo (2014) traveled within 85km from the location of an underwater glider situated north of Puerto Rico. Observations collected before, during, and after the passage of this hurricane were analyzed to improve our understanding of the upper-ocean response to hurricane winds. Analysis of these observations revealed that salinity potentially played an important role in modulating the upper-ocean response to Hurricane Gonzalo. a near-surface barrier-layer likely suppressed the hurricane-induced upper-ocean cooling, leading to smaller than expected temperature changes. Comparison with a coupled ocean-atmosphere hurricane model indicates that model observations discrepancies are largely linked to salinity effects described. These results may potentially lead to improvements in ocean simulations on the coupled model used for hurricane forecasts, which can ultimately bring benefits to the society by improving hurricane predictions.

1. Motivation

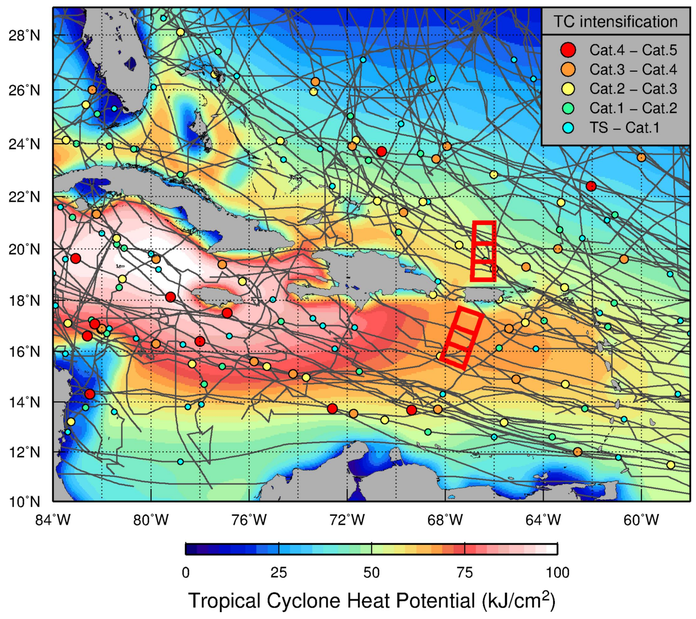


Figure 1. Historical tracks of Tropical Cyclones that travelled through the Caribbean Sea and Tropical North Atlantic waters overlaid on the field of Tropical Cyclone Heat Potential for the Atlantic Hurricane season during 1993-2012. Markers indicate the location where intensification was observed.

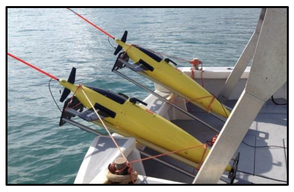
- Tropical Cyclones are commonly observed to travel and intensify over the Caribbean Sea and Tropical North Atlantic in areas off Puerto Rico, which are characterized by high values of Upper Ocean Heat Content during the Atlantic Hurricane Season.
- Yet, very few observations have been collected in these areas during the last few decades
- **Currently, there are no ocean observing system in place in the area to provide data on a sustained fashion to support Hurricane research and forecasts.**

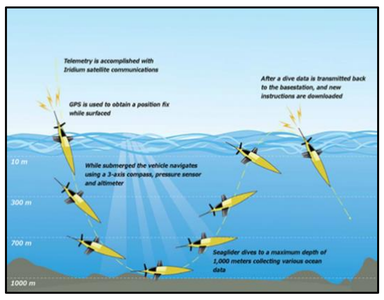
2. Goal & Objectives

Improve understanding about the role that the ocean plays in the intensification of tropical cyclones

- Implement a network of underwater gliders to carry out sustained and targeted ocean observations
- Investigate the response of the ocean to hurricane force winds
- Assess the impact of glider observations on tropical cyclone seasonal and intensity forecasts

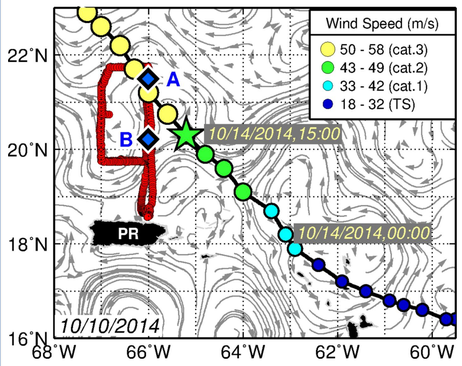
3. Underwater Gliders





An underwater glider is an autonomous underwater vehicle (AUV) that uses small changes in buoyancy together with wings to propel itself by converting vertical motion into horizontal motion. Thanks to a very small consumption of energy, underwater gliders have longer ranges when compared to other AUVs, being able to measure several ocean parameters during months, including temperature, salinity, and dissolved oxygen.

4. Hurricane Gonzalo (2014)



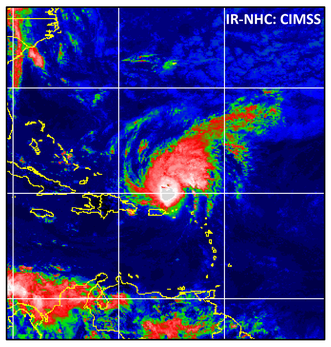


Figure 2. (left) Track followed by the glider (red points) north of Puerto Rico (PR) during July-November 2014. The track of Hurricane Gonzalo is shown by colored circles. (right) Infra-red (IR) image from Gonzalo on October 14, 2014.

- On October 12, 2014, TC Gonzalo developed in the tropical North Atlantic, intensifying into Category 1 hurricane on October 13, and into Categories 2 and 3 on October 14. During its intensification into Category 3, Hurricane Gonzalo travelled ~85 km northeast of the location of the glider.
- The **sampling strategy** adopted during the passage of Hurricane Gonzalo consisted of carrying out observations along section $\overline{AB}$ three times, one before and two after the passage of the hurricane; and of obtaining time-series of temperature and salinity anomalies at site B during the passage of Hurricane Gonzalo. A total of **228** temperature and salinity profiles were obtained by one glider.

5. Pre-storm & During storm

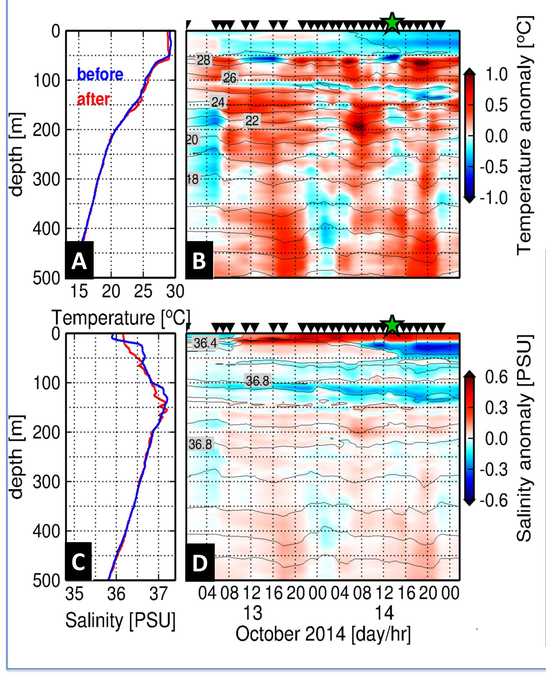


Figure 3. (A) Pre-storm (blue line) and post-storm (red line) temperature profiles at site B. (B) Depth-time diagram of temperature anomalies during October 13-15 at site B. (C) same as Figure 3A, but for salinity. (D) Same as Figure 3C, but for salinity.

- **Pre-storm** conditions at site B were marked by the presence of a **shallow low-salinity layer above 20m** (Figure 3b) that was associated with the presence of a **barrier layer**
- **During the storm: small cooling of -0.4°C** was observed above 50m; below 50m, temperature and salinity anomalies were dominated by alternating positive and negative values.

6. Post-storm

Stronger cooling observed in the proximity of site A possibly linked with two processes: wind-driven **rightward biased cooling**, and **intensified upwelling** in the vicinity of the track of the hurricane. 11 days after the passage of Hurricane Gonzalo, the upper-ocean started warming above 50m

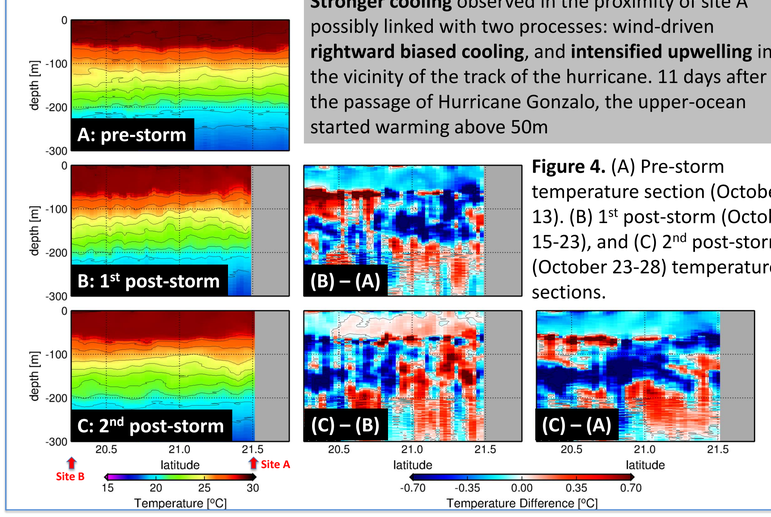
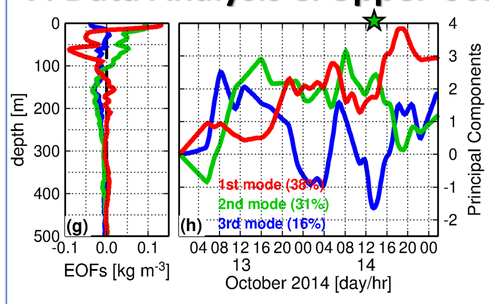


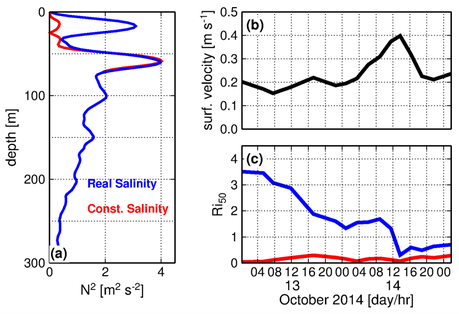
Figure 4. (A) Pre-storm temperature section (October 8-13). (B) 1st post-storm (October 15-23), and (C) 2nd post-storm (October 23-28) temperature sections.

7. Data Analysis & Upper-ocean Processes

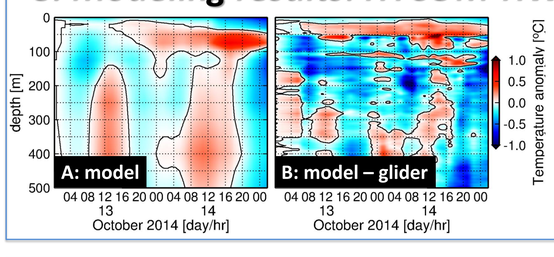


Changes observed during storm above 130m were consistent with **wind-forced mixing**, which were captured by the first mode of the density variability. The second and third modes exhibited periodic changes that indicate background motions due to **internal tides** and **near-inertial baroclinic motions** partly forced by the storm.

Estimates of Richardson Number (Ri_{50}) indicate that initial conditions at site B were characterized by **strong stratification**, with large values of ~3. The large value of Ri50 at the beginning of the record at site B imply the dominance of stratification effects over vertical shear effects, indicating that **turbulent mixing was likely partially suppressed in this location.**



8. Modeling results: HYCOM-HWRF



The **model overestimated the surface cooling** by 0.2°C, possibly because of discrepancies in initial conditions for salinity. Larger SST cooling in the model may have lead to an **underestimated intensity forecast for Gonzalo**.

Key results & Conclusions

- ✓ During the first 18 months of this project, approximately 8,000 temperature and salinity profiles were collected in areas where hurricanes often travel and intensify
- ✓ Observations collected during Hurricane Gonzalo showed that:
  - ❖ Upper-ocean cooling forced by winds of Hurricane Gonzalo was small
  - ❖ Mixing-induced cooling was partially suppressed by near-surface stratification due to salinity conditions, which defined a surface barrier layer
  - ❖ Upper-ocean response to Hurricane Gonzalo involved multiple ocean processes, such as wind-driven mixing and upwelling, and near-inertial baroclinic motions
  - ❖ **Hurricane forecasts:** A better representation of salinity features, such as the shallow low salinity layer observed above 20m, may help improve future hurricane forecasts
  - ❖ These results emphasize the value of sustained and targeted ocean observations by underwater gliders for tropical cyclone intensification studies.

Domingues, R., G. Goni, F. Bringas, S.-K. Lee, H.-S. Kim, G. Halliwell, J. Dong, J. Morell, and L. Pomales (2015), Upper ocean response to Hurricane Gonzalo (2015): Salinity effects revealed by targeted and sustained underwater glider observations, Geophys. Res. Lett., 42, doi:10.1002/2015GL065378.

Acknowledgments

This work was funded by the Disaster Relief Appropriations Act of 2013 known as the Sandy Supplemental, and supported by NOAA/AOML, UPRM, UM/CIMAS, NOAA/NDBC, NOAA/IOOS, CariCOOS, and ANAMAR.

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