Glider Observations of Submesoscale Processes and Hurricanes near Bermuda

MAGIC
Mid Atlantic Glider Initiative and Collaboration

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Located in the center of the North Atlantic's subtropical gyre …

… Bermuda has hosted monthly ship-based observations of physical and biogeochemical properties (Bermuda Atlantic Timeseries Study (BATS) and Hydrostation "S", Fig 1) since the mid 1950s. In 2014, the Mid Atlantic Glider Initiative and Collaboration (MAGIC) Program was established at BIOS (a U.S.-registered, private, non-profit research organization) and has been conducting autonomous sampling of the upper ocean (0-950 m) using a small fleet of 3 Slocum gliders (Anna, Jack and Minnie).

Figure 1. Location of Bermuda and its time series sites.

Deployed as virtual moorings sampling within a 1-km square area, they acquire 8-16 profiles per day (CTD, ECO-puck (FLBBCD), oxygen optode, SUNA and TRDI ADCP) and have been returning measurements that resolve water column properties at the shorter timescales (semi-diurnal and inertial frequencies) required to address a variety of long-standing questions about marine food web dynamics, carbon and nutrient budgets, and the oceanic response to tropical and winter storms. These glider-based observations are symbiotic with the ship-based time series program: i.e. providing critical measurements of submesoscale processes missing from the BATS sampling, while the latter provides calibration / validation of the autonomous sensors.

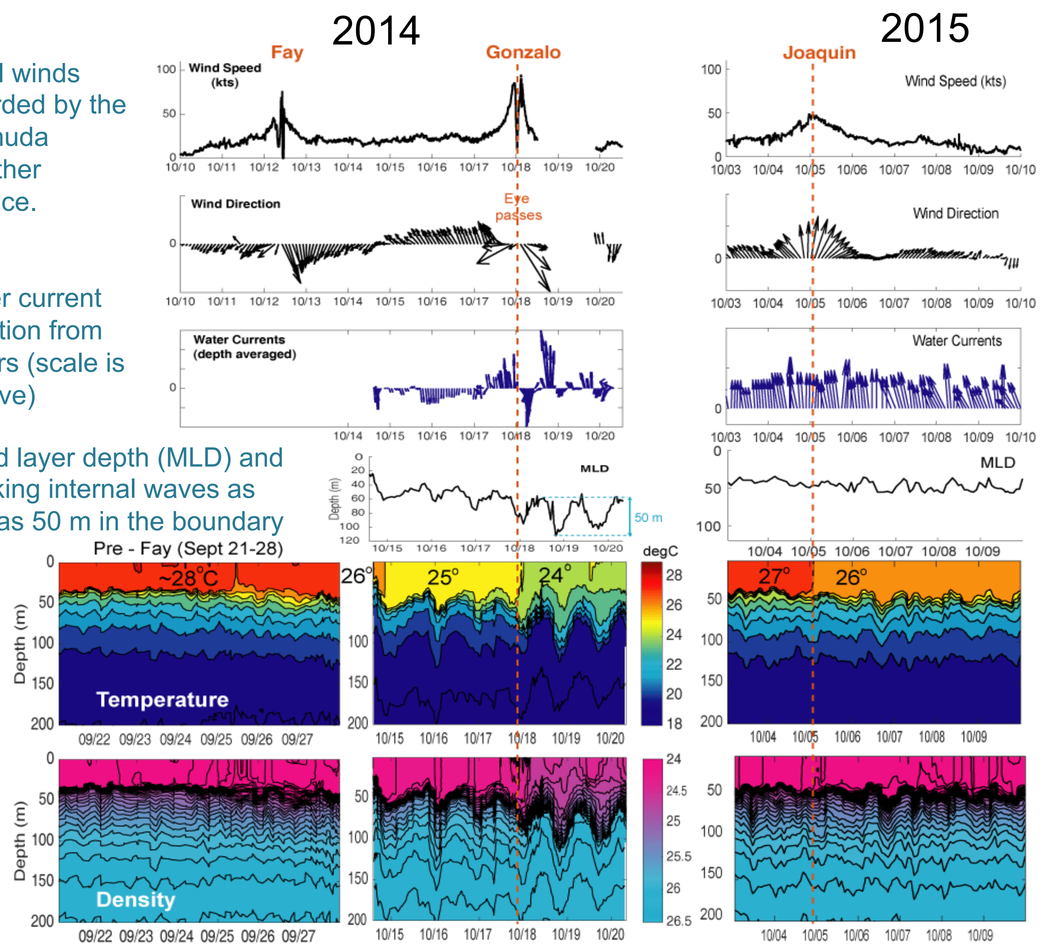
The MAGIC Lab is also pairing glider technology with other disciplines and technologies, for example biological net tows to study active carbon transport by diel vertical migration of zooplankton.

Hurricanes: Winds, currents and internal waves…

Local winds recorded by the Bermuda Weather Service.

Water current direction from gliders (scale is relative)

Mixed layer depth (MLD) and breaking internal waves as high as 50 m in the boundary layer.



Glider-measured time series of temperature and density recorded a 4-deg C cooling and density increases associated with two 2014 storms that passed directly overhead. A stable ocean structure in the last week of Sept (left panels) contrasted sharply with the internal waves and turbulent mixing following Fay and Gonzalo (middle panel). In 2015, Joaquin registered a much smaller response (right panel) as the hurricane's center passed ~80 km to the west of the glider's location.

Phytoplankton Bloom Dynamics

Ocean features such as eddies, fronts and water masses are readily diagnosed from glider-based measurements of temperature, velocity and geopotential anomaly (integrated density). Properties reflecting biogeochemical processes (e.g. oxygen, chl-a, backscatter) align with these features and are being used to establish associations with hydrographic structures and to construct inventories and budgets associated with biological production and carbon/nutrient cycling.

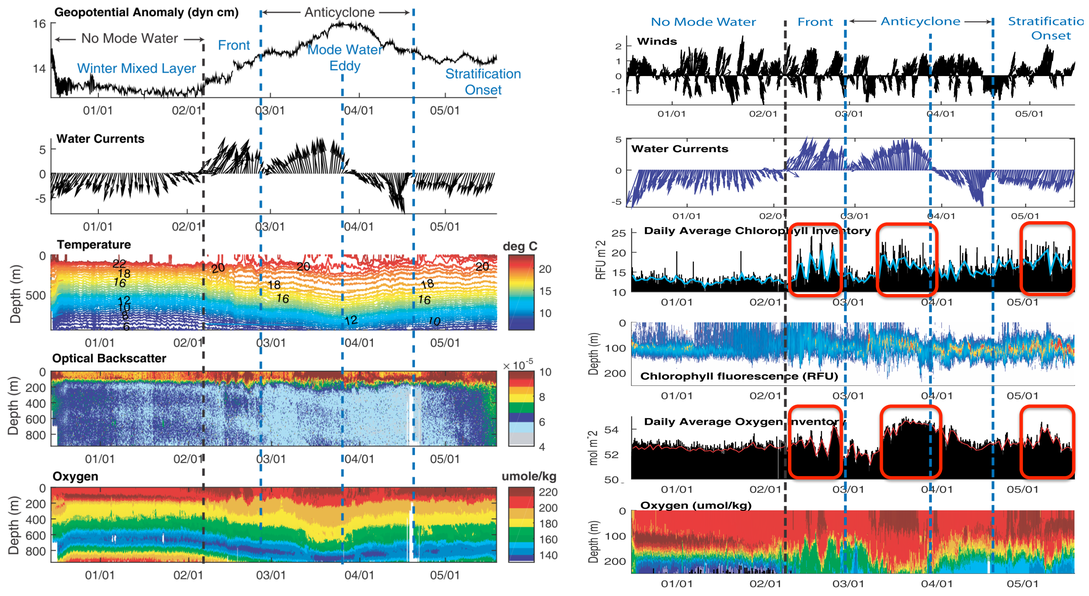


Figure 2. 5-month time series of properties derived from glider-based measurements at the BATS site during the Spring Bloom 2016 mission (15 Dec 2015 to 15 May 2016). Hydrographic features are labeled and denoted by vertical dashed lines. Inventories of chlorophyll and oxygen reveal timing and magnitude of elevated new production (red rectangles). Winds are from the Bermuda Weather Service.

Episodes of nutrient upwelling -- which governs production in the Sargasso Sea – are associated with strong gales. An event captured by glider Minnie carrying a SUNA sensor (Fig. 3) revealed large amplitude internal waves excited by the wind forcing, as well as instabilities and turbulence at the base of the surface mixed layer. Elevated nitrate and low salinity waters were pumped up into the photic zone. Such events are brief, but occurred frequently throughout the Spring Bloom 2016 mission (Fig. 4). It implies that this mechanism exerts an important -- and quantifiable -- control on biological production in the oligotrophic subtropical gyre, where nutrient budgets remain unclosed.

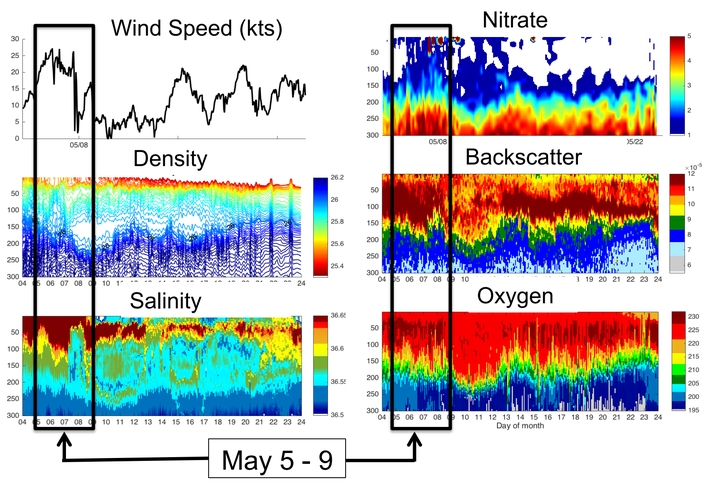


Figure 3. Time series of winds, upper ocean density, salinity, nitrate, optical backscatter and oxygen portray an injection of nitrate into the photic zone as a consequence of strong winds and inertial pumping over a 4-day period. Stretching and squashing of vertical density gradients reflect internal waves generated by winds. The upwelling and turbulent mixing at the base of the mixed layer dissipated in less than a week.

Figure 4. Another glider (Anna) not equipped with a SUNA sampled for multiple months with its CTD, optode and ECO Puck in the Spring Bloom mission. The stretching and squashing of density contours associated with inertial pumping are evident and strongly connected to individual episodes of elevated chlorophyll inventory, and provide a sense of their frequency. Ship-based occupations of the BATS are denoted by black bars to demonstrate the importance of glider sampling to understanding submesoscale phenomena such as these.