NOAA's efforts to improve hurricane forecasts through increased, sustained and targeted ocean observations are tested on *Isaias* with gliders, drifters, and Argo floats

NOAA's Extreme Events-Ocean Observations (EE-OO) Task Team supports the coordination of targeted and sustained ocean observing efforts to improve the understanding of air-sea interaction during high wind events, with the goal of improving the accuracy of hurricane intensity forecasts. The task team coordinated observations in front of and along the track of *Hurricane Isaias* with air deployed drifters and already in place Argo floats and gliders, and are now conducting analysis of data and potential ocean impacts.

Highlights:

- Hurricane Isaias provided a test case to evaluate the ocean component of the full end-to-end hurricane forecast data flow across three regions: the formation zone in the Caribbean, the re-intensification zone just before landfall in the South Atlantic Bight, and an impact zone in the Mid Atlantic Bight.

- The Navy's data-assimilative Global Ocean Forecast System (GOFS) – the start of the ocean forecast value chain for hurricanes – demonstrated that a global model can reproduce key Essential Ocean Features across all three regions through the assimilation of temperature and salinity profile data from the combined Argo plus Hurricane Glider network.

- As of August 4, 2020, Hurricane Weather Research and Forecast System (HWRF), one of the world's leading hurricane forecast models, officially switched to the same ocean initial condition value chain for the ocean component of its coupled atmosphere-ocean forecasts. This will enable realistic, data supported representation of the ocean in regions of hurricane generation and development.

- This effort is made possible with a team of scientists and researchers from AOML, Scripps Institution of Oceanography, Rutgers University, WHOI, University of Miami, and support from GOMO, US IOOS, and NWS. This team worked safely during the COVID-19 pandemic, following CDC and NOAA guidelines, to deploy for the third year an enhanced Hurricane Glider Picket Line to conduct ocean observations that are used in hurricane forecast models with the ultimate goal of protecting life and property in U.S. coastal areas.

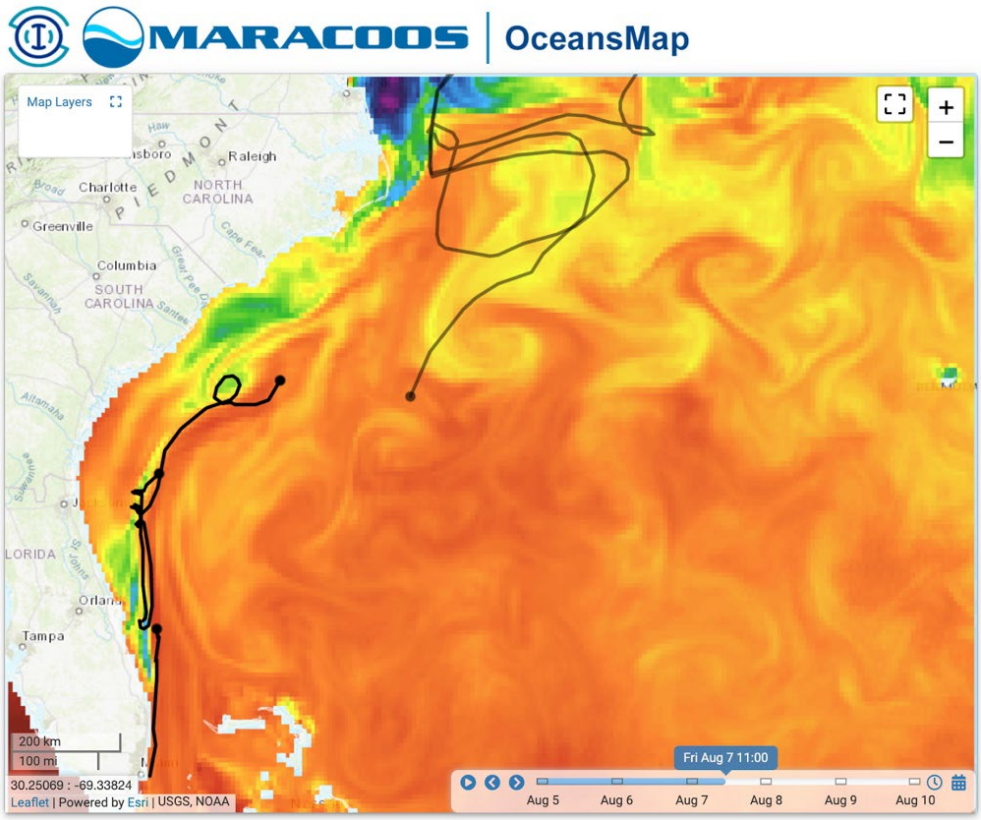
HURRICANE GLIDERS + ARGO NETWORK

Real-time ocean profile data from gliders and profiling floats were used to monitor ocean conditions and to evaluate ocean models along the region under the location and along the forecasted track of Hurricane Isaias, from its genesis in the Caribbean region to the South Atlantic Bight where the hurricane intensified, and just south of the Mid Atlantic Bight where conditions were also being monitored.

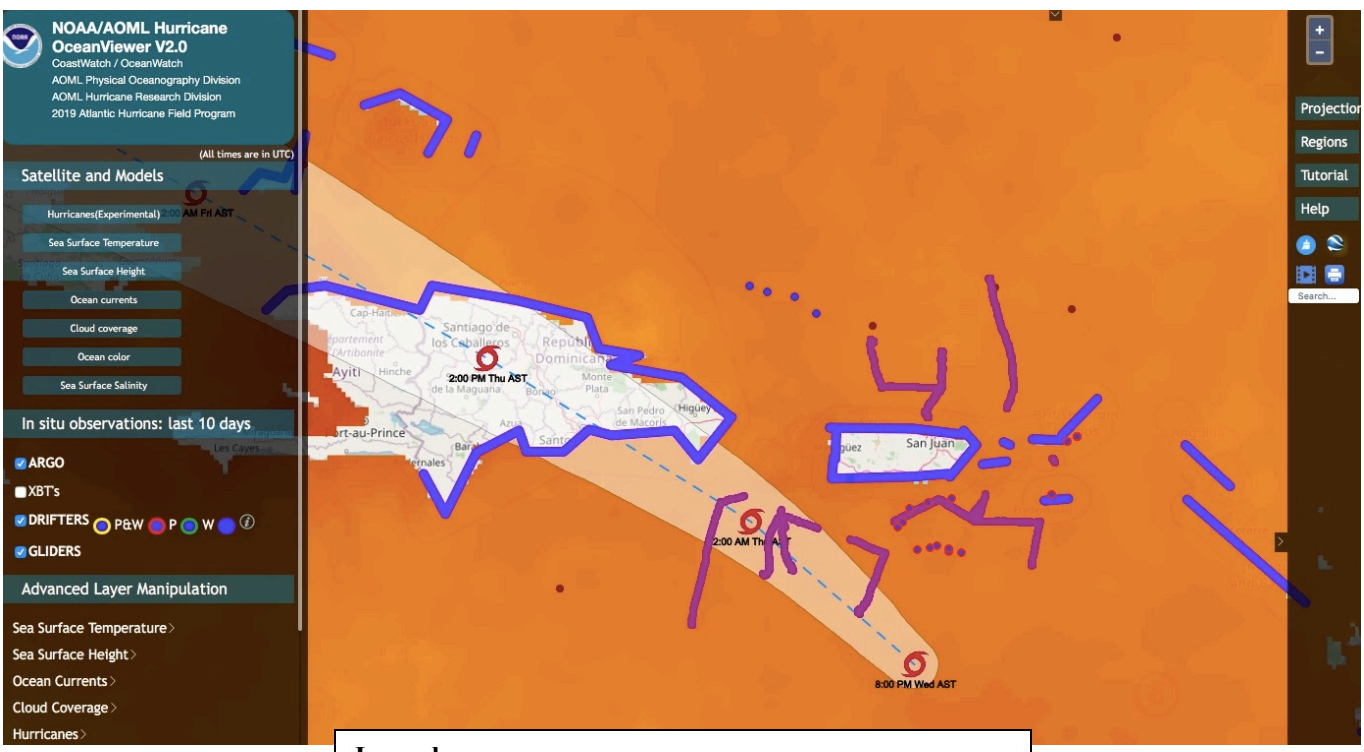
Operations of approximately 30 hurricane gliders are carried out by US IOOS, NOAA, US Navy, the energy industry, and academic institutions. Data from these gliders are being distributed through the U.S. Integrated Ocean Observing System and delivered in near-real time to US and international forecast centers around the world.

In the Caribbean region, where Isaias began developing, nine NOAA and two Navy gliders operated by AOML, CARICOOS, and the University of Miami, provided temperature and profile data of the upper ocean right before the cyclone became a hurricane. Glider data showed the presence of a warm and stable barrier layer which the winds could not mix with the underlying colder waters, therefore providing appropriate ocean conditions for intensification.

In the South Atlantic Bight, SECOORA, US Navy, and AOML operated gliders surveyed the Gulf Stream with the adjacent continental shelf, while Argo floats provided the conditions offshore of the Gulf Stream. In the **OceansMap image below**, the gliders are shown surveying the west wall of the Gulf Stream in the Navy's data assimilative GOFS forecast, including an excursion into a frontal eddy at the Charleston Bump. Five additional gliders (operated by IOOS, Rutgers University, and the US Navy) were in the Mid Atlantic region. Data from these gliders enabled the data assimilative models to properly represent the highly stratified water column in the Mid Atlantic as the storm heavily impacted the region with powerful winds and flooding.

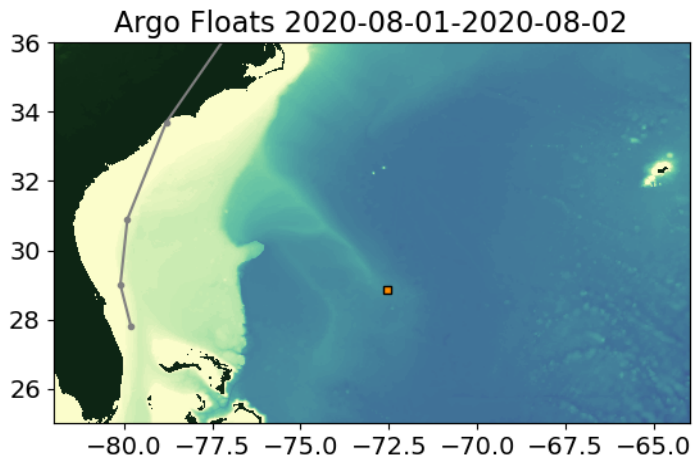


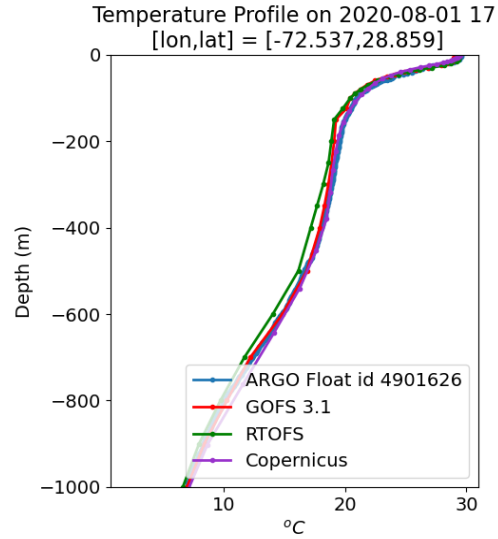
The map below from AOML and NESDIS 's Hurricane OceanViewer shows locations of gliders, Argo floats, and drifter observations when Isaias travelled south of Puerto Rico.



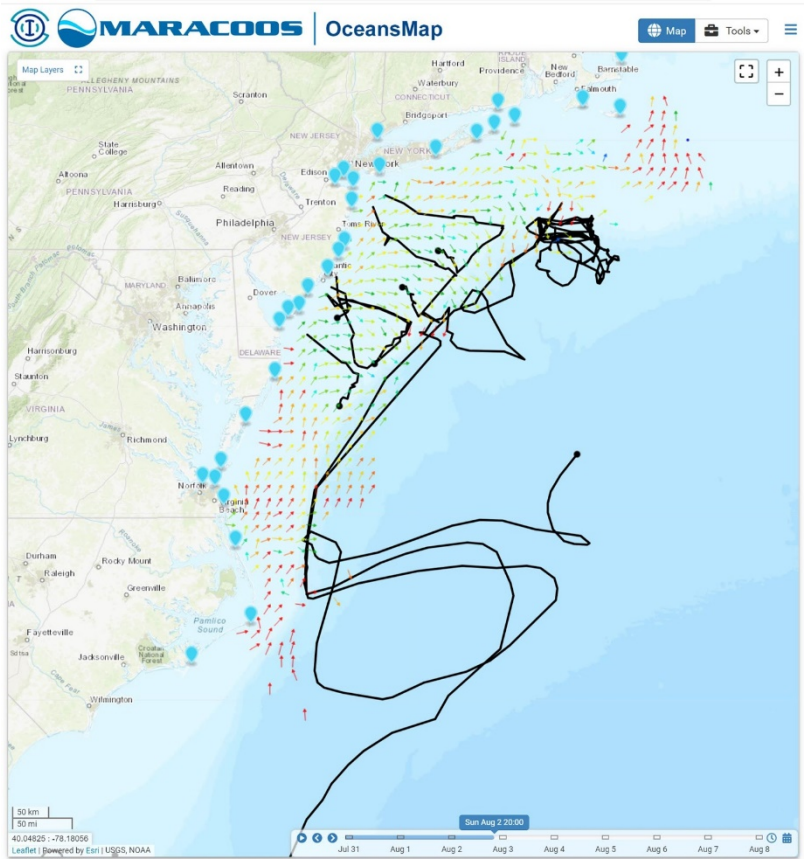
Legend:
Blue coasts: TC warning
Purple lines: points of glider profile observations
Blue dots: regular drifter observation locations
Blue dots with red border: drifters with atmospheric pressure
Red dots: Argo float data

Below the Argo temperature profile data from the deepwater area offshore of the Gulf Stream is in good agreement with all three operational global ocean models (Navy GOFS, NOAA RTOFS, and European Copernicus).



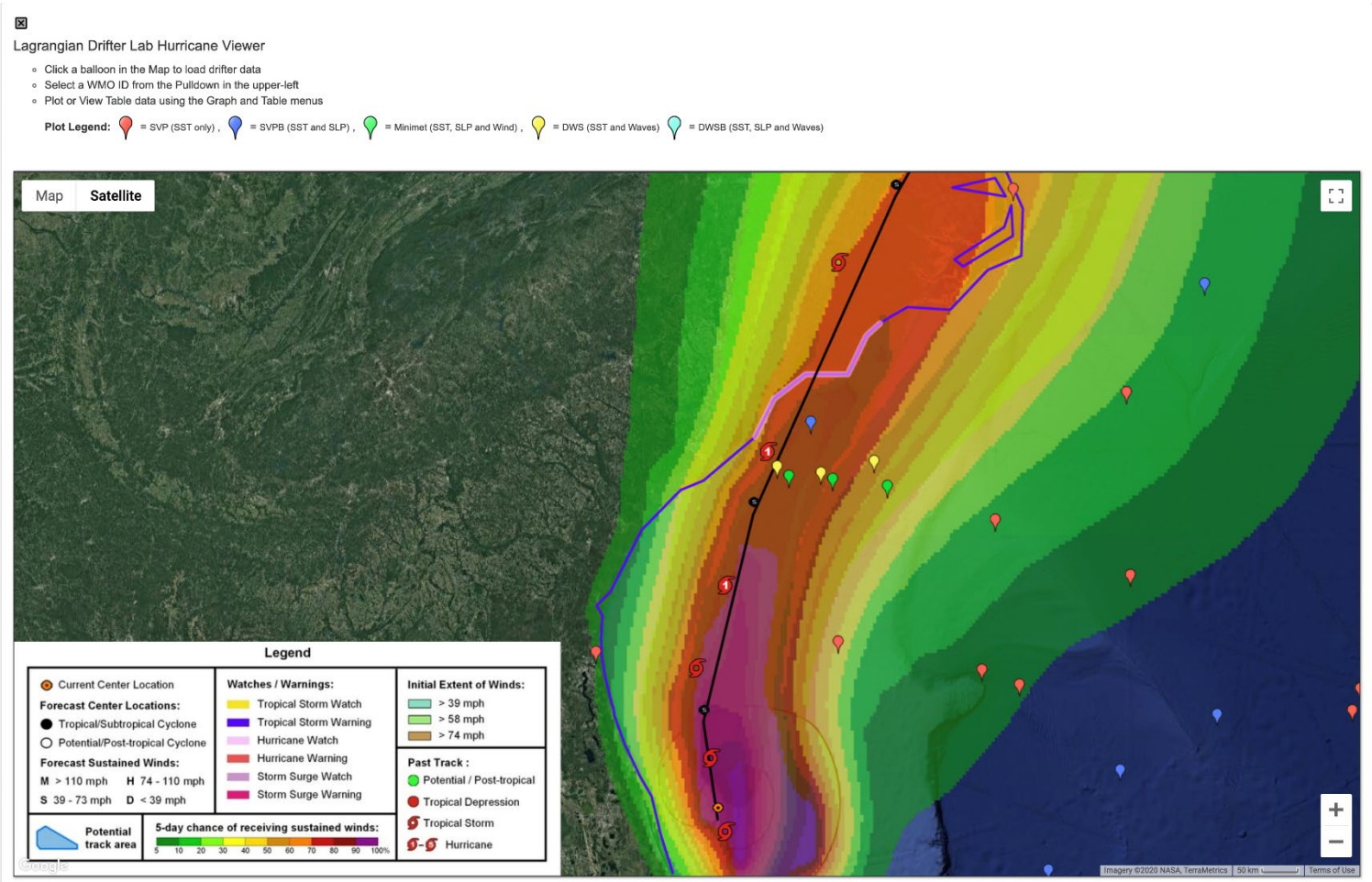


The observing system in the Mid Atlantic Bight also includes the MARACOOS HF Radar Network, the NSF OOI gliders in the Pioneer Array south of Martha's Vineyard at the shelf-slope front, the GOMO gliders surveying the Gulf Stream offshore, and the five MARACOOS-coordinated gliders on the continental shelf that include contributions from IOOS, the Navy and the offshore wind industry.



DRIFTERS

The Global Drifter Program, which has been conducting in-situ air-sea observations for four decades, began conducting targeted air deployments ahead of tropical storms in 2003. As part of this effort, a picket-line of wave (wave frequency, height and direction), mini-met (wind, sea level pressure, surface velocity, sea surface temperature, and water temperature profiles) and barometer drifters were air-deployed in front of Hurricane Isaias off the coast of the Carolinas, with their data transmitted in real-time via the Global Telecommunications System (GTS). The eye of Hurricane Isaias passed the line of drifters at about 00 UTC on August 4th, 2020. This unique data set showed the maximum waves arriving three hours before the passage of the eye, the transition of swell dominated seas to wind dominated seas and the persistence of strong winds for six hours as the storm passed. The array of buoys measured the drop in surface temperatures prior to storm arrival and the cold wake that remained after the storm's passage. With several of the wave and wind drifters collocated, these in-situ ocean observations provide critical insights into the air-wave-ocean boundary layers' coupling mechanisms during hurricanes and other high wind events and will provide scientists with data for evaluation of their forecasts and post-season analysis of this a-typical hurricane.



Scripps Langrangian Drifter Laboratory (LDL) Hurricane Viewer Map Identifying Drifter Locations and TS *Isaias* Track

DATA ASSIMILATION

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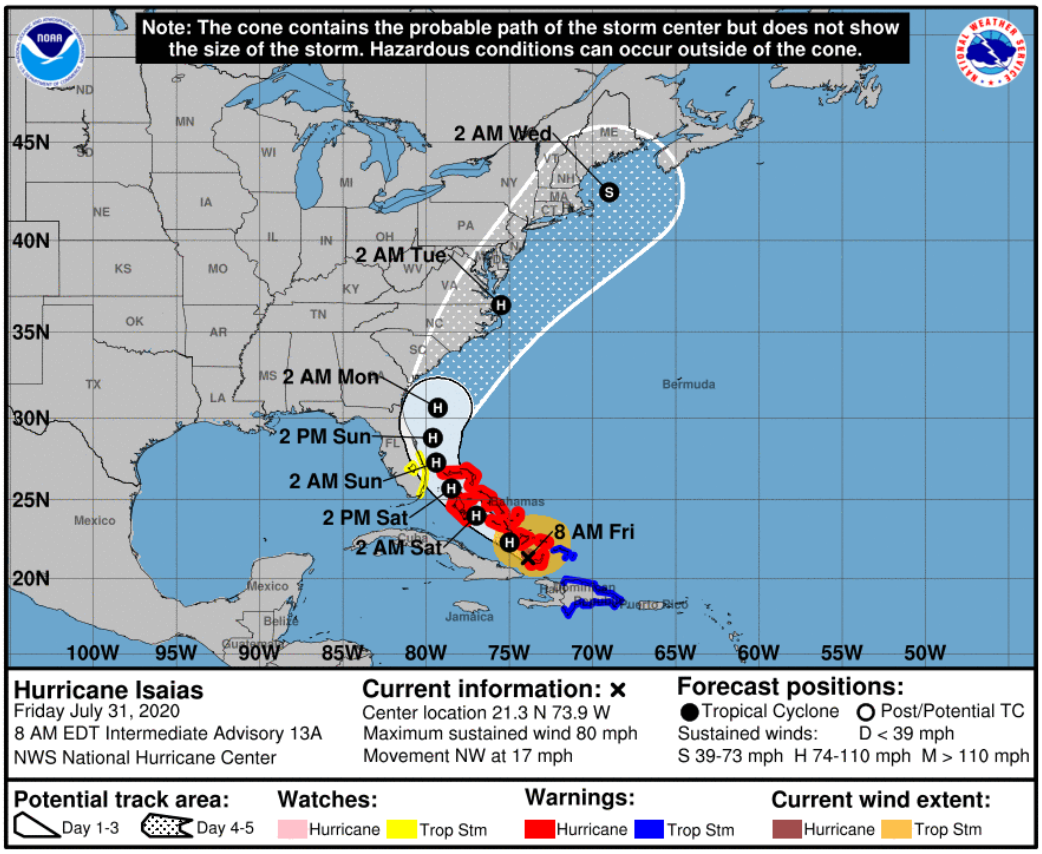
The Navy's data-assimilative Global Ocean Forecast System (GOFS) – the start of the ocean forecast value chain for hurricanes – demonstrated that a global model can reproduce key Essential Ocean Features in all three regions through the assimilation of temperature and salinity profile data from the combined Argo plus Hurricane Glider networks.

Informed by the local profile data, the data-assimilative GOFS correctly reproduced: the low salinity surface barrier layers within the AOML glider array in the Caribbean, the Gulf Stream structure and location in the South Atlantic Bight, and the surface mixed layer temperature and depth, the stratification, and the bottom Cold Pool in the Mid-Atlantic Bight.

This is especially relevant today. The coupled atmosphere-ocean regional hurricane forecast model HMON has long relied on the ocean forecast value chain from data-assimilative GOFS to global RTOFS to its regional HYCOM, and has benefited from the Hurricane Glider Picket Lines from the start. *As of August 4, 2020, Hurricane Weather Research and Forecast System (HWRF), one of the world's leading hurricane forecast models, officially switches to the same ocean initial condition value chain for the ocean component of its coupled atmosphere-ocean forecasts. This will enable realistic, data supported representation of essential ocean features in regions of hurricane generation, and development.*



INTEGRATED OBSERVATIONAL EFFORT

Working together, a team of ocean and hurricane researchers and operators achieved coordinated ocean observations in the generation, re-intensification before landfall, and impact zones throughout the Caribbean, Southeast, and Mid Atlantic. Data aggregation through the IOOS Glider DAC enabled assimilation of glider data into the global models in all regions. This effort continues to allow scientists to evaluate the operational and experimental modeling systems over a broad array of ocean features and regions.

Hurricane research is currently conducted by a distributed team across institutions from the Caribbean into the Gulf of Mexico up to the Gulf of Maine that safely worked within the COVID-19 pandemic constraints, following CDC and NOAA guidelines to deploy for the third year an enhanced Hurricane Glider Picket Line to protect the U.S. coast. This team includes scientists and researchers from NOAA's Atlantic Oceanographic and Meteorological Laboratory, Scripps Institution of Oceanography, Rutgers University, Woods Hole Oceanographic Institution, University of Miami, and support from NOAA's Global Ocean Monitoring and Observing Program, the U.S. Integrated Ocean Observing System, and the National Weather Service.