OCEAN OBSERVING EXPERIMENT
Science Description

Experiment/Module: Sustained and Targeted Ocean Observations

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Science Description: Ocean observations provide data to correctly characterize the water mass characteristics of ocean features in the water column (e.g., temperature, salinity, etc.) and on the surface (e.g., waves, spray, etc.) that may contribute to changes in hurricane intensity. The correct representation of the upper ocean in atmosphere-ocean coupled forecast models has proven in many instances to help reduce the errors in intensity forecasts. The goal of this module is to provide ocean observations in support of hurricane intensity studies and forecasts. The ocean observations can be classified as *sustained,* when they are focused on the sustained monitoring of specific ocean water mass properties or features (e.g., ocean currents, gyres, global ocean heat content) or *targeted*, when they are dedicated to assessing features known to be linked to hurricane intensity changes.

Requirements: Categories 1-5; observations carried out at different stages of the TCs (pre-storm, during, post-storm) from observing platforms already in place or from ships/planes dedicated to targeted observations.

Plain Language Description: The goal of this module is to provide ocean observations to improve how the ocean component is represented in hurricane forecast models. Ocean observations will be provided in *sustained mode,* when they are focused on the sustained monitoring of specific ocean water mass properties or features (e.g., ocean currents, gyres, global ocean heat content) and in *targeted mode*, when they are dedicated to assessing features known to be linked to hurricane intensity changes.

Ocean Observing Science Objective(s) Addressed

1) Collect observations targeted at better understanding air-sea interaction processes contributing to hurricane structure and intensity change. [*APHEX Goals 1, 3*]
2) Collect observations targeted at better understanding the response of hurricanes to changes in underlying ocean conditions, including changes in sea surface temperature, ocean mixed layer depth, turbulent mixing, surface waves and fluxes, and ocean heat content [*APHEX Goals 1, 3*]
3) Test new and improved technologies with the potential to fill gaps in areas and/or parameters that are undersampled [*APHEX Goals 1, 3*]

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Motivation: ocean observations have been increasingly acknowledged by the scientific and operational forecast communities as a critical piece to improve Earth system prediction and their importance will continue to increase as extreme weather events increase with our changing climate. Closing gaps in NOAA's ocean observing system that captures sustained and targeted ocean observations, and coordinates collocated ocean-atmosphere observations, is key to correctly represent the ocean component in ocean-atmosphere coupled intensity models and improving forecasts across all timescales.

Maintaining, developing, and deploying observing systems to generate sustained and targeted, regionally-tailored ocean observations across the complex and rapidly changing ocean environments is a complex task; doing so requires coordinated efforts that result in high-quality, timely, accurate, and authoritative observations. The error in the intensity forecast using atmospheric-ocean forecast models have shown to be reduced when the upper ocean water mass and dynamic features are correctly represented. This module presents a coordinated, multi-institutional, regional and international, multi-platform approach to fully capture many of the ocean features that affect the intensity changes of hurricanes.

Background: ocean observing efforts in support of hurricane intensity forecasts have been in place for several years. This module coordinates the implementation and operation between the different ocean observing platforms, including underwater gliders, surface and special drifters, ALAMO floats, Saildrones, UAS, IR sondes, expendable probes, and other relevant observations and projects. This work derives from coordination efforts being led by the NOAA Global Ocean Observing and Monitoring Program.

Goals:

1. Deploy and operate a suite of ocean observing instruments and platforms to collect observations that can be assimilated into operational and experimental forecast models and used to advance scientific research and improve tropical cyclone (TC) intensity forecasts.
2. Provide tools for monitoring the location of ocean observational assets and ocean conditions and products from in situ and satellite observations.

Hypotheses:

1. Realtime, in situ atmospheric and oceanic data ingested by numerical forecast models have the potential to improve hurricane intensity forecasts.
2. Coordinating ocean and atmosphere observing assets will provide greater opportunities for collocated measurements and improve understanding of air-sea interactions during high wind events.

Objectives: We list here the suite of targeted and sustained ocean observational assets that will be in place during the 2021 Atlantic hurricane season. These assets are primarily geared towards monitoring changes in the upper ocean density field to help identify ocean features linked to the intensification or weakening of TCs and ocean-atmospheric surface parameters key to understanding air-sea fluxes. The main objectives of the 2021 planned work are:

1. Coordinate the deployment of underwater gliders, drifters, Saildrones, ALAMO floats, UAS, in the tropical Atlantic Ocean and Gulf of Mexico during the 2021 Atlantic Hurricane Season.
2. Transmit all data in real-time into the GTS and ensure the data are available for operational forecasts.

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3. Continue to build partnerships with NOAA/EMC scientists to evaluate the impact of ocean observations in operational hurricane forecast models.

Aircraft Pattern/Module Descriptions:
This experiment seeks any opportunity for collocated deployments and collocated observations with the following platforms:

- Underwater Gliders: Autonomous underwater gliders are mobile sampling platforms that provide targeted observations that profile the water column in both nearshore (as shallow as 10 meters) and deep ocean (up to 1000 meters) environments. Gliders typically transit horizontally while diving with average speeds of 20 km/day, collect data with vertical resolutions of 0.25-10 meters, and transmit data to shore every 2 to 6 hours depending on programmed flight characteristics. These systems can be adjusted to sample more rapidly over shallower depths to capture detailed temperature, salinity, and density structure within features of interest or ahead of, during, and after the passage of tropical cyclones. Approximately 29 glider lines/patterns are planned for the 2021 Atlantic Hurricane season from a combination of AOML, IOOS Regional Associations, US Navy, academic institutions and private industry.

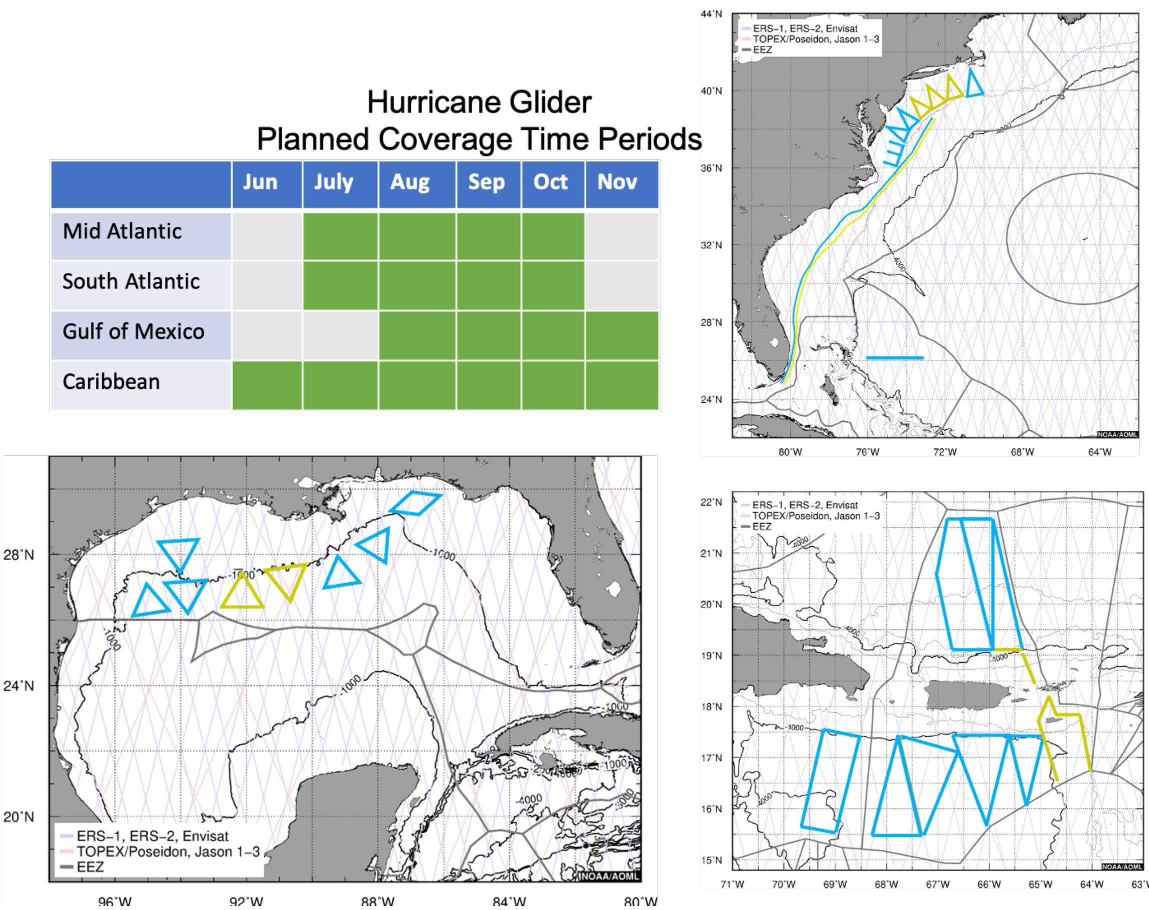

Figure 1. *Planned transects of NOAA supported glider observations (blue), and lines of potential glider trajectories using requested Naval Oceanographic Office gliders (yellow).*

- Drifters: Sustained drifter observations include: SVPB (https://gdp.ucsd.edu/ldl/svpb/) and D-WSB drifters (https://gdp.ucsd.edu/ldl/dwsbd/). Targeted drifter deployments include: Minimet drifters that will operate throughout season after targeted deployment (https://gdp.ucsd.edu/ldl/minimet/), Autonomous Drifting Ocean Station (ADOS) that will operate throughout season after targeted deployments (https://gdp.ucsd.edu/ldl/ados/), and A-sized DWSB drifters that can be deployed via P3 and C-130/C-130J aircraft (estimated 60 total distributed over 6-10 missions). In general, the hurricane packages consisting of Minimets (SVPB+wind speed, direction), ADOS (thermistor chains to 150m depth replacing drogue on Minimet), Directional Wave Spectrum Drifters (DWSB), and SVPB drifters are deployed in a line transecting the projected path of the TC (see Figure 3). Air-deployment practices require this to be in advance of the storm outside the extent of gale force winds. Sustained observations with surface drifters will be distributed in the Caribbean, in the Gulf of Mexico and the north Atlantic approximately west of 70°W.

- ALAMO Floats: Air-deployed from P-3 or C-130 aircraft in advance of or during a tropical cyclone. The ALAMO Floats provide targeted observations of profiles of temperature, salinity, and pressure to a depth of up to 1200 m. All data are transmitted via Iridium each time the float surfaces and will be posted to the GTS. There is two-way communication with the floats, allowing their profiling frequency and depth to be adjusted. For TC deployments, the typical target depths are about 300 m, allowing for 12 profiles per day. The plan is to deploy two floats ahead of a hurricane, one to the right of the eye and one to the left (see Fig. 4). Priorities for deployment are: (1) hurricanes that threaten landfall, (2) major hurricanes, (3) hurricanes passing over a region of the ocean with strong upper-ocean salinity stratification and/or shallow temperature stratification. AOML will have at least two floats ready to deploy during the 2021 season and possibly as many as 10, depending on how long it takes the float manufacturer to deliver them.

- Saildrones: Powered by solar, wind, and hydro energy, these vehicles can stay at sea for up to 12 months (albeit biofouling). Standard targeted measurement includes sea surface (-0.2 m) temperature and salinity, upper ocean (100 m) current at 2 m resolution, surface air temperature/humidity (2 m), pressure (0.5 m), and wind direction/speed (3.2m), wave height and period. Long- and short radiation can also be measured but is not part of the standard package. Data (1-min averaged at the top of every 15 min) are transmitted in real time to GTS bundled once per hour. August - October 2021; western tropical Atlantic Ocean south and north of Puerto Rico (4 drones), and near the East Coast or Bahamas (one drone).

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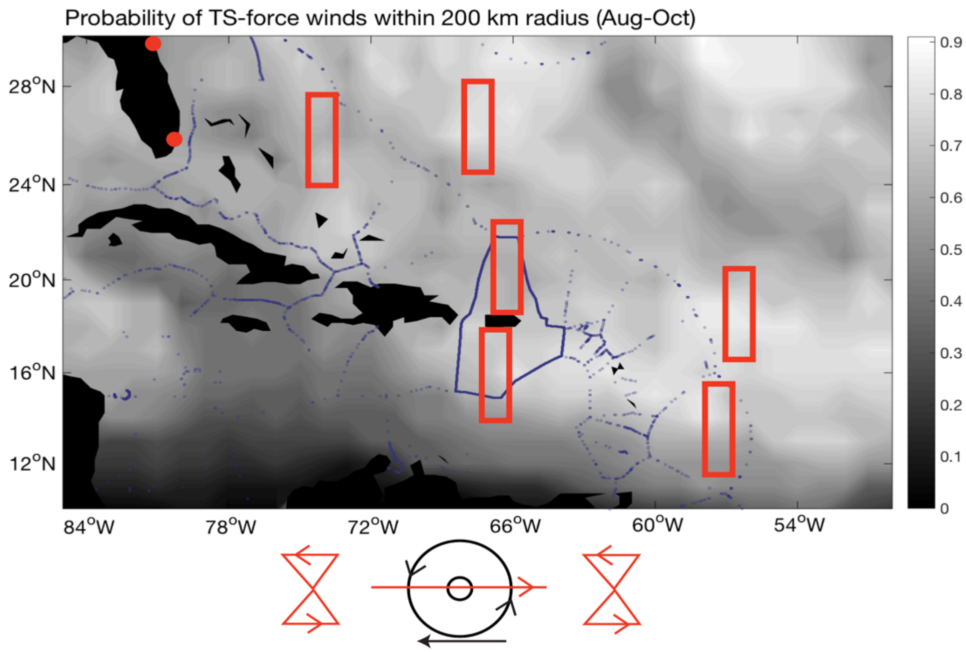

Figure 2. *Potential saildrone mission domain. Red rectangles are repeated saildrone and glider track when no TC is nearby. Blue lines show other glider tracks. Possible saildrone tracks when a TC (black circles, with arrow indicating translation direction) is to pass nearby is shown at the bottom: before TC arrival (bow-tie pattern on left), during passage (transect through middle of TC), and after (bow-tie pattern on right). Red dots are alternative launching sites for landfalling TCs. Shading is the probability of sustained TS-force winds within 200 km of each location during August-September.*

- UAS and IR sondes: [Link to *Research In Coordination with Operations Small Uncrewed Air Vehicle Experiment (RICO SUAVE)* where plans include deploying up to three (3) small Uncrewed Aircraft Systems (sUAS) within the high-wind air-sea transition zone of Tropical Cyclones (TC)]. Planned activities will occur between August - November 2021 within the western tropical Atlantic Ocean, Caribbean Sea and the Gulf of Mexico. Operations will require deployments from NOAA's P-3 aircraft.

- Sustained Observations and Other Observing Projects: Several components of the networks of the global ocean observing system encompass in situ networks, shore-based HF Radars, and satellite observations, including: **Argo floats** (provide temperature and salinity profiles to about 21000m with approximate spatial and temporal resolutions of 3x3 degrees and 10 days; some Argo floats will be able to change their temporal sampling when their locations coincide with the forecasted hurricane track), **surface drifters** (measure surface currents, temperature, and atmospheric pressure), **moored instrumentation** (PIRATA array provides upper ocean and near-surface atmospheric measurements at 18 locations throughout the tropical Atlantic), **expendable bathythermographs** (deployed along three transects across the Gulf stream to measure temperature profiles to 800m), **HF radar networks** (map surface currents in near real time along many U.S. coasts out to a range of 150-200 km, at a spatial resolution of 6 km, and a temporal resolution of 1 hour), and **satellite observations** (sea surface temperature, sea height anomalies, sea surface salinity, and surface and vector winds). The integration of these sustained networks with observations geared towards hurricane studies and forecasts have proven to be of great value, particularly to reduce temperature and density biases in numerical ocean models and for forecast model validation.

Three of the above platforms will be air-deployed using NOAA P-3s (N42, N43) and can be flown with existing HFP modules: A-sized DWSB drifters, ALAMO floats, and UAS.

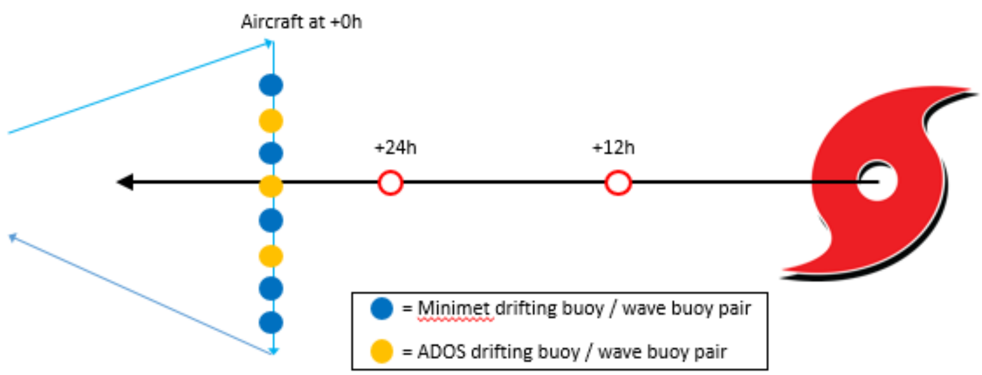

***Figure 3. A-sized DWSB drifters**. Representative deployment line of drifter pairs 24h ahead of the arrival of gale-force winds, from a C-130J.*

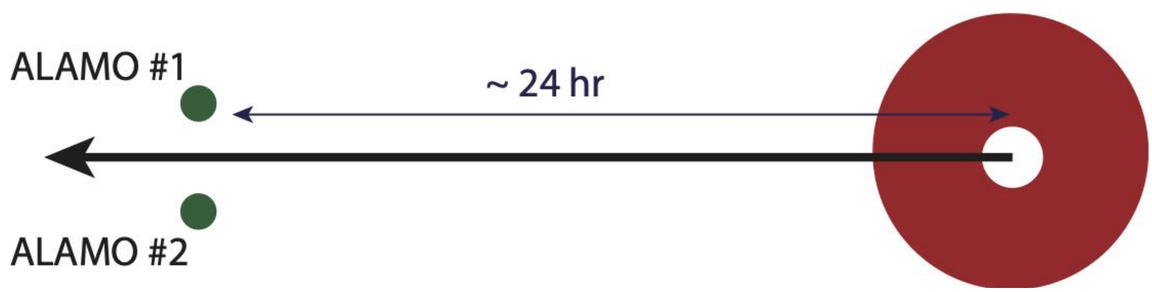

***Figure 4. ALAMO floats**. Schematic of desired ALAMO float deployments ahead of a hurricane.*

Links to Other Experiments/Modules:

- Ocean Survey Experiment, lead: Jun Zhang, NOAA AOML
- Hurricane Boundary Layer Module, lead: Jun Zhang, NOAA AOML
- Research In Coordination with Operations Small Uncrewed Air Vehicle Experiment (RICO SUAVE), lead: Joe Cione, NOAA AOML

Analysis Strategy: the observations described above (plus others that incorporate new key parameters, such as waves, sea spray, heat and moisture fluxes) will serve to advance operational coupled models to improve intensity forecasts. All observing data will report real time or near real-time from the platform to the GTS for its use by the operational and experimental modeling centers. This will be accomplished by using the NOAA next-generation coupled hurricane model system (HAFS) and data assimilation framework (marineJEDI) through the NOAA Unified Forecast System (UFS).

Further, several data visualization tools will be employed throughout the hurricane season to assist with the coordination of deployments and monitoring of opportunities for collocated observations. Several of these tools provide a web-based platform for monitoring GTS ocean observations with hurricane forecast tracks overlaid. Examples include:

- NOAA Hurricane OceanViewer
- Atlantic OceanWatch OceanViewer
- Caribbean and Gulf of Mexico node
- ArgoVis
- Earth Null School
- MARACOOS OceansMap
- Lagrangian Drifter Lab GDP Array Viewer
- Lagrangian Drifter Lab Hurricane Viewer
- IOOS Glider DAC
- IOOS EDS Model Viewer

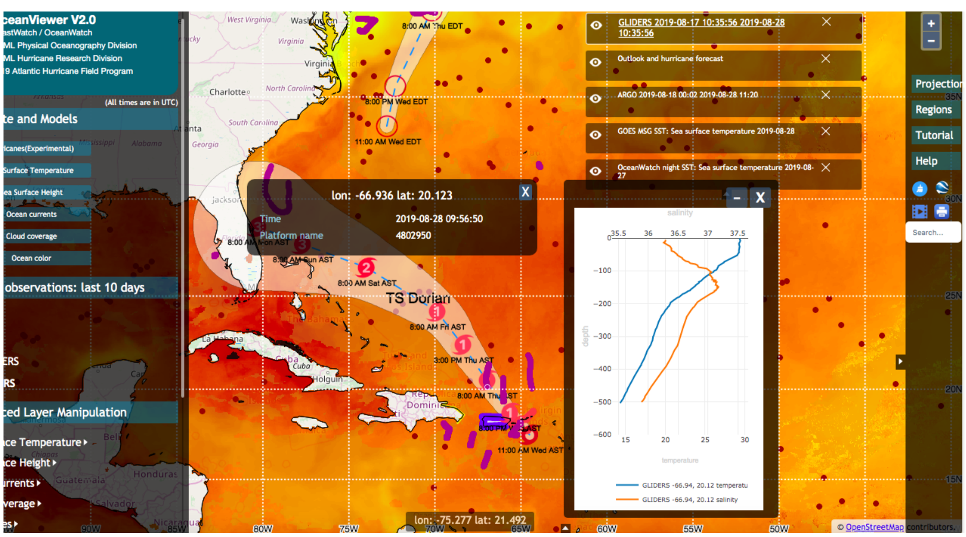

Figure 5. *Screenshot of the NESDIS/CoastWatch AOML Hurricane OceanViewer with Argo floats and glider locations during Hurricane Dorian (2019), overlaid to the sea surface temperature fields.*

Future activities following this work will focus on assessing the impacts of ocean observations to understand the effectiveness of observation types during the course of a storm and to determine the optimal network design when planning a new observing strategy, reorganizing existing observing networks, or investing in future observing systems. Observing System Experiments (OSEs), Observing System Simulation Experiments (OSSEs), and data-denial studies must be done in the future (post-hurricane season) to assess the impacts of different observations and/or combined observations for improving NOAA's ocean observing strategies.

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