OCEAN OBSERVING EXPERIMENT
Science Description

Experiment/Module: CHAOS (Coordinated Hurricane Atmosphere-Ocean Sampling)

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Collaborators: Dave Jones, StormCenter Communications | GeoCollaborate

Requirements: No requirements: flown at any stage of the TC lifecycle

Plain Language Description: CHAOS focuses on the coordination of a diverse suite of innovative observing platforms (i.e., autonomous, uncrewed, expendable) and conventional ones (e.g., aircraft) to support:

- Targeted coordinated observations of the air-sea transition zone to improve the understanding of air-sea interactions, including the ocean's response and recovery to tropical cyclone (TC) forcing, and for improved prediction and modeling of TC intensification changes
- Coordinated atmospheric and oceanic observations with sustained monitoring of key ocean features of the Gulf of Mexico, tropical Atlantic, and/or the Caribbean Sea – e.g., Loop Current, Gulf Stream, eddies and rings, and freshwater barrier layers from the Mississippi & Amazon-Orinoco River Plumes

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 and ocean heat content [*APHEX Goals 1, 3*]

3. Test new (or improved) technologies with the potential to fill gaps, both spatially and temporally, in the existing suite of airborne and surface measurements in TCs. These measurements include improved three-dimensional representation of the hurricane wind field, more spatially dense thermodynamic sampling of the boundary layer, and more accurate measurements of ocean surface winds and underlying ocean conditions [*APHEX Goal 2*]

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Motivation:
This effort seeks to improve our understanding and characterization of the air-sea transition zone in the extreme environmental conditions found within a TC by coordinating in situ and remote observing systems measurements. We present a coordinated multi-platform, multi-institutional approach to better capture the ocean and atmosphere features that affect TC intensity changes.

Background:
Air-sea interactions under high-wind conditions are one of the processes critical to TC intensification changes. Recent progress and developments in understanding air-sea interactions and strongly coupled data assimilation for hurricane forecast models point to the importance of observing the air-sea transition zone (the upper ocean, air-sea interface, and atmospheric marine boundary layer as a single integrated identity). While the ocean provides the energy needed for storms to intensify, to date, collocated measurements of both fluids at the air-sea interface remain limited. Most instances of collocated measurements are from singular profilers that are sparsely distributed in space and time. The goal of this experiment is to observe key features of the air-sea transition zone by coordinating observations by multiple platforms in order to elucidate the physics which guides the evolution of both the ocean and atmosphere.

Goal(s): Deploy and operate a coordinated suite of oceanic and atmospheric observing platforms to facilitate collocated observations of the air-sea transition zone before, during, and after TCs.

1. Improve understanding of processes in the upper ocean and atmospheric boundary layer that impact TC intensity through innovative and conventional observing systems, and observe their coupling via coordinated observations
2. Improve representation of the ocean in coupled models through coordinated atmospheric and oceanic observations with sustained monitoring of key ocean features of the Gulf of Mexico, tropical Atlantic, and/or the Caribbean Sea – e.g., Loop Current, Gulf Stream, eddies and rings, and freshwater barrier layers from the Mississippi & Amazon-Orinoco River Plumes
3. Improve understanding of how in situ and remote sensing platforms perform in TCs to validate and enhance products provided by these platforms.

Hypotheses:

1. Simultaneous and collocated observations of the air-sea transition zone will improve the understanding of hurricane intensity change and the ocean’s response and recovery to TC forcing
2. Dense spatio-temporal coverage of collocated observations of the ocean and atmosphere are necessary for future gains in coupled model forecast improvements

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Objectives:

1. Sample the upper ocean and atmosphere before, during, and after a hurricane using a diverse suite of coordinated observing platforms (Figs. 1 and 2 below):
    a. Sustained, in situ observations from underwater gliders, saildrones, rapid cycling Argo profiling floats, drifters, moorings, etc.
    b. Targeted observations deployed from aircraft – small uncrewed aircraft systems (sUAS), A-sized Directional Wave Spectra Drifters (A-DWSD), atmospheric expendables (i.e., dropwindsondes, IRsondes, StreamSondes), and oceanic expendables (i.e., EM-APEX floats, AXBTS, AXCTDs).
2. Sample the atmosphere and ocean in tropical storm-force wind conditions or stronger in varying conditions with aircraft-based remote sensing instruments coincident with in situ platforms and expendables described in Objective 1 to:
    a. Improve understanding of the response of in situ and remote sensing instrument measurements at the air-sea interface in extreme conditions by comparing collocated observations across a range of conditions
    b. Improve understanding of the turbulent structure of 3-D near-surface winds in TCs, how they relate to the momentum flux (wind stress) and drag coefficient, and how this relationship varies with the ocean state (wave height, period, age, wind-wave angle).
3. Progress towards a more spatio-temporally dense suite of coordinated and collocated observations, and demonstrate the improved understanding of atmospheric and oceanic characteristics that influence TCs and subsequent forecasts.

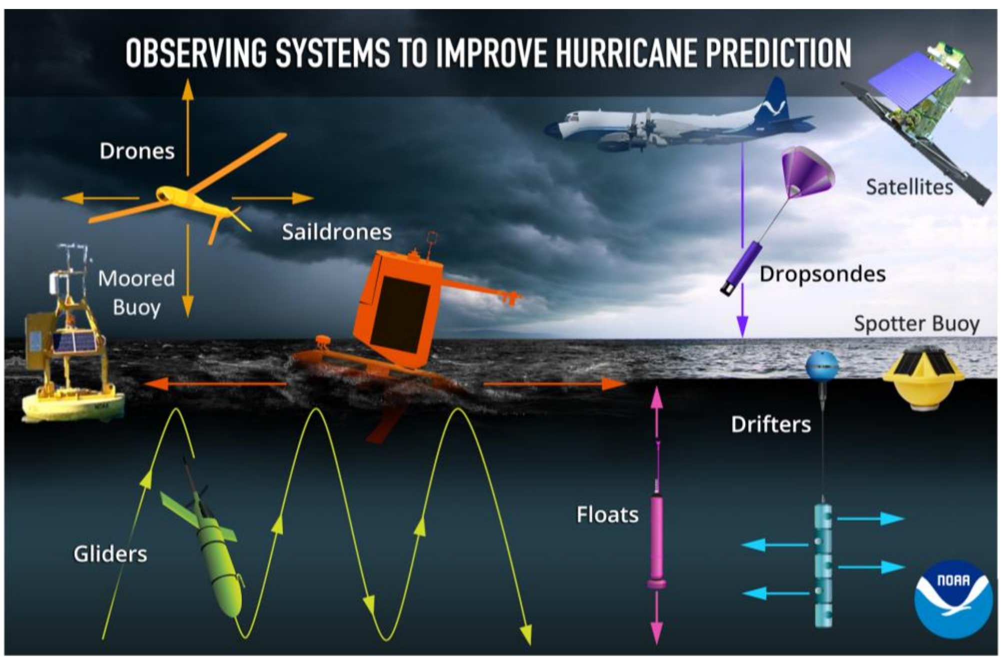

Figure 1: A representation of select platforms used in this experiment to coordinate observations hypothesized to improve the understanding of the evolution of the atmosphere and ocean before. during, and after TCs. Credit: NOAA PMEL, modified by L. Looney.

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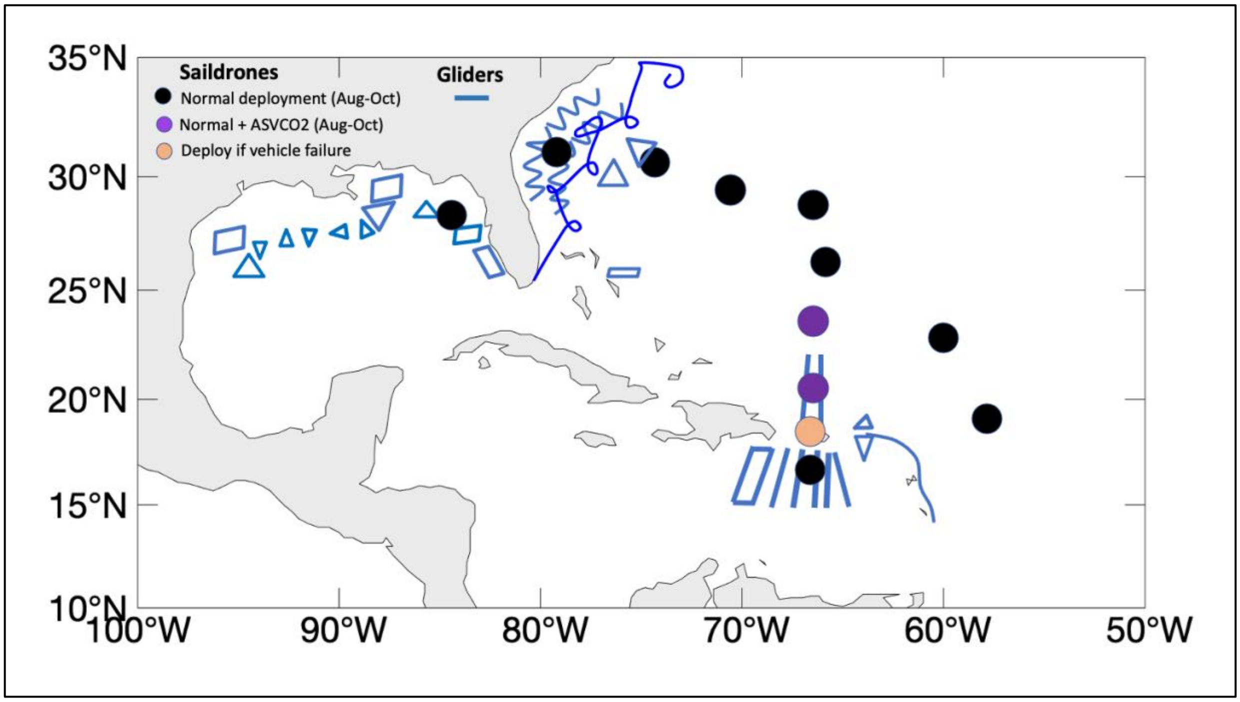

Figure 2: Planned operating areas for saildrones (filled circles) and gliders (blue lines/shapes) during the 2024 hurricane season. The glider tracks displayed here represent a subset of the broader Hurricane Glider Program deployments. Credit: G. Foltz.

Aircraft Pattern/Module Descriptions (see *Flight Pattern* document for more detailed information): 2024_CHAOS_flight_modules

- **Aircraft Pattern #1 (P-3/G-IV Pattern #1): Ocean Observing Platform Overflight**
  - The goal for this pattern is to target a pre-existing ocean observing platform (e.g., saildrone, glider, mooring, drifter, profiling float). There is no specific pattern required. Ideally, the pre-existing flight pattern would be adjusted to get as close as possible to the ocean platform. The only constraint is to be within 25 NM of the platform for a successful module. It is a priority to get as close as possible to the platform, with an overfly being preferred. Further, there is a preference for at least one atmospheric and one oceanic expendable (as available) nearest the in situ platform. If multiple ocean platforms present, see Pattern #2 below. If Pattern #2 cannot be conducted, conduct Pattern #1 multiple times (if possible) to best fit all platforms present.
- **Aircraft Pattern #2 (P-3/G-IV Pattern #2): Multi-Platform Overflight**
  - The goal of this pattern is to target multiple (at least two) pre-existing ocean observing platforms (including saildrones, gliders, moorings, drifters, profiling floats) within TS-force conditions or higher. These ocean observing platforms need to be within 25 NM of each other and the P-3/G-IV would fly in a straight line from

one platform to the other. Further, there is a preference to deploy at least one atmospheric and one oceanic expendable while overhead each individual platform, if available. The direction the pattern is flown and storm-relative position are not constraints. If expendables are limited, the primary expendable deployment should be directly overhead the higher priority platform (i.e., a platform with met-ocean sensors). If the P-3/G-IV cannot fly directly from one platform to the other, or if the platforms are more than 25 NM apart, defer back Pattern #1 above for each platform.

- **Aircraft Pattern #3 (P-3/G-IV Pattern #3): Minimum Saildrone Gradient**
  - The goal of this pattern is to target a saildrone within the region of TS-force winds or higher. The P-3/G-IV would fly in 5-25 NM legs centered over the saildrone. It is preferred that the pattern is flown during the time the saildrone is in the most extreme conditions during the flight. The direction the pattern is flown and storm-relative position are not constraints. The preferred leg is tangential to the winds, however, perpendicular to the winds would be the second preference. During this pattern, expendables (at least one atmospheric and one oceanic, if available) would be deployed 5-25 NM on either side and overhead the saildrone, with the highest priority deployment being overhead the saildrone.
- **Aircraft Pattern #4 (P-3 Pattern #4): A-DWSD Wave Drifter Deployment and Fly Over**
  - The goal of this pattern is to deploy A-DWSDs in targeted areas within the TC, ahead of the center. In operationally-based flights, the deployment areas are preferred to be NE (storm-relative) of the TC's center, nearer to the eye wall, with 15-20 NM separation between deployments. In research-based flights, the deployment area is preferred to be in the eye wall with one being to the NE (storm-relative) of the TC's center and the other being directly to the N (storm-relative) of the TC's center. In both research and operational flights, preference would be to return back to overfly the drifters and deploy atmospheric expendables. However, if overflight is not possible, atmospheric expendables would be co-deployed with the initial drifter deployment.
- **Aircraft Pattern #5 (P-3 Pattern #5): Full Saildrone Gradient**
  - The goal of this pattern is to target a saildrone within the TC environment. The P-3 would fly a Figure 4 pattern centered overhead the saildrone. During the flight, the P-3 would deploy expendables (as available) throughout each leg, with deployments preferred in similar distances away from the saildrone, but no further than 25 NM away. During the cross-leg component, one expendable is requested to be deployed at the midpoint, if available. Likewise, if one or more ocean expendables are available, the priority deployment would be overhead the saildrone. The direction the pattern is flown and storm relative position of the saildrone is not a constraint. However, there is preference to have one leg tangential to the winds, while the other leg is preferred to be perpendicular to the winds.

Likewise, it is preferred that the pattern is conducted during the time the saildrone is in the most extreme conditions during the flight.

- **Aircraft Pattern #6 (P-3 Pattern #6): sUAS/P-3 Saildrone Overflight**
  - The sUAS is released similarly to either an inflow module or an eyewall module. The drop location for the sUAS is a semicircle away (i.e., directly upwind) from the saildrone, with a preferred distance that gives the sUAS time to establish stable communications with the P-3 and descent to a low altitude. The sUAS will attempt to directly overfly the saildrone at a low altitude. Additionally, the P-3 will overfly the saildrone, preferably as close in time as possible as the sUAS. At this time, the P-3 will deploy as many expendables as possible (especially a possible mass streamsonde deployment). After the overflight, this P-3 module can be conducted using any pattern that maximizes inner core coverage and will collect flight level, TDR, dropsonde, streamSonde, AXBT, and SFMR observations for sUAS comparison and validation. Dropsondes, SST-capable dropsondes, and AXBTs (10-15 total) will be deployed in locations that are collocated with sUAS under flights. Further, if it is estimated that the sUAS battery and conditions permit a circumnavigation of the TC with a second saildrone overflight, the saildrone/sUAS/P-3 overflight would be conducted again.

Links to Other Experiments/Modules:
- Ocean Survey Experiment – led by Jun Zhang
- Tropical Cyclone Boundary Layer Module – led by Jun Zhang
- Research In Coordination with Operations Small Uncrewed Air Vehicle Experiment (RICO SUAVE) – led by Joe Cione
- Ocean Winds – led by Paul Chang
- Tropical Cyclones at Landfall Experiment – led by John Kaplan and Heather Holbach

Analysis Strategy:

Collocated atmospheric and oceanic observations will be used to understand processes within the air-sea transition zone. We will focus on better understanding how the evolution of atmospheric and oceanic characteristics and processes before, during, and after TCs influence these dynamic and complex relationships. Further, the collocation of these measurements will permit for a more robust analysis on the ocean's response and recovery to these extreme conditions.

Most data obtained from the observing platforms described above are distributed in real-time and used in analyses and experimental or operational modeling efforts. Observations collected from these platforms incorporate key air-sea interaction parameters (waves, heat and moisture fluxes), as well as subsurface hydrographic observations (temperature, salinity, currents) that serve to advance operational and experimental coupled models aiming to improve hurricane intensity forecasts. This will be accomplished through employing operational RTOFS-DA (coupled to HYCOM) and experimental Marine JEDI-DA (coupled to MOM6). This will lead to improved weakly coupled DA and will advance strongly coupled DA, which is critical in providing balanced initial conditions to a coupled hurricane-ocean forecast system. The impact of the various ocean data collected on the ocean state estimates will be analyzed through ocean Observing System

Experiments (OSEs) performed with the RTOFS-DA system and Marine JEDI DA. Their impact on hurricane forecasts will provide insights on improvements of initialization of the coupled hurricane-ocean HAFS-HYCOM and HAFS-MOM6 systems, respectively.

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