2025 NOAA/AOML/HRD Hurricane Field Program - APHEX

OCEAN OBSERVING EXPERIMENT

Flight Pattern Description

Experiment/Module: *CHAOS*: Coordinated Hurricane Atmosphere-Ocean Sampling

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

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 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]

Note: With limited numbers of assets, the expendables described in the flight patterns below are proposed on an *if-available* basis. Further, there are no specific requirements for regular GPS dropwindsondes over StreamSondes across all flight patterns.

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P-3 Pattern #1: Ocean Observing Platform Overflight

What to Target: Pre-existing ocean observing platform (saildrone, glider, mooring, drifter, profiling float, etc.), with preference to those within the region of TS-force winds or higher

When to Target: Must be within 10 nautical miles (NM) of the ocean observing platform, preferred would be directly overhead the platform, but 10 NM is the maximum distance. The closer, the better (significantly). *Can be during operational or research-based flights.*

Pattern: See CHAOS-1A for mid-track ocean observing platform location and CHAOS-1B for near end point ocean observing platform location. For CHAOS-1A, ensure turns do not exceed a roll angle of 20° to preserve TDR coverage. *Ideally the pre-existing flight pattern would be adjusted to include direct flyover.*

Flight altitude: No constraint

Leg length or radii: No constraint, preference for 10 NM straight legs centered on the ocean observing platform.

Estimated in-pattern flight duration: ~5-10 minutes (pending pre-existing flight pattern)

Expendable distribution: No constraint, preference for at least 1 atmospheric and oceanic expendables as available

Notes: The goal here is to get as close to the ocean observing platform as possible. The pre-existing ocean observing platform may have been deployed from a previous flight. If multiple ocean platforms present, please conduct pattern #1 multiple times to best fit all platforms present. Direction the pattern is flown and storm-relative position is not a constraint.

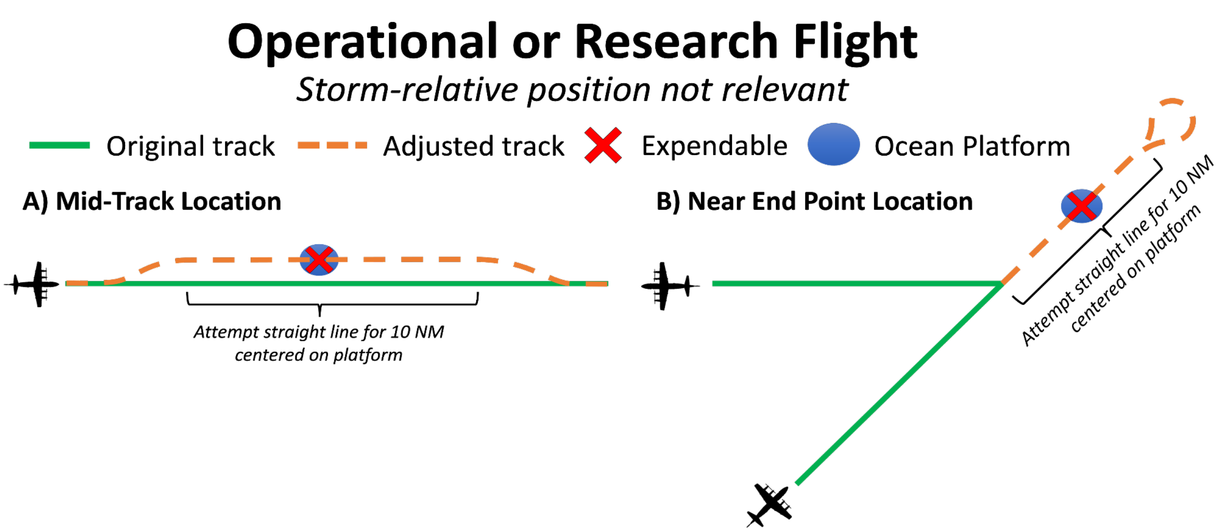

Figure CHAOS-1: *No specific pattern expected. Here, we illustrate a pre-existing flight path (green) adjusted (orange) to fly near/over the ocean observing platform (blue circle) along with the expendable location (red X) for an ocean observing platform located along the track (CHAOS-1A) or near the end point (CHAOS-1B).*

P-3 Pattern #2: Wave Drifter Deployment and Fly Over

What to Target: Area ahead of and slightly to the right of TC center

When to Target: On-flight KaIA must be working and running

Pattern: Figure-4 (e.g., CHAOS-2A) or specially designed pattern (e.g., CHAOS-2B)

Flight altitude: 10k ft or lower for drifter deployment

Leg length or radii: ≥ 20 NM

Estimated in-pattern flight duration: ~10 min (Figure-4); ~15 minutes (specially designed)

Expendable distribution: Priority: 2-4 wave drifters (2 A-DWSDs & 2 microSWIFTs); if available: 2 atmospheric expendables

Notes:
<u>A-sized Directional Wave Spectra Drifters (A-DWSDs):</u>
For operational flights (CHAOS-2A), A-DWSDs should be deployed ahead of the storm in the front-right quadrant with at least 10 NM spacing ahead of the eyewall and 15-20 NM spacing between drifters. For research flights (CHAOS-2B), A-DWSDs can be deployed in locations around the eye wall with repeat radial flights across the eyewall.

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.

<u>microSWIFTs (expendable wave buoys):</u>
For operational flights, microSWIFTs should be deployed ahead of the storm in the front-right quadrant with ideally 50-100 NM spacing ahead of the eyewall and 15-20 NM spacing between buoys. For research flights, microSWIFTs can be deployed in locations 50-100 NM ahead of the eye wall with either repeat radial flights across the eyewall (shown) or downwind legs.

<u>Both:</u>
There is an increased desire for both microSWIFTs and A-DWSDs to be deployed during the same mission as complementary to each other. Further, if a pre-existing ocean observing platform is present, there is increased desire to target some of the wave drifters deployments to the ocean observing platform, as requested by the PIs.

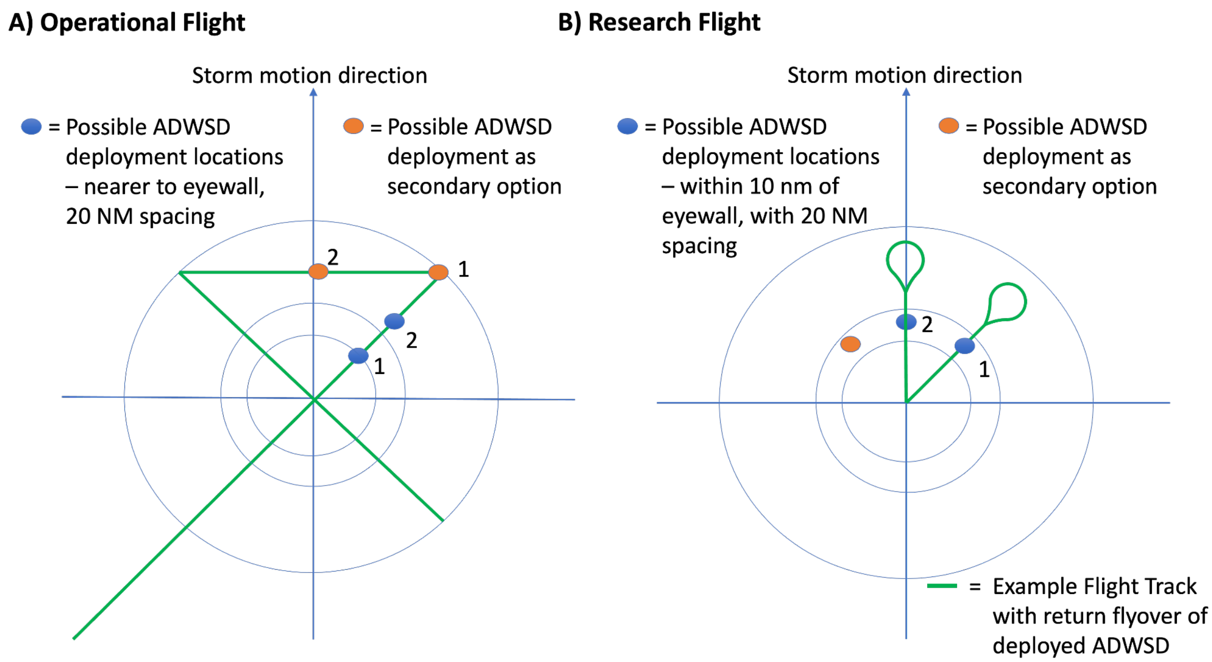

Figure CHAOS-2: *Typical pattern is expected to be a Figure-4 (CHAOS-2A) or other standard patterns in HFP Appendix A, with deployment locations. For research missions, other specially designed P-3 patterns may be used (CHAOS-2B).*

P-3 Pattern #3: small Uncrewed Aircraft Systems (sUAS)/P-3 Saildrone Overflight

***NOTE:** The detailed version of this pattern is described in "Strategic use of Emerging Technologies To Advance Hurricane Prediction" Pattern #5.

What to Target: Saildrone within region of TS-force winds

When to Target: Preferably the estimated time of strongest conditions for the saildrone during TC intercept

Pattern: Pending conditions, possibly Figure-4 (as in CHAOS-3 P-3 Flight Path Orange)

Flight altitude: 10 kft for sUAS deployment, then no constraint

Leg length or radii: Pending conditions, minimum of 10 NM

Estimated in-pattern flight duration: 30+ min (Figure-4)

Expendable distribution: See "Strategic use of Emerging Technologies To Advance Hurricane Prediction" Pattern #5

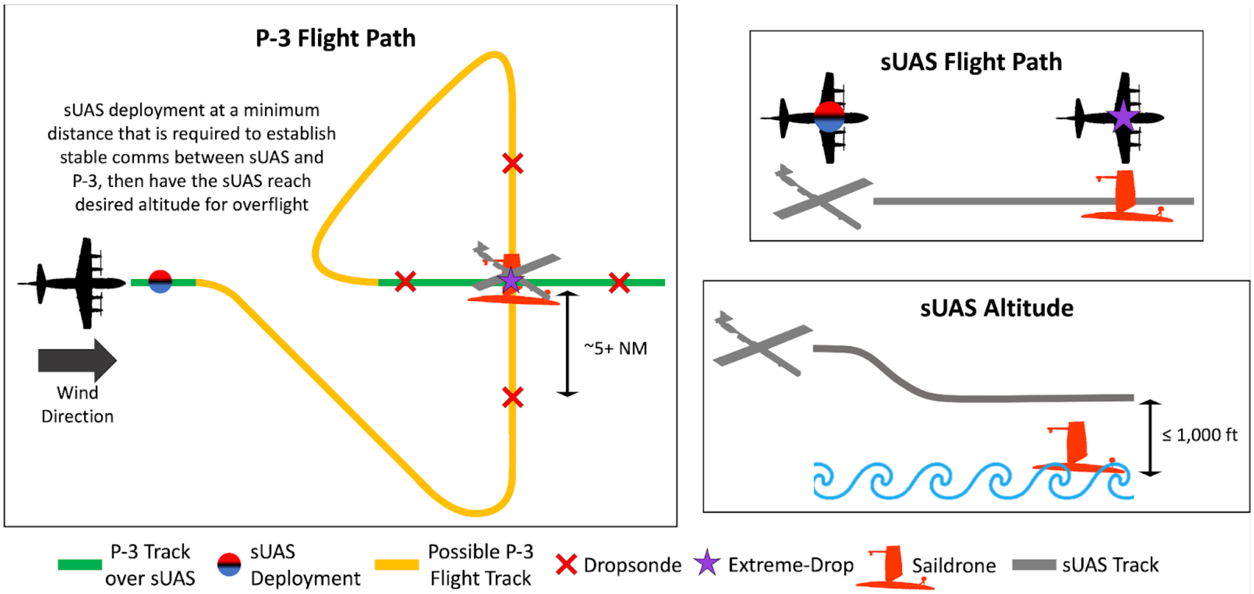

Figure CHAOS-3: *P-3 and sUAS flight patterns for the saildrone overflight module. The sUAS is deployed far upwind (distance pending other variables) of the saildrone at the red/black/blue circle. The following goal would be to have the P-3 fly overhead the saildrone at the nearest time possible as the sUAS overflies the saildrone (depicted in green). The P-3 will (pending safety) deploy expendables ~5 NM either side of the saildrone and a deployment of all available types of expendables directly overhead the saildrone. During the time between the deployment of the sUAS and the overfly, the P-3 pattern depends on conditions, with the orange path depicting what would be preferred. The sUAS flight path (top right; gray) should be downwind directly to the saildrone. During this time, the sUAS will drop to ≤ 1,000 ft (pending conditions) for the overflight. If battery and conditions permit the sUAS to circumnavigate the TC and overfly the saildrone again, then the final leg of the pattern is repeated (final green line).*

P-3 Pattern #4: Tropical Cyclone Boundary Layer

What to Target: Sample the inner core and near environments of the TC.

When to Target: Any strength TC; no land restrictions. This module complements standard TDR missions.

Pattern: Rotated Figure-4 (as in CHAOS-4 A), Butterfly (as in CHAOS-4 B), or Circumnavigation (as in CHAOS-4 C). We will not consider a single Figure-4 pattern.

Flight altitude: 10–12 kft or as high as possible. Either radar or pressure altitude is good.

Leg length or radii: Leg lengths/radius can follow the TDR mission or main pattern.

Estimated in-pattern flight duration: See the listing of standard pattern figures. The P-3 flight duration is ~5 hrs for the Rotated Figure-4 pattern, ~3 hr 25 min for Butterfly, and ~4 hr 5 min for a Circumnavigation.

Expendable distribution: The number of expendables and locations depends on the pattern flown and is detailed as follow:

Rotated Figure-4: This pattern requires 34 dropsondes and 9 AXBTs. Dropsondes are deployed at the storm center, 105 NM (i.e., end point) and 60 NM radii, and the radius of maximum wind (RMW) along each of 8 radial legs (rotated Figure-4 pattern). On 4 of the 8 passes across the RMW, rapid deployment (~1 min spacing) of 3 dropsondes is requested. AXBT deployments are paired with dropsondes at each of the mid-points and the center as indicated in CHAOS-4A.

Butterfly: This pattern requires 20 dropsondes and 7 AXBTs. Dropsondes are deployed at the storm center, 105 NM radii (i.e., end point), the RMW, and the mid-point between the RMW along each of 6 radial legs. AXBT deployments are paired with dropsondes at the mid-point along each of 6 radial legs plus center as indicated in CHAOS-4B.

Circumnavigation: This pattern requires 18 dropsondes and 5 AXBTs. Dropsondes are deployed at the storm center, 105 NM radii (i.e., end point), the RMW, and at the vertices of the octagon. AXBT deployments are paired with dropsondes during a center pass and in each of the four quadrants along the octagon as indicated in CHAOS-4C.

If resources permit, center drops are requested on the initial and final pass through the eye for all patterns flown. If AXBTs are limited, then only one center pass is requested.

Notes: Direction the pattern is flown is not a constraint. Use TDR defaults. Use straight flight legs as safety permits. Optimally, this pattern would be flown in conjunction with sUAS and other uncrewed systems (e.g., saildrones, gliders) to augment the boundary layer measurements from AXBTs and dropsondes.

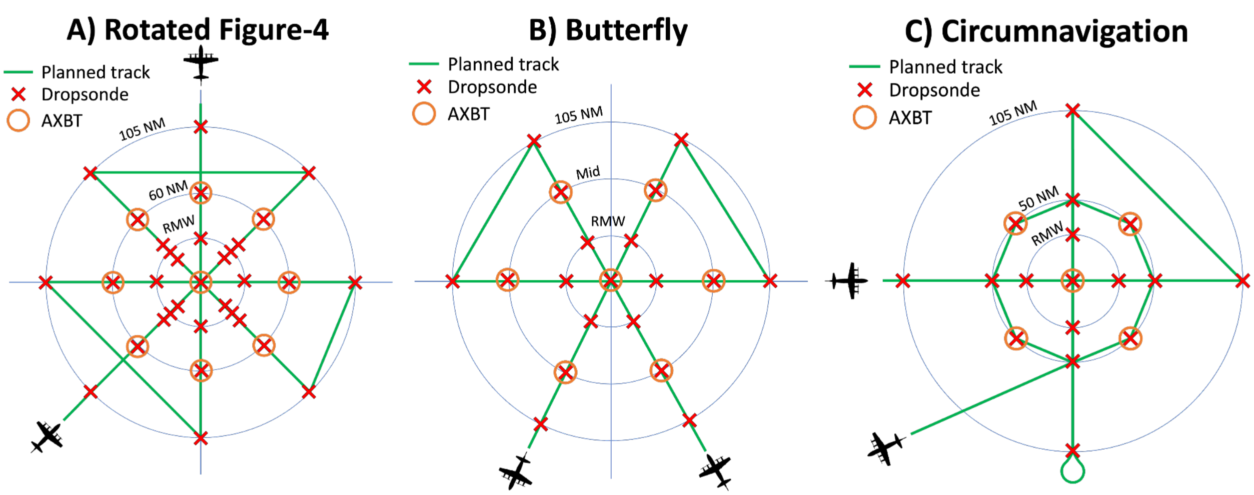

Figure CHAOS-4: *Figure-4 (A), Butterfly (B), and P-3 Circumnavigation (C) patterns shown here. The direction the pattern is flown is not a constraint. The P-3 flight track is depicted in green. Various radii (e.g., 105 NM, 60 NM, RMW) are shown in blue. Expected dropsonde deployments are marked with a red X and AXBT deployment locations with orange circles.*

P-3 Pattern #5: Surface Wind Temporal Sampling

What to Target: Buoys or other ocean platforms within the storm environment that have a reliable anemometer.

When to Target: Any time during the flight when passing near or over a buoy/ocean platform.

Pattern: This module can be flown with any of the standard in-storm flight patterns. This pattern consists of flying a series of 10-minute legs, straight and level parallel to the flight-level wind direction in a region of homogenous wind and rain conditions upwind and downwind centered on the buoy or ocean platform's location for approximately 30 minutes. The necessary conditions are most likely to be encountered on the downwind legs or within the outer vortex away from the stronger wind gradients.

Flight altitude: 8–12 kft (radar altitude is preferred)

Leg length or radii: ~70 km

Estimated in-pattern flight duration: 30 min

Expendable distribution: Release a dropsonde during each pass over the buoy or ocean platform's location.

Instrumentation Notes: Use standard SFMR, flight-level, TDR, IWRAP (if available), and ROARS instrument set-ups. It is important to maintain as straight and level of flight as possible.