END STAGE EXPERIMENT
Flight Pattern Description

Experiment/Module: Tropical Cyclones at Landfall

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This year's experiment is dedicated in memory of our dear friend and colleague, Peter Dodge.

Requirements: TC making landfall, approaching the coastline, undergoing rapid weakening, or extratropical transition.

End Stage Science Objective(s) Addressed:

1) Collect observations targeted at better understanding changes TCs undergo at landfall. Objectives include validation of surface wind speed estimates and model forecasts, understanding factors that modulate intensity changes near and after landfall, and to understand processes that lead to tornadoes in outer rainbands [*APHEX Goals 1, 3*].
2) Test new (or improved) technologies with the potential to fill gaps, both spatially and temporally, in the existing suite of airborne measurements in landfalling TCs, rapidly weakening TCs, and TCs undergoing extratropical transition. These measurements include improved three-dimensional representation of the TC wind field, more spatially dense thermodynamic sampling of the boundary layer, and more accurate measurements of ocean surface winds [*APHEX Goal 2*].

P-3 Pattern #1: SFMR Coastal

What to Target: Onshore and/or offshore flow regions of 50 kt or greater surface winds of a tropical storm or hurricane that is forecast to make landfall in an area with varying bathymetry near the coastline.

When to Target: This module should be performed near the time of landfall in the region where the bathymetry gradient is strongest, and the sustained winds are greater than 50 kt. If feasible, sampling upstream/downstream regions of the mobile radars or profiling systems is preferred.

Pattern: Break-away/non-standard (see Fig. EN-1 and description below):

The P-3 would fly perpendicular to the coastline (EN-1), across the bathymetry gradient, in a region with near constant surface winds. After flying away from the coast for about 27 n mi (50 km), the P-3 would turn downwind and then back towards the coast repeating a similar line as the first leg. This pattern can also be flown in reverse with the first leg flying towards the coast. It is ideal to have the WSRA collecting surface wave spectra data as well. Finally, this pattern may also be adjusted to be offshore of the newly developed U. Florida's Sentinel towers if any of those have been deployed.

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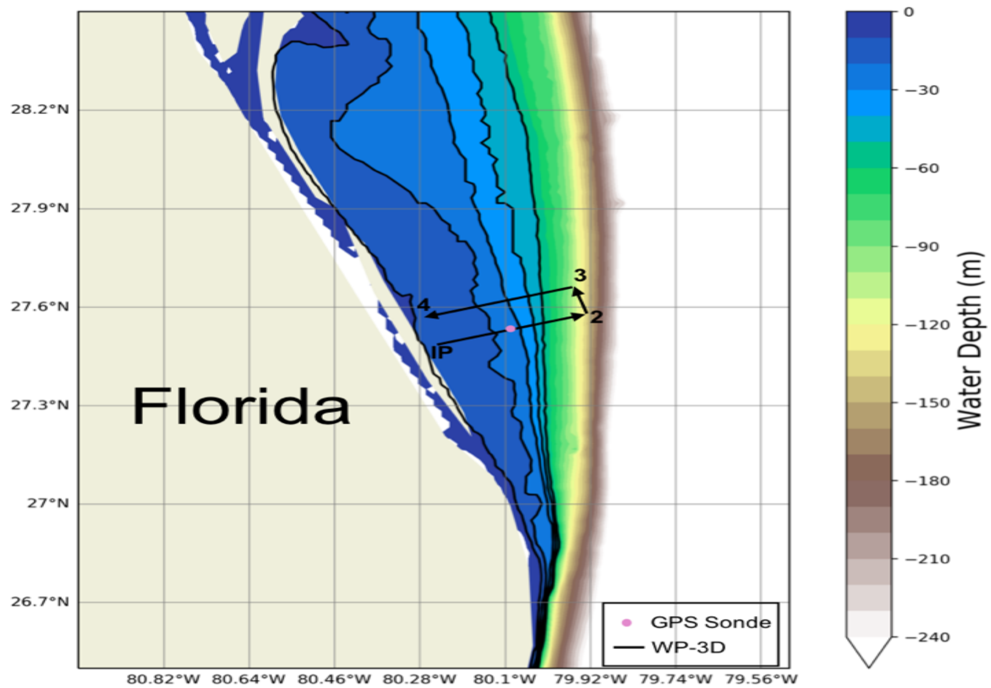

Figure EN-1. *SFMR coastal module*

Flight altitude: Can be performed at an altitude between 5 kft to 12 kft, preferably radar altitude. Aircraft should maintain a constant altitude and attitude throughout the module.

Leg length or radii: ~13-27 n mi (25–50 km).

Estimated in-pattern flight duration: ~30–45 min.

Expendable distribution: Dropsonde at middle of first leg. If winds appear to vary over the leg then an additional dropsonde may be necessary. No AXBTs are required but could be helpful if released with the first dropsonde, when available.

Instrumentation Notes: SFMR should be operating normally. Preferable to also have the WSRA collecting surface wave spectra data. Tail and Lower fuselage radars should also be operated normally, with the lower fuselage (MMR) in HWX mode if conditions permit. Dropsondes should be transmitted to GTS.

P-3 Pattern #2: Coastal Survey

What to Target: The region with winds exceeding 30 kt that is within ~80 n mi (200 km) radius of the center of a tropical storm or hurricane that is forecast to make landfall along the U.S coastline.

When to Target: This module should be performed within ~3-6 h of the time of landfall.
Pattern: Break-away/non-standard (see Fig. EN-2 below and description below):

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Fig. EN-2 shows a sample Coastal Survey pattern for a hurricane landfall near Melbourne, Florida. The P-3 should fly parallel but ~20-25 n mi (40-45 km) offshore so that the SFMR and WSRA, if available, footprints are out of the surf zone. The second pass should be parallel and just offshore ~5 n mi (10 km) from the coast or as close to the coastline as safety permits. Finally, a short leg from the coastline spiraling towards the storm center could be flown if time and safety permit. If mobile radars are deployed, legs should be adjusted so airborne radar data and sondes can be released in the surface dual Doppler lobes (typically ~15-20 n mi (30-40 km) from radar location) when precipitation is present. If other mobile surface observing teams are deployed, dropsondes should be released as close to their locations as possible accounting for any downwind translation. This pattern can also be flown just as the eyewall is coming ashore.

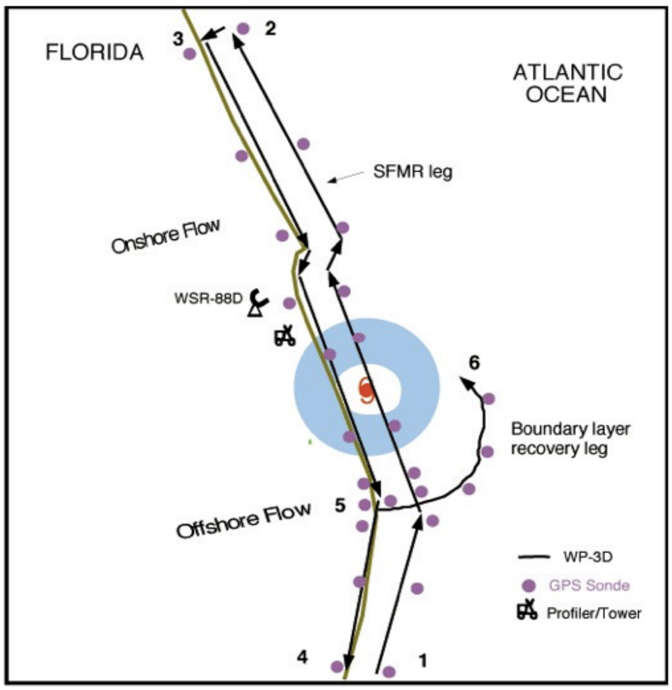

Figure EN-2. *Coastal Survey module*

Flight altitude: ~10 kft (radar altitude preferred)

Leg lengths: ~150 n mi (275 km) for each parallel leg

Estimated in-pattern flight duration: ~2-3 h

Expendable distribution: Dropsondes at the RMW as well as up to four additional drops equally spaced on each side of the storm along both the near shore and offshore legs. One or two drops could be made (at the LPS's discretion) along the leg spiraling toward the center if that portion of the pattern is flown. If surface towers, wind profilers, or portable mesonet stations are present, adjust drops to be upwind of the surface sites.

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Instrumentation Notes: The tail-Doppler radar (TDR) should be turned on and scanning normally. The Lower Fuselage radar (MMR) should be in HWX mode if conditions permit. Aircraft should avoid penetration of intense reflectivity regions (particularly those overland). SFMR and WSRA, if available, should be operating normally. AXBTs are at LPS discretion to sample near-shore oceanic conditions. If available, AXBTs should be paired with dropsondes. Dropsondes should be transmitted to GTS.

P-3 Pattern #3 : Offshore Intense Convection

What to Target: An intense rain band of either a tropical storm or hurricane that is forecast to make landfall along the U.S coastline.

When to Target: This module should be performed within ~12-24 h of the time of landfall as the rainbands begin to encroach on the coastline.

Pattern: Break-away/non-standard (see Fig. EN-3 and description below):

Fig. EN-3 shows a sample Offshore Intense Convection flight pattern near the Carolina coast. The P-3 should (safety permitting) cross the target band 10-15 n mi (20–25 km) downwind of the intense convective cells and then proceed to 15 n mi (25 km) outside the rainband axis all the while maintaining a ~5 n mi (10 km) separation from the outer edge of the band. The aircraft then turns upwind and proceeds along a straight track parallel to the band axis. When the P-3 is 10-15 n mi (20–25 km) upwind of the target cells, the aircraft turns and proceeds along a track orthogonal to the band axis until the P-3 is 15 n mi (25 km) inside the rainband then turns downwind and flies parallel to the rainband axis while maintaining a ~5 n mi (10 km) separation from the edge of the rainband for safety. Minimally, a single downwind leg parallel to the rain band axis may be flown while maintaining ~5 n mi (10 km) separation from the edge of the rainband for safety.

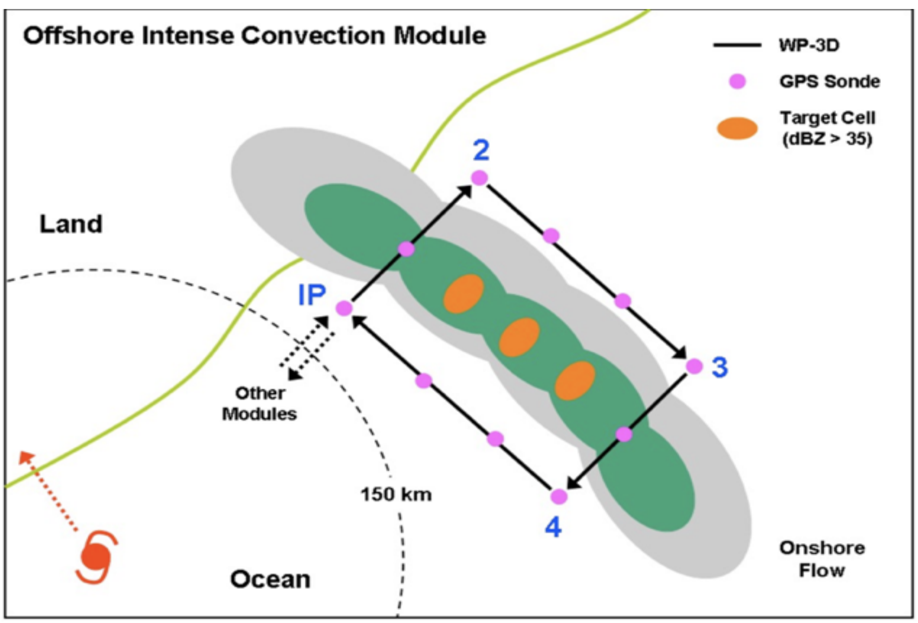

Figure EN-3. *Offshore Intense convection module*

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Flight altitude: 10 kft or higher radar altitude

Leg Lengths: ≥ 40 nm (75 km) for each parallel leg > 20 n mi (30 km) for each orthogonal leg

Estimated in-pattern flight duration: 1–2 h

Expendable distribution: Deploy dropsondes at the start or end points of each leg, at the band axis crossing points, and at 10-15 n mi (20–25 km) intervals along each leg parallel to the band. At least 2 dropsondes should be deployed on either side of the convection and at least 1 dropsonde should be deployed each time the band-axis is crossed (for a minimum of 6 dropsondes).

Instrumentation Notes: The tail-Doppler radar (TDR) should be turned on and scanning normally. The Lower Fuselage radar (MMR) should operate in HWX mode to collect both reflectivity and Doppler velocity. Aircraft should avoid penetration of intense reflectivity regions (particularly over or near land). AXBTs may be released at the discretion of the LPS but are not a requirement. Dropsondes should be transmitted to the GTS.

P-3 Pattern #4: Coastal Air-Sea Interaction

What to Target: A tropical storm or hurricane that is forecast to make landfall perpendicular to the U.S. continental coastline when the storm's center is located ~108 n mi (200 km) offshore. The goal is to sample the onshore and offshore flow of the inner-core of the TC. Ideally, a TC with a translation speed of 5 ms^{-1} or less, but 12 ms^{-1} or less is acceptable.

When to Target: This module should be performed when sustained winds are greater than 30 kt in the region of interest and the center of circulation is approximately 108 n mi (200km) offshore with bathymetry greater than 150 m near the center of circulation. If the center of circulation is over a minimum bathymetry of 150 m, but less than 108 n mi offshore depending on coastline, leg lengths should be scaled with offshore distance. Guidance on bathymetry will be provided by the PIs before or during the flight.\

Pattern: Rotated Figure 4 (see Fig. EN-4) with modified expendables

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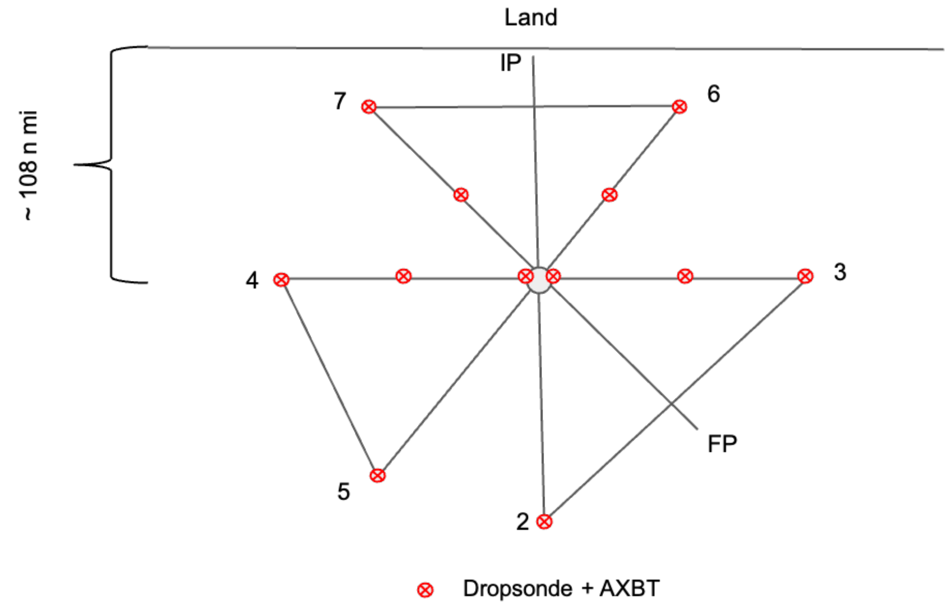

Figure EN-4. *Coastal Air-Sea Interaction module*

Flight altitude: Can be performed at any radar altitude between 8 kft to 10 kft with 8kft being preferred.

Leg lengths: ~108 n mi (~200 km)

Estimated in-pattern flight duration: ~5 h for a dedicated research mission or no additional time if expendables are added to an operationally tasked flight.

Expendable distribution: A total of 12 combo (dropsonde and AXBT) drops as shown in Fig. EN-4. Combo drops at points 2, 3, the inbound RMW, the outbound RMW, at each midpoint between the RMW and endpoint inbound from point 3, outbound to point 4, outbound to point 6, and inbound from point 7. The total number of combo drops can be reduced to 8, in the event that dropsondes and/or AXBTs are low, to follow drop pattern between points 3 and 4 (inbound RMW, outbound RMW, one at each midpoint, one at each endpoint) and drops at points 6 and 7. Combo drops outside of points between 3 and 4 may be augmented to align with any coastal ocean surface measurements that may be present from Ocean Observing modules (i.e., drifters, surface or bottom moorings, gliders, ALAMO floats). Dropsonde data should be transmitted to the GTS (along with AXBT data, if possible). “Shallow” AXBTs are more desirable for this pattern, when available, but “deep” AXBTs are also acceptable.

Instrumentation Notes: SFMR as well as TDR should also be operated normally. Use straight flight legs as safety permits. Dropsondes should be transmitted to the GTS.