EARLY STAGE EXPERIMENT
Flight Pattern Description

Experiment/Module: Analysis of Intensity Change Processes Experiment (AIPEX)

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Requirements: TD, TS, Category 1

Early Stage Science Objective(s) Addressed:

1) Collect datasets that can be used to improve the understanding of intensity change processes, as well as the initialization and evaluation of 3-D numerical models, particularly for TCs experiencing moderate vertical wind shear [*APHEX Goals 1, 3*].
2) Obtain a quantitative description of the kinematic and thermodynamic structure and evolution of intense convective systems (convective bursts) and the nearby environment to examine their role in TC intensity change [*APHEX Goals 1, 3*].
3) Improve our understanding of the physical processes responsible for the formation and evolution of arc clouds, as well as their impacts on TC structure and intensity in the short-term [*APHEX Goals 1, 3*].
4) Test new (or improved) technologies with the potential to fill gaps, both spatially and temporally, in the existing suite of airborne measurements in early stage TCs. 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:

What to Target: Sample the inner core region of a TC

When to Target: Every 12 h [*optimal*] or every 24 h [*minimal*], possibly in coordination with a corresponding G-IV mission (G-IV Pattern #1, Pattern #2, or Pattern #3), depending on the AIPEX *Scenario* chosen

Pattern: Standard Figure-4, potentially rotated or repeated after initial pattern; oriented such that radial passes are aligned through approximately the upshear, downshear, left-of-shear, and right-of-shear directions –or– aligned within quadrants, i.e., downshear right, downshear left, upshear left, and upshear right, or alternatively oriented parallel and perpendicular to the vertical tilt direction of the circulation center. Can be centered on the low-level or mid-level center.

Flight altitude: 10–12 kft, either radar or pressure altitude; potentially up to 20 kft, if hazard avoidance possible

Leg length or radii: 105 n mi (195 km)

Estimated in-pattern flight duration: ~ 4.5 h

Expendable distribution: [*optimal*] (up to 32 dropsondes total) If coinciding G-IV mission, modify standard by moving the midpoint dropsonde to half the radius of innermost G-IV circumnavigation radii. AXBTs preferably paired with dropsondes at mid- and turn points and center. Release a dropsonde at the radius of maximum wind (RMW) and 1.5 x RMW, if that location is significantly different [>10 n mi (19 km)] from any of the standard dropsonde locations. No AXBTs need to be coordinated with these RMW-based drops. Release additional dropsondes along the radial leg between principal rainband and RMW if a rainband exists and location is [>10 n mi (19 km)] from existing drop location, not to exceed >4 additional dropsondes per mission. [*minimal*] (10–12 dropsondes total). Modify standard as stated in [*optimal*], keeping only midpoint drops, as well as center drops on the first and last pass. AXBTs preferably paired with dropsondes at midpoints and center.

Instrumentation Notes: Use TDR defaults. Use straight flight legs as safety permits. Inbound-outbound passes should be uninterrupted.

P-3 Pattern #2:

What to Target: Sample the inner core region of a TC

When to Target: Every 12 h [*optimal*] or every 24 h [*minimal*], possibly in coordination with a corresponding G-IV mission (G-IV Pattern #1, Pattern #2, or Pattern #3), depending on the AIPEX *Scenario* chosen

Pattern: Standard Butterfly; oriented such that the upshear quadrants contain the most radial legs, with an option to orient such that downshear contains most of the radial legs, if precipitation sampling is preferred when a storm exhibits an asymmetric precipitation distribution. Can be centered on the low-level or mid-level center.

Flight altitude: 10–12 kft, either radar or pressure altitude; potentially up to 20 kft, if hazard avoidance possible

Leg length or radii: 105 n mi (195 km)

Estimated in-pattern flight duration: ~ 3 h 25 min

Expendable distribution: [*optimal*] (up to 36 dropsondes total) If coinciding G-IV mission, modify standard by moving the midpoint dropsonde to half the radius of innermost G-IV circumnavigation radii. AXBTs preferably paired with dropsondes at mid- and turn points and center. Release a dropsonde at the radius of maximum wind (RMW) and 1.5 x RMW, if that location is significantly different [>10 n mi (19 km)] from any of the standard dropsonde locations. No AXBTs need to be coordinated with these RMW-based drops. Release additional dropsonde along the radial leg between principal rainband and RMW if a rainband exists and location is >10 n mi (19 km) from existing drop location, not to exceed >4 additional dropsondes per mission. [*minimal*] (12–15 dropsondes total). Modify standard as stated in [*optimal*], keeping only midpoint drops, as well as center drops on the first and last pass. AXBTs preferably paired with dropsondes at midpoints and center.

Instrumentation Notes: Use TDR defaults. Use straight flight legs as safety permits. Inbound-outbound passes should be uninterrupted.

P-3 Module #1 (*"Upshear Circumnavigation Module"*):

What to Target: The relatively dry, precipitation-free upshear region of a weak TC

When to Target: Every 12 h [*optimal*] or every 24 h [*minimal*], depending on the AIPEX *Scenario* chosen

Pattern: Fly upshear semicircle, including the boundary between no convection and convection, if such a boundary exists, at up to three possible radii: 90 n mi (167 km), 60 n mi (111 km), and 40 n mi (74 km).

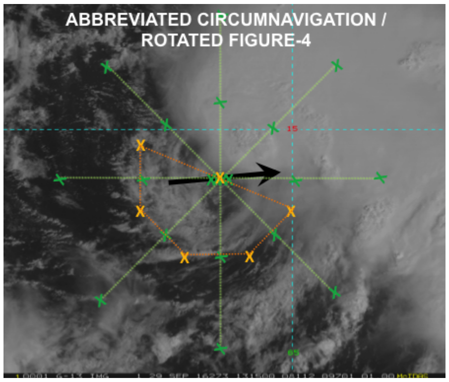

Figure AIPEX1, showing an example of one possible radius (orange) to be flown

Flight altitude: As high as possible above 20 kft radar altitude

Leg length or radii: Up to three possible radii: 90 n mi (167 km), 60 n mi (111 km), and 40 n mi (74 km)

Estimated in-pattern flight duration: 30 min to 2 hr, depending on number and radii chosen

Expendable distribution: Release up to 8 equally-spaced dropsondes along each partial circumnavigation

Instrumentation Notes: None

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P-3 Module #2 (*"Rainband Module"*):

What to Target: The principal rainband

When to Target: Every 12 h [*optimal*] or every 24 h [*minimal]*, depending on the AIPEX *Scenario* chosen

Pattern: Follow the principal rainband inward towards the center by paralleling the band (either radially inside or outside), keeping the band within range (~10 n mi) of TDR sampling

Flight altitude: 10–12 kft, either radar or pressure altitude

Leg length or radii: N/A

Estimated in-pattern flight duration: ~30 min

Expendable distribution: Release dropsondes approximately every 20 n mi (37 km)

Instrumentation Notes: Pattern should be flown such that TDR sampling of the rainband is optimized, but remaining safely outside of the rainband

P-3 Module #3 (*"High Density Eyewall Drops"*):

What to Target: The radius of peak wind and/or rain near the developing eyewall region

When to Target: Every 12 h [*optimal*] or every 24 h [*minimal*], depending on the AIPEX *Scenario* chosen

Pattern: On inbound/outbound pass of center, release a high-density string of dropsondes, distributed such that they cover inbound and outbound of the RMW and peak convection

Flight altitude: 10–12 kft, either radar or pressure altitude

Leg length or radii: N/A, flown part of *AIPEX P-3 Pattern #1* or *#2*

Estimated in-pattern flight duration: No added time to pattern, sequence lasts up to 8 min

Expendable distribution: Release a sequence of up to 8 dropsondes, every [2.5–5 n mi (5–10 km), approximately every 30 seconds to 1 minute]

Instrumentation Notes: Use straight flight legs as safety permits. Inbound-outbound passes should be uninterrupted.

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P-3 Module #4 (*"Dry Air Entrainment Module"*):

What to Target: The relatively dry, precipitation-free region ("dry slot") located between the eyewall or inner core convective region and principal / outer rainbands. This feature is likely best identified using water vapor satellite imagery, precipitable water, and/or model analyses of mid-troposphere relative humidity.

When to Target: Every 12 h [optimal] or every 24 h [minimal], depending on the AIPEX *Scenario* chosen

Pattern: Follow the dry air region, potentially radially inward. Optional to end the pattern early for continuation of Figure 4, utilizing the module within the downwind leg.

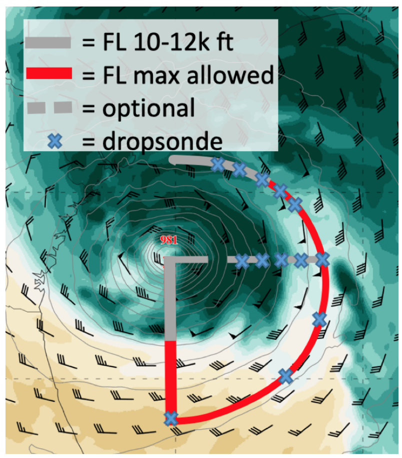

Figure AIPEX2, showing an example of one possible Dry air entrainment module to be flown; shading shows relative humidity (drier air is represented by tan colors; more humid air [clouds] is represented by greener colors)

Flight altitude: 10–12 kft within precipitation regions (grey line), as high as possible above 20 kft radar altitude (red line) in precipitation free regions.

Leg length or radii: N/A

Estimated in-pattern flight duration: 45 min to 2 hr, depending on radius of dry slot and optional or full module

Expendable distribution: Release 4 high-altitude dropsondes on downwind leg. Increase frequency beginning within 20 n mi of precipitation interface with up to 5 dropsondes released approximately every 10 n mi.

Instrumentation Notes: Pattern can also be flown in conjunction with goals of *"Rainband Module"* by flying near enough to the principal rainband for TDR and MMR sampling.

P-3 Module #5 (*"Vortex Alignment Module"*):

What to Target: The vortex and precipitation structure associated with a vertically misaligned (i.e., tilted) TC vortex. The vortex tilt structure can be identified from the most recent TDR analysis generated from a given mission. Ideally, the 2–7-km tilt magnitude is on the order of 50–125 km.

When to Target: Every 6–12 h

Pattern: Fly straight legs beginning 15 n mi (~30 km) upstream of the low-level TC center (at a height of 2 km) to 25 n mi (~50 km) downstream of the mid-level TC center (at a height of 6–7 km). Then the aircraft samples the same transect, following the opposite heading, from upstream of the mid-level TC center to downstream of the low-level TC center. This pattern is repeated for an additional 1–4 times, with potential changes in orientation of the legs as needed to account for evolution in the tilt magnitude and direction.

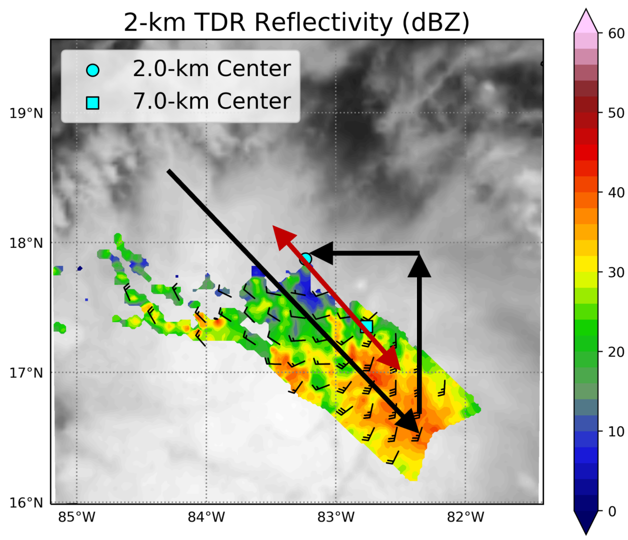

Figure AIPEX3, showing an example of one possible Vortex alignment module to be flown. IR brightness temperatures are shown in grayscale shading and 2-km TDR reflectivity is shown in color shading and wind in black barbs. The vortex tilt structure is identified from an initial Figure-4 pattern, shown by the black arrows, while the Vortex Alignment Module flight track would follow the red arrows, flying in straight lines back and forth between the low-level center (shown here by the cyan circle) and the mid-level center (shown here by the cyan square).

Flight altitude: 10–12 kft within precipitation regions (red line)

Leg length or radii: Dependent upon vortex tilt magnitude as described above

Estimated in-pattern flight duration: 45 min to 2 hr, depending on tilt magnitude, such that at least two complete transects (four radial legs) between the low-level and mid-level TC centers are conducted.

Expendable distribution: Release dropsondes each-time the low-level TC center is transected.

Instrumentation Notes: TDR analyses should be generated for each radial leg (e.g., each leg between either the low-level to mid-level TC center or vice versa.

P-3 Module #6 (*"Flight-Level Assessment of Intensification in Moderate Shear [FLAIMS] Module"*):

What to Target: The quadrant (or azimuthal region) of maximum wind speed in a moderately sheared weak TC, either during a period of intensification or when imminent intensification is likely.

When to Target: Every 6–12 h

Pattern: Fly repeated straight radial legs along the same azimuth, either beginning from the center and continuing outward to 105 n mi, or beginning at the outer point and continuing inward to the center, depending on where the module is initiated relative to the region of maximum winds. At the vortex center (outer point of the leg), the P-3 turns around and flies outbound (inbound), i.e., the center is not crossed. This pattern is repeated such that there are a total of 3–6 combined inbound and outbound radial legs. Optionally, the leg length can be shortened if the inner-core and maximum winds are confined to well within 105 n mi.

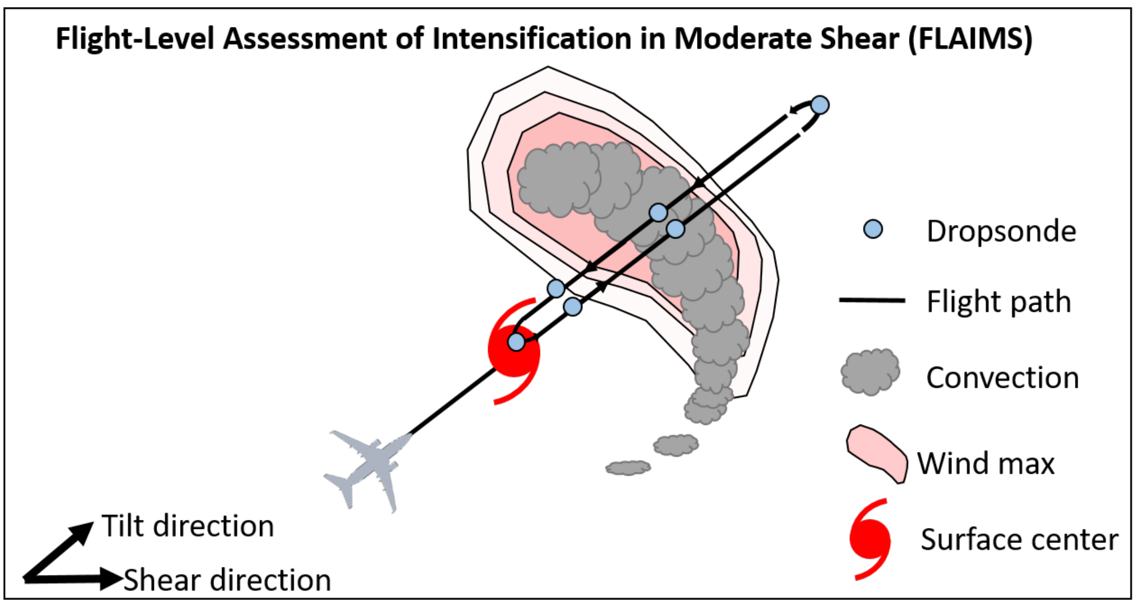

Figure AIPEX4, showing a schematic illustration of the FLAIMS module. In this example, the initial point of the module is the low-level vortex center, and an initial outbound leg is followed by an inbound leg along the same azimuth where the maximum flight-level winds are found. Following this inbound leg and center penetration, the plane turns around at the vortex center location and begins another outbound leg. This can be repeated for a total of 3–6 combined inbound and outbound legs. Note that the initial leg can alternately be inbound, and the module can either end with a center crossing or at the outer point.

Flight altitude: 10–12 kft

Leg length or radii: 105 n mi, but optionally can be shortened as described above.

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Estimated in-pattern flight duration: 1.5–3 hr if standard leg lengths are flown

Expendable distribution: Release dropsondes at each vortex center point and outer point, as well as the leg midpoint and RMW.

Instrumentation Notes: TDR analyses should be generated for each radial leg.

G-IV Pattern #1:

What to Target: Sample the near environment and environment of a TC

When to Target: Every 12 h [*optimal*] or every 24 h [*minimal*], preferably in coordination with a corresponding P-3 mission (P-3 Pattern #1 or #2), depending on the AIPEX *Scenario* chosen

Pattern: Standard G-IV Circumnavigation (octagon). Should be centered on the low-level or mid-level circulation center.

Flight altitude: 40–45 kft

Leg length or radii: 3 circumnavigations at constant radii: 150 n mi (277 km), 90 n mi (167 km), and 60 n mi (111 km). The innermost radii can be adjusted outward if necessitated by hazard avoidance (outer two radii rings should be similarly adjusted, if time allows).

Estimated in-pattern flight duration: ~ 5–6 h

Expendable distribution: Dropsonde at each turn point; 24 in total; additional sondes could be released between turn points when a higher density is desired.

Instrumentation Notes: Use TDR defaults. Use straight flight legs as safety permits.

G-IV Pattern #2:

What to Target: Sample the near environment and environment of a TC

When to Target: Every 12 h [*optimal*] or every 24 h [*minimal*], preferably in coordination with a corresponding P-3 mission (P-3 Pattern #1 or #2), depending on the AIPEX *Scenario* chosen. Supplemental observations can also be made when model sensitivity regions are indicated (e.g., derived from ECMWF and the COAMPS-TC model ensembles) that could positively impact forecasts of TC track, intensity and/or structure.

Pattern: Standard G-IV Star with Circumnavigation

Flight altitude: 40–45 kft

Leg length or radii: 2 circumnavigations at constant radii: 210 n mi (388 km) outer and 90 n mi (167 km) inner radii (*standard*). Depending on the time of day, aircraft duration limitations, and safety considerations, the lengths of the inner (outer) points could be shortened (extended) if an opportunity to sample a diurnal pulse presents itself.

Estimated in-pattern flight duration: ~5 h

Expendable distribution: Dropsonde at each turn point; 20 in total; additional sondes could be released between turn points when a higher density is desired.

Instrumentation Notes: Use TDR defaults. Use straight flight legs as safety permits.

G-IV Pattern #3:

What to Target: Sample the inner core, near environment, and environment of a TC

When to Target: Every 12 h [*optimal*] or every 24 h [*minimal*], depending on the AIPEX *Scenario* chosen

Pattern: Standard single Figure-4 with Double Circumnavigation; if time is not available to complete the full pattern, the Fig. 4 is prioritized with either the inner or outer circumnavigation

Flight altitude: 40–45 kft

Leg length or radii: Up to 150 n mi (275 km) for the Fig. 4; 90 n mi (165 km) and 210 n mi (390 km) for the inner and outer circumnavigation, respectively

Estimated in-pattern flight duration: ~6.5 h

Expendable distribution: Dropsonde at each turn point, midpoint, and center on each pass, and another at the midpoint of downwind leg; dropsonde at each turnpoint of the circumnavigations; 11 total for Fig. 4, 13 total for circumnavigations, and 24 total for pattern. Optionally, can increase the density of sondes in Fig. 4 and/or circumnavigations, potentially doubling the total dropsondes released in the pattern.

Instrumentation Notes: Use TDR defaults. Use straight flight legs as safety permits.