MATURE STAGE EXPERIMENT
Flight Pattern Description

Experiment/Module: TC Diurnal Cycle Experiment

Investigator(s): Jason Dunion (Co-PI), Morgan O'Neill (Co-PI, Stanford Univ.), Daniel Chavas (Purdue Univ.), Allison Wing (Florida State University), Dave Raymond (New Mexico Tech), Zeljka Fuchs-Stone (New Mexico Tech)

Requirements: Categories 2–5

Mature Stage Science Objective(s) Addressed:

1) Collect observations targeted at better understanding internal processes contributing to mature hurricane structure and intensity change [*APHEX Goals, 1 3*].
2) Collect observations targeted at better understanding the response of mature hurricanes to their changing environment, including changes in vertical wind shear, moisture and underlying oceanic conditions [*APHEX Goals 1, 3*].

P-3 Pattern #1

What to Target: Sample the inner core and near environments of the TC and TC diurnal pulses/waves.

When to Target: Any strength TC (though TC diurnal cycle (TCDC) signals tend to be stronger in Cat2+ storms); no land restrictions. There are time restrictions for this experiment: in-storm sampling should occur in the time window from ~0200-1200 LST during the early stages of the TCDC when the TC diurnal pulse/wave (and associated arc clouds) is located at R≤160 n mi (300 km). Approximate radial locations of TC diurnal pulses relative to local time are shown by the TC diurnal clock below (Fig. 1). If possible, this P-3 pattern should be conducted in coordination with G-IV Pattern 1 or G-IV Modules 1-4.

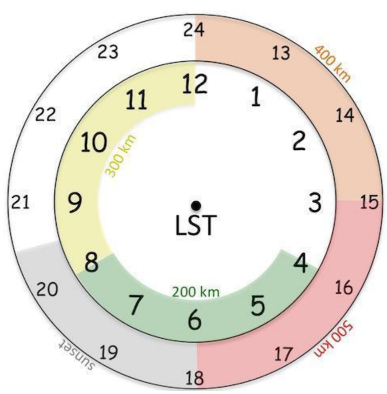

Fig. 1. Conceptual 24-hr TC diurnal cycle clock that estimates the radial location of TC diurnal pulses propagating away from storm.

Pattern: Any standard P-3 pattern that provides symmetric coverage (e.g., Rotated Figure-4, Figure-4 butterfly, etc.). Leg lengths should be adjusted as needed to ensure that the aircraft perpendicularly crosses TC diurnal pulses/waves that are indicated by satellite imagery and/or the P-3 multi-mode radar (MMR).

Flight altitude: 10-12 kft pressure altitude (radar altitude is acceptable) or as high as possible to provide better vertical sampling by GPS dropsondes that are deployed.

Leg length or radii: Standard leg lengths of 105 n mi (200 km), but legs should be extended as needed to ensure that the aircraft perpendicularly crosses at least 10 n mi (20 km) beyond the inside and outside edges of TC diurnal pulses/waves that are indicated by satellite imagery and/or the P-3 MMR. In order to provide adequate inner core coverage, leg lengths should generally not extend beyond R~135-160 n mi (250-300 km). For TC diurnal pulse/wave targets beyond this radius, the ferry to/from the storm can be used to optimize sampling.

Estimated in-pattern flight duration: ~2.5-5.0 hr

Expendable distribution: Standard distribution of GPS dropsondes except increased density of ~15-20 n mi (30-35 km) spacing just ahead of, within, and behind the diurnal pulse/wave convective features that will be identified in real-time using satellite imagery and/or the P-3 MMR (10-25 GPS dropsondes total). AXBTs are not a mission requirement.

Instrumentation Notes: Use TDR defaults. GPS dropsondes should be quality controlled and transmitted to the GTS in real-time. Use straight flight legs as safety permits.

P-3 Module 1 (Arc Cloud Module):

What to Target: Arc cloud features in the near environment of the TC.

When to Target: Any strength TC (though TCDC signals tend to be stronger in Cat 2+ storms); no land restrictions. There are time restrictions for this experiment: in-storm sampling should occur in the time window from ~0200-1200 LST during the early stages of the TCDC when the TC diurnal pulse/wave (and associated arc clouds) is located at R≤160 n mi (300 km). Approximate radial locations of TC diurnal pulses/waves relative to local time are shown by the TC diurnal clock (Fig. 1).

Pattern: This module is a break-away pattern and can be flown as part of any standard P-3 pattern (e.g., Rotated Figure-4, Figure-4 butterfly, etc.) and requires an orthogonal transect across the arc cloud (and associated TC diurnal pulse/wave) feature of interest. The transect can be aligned using guidance from satellite imagery and/or the P-3 MMR. For TC diurnal pulse/wave targets well outside the radius of the P-3 operating area, the ferry to/from the storm can be used to optimize sampling.

Flight altitude: 10-12 kft pressure altitude (radar altitude is acceptable) or as high as possible to provide better vertical sampling by GPS dropsondes that are deployed.

Leg length or radii: There are no specific leg length requirements for this module. Legs can be adjusted/extended as needed to ensure that the aircraft perpendicularly crosses at least 10 n mi (20 km) beyond the inside and outside edges of TC diurnal pulses/waves that are indicated by satellite imagery and/or the P-3 MMR.

Estimated in-pattern flight duration: ~0.5-1 hr

Expendable distribution: GPS dropsonde sampling (~5 GPS dropsondes total) of ~15-20 n mi (30-35 km) spacing just ahead of, within, and behind the TC diurnal pulse/wave convective features that will be identified in real-time using satellite imagery and/or the P-3 MMR. AXBTs are not a mission requirement.

Instrumentation Notes: Use TDR defaults. GPS dropsondes should be quality controlled and transmitted to the GTS in real-time. Use straight flight legs as safety permits.

G-IV Pattern #1

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

When to Target: Any strength TC (though TCDC signals tend to be stronger in Cat2+ storms); no land restrictions. There are time restrictions for this experiment: in-storm sampling should occur in the time window from ~0800-1500 LST during the middle to late stages of the TCDC when the TC diurnal pulse/wave is located at R~105-215 n mi (200-400 km). Approximate radial locations of TC diurnal pulses/waves relative to local time are shown in Fig. 1. If possible, this G-IV pattern should be conducted in coordination with P-3 Pattern 1, P-3 Module 1, and/or G-IV Modules 1-4.

Pattern: Standard G-IV Star with Circumnavigation (optimal) or Star (minimal) pattern. Leg lengths should be adjusted as needed to ensure that the aircraft perpendicularly crosses TC diurnal pulses/waves that are indicated by satellite imagery and/or the P-3 MMR (if available). For TC diurnal pulse/wave targets at large radii [e.g., R=160-215+ n mi (300-400+ km)], the ferry to/from the storm can also be used to optimize sampling.

Flight altitude: 40–45 kft

Leg length or radii: 190-215 n mi (350-400 km) for the outer points and ~60-90 n mi (110-165 km) for the inner points. If a circumnavigation is being performed, a constant radius [typically 60-90 nm (110-165 km)] should be selected. Selection of the inner points and circumnavigation radii should be as close to the edge of the inner core convection as possible (this distance will be dictated by safety considerations) and will require coordination between the HRD LPS/ground-based LPS and the G-IV flight director.

Estimated in-pattern flight duration: ~4 hr without circumnavigation and ~5.25 hr with circumnavigation.

Expendable distribution: Standard plus mid-points of Star Pattern (25-31 GPS dropsondes total) except increased density of ~15-20 n mi (30-35 km) spacing just ahead of, within, and behind the TC diurnal pulse/wave convective features that will be identified in real-time using satellite imagery and/or the P-3 MMR (if available).

Instrumentation Notes: Use TDR defaults. GPS dropsondes should be quality controlled and transmitted to the GTS in real-time. Use straight flight legs as safety permits.

G-IV Module 1 (Arc Cloud Module):

What to Target: Arc clouds in the near and peripheral environments of the TC.

When to Target: Any strength TC (though TCDC signals tend to be stronger in Cat2+ storms); no land restrictions. There are time restrictions for this experiment: in-storm sampling should occur in the time window from ~0800-1500 LST during the middle to late stages of the TCDC when the TC diurnal pulse/wave is located at R~105-215 n mi (200-400 km). Approximate radial locations of TC diurnal pulses/waves relative to local time are shown in Fig. 1. If possible, this G-IV pattern should be conducted in coordination with P-3 Pattern 1 or Module 1.

Pattern: This module is a break-away pattern and can be flown as part of any standard G-IV pattern and requires an orthogonal transect across the arc cloud (and associated TC diurnal pulse/wave) feature of interest. The transect can be aligned using guidance from satellite imagery and/or the P-3 MMR. For arc cloud targets at large radii [e.g., R=160-215+ n mi (300-400+ km], the ferry to/from the storm can also be used to optimize sampling.

Flight altitude: 40–45 kft

Leg length or radii: There are specific no leg length requirements for this module. Legs can be adjusted/extended as needed to ensure that the aircraft perpendicularly crosses at least 10 n mi (20 km) beyond the inside and outside edges of arc clouds that are indicated by satellite imagery and/or the P-3 MMR.

Estimated in-pattern flight duration: ~0.5-1 hr

Expendable distribution: GPS dropsonde sampling (~5-7 GPS dropsondes total) of ~15-20 n mi (30-35 km) spacing just ahead of, within, and behind the arc cloud that will be identified in real-time using satellite imagery and/or the P-3 MMR (if available).

Instrumentation Notes: Use TDR defaults. GPS dropsondes should be quality controlled and transmitted to the GTS in real-time. Use straight flight legs as safety permits.

G-IV Module 2 (Transect Module):

What to Target: Sample a broad radial cross-section from the far environment to the outer edge of the inner core of the storm, ideally including using the ferry as an opportunity to deploy far-field GPS dropsondes.

When to Target: Any strength TC (though TCDC signals tend to be stronger in Cat2+ storms); no land restrictions. There are time restrictions for this experiment: optimal sampling should occur shortly after 0000 LST or 1200 LST. If possible, this G-IV pattern should be conducted in coordination with P-3 Pattern 1, P-3 Module 1, or G-IV Pattern 1.

Pattern: This module is a break-away pattern and can be flown as part of any standard G-IV pattern and/or during ferries to/from the storm. It can be done as a combination of a ferry to-from the storm and a breakaway from a different pattern, in order to get a large-radius cross section of the storm that includes strong outflow in at least one leg (avoiding the eye/eyewall region). The transect should cover as large a range of radii as possible, subject to operational limitations. For a non-ferry leg on the opposite side of storm, begin outbound leg as close to the inner core as safety permits [e.g., R=60-90 n mi (110-165 km)] and proceed outward radially in the direction of largest outflow as identified by water vapor winds, as far as practicably possible [e.g., R=350-430 n mi (650-800 km)]. Back-to-back missions that capture midnight LST and once shortly after 1200 LST are preferable.

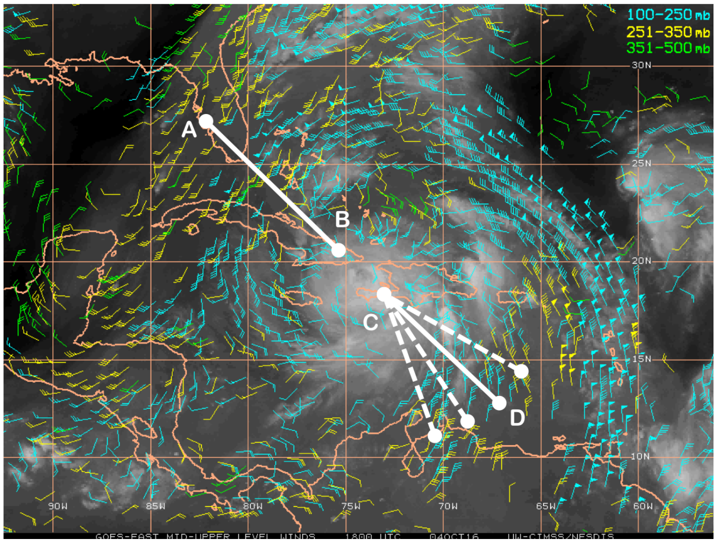

Fig. 2: Utilize ferry from land toward inner core. Later during same flight breakaway from another pattern and continue through outflow region to clear sky on other side. Second flight need not be exactly parallel to first flight, just somewhere on the opposite side of the storm, and aim for a local outflow jet core.

Flight altitude: 40–45 kft

Leg length or radii: There are no specific leg length requirements for this module but it should cover as large a range of radii as possible, total length including ferry ideally ~750 n mi (1400 km).

Estimated in-pattern flight duration: ~1-1.5 hr total. The inbound and outbound legs can be staggered in time (e.g., the 1st can be completed early in the mission and the 2nd later in the mission).

Expendable distribution: GPS dropsonde sampling (~16 GPS dropsondes total, 8 per leg) of ~45 n mi (85 km) spacing.

Instrumentation Notes: Use TDR defaults. GPS dropsondes should be quality controlled and transmitted to the GTS in real-time. Use straight flight legs as safety permits.

G-IV Module 3 (Outflow Axis Module):

What to Target: Along-axis and cross section of the principal upper-level TC outflow jet.

MATURE STAGE EXPERIMENT
Flight Pattern Description

When to Target: Any strength TC (though TCDC signals tend to be stronger in Cat 2+ storms); no land restrictions. There are time restrictions for this experiment: optimal sampling should occur shortly after 1200 LST in order to sample a potential diurnal pulse/wave along the axis of the outflow jet. If possible, this G-IV pattern should be conducted in coordination with P-3 Pattern 1, P-3 Module 1, or G-IV Pattern 1.

Pattern: This module is a break-away pattern and can be flown as part of any standard G-IV pattern and/or during ferries to/from the storm. This can potentially be flown as a modified ferry to/from another pattern. Minimal requirement is one flight along a major outflow axis [e.g., A-B or E-F, inbound or preferably outbound (to maximize tailwinds) to/from the storm, starting ~200 n mi (370 km) from center and following outflow axis for ≥540 n mi (1000 km), Fig. 3], and one transect across it at large radii [e.g., C-D or H-G respectively, ≥160 n mi (300 km) ending ~540 n mi (1000 km) from the storm center]. Back-to-back missions that capture midnight LST and once shortly after 1200 LST are preferred but not required. Alternatively, the outflow axis path may be replaced with a constant-radius path from the storm center, with the goal of intersecting the primary outflow jet at large radii, with the corresponding transect leg being one that flies parallel or antiparallel to the outflow jet at large radii, as flown successfully during the 2020 TCDC experiment.

The outflow jet location will be determined by operational streamlines using the procedure from Merrill (1988 JAS): “All streamlines crossing a circle of 270 n mi (500 km) radius around the hurricane and having an outward component are defined as outflow streamlines”. The outflow streamline having the highest wind speed within 810 n mi (1500 km) of the center is designated the ‘outflow jet’.” This jet is most likely to be oriented N/NE from the center of the storm. For TC diurnal pulse/wave targets beyond this radius, the ferry to/from the storm can also be used to optimize sampling.

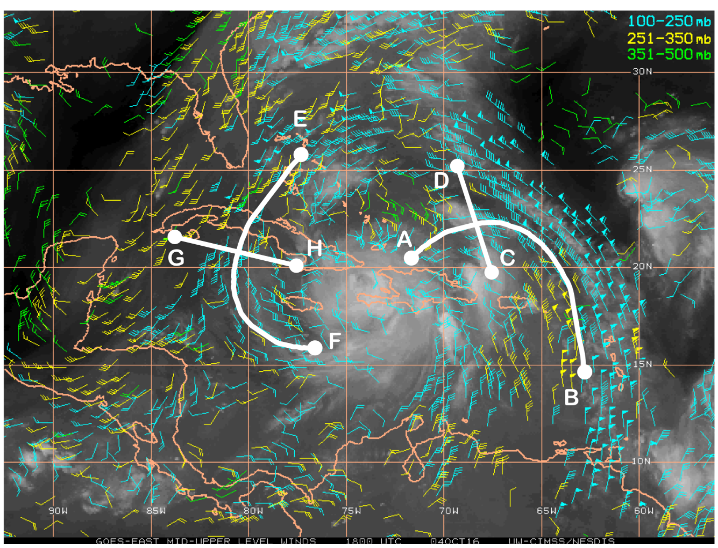

Fig. 3: Fly along and across primary outflow jet. Aim for the strongest outflow at large radii as identified by forecast models and updated by water vapor winds. Transect is intended to capture more than the full width of the outflow jet.

Flight altitude: 40–45 kft

MATURE STAGE EXPERIMENT
Flight Pattern Description

Leg length or radii: There are no specific leg length requirements for this module. The outflow axis flight should be as long as possible given time/distance constraints, ideally ~540 n mi (1000 km) along axis (not same as away from TC center). The transect is ideally ~324 n mi (600 km) long.

Estimated in-pattern flight duration: 1.5-2 hr

Expendable distribution: Outflow axis: GPS dropsonde sampling (~12 GPS dropsondes total) of ~45 n mi (85 km) spacing. Transect: GPS dropsonde sampling (~8 GPS dropsondes total) with ~40 n mi (75 km) spacing.

Instrumentation Notes: Use TDR defaults. GPS dropsondes should be quality controlled and transmitted to the GTS in real-time. Use straight flight legs as safety permits.