MATURE STAGE EXPERIMENT
Science Description

Experiment/Module: Eye-Eyewall Mixing

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Requirements: Categories 2–5

Plain Language Description: Small features in the eyewalls of very intense tropical cyclones have been hypothesized to increase the amount of energy available for hurricane intensification, or to be responsible for damaging surface wind at landfall or intense turbulence features impacting flight operations. However, the structures of these features, especially the temperature and humidity structures, have never been documented.

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) Test new (or improved) technologies with the potential to fill gaps, both spatially and temporally, in the existing suite of airborne measurements in mature hurricanes. 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 oceanic conditions [*APHEX Goal 2*]

Motivation and Background: Eyewall miso- and mesovortices have been hypothesized to mix high-entropy air from the eye into the eyewall, thus increasing the amount of energy available to the hurricane. They may also produce very high wind-speed signatures at the surface leading to small regions of extreme damage at landfall. Signatures of such mesovortices have been seen in cloud formations within the eyes of strong TCs, in radar reflectivity signatures (Hurricane Fabian), from above during aircraft penetrations (Hurricanes Hugo and Felix), and in damage surveys (Hurricane Andrew). However, meso-scale vortical features have never been sampled by reconnaissance aircraft at flight level, and only rarely at very low levels by land-based Doppler radar. Dropwindsondes released in very intense tropical cyclones, in conjunction with large-eddy simulations, have provided some thermodynamic data, especially in instances with multiple soundings sampling the same feature. However, the kinematic and thermodynamic structures of these features have never been directly observed, nor do we know whether these features ultimately impact intensity changes. Observations within the eye and eyewall can allow for the study of these features and improve knowledge of intensity changes in very strong TCs.

Hypothesis: Eyewall meso- and miso-vortices play an important role in TC intensity change.

Aircraft Pattern/Module Descriptions (see *Flight Pattern* document for more detailed information): The proposed aircraft pattern has three parts. The three parts do not need to be completed during the same pass or even during the same flight

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P-3 Pattern #1:
The purpose of this pattern is to gather Doppler radar data in the eyewall at an approximately constant sampling rate in the search for low-level small-scale features, and to track these features as they move rapidly around the eye. It is a break-away pattern that is compatible with any standard pattern with an eye passage (all P-3 patterns except the Square spiral or Lawnmower). The eye must be large enough for the P-3 to safely perform circles within the eye. The P-3 will penetrate the eyewall at the standard-pattern altitude. Once inside the eye, the P-3 will perform at least three clockwise or counter-clockwise orbits of the eye at an approximately constant bank with the flight-level circulation center within the orbits. The size of all the orbits will be the same, and should allow for the completion of each orbit approximately every 6 min, 7.5 min, or 10 min (circle diameter about 7-13 n mi depending on ground speed) at crew discretion. The flight level of the orbits can be adjusted for safety considerations at the pilot's discretion. If a center fix is required, this pattern can be done either before or after the center fix. It is highly desirable, though not required, that an sUAS be conducting an Eyewall/Radius of Maximum Winds Module while this pattern is being executed.

P-3 Pattern #2:
The purpose of this pattern is to search for small-scale features near the eyewall at flight level and at low levels directly below the aircraft at or near the surface radius of maximum wind speed. It is a break-away pattern that is compatible with any standard pattern with an eye passage (all P-3 patterns except the Square spiral or Lawnmower). The module should be performed using the aircraft on which either the IWRAP and/or a lidar is available. The eye must be ≥ 25 n mi in diameter, and for asymmetric or non-circular eyes, the narrowest cross section from eyewall to eyewall must be ≥ 25 n mi. Additionally, a constant separation distance of 2-5 n mi from the inner edge of the eyewall should be maintained; the separation distance will be selected based on the flight level and eye size and will be determined in real-time by the LPS in consultation with aircraft crew. The P-3 will penetrate the eyewall at the standard-pattern altitude. Once inside the eye, the P-3 will maintain the flight level of the main mission and perform a single orbit (in either a clockwise or counter-clockwise direction) of the eye with a separation distance of at least 2 n mi from the edge of the eyewall, with the goal of being within about 2 n mi of the inside of the radius of maximum wind speed. Neither straight flight legs nor a constant bank are required for this pattern; it is most important to try to keep a nearly constant distance from the radar eyewall during the pattern. The flight level of the orbit can be adjusted for safety considerations at the pilot's discretion with the caveat that a goal of the pattern is to gather data from the IWRAP or profiler. If a center fix is required, this pattern can be done either before or after the center fix. It is highly desirable, though not required, that an sUAS be conducting an Eyewall/Radius of Maximum Winds Module while this pattern is being executed.

P-3 Pattern #3:
The third part of the module occurs during the eyewall penetration of what is believed to be the strongest part of the eyewall. During the penetration, seven or eight dropwindsondes will be released as fast as possible to try to obtain kinematic and thermodynamic observations in a single small-scale vortex. The dropwindsonde releases should be spaced as close together as every 2 s. *The goal is to have the second-outermost dropwindsonde to be coincident with the flight-level*

radius of maximum wind speed, and the second-innermost dropwindsonde to be coincident with the surface radius of maximum wind speed.

Links to Other Mature Stage Experiments/Modules: This can be coordinated with any other mature-stage experiment or module.

Analysis Strategy: The data will be examined to look for meso- or miso-scale vortices at the eye-eyewall interface and characterize their structure. Analyses with an advanced data assimilation system will also be conducted.

References:

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Marks, F.D., P.G. Black, M.T. Montgomery, and R.W. Burpee. Structure of the eye and eyewall of Hurricane Hugo (1989). *Mon. Wea. Rev.,* **136**, 1237–1259.

Rogers, R. F., S. Aberson, M. M. Bell, D. J. Cecil, J. D. Doyle, T. B. Kimberlain, J. Morgerman, L. K. Shay, and C. Velden, 2017: Re-writing the tropical record books: The extraordinary intensification of Hurricane Patricia (2015). *Bull. Amer. Met. Soc.,* **98***,* 2091-2112.

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