EXPERIMENT DESCRIPTION
6. TC Diurnal Cycle Experiment

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Links to IFEX goals:

- **Goal 1**: Collect observations that span the TC lifecycle in a variety of environments;
- **Goal 3**: Improve understanding of the physical processes important in intensity change for a TC at all stages of its lifecycle;

Program Significance:
Numerous studies have documented the existence of diurnal maxima and minima associated with tropical convection. However, predicting the timing and extent of this variability remains a difficult challenge. Recent research using GOES satellite imagery has identified a robust signal of tropical cyclone diurnal pulsing. These pulses can be tracked using new GOES infrared satellite image differencing and may represent an unrealized, yet fundamental process of mature TCs. The new satellite imagery reveals “cool rings” in the infrared that begin forming in the storm’s inner core near local sunset each day. Similar to ripples that form after a pebble is thrown into a pond, the cool ring, or pulse, continues to away from the storm overnight, reaching areas several hundred km from the storm center by the following afternoon. There appear to be significant structural changes and disruptions to a storm [as indicated by GOES IR and microwave (37 and 85 GHz) satellite imagery] as this pulse moves out from the inner core each day and the timing/propagation of these cool rings also appears to be remarkably predictable. The goal of this experiment is to sample the thermodynamic and kinematic environment of these diurnal pulses at various stages of their life cycles, including their initial formation and subsequent evolution, and to observe any corresponding fluctuations in TC structure and intensity during these events.

Objectives:
To employ both NOAA P-3 and G-IV aircraft to collect kinematic and thermodynamic observations both within the inner-core (i.e., radius < 200 km) and in the surrounding large-scale environment (i.e., 200 km < radius < 600 km) for systems that have exhibited signs of diurnal pulsing in the previous 24 hours. Satellite imagery available from the experimental UW-CIMSS/HRD Diurnal Pulsing web page and a recently developed conceptual clock that describes the timing and position of TC diurnal pulses at various stages of their life cycle will be used to monitor storms and identify optimal aircraft sampling strategies and takeoff times.

Hypotheses:

- Although the exact nature of diurnal pulses is not yet clear, new GOES IR satellite imagery and recent model simulations indicate a diurnal process that is likely being driven by rapid changes in incoming shortwave radiation (resulting in rapid cooling at the CDO level) around sunset each day;
- Rawinsonde data from Caribbean stations suggests that are two necessary conditions needed to initiate TC diurnal pulsing: a cirrus canopy over an area of deep convection and rapid cooling of the cloud tops (i.e. sunset). These conditions appear create large (~4-7 C) temperature inversions at the cloud top level that may help trigger diurnal pulse formation;
- Diurnal pulses may be signatures of outwardly propagating gravity waves, harmonic oscillations of the CDO as it warms (cools) during the day (night), a response to changes

in inertial stability in the upper-levels of the storm, or temperature responses that lead to previously documented anvil expansion.

- Diurnal pulses appear to stimulate outward propagation of mass from the inner core as seen in GOES IR imagery (i.e. upper-levels) and 37/85 GHz microwave imagery (i.e. low to mid-levels);
- The aforementioned multi-scale TC Diurnal Pulsing Experiment datasets can be used to improve our understanding of this recently discovered phenomenon and test its observability in model simulations;

Mission Description:

The experimental UW-CIMSS/HRD Diurnal Pulsing web page will be used to monitor the development and propagation of TC diurnal pulses and associated cool ring propagation for storms of interest. Additionally, the timing and propagation of the cool rings appears to be remarkably predictable: after its initial formation in the inner core region, it propagates outward at ~10 m s^{-1} and reaches peripheral radii (e.g. 200-500 km) at very specific times of day (local time). Therefore, a conceptual clock describing the evolution of this phenomenon has been developed. Figure 1 shows a conceptual 24-hr clock that predicts the approximate times that the pulse passes various radii. This conceptual clock will be used in concert with the UW-CIMSS/HRD real-time diurnal pulsing imagery to plan aircraft sampling strategies and takeoff times.

The P-3 aircraft will dispense GPS dropsondes and collect Doppler radar data while flying a rotating figure-4 pattern (see sample pattern shown in Fig. 2) in the inner-core with leg lengths of ~120-180 km at the maximum safe altitude (~8k-12k feet) for avoiding graupel. The GPS dropsondes should be dispensed on each leg with a spacing of ~50 km to provide adequate coverage for sampling the radial gradients of kinematics and thermodynamics. The GPS dropsonde sampling density should be increased to ~20 km just ahead of, within, and behind the cool ring that will be identified in real-time using the UW-CIMSS/HRD Diurnal Pulsing satellite imagery. Since the cool ring begins forming around local sunset (~1800-2030 LST) and typically passes the 200 km radius at ~0400-0800 LST the following morning, optimal P-3 sampling will occur from ~2000-0400 LST so that the aircraft can adequately sample the formation (just after sunset) and early-stage (inner core out to 200 km) propagation of the cool ring. The P-3 may also fly an arc cloud module or convective burst module as opportunities present. The execution of these optional modules will be at the discretion of the LPS.

The NOAA G-IV (flying at ~175-200 hPa/~45,000-41,000 ft) GPS dropsonde drop points will be based on a star pattern selected using real-time information from the UW-CIMSS/HRD diurnal pulsing satellite imagery (Fig. 3). The flight pattern will consist of several radial runs toward and away from the storm that will allow for sampling of radial gradients of winds and thermodynamics. GPS dropsondes will be deployed at the turn points in the pattern as well as at mid-points along each leg in the pattern. Additional GPS dropsondes will be deployed just ahead of, within, and behind the diurnal pulse cool ring (Fig. 3, yellow to pink shading) and will be determined by the LPS during the mission. Since the cool ring typically passes the TC outer radii (e.g. 300-400 km) later in the morning and early afternoon, the optimal G-IV sampling will occur slightly later than the optimal P-3 sampling. The diurnal cycle conceptual clock (Fig. 1) indicates that the cool ring passes the 300 (400) km radius at ~0800-1200 LST (~1200-1500 LST). Therefore, the optimal G-IV sampling will occur from ~0800-1500 LST and will target the later stages of the diurnal cycle cool ring evolution. The G-IV may also fly an arc cloud module as opportunities present. The execution of this optional module will be at the discretion of the LPS.

When possible, TC Diurnal Cycle Experiment missions will be coordinated with the HRD Tropical Cyclone Genesis Experiment (GenEx) and Rapid Intensity Experiment (RAPX). This coordination will involve the WP-3D and G-IV and will be executed on a case-by-case basis.

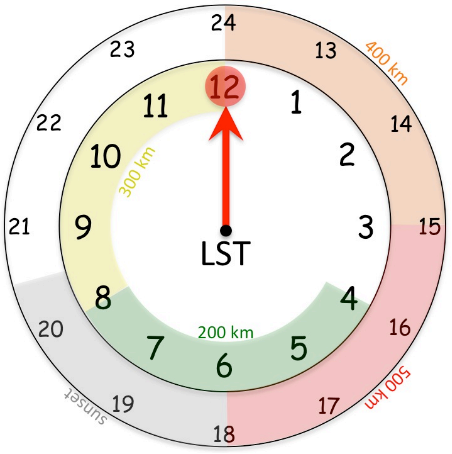


Figure. 6-1. Conceptual 24-hr TC diurnal pulsing clock that outlines the lifecycle of cool rings propagating from the TC inner core. For example, the pulse forms at local sunset (~1800-2030 LST, gray shading) and begins to propagate away form the inner core, passing the 200 km radius at ~0400-0800 LST (green shading) the following morning. It eventually reaches the 400 km radius at ~1200-1500 LST (orange shading) in the early afternoon.

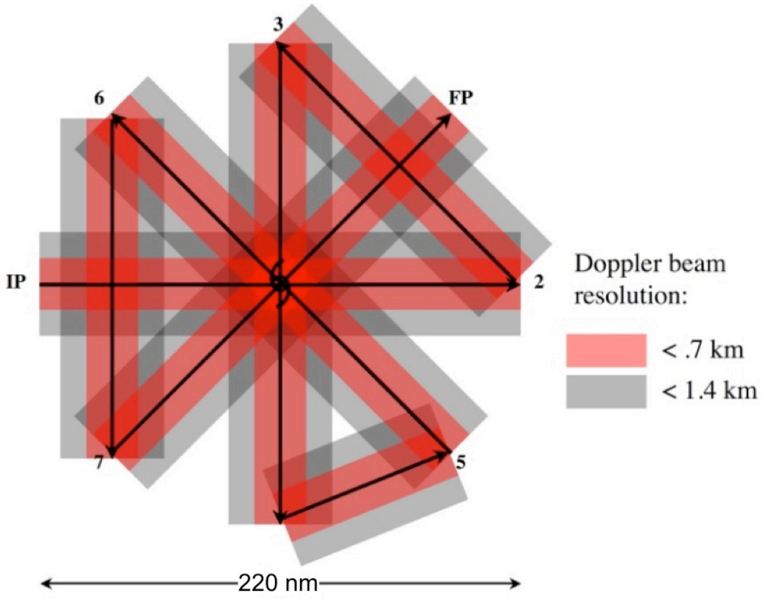


Figure. 6-2. Sample rotated figure-4 flight pattern for TC Diurnal Cycle Experiment mission. The red shading denotes locations where vertical spacing of Doppler beam < 0.7 km, grey

shading where vertical spacing < 1.4 km. GPS dropsondes should be released at all turn points (past the turn after the aircraft has leveled), at midpoints of inbound/outbound legs, and at center point between IP/2 and 5/6.

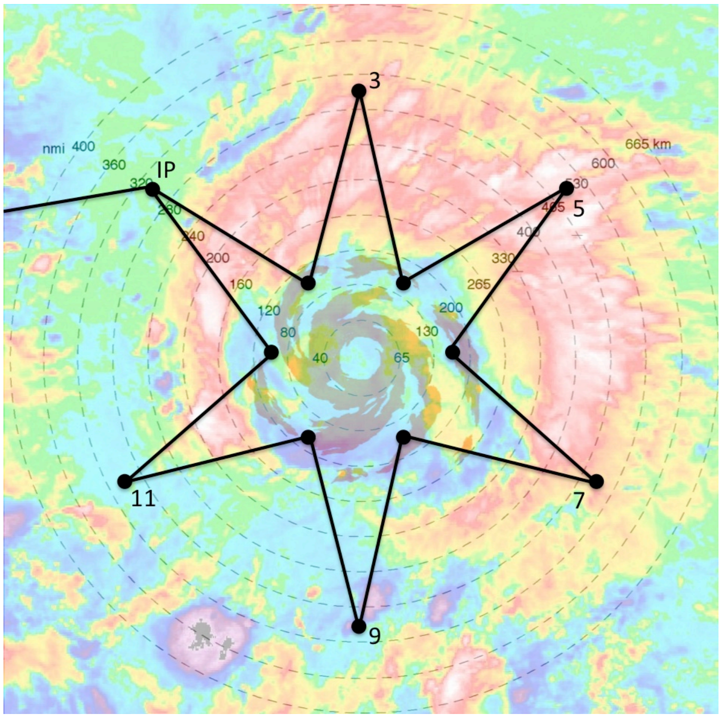


Figure. 6-3. Sample G-IV star pattern for the TC Diurnal Cycle Experiment. The endpoints of the pattern will be ~400 km from the storm center, but could be adjusted inward or outward depending in the exact position of the outwardly propagating diurnal pulse cool ring. The pattern is overlaid on a sample GOES IR diurnal pulsing image. The yellow to pink shading indicates a cool ring propagating away from the storm during this time and shows its typical evolution at ~1500 LST when it has reached the ~400 km radius.

Analysis Strategy

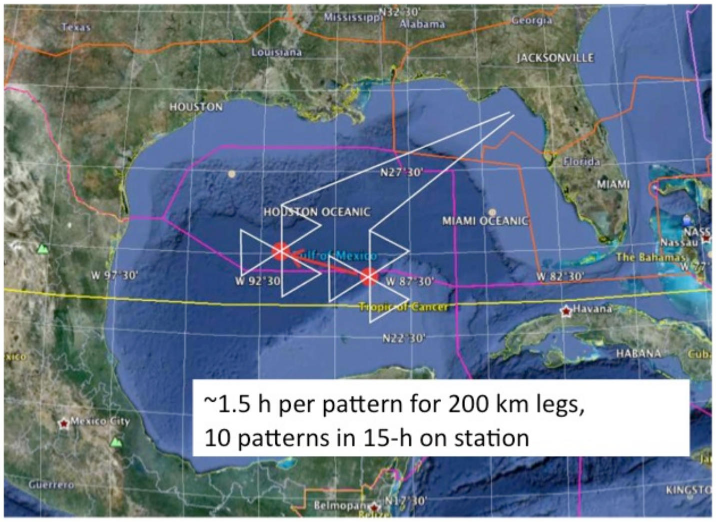
This experiment seeks to observe the formation and evolution of TC diurnal pulsing. Specifically, GPS dropsonde and radar observations will be used to analyze both the inner-core and environmental kinematics and thermodynamics that may lead to the formation of diurnal pulsing and to document the kinematics and thermodynamics that are associated with TC diurnal pulses at various stages of their evolution.

Coordination with Supplemental Aircraft

NASA will be conducting its Hurricane Severe Storm Sentinel (HS3) mission from 01 Sep – 05 Oct 2012. This mission will consist of two unmanned Global Hawk (GH) aircraft, flying at approximately 60,000 ft altitude with mission durations of up to 30 h. One GH will focus on flying patterns over the inner-core of TCs, while the other GH will focus on patterns in the environment of TCs. The primary science goals of HS3 are to better understand inner-core and environmental processes important in TC genesis, intensification, and extratropical transition.

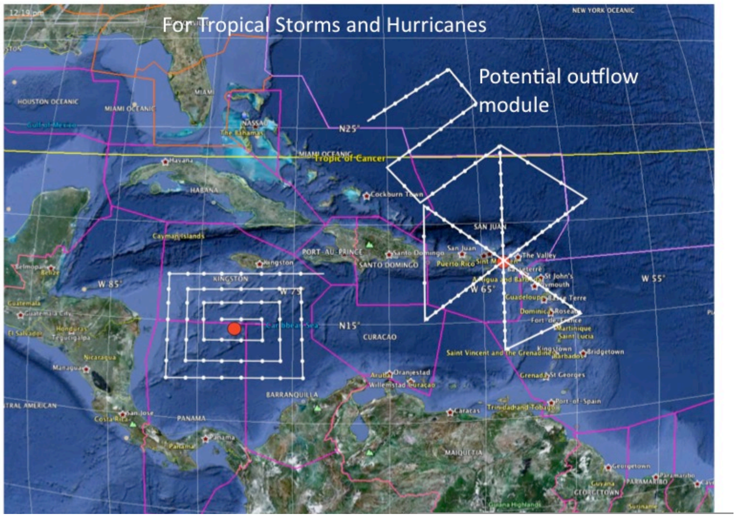
When possible, it will be desirable to fly P-3 and G-IV patterns that are coordinated with the GH aircraft (see Fig. 4 for sample GH flight patterns). For the NOAA P-3, “coordinated” means flying radial penetrations where the P-3 and GH are vertically-stacked for at least a portion of the flight leg, preferably when the aircraft are approaching the center of the TC. The across-track displacement during such coordination should be kept as small as practicable, e.g., no greater than 5-10 km. In practice, the NOAA P-3 will likely fly its planned figure-4/butterfly/rotating figure-4 patterns as indicated in Fig. 2. The inner-core GH can fly patterns that are similar in geometry to the NOAA P-3 patterns (Fig. 3). To achieve coordination, the inner-core GH would align its legs such that the GH will be stacked with the P-3. The G-IV pattern could either be designed/timed to supplement simultaneous coverage by the GH environmental aircraft or could supplement storm environment coverage on days when the GH environmental aircraft is not flying the storm.

Over-Storm Global Hawk Flights



~1.5 h per pattern for 200 km legs, 10 patterns in 15-h on station

Environmental Global Hawk Flights



For Tropical Storms and Hurricanes

Potential outflow module

Figure 6-4. Sample flight pattern for the (top) over-storm and (bottom) environmental Global Hawk aircraft for TCs located in the Gulf of Mexico, Caribbean, and western North Atlantic.