2023 NOAA/AOML/HRD Hurricane Field Program - APHEX

MATURE STAGE EXPERIMENT
Science Description

Experiment/Module: Tropical Cyclone Diurnal Cycle Module

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Requirements: Categories 2–5

Plain Language Description: This module aims to collect observations that improve the understanding of how day-night fluctuations in radiation affect the intensity and structure of hurricanes. One component of these oscillations is a phenomenon called the tropical cyclone diurnal cycle where the cloud fields of storms are seen to expand and contract each day. These daily expansions are associated with a pulse of thunderstorms and rain that travel hundreds of kilometers away from the storm center that affects the flow of air into the storm at the lowest levels above the ocean.

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*].

Motivation: The objectives are to obtain quantitative information of the 3-dimensional kinematic and thermodynamic structure and evolution of tropical cyclone (TC) diurnal pulses/waves and examine their effect on TC structure, intensity and the environment surrounding the storm. A study of a large sample of GPS dropsonde data in the context of the TC diurnal cycle (TCDC) showed that the hurricane boundary layer inflow tends to be deeper and stronger at night and shallower and weaker during the day (Zhang et al. 2020). This diurnal fluctuation of the TC boundary layer suggests that there may be times of day when low level inflow into the storm is more versus less favorable, which has implications for TC intensity change and structure. Evidence also suggests that the tropical marine boundary layer, that is, the hurricane environment, decreases at night and increases during the day (e.g., Lu and Liang 2010), and likely promotes more boundary layer inflow at night when the surrounding boundary layer is typically shallow. Dropsonde and tail Doppler radar observations from NOAA aircraft observations offer an opportunity to more closely examine these potentially fundamental diurnal fluctuations of the hurricane boundary layer.

Background: Although numerous studies have documented the existence of diurnal maxima and minima associated with tropical oceanic convection and the TC upper-level cirrus canopy, we lack a thorough understanding of the nature and causes of these variations and especially the extent to which these variations are important for TCs. It is well known that the coherent diurnal cycle of deep cumulus convection and associated rainfall is different over the land and ocean (Gray and

Jacobson 1977; Yang and Slingo 2001), with a peak over land in the late afternoon/early evening due to daytime boundary layer heating and a peak in the early morning over the ocean. In addition, Gray and Jacobson (1977), Mapes and Houze (1993), and Liu and Moncrieff (1998) found that the oceanic peak was more prominent when the preexisting convection was more intense and associated with an organized weather system such as an African easterly wave or mesoscale convective system. Browner et al. (1977) found that the areal extent of the TC cirrus canopy was a minimum at 0300 LST and a maximum at 1700 LST and suggested that this diurnal oscillation might be important for the TC. More recently, Kossin (2002) used storm-centered GOES infrared imagery to calculate azimuthally averaged brightness temperatures and create Hovmöller-type diagrams of brightness temperature diurnal oscillations over time.

Dunion et al. (2014) examined all North Atlantic major hurricanes from 2001 to 2010 and documented a phenomenon they referred to as the TCDC and associated TC diurnal pulses in mature TCs. Other studies (Knaff et al. 2019, Ditchek et al. 2019) showed that diurnal variations in infrared imagery occur in the majority of TCs, and at all intensities. They examined infrared (IR) geostationary satellite imagery and found a diurnal pulsing pattern in the cloud field that appears to occur with remarkable regularity through a relatively deep layer of the TC. One prominent characteristic of these oscillations is an IR cooling trend that begins forming in the storm's inner core (R~≤150 km) near the time of sunset each day. This cooling takes on a ring-like shape (i.e., TC diurnal pulse) as it continues to move away from the storm overnight, reaching areas several hundred kilometers from the circulation center by the following afternoon. A marked warming of the cloud tops occurs behind this propagating feature and structural changes in the storm are noted as it moves away from the inner core, suggesting that it may have implications for TC intensity change and structure.

Navarro et al. (2017) and O'Neill et al. (2017) showed evidence in numerical TC simulations that these diurnal pulses are internal inertial gravity waves. Ruppert and O'Neill (2019) found in addition that simulated TCs oscillate daily between a single-celled overturning circulation and a stacked two-cell overturning circulation, a balanced response in concert with the diurnal wave response. The diurnal and inertial frequencies can be very similar depending on the environmental flow, and so better understanding of this radial oscillation at midlevels will help disentangle diurnal impacts from dynamic impacts on mechanical work available for driving the primary cyclonic circulation. Additionally, Dunion et al. (2019) examined a hurricane nature run and found strong radially propagating diurnal signals in temperature, winds, and precipitation throughout the depth of the troposphere in that simulated TC.

Chavas et al. (2015) and Chavas and Lin (2016) developed a physical model for the complete radial structure of the TC low-level wind field and showed that it can reproduce the wind structure and its variability of TCs in nature. This model is also able to capture variability in the wind field in models across a wide range of climate states (Reed and Chavas 2015, Cronin and Chavas 2019). The model combines theory for the inner-core convecting region circulation (Emanuel and Rotunno 2011), where the low-level wind-field is dynamically linked to the upper-level turbulent outflow, and the outer non-convecting circulation (Emanuel 2004), where the low-level wind field depends on the radiative-subsidence rate within the free troposphere. The timescales of both model components are very fast (<12 hr) suggesting that the model may also be able to explain variations in the wind field induced by TC diurnal pulses/waves.

Beyond the influence of the TCDC specifically, radiative feedbacks more generally have been shown in numerical TC simulations to accelerate TC intensification (Nicholls 2015, Wing et al. 2016, Muller and Romps 2018, Smith et al. 2020, Ruppert et al. 2020). These feedbacks result from interactions between spatially and temporally varying radiative heating and the developing TC, in which differential heating between deep convection and the surrounding cloud-free region favors rising motion and moistening in the region of deep convection and amplifies the TC overturning circulation, favoring intensification. These feedbacks can be quantified by considering the co-variability of column moist static energy, radiative heating, and surface fluxes across the TC and outer tropical environment (Wing et al. 2016, Wing et al. 2019) and the depth and strength of the boundary layer in the hurricane near environment (Zhang et al. 2020).

Goal(s): Collect observations targeted at better understanding how the TCDC affects the boundary layer in the near-environment (R~80-160 n mi / R~150-300 km) of mature TCs.

Hypotheses:

1. The near-environment hurricane boundary layer is stronger and deeper at night and relatively shallower and weaker during the day.
2. Diurnal fluctuations in the hurricane boundary layer are important for TC intensity and structure.

Objectives:

1. Use GPS dropsondes to measure diurnal variability of the full 3-D thermodynamic and kinematic structure of the near-environment hurricane boundary layer.
2. Sample the near-environment hurricane boundary layer for 2 consecutive P-3 missions that are separated by ~12 hr [e.g., day mission (~15-21 LT) and night mission (~03-09 LT)].

Aircraft Pattern/Module Descriptions (see *Flight Pattern* document for more detailed information):

The experimental UW-CIMSS/HRD TCDC web page:
http://tropic.ssec.wisc.edu/real-time/tc_diurnal_cycle/tc_diurnal_cycle.php
will be used to monitor the development and propagation of TC diurnal pulses/waves for storms of interest. Figure 1 shows the TCDC clock that predicts the approximate times that the diurnal pulse/wave passes various radii and will be used in concert with the UW-CIMSS/HRD TCDC page to plan optimal aircraft sampling strategies and takeoff times.

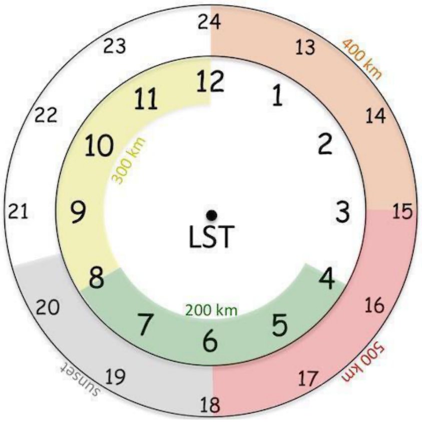

Fig. 1. Conceptual 24-hr TCDC clock that estimates the radial location of TC diurnal pulses/waves propagating away from the storm. TC diurnal pulses typically form around local sunset (~ 1800-2030 LST, gray shading) and begin to propagate away from the inner core, passing R~200 km the following morning (~0400-0800 LST, green shading) and R~400 km by the early to middle afternoon (~1200-1500 LST, orange shading).

P-3 Pattern 1:
For mature stage TCs, during the inbound ferry to the IP [Option A] or during the final outbound leg in the pattern [Option B], a series of dropsondes will be deployed in a straight radial leg to (or from) the storm. Optimally, this module should be conducted during the peak day (~12-18 LT) or night (~00-06 LT) phases of the TCDC and over 2 consecutive missions (to capture the full diurnal cycle).

- Option A (inbound): a series of 6 dropsondes should be deployed, the 1st at R=215 n mi (~400 km). If there is a primary rainband near R=215 n mi (~400 km), the 1st drop should be adjusted to be just inside that band. Deploy the 2nd dropsonde at R=160 n mi (R~300 km) and then dropsondes every 20 n mi starting at R=140 n mi (~260 km) and ending at R=80 n mi (~150 km).
- Option B (outbound): a series of 6 dropsondes should be deployed, the 1st at R=80 n mi (~150 km), then every 20 n mi and ending at R=160 n mi (~300 km). The 6th dropsonde should be deployed at R=215 n mi (~400 km). If there is a primary rainband near R=215 n mi (~400 km), the 6th drop should be adjusted to be just inside that band.

This pattern can also be flown as part of a Gravity Wave Module. However, this will only be practical if the GW module is preceded or followed by an inbound or outbound leg to or from the center of the storm. This allows for dropsonde sampling that spans the required R=80-215 n mi (~150-400 km) radial leg.

Links to Other Mature Stage Experiments/Modules: The TCDC Module can be flown in conjunction with the following Mature Stage experiments/modules: Gravity Wave Module

Analysis Strategy: This experiment seeks to observe the diurnal variability of the near-environment hurricane boundary layer. GPS dropsonde observations will be used to examine the day (~15-21 LT) versus night (~03-09 LT) variability of boundary layer depth, inflow strength, and thermodynamics. GPS dropsonde observations will be quality controlled and transmitted to the GTS in real-time for assimilation into numerical models.

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