15. Structure and Evolution of TC Warm Core Module

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Significance and Background:

Forecasting TC intensity continues to be a challenge, and analyzing the thermodynamic structure of TCs is shown to be important in understanding intensity changes. Despite the significance in understanding the structure of the maximum perturbation temperature, the relationship between the warm core and intensity is not fully understood. The wind-induced-surface-heat-exchange (WISHE) theory explains how a TC intensifies and suggests that the maximum perturbation temperature is located in the upper level troposphere (Emanuel 1986). However, recent modeling studies propose a variety of distinctive warm core heights in their TC simulations. Stern and Nolan (2012), Stern and Zhang (2013), and Wang and Wang (2014) found that a maximum perturbation temperature exists in the mid-level troposphere due to mean descent and a mid-level static stability maximum. They claim that the scarcity of observations inhibits the ability to determine a typical TC warm core structure. Therefore, a higher resolution of thermodynamic quantities is desired to determine standard warm core characteristics.

The evolution of the warm core throughout a TCs life cycle is not well documented, though some modeling studies have investigated the relationship between the maximum perturbation temperature and rapid intensification. During the RI process in their idealized simulations, Stern and Zhang (2013) found the greatest warming at the mid-level troposphere. They determined that the warm core is maximized at this height due to eddy radial advection as indicated by upward motion in the mid-level eye region. In later stages of RI, they deduced that mean vertical advection warms the eye. Wang and Wang (2014) found that in addition to the mid-level maximum in their simulation of Super Typhoon Megi, an upper-level warm core developed during the onset of RI, which dominated over the mid-level maximum throughout the rapid intensification process due to detrainment and downdrafts from convective bursts. Chen et al 2011 and Chen and Zhang (2013) also suggest that descent and detrainment from convective bursts cause an upper-level warm core to form, and claims this triggers RI in their simulation of Hurricane Wilma.

Both Stern and Nolan (2012) and Stern and Zhang (2013) concluded that there was no relationship between the TC intensity and the height of the warm core in their simulations. However, observational analyses of TC soundings in Durden (2013) indicate that there is a tendency for the height of the TC warm core to increase with increasing intensity. The study explains that a large variability in the height of the maximum perturbation temperature is exhibited ranging from 760 to 250 mb. Durden discovered a positive correlation between the maximum warm core height and TC size, environmental instability, and upper-level divergence. In an analysis on the evolution of Hurricane Humberto, Dolling and Barnes (2012, 2014) discovered a low-level warm core in the early stages of development. Similar to Durden (2013), the height of the maximum temperature perturbation in Humberto rises and falls as Humberto intensifies and then weakens. The warm core structure depends on the stage of Humberto's life cycle, the physical processes creating the warm core, and the environmental shear and moisture.

The effects of VWS on TC intensity are known to be detrimental (DeMaria 1996), yet the influence of shear on the warm core is not well known. Frank and Ritchie (2001) observed a weakening of the maximum perturbation temperature from the top down due to radially outward eddy fluxes of entropy influenced by VWS at upper levels in their TC simulation. Riemer et al. 2010 and Riemer and Montgomery (2011) propose that VWS reduces the moist entropy into the eyewall, therefore decreasing the overall magnitude of the warm core. However, in Stern and Zhang (2013), the presence of shear in their simulations does not affect the structure or evolution of the TC warm core. Dolling and Barnes (2012, 2014) determined that Hurricane Humberto intensified under increasing vertical shear, and the maximum perturbation temperature remained in the lower troposphere through intensification and dissipation stages. The discrepancy between studies gives rise to the need for additional observational analyses that focus on how shear influences the development and evolution of the TC warm core.

Objectives:

- The main goal for this experiment is to sample and examine the thermodynamic structure of the TC inner core during formation, intensification, rapid intensification, dissipation, and re-intensification stages.

- Using NOAA P-3 and NOAA G-IV every 12 hours, and Global Hawk and their dropsondes every 3 hours in the inner core (radius < 200 km) and environment (radius > 200 km), sample temperature, moisture, and wind velocity to determine the height and 3D structure of the maximum perturbation temperature and to determine the number of vertical local maxima that exist during each stage of the TC lifecycle.
- Employ NOAA P-3, NOAA G-IV jet, and their dropsondes (every 12 hours) to collect thermodynamic and kinematic measurements to explore the mechanisms affecting warm core formation and evolution in the TC inner core and environment. Flight level data will be used to support dropsonde information.
- Using data from past experiments and this years field campaigns, composite views of TC warm cores will be averaged depending on intensity, life cycle, shear, etc. in order to identify a "typical" warm core structure that may be compared to numerical simulations.

Hypotheses:

- During the initial stages of warm core development, the maximum temperature perturbation is located underneath a light stratiform precipitation region free from any deep convection.
- As a TC strengthens, the maximum temperature perturbation increases (decreases) with height with increasing (decreasing) intensity.
- During rapid intensification, detrainment and descent of stratospheric air due strong convective bursts in the eyewall aids in the development of an upper-level warm core.
- The structure of the warm core in both the horizontal and vertical directions will be affected by environmental parameters (vertical wind shear, dry air, environmental stability, etc…)

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.

Mission Description:

Global Hawk

NOAA will be conducting its SHOUT field campaign during the 2015 hurricane season and will utilize one Global Hawk (GH) aircraft, flying at ~55-60,000 feet and capable of mission durations of ~24 hr. The GH will be equipped with 3 instrument platforms that can be used to study the TC warm core:

i. AVAPS dropsonde system: capable of deploying up to 88 dropsondes per mission. provides pressure, thermodynamic, and wind information at 2 Hz (~5 m, PTH) and 4 Hz (~2.5 m, winds) vertical resolution;
ii. The High Altitude Monolithic Microwave Integrated Circuit (MMIC) Sounding Radiometer (HAMSR): microwave sounder with 25 spectral channels in 3 bands (50-60 GHz, 118 GHz, and 183 GHz); provides 3-D distributions of temperature, water vapor, & cloud liquid water; 2 km vertical and 2 km horizontal (nadir) resolution; 40 km wide swath;
iii. High-Altitude Imaging Wind and Rain Airborne Profiler (HIWRAP): dual-frequency (Ka- & Ku-band), dual beam, conical scanning Doppler radar; provides 3-D winds, ocean vector winds, and precipitation; 60 m vertical and 1 km horizontal resolution;

Since SHOUT GH missions will typically include multiple eye crossings and extended radial legs from the storm center (~215-270; 400-500 km), GPS dropsonde, HAMSR, and HIWRAP observations can be used to observe the temporal and spatial variability of the TC warm core region (Fig. 15-1). When possible, the P-3 and G-IV should coordinate with the GH to maximize sampling of the TC warm core. GPS dropsondes, HAMSR, and HIWRAP will be utilized to retrieve higher time density observations of thermal structure and associated eyewall convective bursts, wind speeds, and reflectivity changes.

Global Hawk Dropsondes:

The sampling strategy for the GH targets the eye with a high density of GPS dropsondes out to approximately 2 RMWs. GPS dropsondes will be deployed on each radial transect with a drop over the low level circulation center and a drop near 0.5 RMW. Radially outward of 0.5 RMW, the GPS dropsondes will sample approximately every 0.25 RMW out to 2 RMW. Between 2 and 3 RMW (out to about 400 km), approximately 0.5 RMW intervals are required.

TCs that are in their initial spin-up phase (Depression and TS) require GPS dropsondes deployed over the low level circulation center (whether that is under convection, stratiform rain, or clear skies) starting with a center drop and sondes at radial intervals of 10 km out to a radius of 50 km. From 50 km to 150 km, GPS sondes are launched at 25 km intervals. Outside 150 km, the GPS sondes are deployed at larger intervals of 50-100 km. Any large primary convective bands are sampled at higher intervals of (~5-10 km) with at least one drop on the inner edge of the convective band.

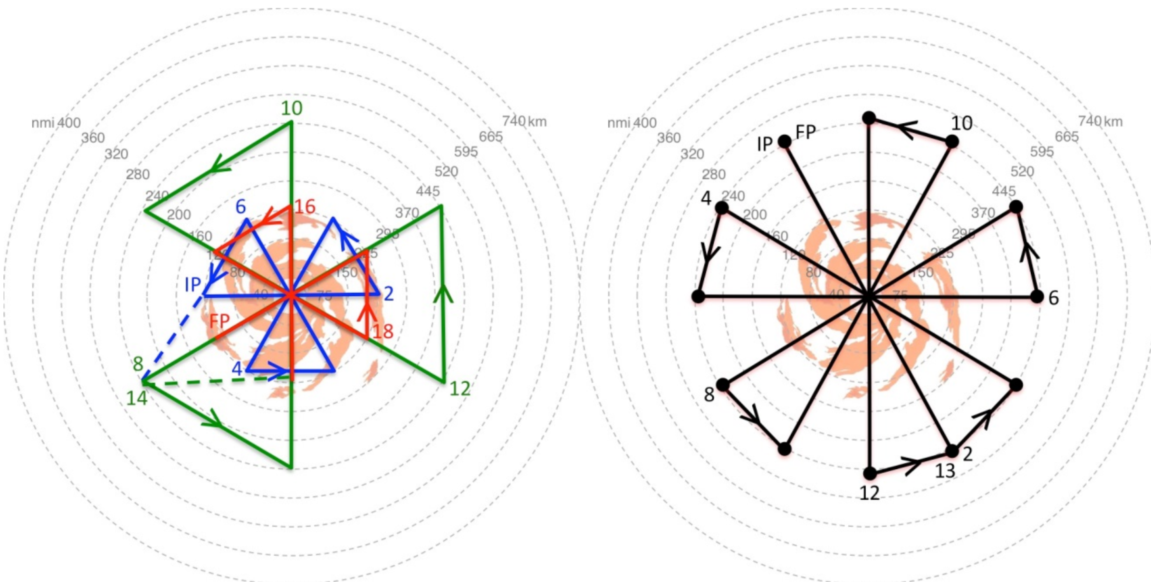

Fig. 15-1. Sample Global Hawk flight patterns that will be conducted during the 2015 NOAA SHOUT field campaign. (Left) Repeated butterfly pattern that includes a series of alternating small (blue curve)-large (green curve)-small (red curve) tracks. The small and large butterflies have radial legs that will range from ~80-160 nm (~150-300 km) and ~215-270 (400-500 km) respectively. (Right) rotated butterfly pattern with 30 degree rotated radials and ~215-270 (400-500 km) radial legs.

NOAA P-3:

The P-3 should be coordinated with the Global Hawk when possible and will obtain TC center fixes at 12,000 feet to guide the upper-level GH flight pattern. Any dropsondes used for the coordinated experiment can be utilized to study the low-level warm core structure, especially during early stages of the TC development. All stages of the TC life cycle under any shear environment are of interest. Temperature, moisture, and wind measurements are to be obtained using GPS dropsondes, TDR and flight-level observations, and a figure-4 flight pattern should be used. The P-3 should be coordinated with the corresponding G-IV mission, deploying every 12 hours.

NOAA P-3 Dropsondes:

A direct center drop from the P-3 is required for this mission. If deep convection is present in the eyewall, GPS sondes may be deployed at smaller radial intervals (~5-10 km). This requires a drop just on the inner edge of the convective burst and at these higher intervals throughout the convective element.

NOAA G-IV:

The G-IV flight pattern will sample the environment from 300 to 500 km in a star shaped ring. Experiment and is used to observe the state of the environment from an altitude of 41-45,000 ft. Flight deployment should be obtained in coordination with the P-3 aircraft.

NOAA G-IV Dropsondes:

GPS dropsondes will be jettisoned in each quadrant at 50-100 km radial intervals in the environment, overlapping the coverage of the corresponding GH.

Coordination Requirements: This module can be conducted in concurrence with other experiments such as the Tail Doppler Radar, TC Shear, and Rapid Intensification Experiments. Flight coordination among P-3, G-IV, and Global Hawk aircraft is ideal when possible. Missions conducted in a variety of shear environments and encompassing all TC life cycle stages is desirable.

Analysis Strategy: This experiment focuses on observing the structure, formation, and evolution of the TC warm core in various environments. For all stages of the TC life cycle, composite depictions of the thermal structure will be created using thermodynamic inner core and environmental observations taken from dropsondes, HAMSR, TDR, and in situ aircraft observations. By analyzing the height and structure of the maximum perturbation temperature during formation, intensification, rapid intensification, dissipation, and re-intensification stages, a relationship between the warm core evolution and TC intensity can be investigated. Environmental observations during each stage of the TC life cycle will be used to explore the mechanisms that influence the warm core structure and its relationship to intensity. This allows for the development of a database of typical warm core structures in various environments.

Modeling Component:

Understanding the evolution of the warm core during the various stages of a TC life cycle would expose similarities and differences between the thermal structure seen in real-time TCs and TC simulations. This leads to an evaluation of current model schemes and parameterizations and ideally will improve operational model intensity forecasts. Observations taken during formation of the warm core at early stages of the TC life cycle may provide an alternative approach to initializing TC simulations. In addition, assimilating higher resolution warm core observations has the potential to improve the accuracy of TC simulations.