# Dropsonde and CPL Observations of Tropical Cyclone Cirrus Structure

Patrick Duran and John Molinari

Department of Atmospheric and Environmental Sciences, University at Albany, SUNY

## Introduction

- Theory suggests that tropical cyclones (TCs) create their own outflow layer temperature stratification, largely independent of the environment (Emanuel and Rotunno 2011).
- Radiative processes within cirrus appear to play an important role in determining TC structure and evolution (Fovell et al. 2010; Bu et al. 2014)
- Global Hawk dropsonde and CPL observations allow for an analysis of the full depth of the TC cirrus canopy with unprecedented spatiotemporal resolution.

## Science Questions

- What is the thermodynamic structure near the top of the TC cirrus canopy?
- Is there evidence that the cirrus canopy significantly alters the upper-tropospheric temperature profile?
- Does the upper-tropospheric temperature profile change with time of day?

## Rawinsonde Observations

- Duran and Molinari (2015; In review) composited rawinsonde observations of the TC outflow layer.
  - 8499 sondes released between 1998-2011.
  - Stratified by intensity to see how hurricanes modify their upper-tropospheric environment.
    - Two categories: Hurricanes and Weak TCs (tropical depressions and tropical storms)

### Temperature

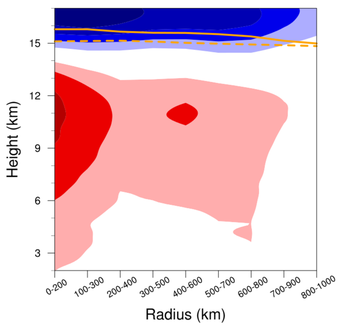



**Fig 1.** Temperature (T) in hurricanes minus T in weak TCs (Blue shading corresponds to lower T in hurricanes.) Units K.

Solid orange line is the average tropopause in hurricanes; dashed orange line is the average tropopause in weak TCs.

- On average, hurricanes are warmer than weak TCs below 14 km altitude.
  - At inner radii, warming is consistent with a strengthening warm core as TC intensifies.
  - At outer radii, weak, deep warming is consistent with subsidence and absorption of longwave radiation by the cirrus canopy (e.g. Bu et al. 2014).
- On average, hurricanes are cooler than weak TCs above 14 km altitude.
  - Consistent with an elevation of the tropopause (orange lines) by strong convection.

## Vertical Temperature Gradient

- Warming overlaid by cooling steepens the lapse rate near the tropopause in hurricanes.

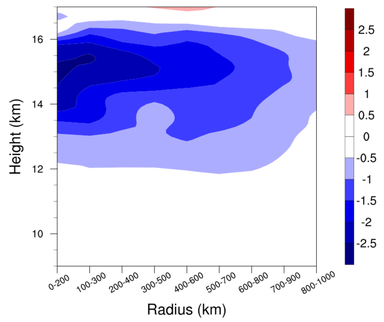



**Fig 2.** Vertical temperature gradient (dT/dz) in hurricanes minus dT/dz in weak TCs. (Blue shading corresponds to smaller dT/dz in hurricanes.) Units K/km.

Smaller (more negative) dT/dz indicates decreased static stability in hurricanes.

## Turbulence in Hurricanes vs. Weak TCs

- Smaller static stability is very closely related to increased upper-tropospheric turbulence in hurricanes.

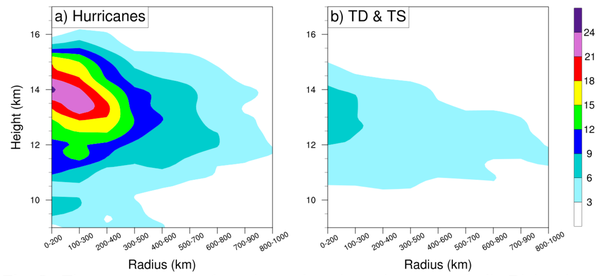



**Fig 3.** The percentage of rawinsondes that observe a bulk Richardson number less than 0.25 in (a) hurricanes and (b) weak TCs.

***Next question: How does the temperature stratification change with space and time within the cirrus canopy of an individual storm?***

- ***Rawinsonde composites cannot answer this question.***

## Advantages of Global Hawk Sondes and CPL Observations

- Sondes dropped from the stratosphere observe a full profile of the cirrus canopy.
- Large sonde drop density allows an analysis of how the upper-tropospheric environment changes across the cirrus canopy at a given time.
- CPL provides a good measure of cloud top height.
  - Very important when considering the potential effects of radiative processes at cloud top.

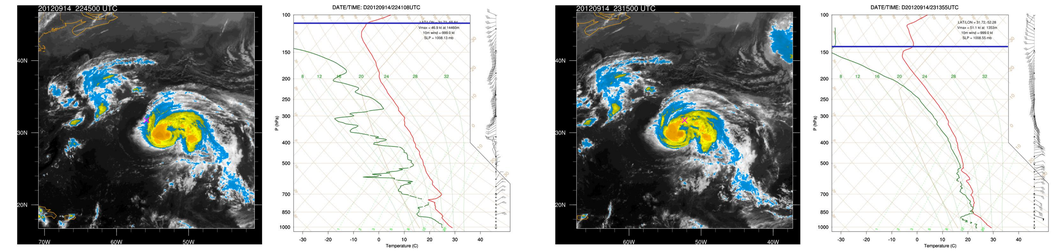
## Case Study of TS/Hurricane Nadine, 2012

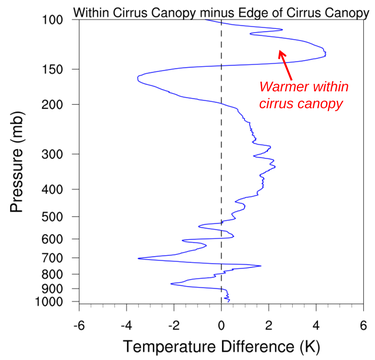
- Global Hawk flight on September 14-15 2012 deployed 70 sondes in and around Nadine.
- NHC upgraded Nadine from a 60 kt tropical storm to a 65 kt hurricane during the flight.
- Nadine had a well-developed cirrus canopy throughout the flight.
  - Global Hawk completed a number of transects across the cirrus canopy, crossing the same region of the cirrus canopy multiple times.

We will use these sondes to assess the upper-tropospheric structure of Nadine, and how it evolves throughout the flight.

## Case Study of TS/Hurricane Nadine, 2012

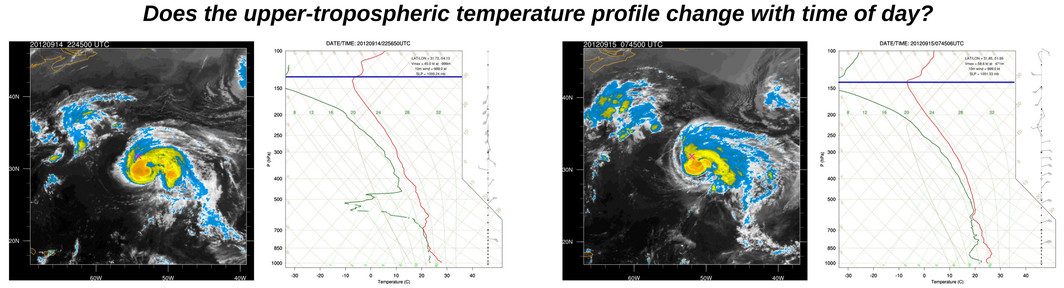
***Does the upper-tropospheric temperature profile change across the cirrus canopy?***



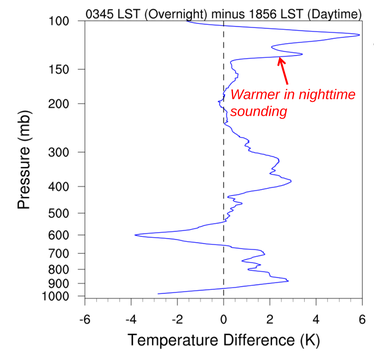




- Dropsondes were deployed 32 minutes apart, one at the edge of the cirrus canopy (top left), and one within it (top right).
  - The sounding from within the cirrus canopy (top right) exhibits a double inversion between the 100 and 150 mb levels.
    - This is associated with a much warmer 100-150 mb layer temperature within the cirrus canopy than on the edge (left).
    - Cloud top (thick blue line) is located at the level of the lower inversion.
      - *Open question: What causes this double inversion? Is the lower cloud top height within the cirrus canopy a consequence of the lower inversion, or does the cloud top play a role in creating the lower inversion through radiative processes?*

***Does the upper-tropospheric temperature profile change with time of day?***




**1856 LST (Daytime)** **0345 LST (Nighttime)**




- Two soundings were collected at nearly the same location within the cirrus canopy, about 9 hours apart.
  - The daytime sounding (top left) exhibits a double inversion structure in the upper troposphere, but 9 hours later in the nighttime sounding, the upper inversion is not present.
    - The disappearance of the upper inversion is associated with strong warming in the 100-150 mb layer during the 9 hour period.
      - *Open question: What causes this strong warming, and does it relate to the TC diurnal cycle of Dunion et al. (2014)?*

## Summary

- In the mean, hurricanes significantly modify the upper-tropospheric temperature profile.
- A case study of TS/Hurricane Nadine (2012) reveals that large upper-tropospheric temperature variations can occur with both space and time within the cirrus canopy.
- Cloud top height also varies with space and time, which may have implications for radiative tendencies in the cirrus canopy.

## Acknowledgements

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