Observations of the Tropical Cyclone Diurnal Cycle Using NUCAPS Satellite Sounding Retrievals

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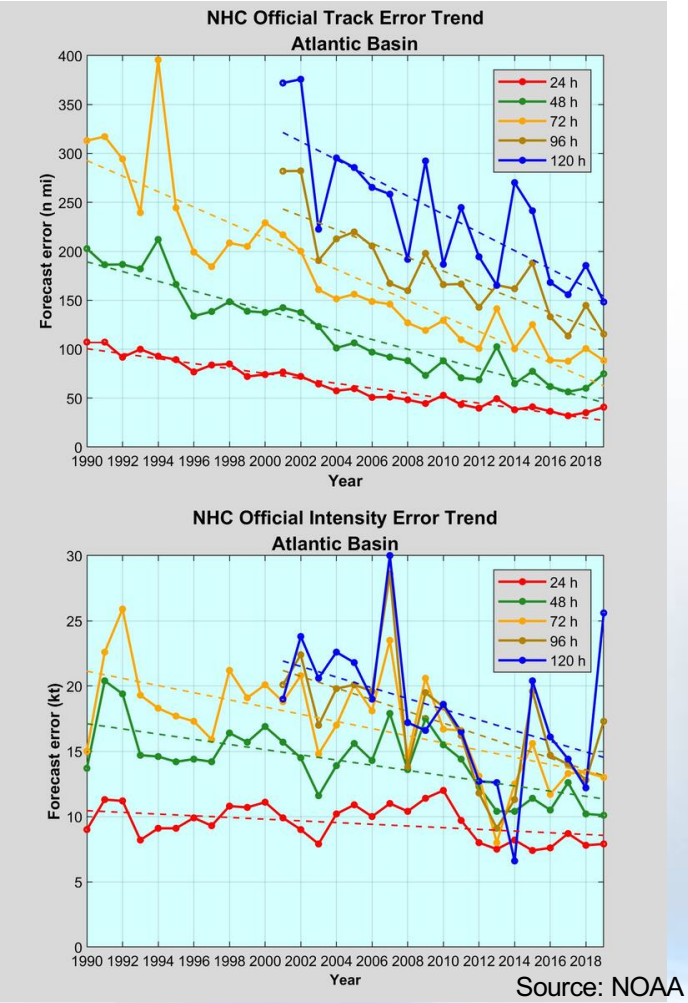
Tropical Cyclones

- Consistently ranked among the most devastating natural disasters
- Recent years have produced several stronger and more rapidly-developing systems
- While recent decades have exhibited substantial improvement to track forecasts, intensity forecast error trends have been much more modest
  - **Especially true at short-lead times, which are crucial for accurate warnings**

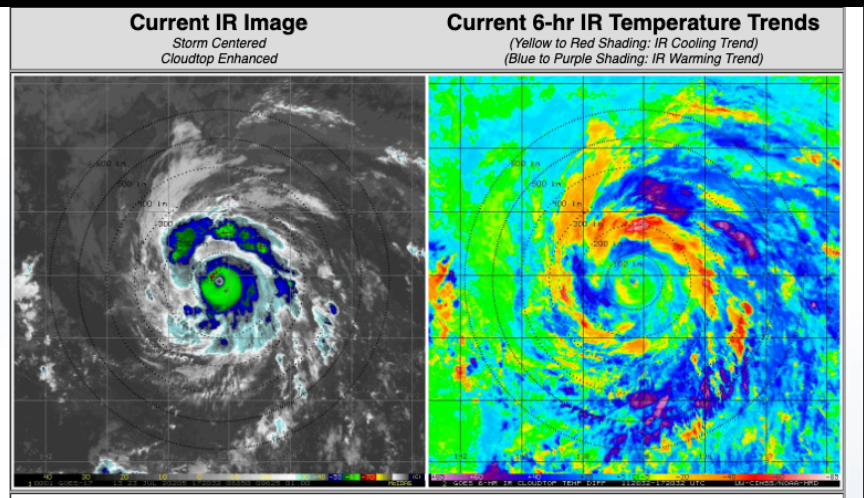


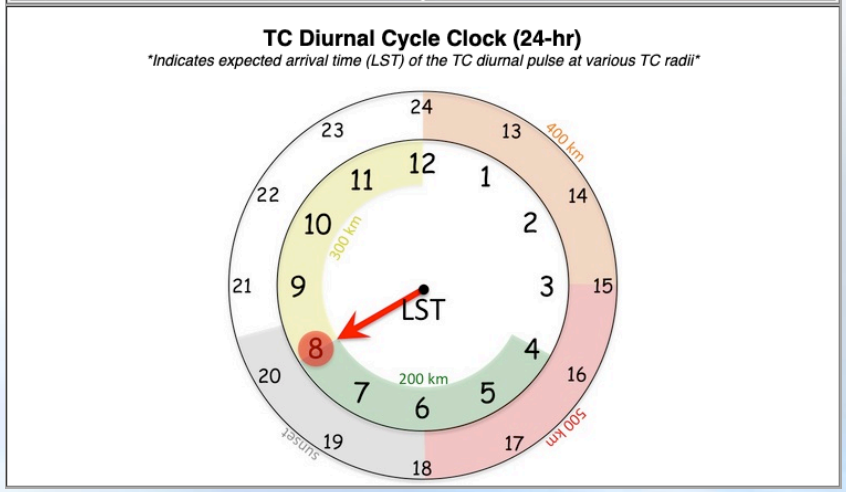
Source: NOAA NHC

Tropical Cyclone Diurnal Cycle

- The diurnal cycle of radiation is one example of a short-term dynamic process
- **The daily cycle of radiation affects significant change in hurricanes throughout the day, promoting larger storms in the afternoon and stronger storms in the early morning**
  - Linked with outward-propagating bands of enhanced rainfall and convection

- **Improved understanding of the science and an effective transition into operations can lead to improved short-term forecasts and enhanced societal benefit**



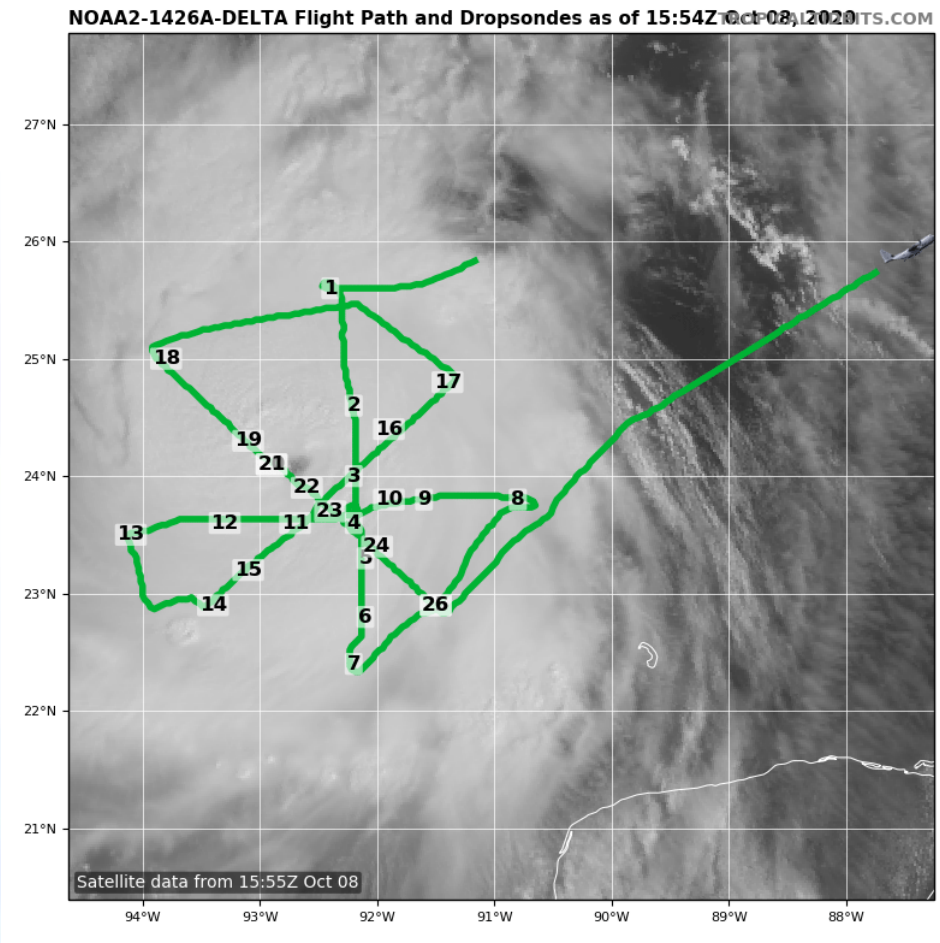


Source: Jason Dunion and UW-Madison/CIMSS/NOAA HRD

Satellite Soundings

- **Little is known about if and how the diurnal cycle of radiation affects a deep layer of TCs**
- Soundings can be used to measure thermodynamic properties throughout the depth of the storm
- For TCs, radiosonde launches are sparse in both space and time
- Aircraft reconnaissance is only available about 30% of the time in the Atlantic (Rappaport et al. 2003), and less elsewhere

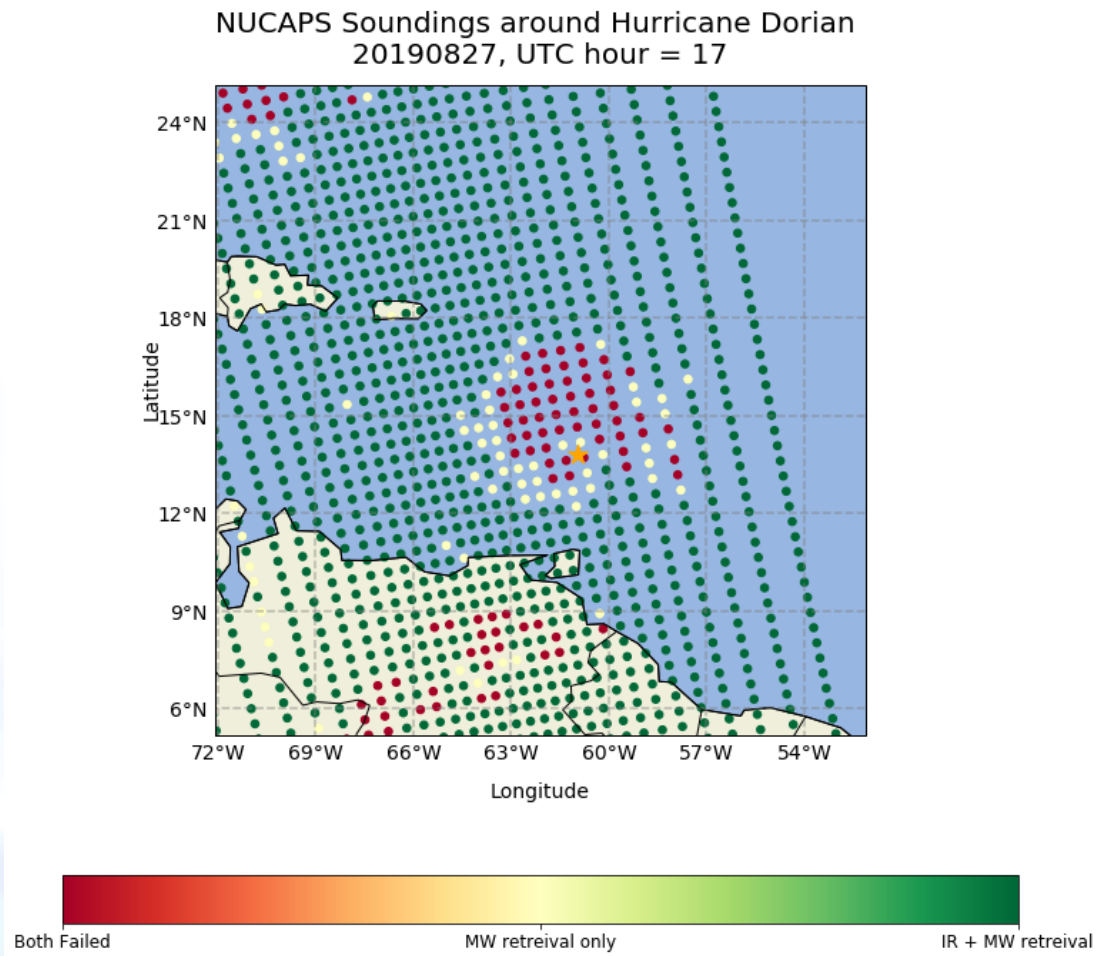
- **Remote sensing provides increased spatial and temporal coverage over aircraft reconnaissance and the radiosonde network**



Source: tropicaltidbits.com

NUCAPS and the TC Diurnal Cycle

- **Utilize NUCAPS profiles to measure daily changes in temperature and moisture in the hurricane environment**
  - Analysis not limited to NUCAPS soundings!
- Three cases: Hurricane Dorian (2019), Hurricane Florence (2018), and Hurricane Irma (2017)
  - Exclude genesis and landfall periods
- Combination of NUCAPS retrievals from S-NPP, NOAA-20, and MetOp A/B
  - Spans the diurnal cycle
- Utilize both IR+MW and MW-only retrievals
  - Temperature and moisture

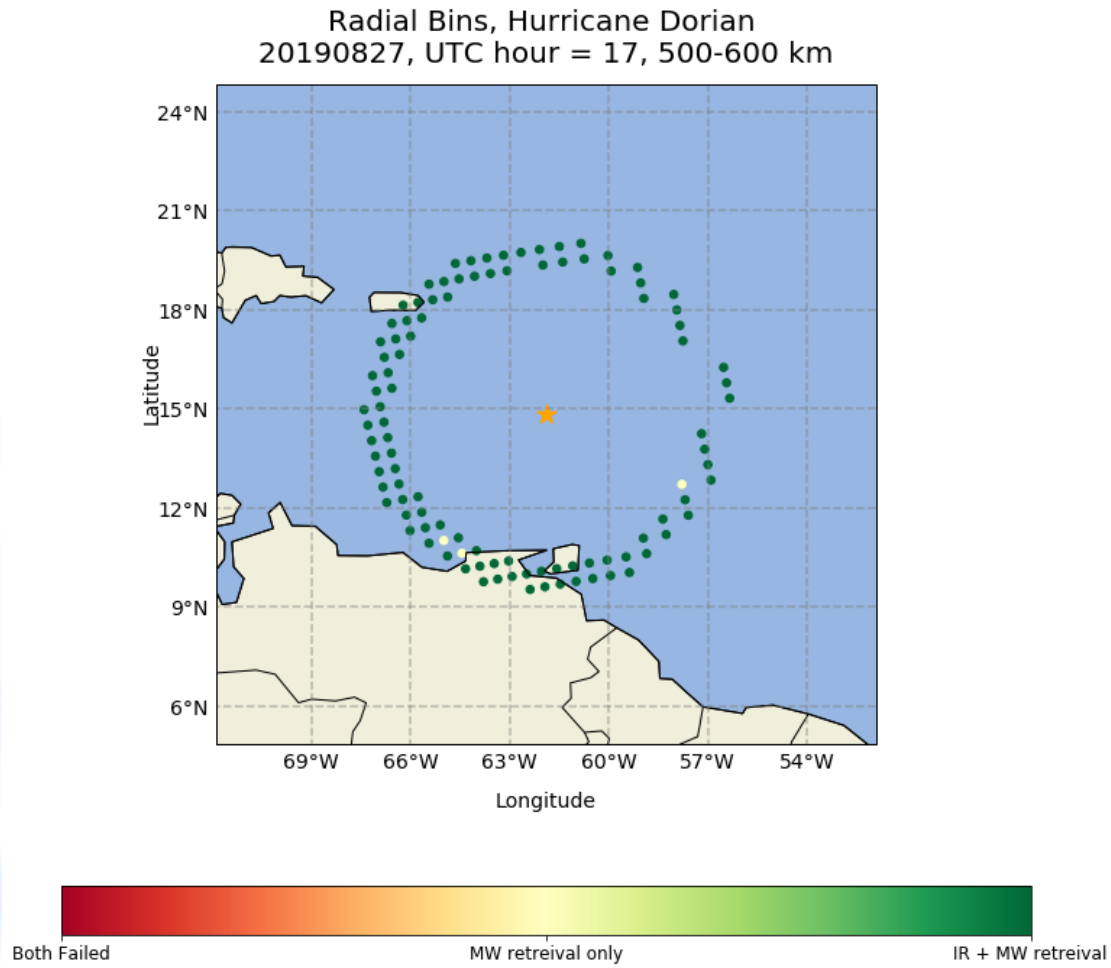


Methodology

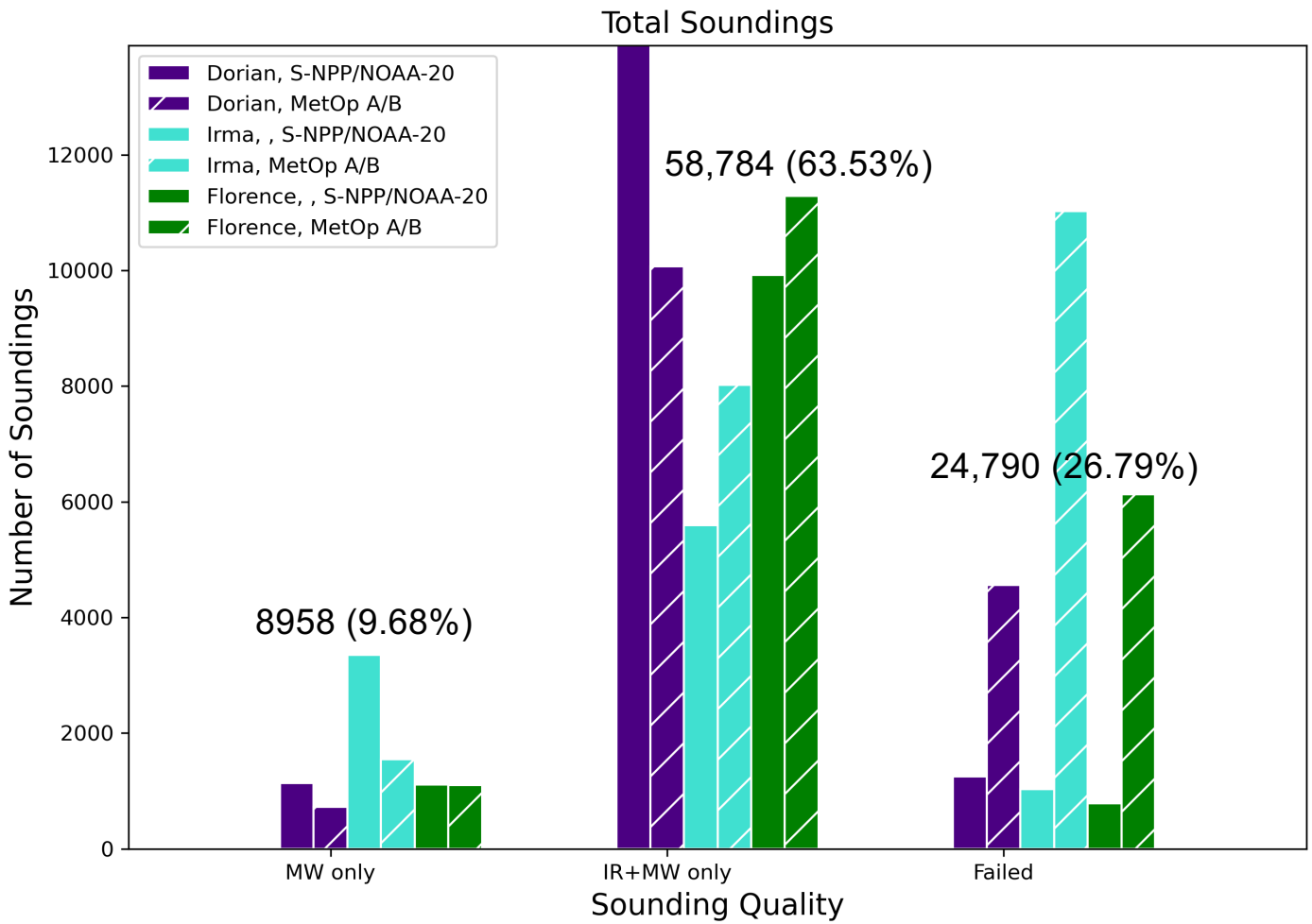
- Approach:
  - Analyze profiles in a storm-relative framework
  - Calculate **anomalies** from a daily mean sounding

- Method:
  1. Bin soundings by radial distance from storm center (every 100 km)
  2. Average all soundings in each radial bin to get daily mean sounding
  3. Subtract the daily mean sounding from each profile to get an **anomaly profile**
  4. Convert from UTC to Local Time

- ***Composite all NUCAPS anomaly profiles at each hour and radial bin over the storm lifetime to yield a mean diurnal evolution***
  - *Compare results to numerical simulation (Cloud Model 1)*

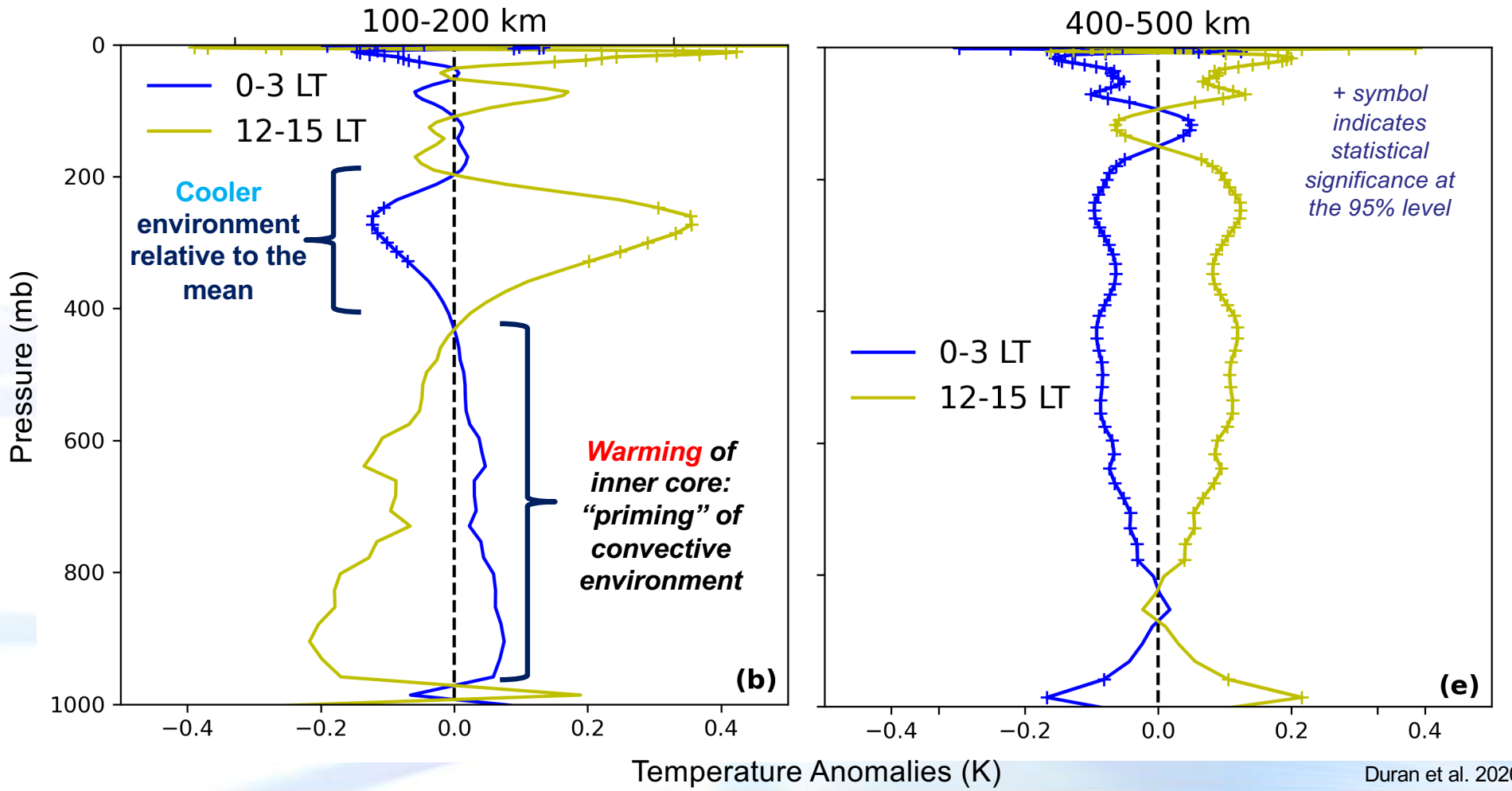


Results



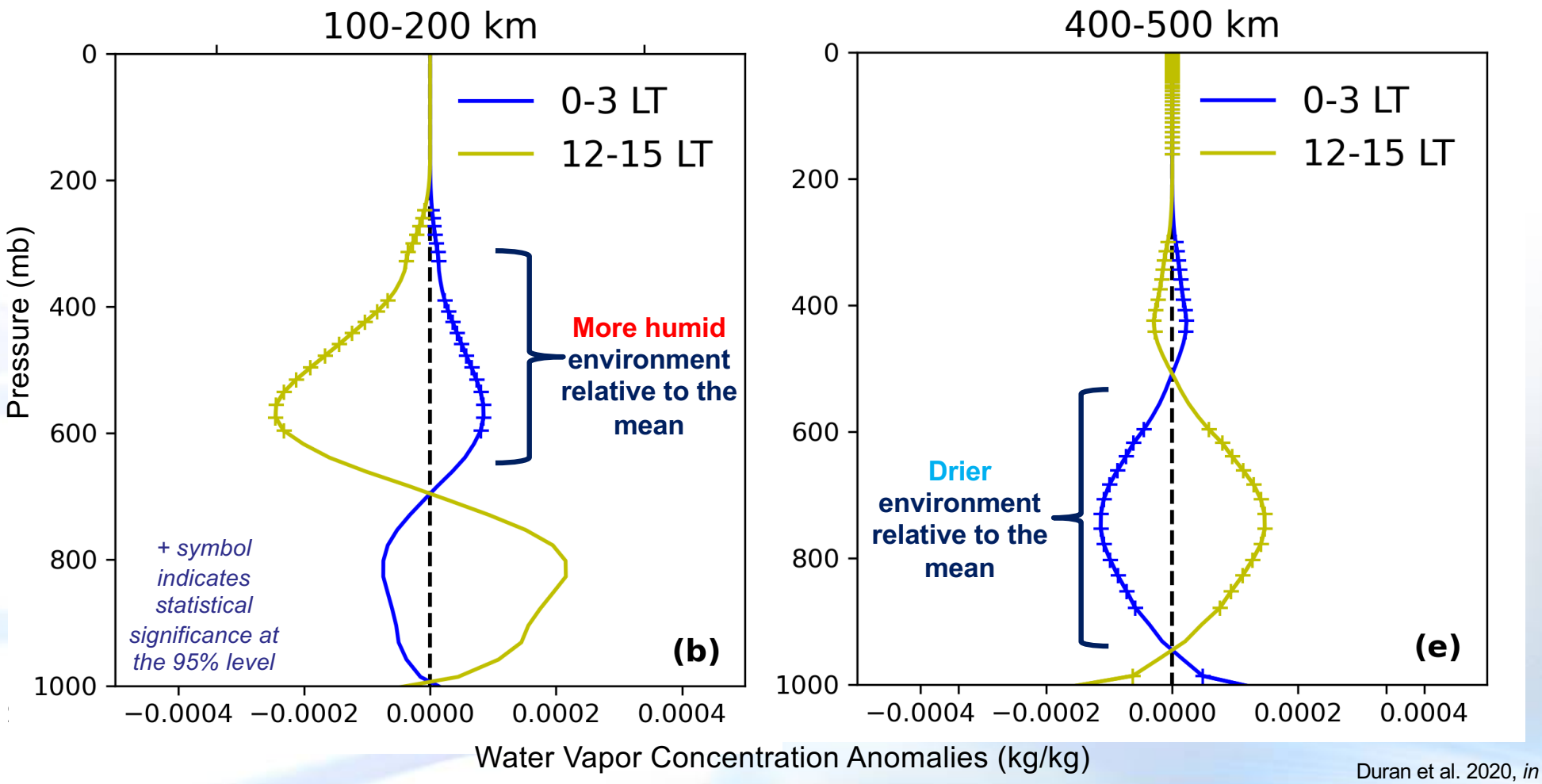
Duran et al. 2020, *in prep*

Temperature Anomalies



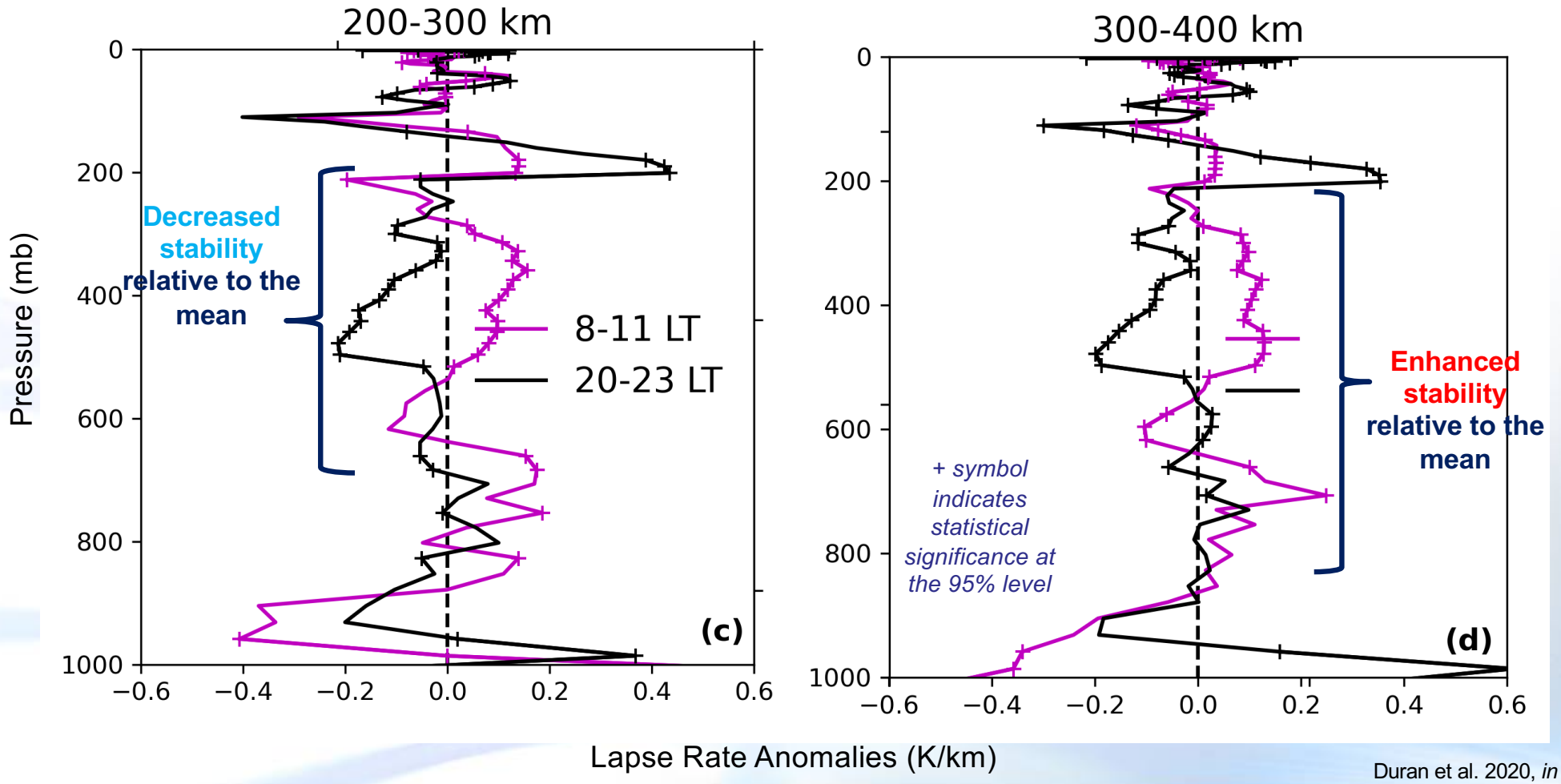
Duran et al. 2020, *in prep*

Moisture Anomalies



Duran et al. 2020, *in prep*

Stability Anomalies



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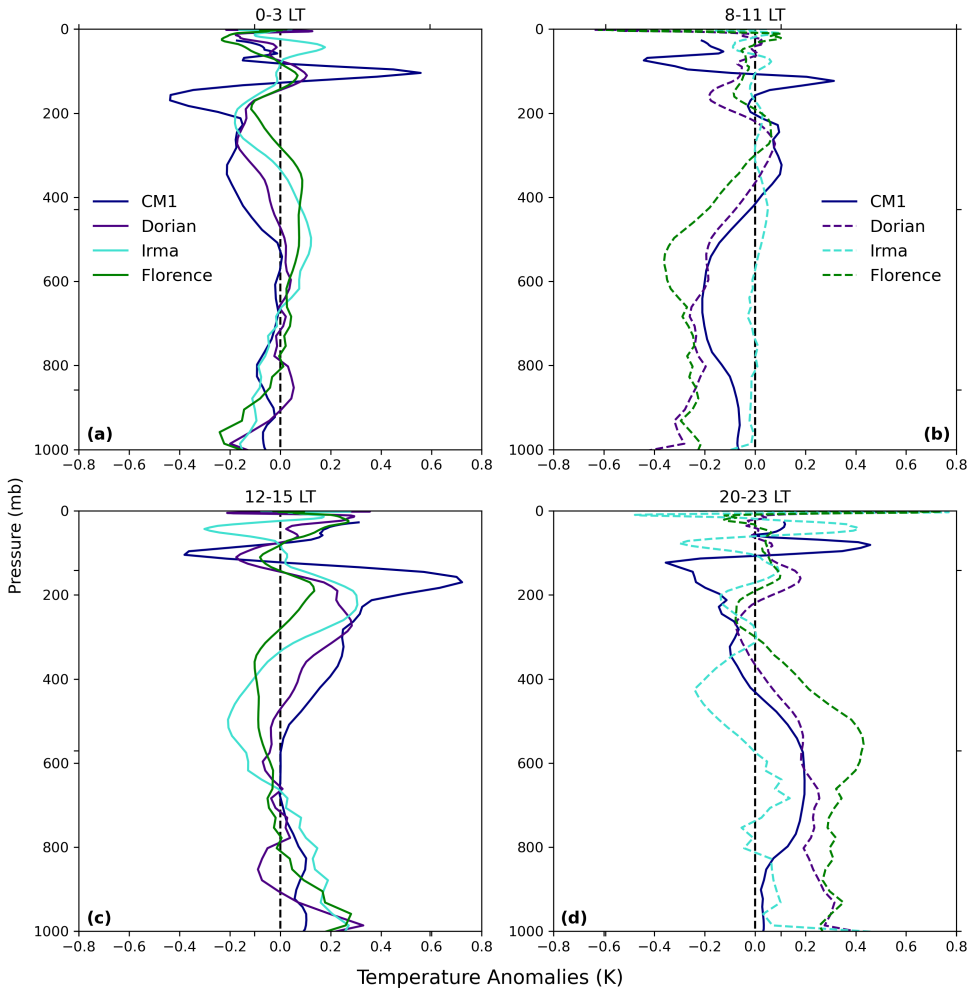
Comparison of Cases

IR+MW Retrievals

S-NPP/NOAA-20



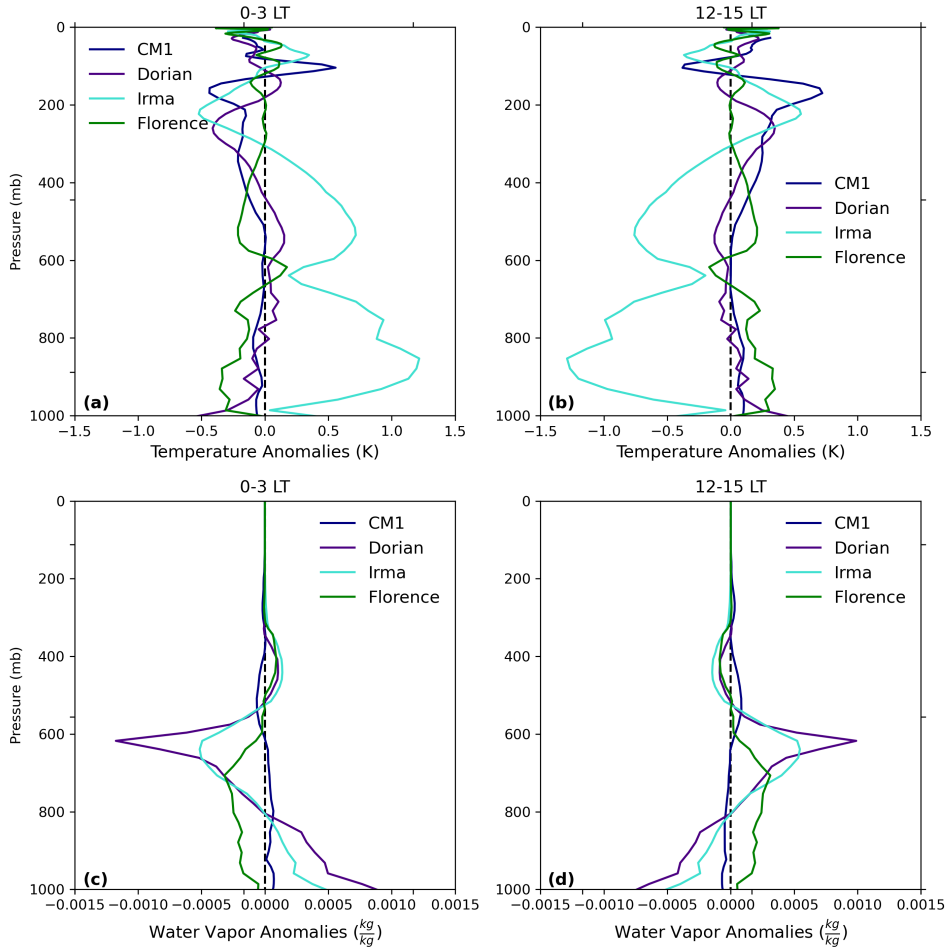
MetOp A/B

Duran et al. 2020, *in prep*

Comparison of Cases

MW-only Retrievals

S-NPP/NOAA-20

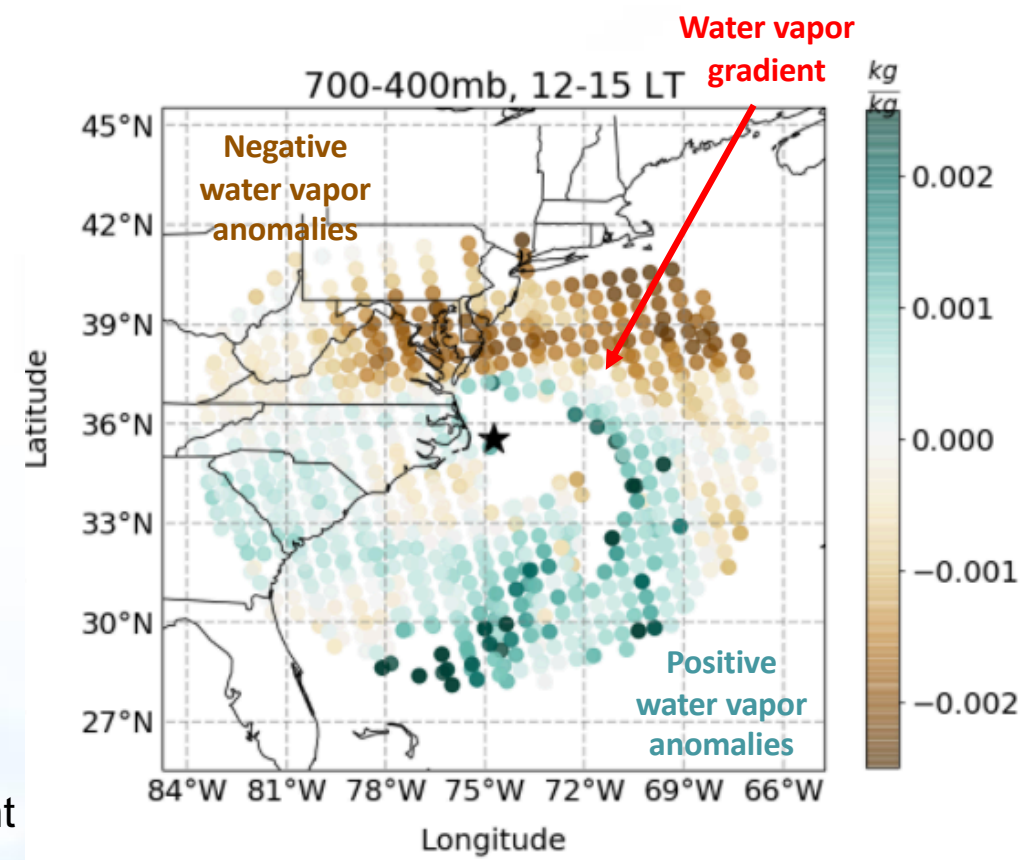


MetOp A/B

Duran et al. 2020, *in prep*

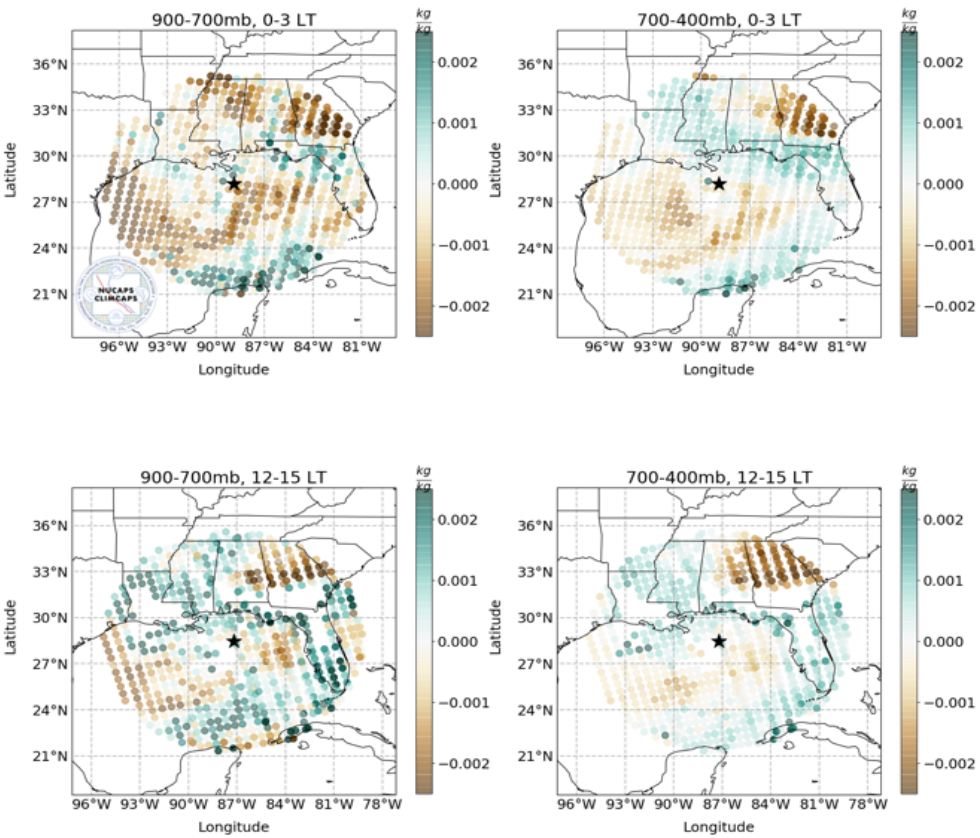
Transition of Research: Plan view images

- **Goal: transition of research into operations**
  - Work with end-user to improve product
- Plan view images facilitate the visualization and interpretation of anomalies
  - Allow end-users to easily identify thermodynamic changes across the entire storm
- Example: Tropical Storm Fay (2020):
  - **Negative anomalies** help identify areas of relatively drier air
  - **Positive anomalies** indicate areas of moistening, or show areas potentially conducive for further convective development
  - **Gradients** help identify boundaries or intrusions of dry/moist air

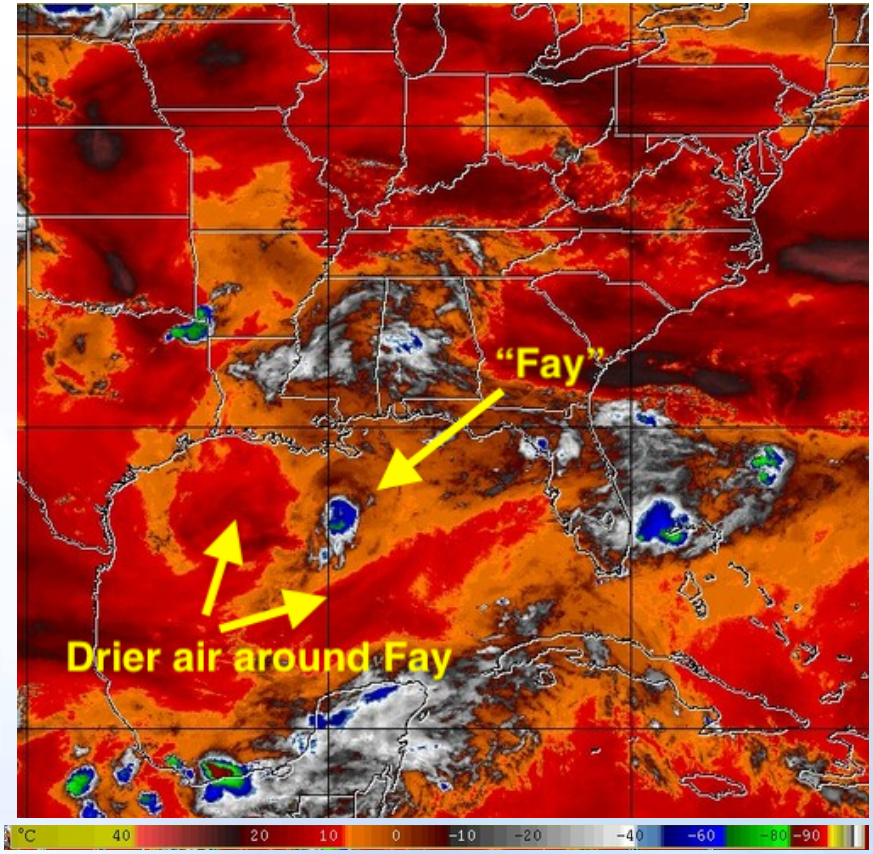


Transition of Research: Plan view images

20200705 (AL06) N20+SNPP
NUCAPS Water Vapor Mixing Ratio Anomalies



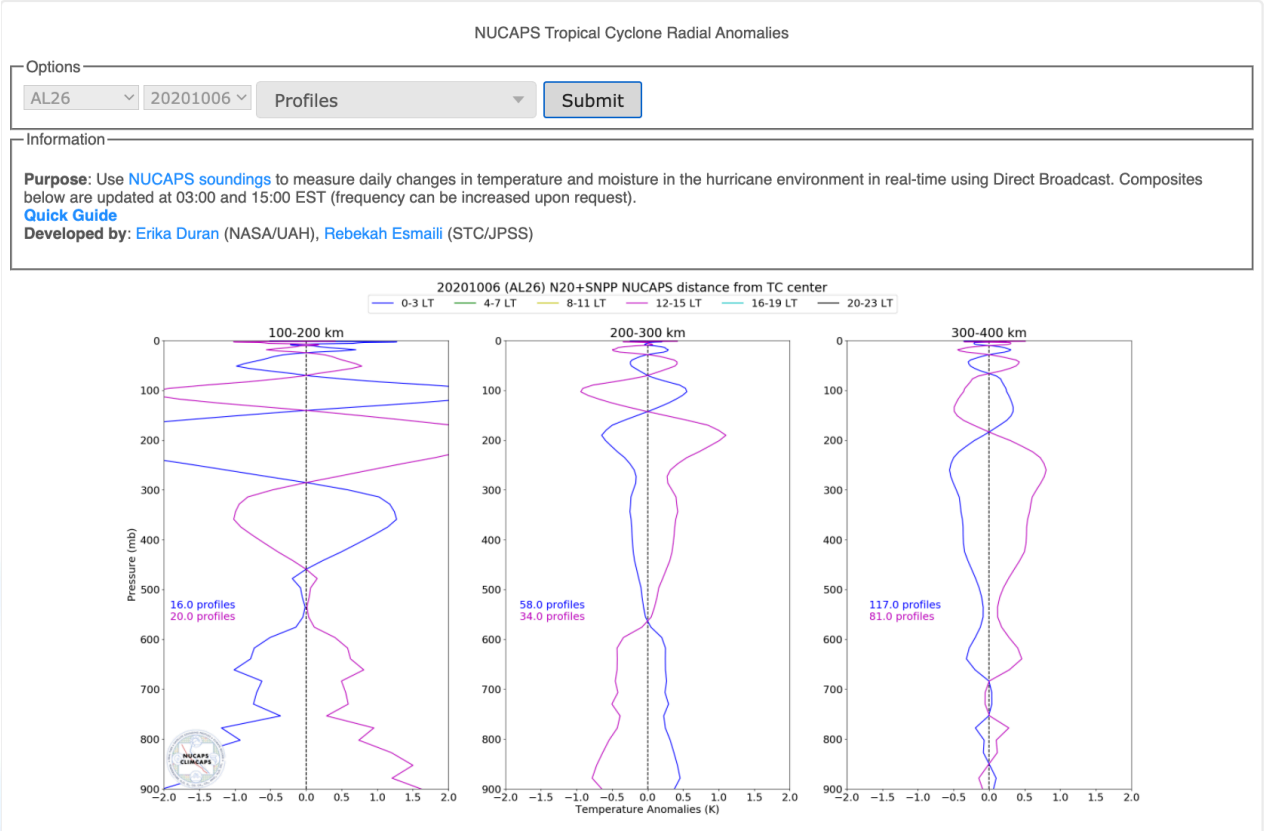
GOES-East Low-level Water Vapor Imagery (Band 10)
05 July 2020 0600 UTC



Source: UW-CIMSS/NOAA HRD

User Engagement

- Rapidly integrated NUCAPS TC radial anomaly products for the 2020 Atlantic Hurricane Season
- Real-time products using direct broadcast are available on the web
- Originally geared toward the 2020 NOAA HRD IFEX field campaign
  - Unable to test/solicit feedback due to decreased number of research flights from COVID-19
- These products are introduced to the NOAA NHC and are included with experimental products for validation/feedback



http://sigma.umd.edu/resmaili/rad_bin.html

User Engagement

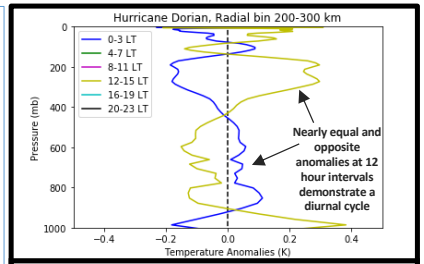
- NOAA HRD daily tropical map discussions provide additional opportunities to share products and solicit feedback
- Quick guide available to provide scope and aid in interpretation of TC radial anomalies
- Blog post on TC radial anomaly products available on SPoRT website

Tropical Cyclone Radial Anomalies

Quick Guide

Why are Tropical Cyclone Radial Anomalies Important?

Tropical cyclone radial anomalies show differences in thermodynamic fields in both the near-storm and the surrounding environment. Plan view imagery of radial anomalies demonstrate gradients in temperature and moisture, capturing important features such as dry air intrusions. Vertical anomaly profiles demonstrate patterns such as the tropical cyclone diurnal cycle (e.g., Dunion et al. 2014). Anomalies are calculated in a storm-relative framework, using a daily mean sounding to create azimuthal averages within 100km radial bins.



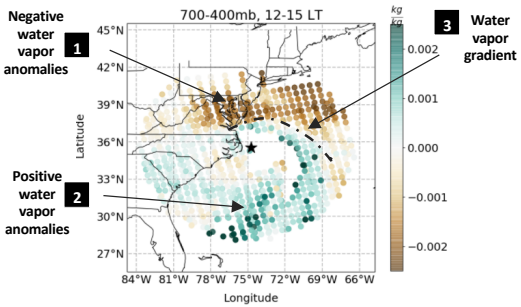
Composite temperature anomaly profiles in Hurricane Dorian using S-NPP and NOAA-20 CrIS/ATMS NUCAPS, valid from 0-3 and 12-15 local time (LT)

How are Tropical Cyclone Radial Anomalies Created?

The NOAA Unique Combined Atmospheric Processing System (NUCAPS) is the algorithm used to process temperature and moisture soundings from hyperspectral infrared and microwave sounders such as CrIS and ATMS onboard S-NPP and NOAA-20 and IASI and AMSU onboard MetOp A and B. For each overpass, soundings are sorted into 100 km wide radial bins centered on the TC, extending to 800 km from the TC center. A daily mean sounding is calculated for each radial bin using available soundings in that bin for a given day. This daily mean profile is subtracted from each sounding within each radial bin to yield a temperature or moisture anomaly. Anomalies are then converted to local time (LT), and composited every 4 hours (e.g., 0-3 LT, 4-7 LT, etc.).

Tropical Cyclone Radial Anomalies Interpretation Example: Water Vapor

1. **Negative anomalies** in water vapor concentrations can help identify areas of relatively drier air
2. **Positive anomalies** can indicate areas of moistening, or show areas potentially conducive for further convective development.
3. **Gradients** in values can help identify boundaries or intrusions of dry/moist air



Contributor: Dr. Erika Duran, UAH/NASA SPoRT https://weather.msfc.nasa.gov/sport/

Summary

- NUCAPS satellite sounding retrievals are a valuable tool for observing the the tropical cyclone diurnal cycle
  - Show statistically significant differences between morning and afternoon overpasses throughout a deep layer of the storm
  - both infrared and microwave retrievals are useful
- Plan-view TC radial anomaly products facilitate the interpretation and visualization of thermodynamic changes for end-users
  - These products were quickly adapted for real-time capabilities in 2020 and made available to the community
- Moving forward: Continue to refine products through further case studies and implementing additional derived products (CAPE, equivalent potential temperature, etc.)
  - Continue to solicit and incorporate feedback from forecasters and end-users