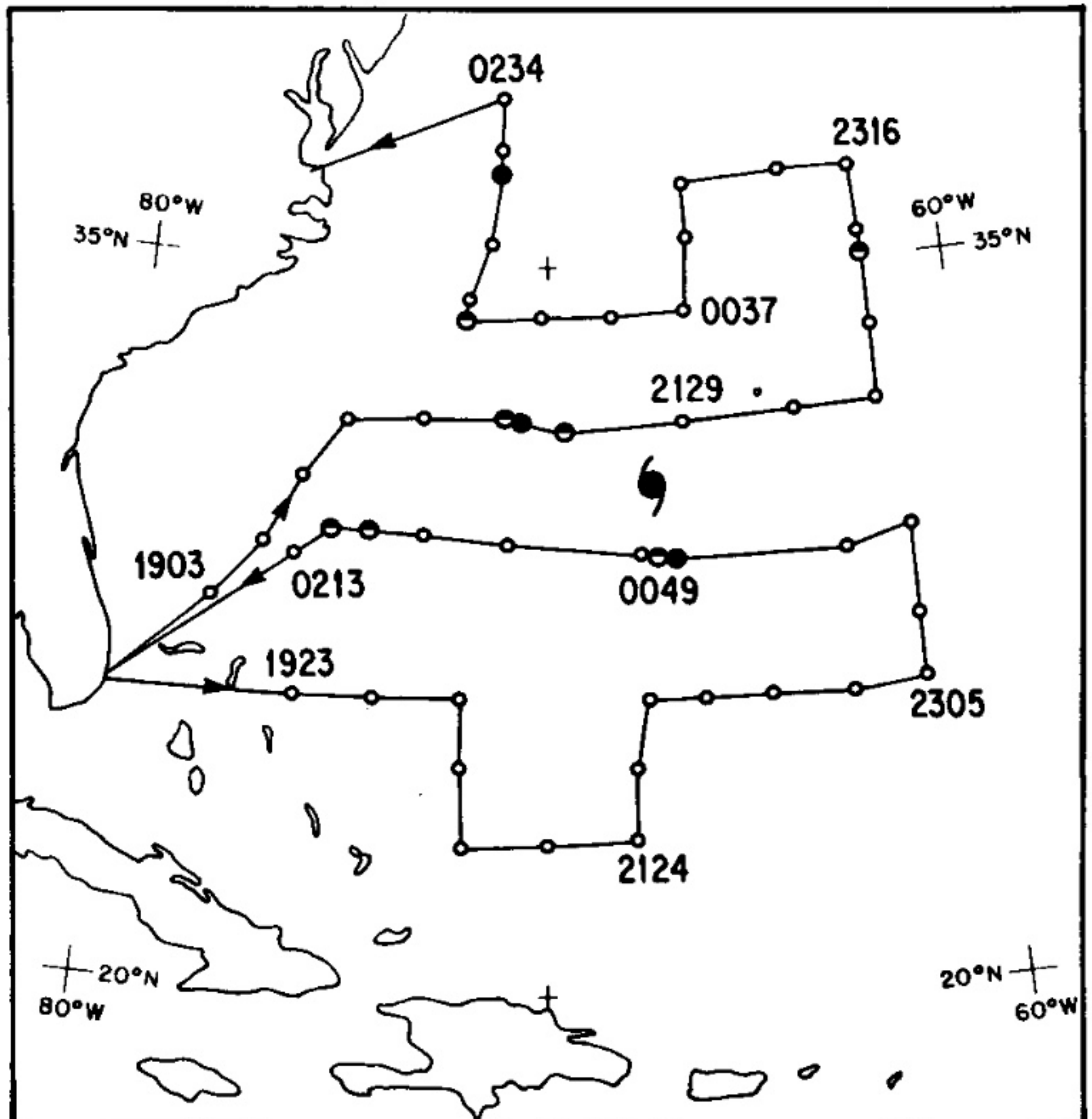
Recent Research with Dropwindsondes at AOML/HRD

Sim D. Aberson
NOAA/AOML/Hurricane Research Division

2018 AVAPS Users Group Meeting

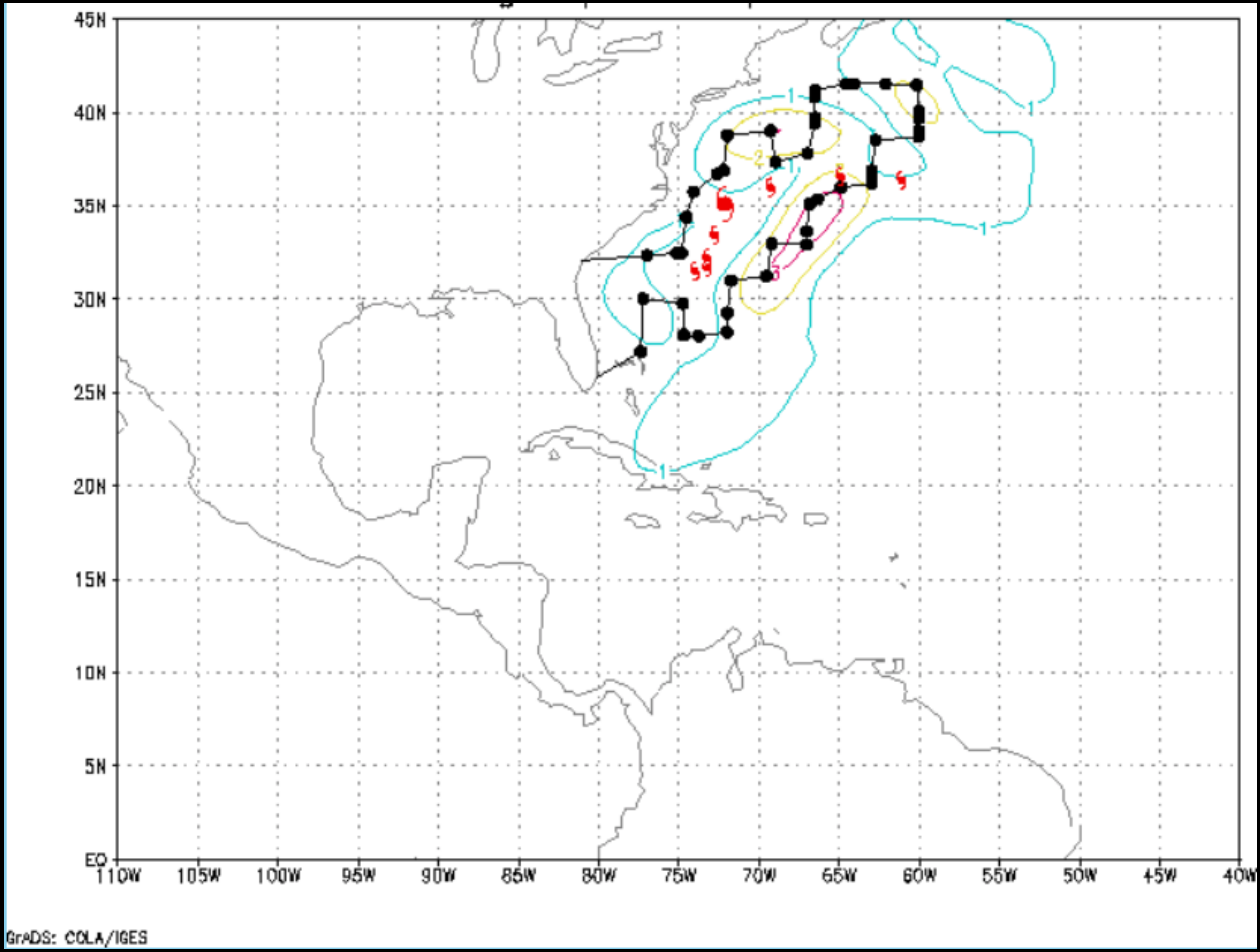
25 April, 2018

Anniversaries



14 September 1982: First synoptic flow Hurricane Debby

Anniversaries



14 July 1997: First G-IV synoptic surveillance mission
Tropical Storm Claudette

Anniversaries

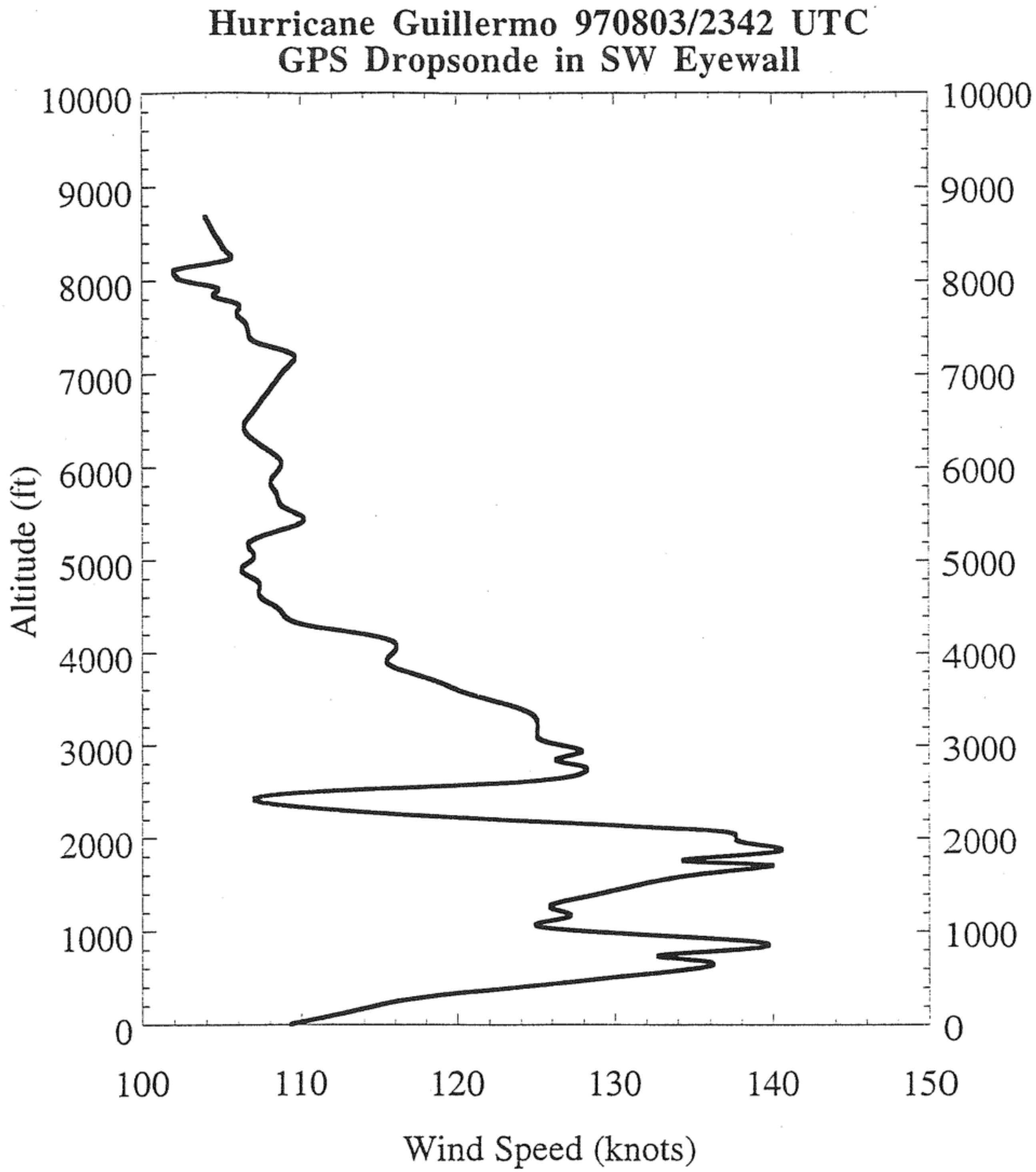
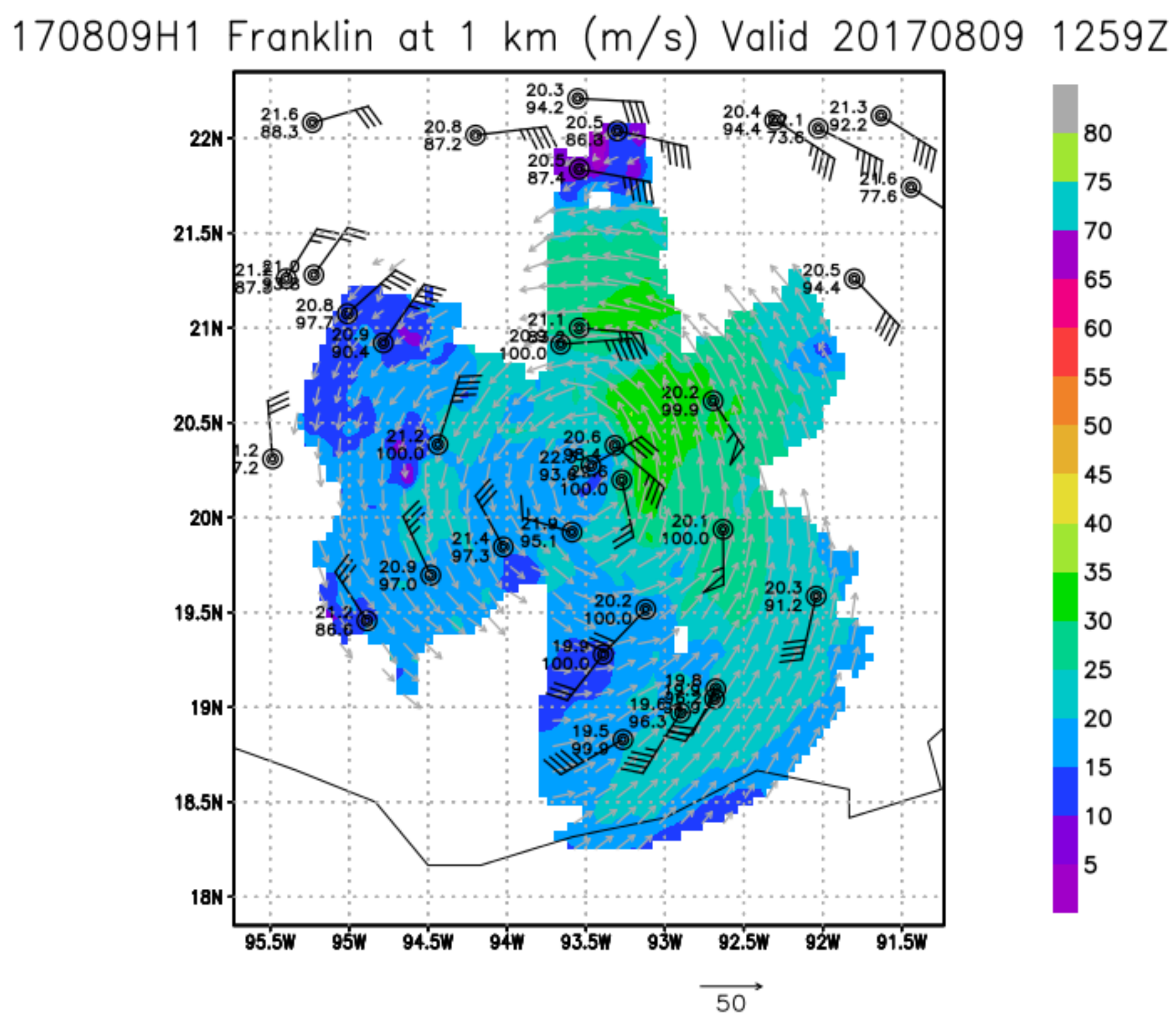
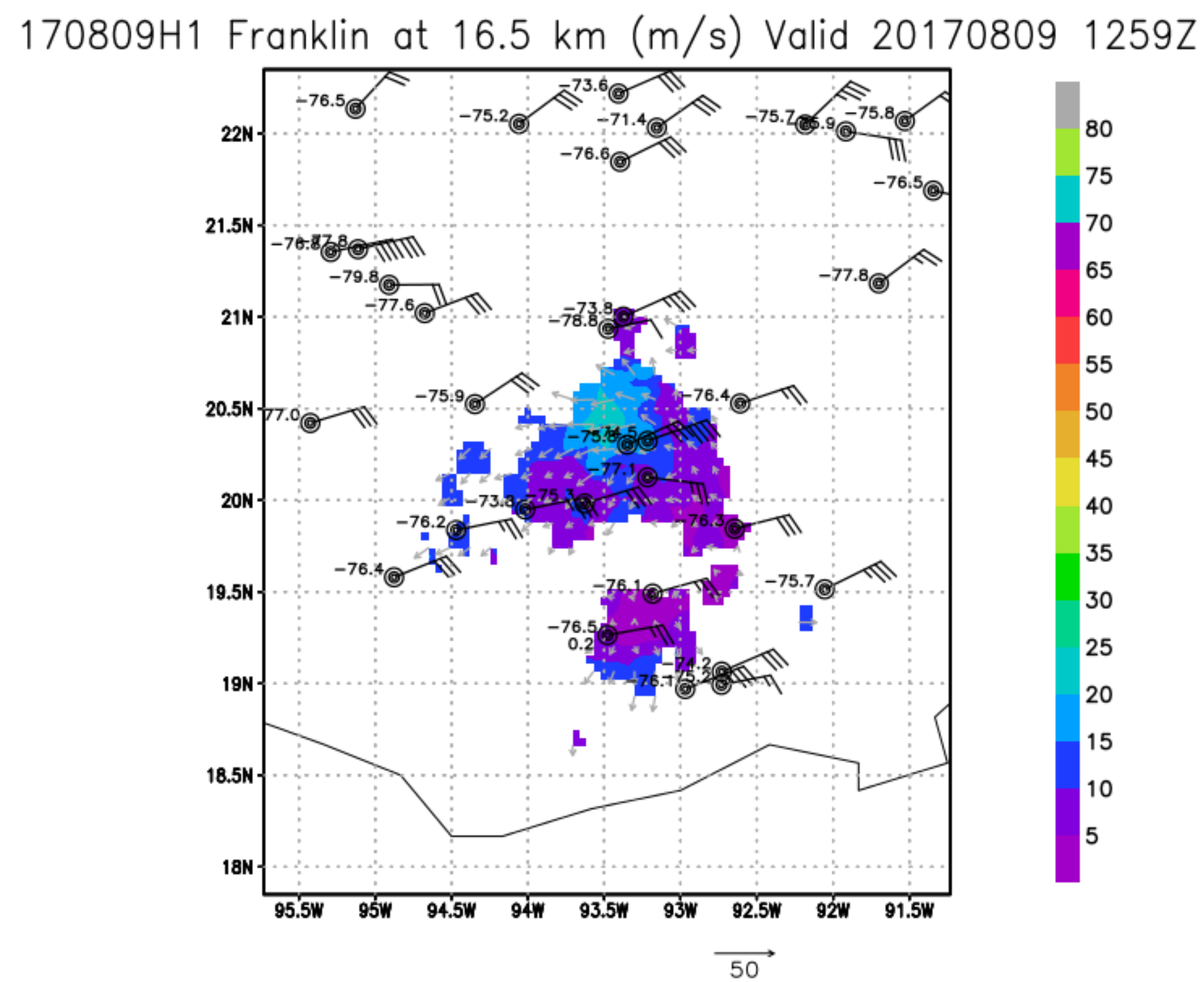


Fig. 4. Profile of wind speed (knots) versus altitude (feet) from a GPS dropwindsonde released within the southwest quadrant of the eyewall of Hurricane Guillermo at 2342 UTC 3 August. (Courtesy of the Hurricane Research Division)

03 August 1997: First eyewall dropwindsonde

Dropwindsonde data from Global Hawk used in NOAA GFS for the first time during Hurricane Franklin





Sim Aberson: Extreme Horizontal and Vertical Wind Speeds Measured During 2017

In examination of all NOAA sondes from 2017, only three sondes measured extreme horizontal or vertical motions, all in Irma. AF sondes not yet examined.

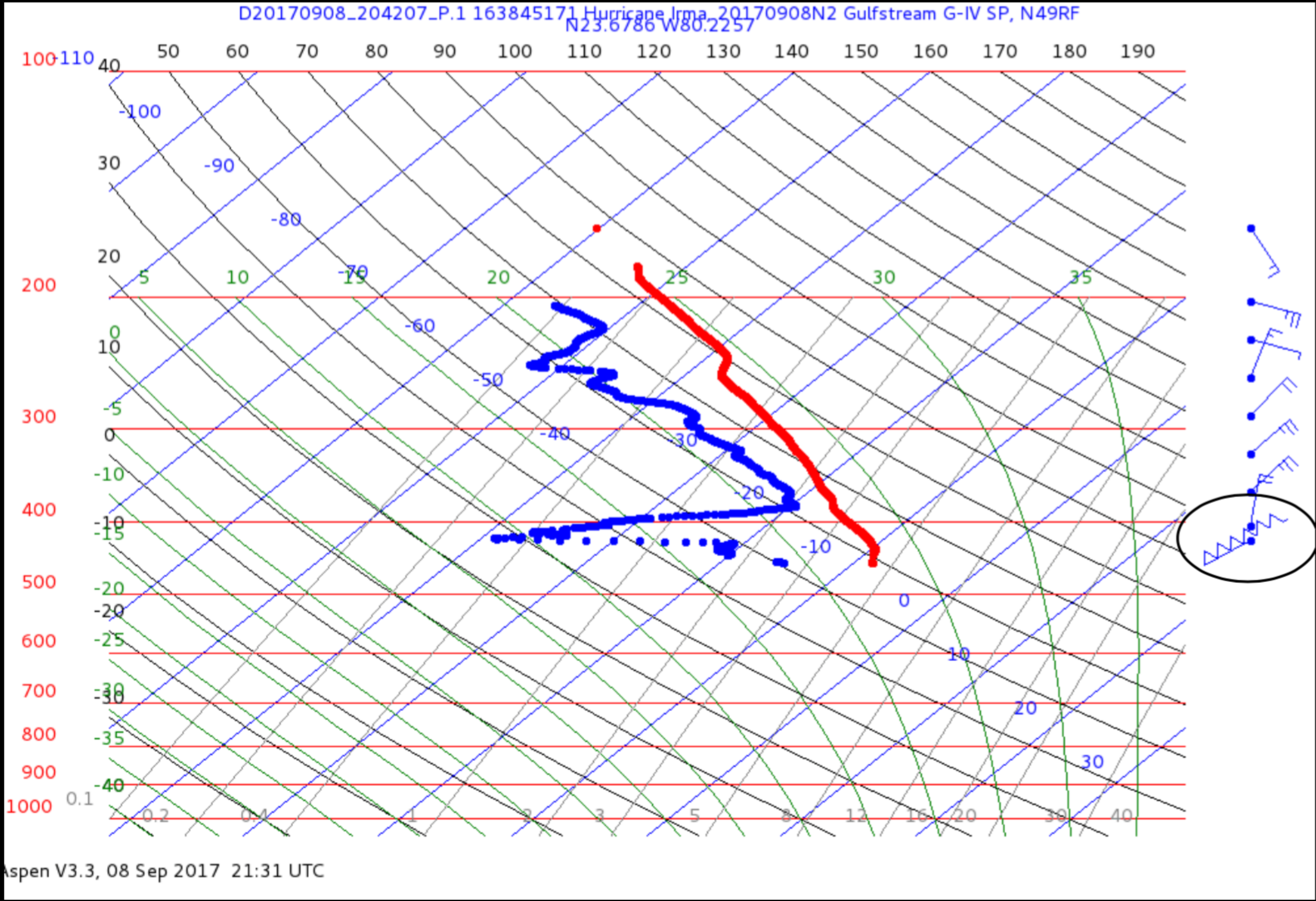
This continues to confirm that the strongest low-level vertical velocities are in the strongest TCs.

Strong updrafts are sometimes measured near flight level.

Strong horizontal winds are sometimes found close to the surface.

Only some of the sondes with strong downward motion show dry air or inversions at those locations.

Fastest wind from a NOAA sonde, approximately 300 kt



Sim Aberson: Synthetic Humidity Data During the 2017 Hurricane Season

RH sensors have historically been unable to accurately measure at low temperature.

Modeling centers automatically reject observations at low temperature and pressure because of this.

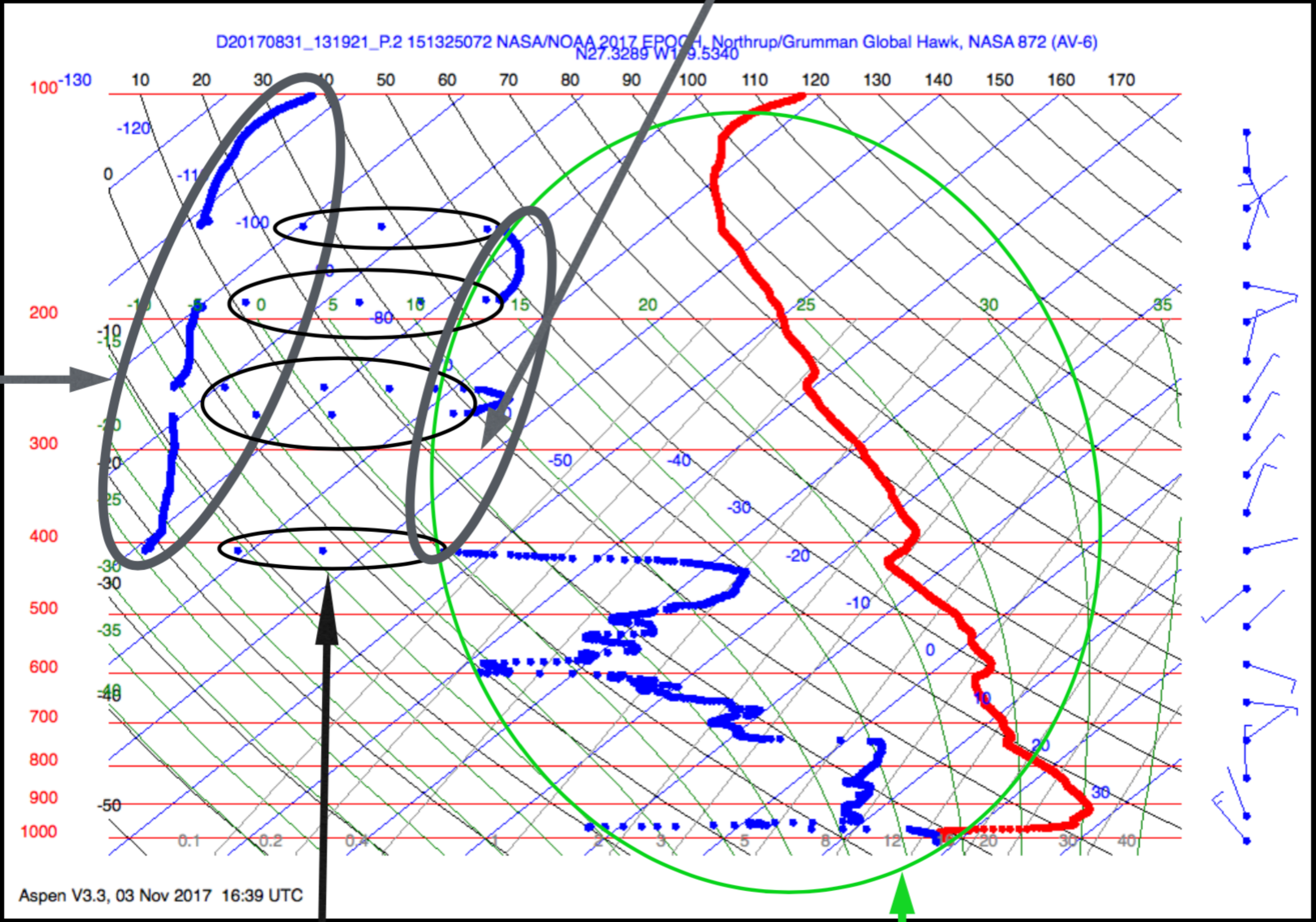
Operational center	**Temperature**	**Pressure**
European Centre for Medium-Range Weather Forecasting (ECMWF)	$< -40\ ^{o}\mathrm{C}$	< 300 hPa
United Kingdom Meteorological Office (UKMET)	$< -40\ ^{o}\mathrm{C}$	
National Oceanic and Atmospheric Administration (GFS)		< 300 hPa

As a result of a bug correction in 2016, moisture data that were previously reported cannot now reliably be reported. During the 2016 season, these data were reported as missing. NHC requested that these missing values be reported as having 0.1% RH. The true values could, in reality, be between 0% and 12% RH. As the dropwindsonde data are quality controlled, the 0.1% RH values are filtered with other data and transmitted in real time via TEMP DROP; some may be indistinguishable from true RH data. No tests of the impact of this change to operational models was conducted.

100% of sondes released by the Gulfstream-IV and Global Hawk have these synthetic humidity data.

16% or GH sonde RH data and 3% of G-IV sonde RH data are synthetic.

	# of Dfiles	# data lines (4 Hz)	# moisture data lines (2 Hz)	# of lines with 0.1% RH	% of RH data that are synthetic
GH	217	927,363	423,510	67,581	16%
G-IV	892	3,446,496	1,662,097	48,147	3%



Synthetic (0.1%) RH

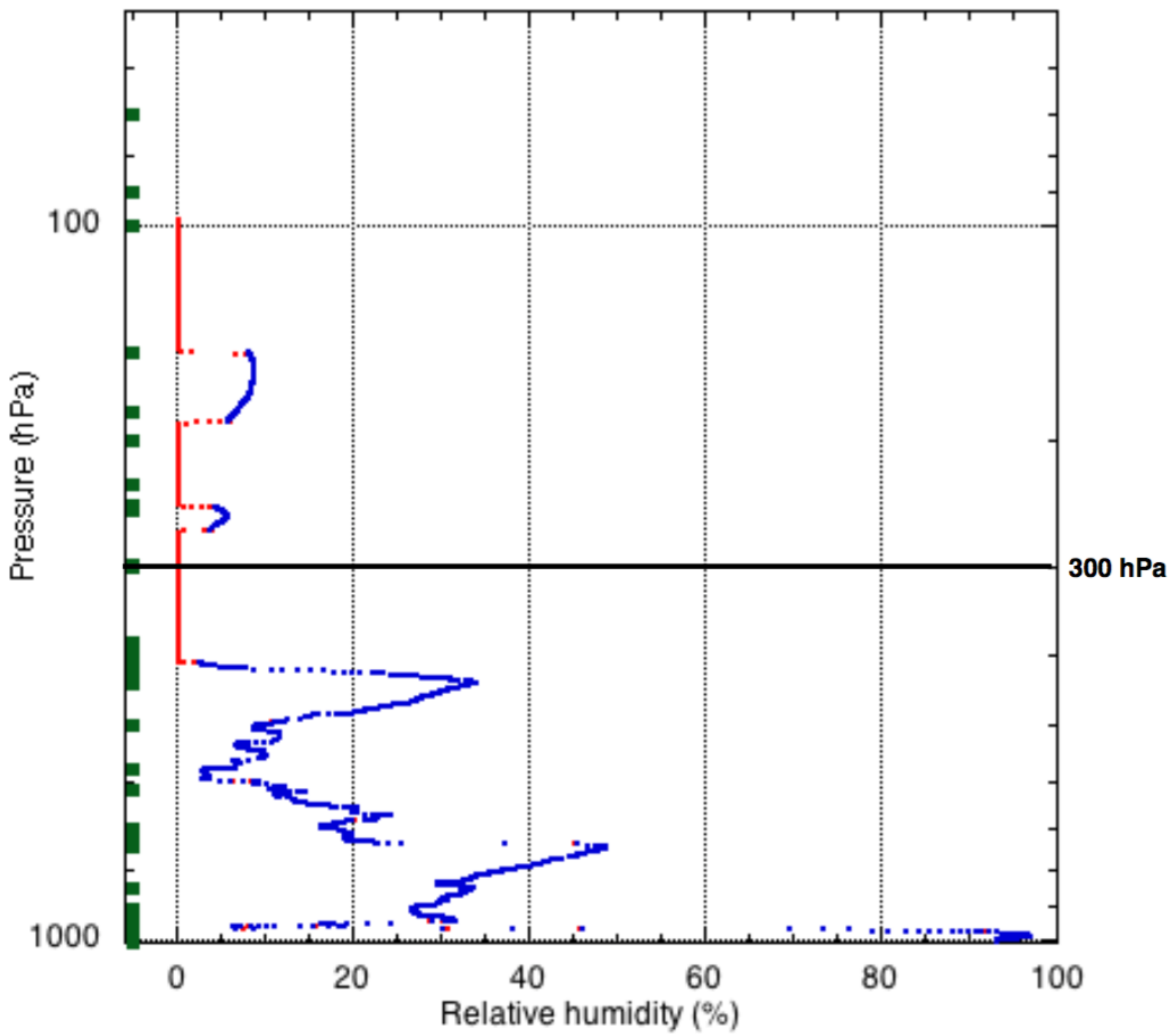
The result of filtering between real and synthetic RH

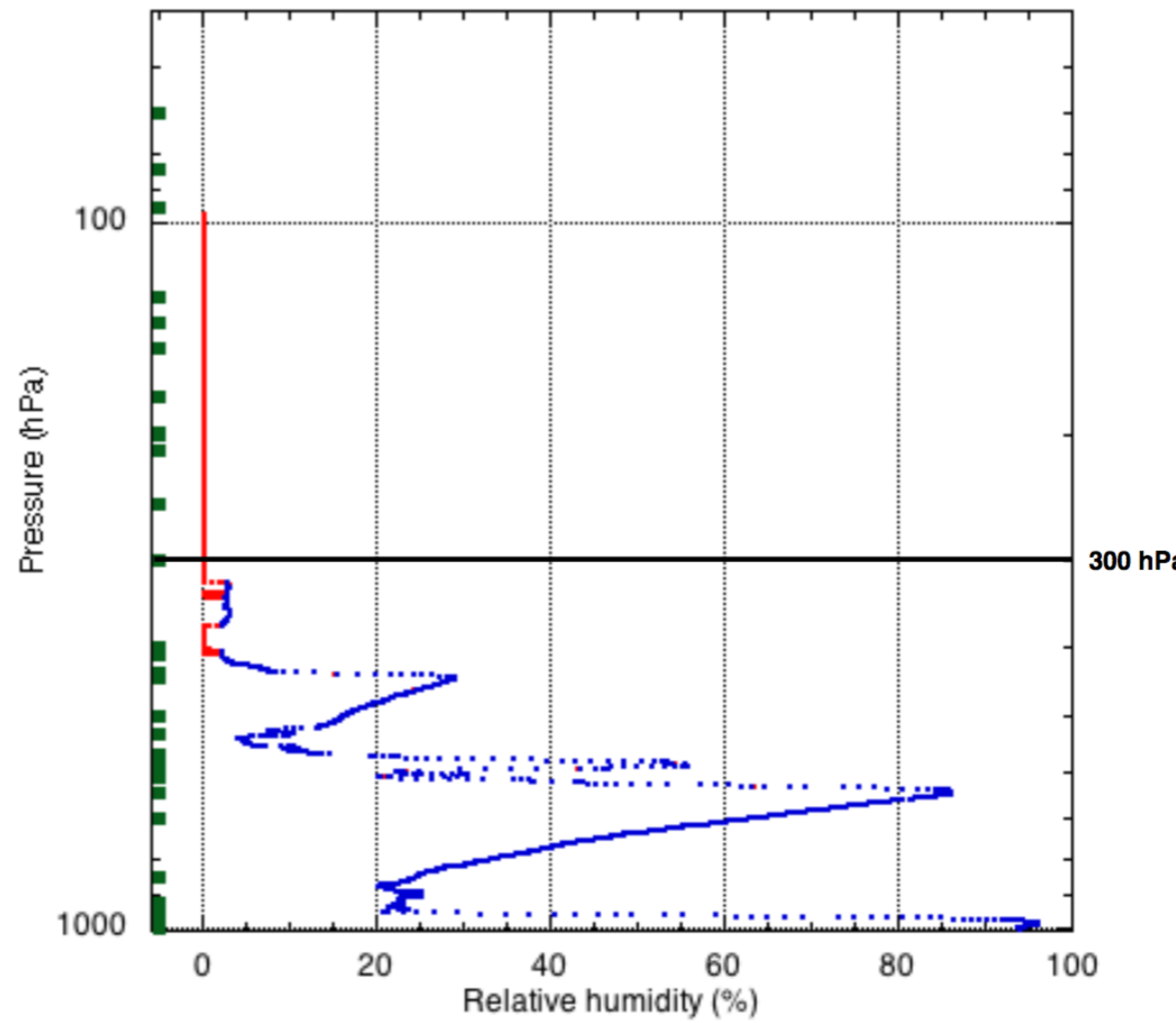
Real RH

QC with all data

QC with synthetic RH removed

Green squares represent TEMP-DROP levels





The 2018 National Hurricane Operations Plan will require that these synthetic data no longer be reported.

Also, the requirements that dew-point depressions for relative humidities less then 20% are to be encoded as 80, and that all dew-point depressions below –40C are to be reported as Dnn // have been deleted.

Kelly Ryan: Sensitivity of G-IV Dropsonde Configuration on TC Prediction Using a Regional OSSE Framework

Current targeting technique developed based on 1997 version of NOAA Global model.

Need to revisit this based on current global model, regional model system, DA systems, sensitivity techniques, and new observations.

Synoptic flow is back in the 2018 Hurricane Field Program after many years' absence. Goal is to obtain oversampled datasets to test techniques.

At the same time, OSSE studies are ongoing.

Brittany Dahl: OSSE Evaluation of Global Hawk Dropsonde Sampling Strategies in a TC

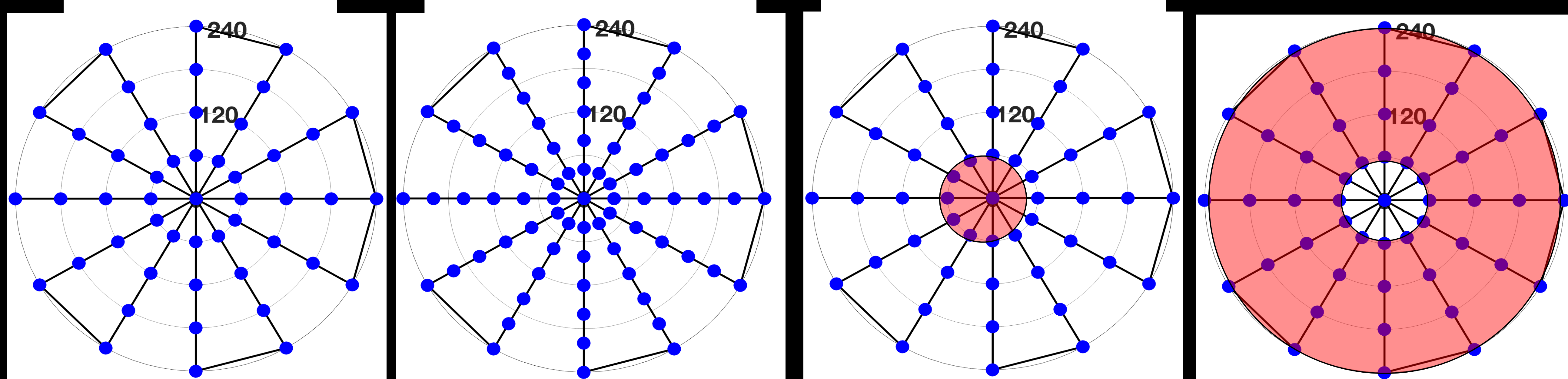
Forecast Impacts

- Intensity forecast is best with evenly spaced sampling around storm, or sampling inside 2xRMW.
- Track forecast is similar in all distributions through 36 h.

Considerations for Future Global Hawk Flight Planning

- Impacts may be maximized by targeting the area inside 2xRMW with additional dropsondes
- Temporal alignment of flight pattern with data assimilation cycles for forecast models may affect data impact

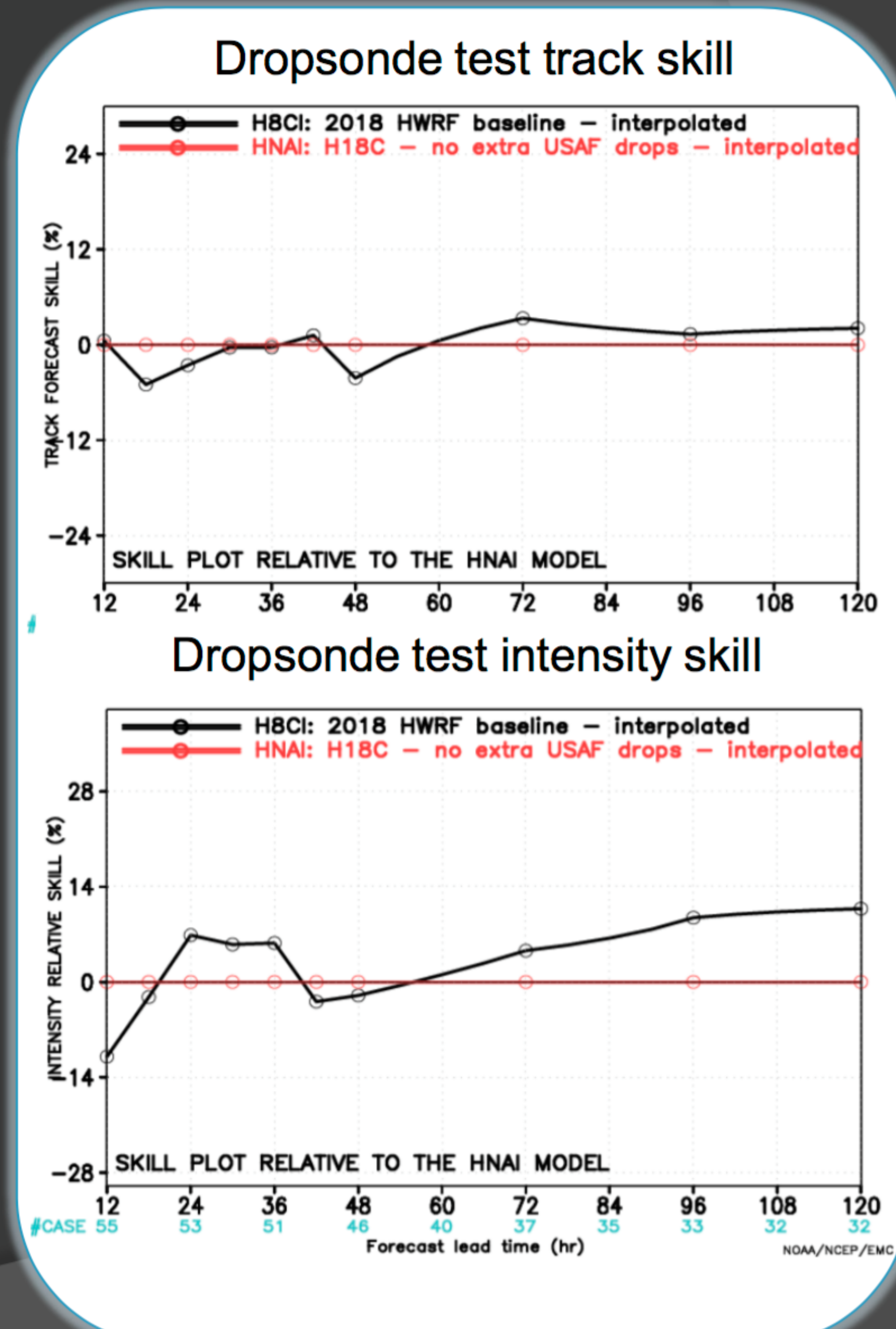
GH Original | GH Add Evenly | GH Add Inside | GH Add Outside 2xRMW



63 dropsondes | + 28 additional dropsondes

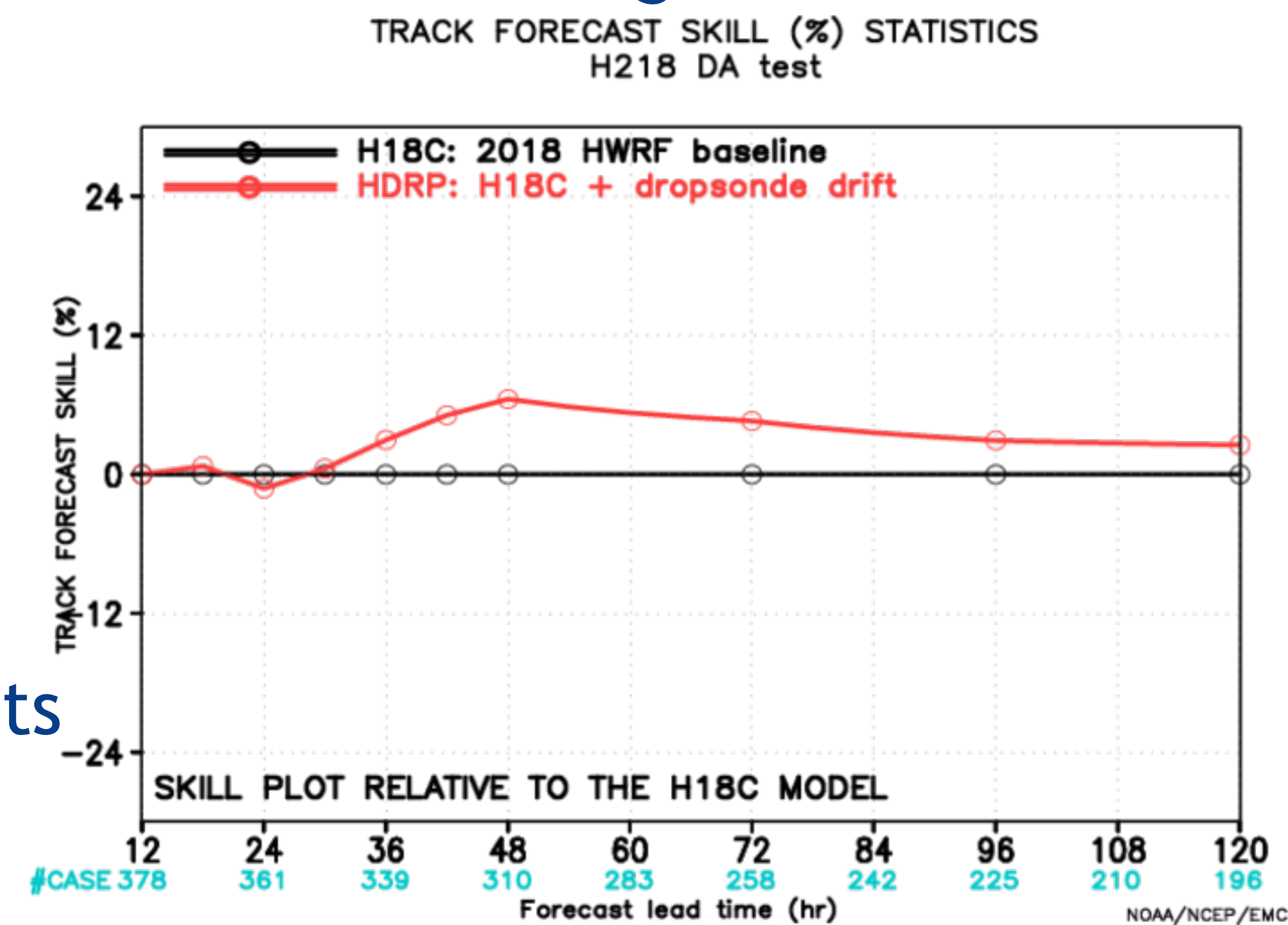
Jason Sippel: Impact of Turn-Point Dropwindsondes on Operational Models

- End-point dropsondes were requested for Franklin, Harvey, Jose, Maria, and Nate
- Requests made for periods when P3 was absent/unavailable
- Data denial expts in HWRF reveal a +10% impact on intensity skill



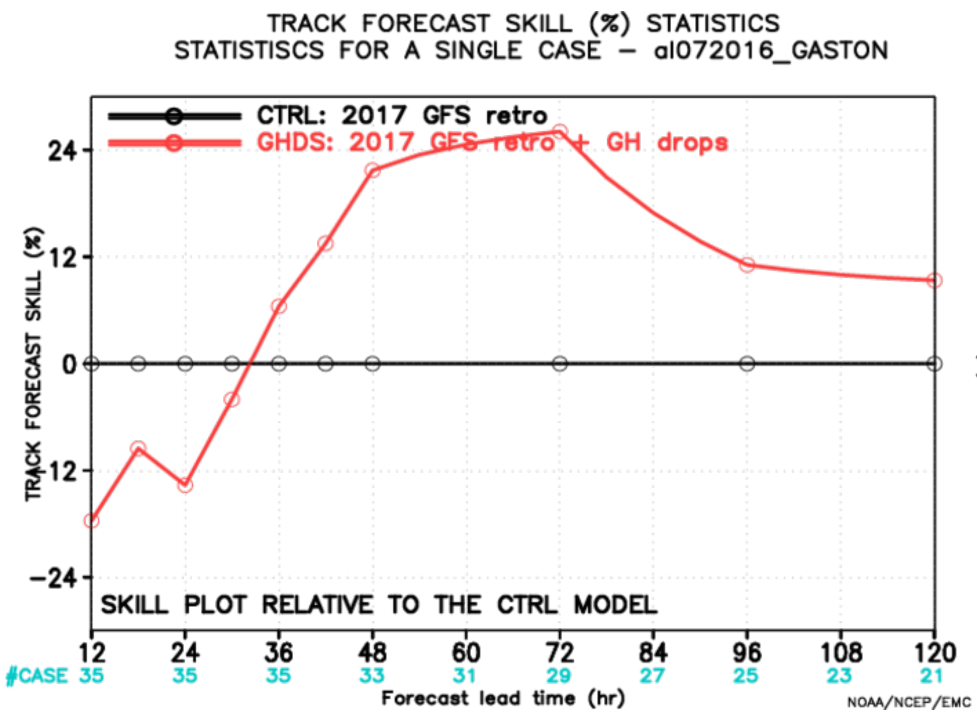
Henry Winterbottom/Jason Sippel: Using more dropwindsonde observations in operational models

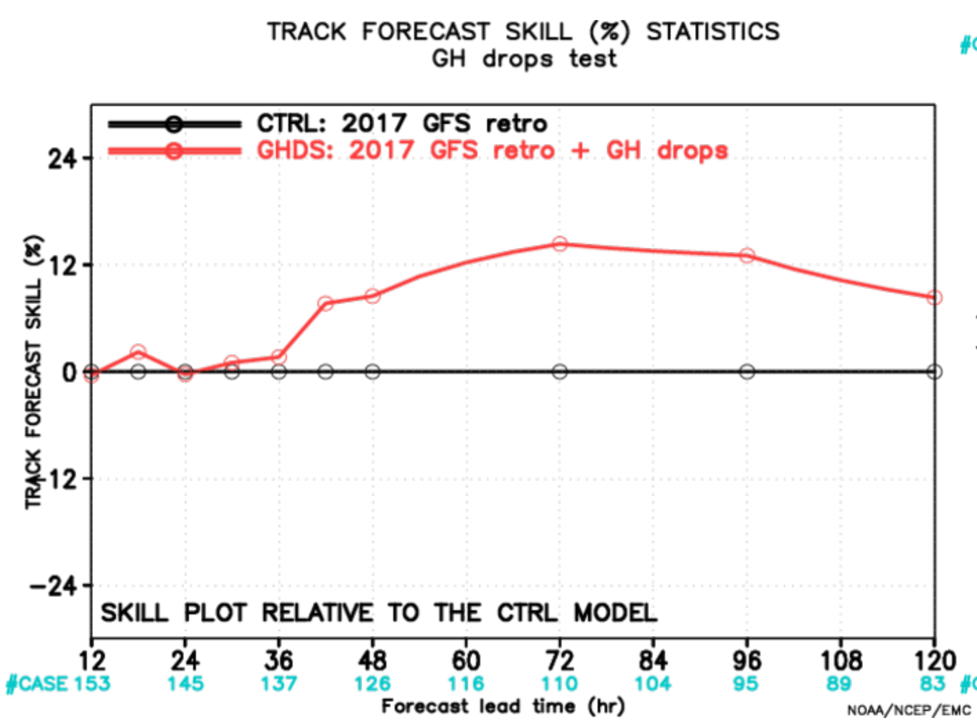
- Wind observations have been rejected in vortex [within max(111 km, 3*RMW)] due to lack of knowledge of sonde location.
- Location can be estimated using REL/SPG information in TEMP-DROP message using technique of Aberson et al.
- Using the additional data leads to track improvements of 5-10%. No intensity improvements are seen.



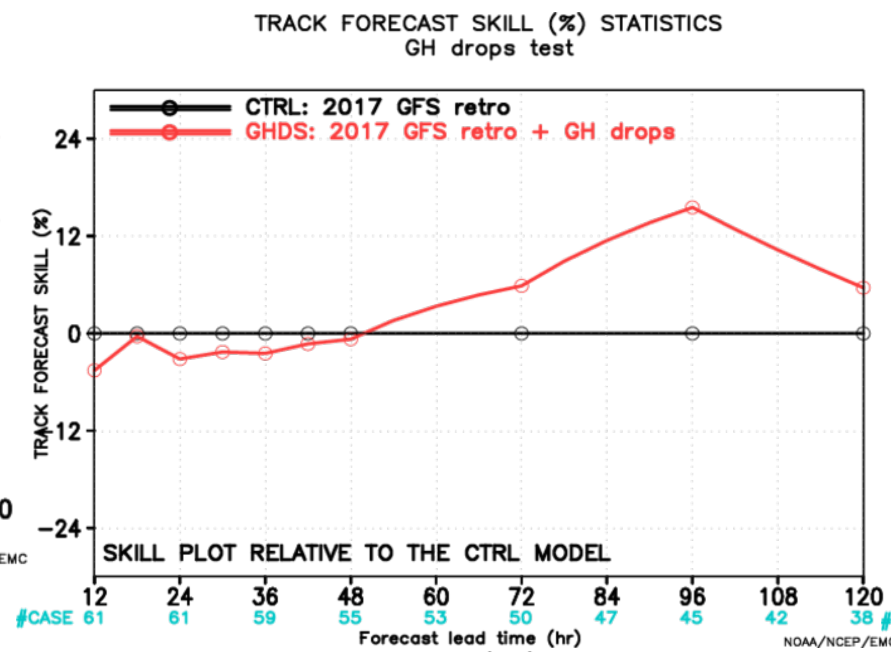
Impact of Global Hawk dropwindsonde data in the Atlantic on GFS forecasts - 2016 cases, 2017 version of HWRF

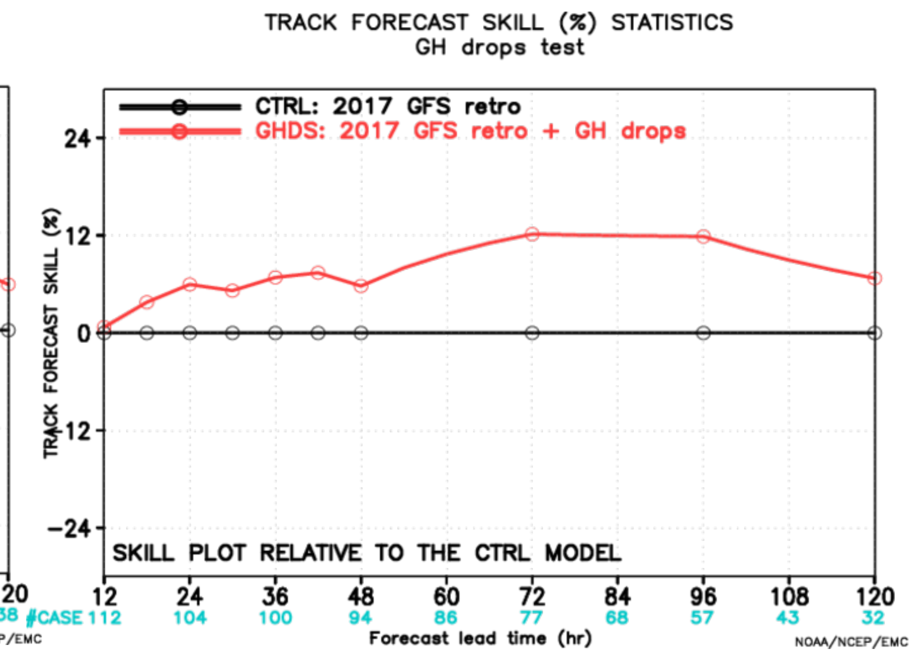
Substantial positive impact in Atlantic

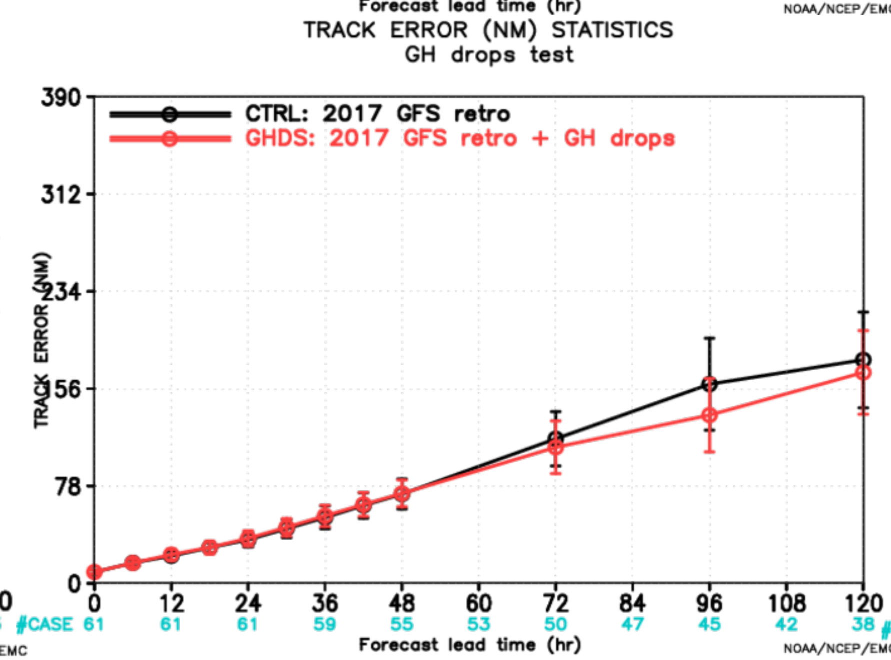


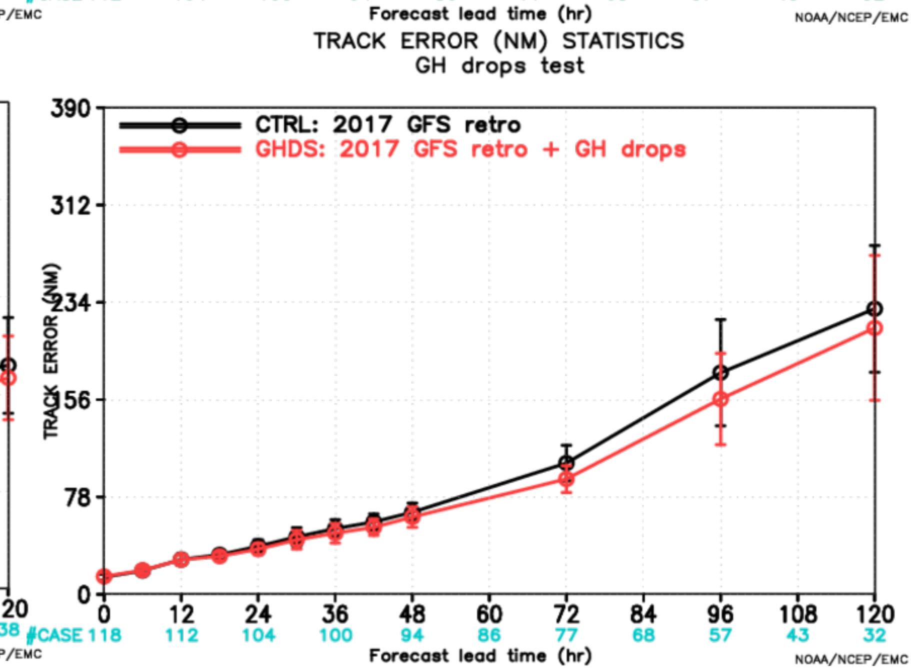


Positive impacts in other basins
Western Pacific (left) and Eastern Pacific (right)

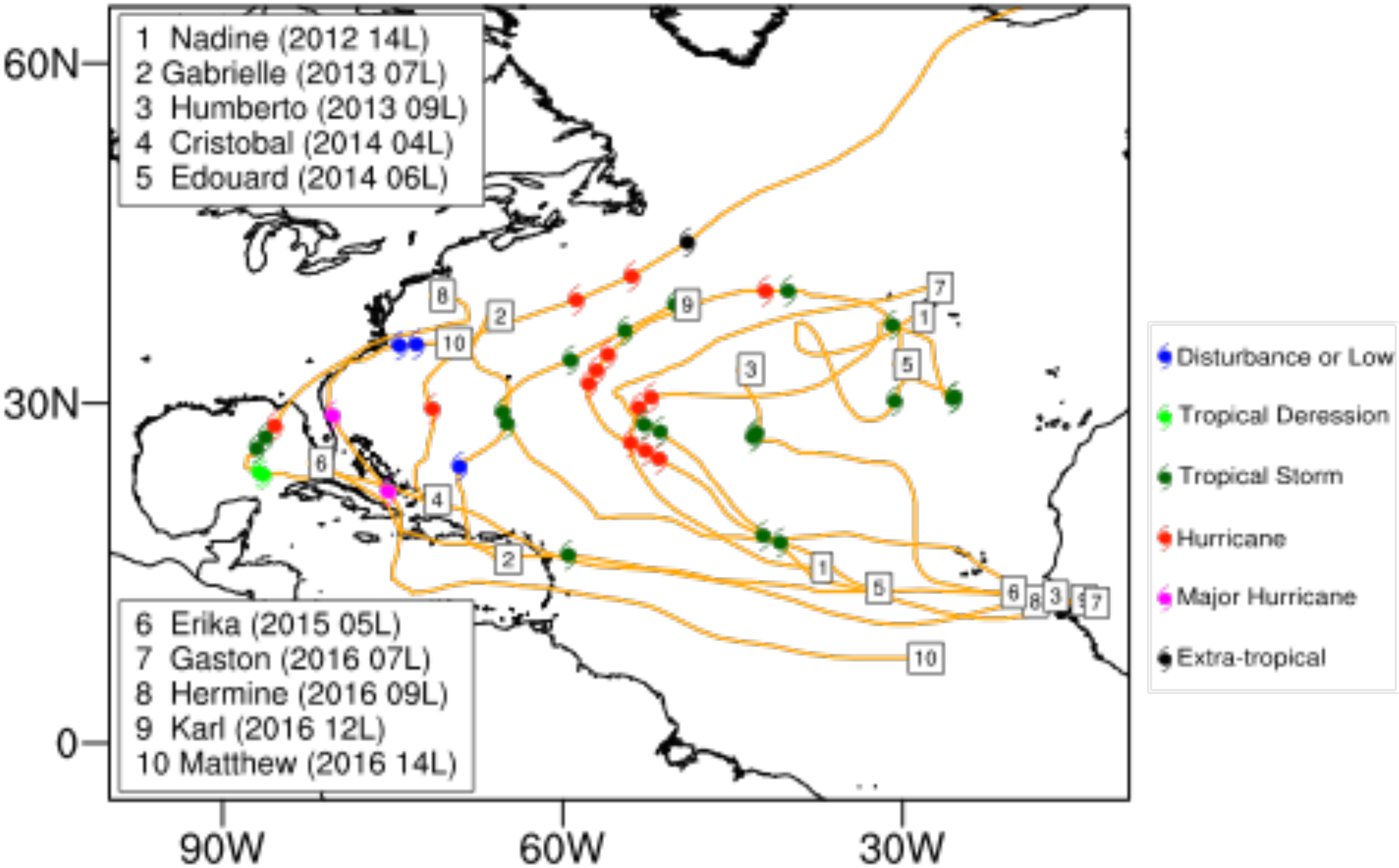








Hui Christophersen: Impact of Global Hawk Dropsondes on TC Analyses and Forecasts



Storm name	# of Cases	Int. (kt)
Nadine (2012)	6	70
Gabrielle (2013)	1	30
Humberto (2013)	2	40
Cristobal (2014)	4	75
Edouard (2014)	10	95
Erika (2015)	1	40
Gaston (2016)	2	75
Karl (2016)	5	60
Hermine (2016)	5	70
Matthew (2016)	4	105

- Overall, GH dropsondes demonstrate great values in improving TC analyses and forecasts
  - ~10-20% significant improvement of track forecast up to lead time 84 h
  - ~10% improvement of MSLP forecasts up to 108 h

- GH dropsondes significantly improve track forecasts regardless of the presence of crewed aircraft data, but only positive improvement on intensity at long lead time in absence of crewed aircraft -> important coordination of different platforms

The Impact of NASA Global Hawk Unmanned Aircraft Dropwindsonde Observations on Tropical Cyclone Track, Intensity, and Structure: Case Studies

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(Manuscript received 26 August 2016, in final form 8 February 2017)

ABSTRACT

The impact of Global Hawk (GH) dropwindsondes on tropical cyclone analyses and forecasts is evaluated in an ensemble-based vortex-scale data assimilation system. Two cases from Hurricane Edouard (2014) are presented. In the first case, inner-core observations were exclusively provided by GH dropwindsondes, while in the second case, GH dropwindsondes were concentrated in the storm's near environment and were complemented by an extensive number of inner-core observations from other aircraft. It is found that when GH dropwindsondes are assimilated, a positive impact on the minimum sea level pressure (MSLP) forecast persists for most lead times in the first case, conceivably due to the better representation of the initial vortex structure, such as the warm-core anomaly and primary and secondary circulations. The verification of the storm's kinematic and thermodynamic structure in the forecasts of the first case is carried out relative to the time of the appearance of a secondary wind maximum (SWM) using the tail Doppler radar and dropwindsonde composite analyses. A closer-to-observed wavenumber-0 wind field in the experiment with GH dropwindsondes is seen before the SWM is developed, which likely contributes to the superior intensity forecast up to 36 h. The improvement in the warm-core anomaly in the forecasts from the experiment with GH dropwindsondes is believed to have also contributed to the consistent improvement in the MSLP forecast. For the latter case, a persistent improvement in the track forecast is seen, which is consistent with a better representation of the near-environmental flow obtained from GH data in the same region.

1. Global Hawk dropsonde data can be combined with data from regular Hurricane Hunter aircraft and from satellites to improve tropical cyclone forecasts.
2. Global Hawk dropsonde data close to the center improves intensity forecasts. This is due to the large amount of accurate data obtained in that region that cannot be gathered in any other way.
3. Global Hawk dropsonde data further away from the center may improve track forecasts.
4. This study can help to design Global Hawk flights to get the largest forecast improvement possible.

Jon Zawislak: Tropical Cyclone – Dropsonde Research and OPerationS (TC-DROPS)

WHAT IS IT?

Level-2 product suite that accumulates dropsonde data from all (recent; i.e., 1996) TC flights to facilitate advanced real-time analysis and historical compositing

RESEARCH MODE:

- Combine dropsondes from all aircraft into a single, searchable storm dataset file
- More easily facilitates dropsonde composite studies
- Differentiate observations by metrics, ex., intensity, intensity change, vertical wind shear, and storm/shear/motion-relative location

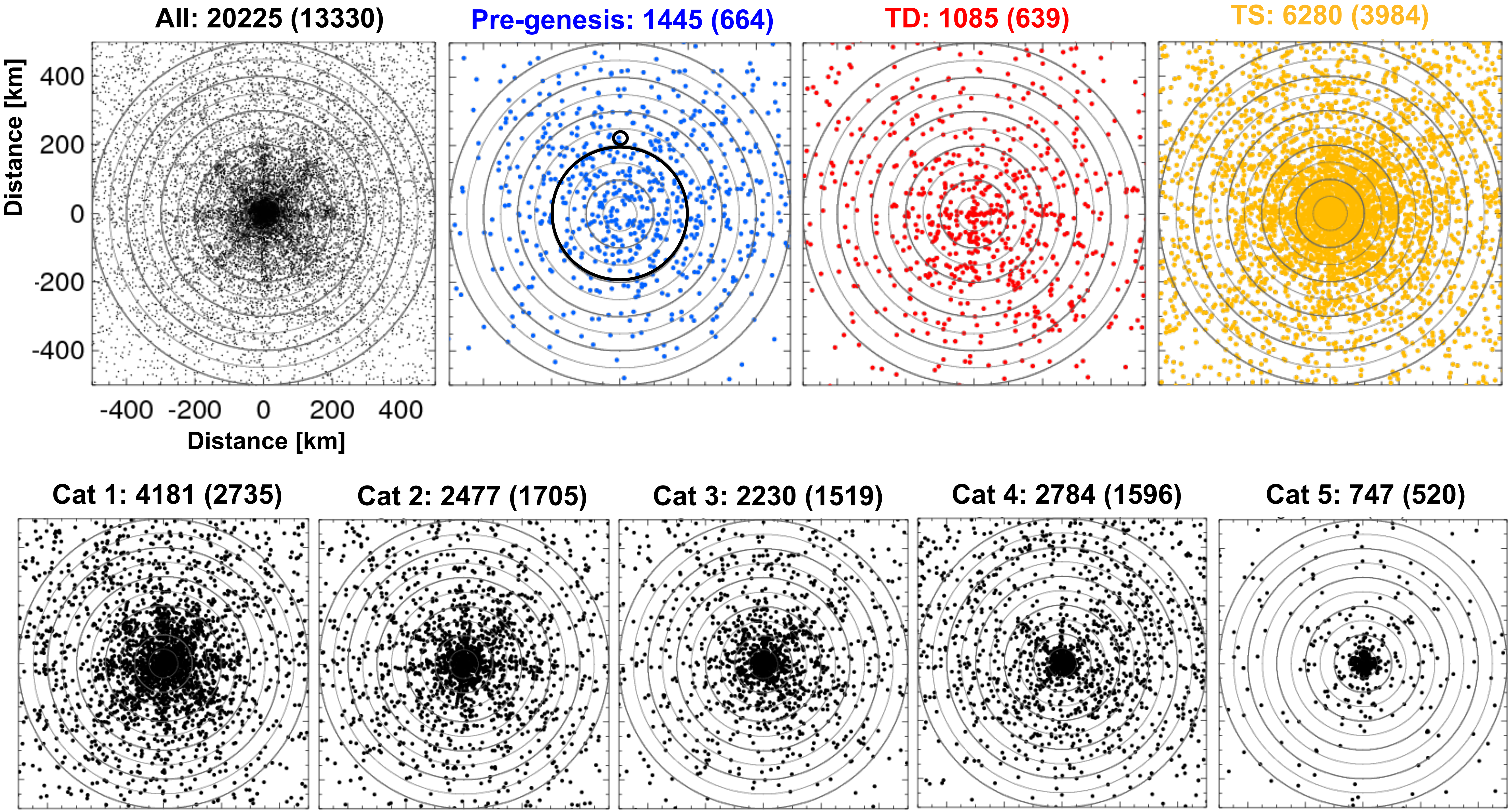
OPERATIONAL/NEAR-REAL TIME MODE:

- Can be run after each flight
- Visualize dropsonde observations at a higher level than ASPEN
- Dropsonde pattern planning purposes (where did we miss? interesting features that we should sample again?)

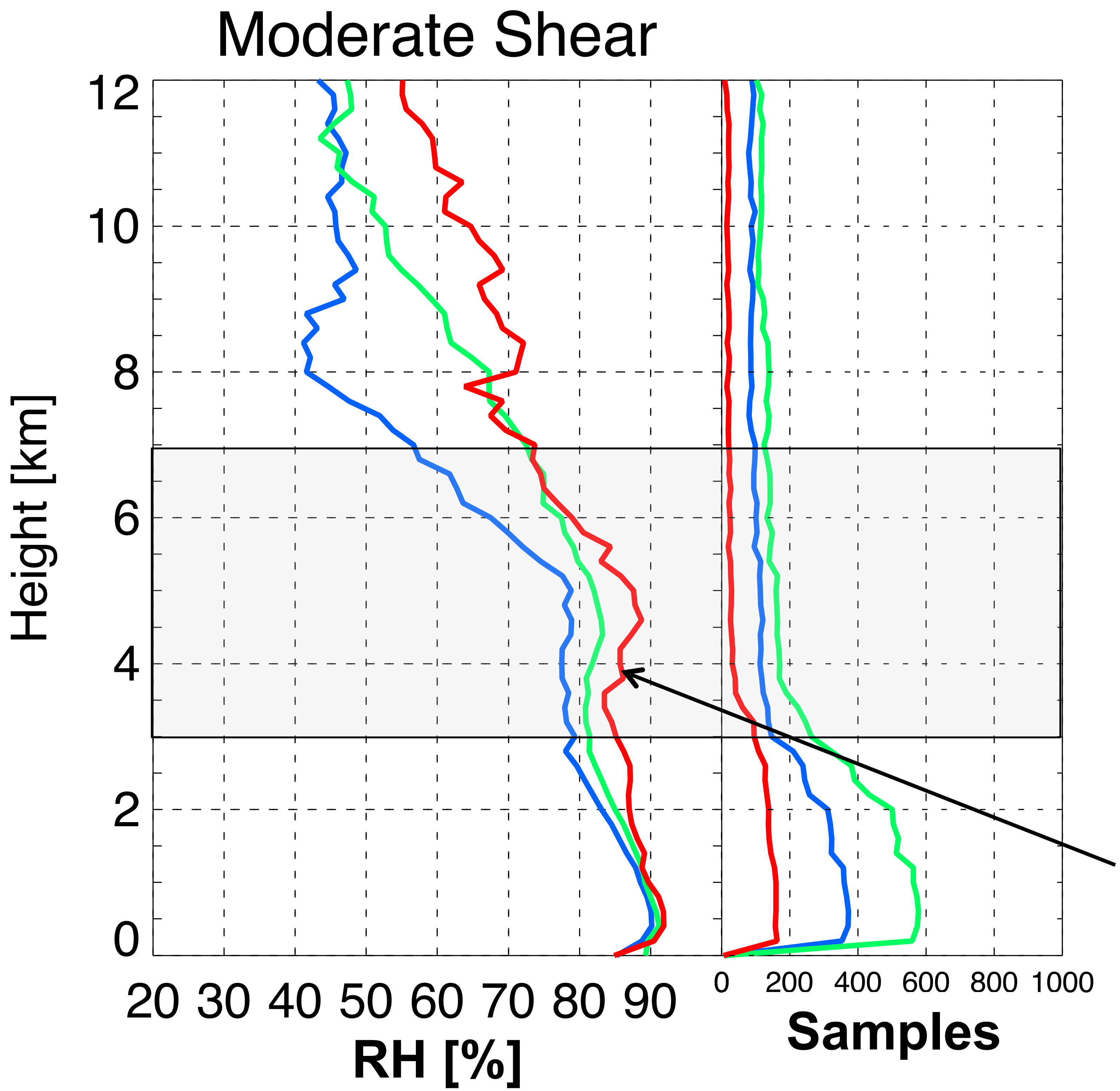
What does it offer?

- Dropsonde data are located with respect to the interpolated TC center (currently best track…coming soon, 2-min track)
- Hour of drop before/after genesis
- Interpolated to the same pressure and height levels
- SHIPS vertical wind shear
- Shear and motion relative azimuths
- Corresponding best track intensity (vmax, mslp)
- Additional kinematic and thermodynamic variables (storm relative u & v, θ, θ_E, θ_V, Z_{PBL})
- SST
- 6-, 12-, 18-, 24-h intensity change

Jon Zawislak: The Relationship Between Observed Thermodynamic and Precipitation Properties During TC Intensity Change



RESULTS

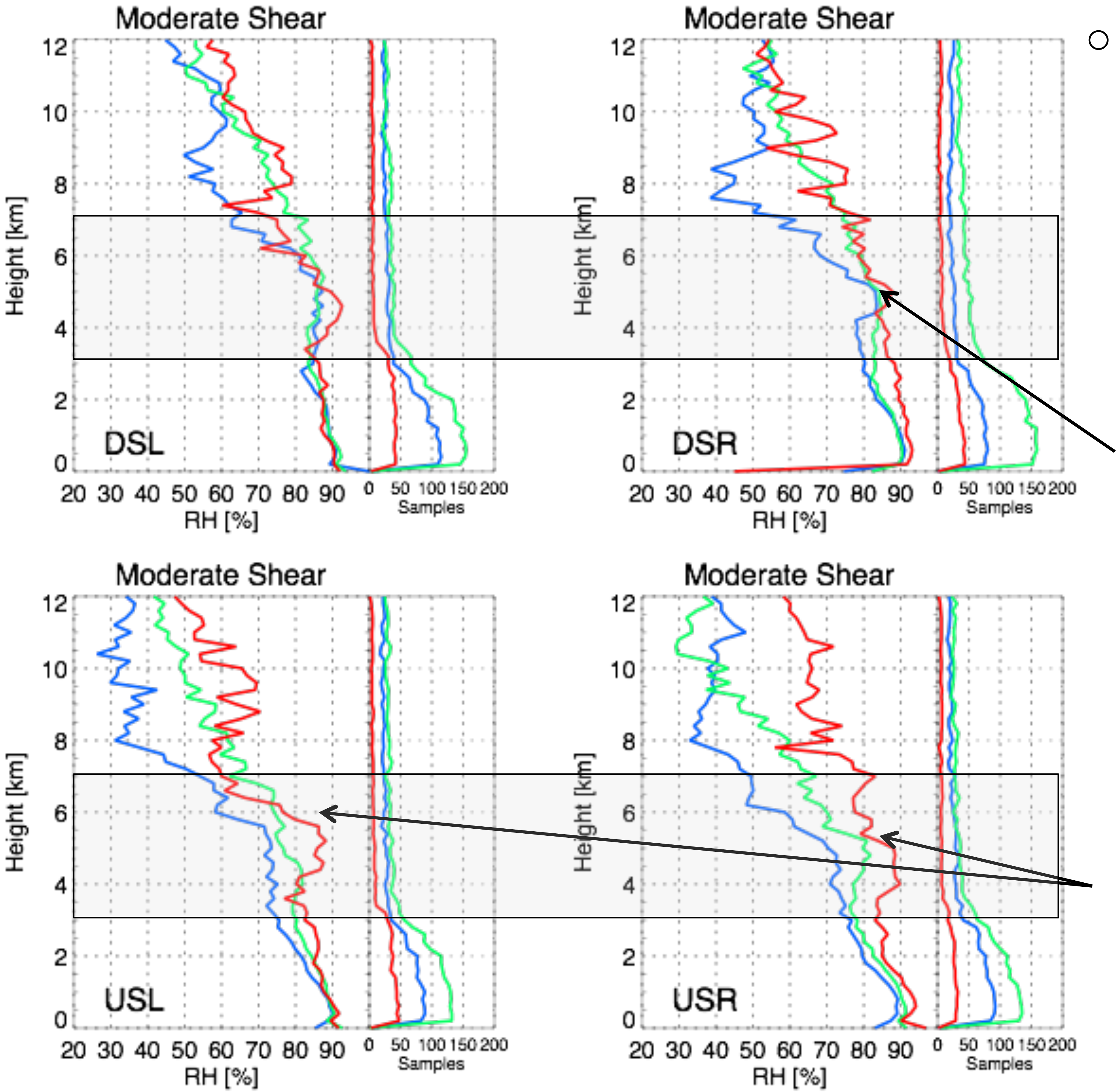


- Mean RH profiles for all shear-relative quadrants combined for MODERATE SHEAR

NI (**"Steady State"**) is less humid than both **RI** and **SI**

SI somewhat less humid than **RI** between 3-7 km

RESULTS



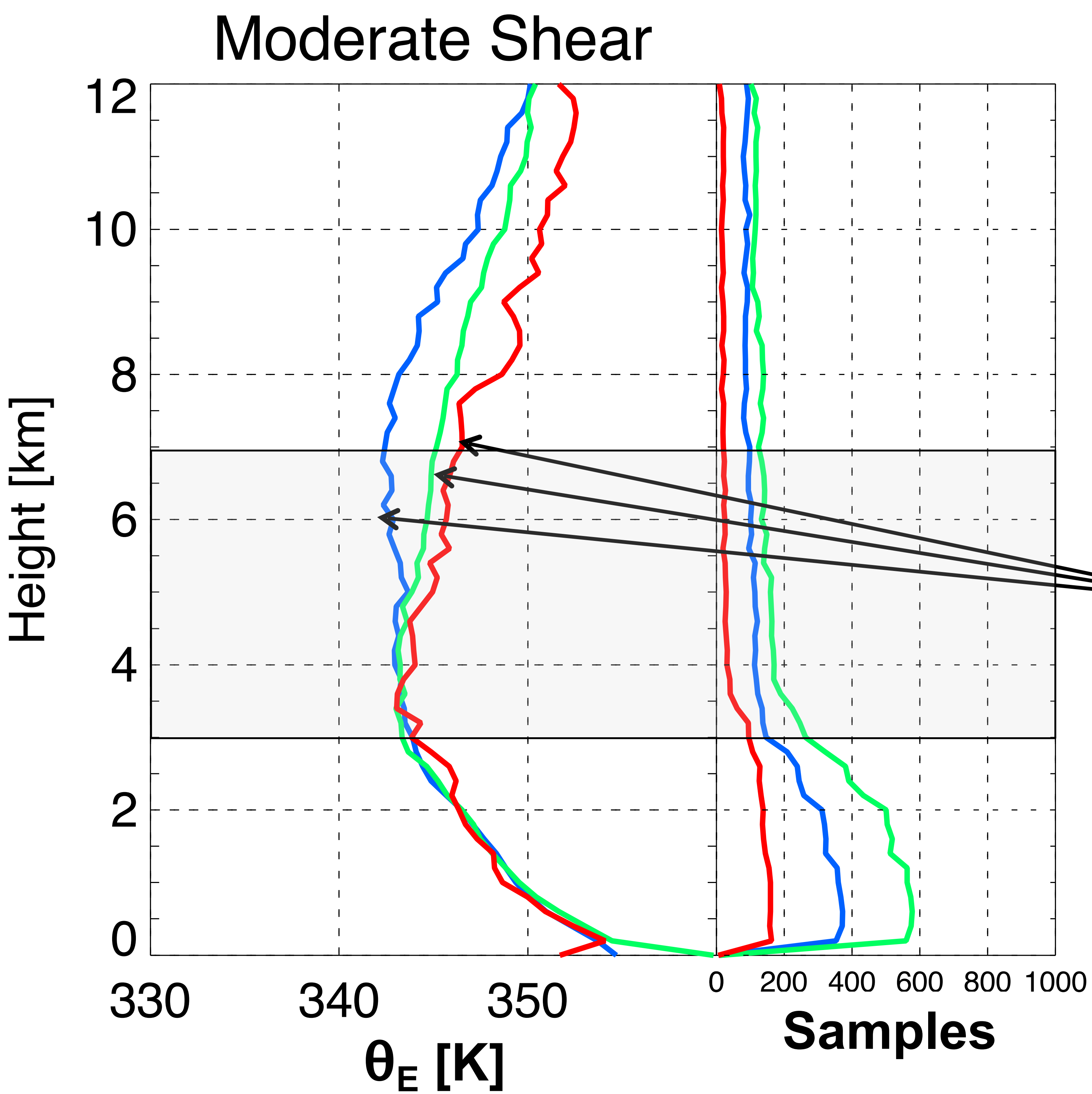
- Mean RH profiles <u>in each shear-relative quadrant for MODERATE SHEAR</u>

Middle and upper troposphere <u>generally similar downshear</u>

In the upshear quadrants, <u>increase in RH for greater intensity change rate</u>

Difference largest <u>USR</u>

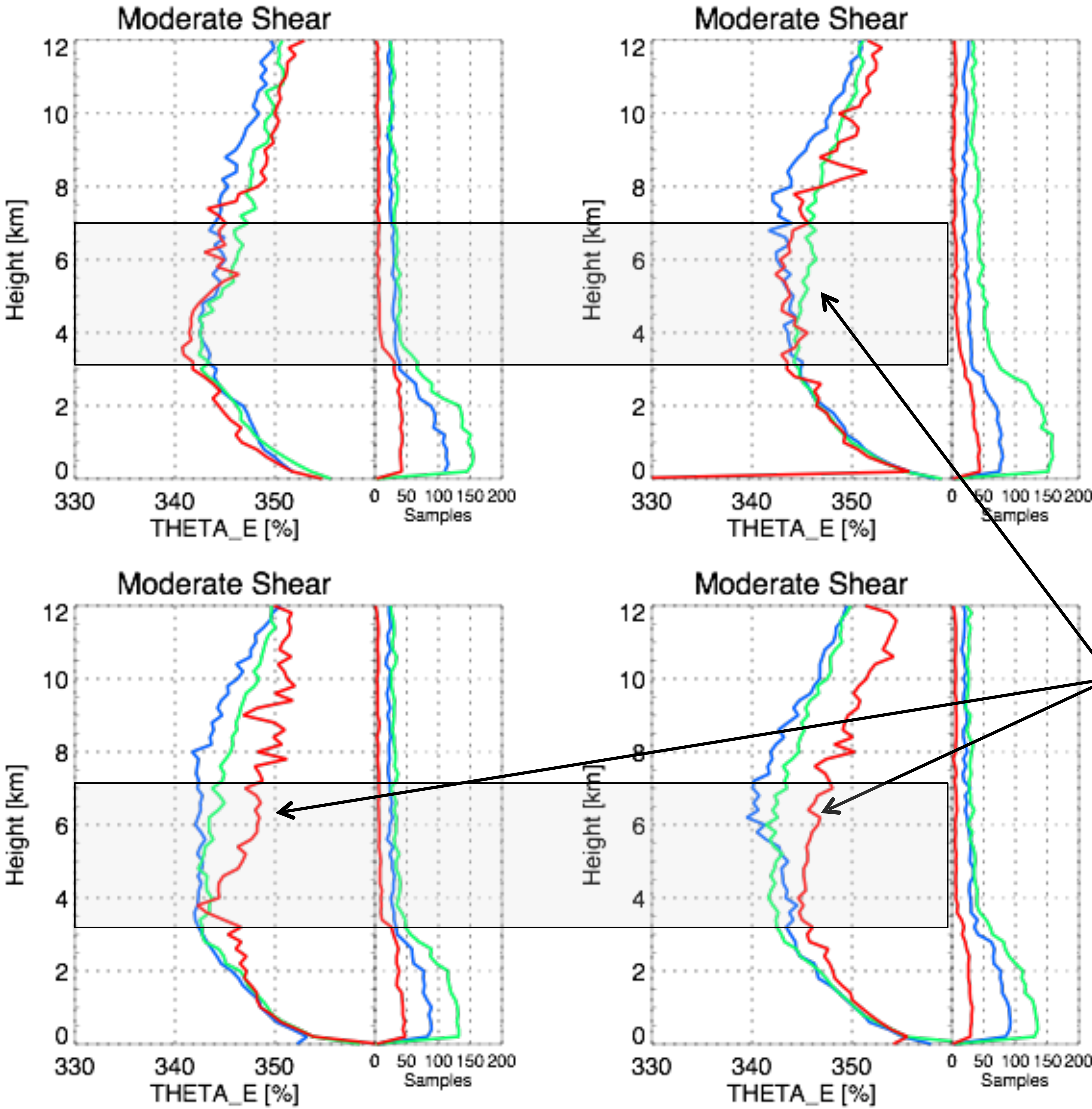
RESULTS



- Mean θ_E profiles for all shear-relative quadrants combined for MODERATE SHEAR

Progressive increase from **NI** to **SI** to **RI**

RESULTS



- Mean θ_E profiles <u>in each shear-relative quadrant for MODERATE SHEAR</u>

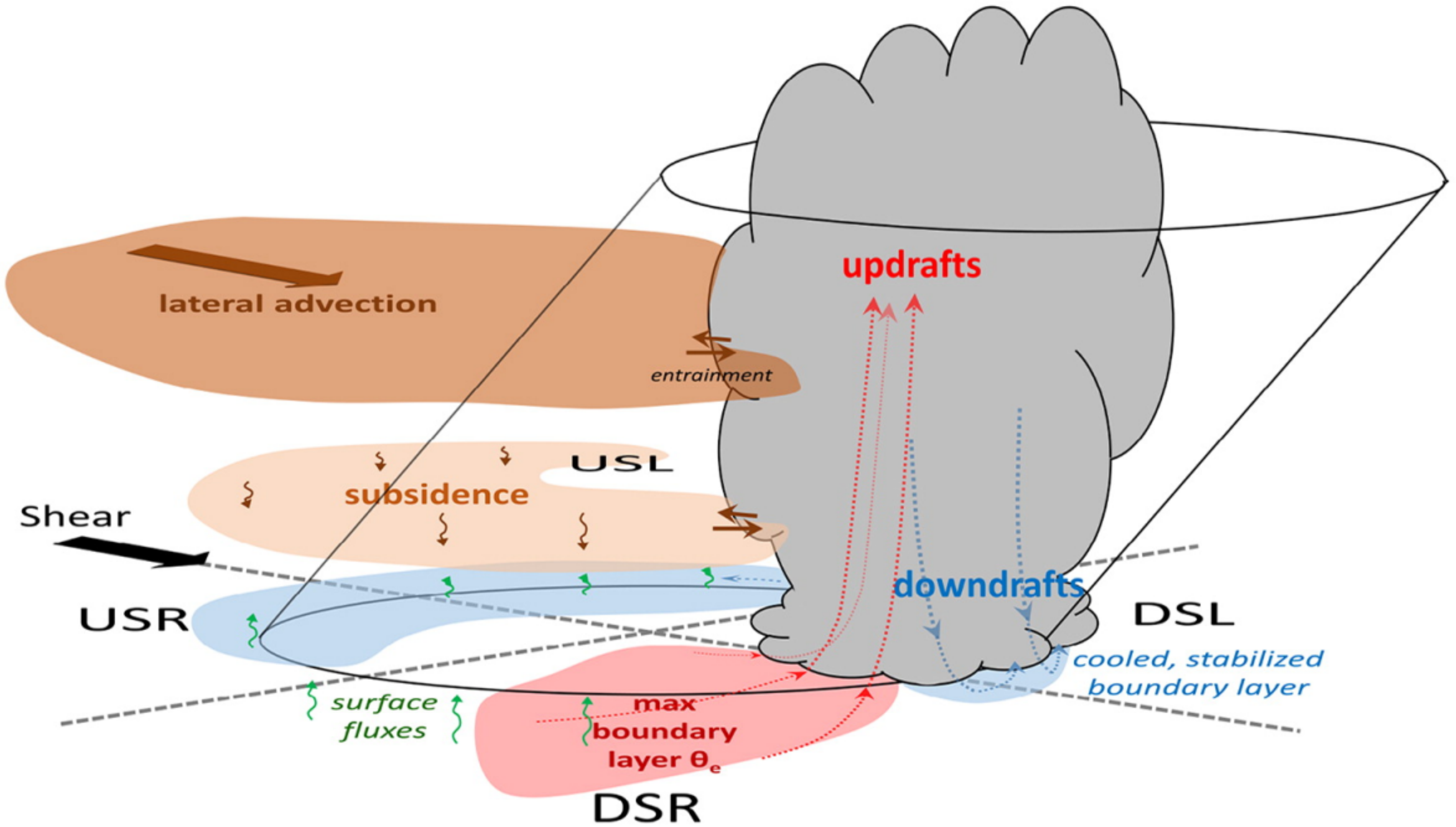
Upshear differences <u>noticeably greater</u> **than downshear**

Leon Nguyen: Assessing tropical cyclone intensity change in moderate vertical shear using dropsondes: Thermodynamics of the lower troposphere

- Moderately sheared tropical cyclones have emerged as a research and operational priority due to their lack of predictability.

- Several recent observational and modeling studies have pointed to the importance of various processes to the development of precipitation symmetry and/or the intensification of moderately-sheared TCs, including:

  - Downdraft cooling/drying
  - Surface enthalpy fluxes
  - Warming and drying via local subsidence
  - Horizontal advection of dry air into the core
  - Role of convection in helping to reduce the vortex tilt



Dropsonde selection criteria:

- $V_m \leq 80$ kt
- $4.5 < V_{200\text{-}850shr} < 11.0$ m/s (25th and 75th percentile from Rios-Berrios and Torn 2017).
- 25-200 km from TC center (interpolated from aircraft fixes using methodology of Willoughby and Chelmow 1982).

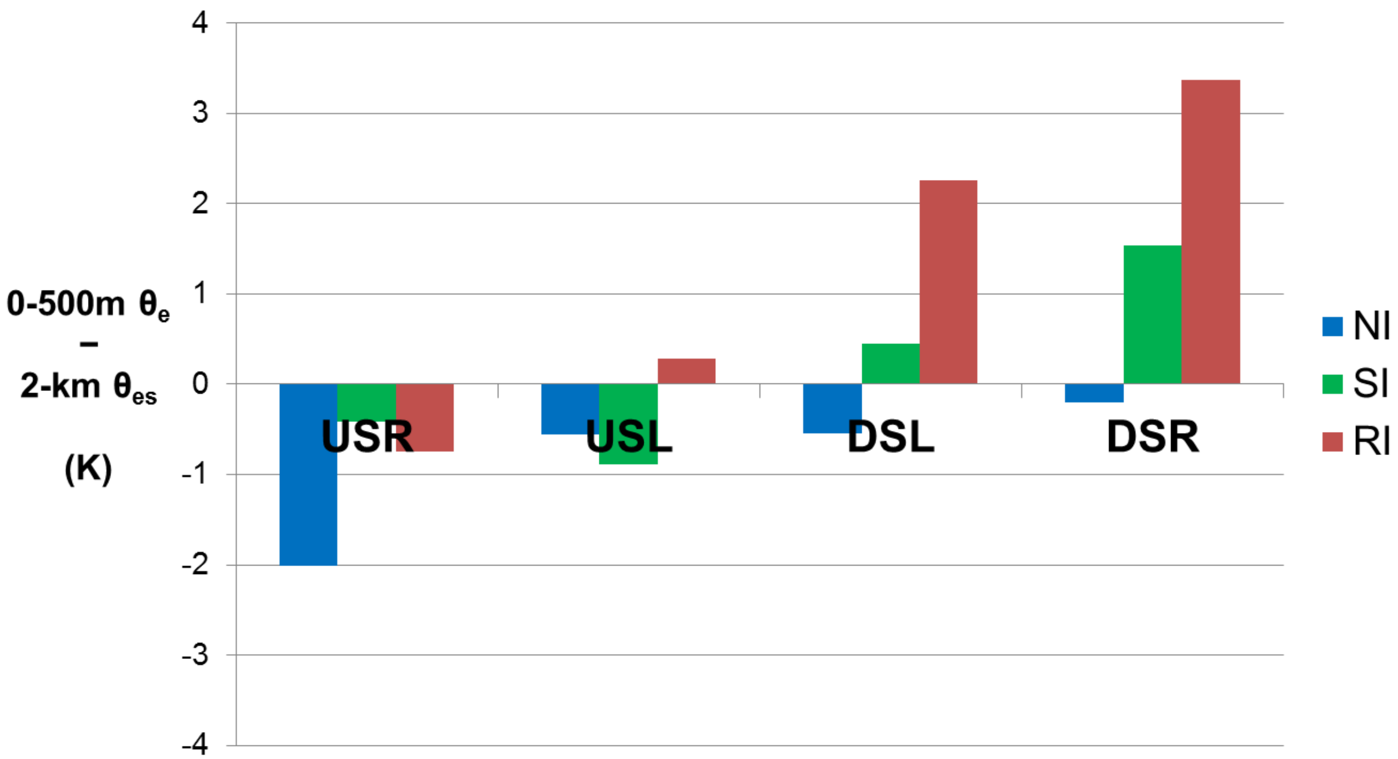
0-24 hour intensity change bins:

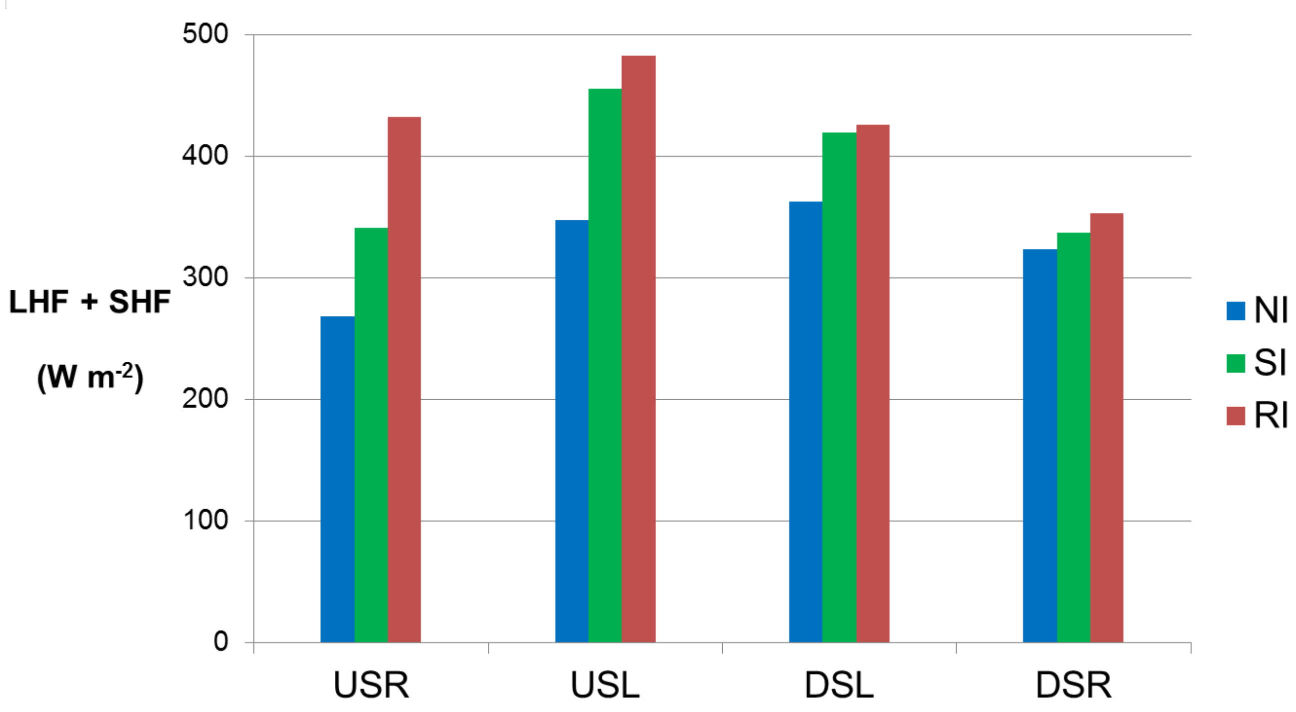
"Non-intensifying" (NI)	"Slowly-intensifying" (SI)	"Rapidly-intensifying" (RI)
$\Delta V_{m,\,0\text{-}24h} \leq 0$ kt	$+5 \text{ kt} \leq \Delta V_{m,\,0\text{-}24h} \leq +15$ kt	$\Delta V_{m,\,0\text{-}24h} \geq +20$ kt

Preliminary Conclusions

In comparison to non-intensifying cases, slowly and (in particular) rapidly intensifying moderately sheared cases have:

- Larger lower-tropospheric convective instability, particularly in the downshear quadrants.
  - ➢ Function of both boundary layer θ_e and temperatures aloft (more subsidence aloft in non-intensifying cases?)
- Larger surface enthalpy fluxes, particularly in the upshear quadrants. Contributes to larger instability observed downstream.





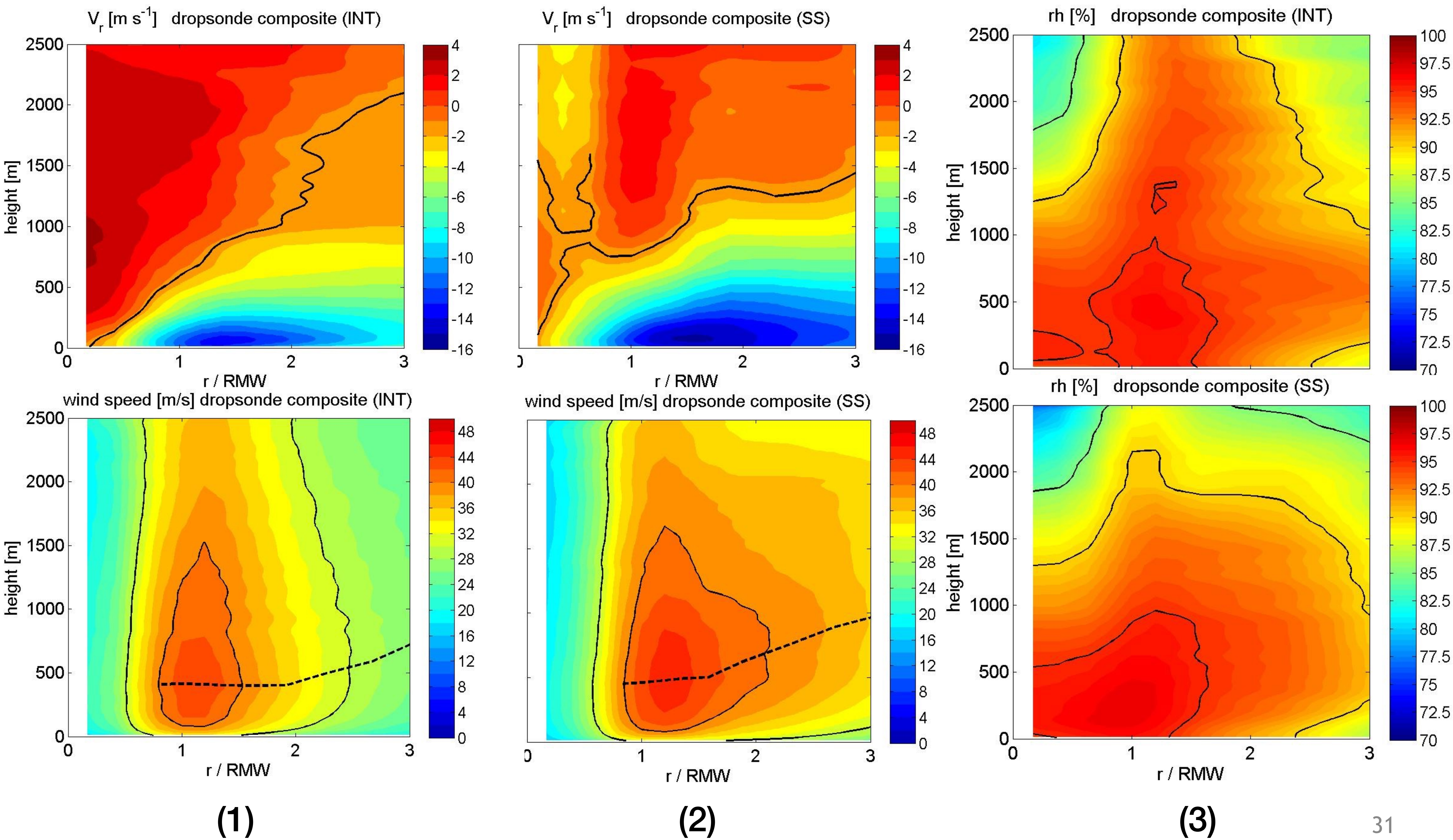
Jun Zhang: Dropsonde Composites of Symmetric Boundary-layer Structure in Intensifying and Steady-state hurricanes

- Observational studies of intensifying vs. steady-state hurricanes found that deep convection tends to stay inside the radius of maximum wind speed (RMW) with greater azimuthal coverage at downshear and upshear left quadrants (Rogers et al. 2013; 2015; 2016; Zagrodnik and Jiang 2014; Zawislak et al. 2016; Nguyen et al. 2017).

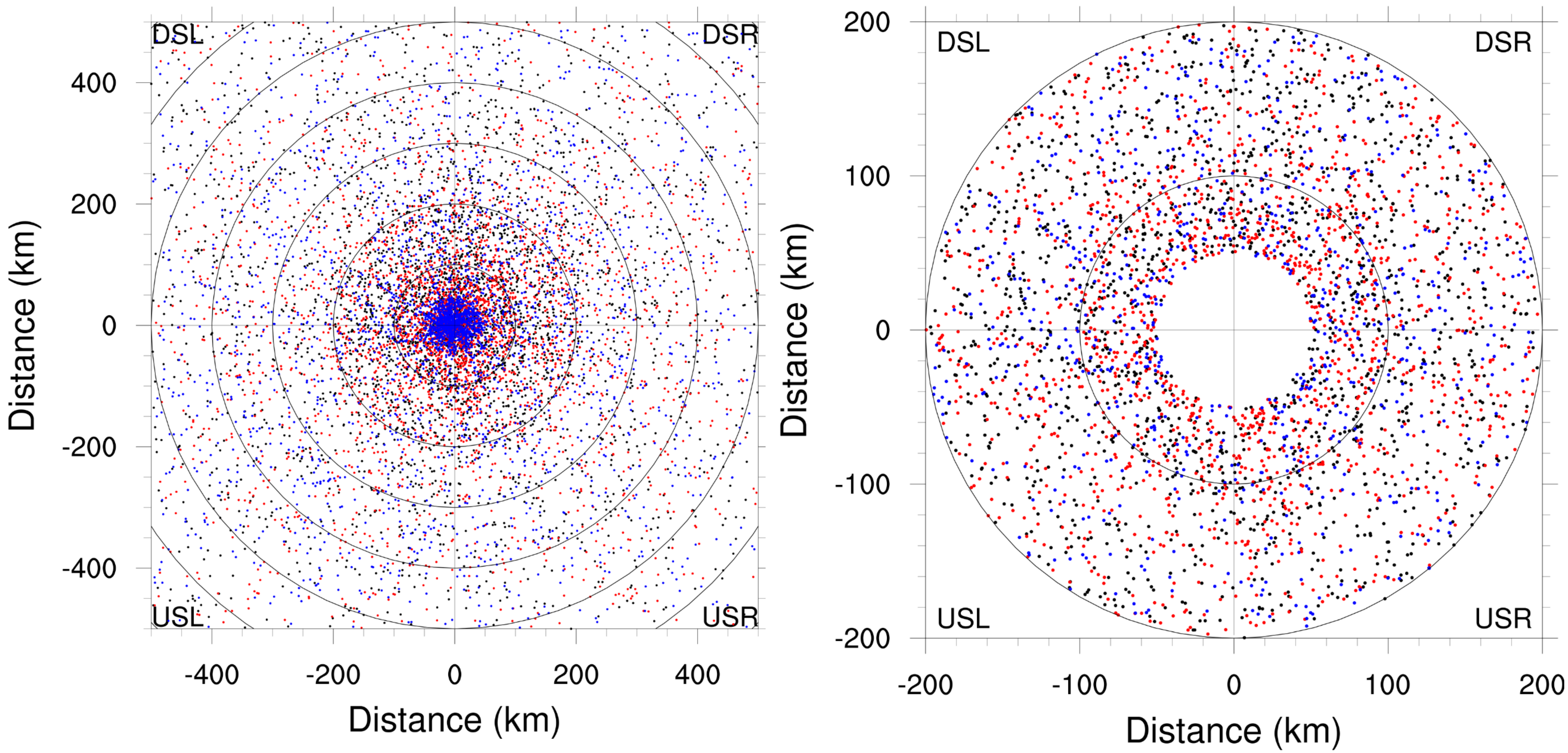
- Theoretical and numerical studies found that boundary-layer processes are crucial to hurricane intensification and/or weakening (e.g., Emanuel 1995; Smith et al. 2009; Riemer et al. 2010; Bryan 2012; J. Zhang et al. 2017). Boundary-layer convergence may be one of the mechanisms that is responsible for the different distributions of the deep convection between intensifying and steady-state storms (Rogers et al. 2016).

➢ Dropsonde data are used in a composite framework to study the structural difference of the boundary layer between intensifying and steady-state hurricanes.

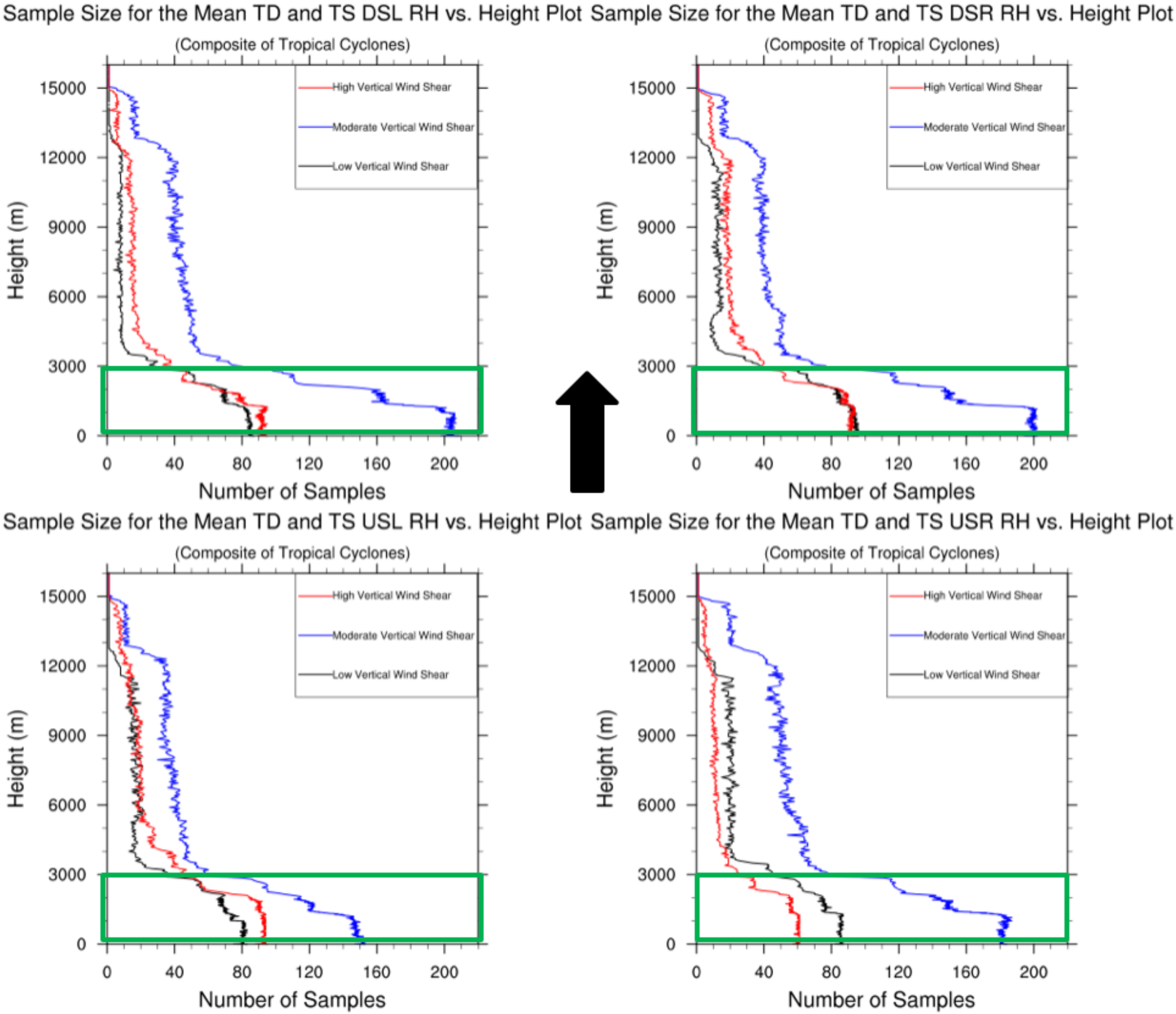
Intensifying TCs have (1) a deeper inflow layer, (2) narrower tangential wind field, and (3) higher relative humidity near the top of the boundary layer than steady-state TCs.



Emily Paltz: Analyzing the Impact of Shear on TCs using Dropsondes

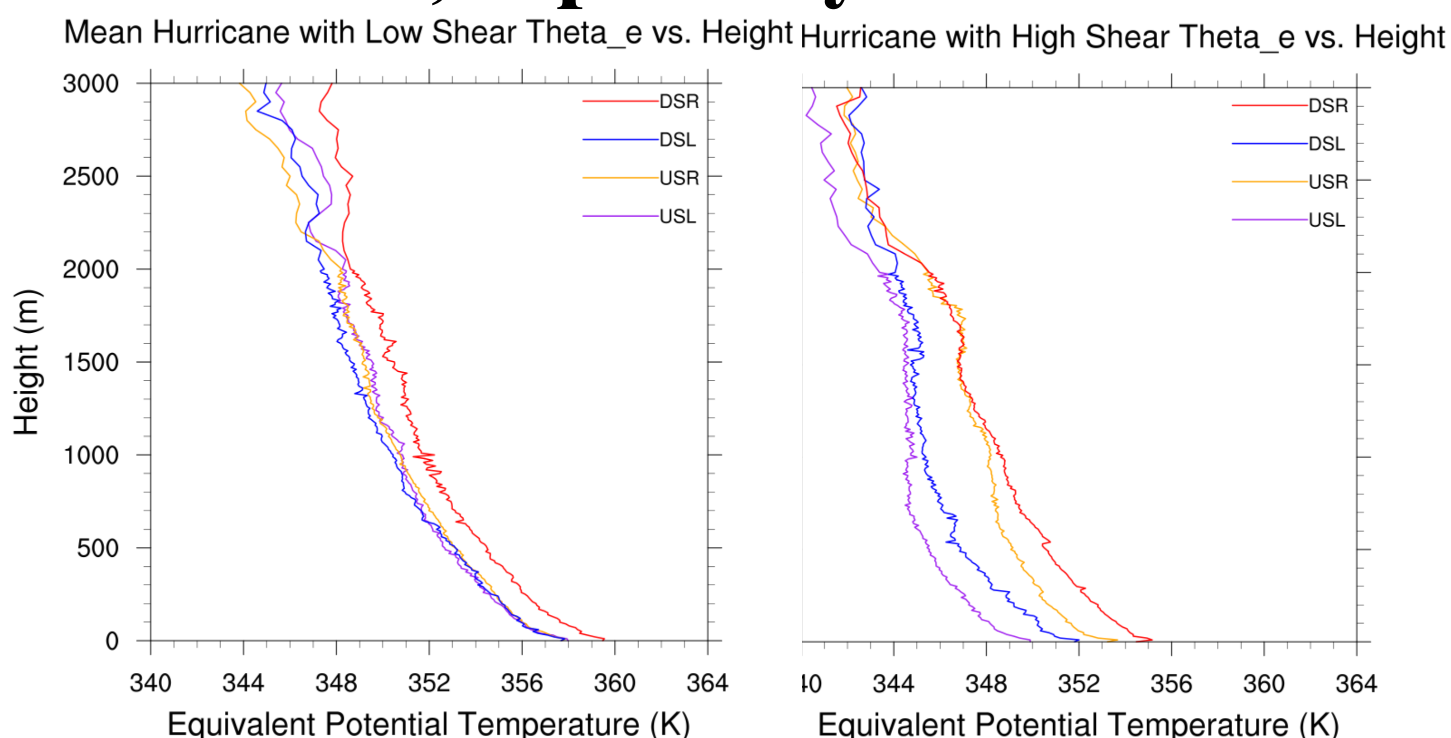


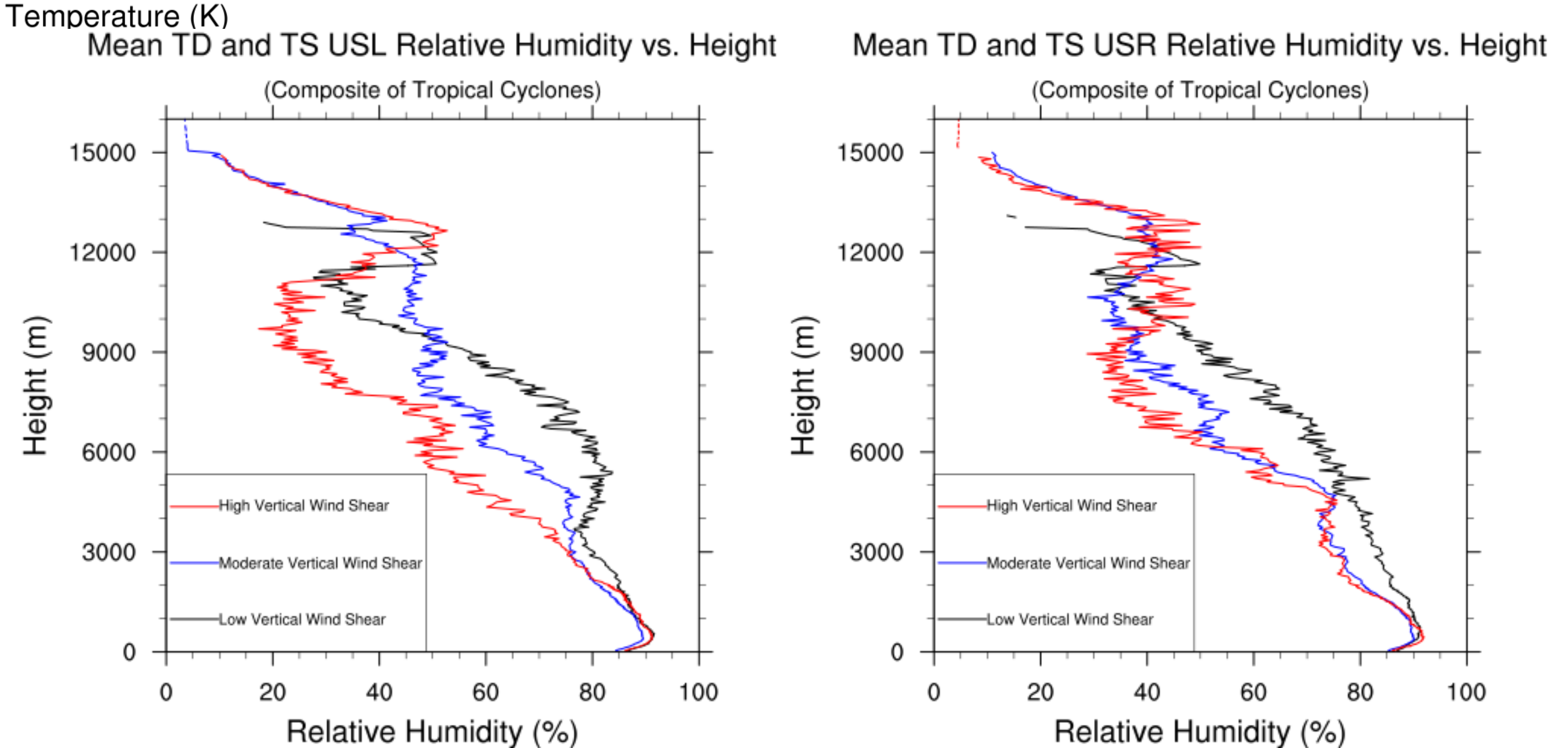
Tropical Depressions and Storms
Hurricanes
Major Hurricanes


Sample Size for the Mean TD and TS DSL RH vs. Height Plot
(Composite of Tropical Cyclones)
High Vertical Wind Shear
Moderate Vertical Wind Shear
Low Vertical Wind Shear
Height (m)
Number of Samples
Sample Size for the Mean TD and TS DSR RH vs. Height Plot
(Composite of Tropical Cyclones)
High Vertical Wind Shear
Moderate Vertical Wind Shear
Low Vertical Wind Shear
Height (m)
Number of Samples
Sample Size for the Mean TD and TS USL RH vs. Height Plot
(Composite of Tropical Cyclones)
High Vertical Wind Shear
Moderate Vertical Wind Shear
Low Vertical Wind Shear
Height (m)
Number of Samples
Sample Size for the Mean TD and TS USR RH vs. Height Plot
(Composite of Tropical Cyclones)
High Vertical Wind Shear
Moderate Vertical Wind Shear
Low Vertical Wind Shear
Height (m)
Number of Samples

Cool, stable air is present in the boundary layer in all quadrants when TCs experience high shear with maximum cooling occurring in the upshear left quadrant.

As shear increases, relative humidity in the upshear quadrants decreases, especially at mid-levels.





Observations of Infrared Sea Surface Temperature and Air–Sea Interaction in Hurricane Edouard (2014) Using GPS Dropsondes

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(Manuscript received 25 October 2016, in final form 3 April 2017)

ABSTRACT

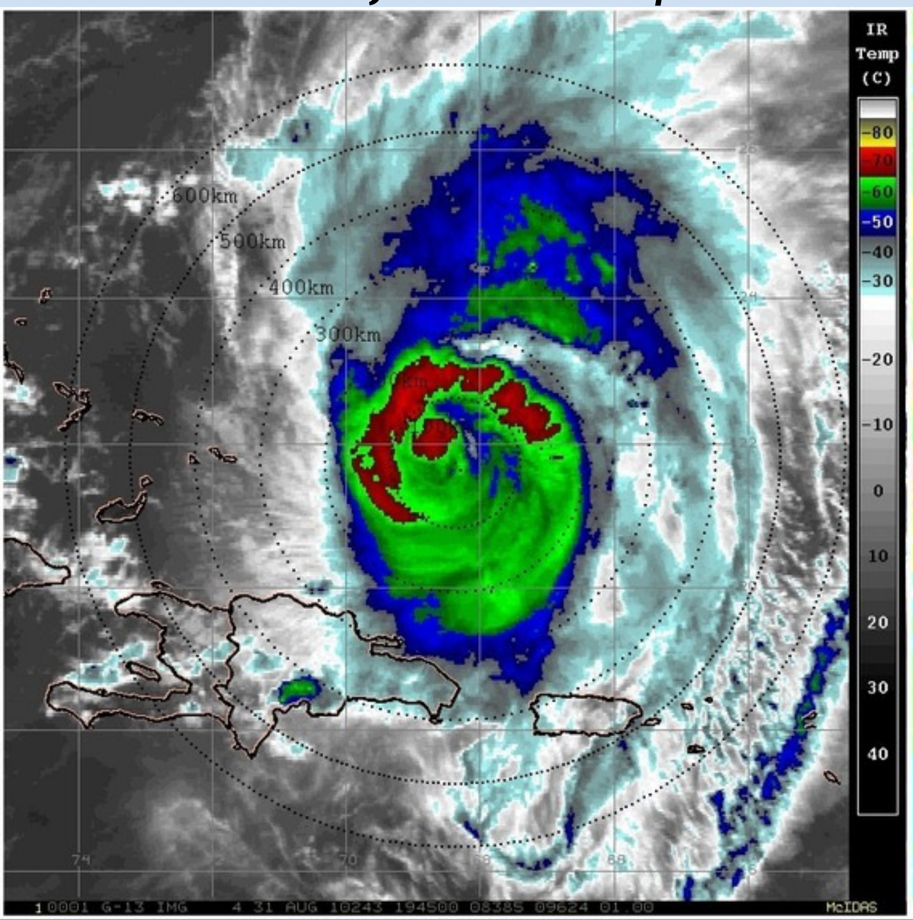
This study highlights infrared sensor technology incorporated into the global positioning system (GPS) dropsonde platforms to obtain sea surface temperature (SST) measurements. This modified sonde (IRsonde) is used to improve understanding of air–sea interaction in tropical cyclones (TCs). As part of the Sandy Supplemental Program, IRsondes were constructed and then deployed during the 2014 hurricane season. Comparisons between SSTs measured by collocated IRsondes and ocean expendables show good agreement, especially in regions with no rain contamination. Surface fluxes were estimated using measurements from the IRsondes and AXBTs via a bulk method that requires measurements of SST and near-surface (10 m) wind speed, temperature, and humidity. The evolution of surface fluxes and their role in the intensification and weakening of Hurricane Edouard (2014) are discussed in the context of boundary layer recovery. The study's result emphasizes the important role of surface flux–induced boundary layer recovery in regulating the low-level thermodynamic structure that is tied to the asymmetry of convection and TC intensity change.

1. The Sea Surface Temperature measured by the IRsonde agrees with other measurements at the same location.
2. The IRsonde data can estimate the energy exchanged between the ocean and the atmosphere. This energy exchange is important for hurricane intensity changes.
3. The amount of this energy exchange is related to how much the hurricane intensifies; the hurricane intensity itself is related to how warm and moist the region near the surface (the boundary layer) becomes due to these exchanges.

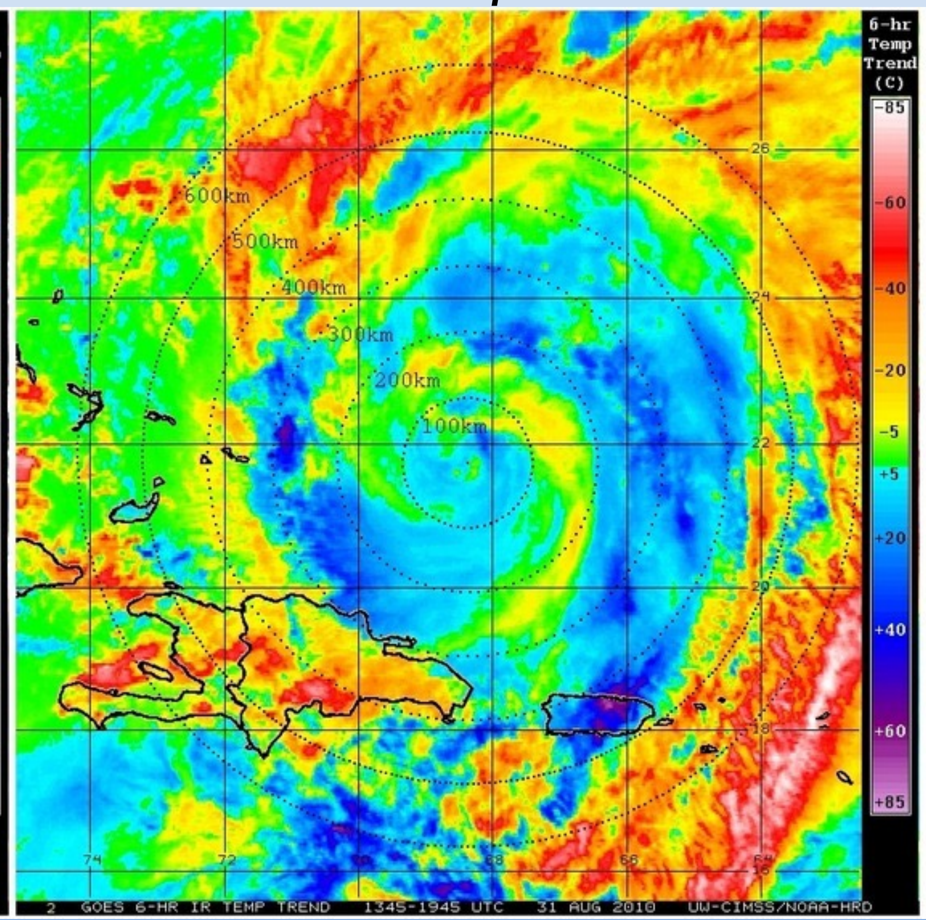
Jason Dunion: TC Diurnal Cycle

Hurricane Earl: 31 Aug 2010

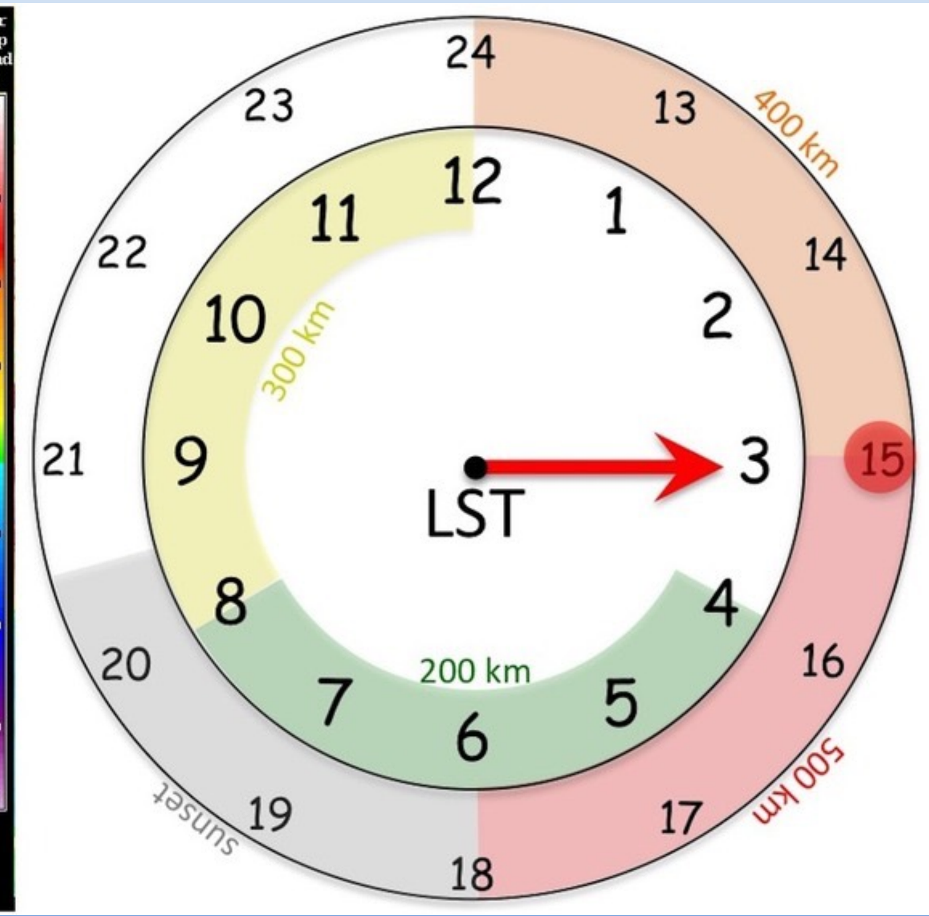
GOES Infrared: 11 μm



GOES IR 6-hr Temperature Trend



TC Diurnal Clock

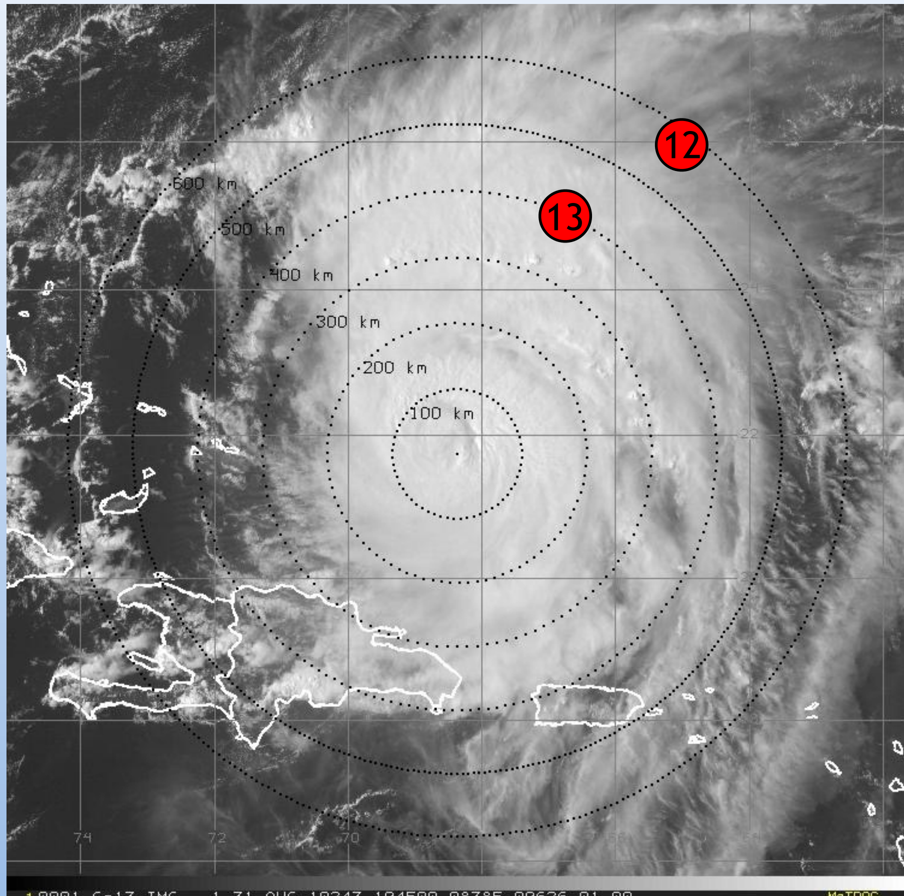


- TC diurnal clock: predicts the radial position of TC diurnal pulses according to local time
- TC diurnal pulses appear to behave like squall lines and also advect cirrus canopy ice radially outward from the storm as they propagate.

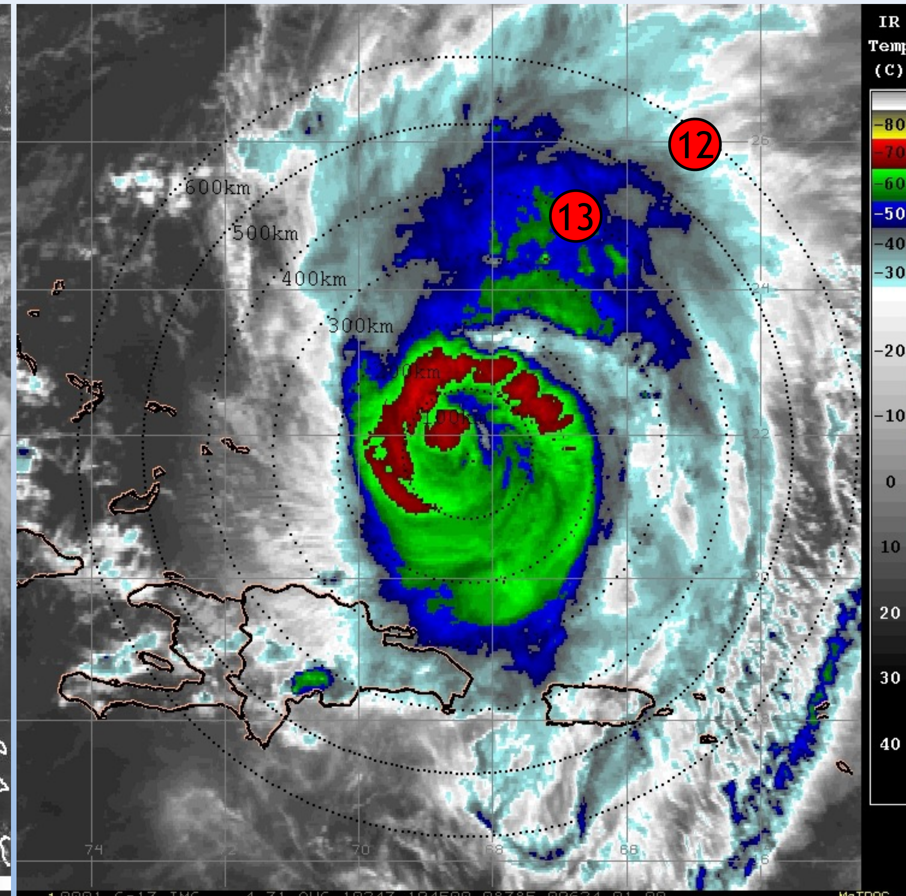
Hurricane Earl: 31 Aug 2010

NOAA G-IV Dropsondes: TC Diurnal Cycle & Sublimation Layers

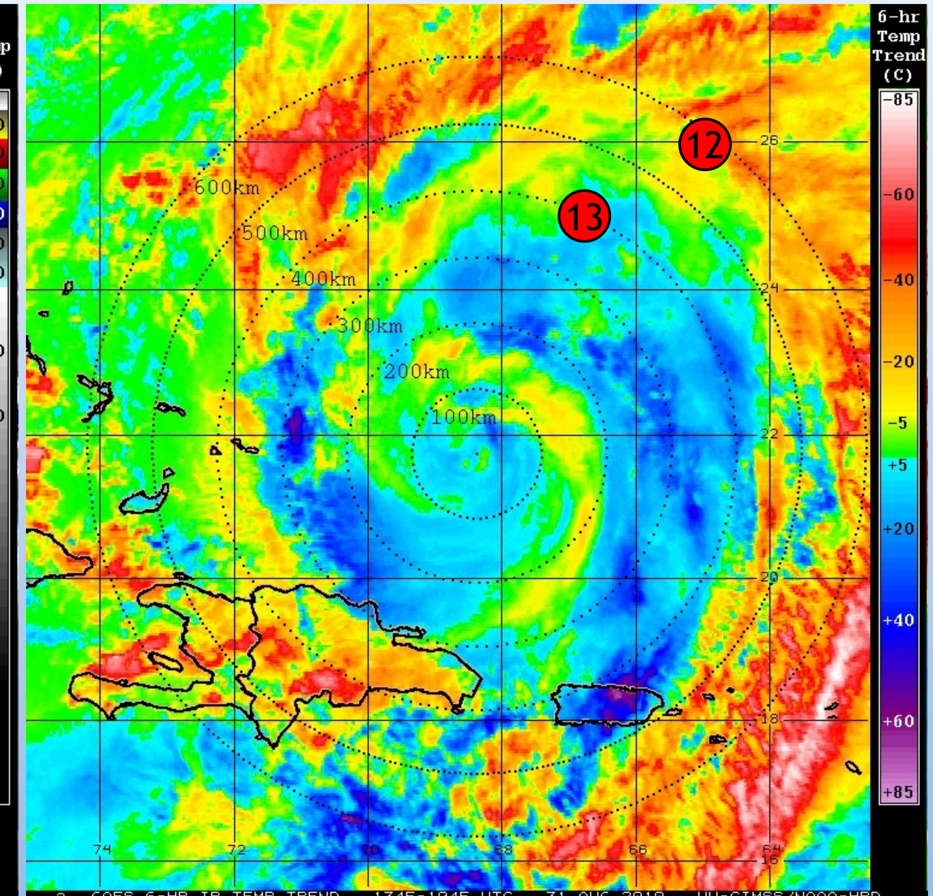
GOES Visible/Shortwave IR

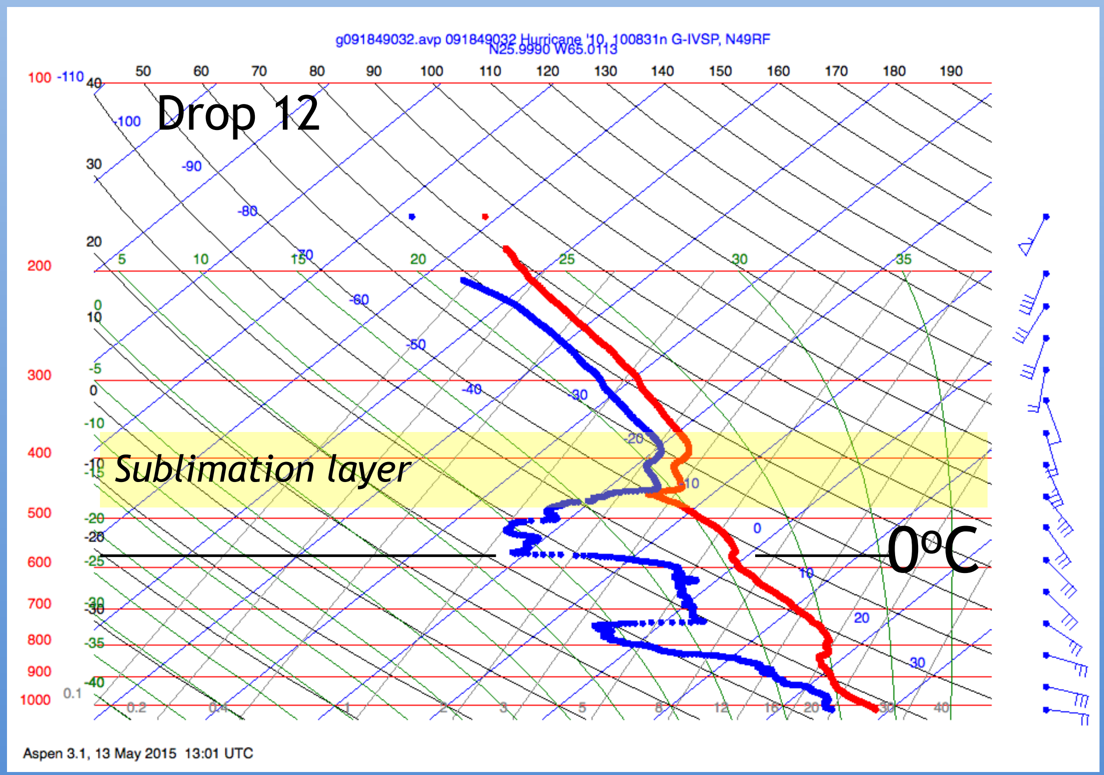


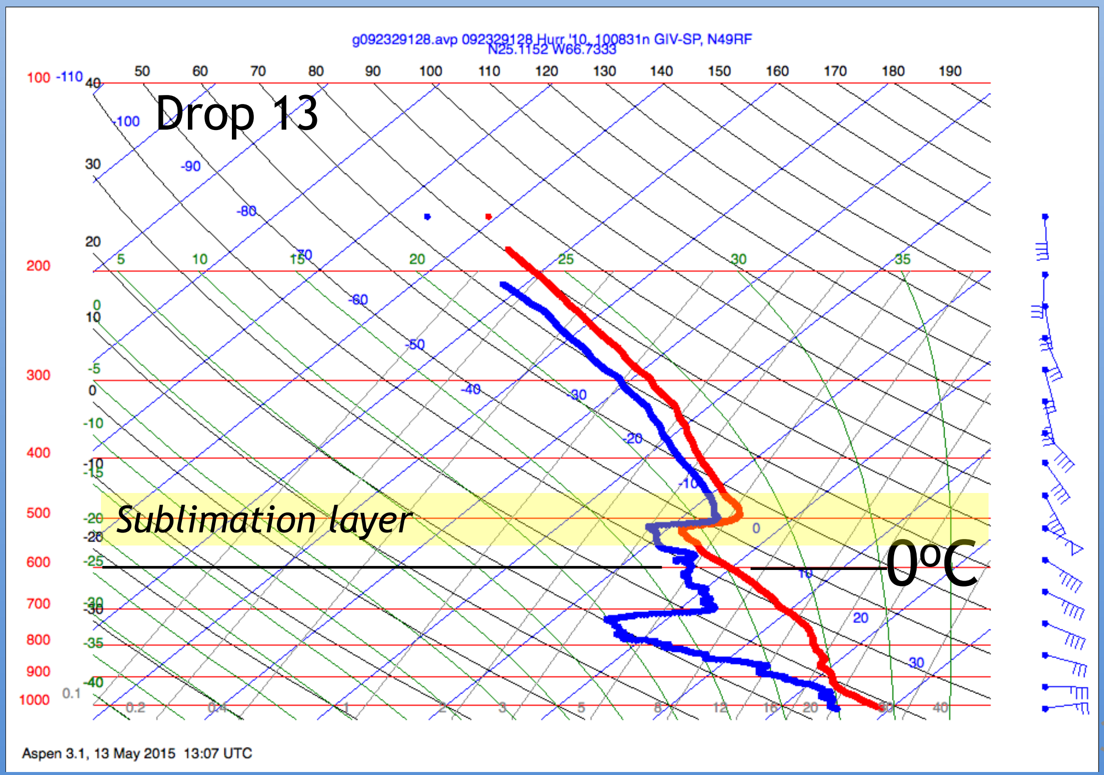
GOES Infrared: 11 μm



GOES IR 6-hr Temperature Trend







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Conclusions

The TC diurnal cycle and associated TC diurnal pulses:

- Behave like squall lines and may be a fundamental TC process

G-IV dropsondes launched near TC diurnal pulses:

- Evidence of sublimation (through cooling by latent heat of sublimation)
- Sublimation is especially evident during the day and when strong winds and a significant dry layer exists in the sounding profile

TC diurnal pulse hypotheses:

- Cause outward surges in cirrus canopy ice content that can invigorate peripheral convection via a seeder-feeder forcing mechanism
- Can greatly affect the thermodynamics of the environment just outside the TC inner core (R~150+ km)

Future work:

- Use satellite imagery to track candidate G-IV missions to sample the environment ahead of, through, and behind TC diurnal pulses to document how these squall line-like features affect the TC environment

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