HWRF Surface Layer Evaluations

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Special thanks to HRD HWRF Model Team:
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Motivation….

- Objective: Improve HWRF forecast performance through a systematic evaluation process, whereby model biases are documented, understood, and ultimately eliminated by implementing accurate observation-based physical parameterizations

- Goals:
  - Assemble comprehensive observational databases (buoy, dropsonde, Doppler radar, microphysics, etc)
  - Establish a framework for comparing numerical model output with observations (sampling, statistics, etc)
  - Systematically evaluate numerous physical and dynamical aspects of HWRF coupled model system against historical observational database at HRD
  - Seek to eliminate model biases by developing observation-based parameterizations of physical processes

Evaluation of coupled air-sea thermodynamics

- Observations from Tropical Cyclone Buoy Database (TCBD, Cione et al. 2000,2003)
- HWRF-3.2 2011 retrospective model runs

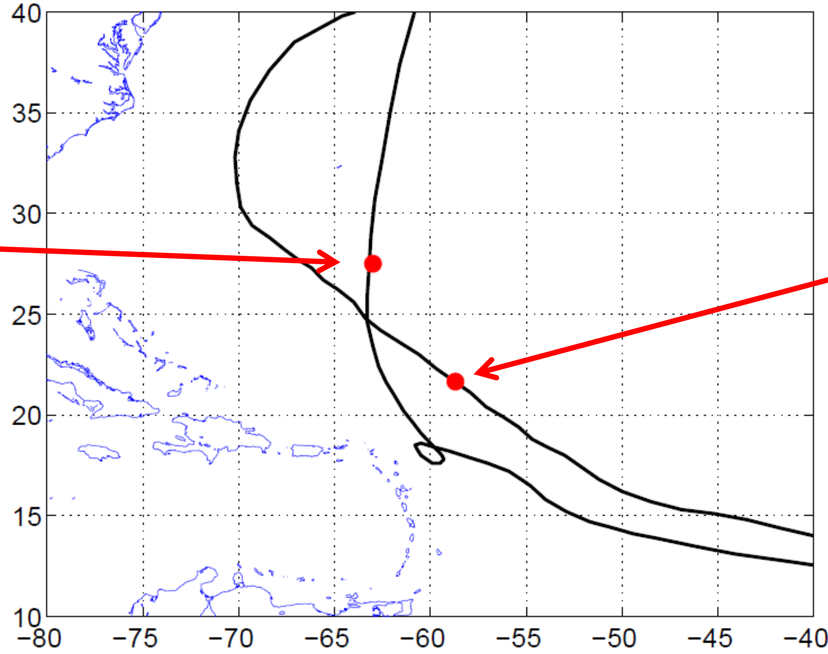
TC Buoy Observations

- Cione et al. 2000,2003
- Temperature and humidity reported hourly
- Winds (10-min mean) reported every 10 mins.
- Obs. adjusted to 10-m level
- Winds converted to 1-min mean

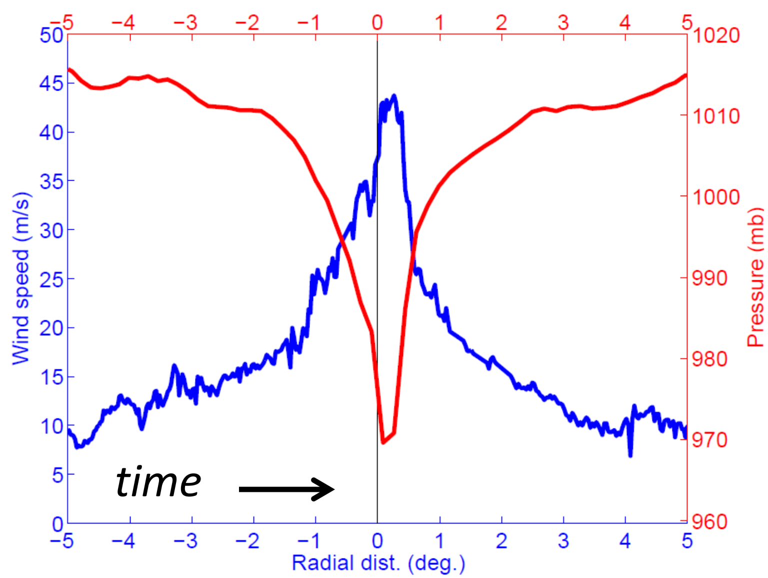
Specific Observational Case Study

- Hurricane Katia (2011)

Ophelia



NDBC 41044 – Katia
4 September



HWRF-3.2 Retrospective Runs 2011

- Storms
  - Irene-09L (34 runs)
  - Katia-11L (46 runs)
  - Maria-14L (41 runs)
  - Ophelia-16L (48 runs)
  - Philippe-17L (60 runs)
  - Rina-18L (20 runs)
- 126 hr simulations, output every 3 hours

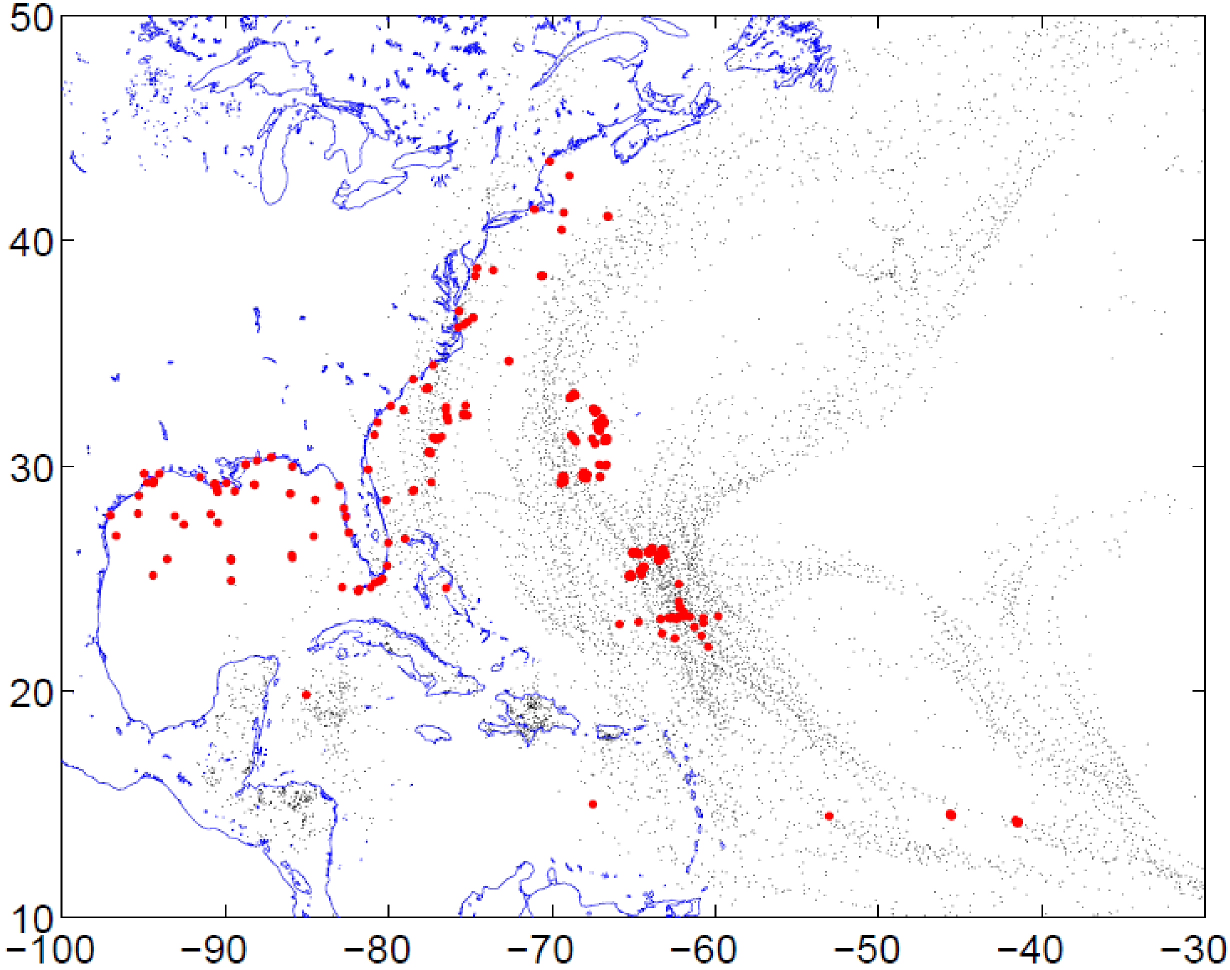
HWRF-3.2 Configuration

- 3 km inner nest
- Coupled to ocean (POM)
- Modified C_k, C_d (CBLAST)
- Modified eddy diffusion (Zhang 2011)
- Operational in 2012
- No sea spray contribution to fluxes

Methodology

- Compute T_{10}, q_{10} from output model fields
- Sample model at TCBD buoy locations falling within model grid as cyclones translate/evolve
- Compute statistical distributions and compare with observations

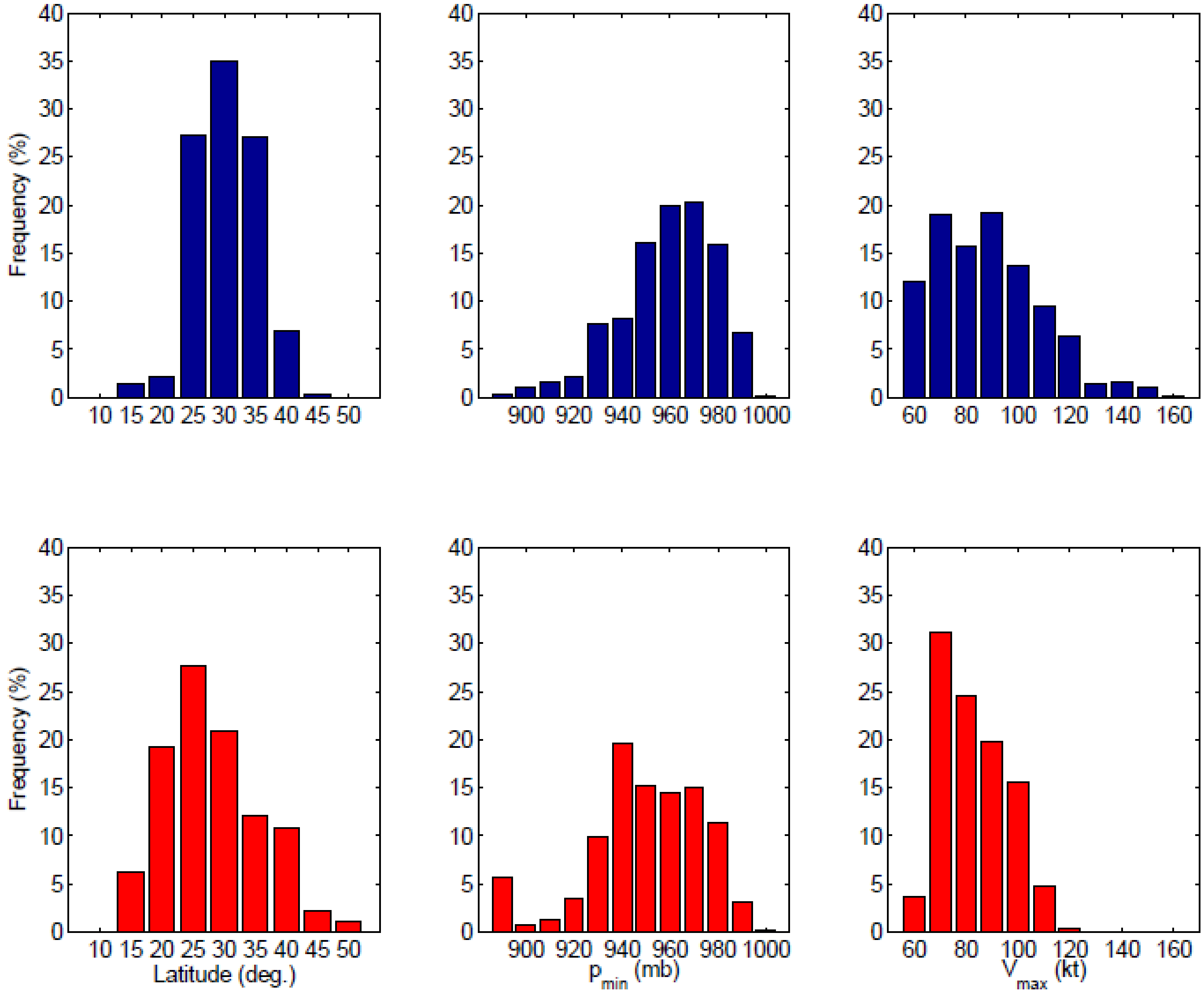
HWRF Forecast Tracks and TCBD Obs. Locations



2011 HWRF & TCBD Storm Stats

TCBD

HWRF



Computing T_{10}, q_{10}

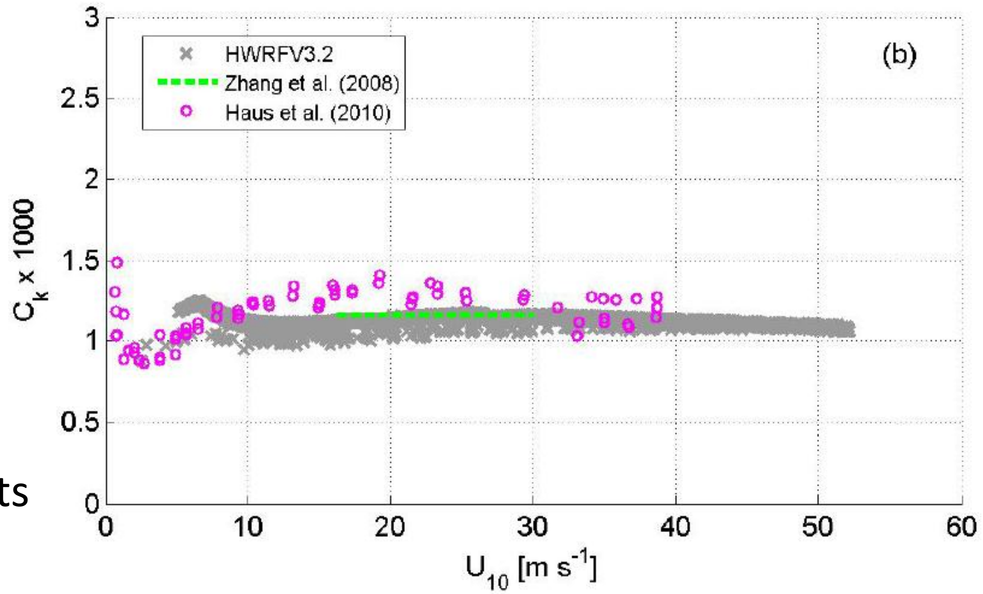
- Fields of SST, latent (H_l) and sensible (H_s) heat fluxes, and 10-m winds (U_{10}) are provided as model output

$$T_{10} = SST - \frac{H_s}{\rho c_p C_h U_{10}}$$

$$q_{10} = q_s(SST) - \frac{H_l}{\rho L_v C_e U_{10}}$$

$$C_h = C_e = C_k$$

Exchange coefficients defined at the 10-m level

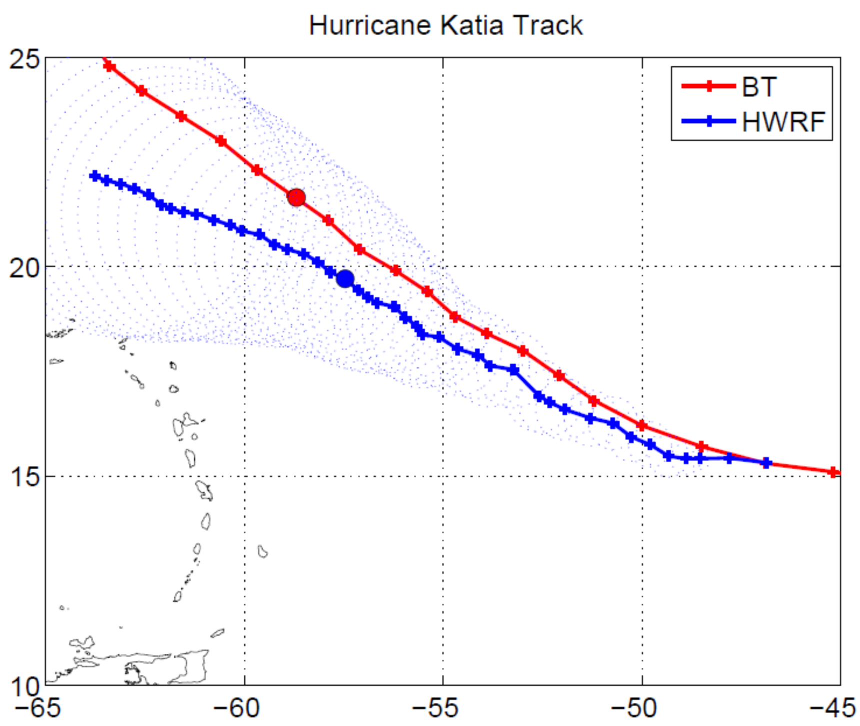


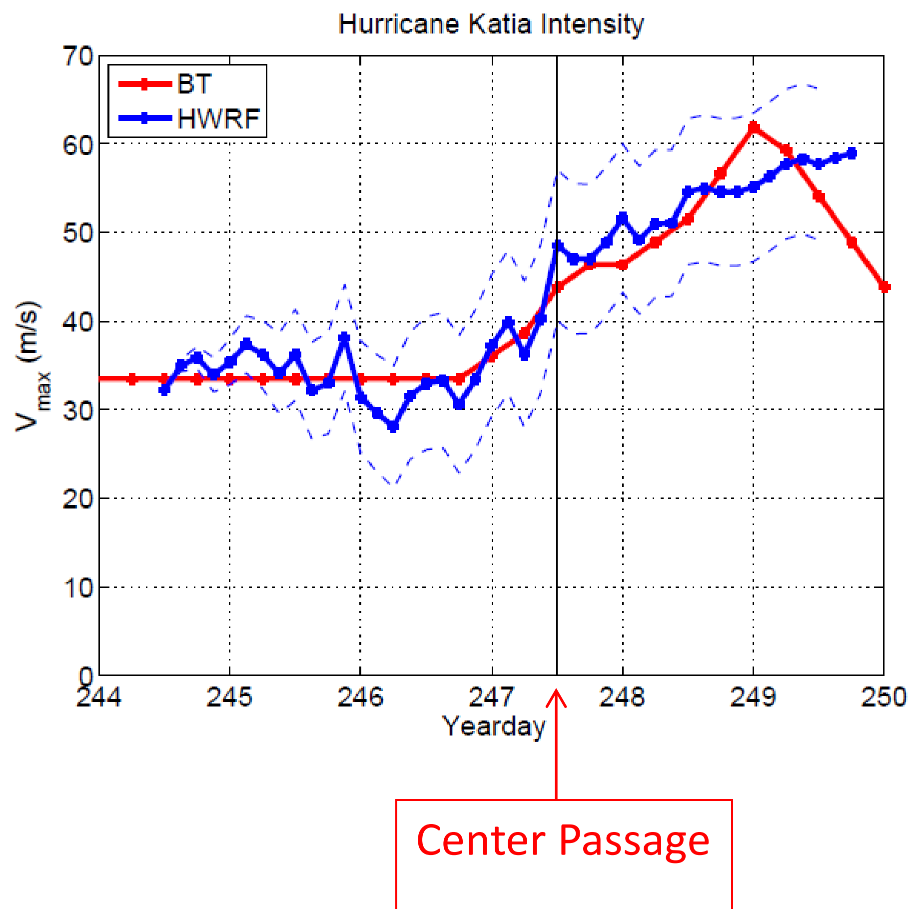
Case Study Comparisons

- Hurricane Katia
  - “Good” forecast
  - “Bad” forecast (intensity under-prediction)

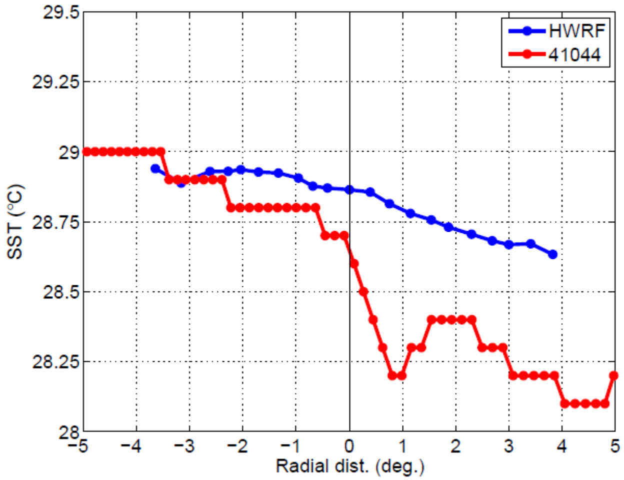
Simulated Buoy Observations: Hurricane Katia “Good” Forecast Example

- HWRF forecast initialized at 01 September 12Z (YD 244.5)
- Buoy passage at 04 September 12Z (YD 247.5)

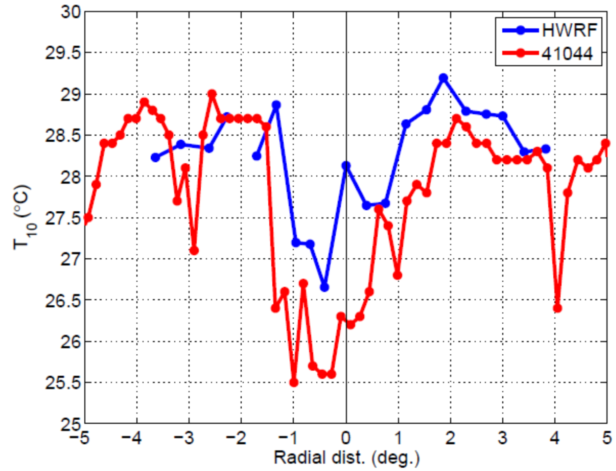




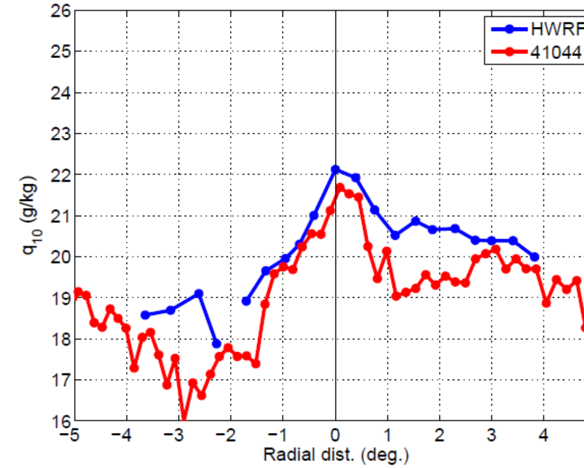
SST ($^\circ$C)



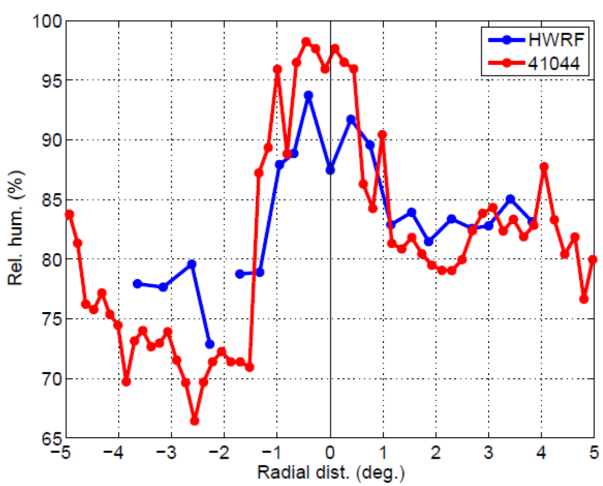
T_{10} ($^\circ$C)



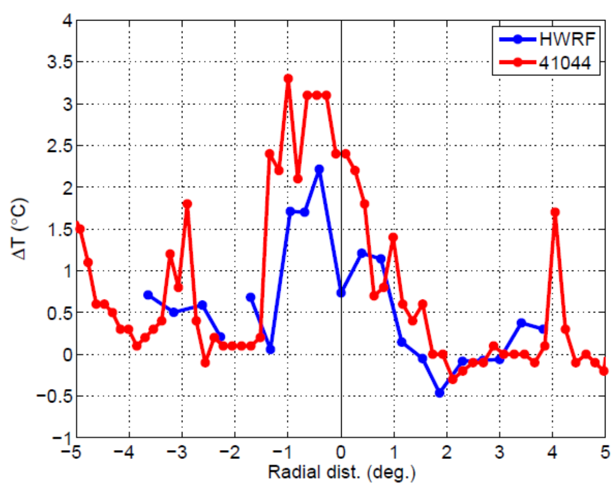
q_{10} (g/kg)



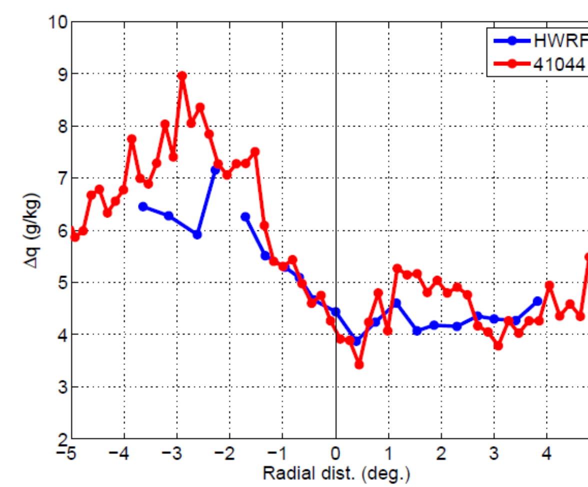
RH (%)



ΔT ($^\circ$C)

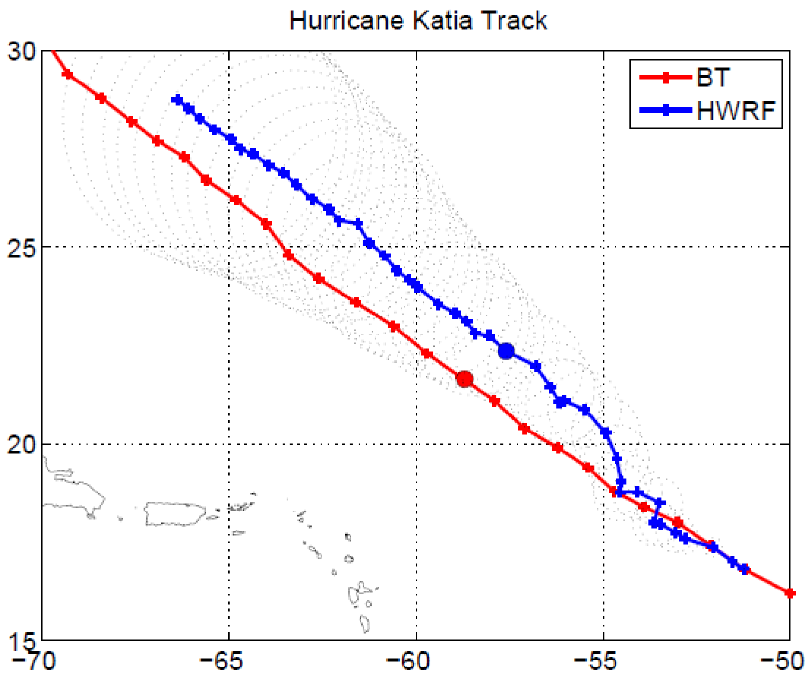


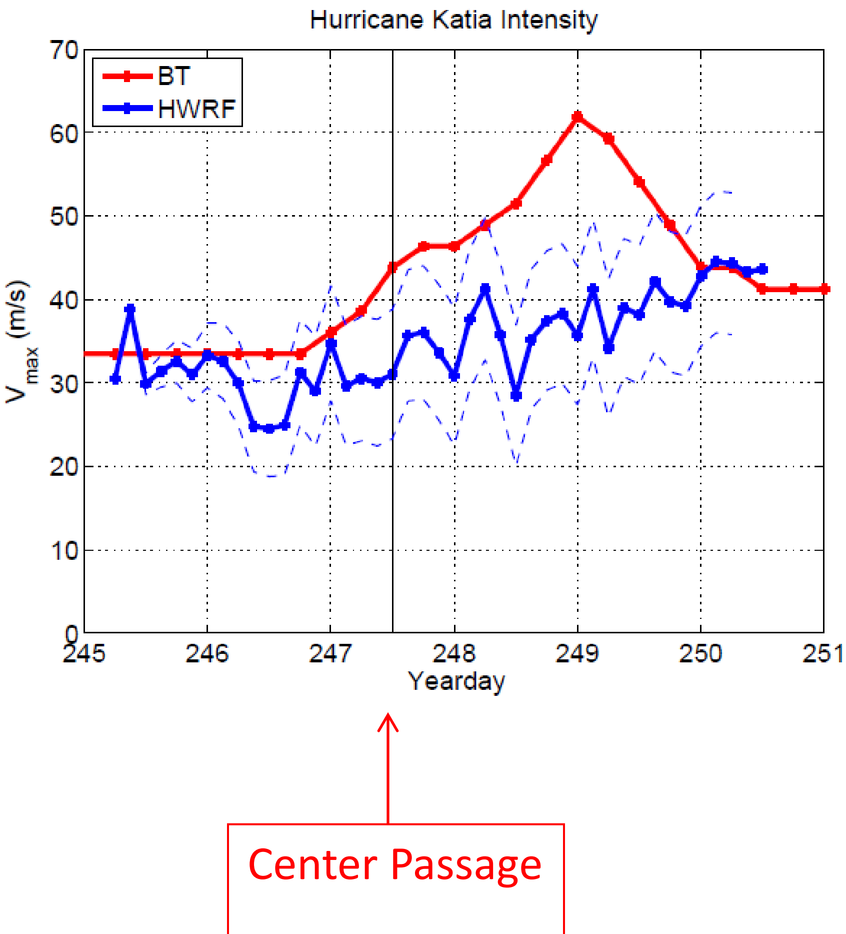
Δq (g/kg)



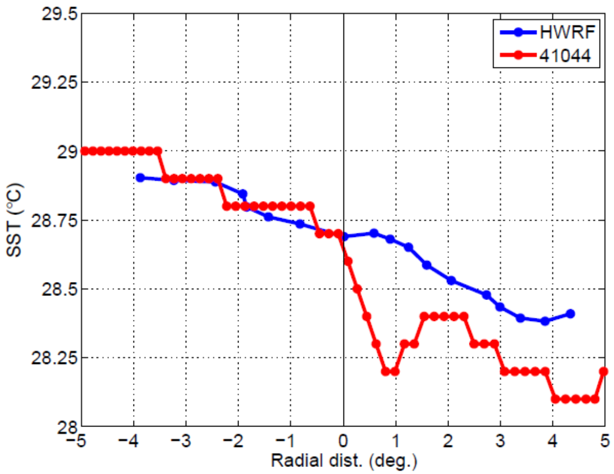
Simulated Buoy Observations: Hurricane Katia Under-forecast Example

- HWRF forecast initialized at 02 September 06Z (YD 245.25)
- Buoy passage at 04 September 12Z (YD 247.5)

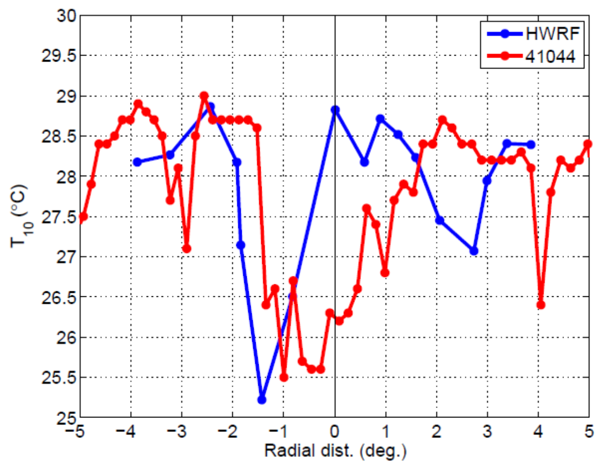




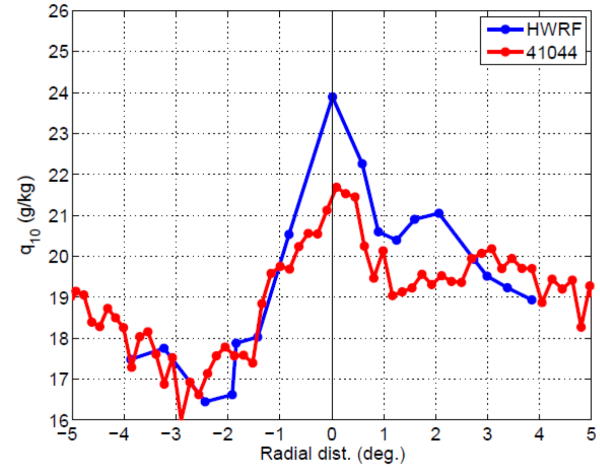
SST (° C)



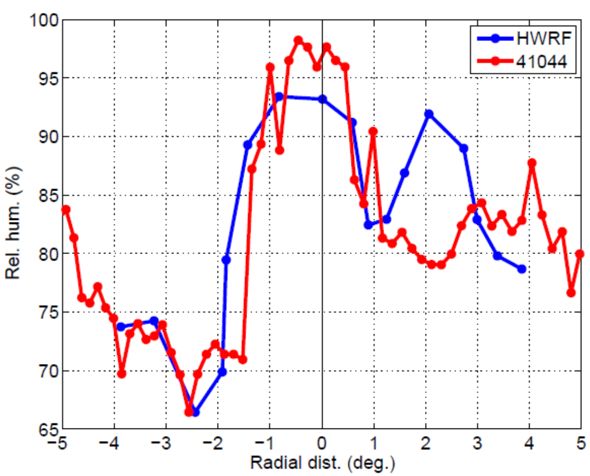
T_{10} (° C)



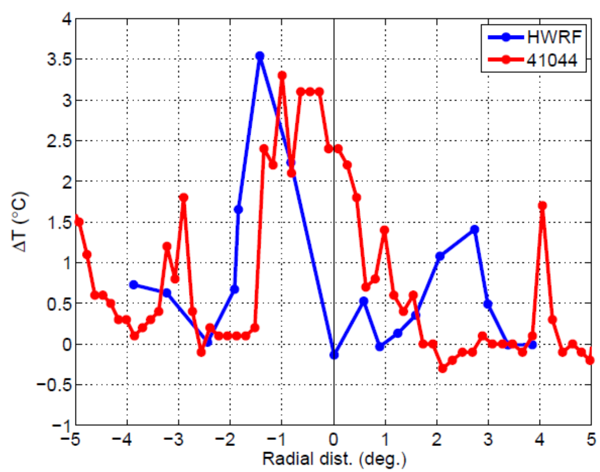
q_{10} (g/kg)



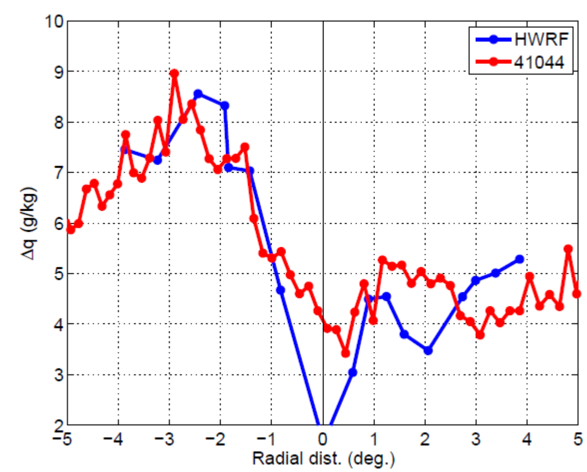
RH (%)



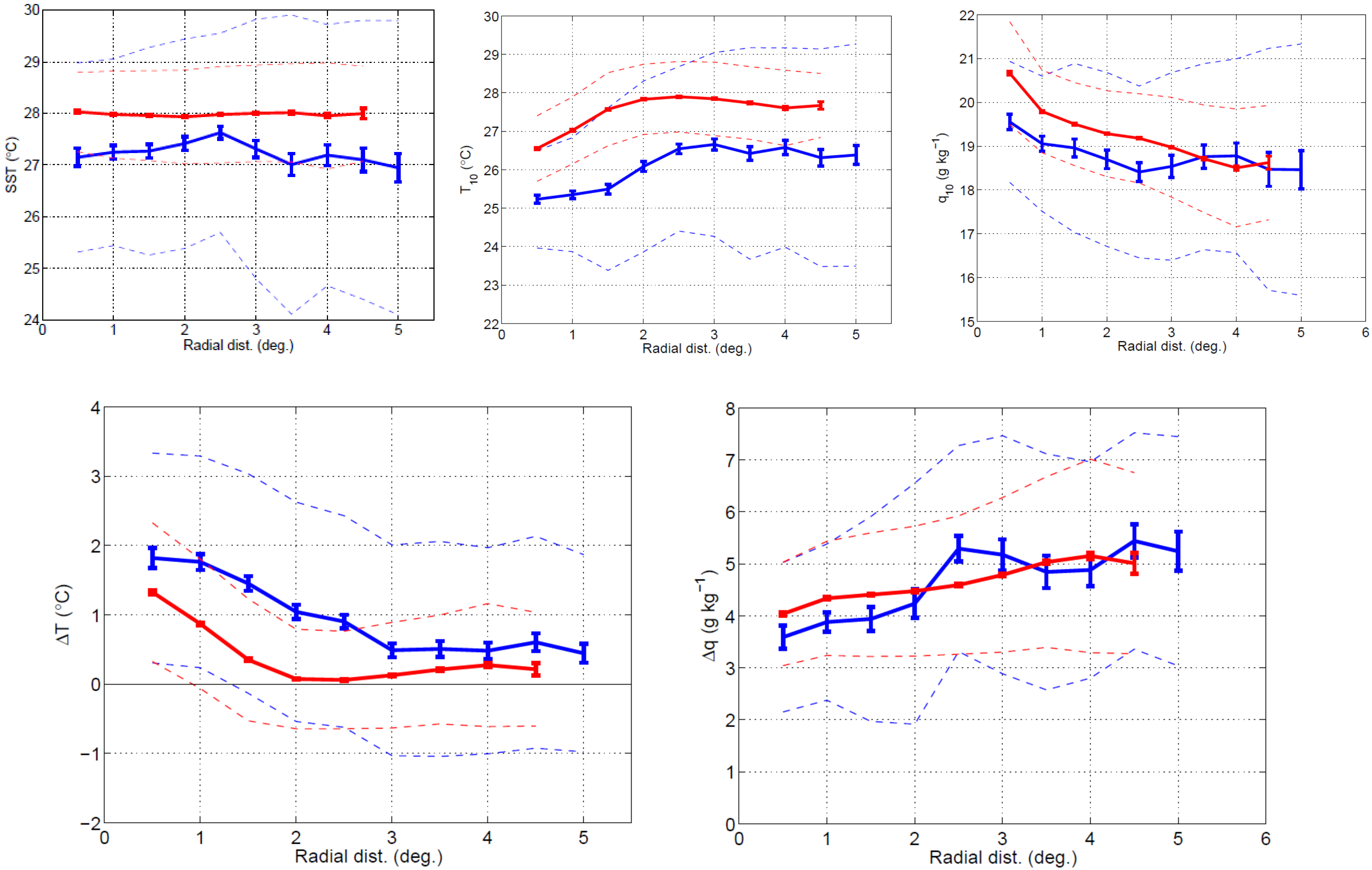
ΔT (° C)



Δq (g/kg)



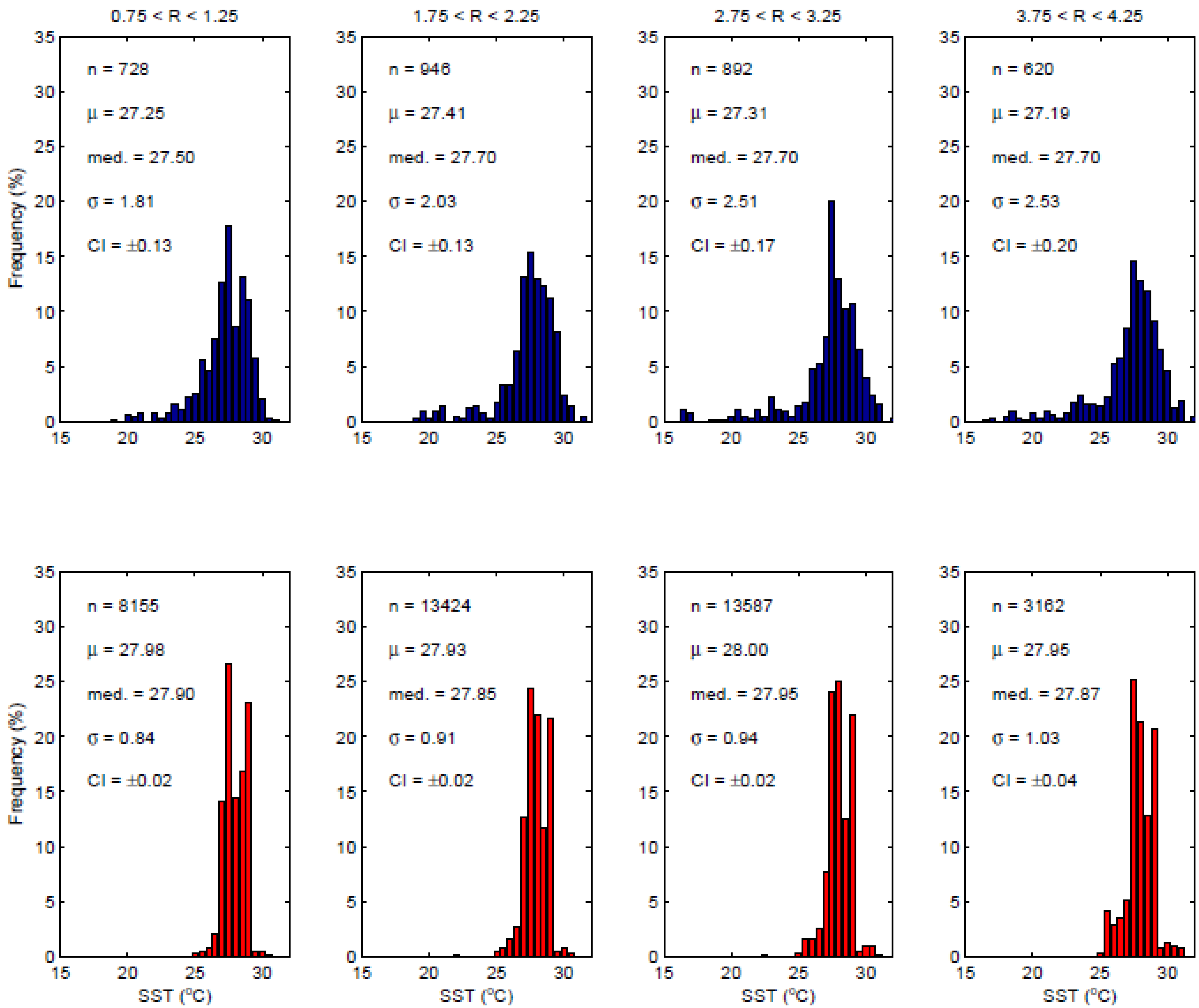
General Results…
Radial Distributions



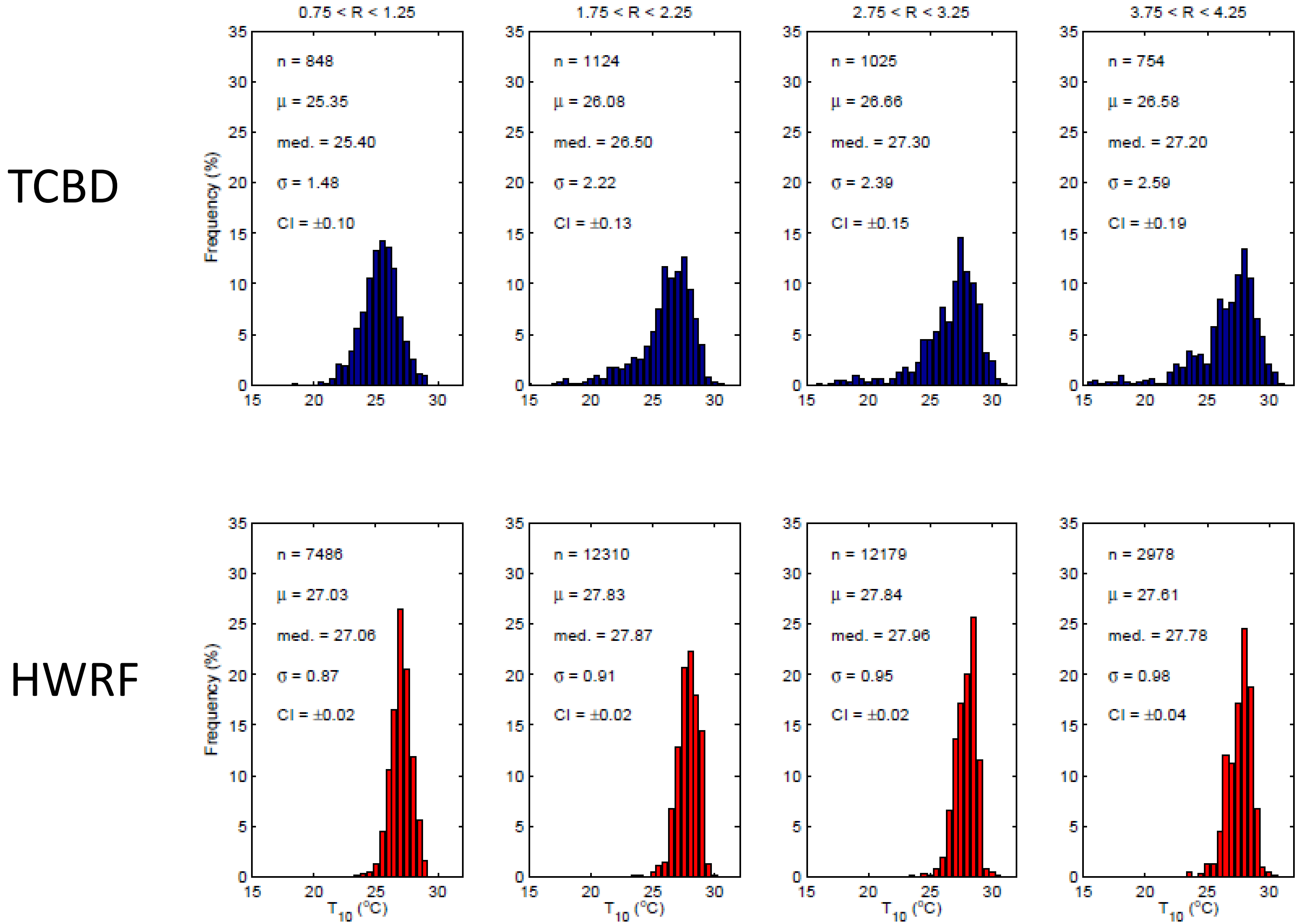
SST

TCBD

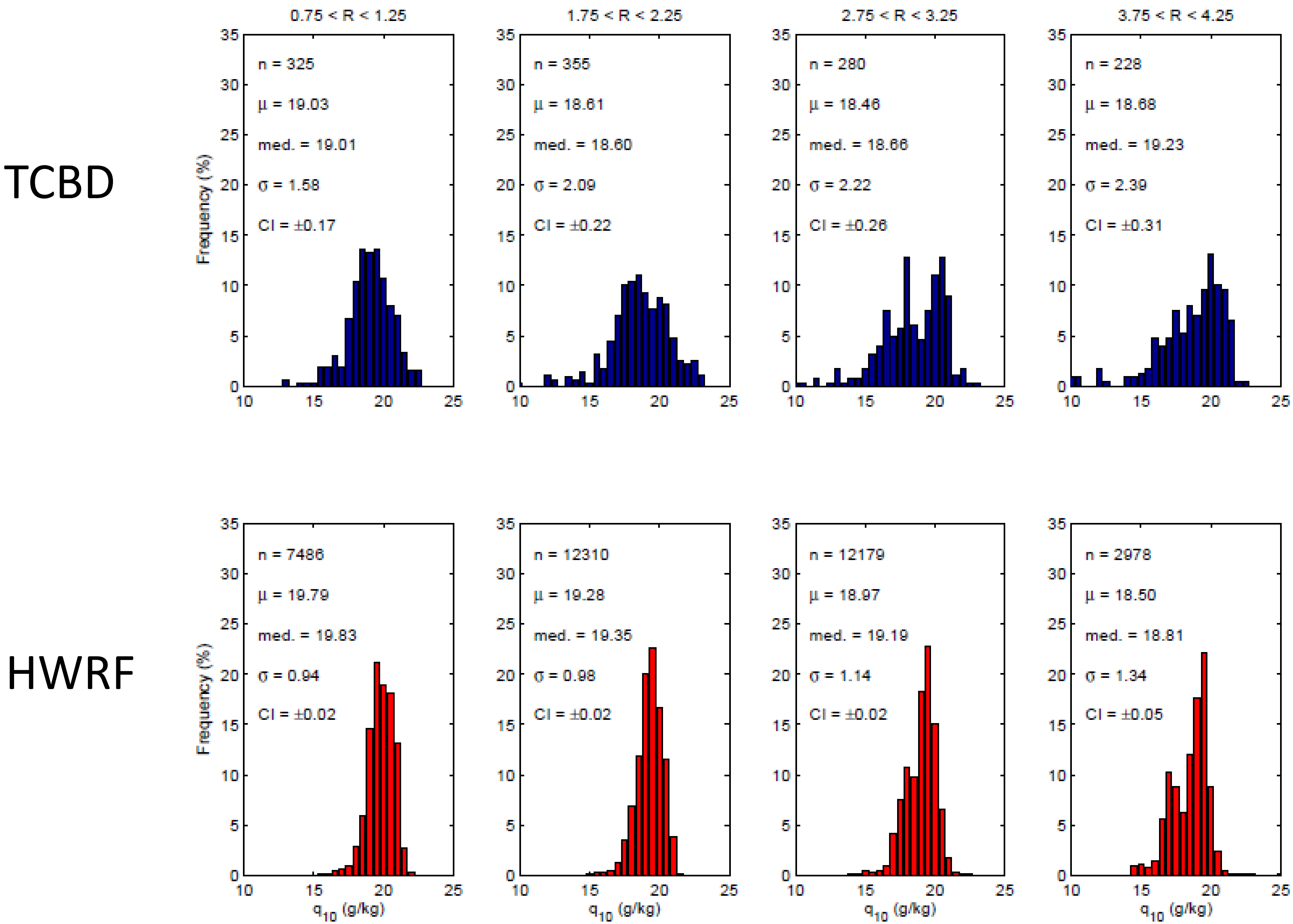
HWRF



T_{10}


TCBD
HWRF
0.75 < R < 1.25
1.75 < R < 2.25
2.75 < R < 3.25
3.75 < R < 4.25
n = 848
μ = 25.35
med. = 25.40
σ = 1.48
CI = ±0.10
n = 1124
μ = 26.08
med. = 26.50
σ = 2.22
CI = ±0.13
n = 1025
μ = 26.66
med. = 27.30
σ = 2.39
CI = ±0.15
n = 754
μ = 26.58
med. = 27.20
σ = 2.59
CI = ±0.19
n = 7486
μ = 27.03
med. = 27.06
σ = 0.87
CI = ±0.02
n = 12310
μ = 27.83
med. = 27.87
σ = 0.91
CI = ±0.02
n = 12179
μ = 27.84
med. = 27.96
σ = 0.95
CI = ±0.02
n = 2978
μ = 27.61
med. = 27.78
σ = 0.98
CI = ±0.04
Frequency (%)
T10 (°C)

q_{10}

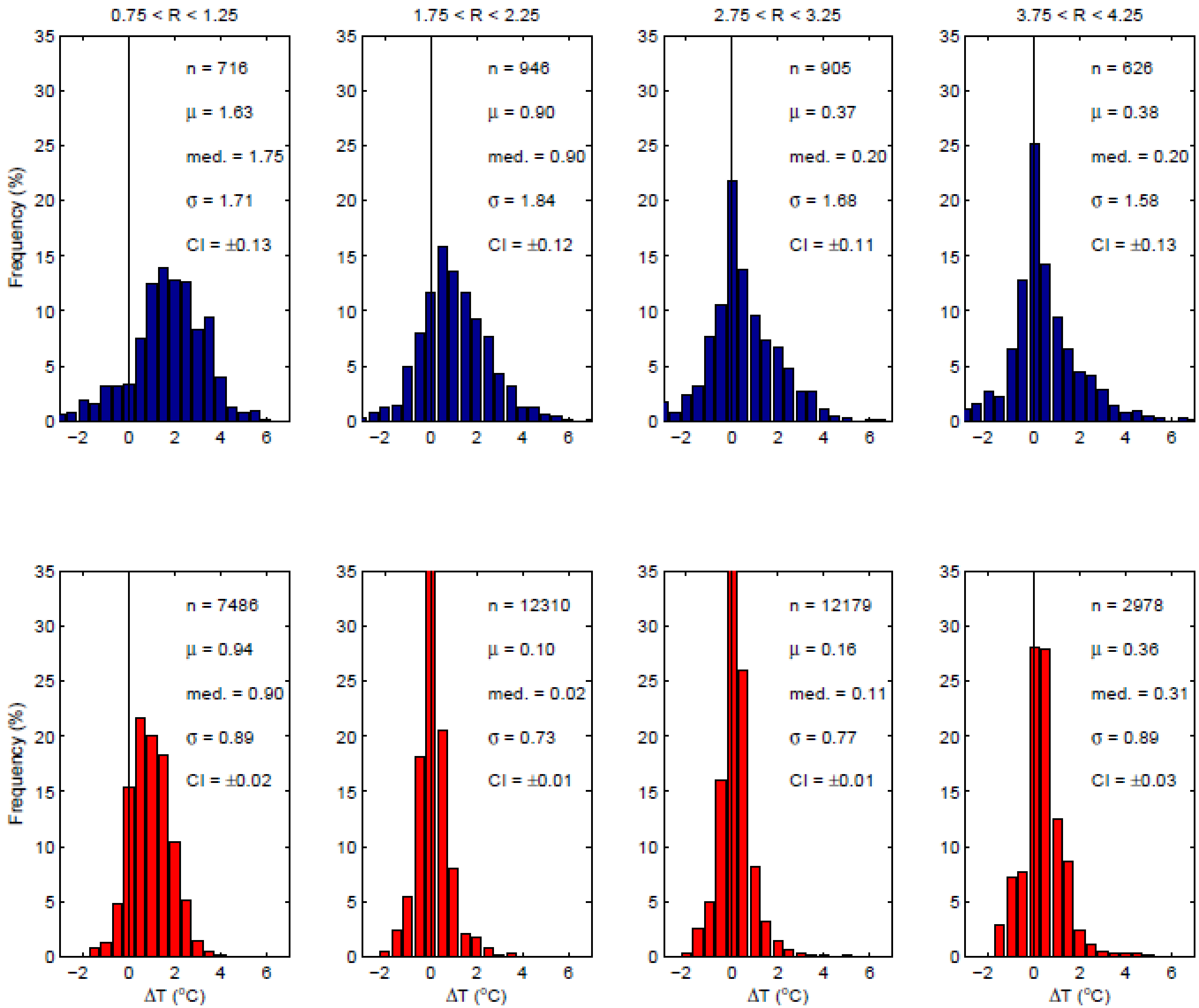


TCBD
HWRF
0.75 < R < 1.25
1.75 < R < 2.25
2.75 < R < 3.25
3.75 < R < 4.25
Frequency (%)
n = 325
μ = 19.03
med. = 19.01
σ = 1.58
CI = ±0.17
n = 355
μ = 18.61
med. = 18.60
σ = 2.09
CI = ±0.22
n = 280
μ = 18.46
med. = 18.66
σ = 2.22
CI = ±0.26
n = 228
μ = 18.68
med. = 19.23
σ = 2.39
CI = ±0.31
n = 7486
μ = 19.79
med. = 19.83
σ = 0.94
CI = ±0.02
n = 12310
μ = 19.28
med. = 19.35
σ = 0.98
CI = ±0.02
n = 12179
μ = 18.97
med. = 19.19
σ = 1.14
CI = ±0.02
n = 2978
μ = 18.50
med. = 18.81
σ = 1.34
CI = ±0.05
q10 (g/kg)

ΔT

TCBD

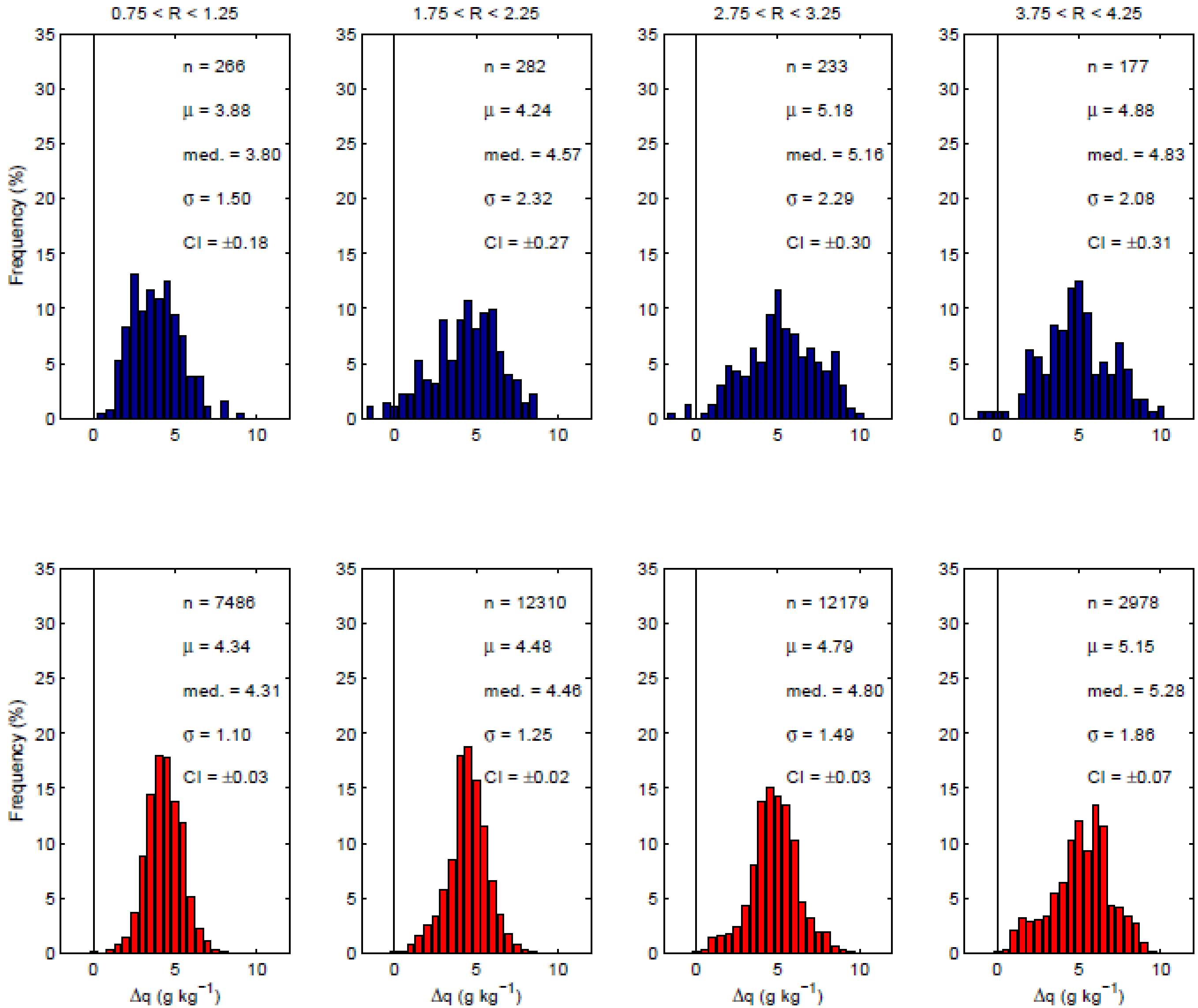
HWRF



Δq

TCBD

HWRF



Summary

- A framework for evaluating HWRF near-surface thermodynamic fields has been developed

- Relative to TCBD obs., generally HWRF-3.2 is:
  - Warmer (SST and T_{10}) at all radii inside 250km
  - More moist (q_{10}) at all radii

- Cases studied suggest ambient/initial SST conditions are reasonable but model under-cools in wake
  - Contrasts previous notion of overcooling (IHC 2009)
  - Initial *sub-surface* structure is not well known

Summary (cont'd)

- Variability of model SST, T_{10} and q_{10} (and derived fields of ΔT, Δq) are significantly lower relative to the TCBD
  - Least 42% (SST); 43% (T_{10}); 48% (ΔT); 53% (q_{10}); Most 70% (Δq)
- In most cases 'ambient' model fields (>350km from the TC) compare well with mean obs from the TCBD (SST, T_{10})
  - Model q_{10} is the exception where modestly drier ambient moisture conditions were found when compared to the TCBD (despite relatively more moist conditions simulated inside 350km)
- HWRF ΔT was significantly less than TCBD ΔT < 250km
- HWRF ΔQ similar to TCBD ΔQ at most radial distances
  - Here however, this is a classic example of getting the right answer (ΔQ) for the wrong reason (SST too warm, q_{10} too moist)
  - > Leading to other, unintended impacts within the model?

Next Steps…

Hurricane Air-Sea Interaction Model Evaluation and Improvement Methodology…

- Establish a 'clear picture' of air-sea conditions based on 30+ years of direct measurements collected within the inner and outer core hurricane environment over a wide array of storm conditions.
- Compare observed fields with comparable/appropriately-scaled model air-sea analyses over a wide array of storm conditions (e.g. hurricane, tropical storm, intensifying, weakening, fast/slow moving, etc).
- In addition, model/observational comparisons using various flow-relative frameworks (e.g. earth-relative, storm motion-relative, shear-relative).
- Consistent with the project's objectives, analyses and inter-comparisons would concentrate on model/observational differences associated with mean and asymmetric structure (i.e. wave # 0/1).
- Analyses would include assessment of near surface atmospheric and oceanic model performance.
- Once specific areas of improvement are targeted, key HRD, AOML, ESRL and EMC personnel would work closely and interactively to improve atmospheric model surface layer, upper ocean physics and associated parameterization routines.
- After necessary improvements to the modeling system have been made, conduct targeted idealized modeling studies to ensure documented findings are correct for the right (physical) reason(s). Such studies should also help improve overall physical understanding and better document model variability associated with the air-sea coupled system.
- Highlight any "observational gaps" that may exist within the air-sea interactive environment and provide an assessment of how to best target such gaps going forward (e.g. new field experiments, new observing platforms (UAS, UOV), new/improved sensors, etc).
- If appropriate, work closely with AOML, ESRL and other collaborative scientists to implement targeted OSE/OSSE experiments designed to determine the optimal mix of new and existing observations most likely to improve future forecasts of hurricane intensity change.
- Once/if significant changes have been made to the model, conduct "before and after" simulations that highlight the improvements that were achieved (e.g. improved physical representation of the air-sea environment (mean and asymmetric fields), appropriate variability attained, and (hopefully) a measure of improved forecast accuracy).
- As needed, conduct periodic updates to HFIP and other NOAA leadership as progress is made.
- Maintain existing funding & explore avenues for additional resources (i.e. new data/funding opportunities as they arise).