Improving the HWRF model physics using observations and model diagnostics

Jun Zhang

University of Miami/RMSAS & AOML/HRD

HFIP telecon presentation, April 25, 2012

Many thanks to my colleagues!

- Zhang, J. A., P. G. Black, J. R. French, and W. M. Drennan, 2008: First direct measurements of enthalpy flux in the hurricane boundary layer: The CBLAST results. *Geophys. Res. Lett.*, 35(11):L14813, doi:10.1029/2008GL034374.
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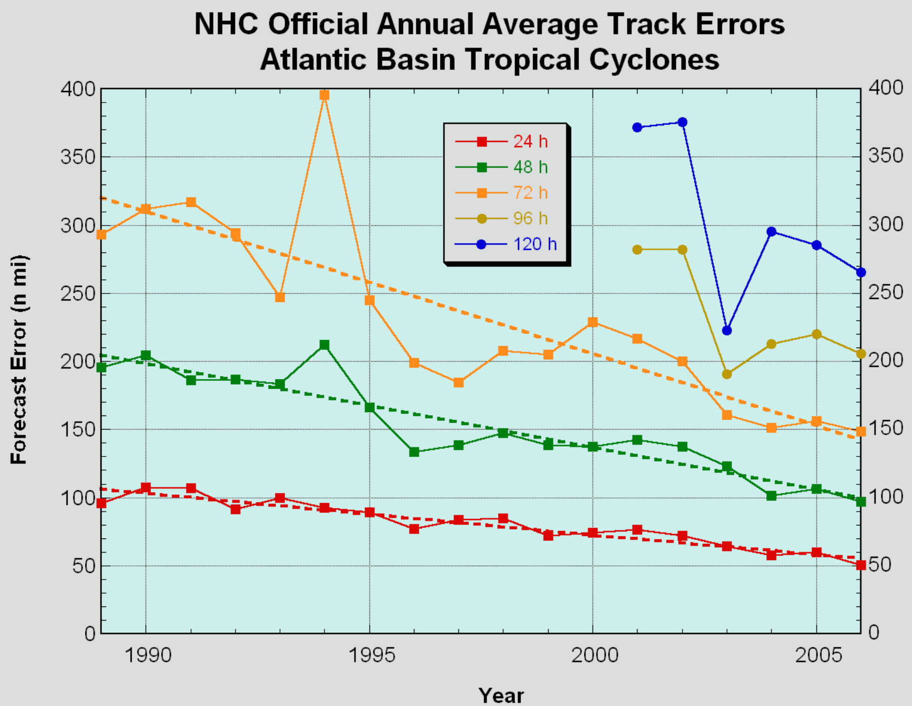
- Cione, J. J., E. A. Kalina, J. A. Zhang, and E. W. Uhlhorn, 2012: Observations of air-sea interaction and intensity change in hurricanes. *Mon. Wea. Rev.*, revised and submitted.
- Gopalakrishnan, S. G., F. Marks, Jr, J. A. Zhang, X. Zhang, J. Bao and V. Tallapragada, 2012: A Study of the Impacts of Vertical Diffusion on the Structure and Intensity of the Tropical Cyclones Using the High Resolution HWRF system. *J. Atmos. Sci.,* submitted.

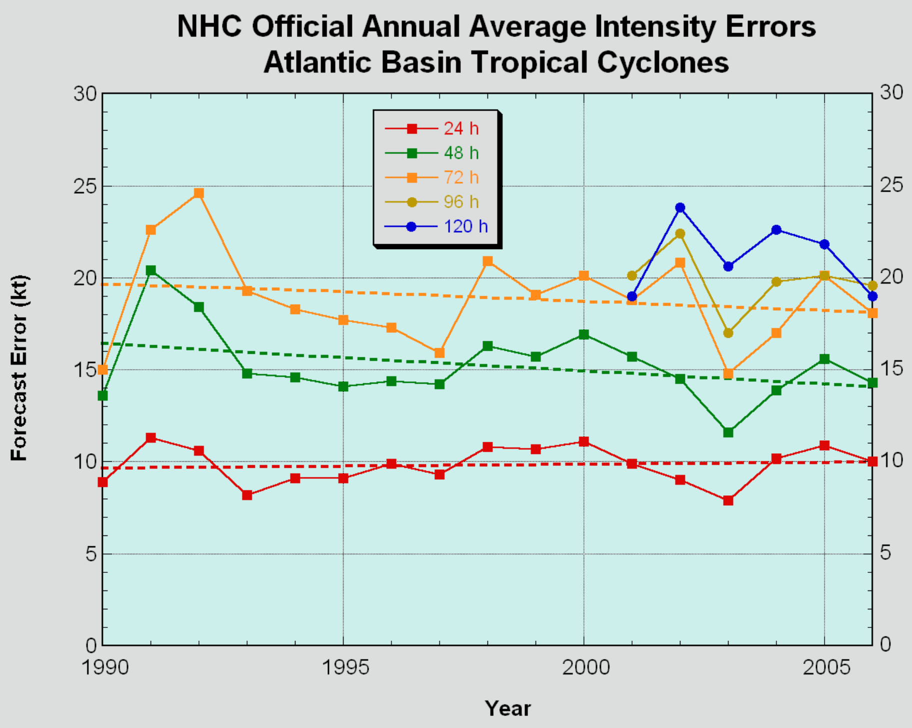
Acknowledge the support from HFIP

Acknowledge HRD and EMC HWRF modeling team members

Outline

- Motivation and objectives
- Model diagnostics using observations
- Observation-based model physics upgrade in HWRF
- Future work





Why is hurricane Intensity so hard to be predicted?

Model initialization
Model resolution
Model physics

Environmental control

Microphysics

Air-sea Interaction

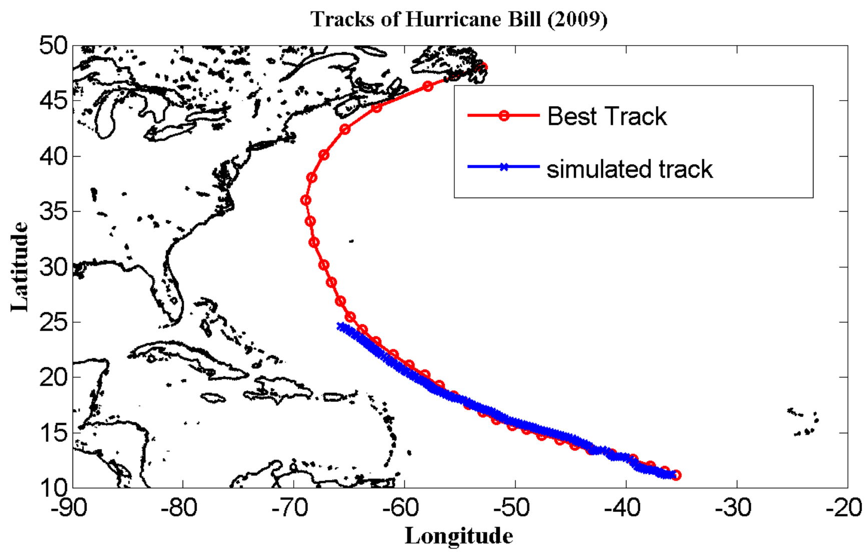
Boundary layer physics

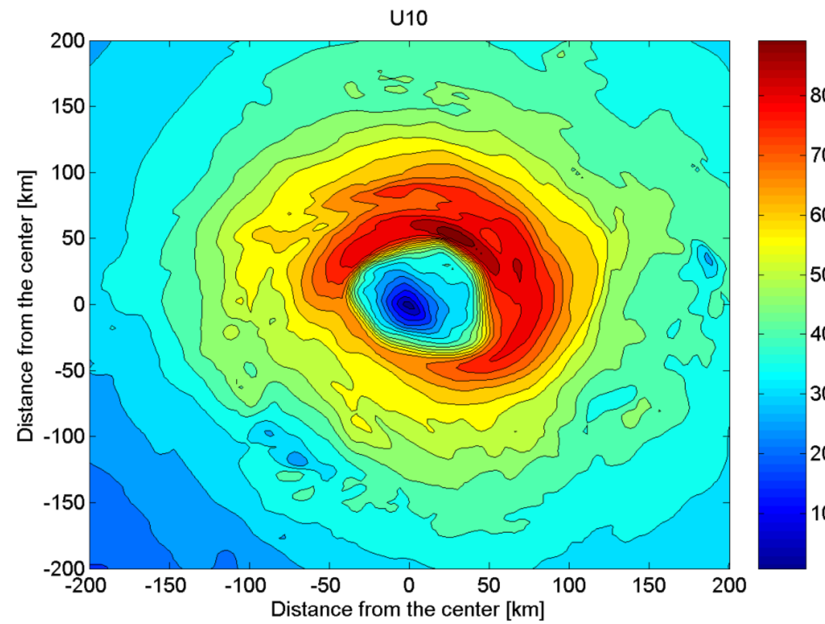
Objectives

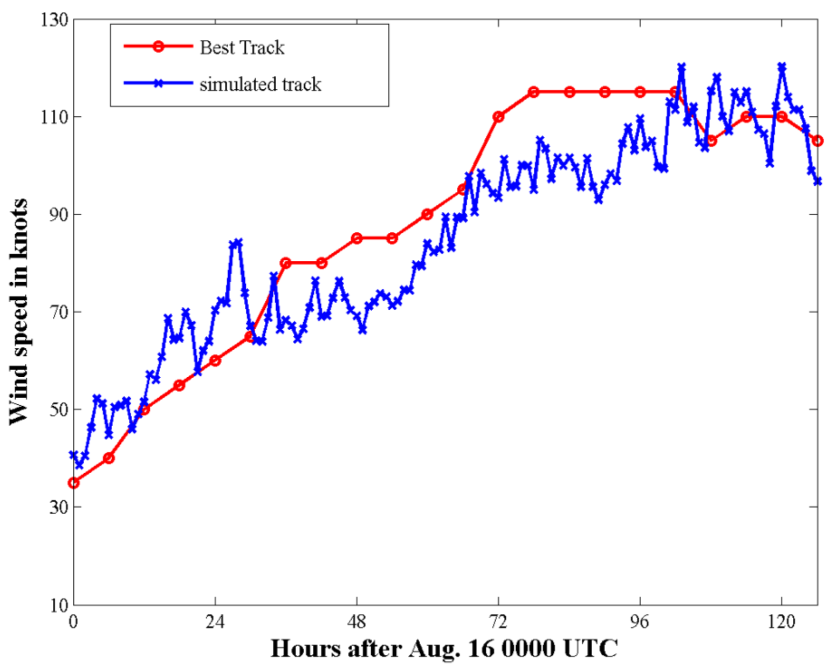
- Increase usefulness of observations in high resolution (e.g. regional) hurricane modeling systems.
- Develop advanced model diagnostic techniques to support model improvements and identification and analyses of sources of model errors.

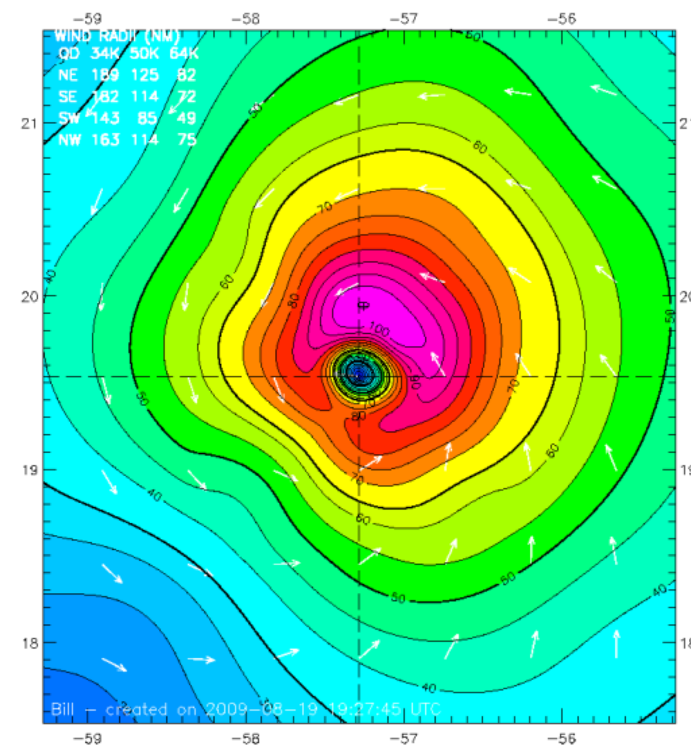
Develop advanced model diagnostics to identify model deficiency and errors through comparison with observations

The experimental version HWRF









HFIP Hurricane High-Resolution Hurricane (HRH) HWRF-X Forecasts with HWRF initialization

Zhang, Rogers, and Cangialosi 2010

Rapid Intensification (Hits and Misses)

Best Track/Model	Hits	Misses
Observed	**17**	**--**
HWRF-x (hwrf) low res	**10**	**7**
HWRF-x (hwrf) high res	**13**	**4**
HWRF-x (gfdl) low res	**10**	**7**
HWRF-x (gfdl) high res	**13**	**4**

Rapid Intensification (False Alarms and Correct Rejections)

Best Track/Model	False Alarms	Correct Rejections
Observed	**--**	**38**
HWRF-x (hwrf) low res	**1**	**37**
HWRF-x (hwrf) high res	**7**	**31**
HWRF-x (gfdl) low res	**1**	**37**
HWRF-x (gfdl) high res	**8**	**30**

A total of 9 Storms, 69 Cases

2005 Storms: Emily, Katrina, Ophelia, Phillipe, Rita, Wilma

2007 Storms: Ingrid, Humberto, Karen

HWRFx runs selected for analysis

HWRF initialization 27-9 km

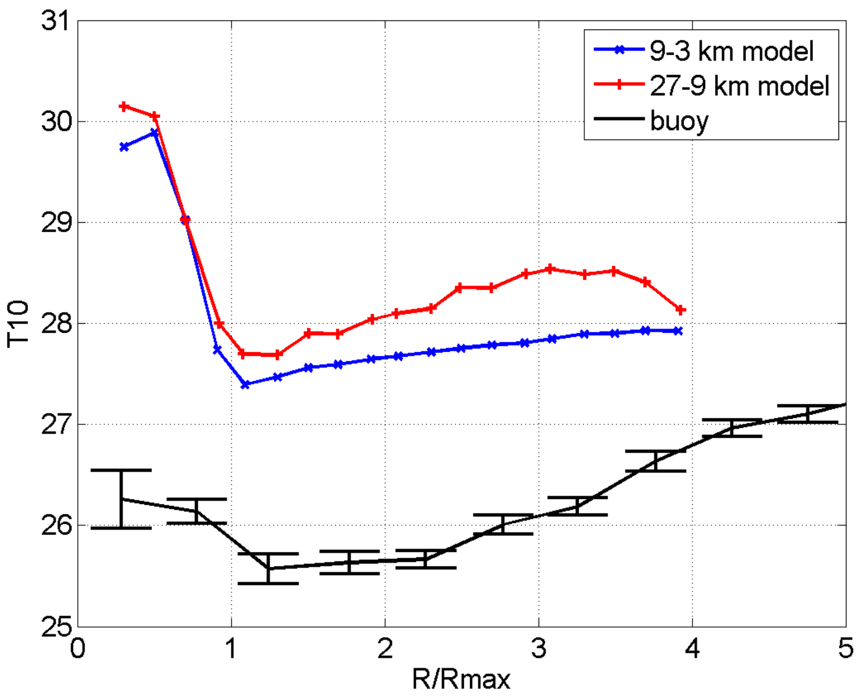
Initialization Time	Hit or Miss	Time period in simulation	Intensity range during SS
07_13_00	Hit	58 h – 77 h	95 – 105 kt
07_14_00	Hit	55 h – 72 h	92 – 102 kt
07_15_00	Hit	17 h – 38 h	105 – 115 kt
8_24_00	Hit	67 h – 85 h	104 – 113 kt
8_26_00	Hit	32 – 46 h	105 – 115 kt
8_27_00	Hit	12 – 28 h	105 – 115 kt
10_19_00	Hit	33h – 49 h	100 – 110 kt
10_20_00	Hit	12h - 32 h	125 – 135 kt

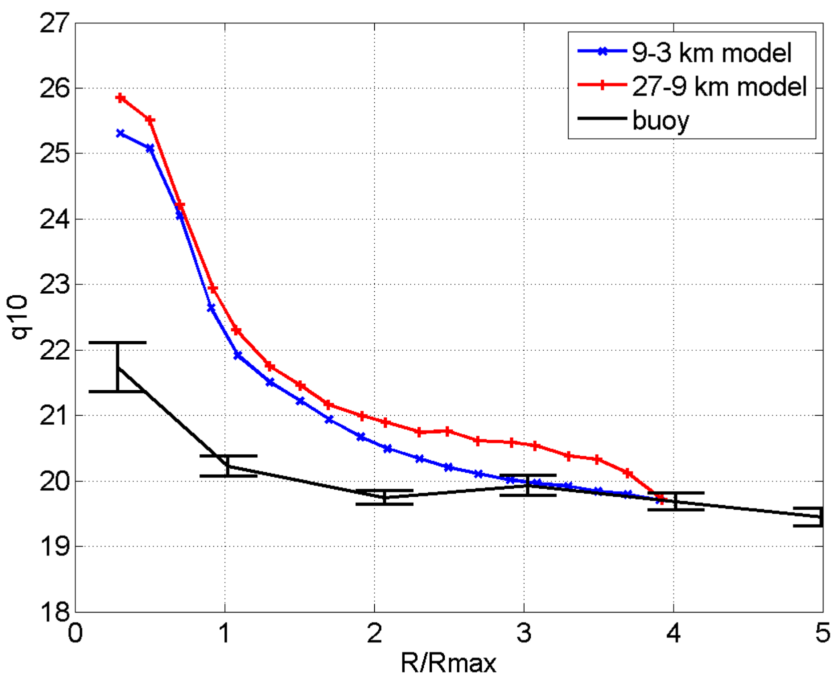
HWRF initialization 9-3 km

Initialization Time	Hit or Miss	Time period in imulation	Intensity range during SS
07_13_00	Hit	76 h – 96 h	125 – 135 kt
07_14_00	Hit	45 h – 61 h	108 – 118 kt
07_15_00	Hit	12 h – 40 h	125 – 135 kt
07_16_00	Hit	13 h – 37 h	110 – 120 kt
8_24_00	Hit	59 h – 73 h	105 – 113 kt
8_26_00	Hit	26 – 38 h	106 – 117 kt
10_19_00	Hit	31h – 38 h	122 – 132 kt
10_20_00	Hit	12h - 28 h	140 – 150 kt

Surface layer structure diagnostics

Zhang, Cione, Uhlhorn and Rogers, 2010

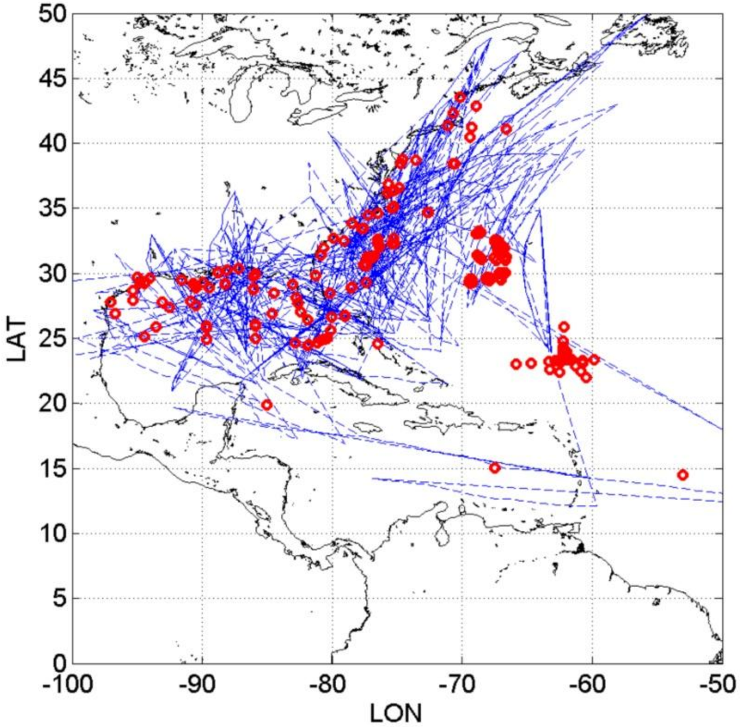


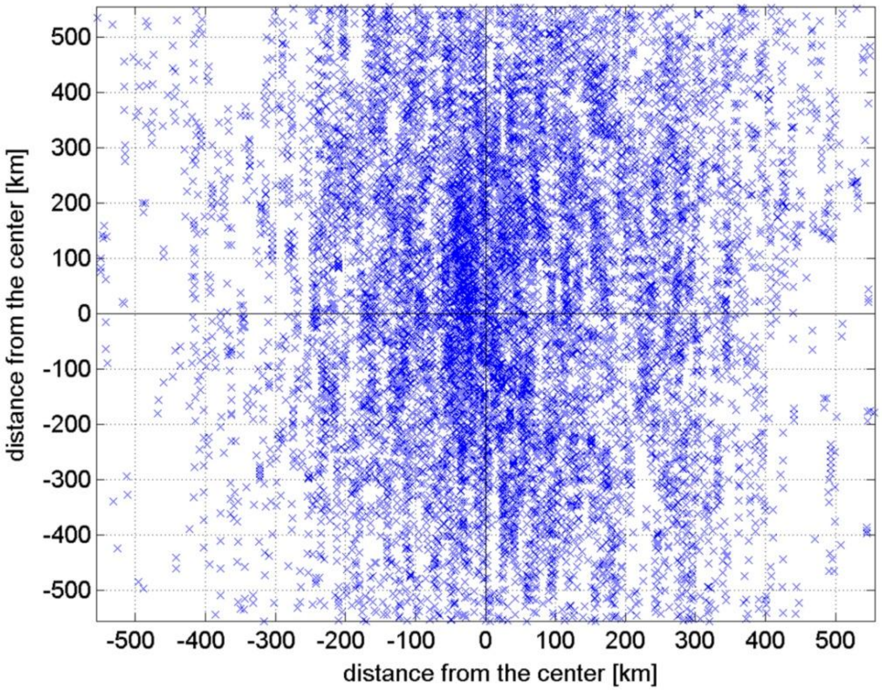


The simulated surface layer is too warm and too moist compared to observations.

1975-2007 TCBD individual buoy and C-Man observations

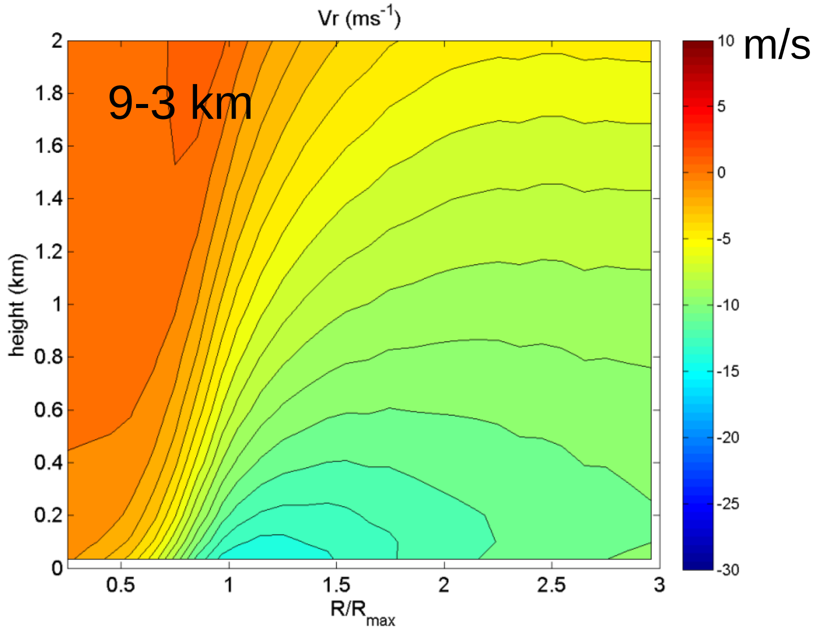
Cione, Kalina, Zhang and Uhlhorn, 2012

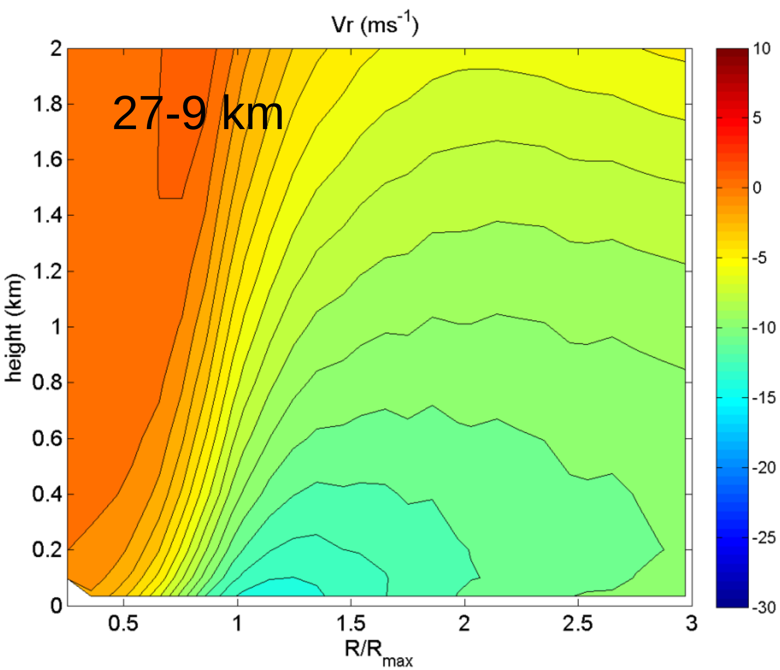


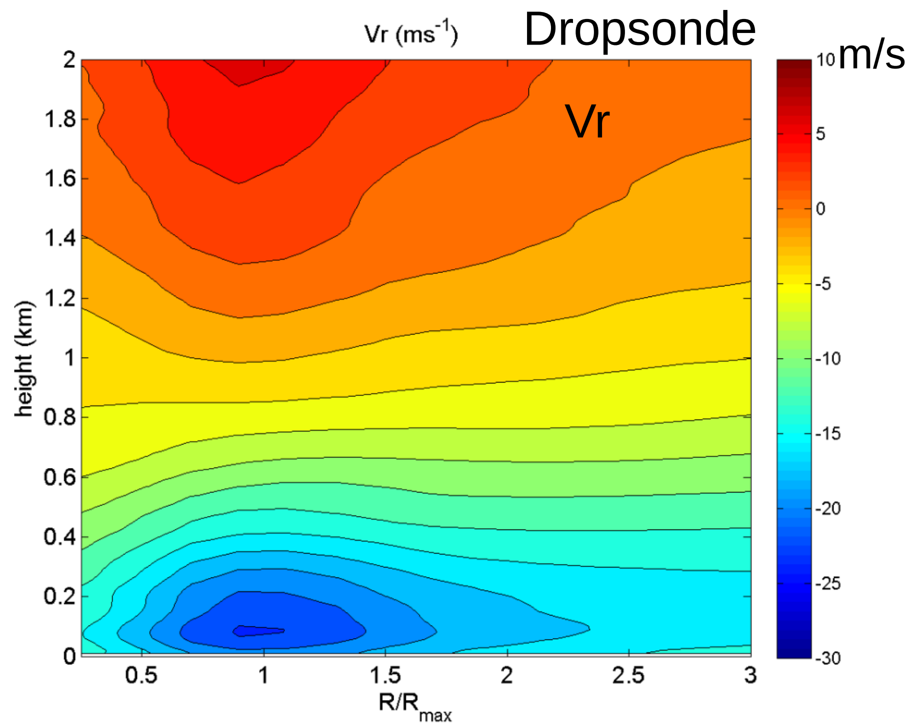


Boundary layer structure diagnostics

Zhang, Rogers, and Cangialosi 2011



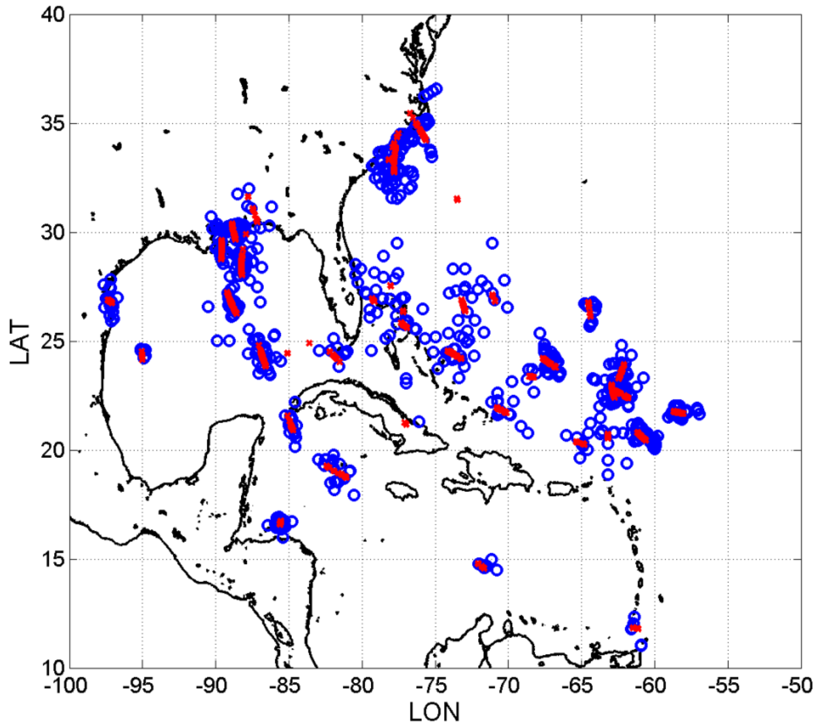


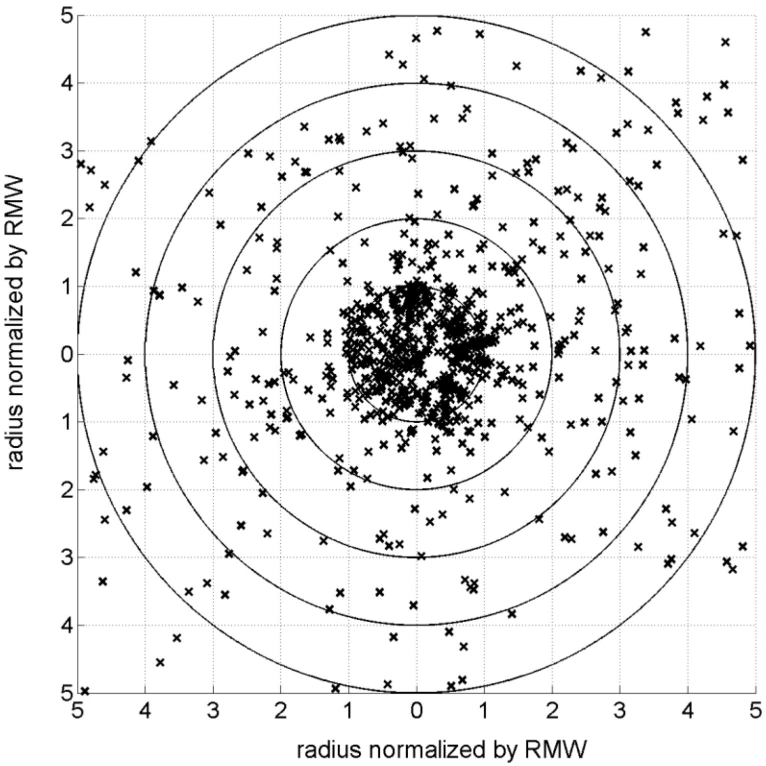


Simulated boundary layer is too deep compared to observations!

Compositing Dropsonde data

Zhang, Rogers, Nolan and Marks, 2011 MWR

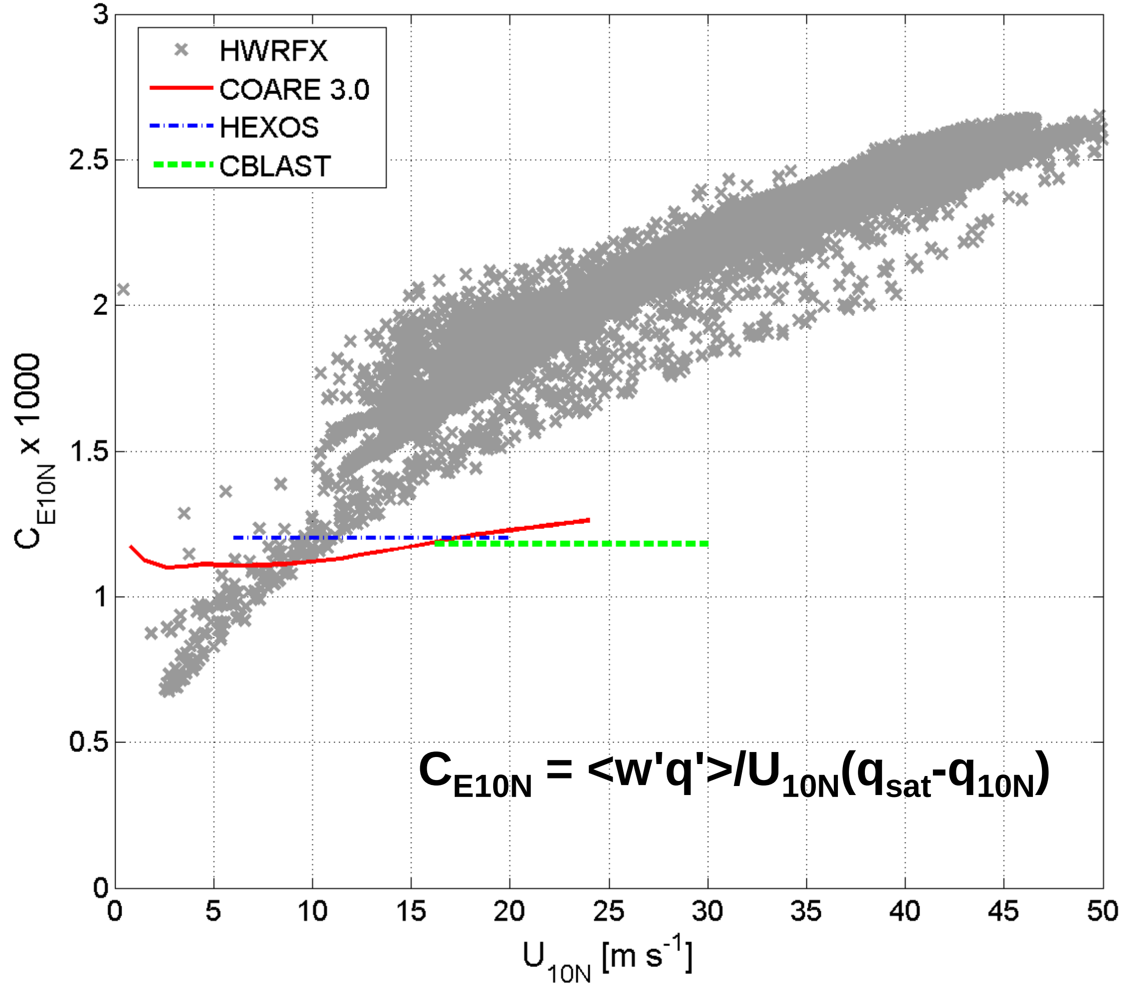




A total of 2231 dropsonde data from 13 hurricanes have been analyzed, and 794 of them are used in the final analysis.

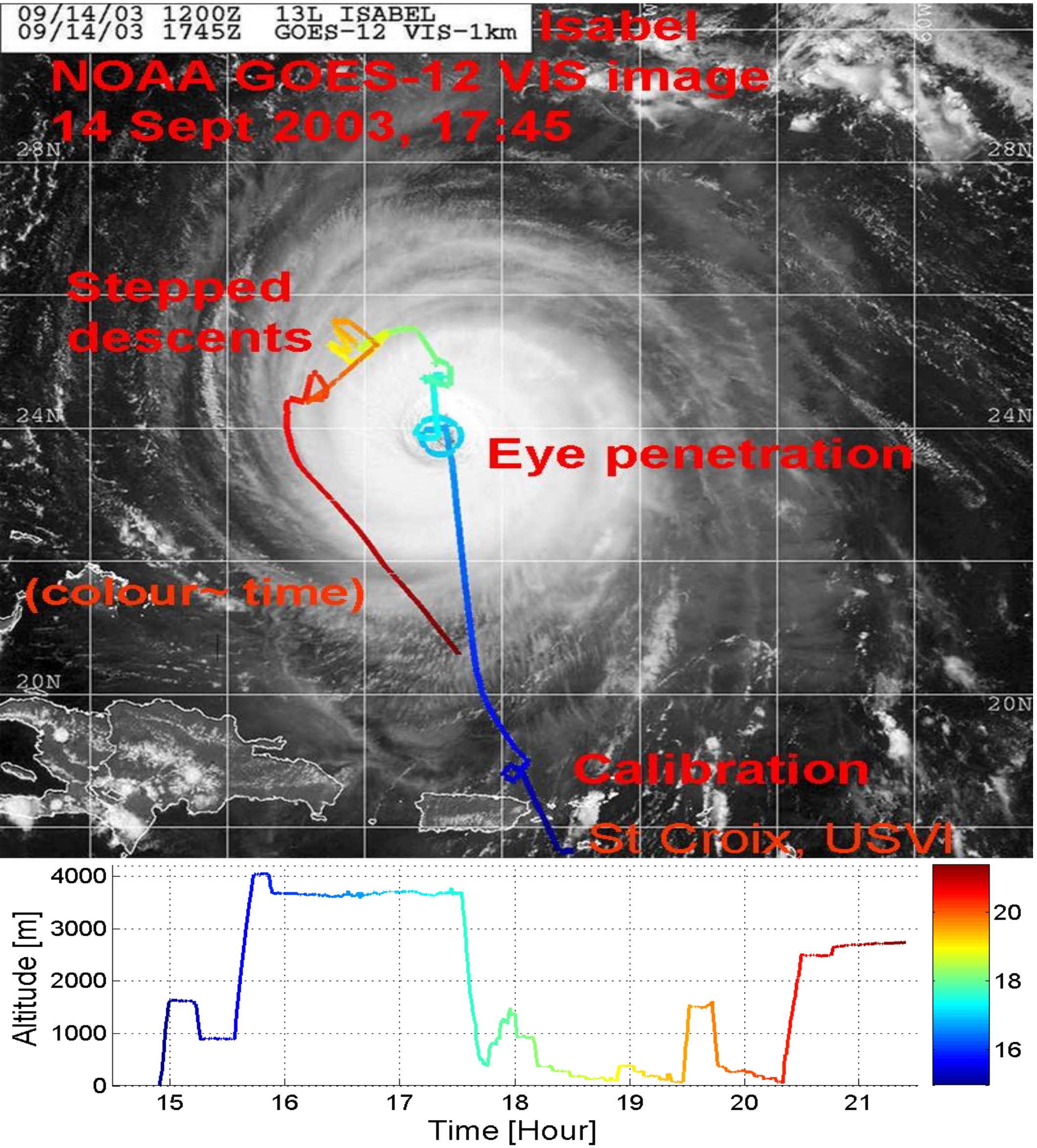
Identify deficiency of the surface layer and boundary layer schemes

Why is the simulated surface layer so warm and moist?



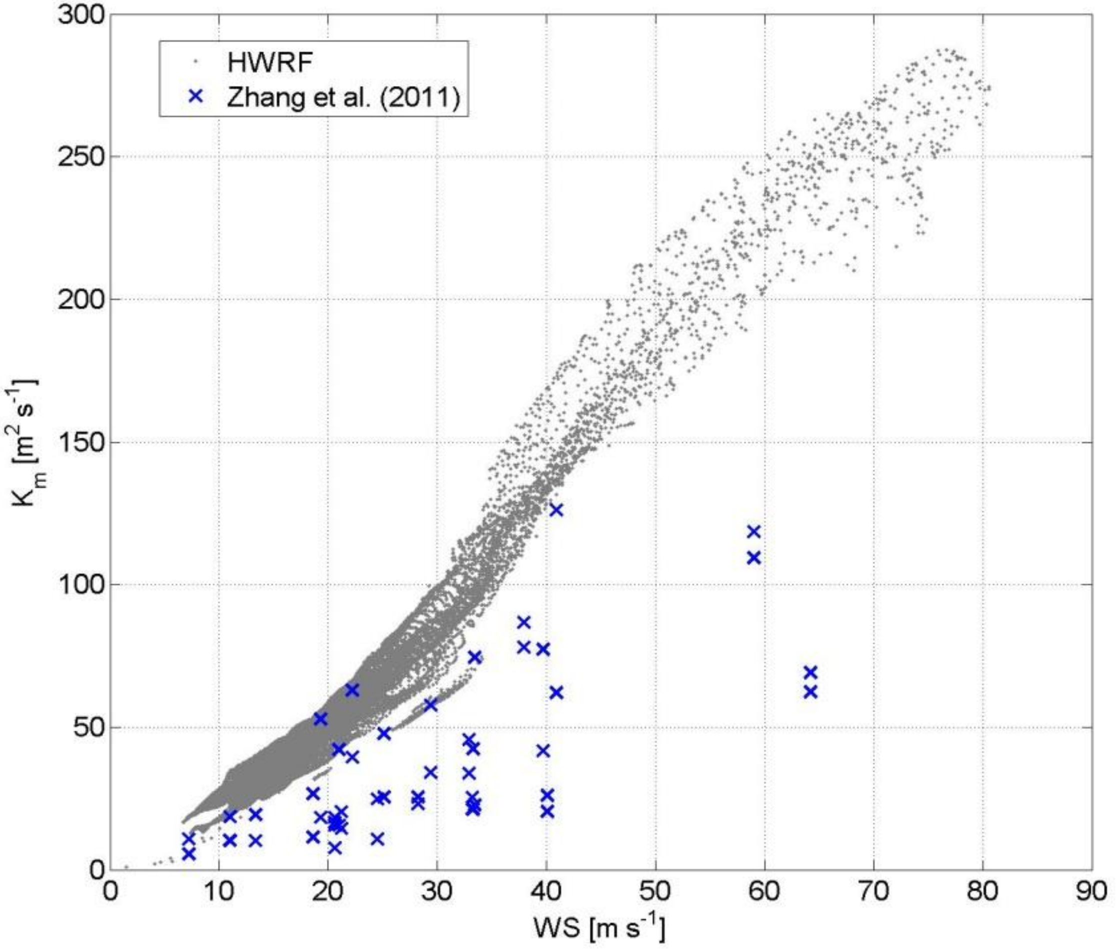
Feedback to Young Kwon and Bob Tuleya when they visited HRD in 2010

The Coupled Boundary Layer Air-sea Transfer Experiment (CBLAST)



Black et al. 2007 BAMS
Drennan et al. 2007 JAS
French et al. 2007 JAS
Zhang et al. 2008 GRL
Zhang et al. 2009 JAS
Zhang 2010 a,b QJ, JAS

Why is the simulated boundary layer so deep?



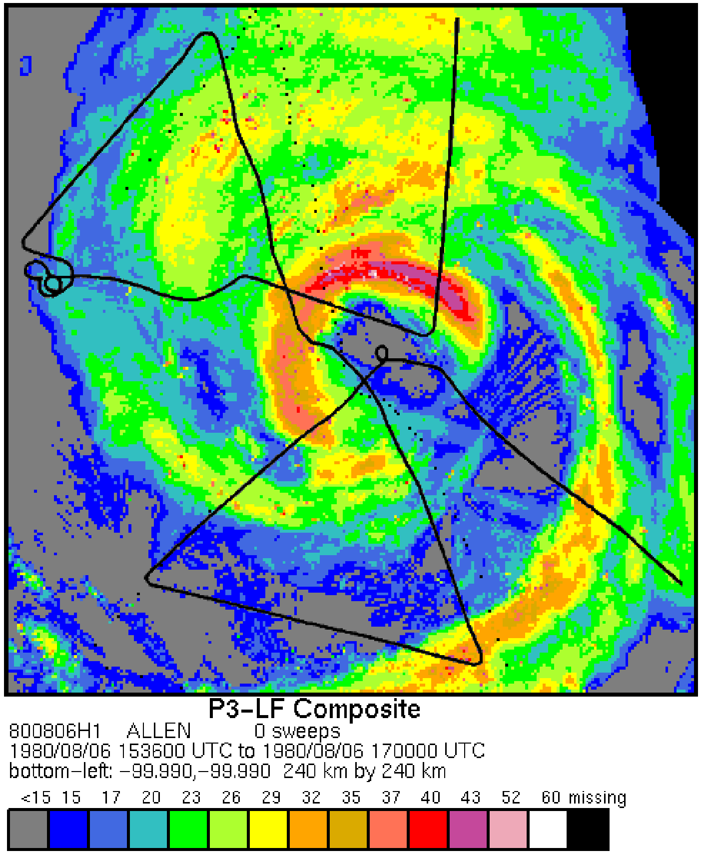
Working with Gopal and Frank to identify the problem

MRF type PBL schemes are too diffusive!

Data

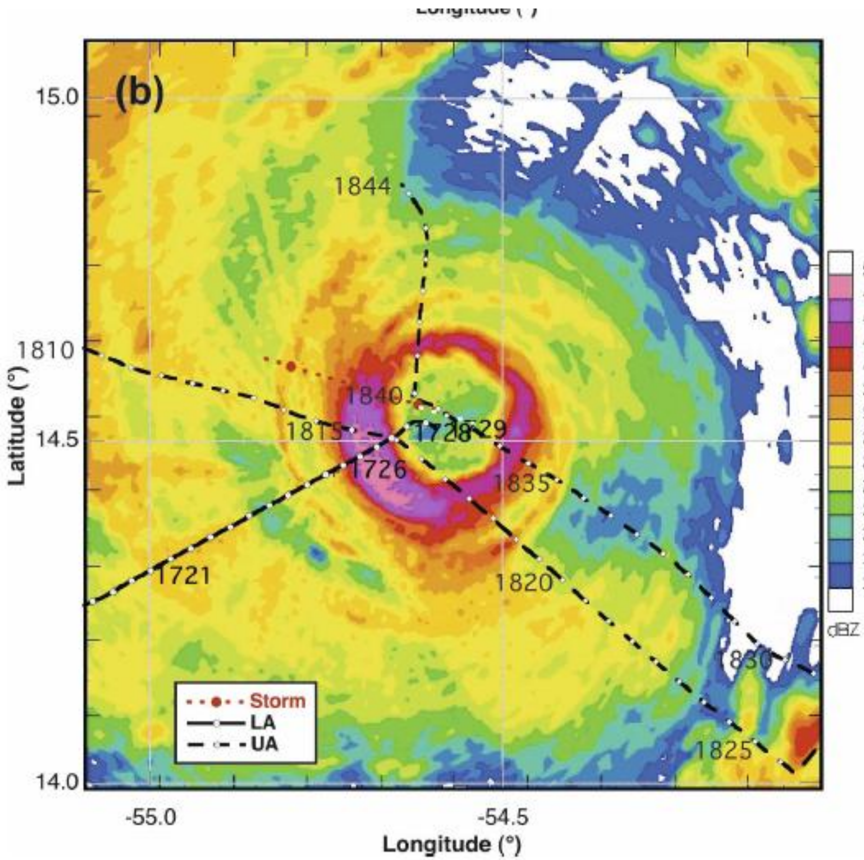
We use the flight-level data that were collected using the low-level eyewall penetrations of Hurricanes Allen (1980), Hugo (1989) and David (1979).

Allen, Aug. 6, 1980



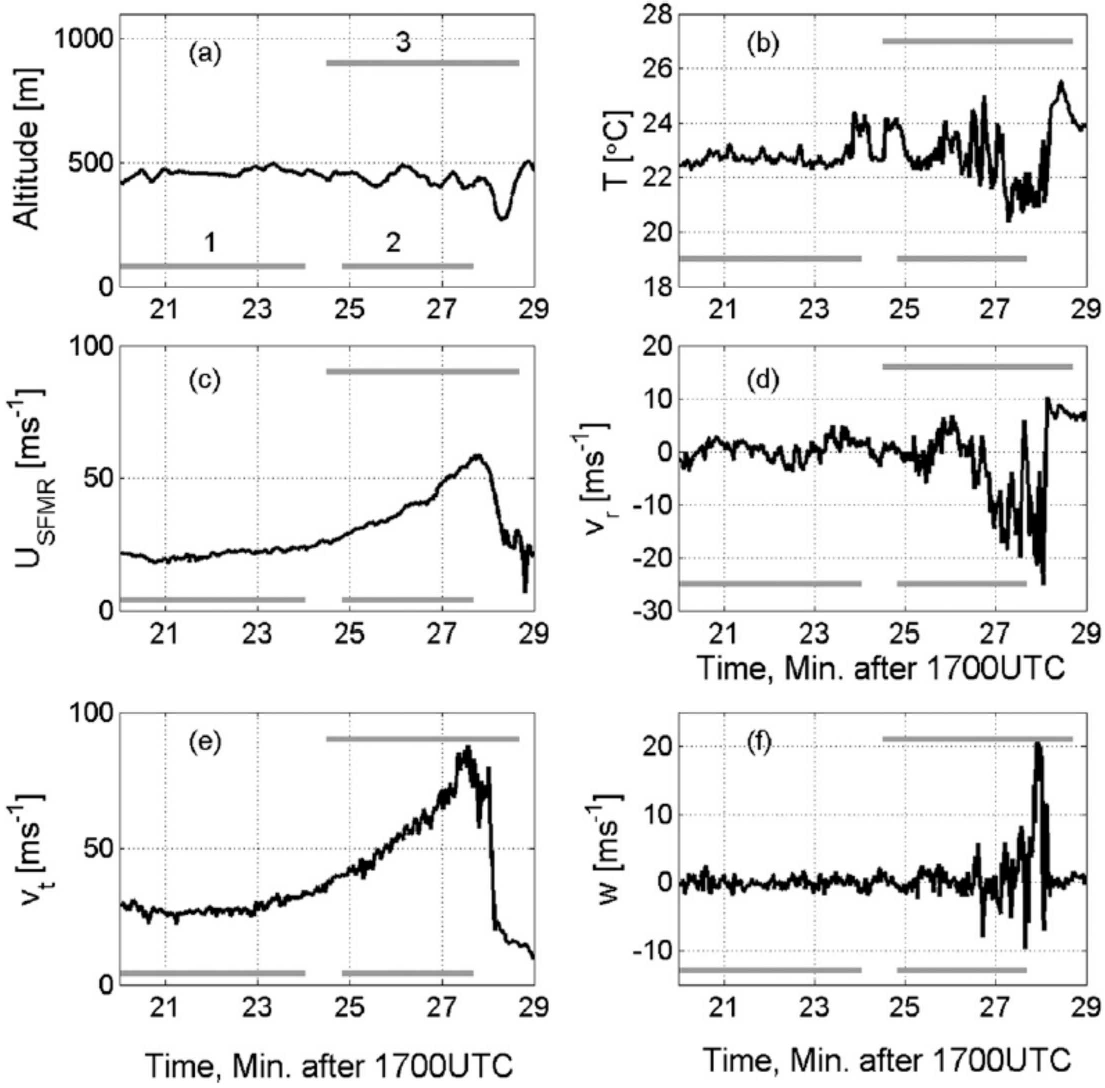
(Marks 1985 MRW)

Hugo, Aug. 15, 1989



(Marks et al. 2008 MWR)

Hurricane Hugo flight



Run # 3 includes Eyewall Vorticity Maxima (EVM)

Methodology

1. Vertical and horizontal momentum fluxes:

$$\hat{\tau} = \rho(-\overline{w'v_t'}\,\hat{i} - \overline{w'v_r'}\,\hat{j}) \quad \text{and} \quad F_h = -\rho(\overline{v_t'v_r'})$$

2. Turbulent kinetic energy: $e = \frac{1}{2}(\overline{v_t'^2} + \overline{v_r'^2} + \overline{w'^2})$

3. Vertical eddy diffusivity :

1) definition: $K = |\hat{\tau}|(\frac{\partial V}{\partial z})^{-1}$

2) Hanna (1969) method: $K_1 = cl\sigma_w \qquad l = \sigma_w^3/\varepsilon$

3) TKE-closure method: $K_2 = c_2 e^2/\varepsilon$

4. Horizontal eddy diffusivity: $K_h = |F_h|(\rho|S_h|)^{-1}, \; L_h = (K_h D_h^{-1})^{1/2}$

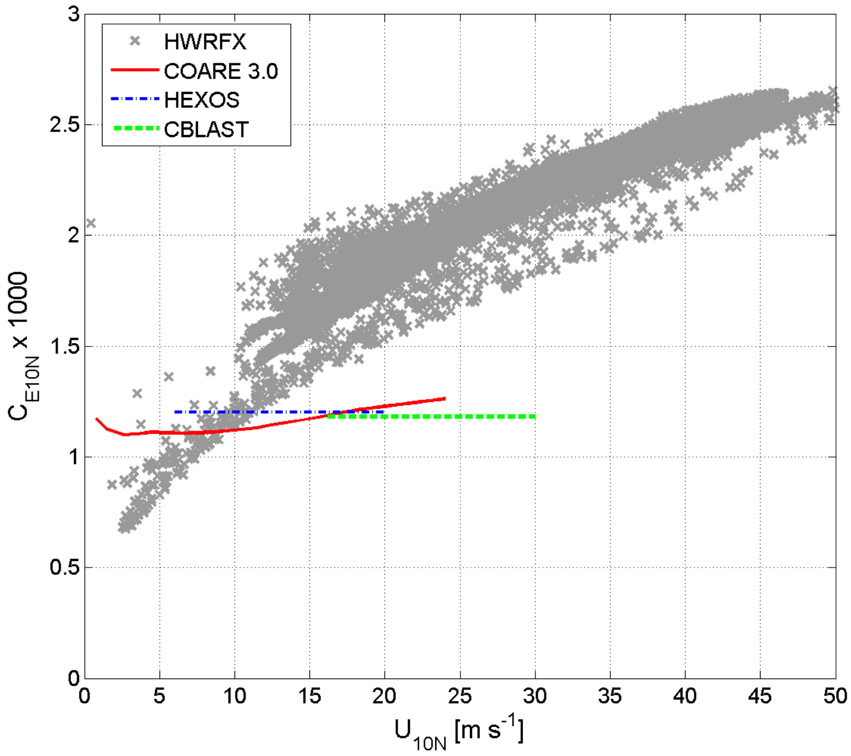
$$F_h = \rho K_h S_h \qquad S_h = (\frac{\partial v}{\partial x} + \frac{\partial u}{\partial y}) \qquad S_h = (\frac{\partial v_t}{\partial r} - \frac{v_t}{r})\cos 2\lambda + (\frac{\partial v_r}{\partial r} - \frac{v_r}{r})\sin 2\lambda$$

$$D_h^2 = (\frac{\partial v}{\partial x} + \frac{\partial u}{\partial y})^2 + (\frac{\partial u}{\partial x} - \frac{\partial v}{\partial y})^2 \qquad D_h^2 = 2(\frac{\partial v_r}{\partial r})^2 + 2(\frac{v_r}{r})^2 + (\frac{\partial v_t}{\partial r} - \frac{v_t}{r})^2$$

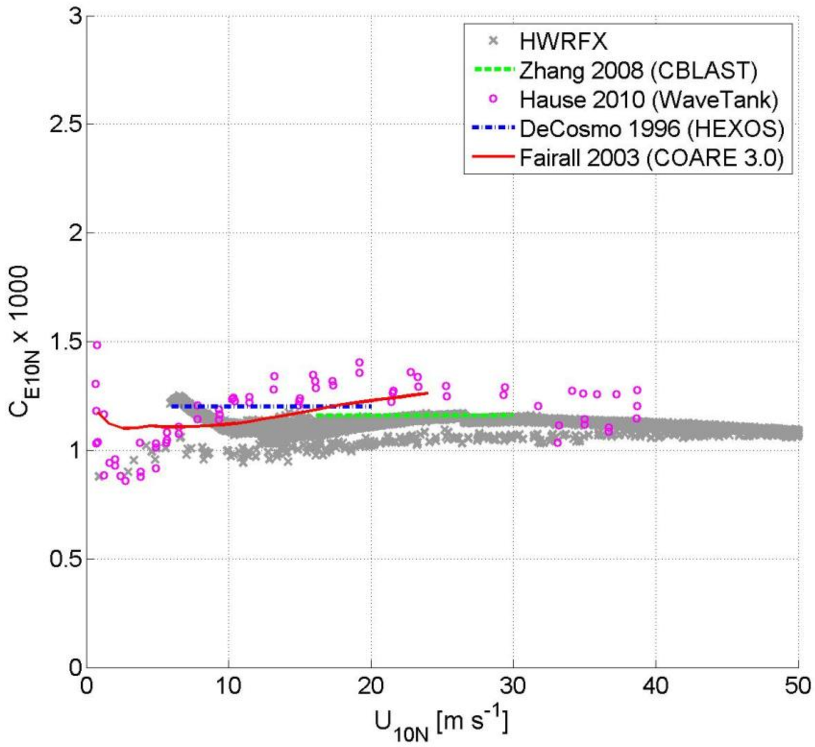
Work with model developers to improve model physics based on observations

Implementation of observation-based physics in hurricane models

Pre 2010 HWRF



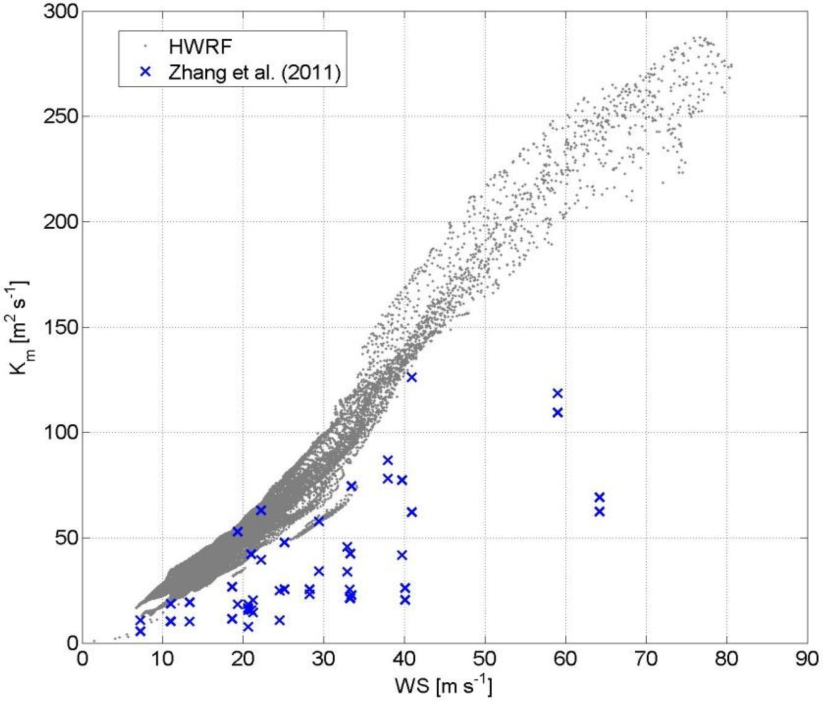
2010 HWRF and V3.2



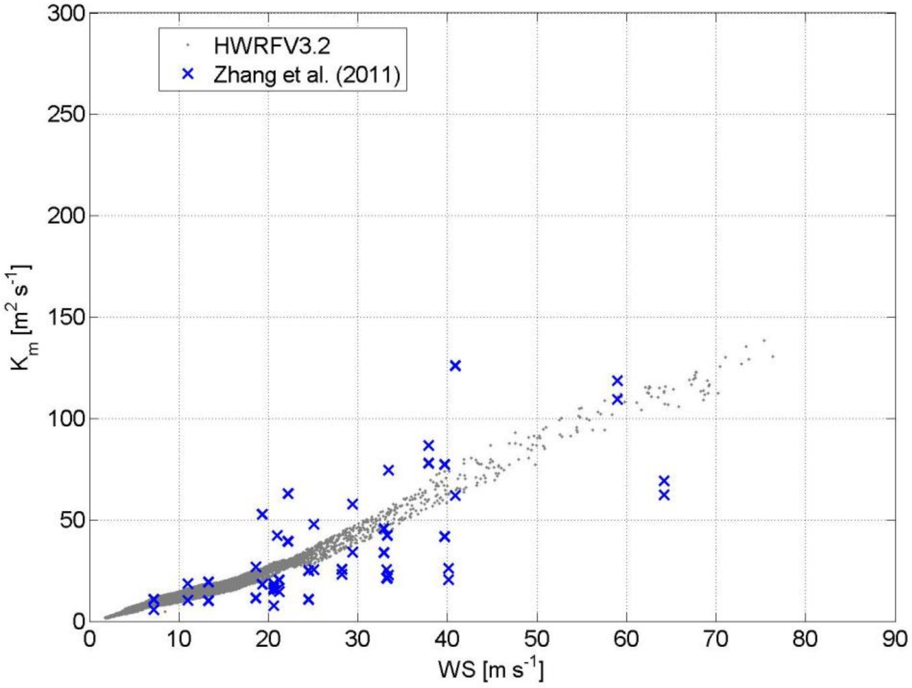
Thanks to Young Kwon and Bob Tuleya who modified the surface layer scheme code in HWRF to be consistent with observations!

Use observations to improve PBL physics in operational hurricane models

Before modification (operational HWRF)



After modification (HWRF 2012)



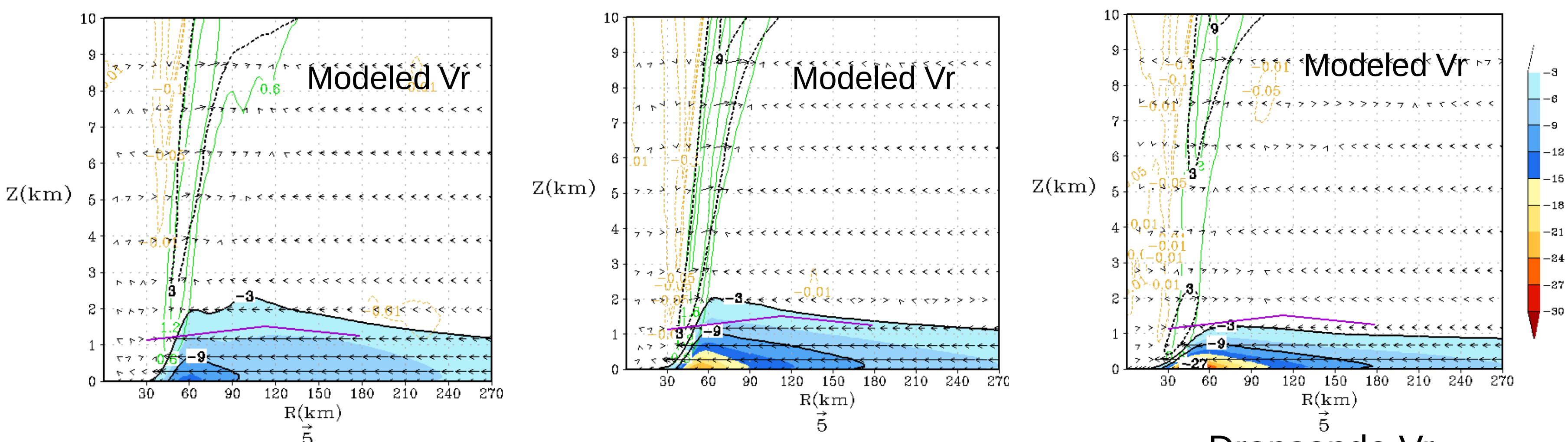
Thanks to Gopal who modified the GFS boundary layer scheme code to lower Km and match with observations!

Impacts of the modified physics on the simulated storm structure and intensity forecast

Sensitivity of axisymmetric radial wind to vertical diffusivity

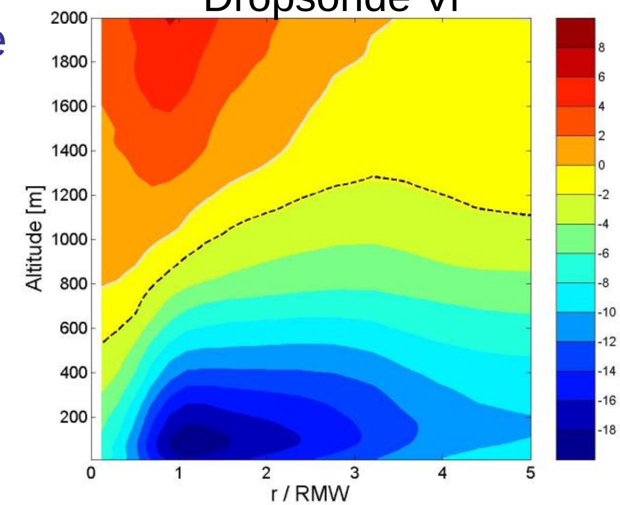
(Gopalakrishnan et al. 2012 JAS, in submission)

Original Km in HWRF | Km / 2 | Km / 4

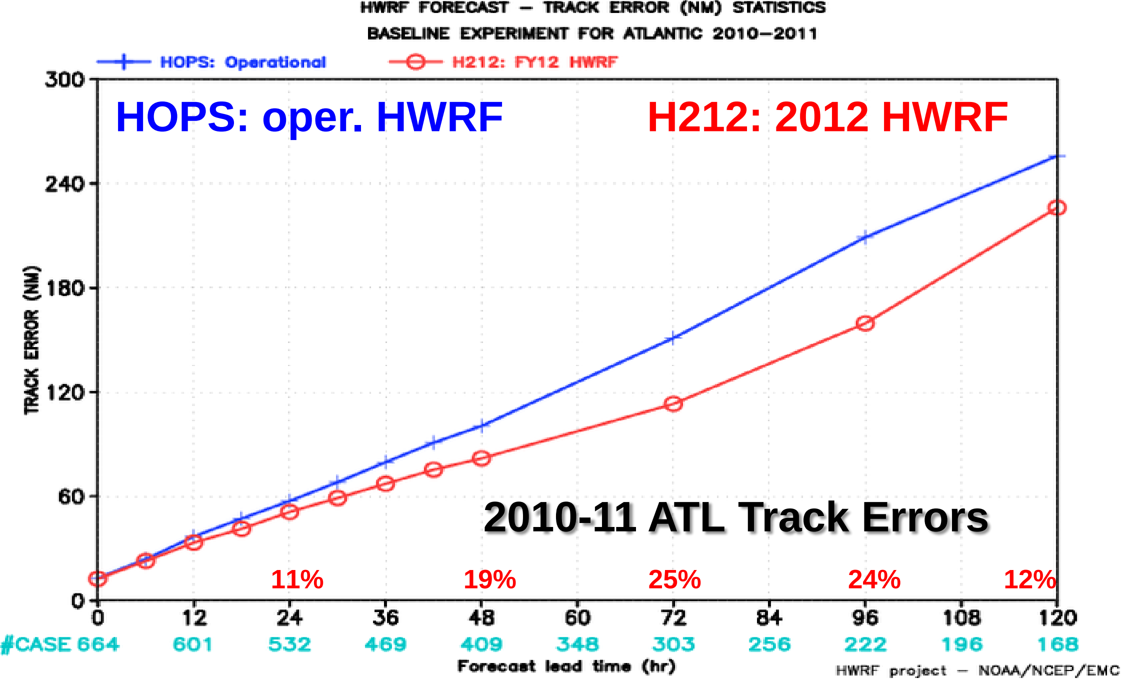


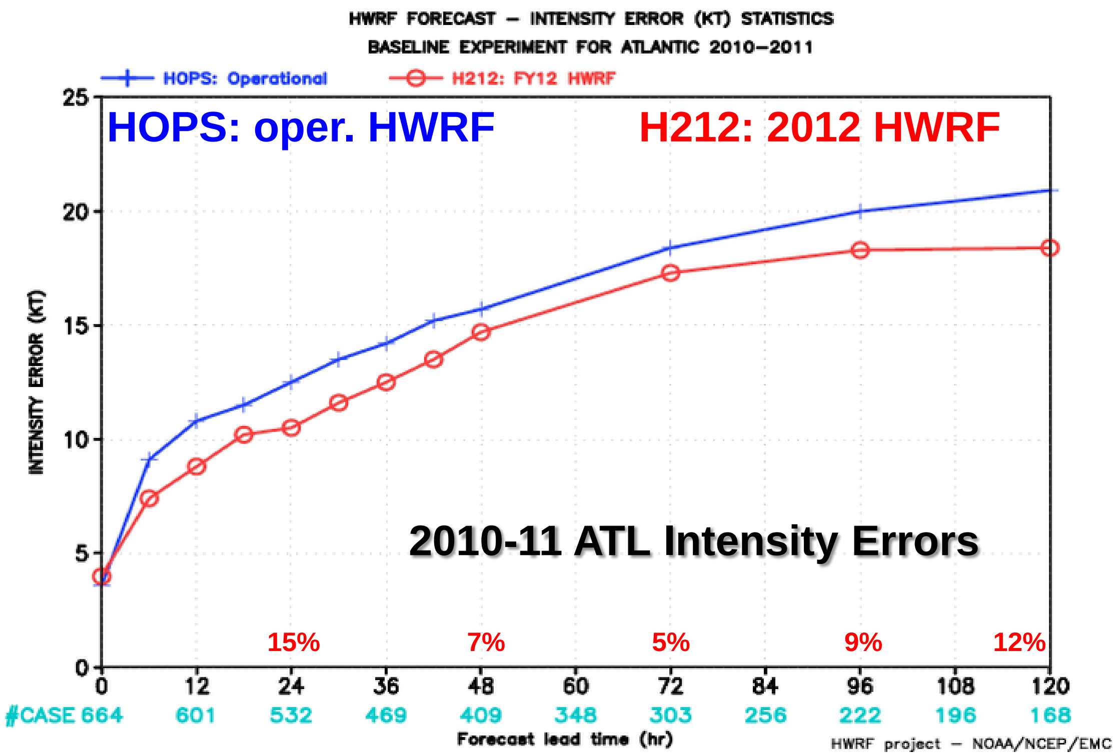
• depth of inflow layer more consistent with dropsonde composites
• peak radial inflow stronger with more accurate Km
• more prevalent role of BL dynamics in spin up process

Dropsonde Vr



The purple line is the inflow layer depth from the composite analysis using hundreds of dropsonde data (Zhang et al. 2011b MWR, on the characteristic height scales of the hurricane boundary layer).





EMC verification of the 2012 version HWRF model with new surface layer and boundary layer physics and high horizontal resolution (3km)

87% of total retrospective runs from 2010-2011 seasons show 10-25% reduction in track errors and 5-15% reduction in intensity errors

37 Storms

2010: Alex, Two, Bonnie, Colin, Five, Danielle, Earl, Fiona, Gaston, Hermine, Igor, Karl, Matthew, Nicole, Otto, Paul Richard, Shary, Tomas

2011: Arlene, Bret, Cindy, Don, Emily, Franklin, Gert, Harvey, Irene, Ten, Lee, Katia, Maria, Nate, Philippe, Rina, Sean

Slide Courtesy to Vijay Tallapradada (HWRF team leader)

Summary

1. HRD's aircraft observation data are unique for model diagnostics in terms of hurricane structure;

2. Observations also provide baseline for physics development and improvement in hurricane models;

3. Model deficiency can be identified through model diagnostics of TC structures based on observations;

4. Feedback to model developers leads to model improvements;

5. HFIP provides a bridge for model developers and observation scientists to work closely, which is promising.

Future work

1. Evaluate the surface layer and boundary layer structure in hurricane simulations with the 2012 version operational HWRF;

2. Further improve the parameterization of vertical eddy diffusivity in HWRF;

3. Evaluate the horizontal eddy diffusivity in HWRF;

4. Evaluate the vortex-scale and convective scale structures in HWRF simulations.

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NOAA/OMAO
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