Advances and Challenges in Tropical Cyclone Structure and Intensity Predictions: Convection

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NOAA HURRICANE FORECAST IMPROVEMENT PROJECT

Who are we ?

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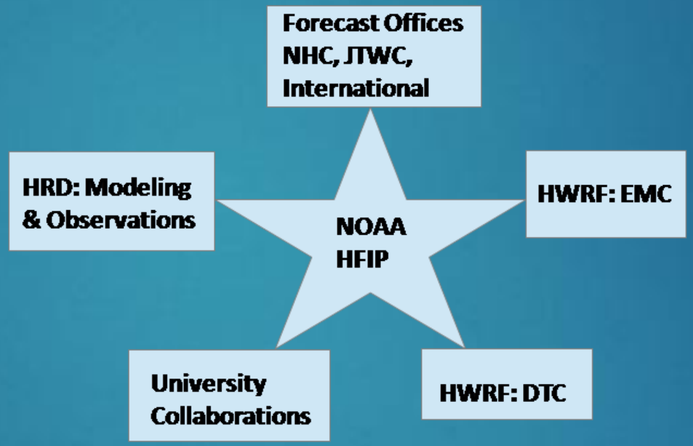

DTC/NCAR

code support and management

Partners

JPL/NASA, Pasadena

Purdue University

IIT.BBSR & IMD/MOES, India

Indo US forum for S&T

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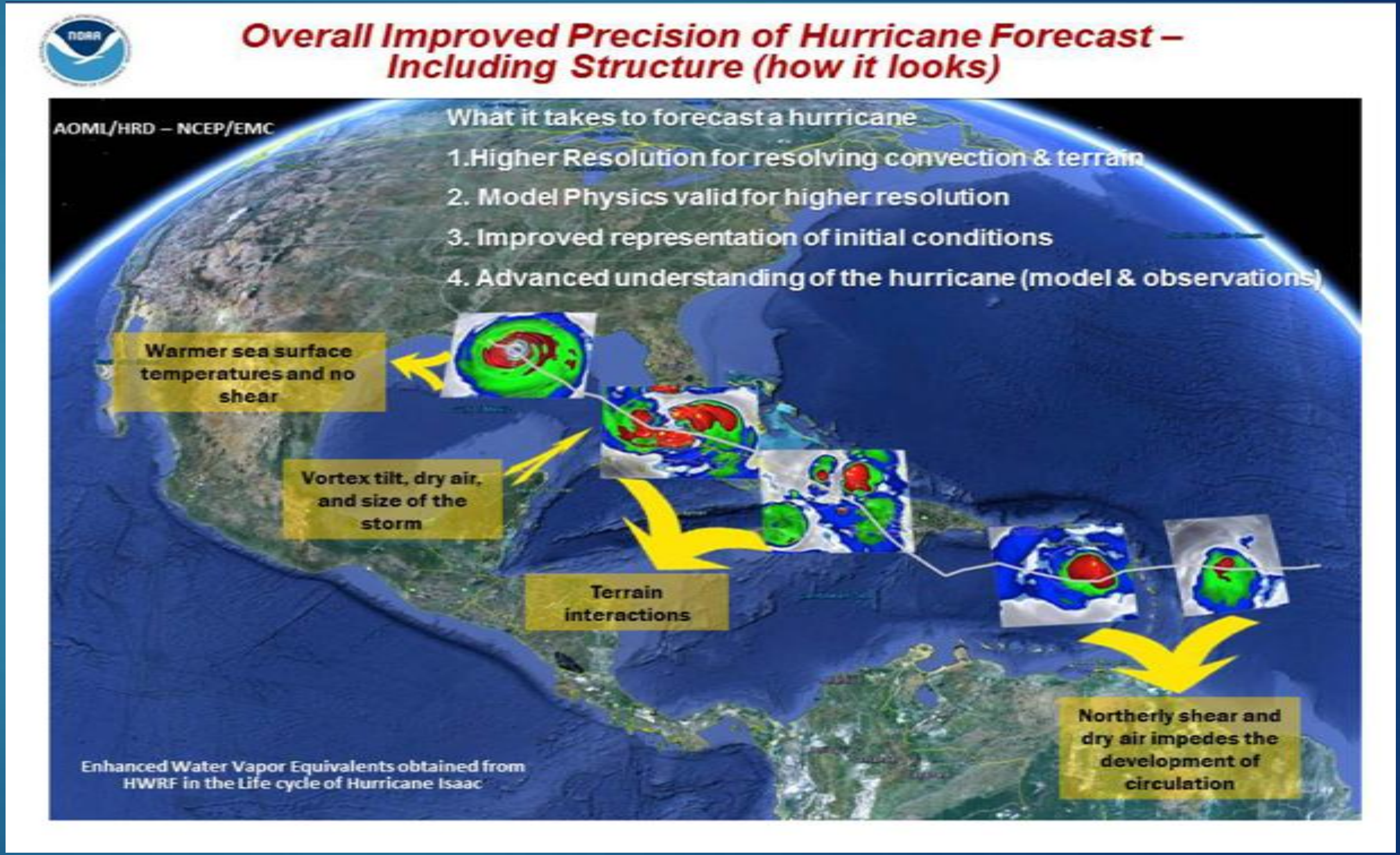
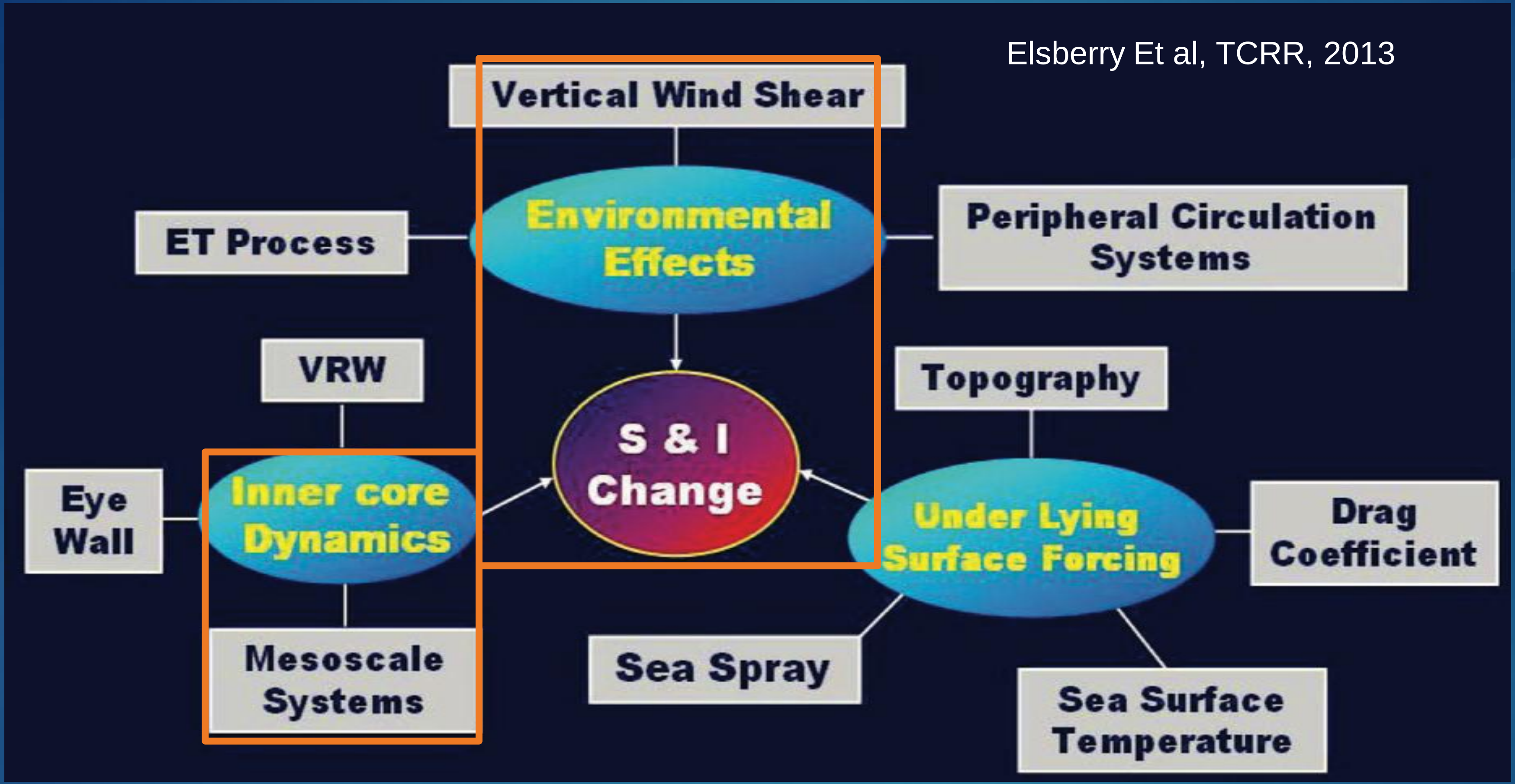
NOAA HURRICANE FORECAST IMPROVEMENT PROJECT

HFIP Motivation
Decrease Evacuations

- Increase forecast accuracy,
  - especially at longer lead times
  - especially during periods of rapid intensity changes;
- Raise confidence levels for all forecast periods

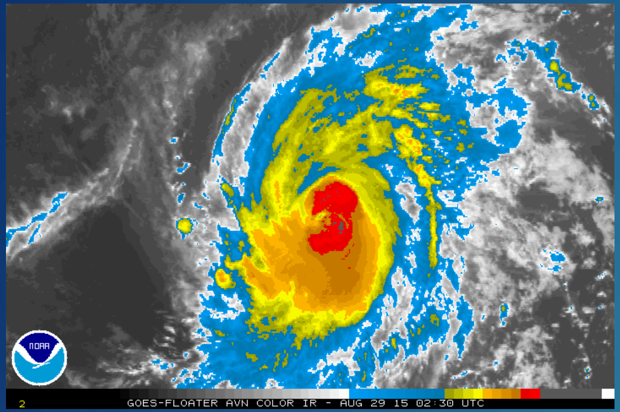


Challenges: Factors Influencing TC Intensification



Factors that influence influence intensity changes interact in a non-linear manner. HWRF may be for conducting control experiments and for understanding modeled intensification process [Gopal et al, 2011 (MWR), Bao et al., 2012 (MWR), Gopal et al, 2013 (MWR), Kieu et al, 2014 (GRL), Halliwell et al, 2014 (MWR), D.-L. Zhang et al. ,2014 (MWR); Zhu et al, 2015 (GRL)]

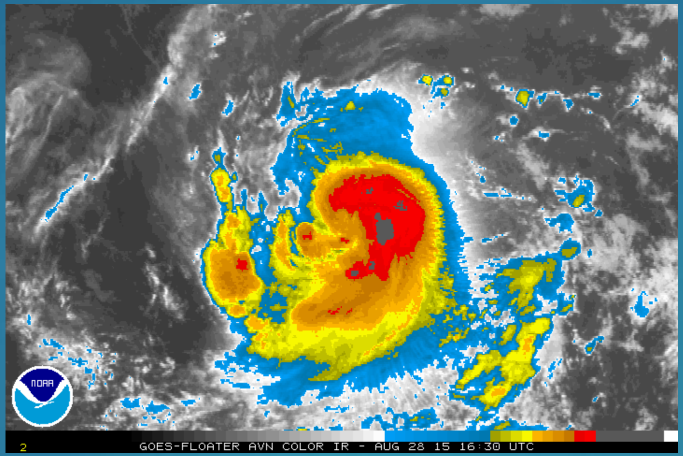
Forecasters Challenge: Shear & Convection



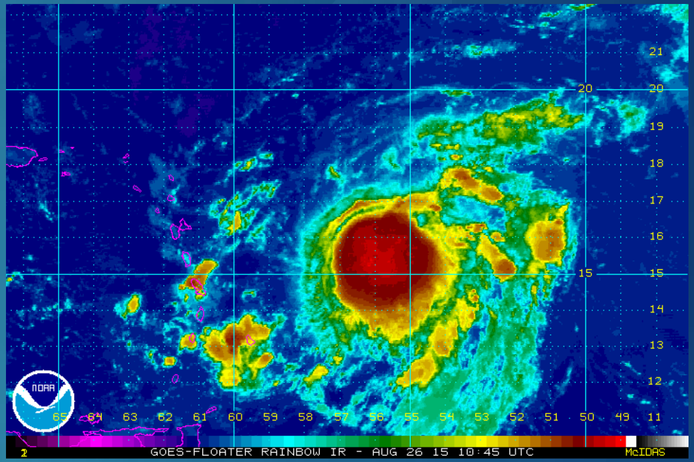
Weak shear/ near-symmetric intensification

Intensification Pathway 1: Heating → Pressure Adjustments → Secondary Circulation → Convergence

Intensification Pathway 2: Symmetric vertical plumes → Warm Core → Pressure drop --→ Secondary circulation



Strong shear/ Assymetic intensification



Large shear/ Dissipating vortex

Gopalakrishnan, S. G., F. Marks, X. Zhang, J.-W. Bao, K.-S. Yeh, and R. Atlas, 2011: The experimental HWRF system: A study on the influence of horizontal resolution on the structure and in- tensity changes in tropical cyclones using an idealized framework. Mon. Wea. Rev., 139, 1762–1784, doi:10.1175/2010MWR3535.1.

Gopalakrishnan, S. G., F.Marks, J. A. Zhang, X. Zhang, J.-W. Bao, and V. Tallapragada, 2013: 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., 70, 524–541, doi:10.1175/ JAS-D-11-0340.1.

Convection in sheared storms: Observations

SEPTEMBER 2016 ZAWISLAK ET AL. 3341

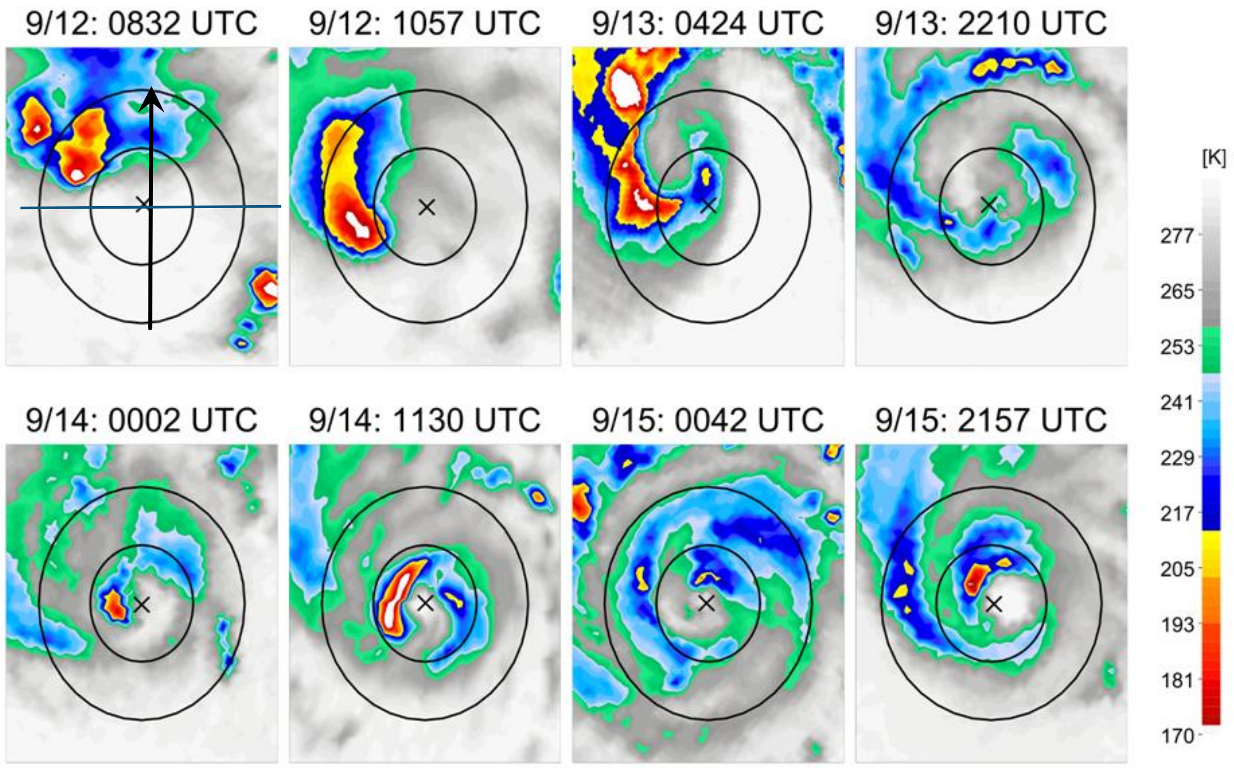


FIG. 6. The 85–91-GHz PCT from a selection of passive microwave overpasses rotated with respect to the shear-relative azimuth (shear heading is pointing up, or the 0° azimuth) during the intensification period of Edouard. Radial distances are 50 and 100 km from the interpolated best track centers (marked by "×").

Zawislak, J., H. Jiang, G. R. Alvey III, E. J. Zipser, R. F. Rogers, J. A. Zhang, and S. N. Stevenson, 2016: Observations of the Structure and Evolution of Hurricane Edouard (2014) during Intensity Change: Part I: Relationship between the Thermodynamic Structure and Precipitation. *Monthly Weather Review,* 144, 3333–3354.

Rogers, R. F., J. A. Zhang, J. Zawislak, H. Jiang, G. R. Alvey III, E. J. Zipser, S. N. Stevenson, 2016: Observations of the Structure and Evolution of Hurricane Edouard (2014) during Intensity Change: Part II: Kinematic Structure and the Distribution of Deep Convection. *Monthly Weather Review*, 144, 3355–3376.

Feb 2015

AMERICAN METEOROLOGICAL SOCIETY

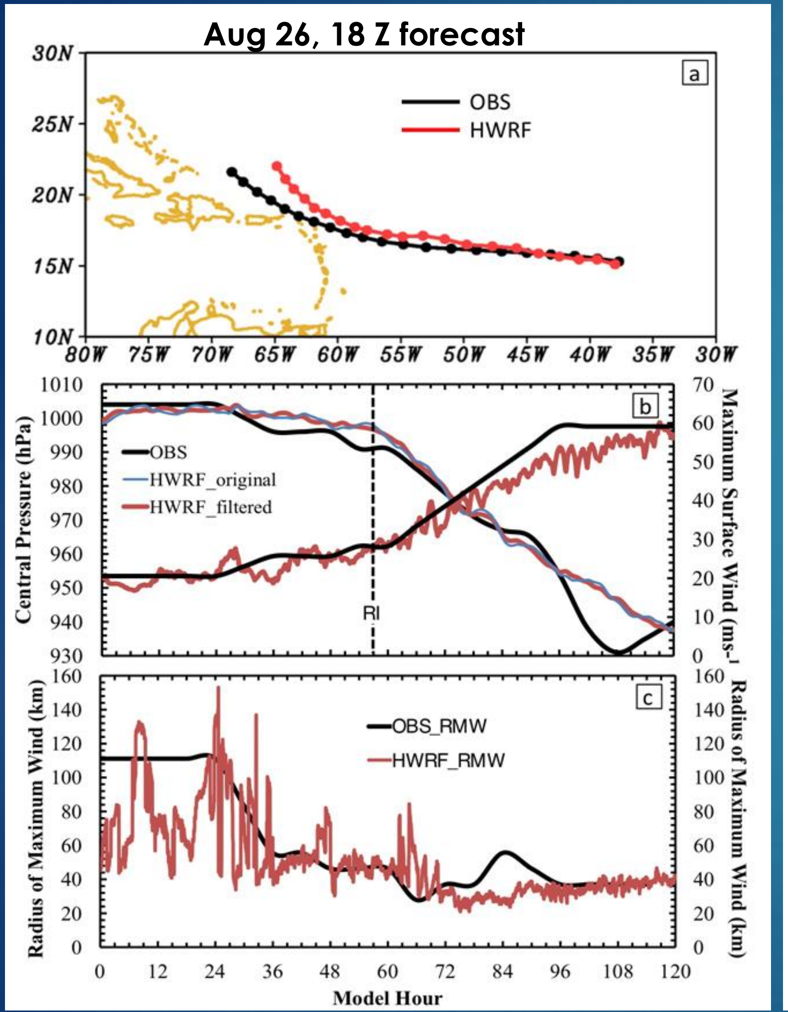
Journal of the Atmospheric Sciences

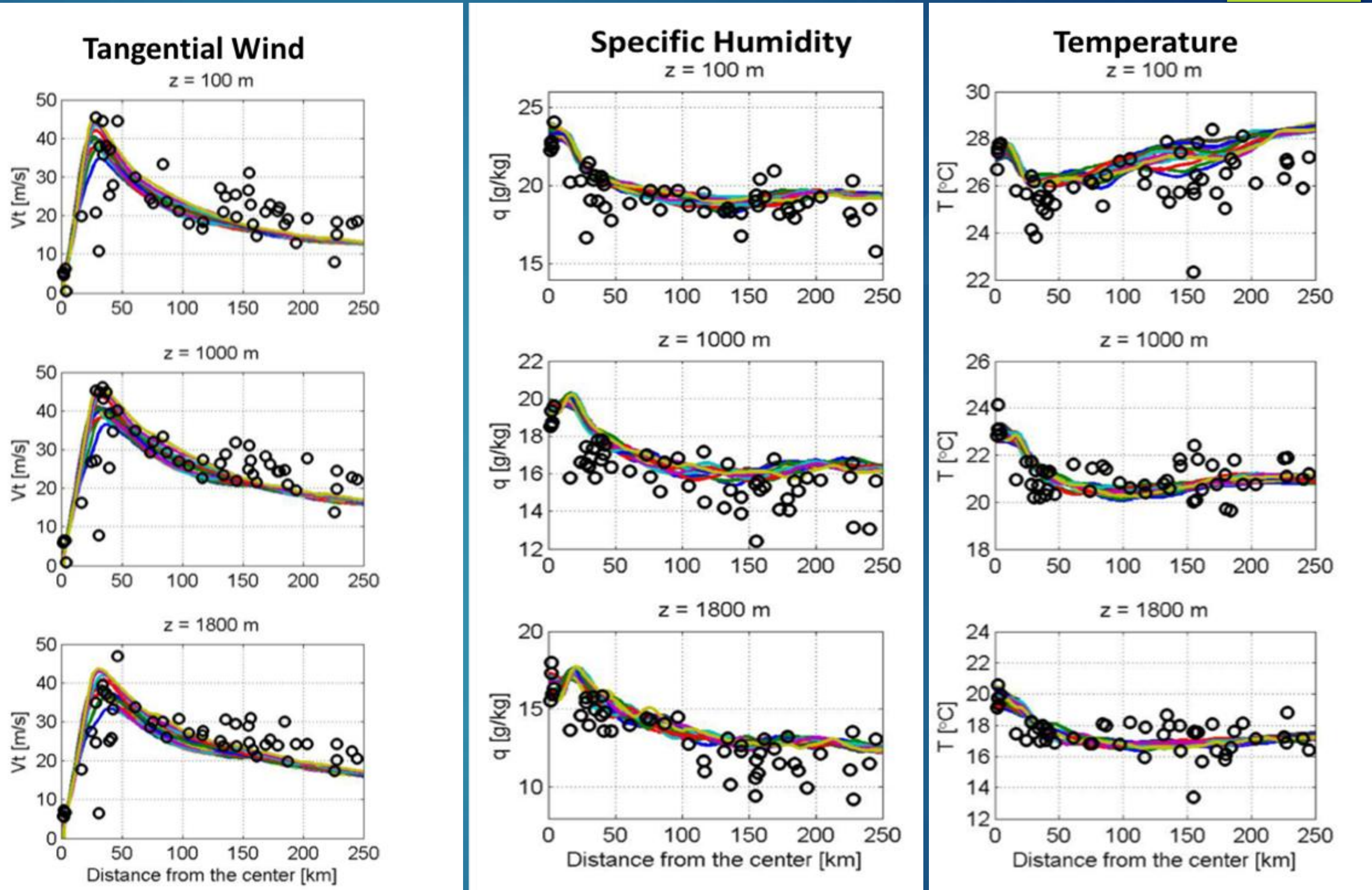
A Study on the Asymmetric Rapid Intensification of Hurricane Earl (2010) using the HWRF System

Hua Chen and Sundararaman G. Gopalakrishnan

For the first time NOAA’s HWRF hurricane track and intensity forecast model was used to help understand the complex processes of asymmetric Rapid Intensification (RI) in tropical cyclones. An important key to understanding the RI process was the availability of detailed aircraft observations in the inner core of the hurricane with which to compare the model results. The model was able to reproduce the evolution of the hurricane structure that caused the RI process similar to what was seen in the actual detailed observations. During the times and in the regions of the hurricane where detailed aircraft observations were not available, the model was able to used as a proxy to gain even more understanding of the four-dimensional intensification process.

Hurricane Earl (2010): How close are we to reality?





Credits: Jun Zhang

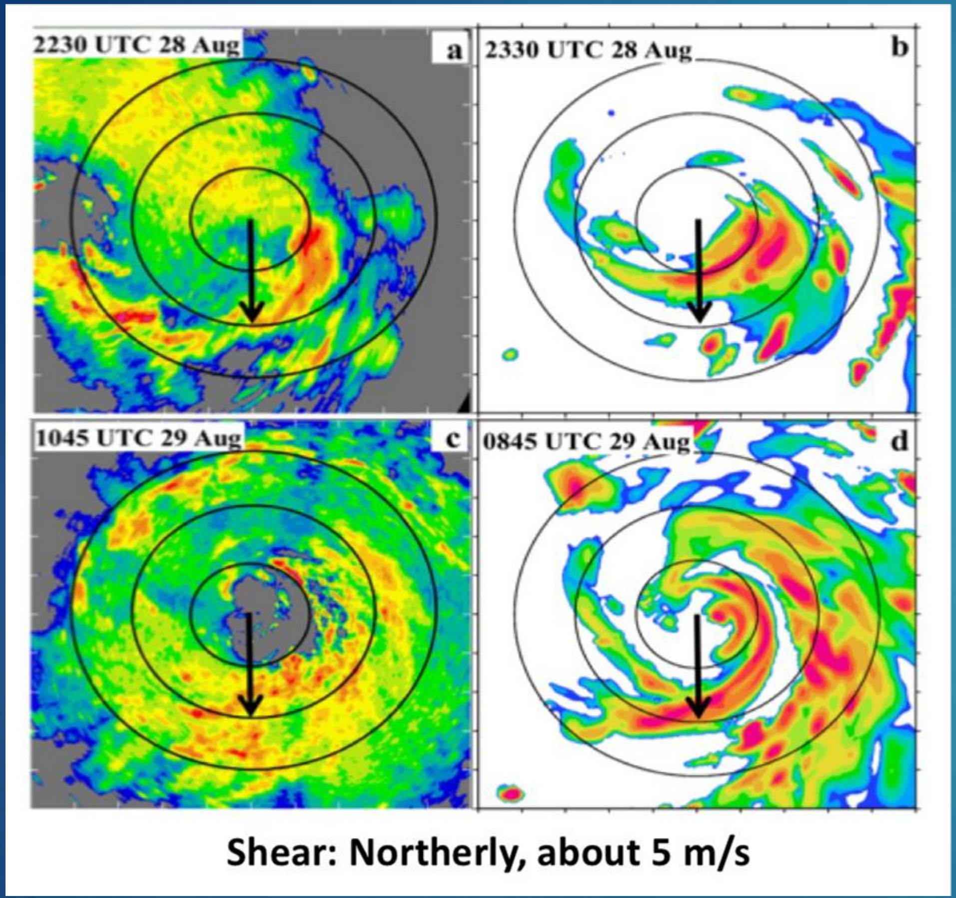
Apart from the standard verification metrics (track and peak winds), HWRF reproduced the storm structure extremely well making this an unique data set

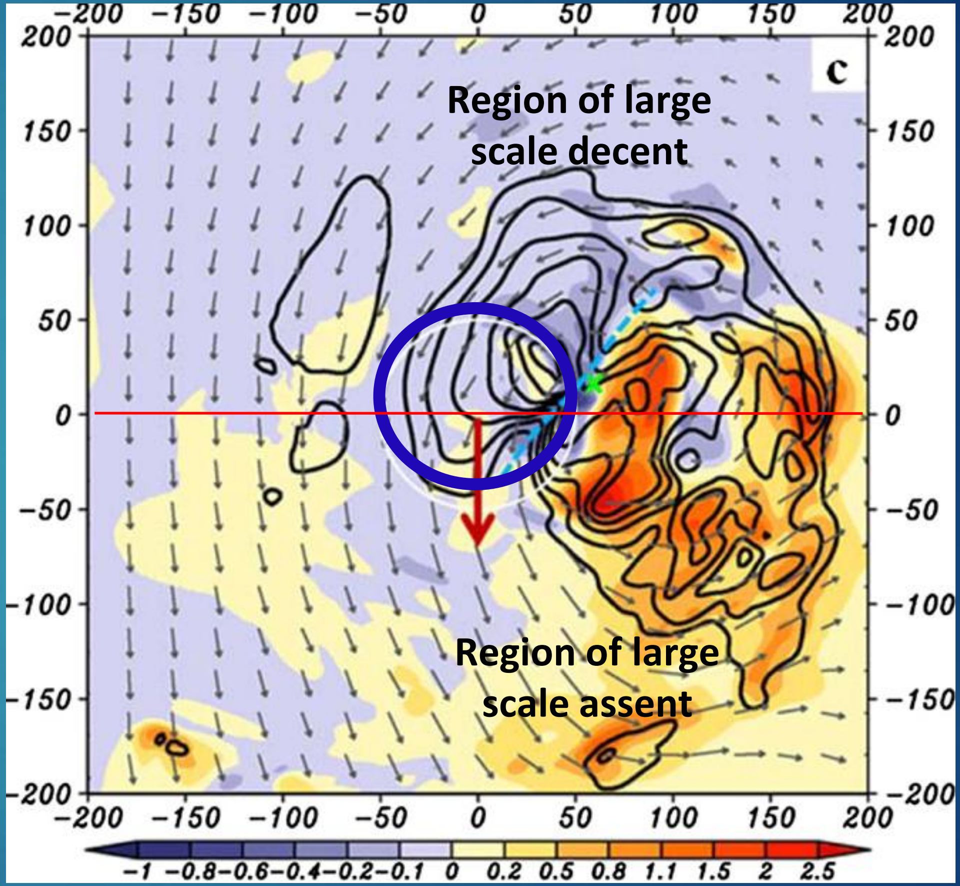
Hurricane Earl (2012): Large Scale - Vortex Interactions

P-3 Lower fuselage **HWRF simulated**

Pre-RI

RI





Persistent convection down shear left, pre-RI; Down shear left & up shear left during RI. Convection was asymmetric during RI

Horizontal advection of potential temperature perturbations associated with downdrafts/ subsiding motion in a region of large scale descent. This configuration supports intensification

Down-Shear convection: what we know ?

- HWRF model reproduces assymetric intensification process in Earl very well
- RI occurs after persistent deep convection taking place inside RMW in downshear-left quadrant;
- Horizontal advection plays an important role in developing upper level warm core when the vortex is tilted;
- Will storms always intensify as long as deep convection takes place in preferred location (downshear-left and inside RMW)?

Submission

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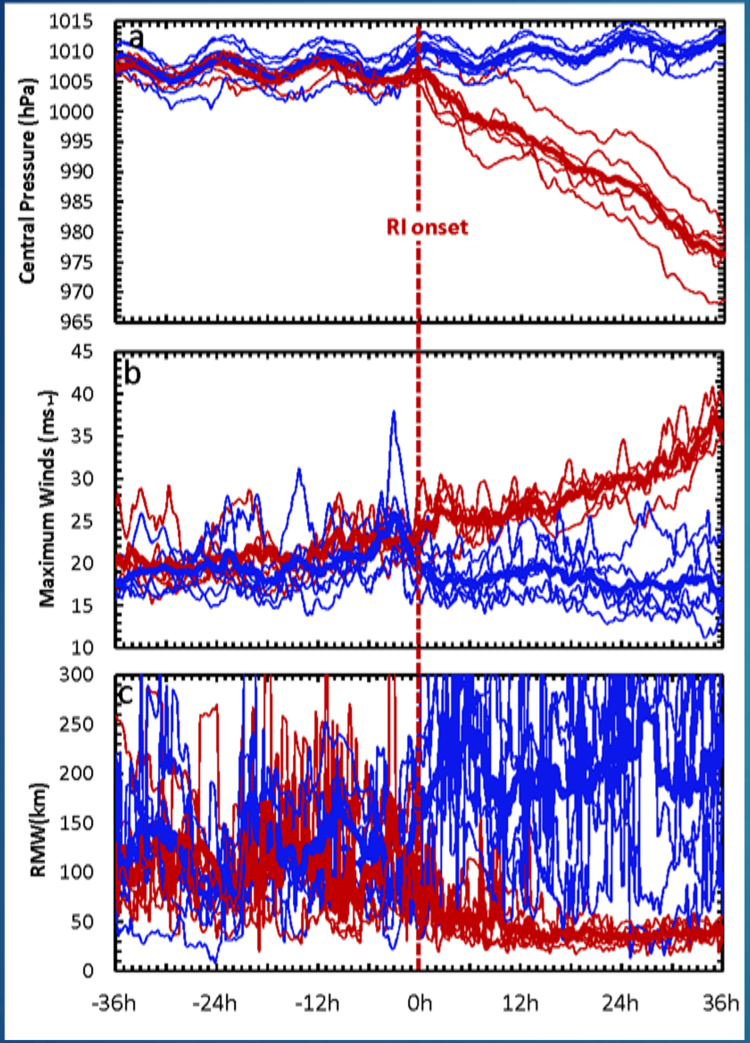
Journal of the Atmospheric Sciences

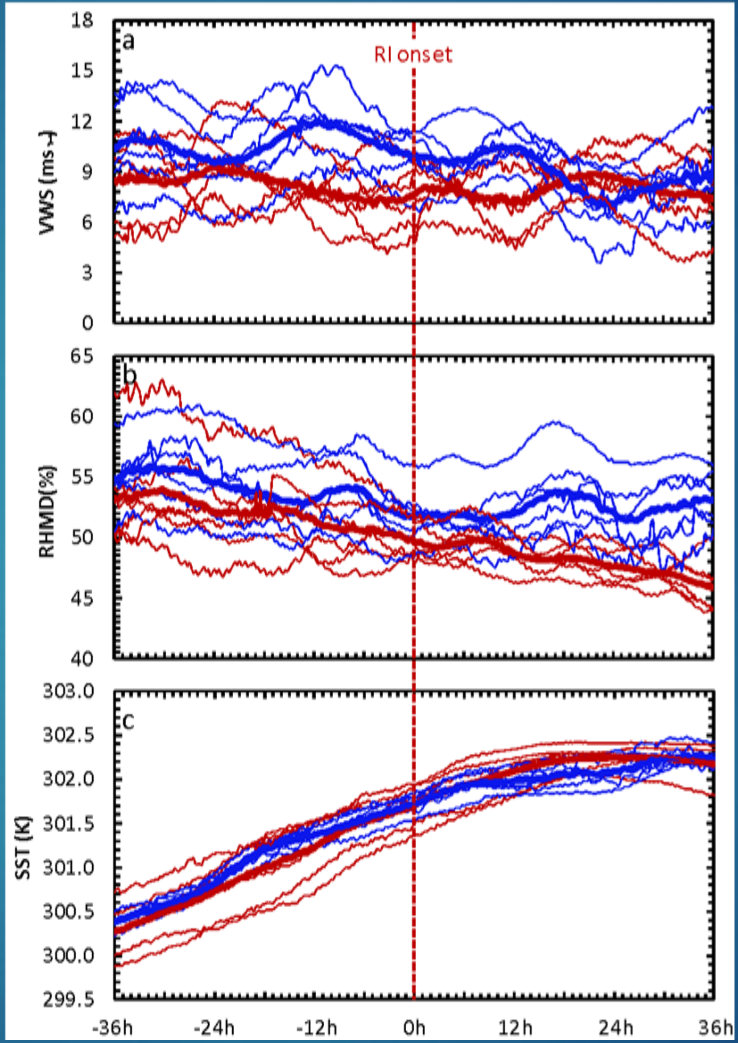
Azimuthal distribution of deep convection, environmental factors and tropical cyclone rapid intensification: A perspective from HWRF ensemble forecasts of Hurricane Edouard (2014)

Hua Chen, Sundararaman Gopalakrishnan, Jun A. Zhang, Robert F. Rogers, Zhan Zhang and Vijay Tallapragada

In this study, forecasts from the operational Hurricane Weather Research and Forecasting (HWRF) based ensemble prediction system for Hurricane Edouard (2014) are analyzed to study the differences in both the tropical cyclone inner-core structure and large-scale environment between rapidly intensifying (RI) and non-intensifying (NI) ensemble members.

Hurricane Edouard (2014): HWRF Ensembles

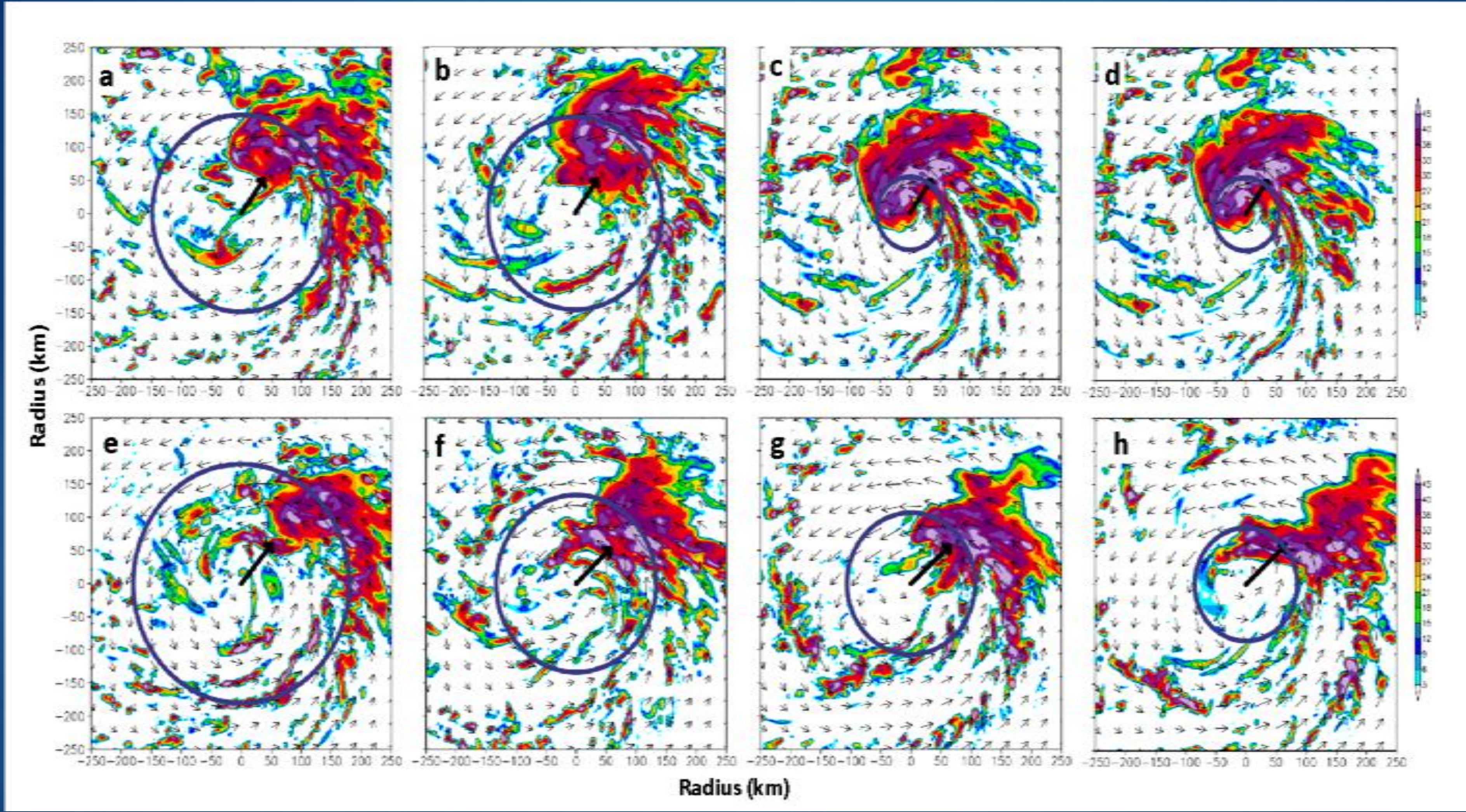




Hurricane Edouard (2014): Convective Bursts RI vs NI

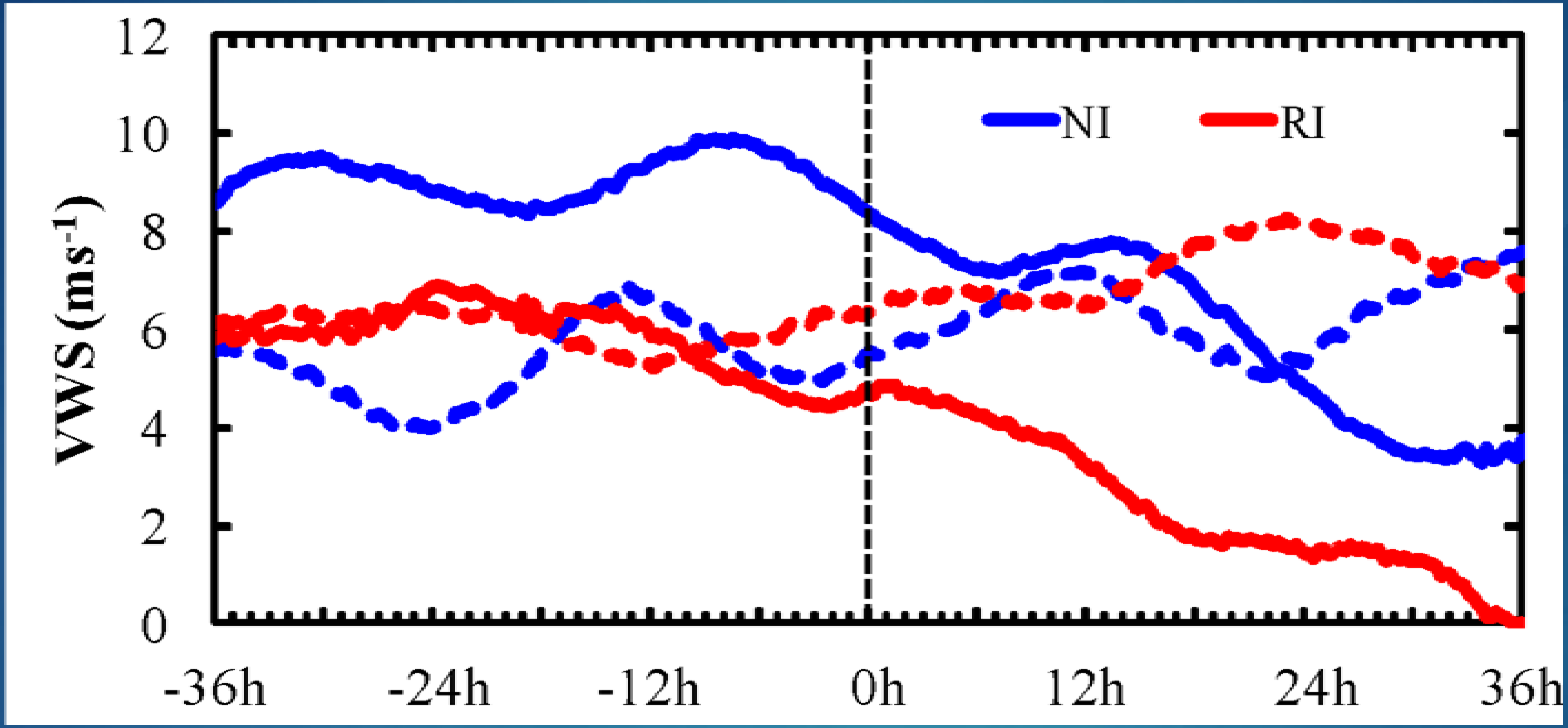
RI

NI



Deep convection did not wrap around for non-intensifiers

Hurricane Edouard (2014): Influence of large-scale



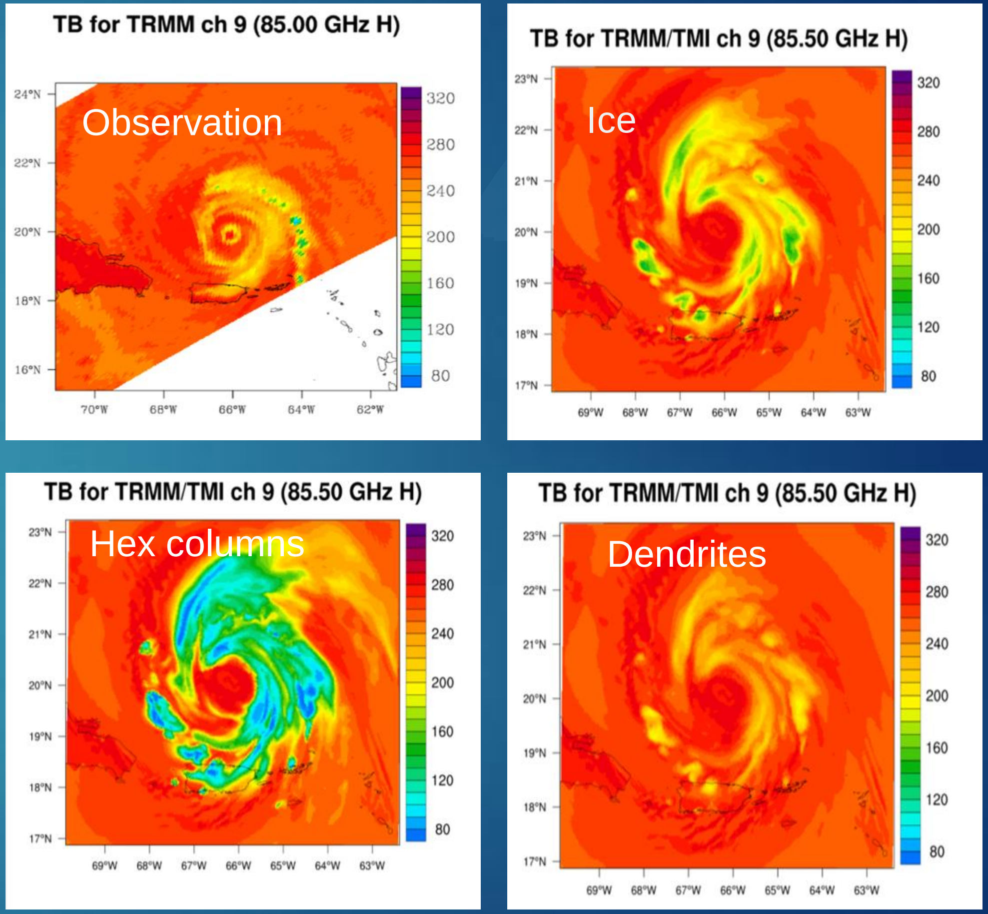
Time series of composite zonal (solid line)and meridional shear (dashed line) for RI members (red line) and NI members (blue line).

Hurricane Edouard (2014): Conclusions

- Whether the deep convection can make its way to the upshear-left quadrant is the key process to determining if the storm is going to intensify or not.
- Flow field in the left-shear hemisphere becomes important since it will either block or help the cyclonic downstream propagation of the deep convection into the upshear-left quadrant
- Environmental moisture in down-shear right quadrant, where deep convection originates, is more important.

Towards Guidance on Guidance: Convection

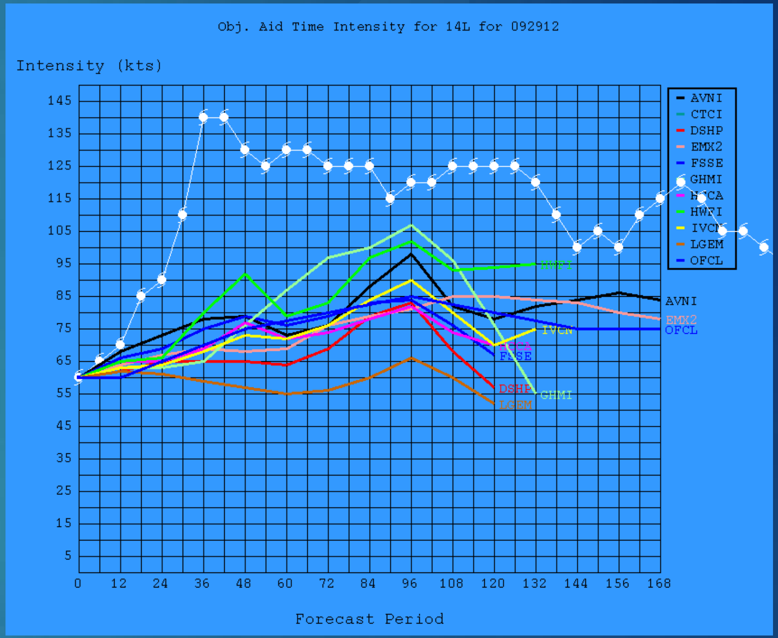
- Relating Satellite data to model for large scale as well as inner core/convective structure is critical. We are not there as yet!
- Forward models especially in the microwave region needs improvements because modeled microphysical processes is not what you see in reality (size distribution)
- Combination of spectral (bin) microphysics and some flight-level observations to improve existing model microphysics ?



Impact of size distribution on brightness temperature.
Credits to the group at NASA JPL!

Challenges in TC RI/RW prediction

- It is often too late before an intensity forecast failures is realized
- Multi-scale problem (inner-core, convection, large scale and Ocean); RI and RW events continue to pose challenges to forecasters.
- Apart from ERC and CBs, influence of radiation on CBs (diurnal variations) are important especially at initial stages of TCs
- Role of ocean heat content ?



Matthew forecast failure

Suggested path forward

- 1-3 km coupled global models will be reality in 5-10 years time.
- Continue with Coupled Mesoscale models down to 1 km resolution
- Multi-scale problem needs vortex to synoptic scale DA
- Focus on Satellite data assimilation techniques
- While we continue aggressive developments in high resolution models, understanding of processes key for TC Intensification should continue in parallel (use of observations for evaluation)
- Academic and operational community should work together to advance predictions further using a common modeling framework (e.g. HWRF, GFS)