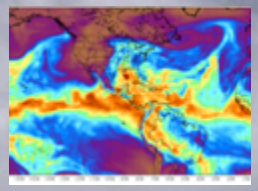
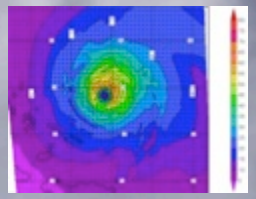
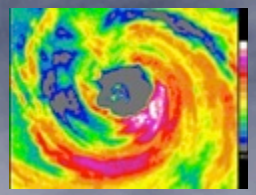
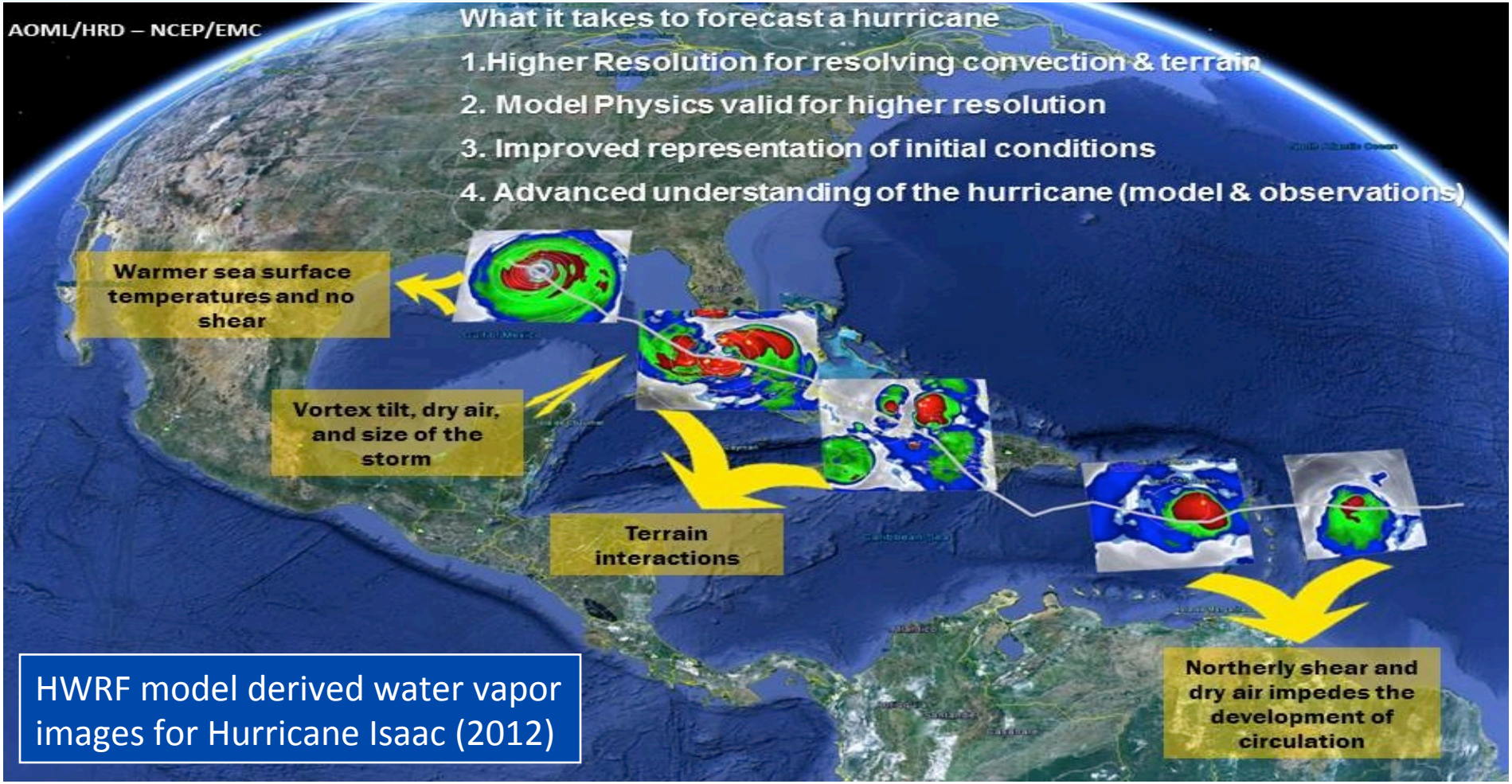
Model Advancements and Challenges in Tropical Cyclone Structure and Intensity Predictions

"How can high resolution models be improved to better represent structure and intensity change in tropical cyclones?"

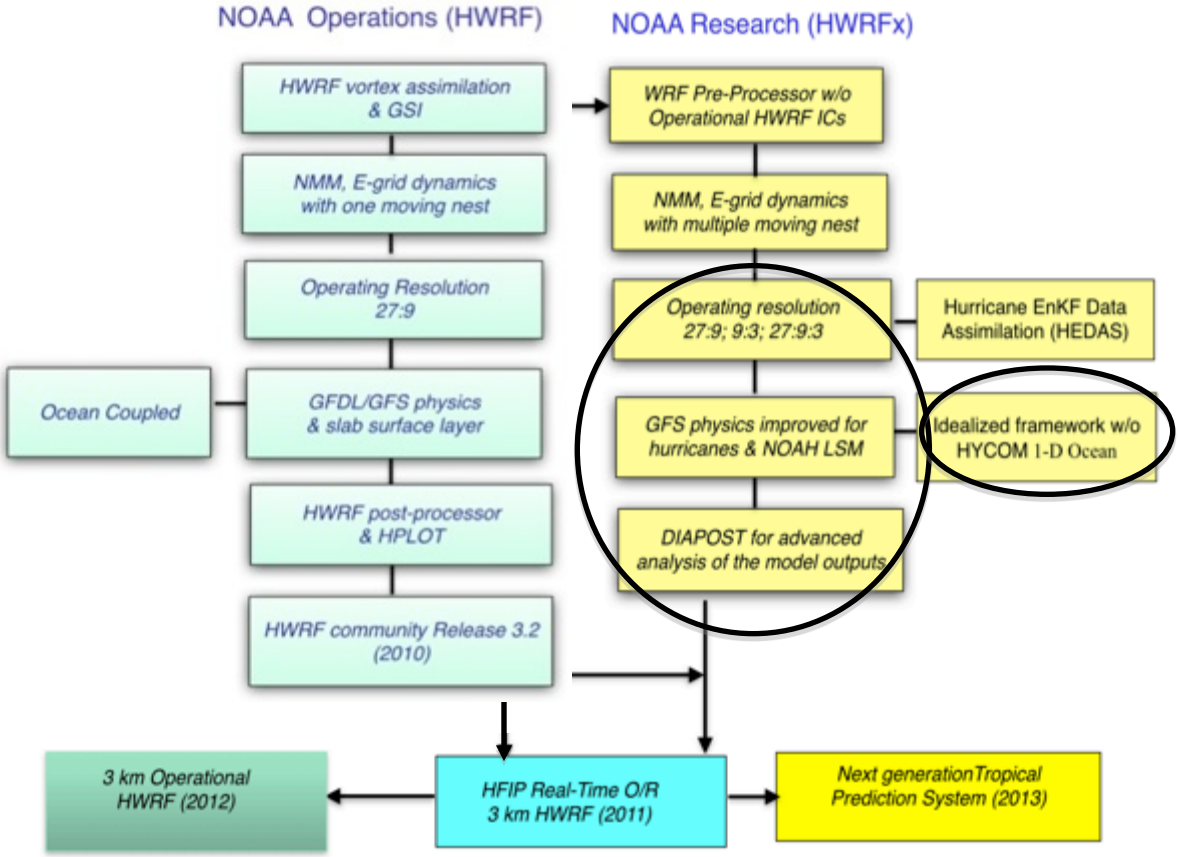
Sundararaman Gopalakrishnan (Gopal)
AOML Program Review
4-6 March 2014

NOAA HURRICANE MODEL: STATE-OF-THE-ART



AOML and their partners at NCEP are developing the HWRF model to address NOAA's immediate and future operational needs

ROAD MAP: HWRF DEVELOPMENTS



HIGHLIGHTS

2011: First cloud resolving operational TC forecasting system for Atlantic and East Pacific basins

2012: Official guidance model for JTWC and India Meteorological Department

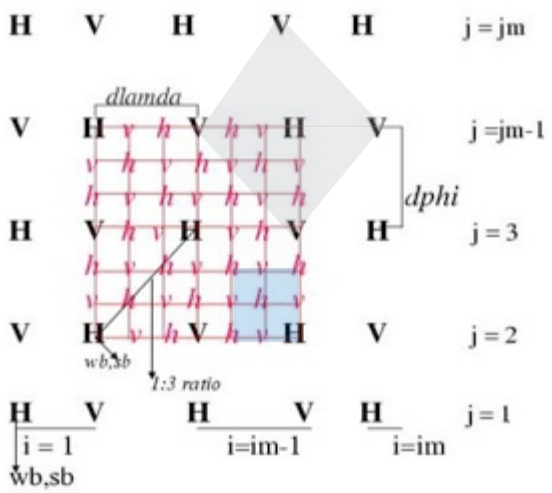
2013: Significant progress in TC structure, intensity and RI predictions over all basins

2013: 12 R2O transitions, 11 Peer Reviewed publications, 4 in preparation/review, 1 text book chapter,

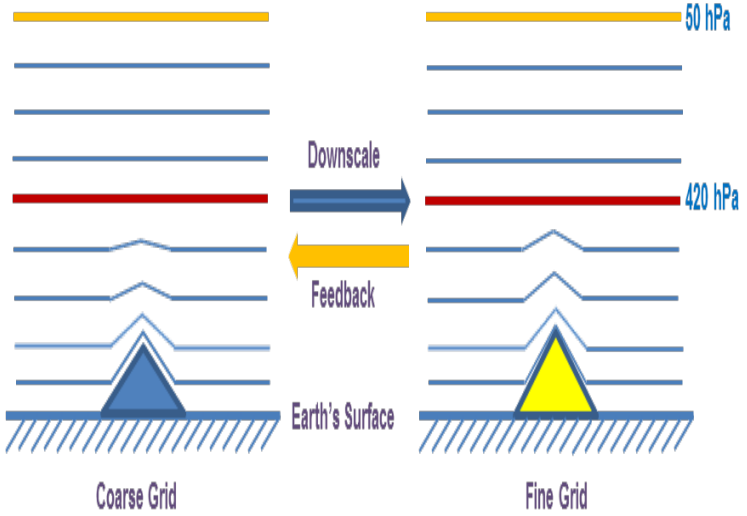
HURRICANE GRID DYNAMICS:
ADDRESSING CURRENT & FUTURE FORECAST NEEDS

The Backbone of HWRF: Operational 3-km Moving Nest

E-grid



Terrain interaction



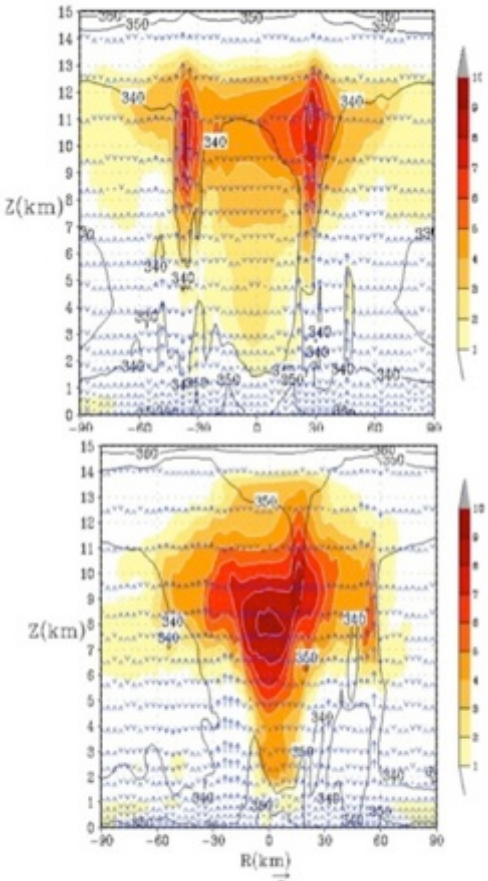
HIGHLIGHTS

(1) Two-way interactive Arawaka E- grid nests and advanced mass adjustment algorithms for handling steep terrain

(2) Any number of nests can be placed anywhere in the domain

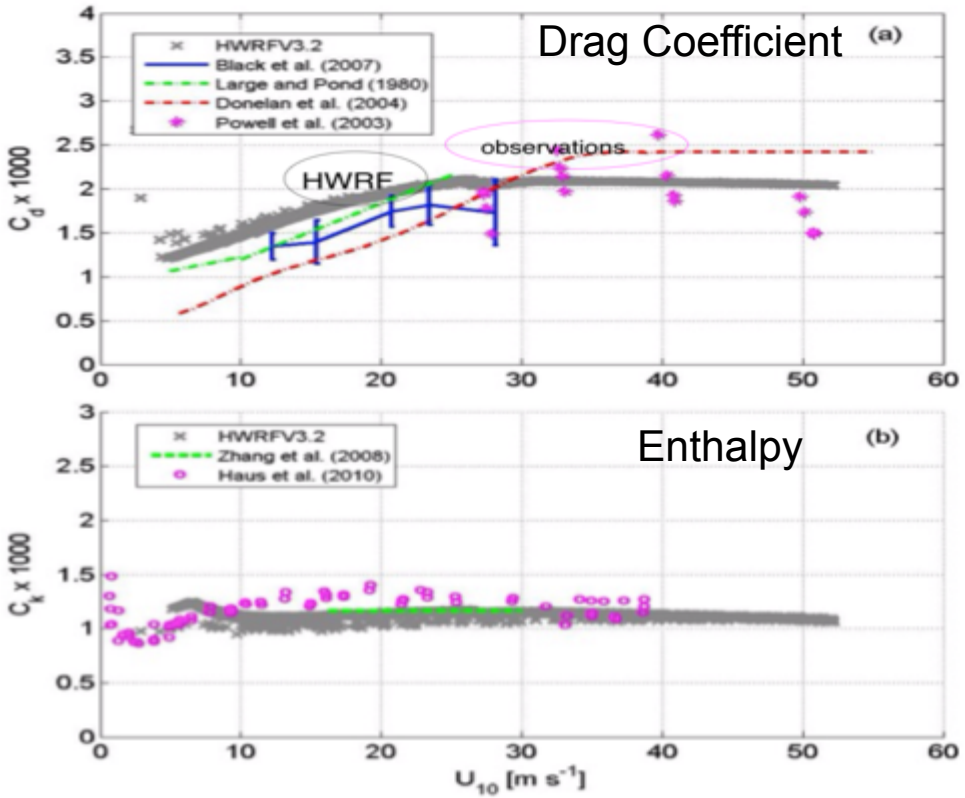
Gopalakrishnan et al., 2011 (HWRF Scientific Documentation) and Tallapragada et al., 2013 (MWR)

HURRICANE PHYSICS:
IDEALIZED FRAMEWORK FOR ADVANCING PREDICTIONS



"Vortical" Thermal Plumes and Axissymetric development of warm core in HWRF (Gopalakrishnan et al, 2011)

HWRF idealized framework: Improved understanding of modeled intensification processes & high resolution physics developments

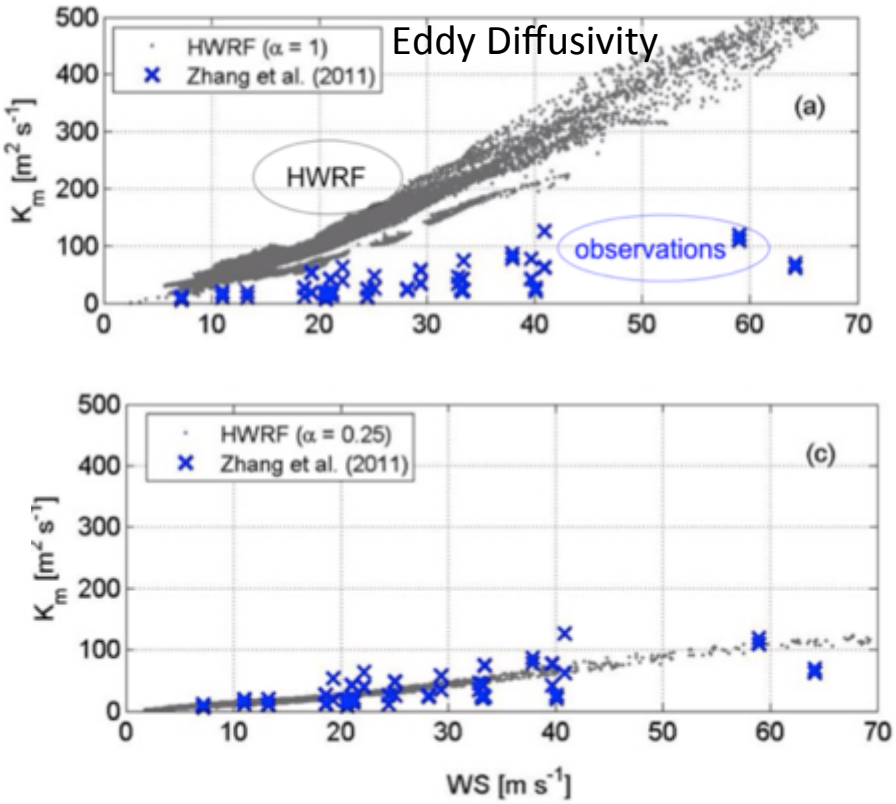


Improved observation-based surface layer physics in the High Resolution HWRF. Findings: More realistic enthalpy fluxes

Gopalakrishnan et al. , 2011 (MWR), Bao et al., 2012 (MWR), and Gopalakrishnan et al., 2013 (JAS)

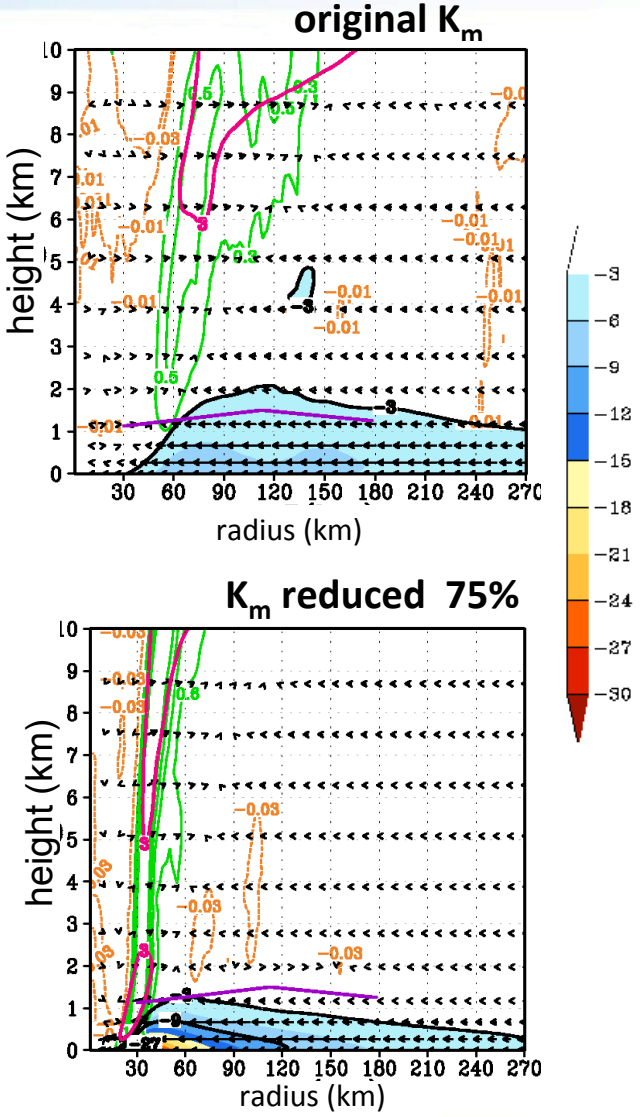
ADVANCES IN HURRICANE PHYSICS:
USE OF P3s & G-IV IN IMPROVING PBL

$K_m = k\,(U_*/\Phi_m)\,Z\,\{\alpha(1 - Z/h)^2\}$



Before

Improved

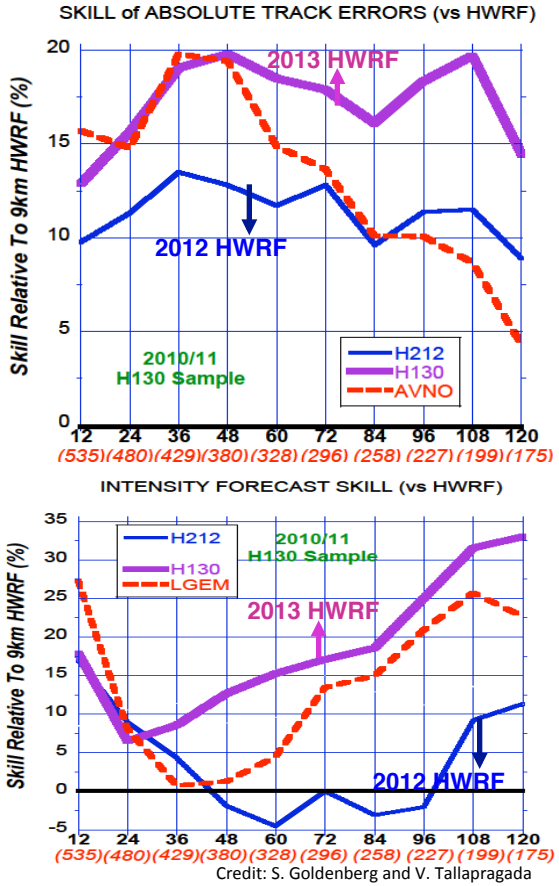


Improved observation-based PBL in the High Resolution HWRF. Findings: Improved secondary circulation, stronger inflow & smaller mature storms

Gopalakrishnan et al., 2013 (JAS) and Zhang et al., 2011 (MWR)

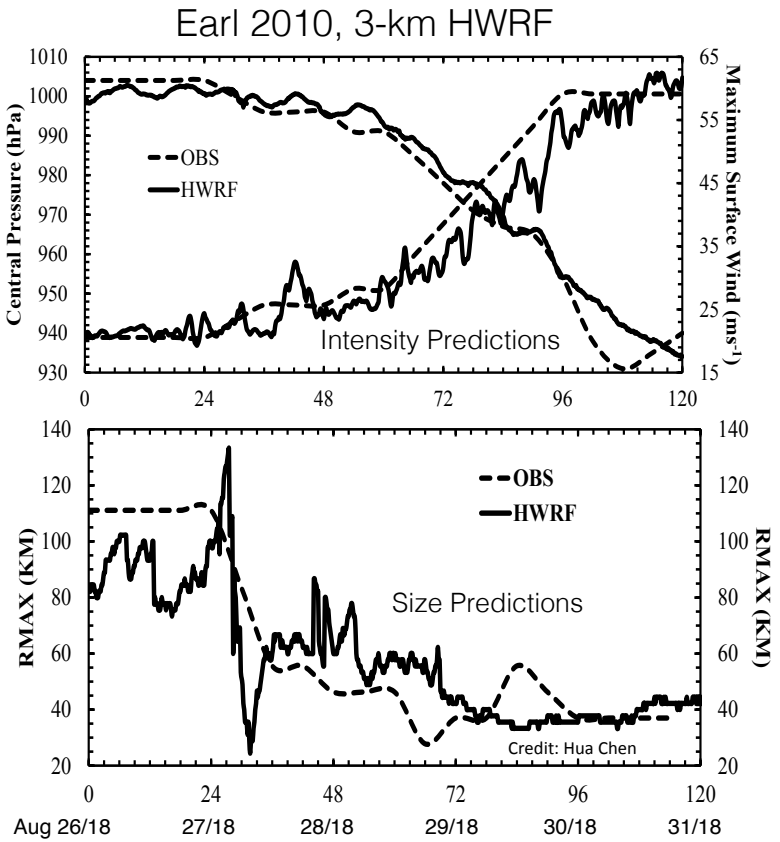
OPERATIONAL HWRF FORECAST:
SIGNIFICANT PROGRESS IN ALL BASINS

Multi-seasonal ATL and EPAC statistics



Credit: S. Goldenberg and V. Tallapragada

Example of an RI case



HIGHLIGHTS:

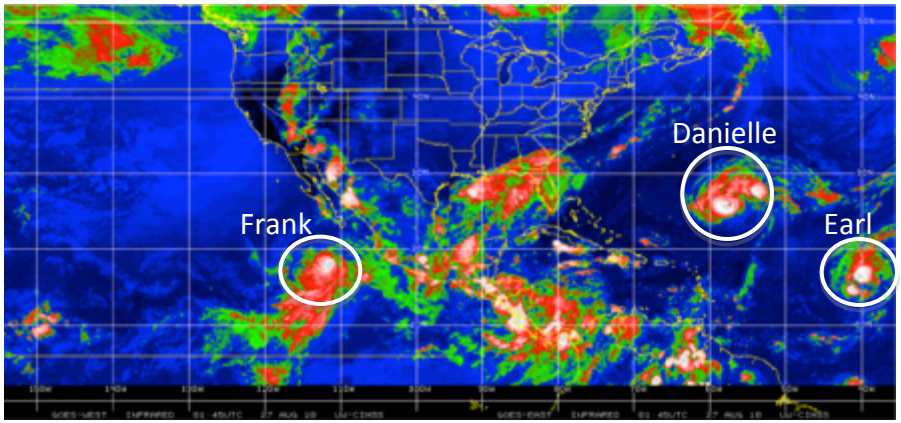
(1) For the first time, our numerical model shows consistent skill over statistical models.

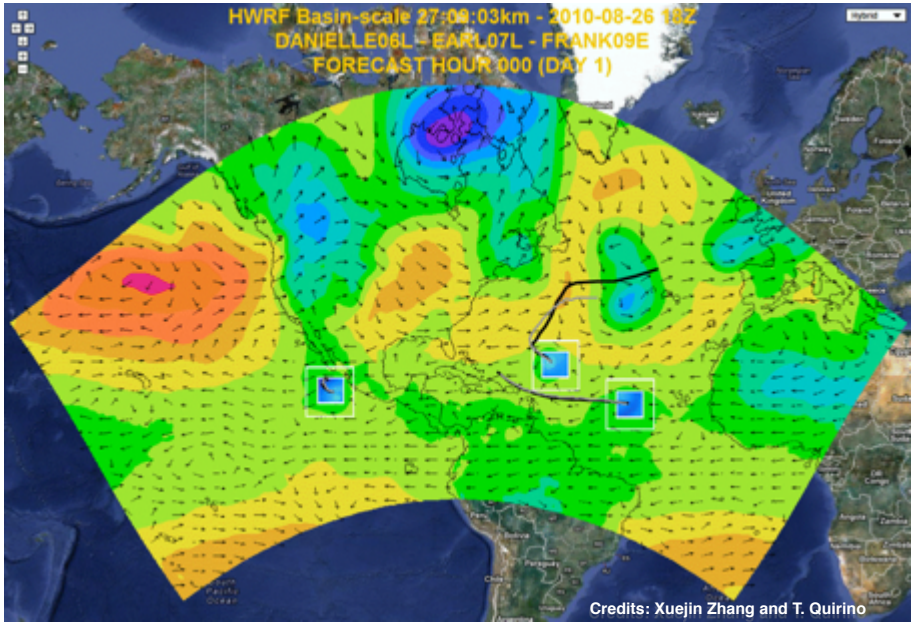
(2) Improved skill in intensity predictions in all the North Hemispheric Basins (AL, PAC, BOB)

(3) Improved RI and structure predictions

BASIN SCALE HWRF:
ADDRESSING FUTURE FORECAST NEEDS

A busy day in the tropics





Storm Centric -VS- Domain Centric Forecasts

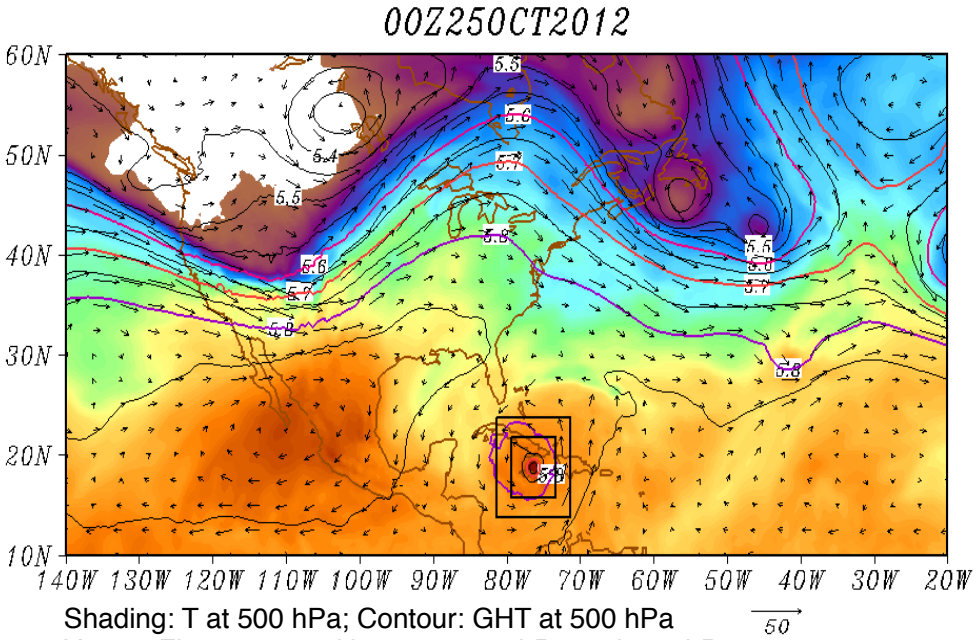
- Improved Storm-Storm & Multi-Scale interactions
- Landfall and post landfall (storm surge & rainfall)
- High Resolution Tropical Prediction System
- Data Assimilation/Satellite Data Assimilation advancements
- Advancement of downstream applications
- Tropical products: Easterly Waves/Surge/Genesis
- Mesoscale Ensembles

Next Generation Effort: **Advanced nest motion algorithm & initialization for multiple moving nest in regional scale domain**

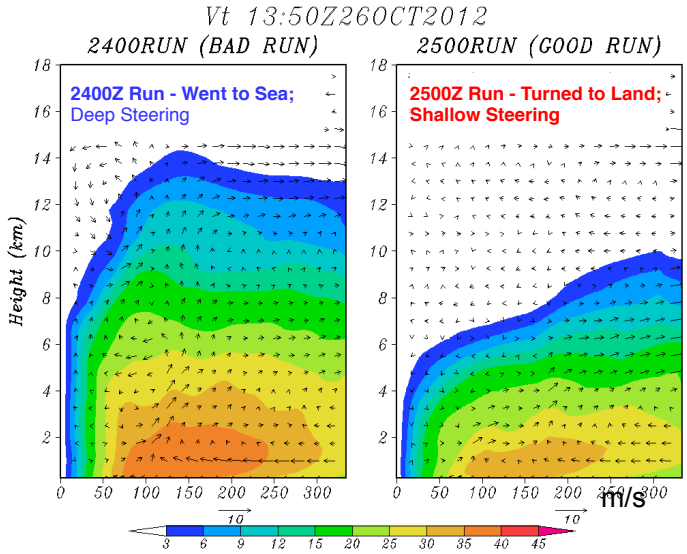
AOML RESEARCH:
ANALYZING FORECAST FAILURES USING HWRF

Case study: Hurricane Sandy 2012

Improved scale interactions and improved track & size forecasts
(25 00Z Predictions**)

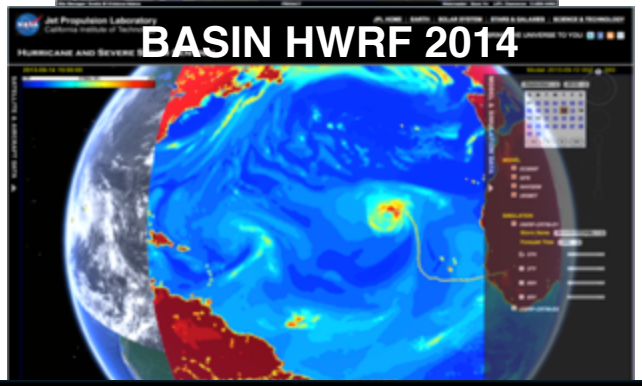


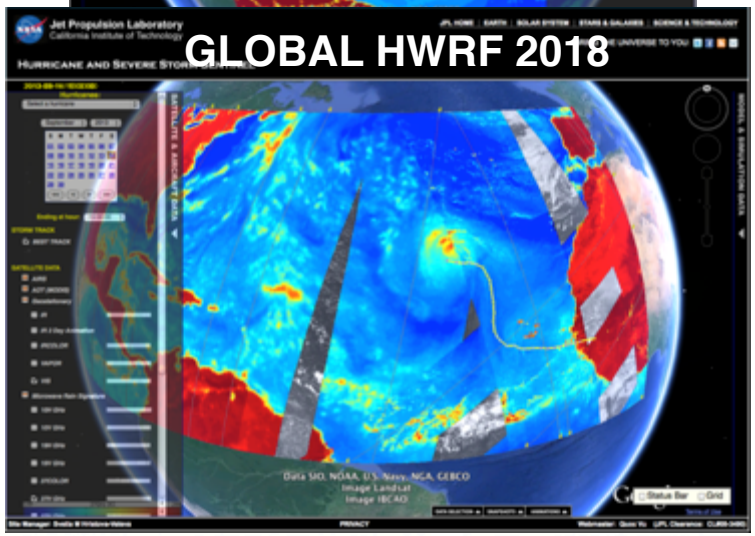
Shading: T at 500 hPa; Contour: GHT at 500 hPa
Vector: Flow averaged between 500 hPa and 200 hPa



** At this time the track skills of the Basin Scale HWRF exceeds those of the 2013 version of the operational HWRF system at all times for the 2012-2013 seasons (481 cases)

SUMMARY:





- AOML is making substantial progress in improving NOAA's Hurricane Forecast
- Hurricane observations are used in the high resolution HWRF parameterization scheme
- Significant improvements in HWRF track, intensity, structure and RI predictions are presented
- NOAA is moving towards the Basin Scale HWRF system due to the work done at AOML
- HWRF will be run global by 2018. We are currently building the system.
- Sustained partnership between NOAA operations (NCEP) and other agencies and universities hold the key to our future success.

QUESTIONS?

CREDITS AND ACKNOWLEDGEMENTS

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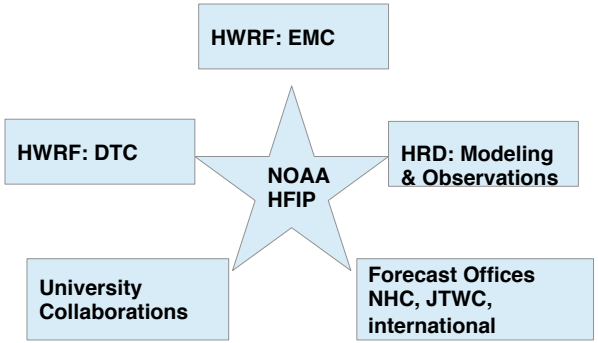

NOAA HURRICANE FORECAST IMPROVEMENT PROJECT

PRESENTATION PUBLICATIONS 2011-2013

1. Bozeman, M., D. Niyogi, S. Gopalakrishnan, F. D. Marks, Jr., X. Zhang, and V. Tallapragada, 2012: "An HWRF-based ensemble assessment of the land surface feedback on the post-landfall intensification of Tropical Storm Fay (2008)," *Natural Hazards*, 63(3), p.1543-1571.

2. Bao, J.-W., S. G. Gopalakrishnan, S. A. Michelson, F. D. Marks, M. T. Montgomery, 2012: Impact of Physics Representations in the HWRFX on Simulated Hurricane Structure and Pressure–Wind Relationships. *Mon. Wea. Rev.*, 140, 3278–3299.

3. Gopalakrishnan, S., F. Marks, J. Zhang, X. Zhang, J.-W. Bao, and V. Tallapragada, 2013, "A study of the impact of vertical diffusion on the structure and intensity of tropical cyclones using the high-resolution HWRF system," *J. Atmos. Sci.* 70(2), 524-541.

4. Gopalakrishnan, S.., S. Goldenberg, T. Quirino, X. Zhang, F. D. Marks Jr., K.-S. Yeh, R. Atlas, V. Tallapragada, 2012: "Toward Improving High-Resolution Numerical Hurricane Forecasting: Influence of Model Horizontal Grid Resolution, Initialization, and Physics," *Weather and Forecasting*, 27(3), p. 647-666

5. Gopalakrishnan, S., F. Marks, Jr., Zhang X, Bao, Jian-Wen, Yeh, Kao-San, and Atlas, Robert, 2011a: "The Experimental HWRF System: A Study on the Influence of Horizontal Resolution on the Structure and Intensity Changes in Tropical Cyclones Using an Idealized Framework", *Monthly Weather Review* 139(6) , p. 1762-1784.

6. Gopalakrishnan, S., Q. Liu, T. Marchok, D. Sheinin, N. Surgi, M. Tong, V. Tallapragada, R. Tuleya, R. Yablonsky, and X. Zhang, 2011b: Hurricane Weather and Research and Forecasting (HWRF) model: scientific documentation. NOAA/Development Tech Center, 81 pp. [online: http://www.dtcenter.org/HurrWRF/users/docs/scientific_documents/HWRFScientificDocumentation_August2011.pdf]

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8. Rogers, Robert, and Coauthors, 2013: NOAA'S Hurricane Intensity Forecasting Experiment: A Progress Report. *Bull. Amer. Meteor. Soc.*, 94, 859–882.

9. Yeh, K.-S., X. Zhang, S. Gopalakrishnan, S. Aberson, R. Rogers, F Marks, and R. Atlas, 2012: "Performance of the experimental HWRF in the 2008 Hurricane Season," *Natural Hazards*, 63(3), p.1439-1449.

10. Zhang, X., T. S. Quirino, K.-S. Yeh, S. Gopalakrishnan, F. D. Marks, Jr., S. B. Goldenberg, and S. Aberson, 2011: HWRFx: Improving Hurricane Forecast with High-Resolution Modeling. *Computing in Science and Engineering*, 13(1), 13-21.

11. Zhang, J. A., F. D. Marks, M. T. Montgomery, and S. Lorsolo, 2011: An estimation of turbulent characteristics in the low-level region of intense Hurricanes Allen (1980) and Hugo (1989). on. Wea. Rev., 139, 1447-1462.

12. Zhang, J. A., S. Gopalakrishnan, F. D. Marks, R. F. Rogers, and V. Tallapragada, 2013: A Developmental Framework for Improving Hurricane Model Physical Parameterizations Using Aircraft Observations. Trop. Cycl. Res. Rev, 1(4), 419-429.

AOML Research Transitions

	Transition Description	Product Users	Collaborator
1	Advanced nest motion algorithm for the High resolution HWRF system	WFO/DTC/India Met Dept	EMC/NCEP
2	High resolution HWRF system at 27:9:3 km for potential 2012 operations	EMC/NCEP	EMC/NCEP
3	Advanced vortex initialization for the 3 km moving nest	EMC/NCEP/DTC/IMD, India	EMC/NCEP
4	Vortex initialization for the 2011 operational HWRF system (at 9 km)	EMC/NCEP	EMC/NCEP
5	Advanced PBL physics for high resolution HWRF system	EMC/NCEP	EMC/NCEP
6	Advanced diagnostics for the high resolution HWRF system	NCEP/ WFO/DTC/IMD, India	EMC/NCEP
7	9 km static nest products from HWRF	WFO/Melbourne and Miami	-
8	Advanced diagnostic products from the high resolution HWRF system (web based products)	HFIP/TCMT/Tropical research community	-
10	High resolution HWRF system	India Met Dept	EMC/NCEP
11	Idealized HWRF framework	Research Community/EMC	ESRL/PSD
12	Basin Scale HWRF	HFIP/India/EMC (research)	EMC/NCEP