Hurricane Forecast Improvement Project (HFIP): Where do we stand after 4 years?

Research and Innovation Transition Team (RITT)

Fred Toepfer—HFIP Project Manager

May 15, 2013

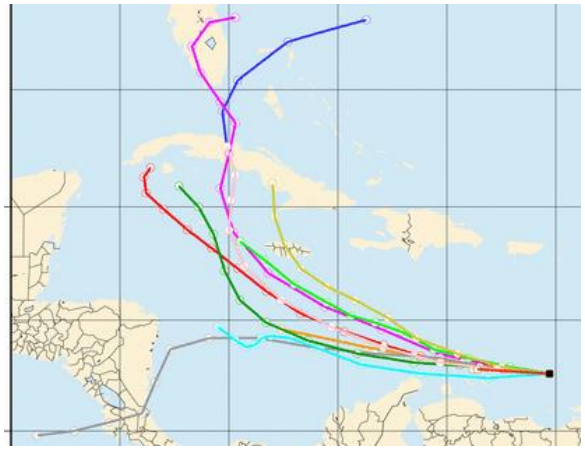
HFIP OVERVIEW

10-year program with ambitious forecast improvement goals

Designed and run by NOAA with non-NOAA collaborators

Began in fiscal year 2009

Focus on improving numerical weather prediction model forecast guidance provided to the National Hurricane Center



Drivers for a HFIP Program

- **Lives**: More than 50% of U.S. population lives within 50 miles of coast; Number of people at risk increasing along coast and inland; 180 million people visit the coast annually


Bolivar peninsula after Ike (2008)

- **Property**: Value of coastal infrastructure and economy rising… now > $3 trillion; annual U.S. tropical-cyclone-related damage losses averaged about $10 billion circa 2008; averaged losses double about every ten years

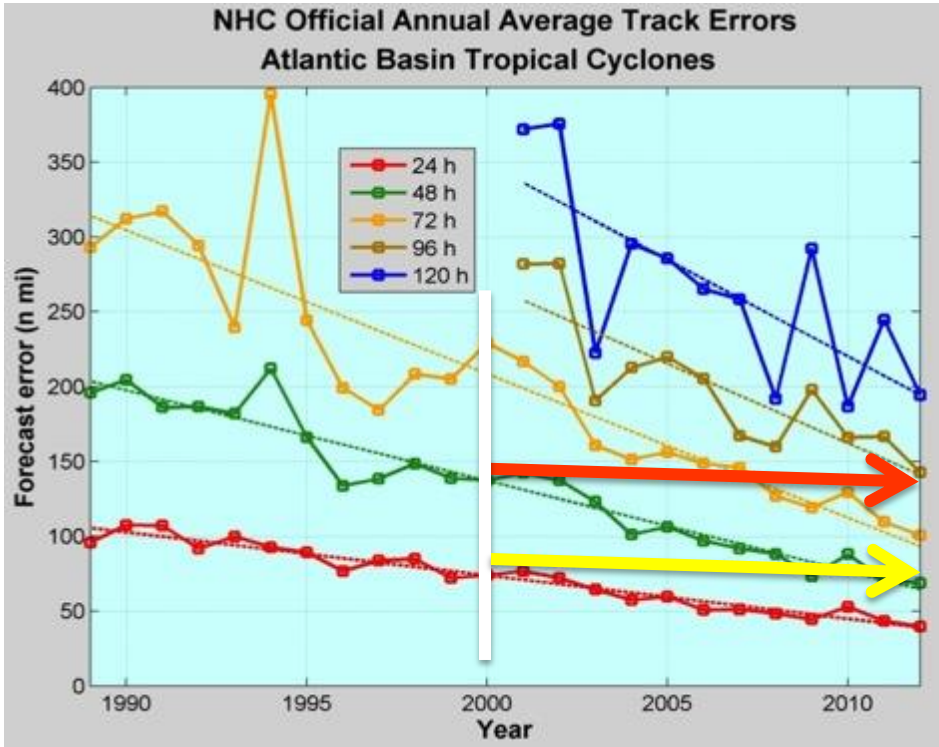
- **Forecasts**: Hurricane track forecasts have improved greatly; intensity forecasts have not

- **Research**: Tropical cyclone research has been under-resourced and not well-coordinated within the meteorological community

Courtesy: Ed Rappaport

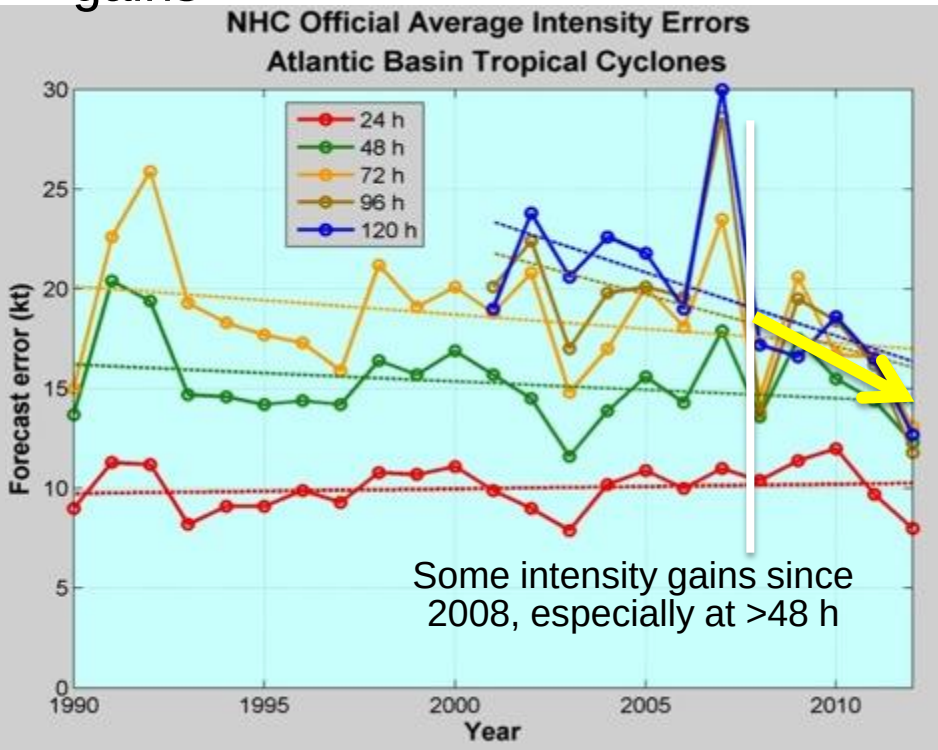
Operational Forecast Performance

Good – track forecast improvements



- Errors cut in half over past 15
- 10-year improvement - As accurate at 48 hours as we were at 24 hours in 2000

Not so Good – Modest intensity gains



- 24-48h intensity forecast off by **1** category
- Off by **2** categories perhaps 5-10% of time

http://www.nhc.noaa.gov/verification/verify5.shtml

Courtesy of Frank Marks

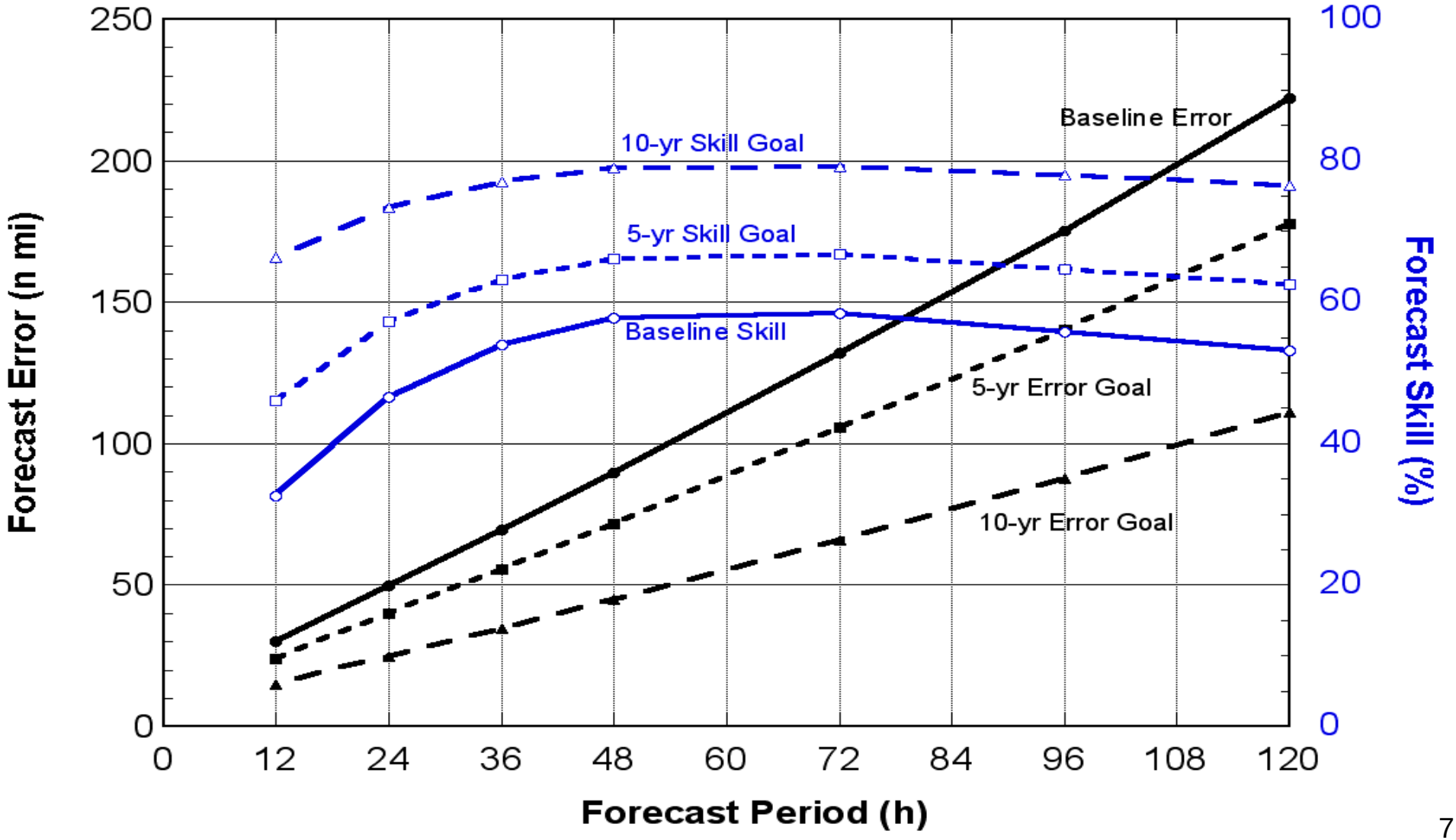
HFIP Scope

- Improve hurricane forecast system/global forecast system to reduce error in intensity and track
- Make better use of existing observing systems; define requirements for future systems to enhance research and operations capabilities and impacts
  - Does not include acquisition or operation of operational observing systems
- Expand and improve forecaster tools and applications to add value to model guidance

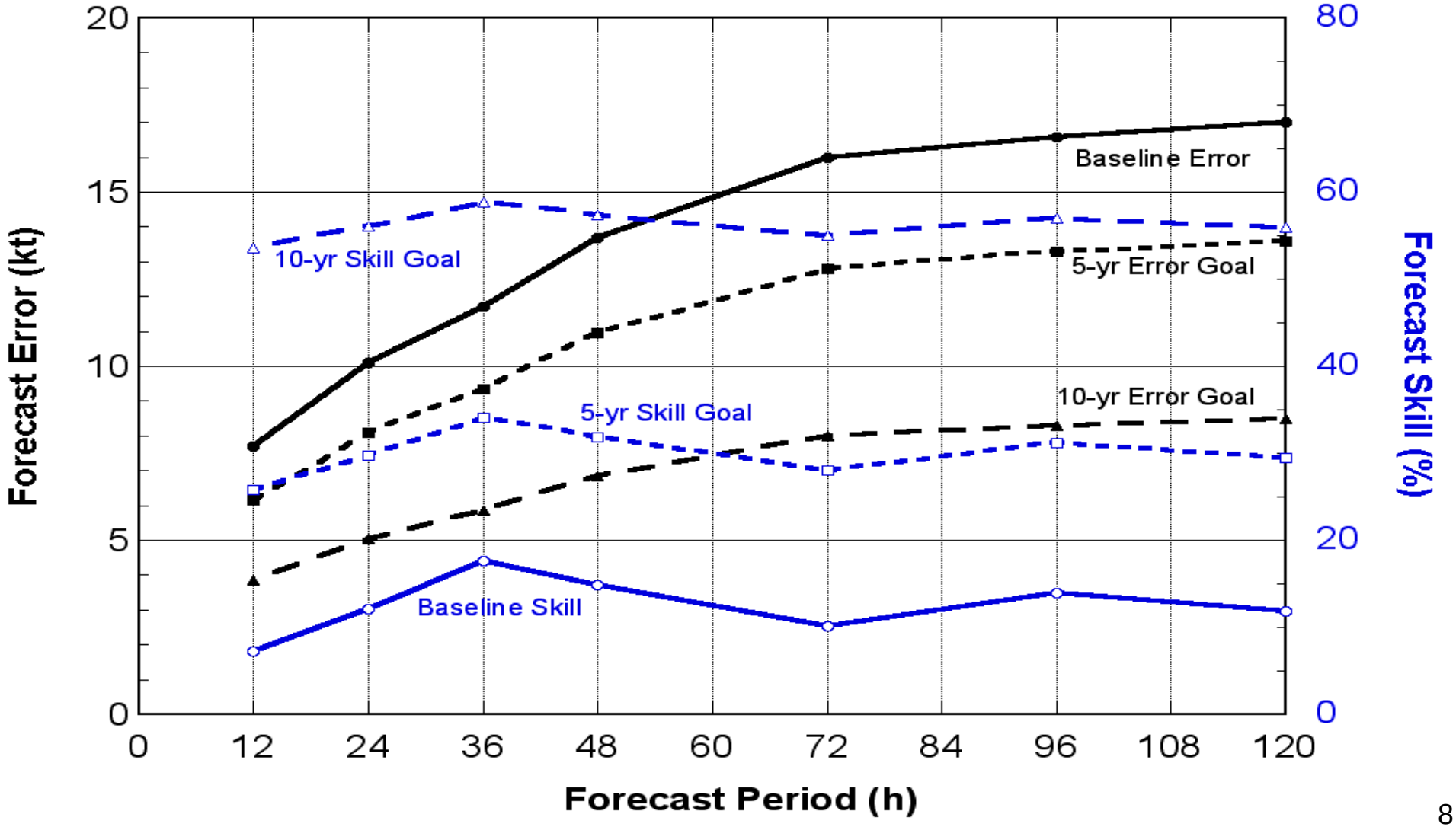
The HFIP Project – Vision/Goals

- Vision
  - Organize the hurricane community to dramatically improve numerical forecast guidance to NHC in 5-10 years
- Goals
  - Reduce numerical forecast errors in track and intensity by 20% in 5 years, 50% in 10 years
  - Extend forecasts to 7 days
  - Increase probability of detecting rapid intensification at day 1 to 90% and 60% at day 5

HFIP Baselines and Goals: Track



HFIP Baselines and Goals: Intensity



HFIP Charter and Leadership

- **HFIP Charter signed August 1, 2007**
- **Hurricane Executive Oversight Board**
  - Jointly chaired by AA for National Weather Services and AA for Oceanic and Atmospheric Research
  - Cross-NOAA Membership
- **HFIP Management**
  - Project Manager: Fred Toepfer, NWS/OST
  - Development Manager: Robert Gall, UCAR
  - Research Lead: Frank Marks, OAR/AOML/HRD
  - Operations Lead: Ed Rappaport, NWS/NHC

Technical Team Leadership 2013

FY 2013 Strategic Planning Teams

FY 2013 Teams	FY 2013 Team Leads
1. HFIP Model Strategy	Vijay Tallapragada, Stan Benjamin
2. Model Physics	Young Kwon, Jian-Wen Bao
3. Data Assimilation/Initialization	John Derber, Xuguang.Wang
4. Ensemble Development	Jeff Whitaker, Jiayi Peng
5. Post Processing and Verification Development Team	Mark DeMaria, David Zelinski, Tim Marchok
6. Societal Impacts	Jennifer Sprague, Rick Knabb

FY 2013 Tiger Teams

FY 2013 Teams	Strategic Team	FY2013 Team Leads
1. Web Page Design	5	Paula McCaslin, Thiago Quirino
2. 3 KM Physics Package	2	Joe Cione, Chan Kieu
3. Regional Hybrid DA System	3	John Derber, Jeff Whitaker
4 Use of Satellite Data in Hurricane Initialization	3	Xiaolei Zoa, John Knaff, Emily Liu
5. Stream 1.5 and Demo System Implementation	1	James Franklin, Barb Brown
6. Recon Data Impact Tiger Team.	1	James Franklin (NHC), Vijay Tallapragada (EMC)

Federal Funded Opportunity Current Grants

Institution	PI Name	NOAA Collab	Project Title	Actual Award Yr1	Actual Award Yr2	Total Budget
University of Oklahoma	Xugang Wang & M. Xue	EMC and HRD	Improving High-Resolution Tropical Cyclone Prediction Using a Unified GSI-based Hybrid Ensemble-Variational Data Assimilation System for HWRF	125,092	24,898	149,990
U Colorado - Boulder	T. Galarneau // T. Hamill & J. Whitaker (unfunded collab.)	ESRL/Hamill & Whitaker	HFIP Using Global Forecast System Reforecasts to Generate Tropical Cyclone Forecast Products	64,090	69,130	133,220
University of Miami	Jun Zhang, D. Nolan, and S. Lorsolo	HRD (generic)	Improving Sampling Strategies Through OSSEs for Optimal Assimilation of Airborne Doppler Radar Observations Using HRD's HEDAS	98,979	103,613	202,592
University of Miami	san Yeh & Da-Lin Zhang	HRD (generic)	Development of Multiple Moving Nests Within a Basin-Wide HWRF Modeling System	78,000	77,009	155,009
University of Miami	Aksoy, J. Chang & B. Klotz	HRD	Investigation of HWRF Model Error Associated with Surface-Layer and Boundary-Layer Parameterizations to Improve Vortex-Scale, Ensemble-Based Data Assimilation Using HEDAS	107,043	106,393	213,436
The Pennsylvania State University	Fuqing Zhang, Y. Weng & X. Ge	NESDIS (J. Knaff)	Real-time convection-permitting ensemble analysis and prediction of Atlantic hurricanes through assimilating airborne, radar and satellite obs	149,741	149,999	299,740
U. of Albany	Ryan Torn	NA	Evaluating Hurricane Intensity Predictability using the Advanced Hurricane WRF	57,120	92,880	150,000
Florida State University	T. Krishnamurti	NA	Further Reduction in Intensity Forecast Errors for Hurricane by Extension of the Correlation Based Consensus (CBC) Method	109,983	110,850	220,833
UCLA	Robert Fovell, K. L. Corbosiero, H. Su (JPL) & K-N Liou	NA	Hurricane Forecast Improvement Through Optimization and Validation of Model Physics	111,806	115,655	227,461
UCLA	Z. S. Haddad & S. Hristova-Veleva	NA	Assimilation of precipitation observations into HWRFX without the pitfalls of microphysical representations	130,000	130,000	260,000
University of Maryland	Da-Lin Zhang	EMC	Improving Hurricane Intensity Forecasts with Consistent Resolutions	72,000	149,999	221,999
University of Rhode Island	Isaac Ginis and R. Yablonsky	NA	Advancing NOAA's HWRF Prediction System through New and Enhanced Physics of the Air-Sea-Wave Coupling	113,264	120,912	234,176
			TOTAL	**1,217,118**	**1,251,338**	**2,468,456**

HFIP Scientific Review Committee

- The SRC provides feedback and guidance contributing to the cohesion of near-term (next year or two) and longer range strategies for improving hurricane forecasts
- Being outside of the daily project functioning, the SRC provides a broader assessment of HFIP progress and future approaches
    - Review and suggest possible changes to annual HFIP plans
    - Review proceeding year accomplishments
    - Review the long term HFIP model system development and observing strategy plans
    - Review the objectives and makeup of the demonstration system each season
- Organizational meeting 4th Quarter 2012

- 2 day review held 26 and 27 February, 2013.

HFIP Scientific Review Committee Membership

Name	Organization	Area of Expertise	Term of Service
Mike Montgomery	NPS	TC dynamics	3 years
Dave Nolan	Miami	TC regional models	3 years
Gary Barnes	UH/Manoa	TC structure	3 years
Jim Price	Woods Hole	Coupled models	2 years
Bob Hart	FSU	TC environment interaction	2 years
Jim Goerss	NRL Monterey	Global models/ensembles	2 years

HFIP Overall Strategy

- Use global models at as high a resolution as possible to forecast track out to 7 days
- Use regional models at 1-3 km resolution to predict inner core structure to meet intensity goals out to 5 days including rapid intensification
- Hybrid DA for both regional and global using as much satellite and aircraft data as possible
- Both regional and global models run as ensembles
- Statistical post processing of model output to further increase forecast skill

Real-time Experimental Guidance Stream 1.5

- Real-time experimental guidance made available to NHC in real-time
  - Called Stream 1.5 “experimental operations”
  - Verification evaluation of candidates completed by NCAR
  - NHC evaluate results and selects which models will be included as Stream 1.5
  - Includes both experimental new and projected future capabilities of current system
- Typically runs August 1 through October 15
- www.hfip.org to access results

HFIP dedicated HPC for development/demonstration NOAA Jet system

	Install Date	Total Cores	Performance (Tflops)	Storage (Tbytes)
Phase 1 (Njet)	Aug 2009	3184	35.6	350
Phase 2 (Tjet)	Sep 2010	10600	113.0	416
Phase 3 (Ujet)	Nov 2011	16648	182.0	1166
Phase 4 (Sjet)	Aug 2012	22088	272.0	1613

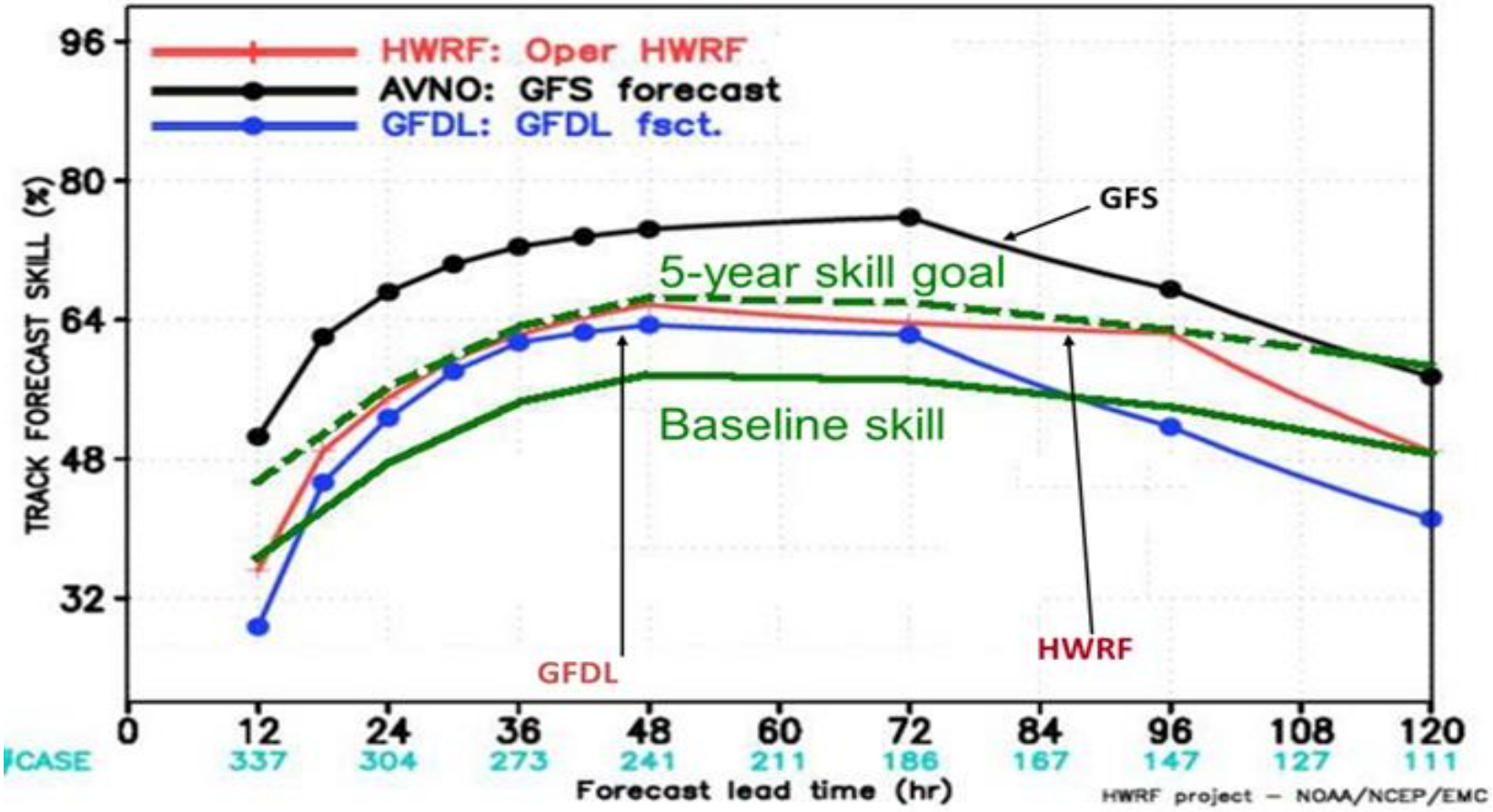
- "Jet" system performance in 2012 peaks at 272 Tflops
- Current Operations Computing peaks at 74 Tflops
- Components of the operational system that contribute to hurricane forecasts 26%
- HFIP computer provided 10 times more compute

Progress and Accomplishments

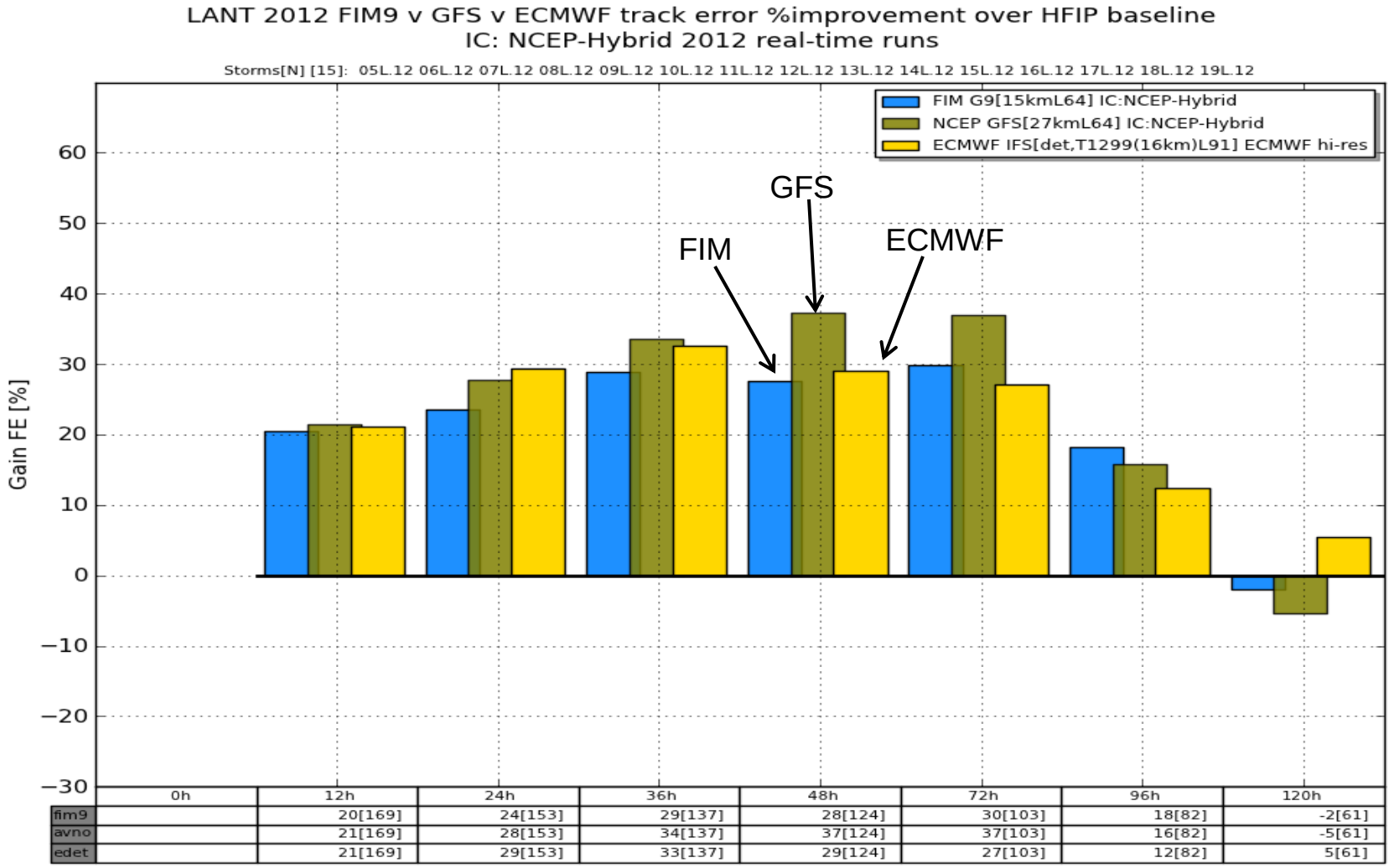
- 5-year Performance Goals Exceeded or Within Reach
  - New Hybrid DA Systems went operational in the GFS in May 2012: track forecasts exceeded the 5-yr and approached the 10-yr goal. Among the best dynamical models for hurricane track prediction, beating ECMWF most lead times.
  - A third nest was added to operational HWRF allowing an inner core resolution of 3 km. This and other changes led to a 20% improvement in both track and intensity forecasts over previous year.
  - Real-time confirmation of the impact of radar data on intensity forecasts from the operational HWRF: Improvement Additional 10%-20% out to 72 hours; independently verified with similar results from AOML using experimental HWRF.

Operational GFS Track Forecasts in CY12 Exceed the 5-year Goal

Track Skill for NCEP Operational models

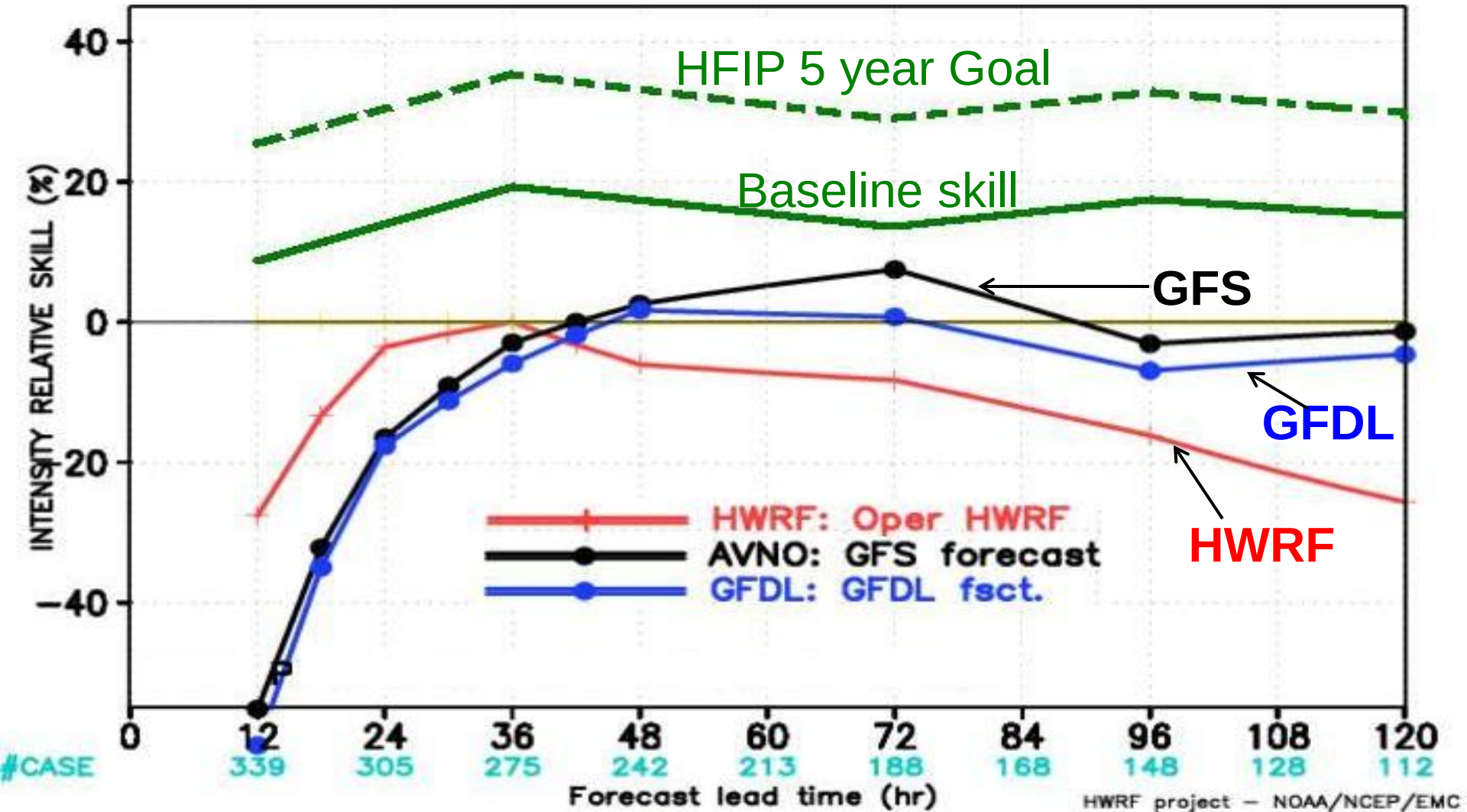


Global Model Track Error 2012
(% Improvement over HFIP baseline)

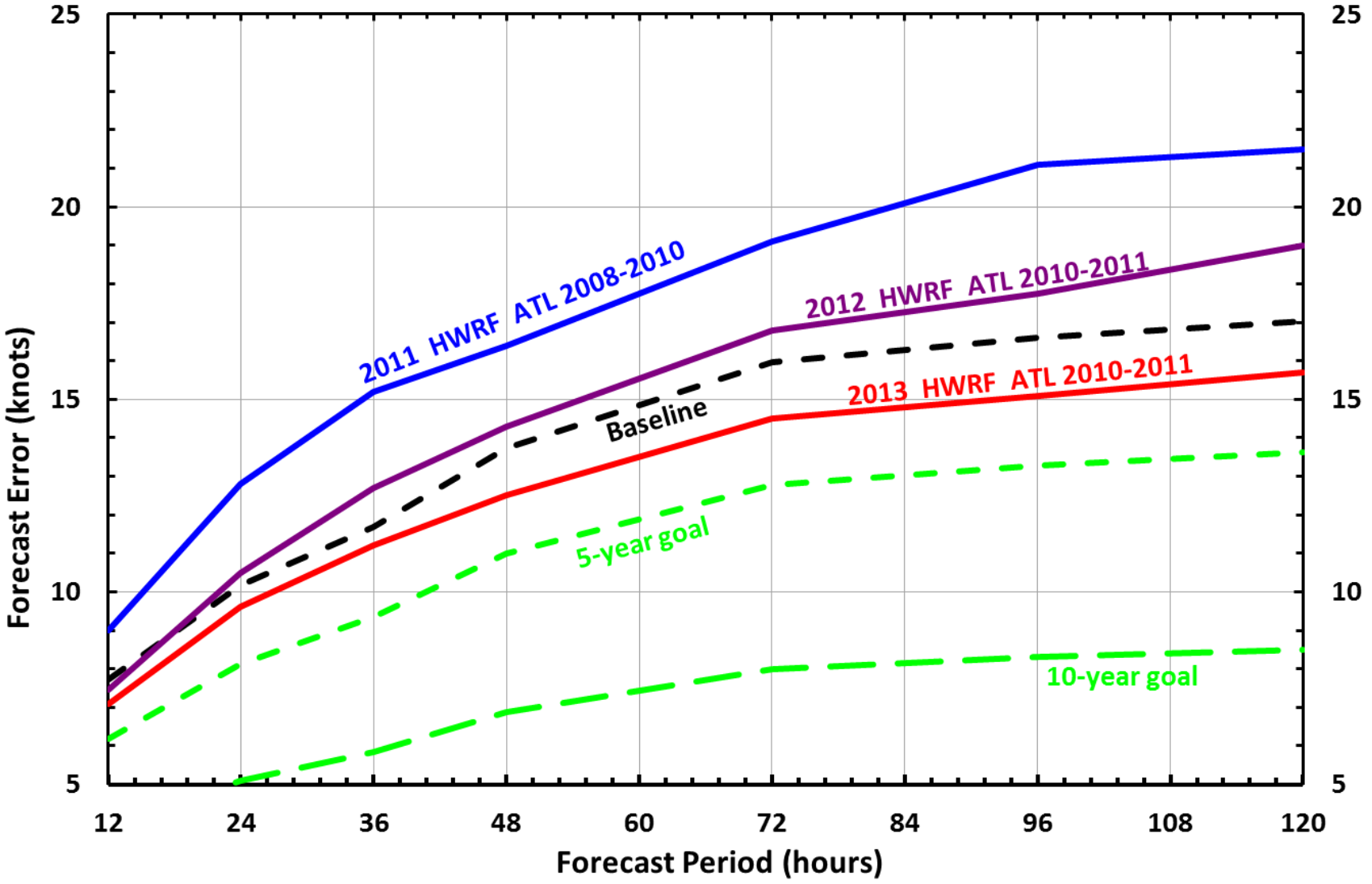


	0h	12h	24h	36h	48h	72h	96h	120h
fim9		20[169]	24[153]	29[137]	28[124]	30[103]	18[82]	-2[61]
avno		21[169]	28[153]	34[137]	37[124]	37[103]	16[82]	-5[61]
edet		21[169]	29[153]	33[137]	29[124]	27[103]	12[82]	5[61]

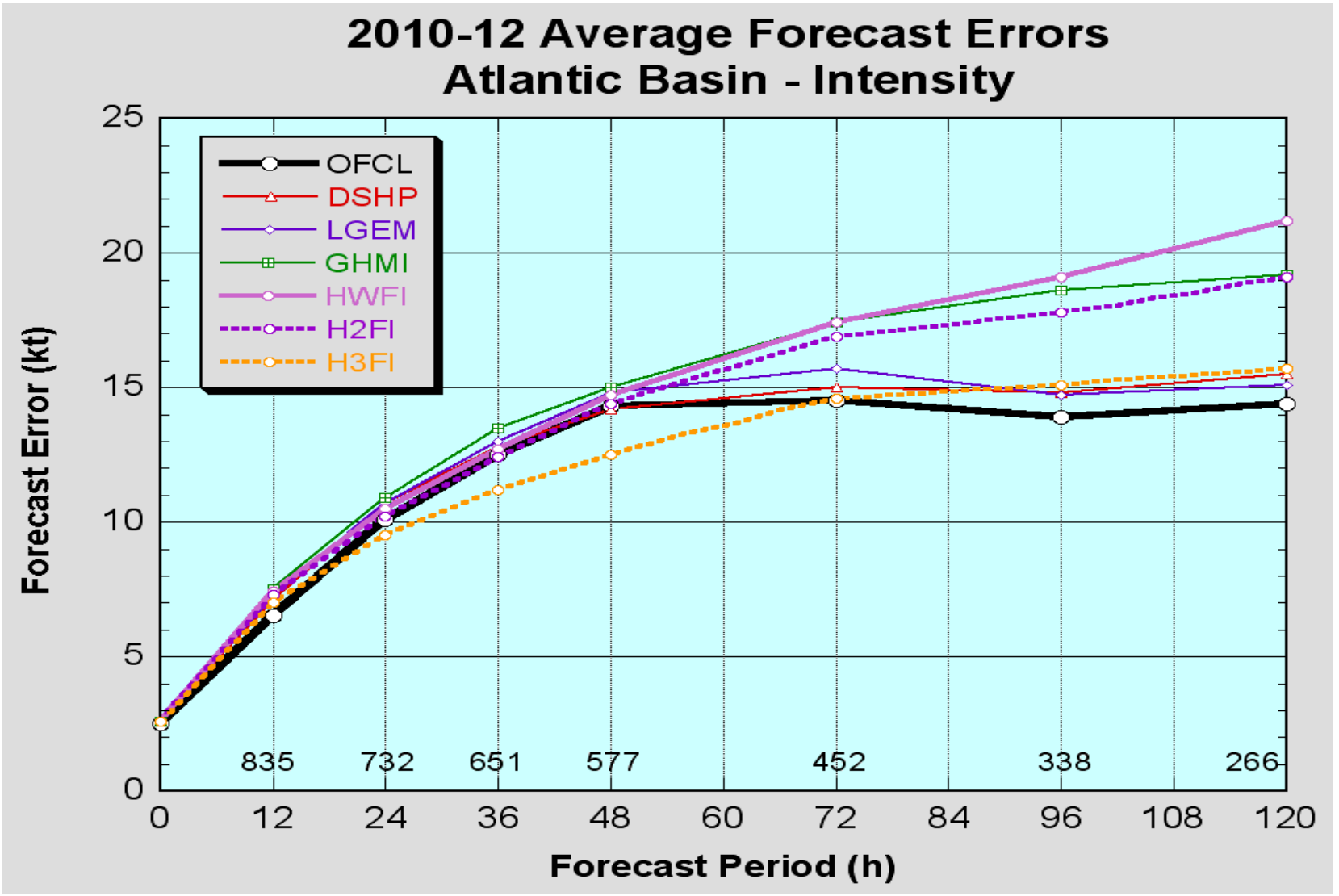
Comparison of 2012 NCEP Operational Models to the 5 Year HFIP Goal: Intensity



HWRF Intensity ATL Basin Cumulative Forecast Improvements



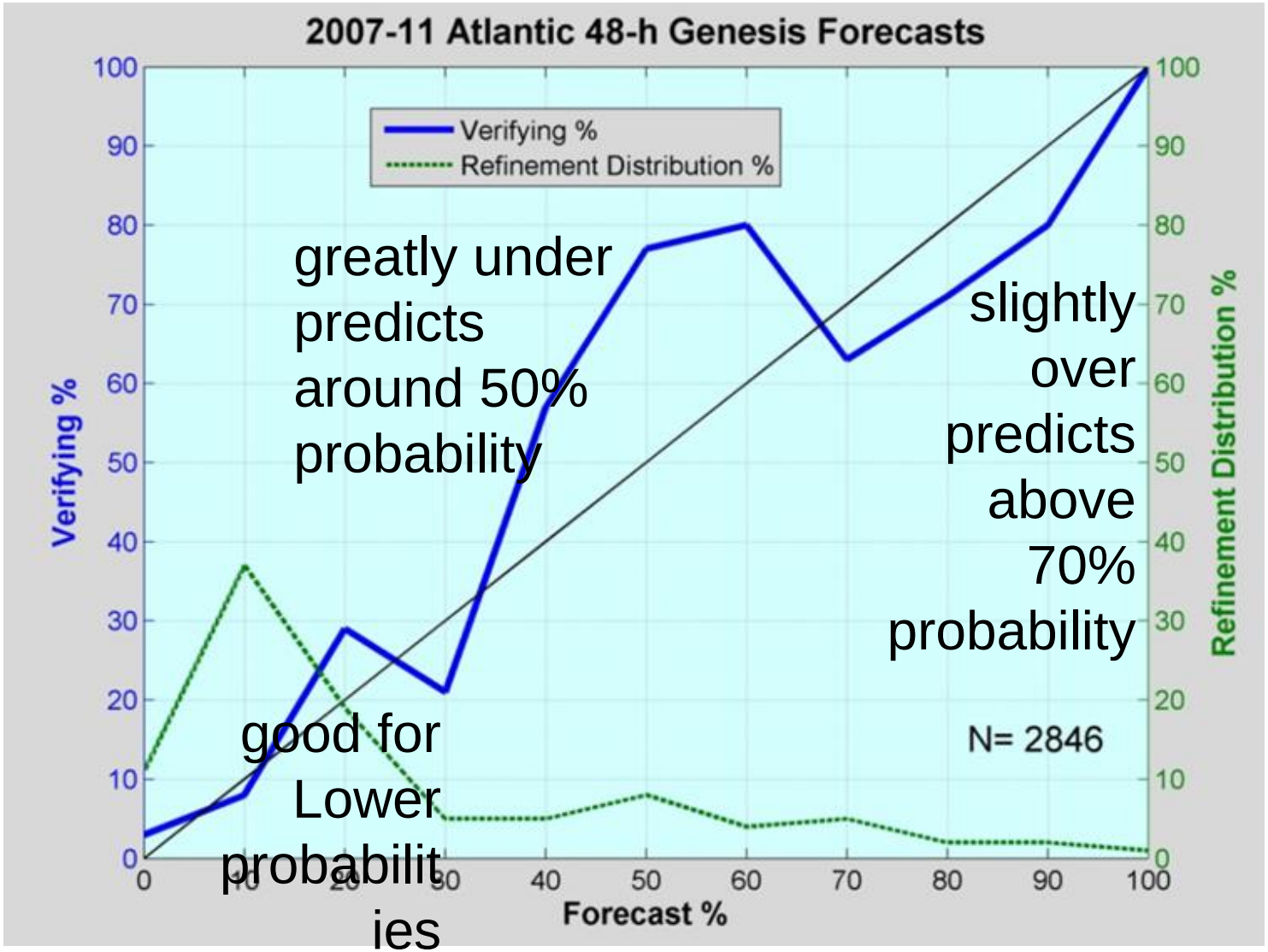
2013 Operational HWRF (H3FI) upgrade Retrospective Testing



Progress and Accomplishments(cont.)

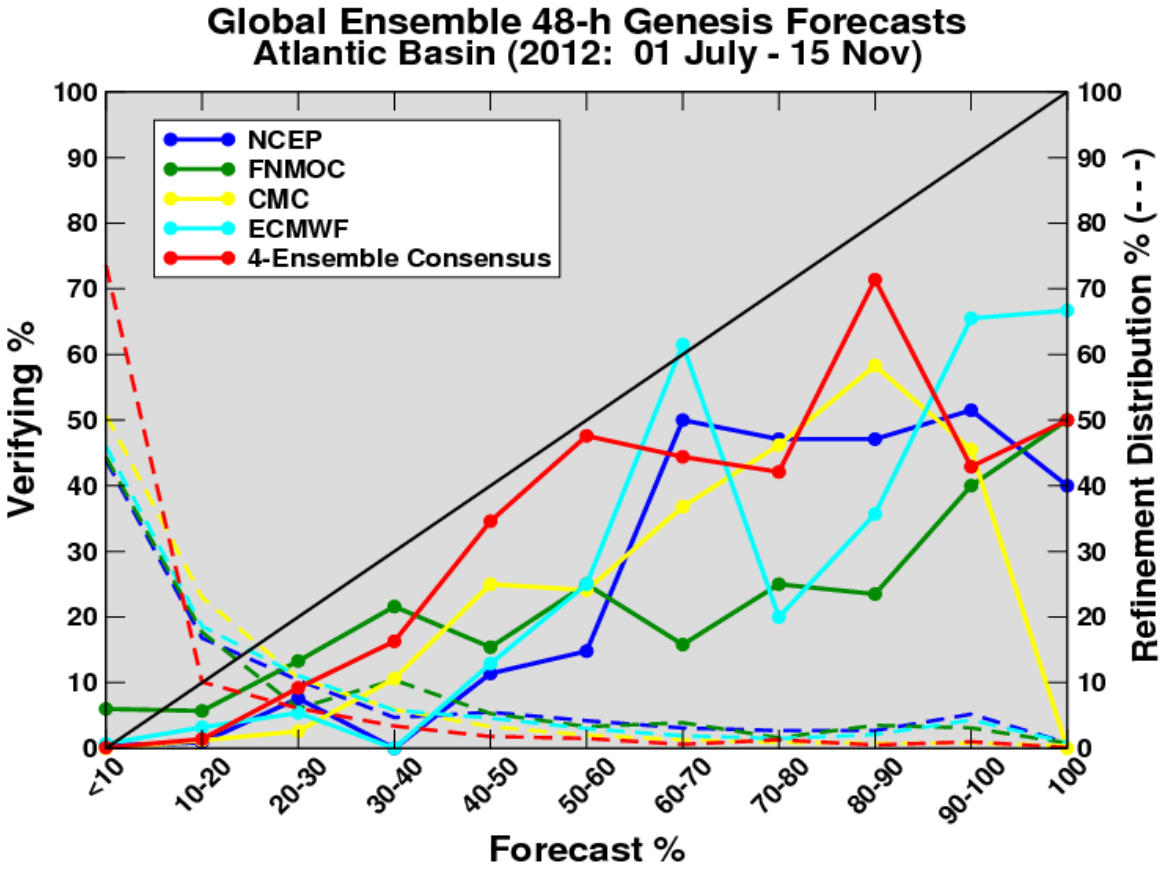
- Other Development Areas:
  - A real-time product for potential genesis using the HFIP global ensembles was demonstrated
  - Experimental 7-day model guidance
  - Next generation hurricane storm surge model demonstrated. A forecast for hurricane Sandy made 36 hours before landfall showed surprising skill in forecasting the surge in New York City and along the New Jersey coast.
  - Statistical Post processing and products development
  - Operational HWRF Development Process initiated

NHC Operational Genesis Forecasts



Refinement distribution indicates the percentage of times the forecast falls in a particular category. So for example forecasts of 50% probability of formation occur about 10% of the time

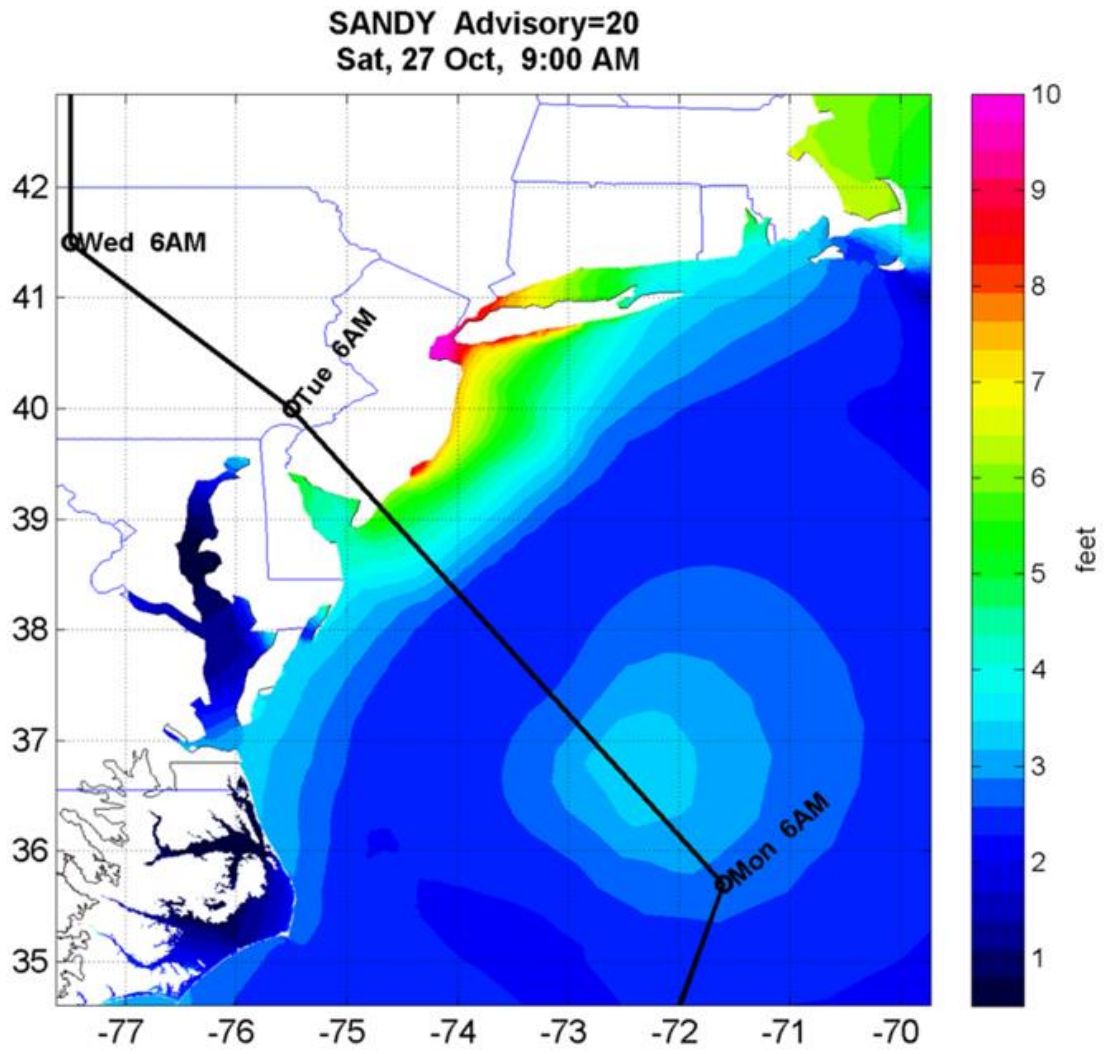
Verification of model genesis for operational global models



- All models have a bias towards over-prediction, caused by both false alarms as well as genesis occurring in the forecast long (>>48h) before observed genesis.
- 4-ensemble consensus close to reliable up through 50-60%.

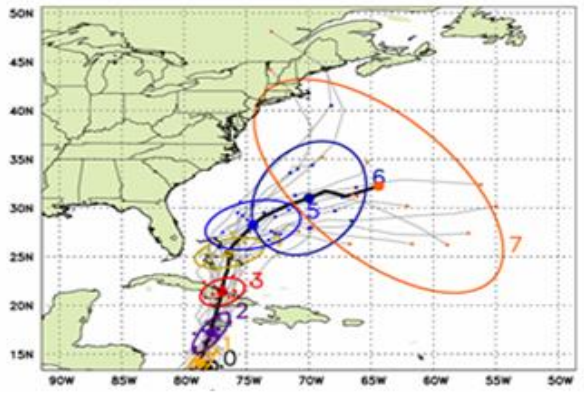
HFIP Working With Hurricane Surge Models

Maximum storm surge forecast for Hurricane Sandy from the ADCIRC storm surge model made 36 hours before landfall. Sandy's track is shown in black

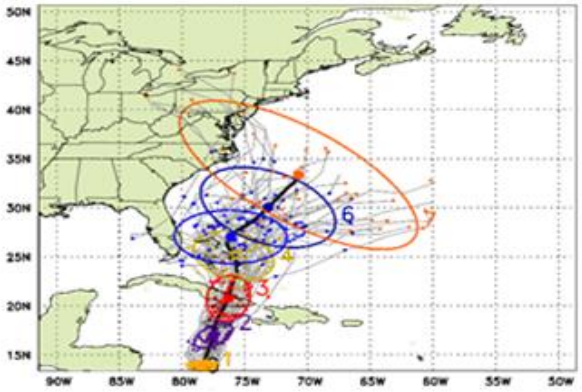


HFIP GFS Ensemble 7day Forecast for Hurricane Sandy

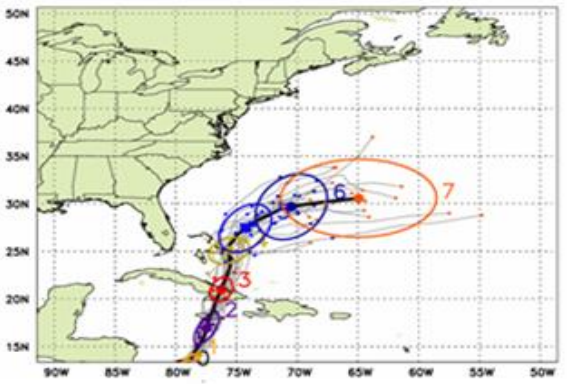
HFIP GFS



ECMWF



GEFS



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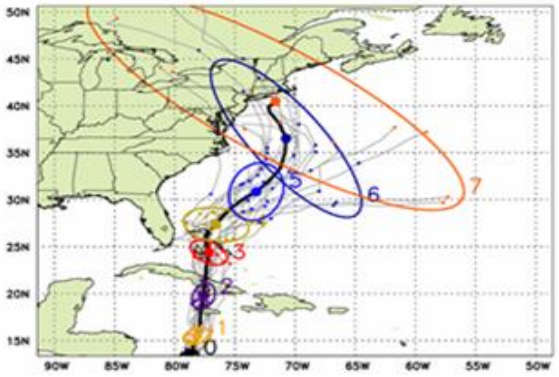
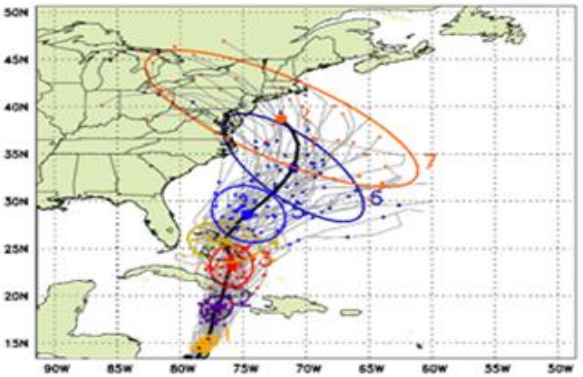
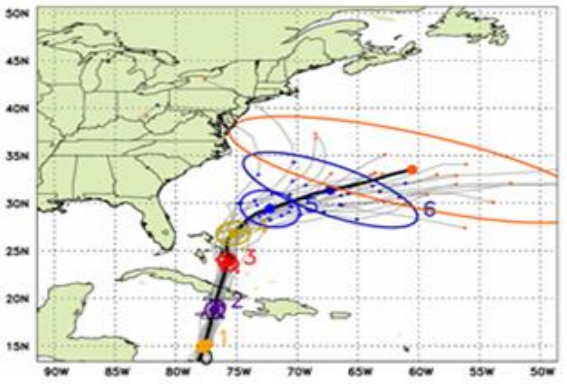




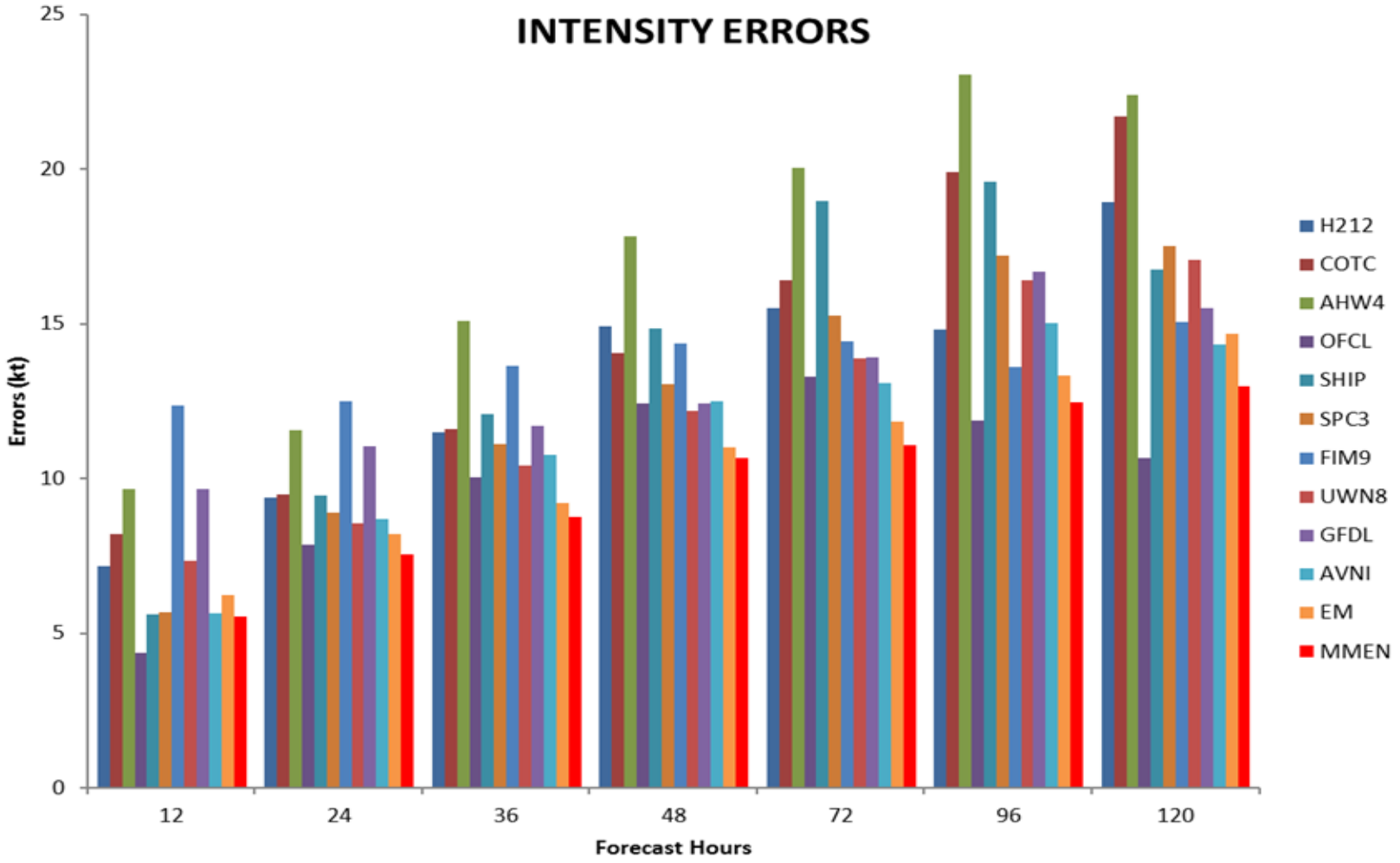


Tuesday October 23, 2012 00Z

Statistical Post Processing

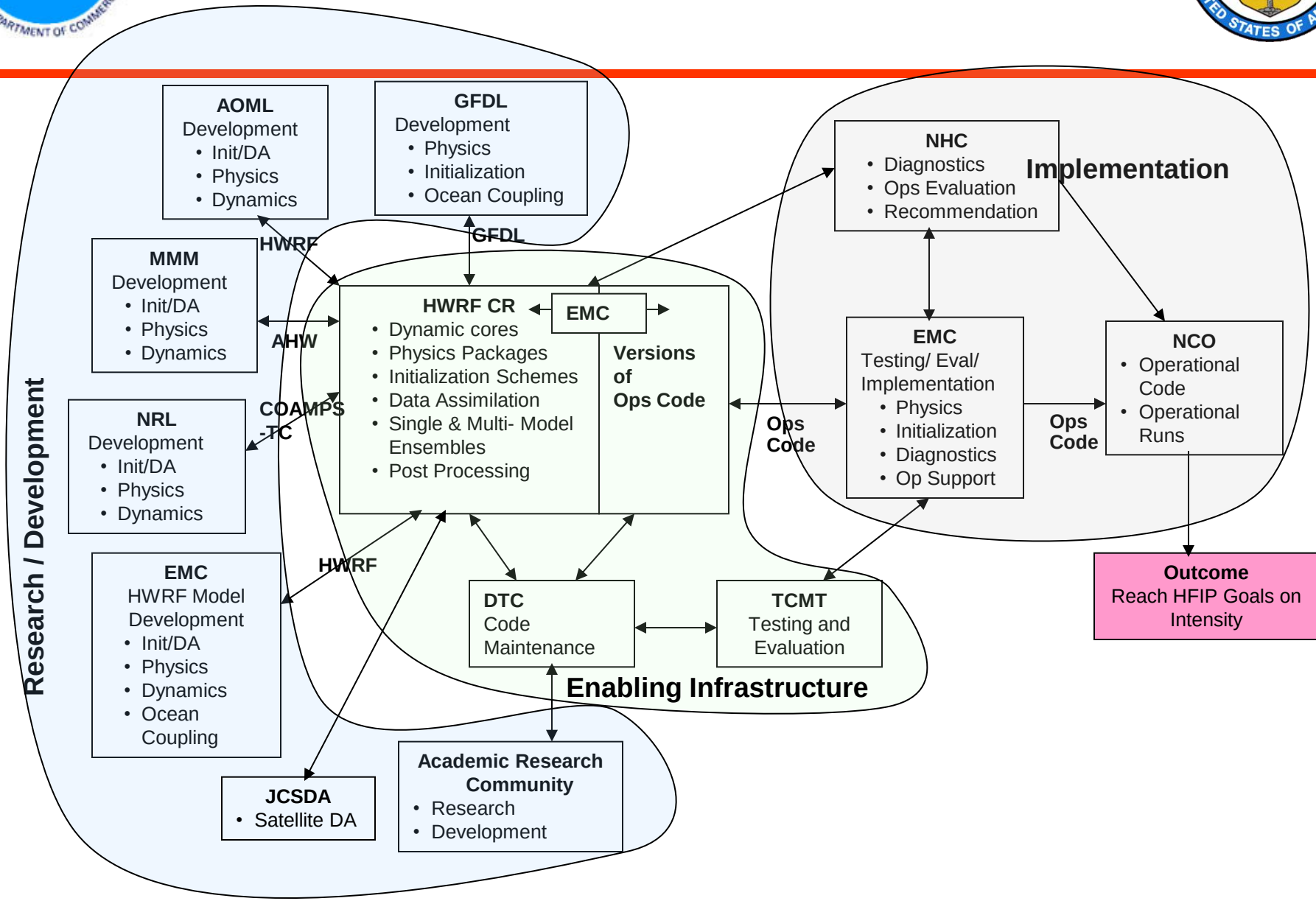
- Statistical Post Processing can add skill to dynamical forecasts.
- There are a number of techniques based on ensembles or individual models.
- One method is shown in the following figure
  - From the FSU Multi-Model Ensemble (MMEN) which forms a weighted mean of the many global and regional models run both operationally and by HFIP in real time.

2012 all storms



No. of cases	136	135	129	122	113	97	79

Operational HWRF Development Process



HWRF

Advanced Next Generation High-Resolution Physics for Operational HWRF

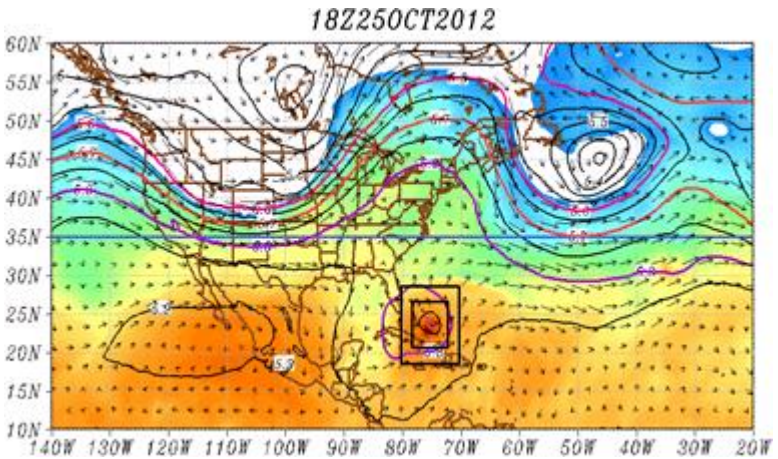
- Develop the next generation physics appropriate for 1-3 km resolutions
- Comprehensive use of aircraft and buoy observations to improve model physics, special flight modules to obtain targeted observations in data void regions
- Advanced air-sea-wave coupled system with sea-spray parameterization
- Meso-SAS convection scheme for high-resolution grids, Higher moment microphysics and advanced Radiation
- TKE based PBL schemes for more accurate representation of horizontal and vertical mixing
- NOAH LSM for improved representation of land surface processes
- Holistic approach in the design of high-resolution physics appropriate for hurricane conditions

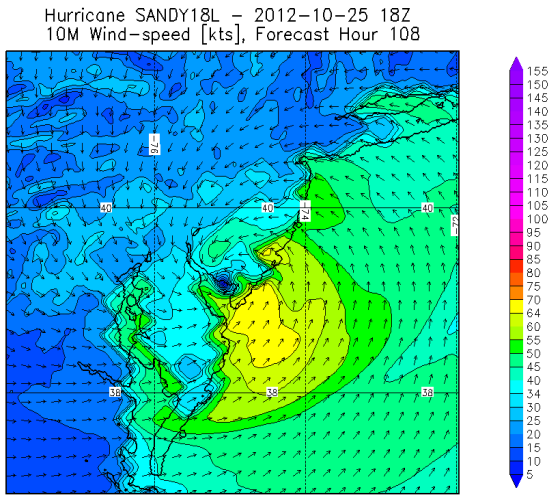
Planned Real-time High-Resolution Physics experiments for 2013 Hurricane Season

HFIP Stream 2.0	3km Physics Package
Control	FY13 HWRF
PBL	MYJ
Radiation	RRTMG
Micro-Physics	Thompson
Convection	Meso-SAS
Land Surface	NOAH LSM
Ocean	HYCOM
Waves	Sea-Spray parameterization and coupling to Wave Watch III

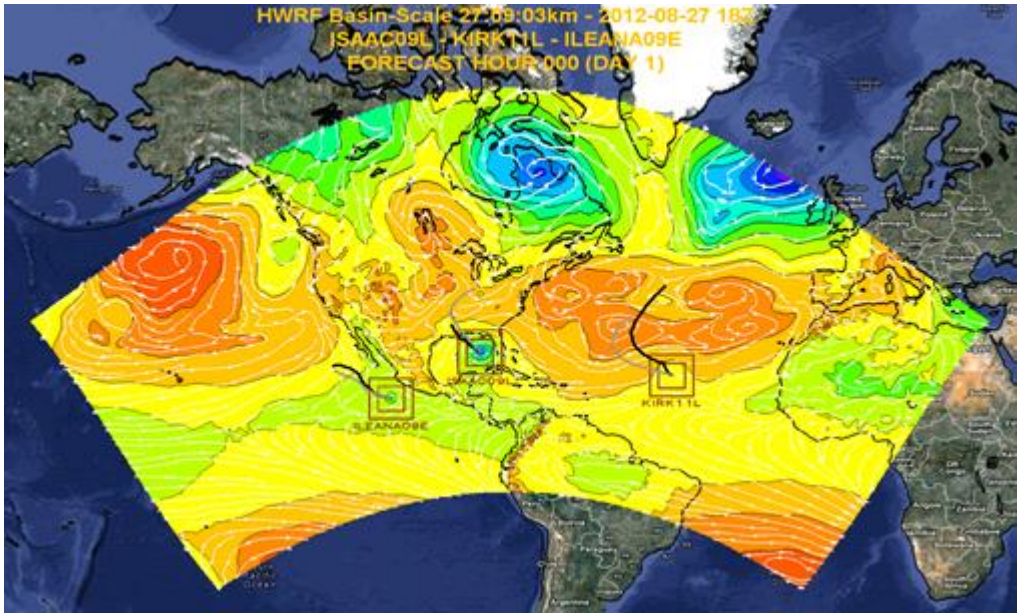
Future advancements for Operational HWRF

Improved Scale Interactions and Improved Track and Size Forecasts

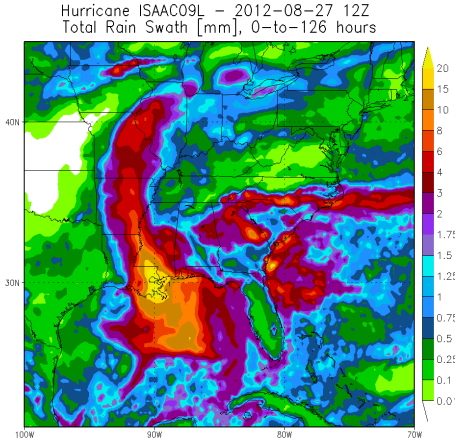




Basin-Scale HWRF: Real-time Multi-nested 3km predictions

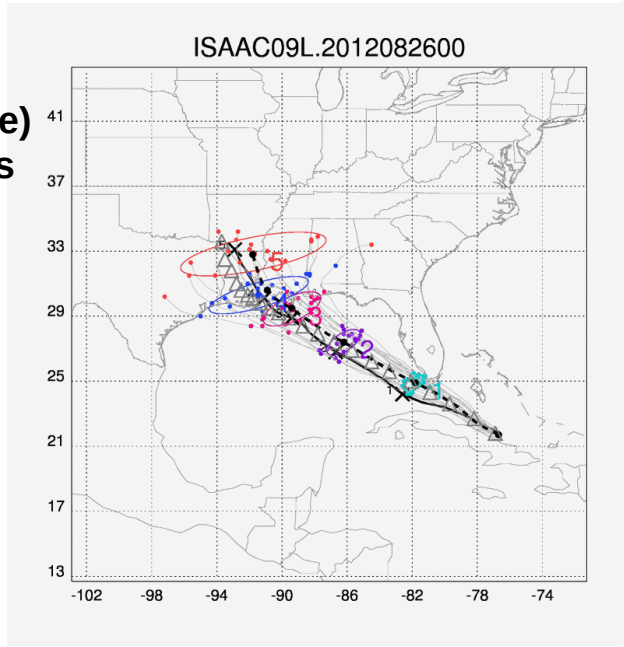


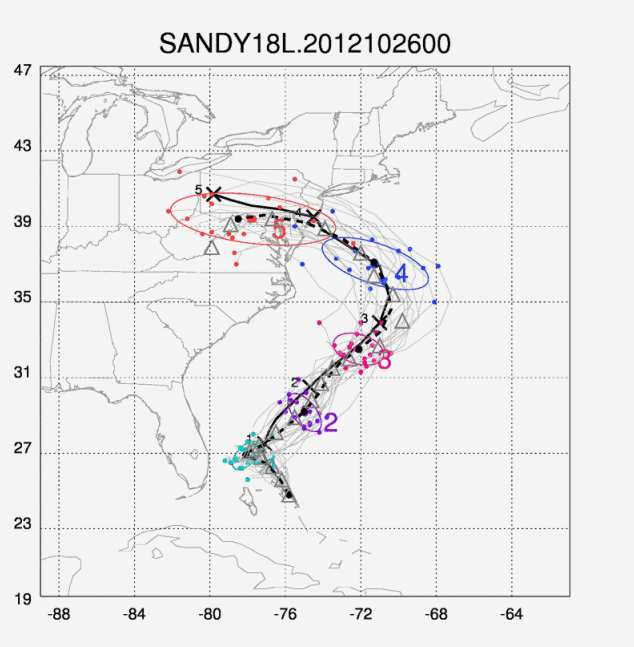
Comprehensive large-scale/vortex-scale interactions in a unified framework, with high-resolution hurricane forecast guidance

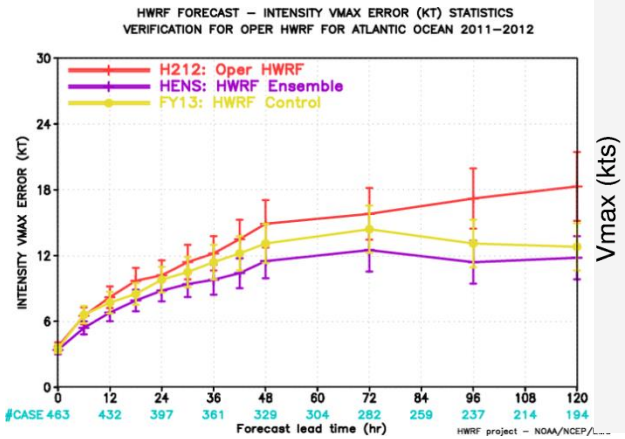


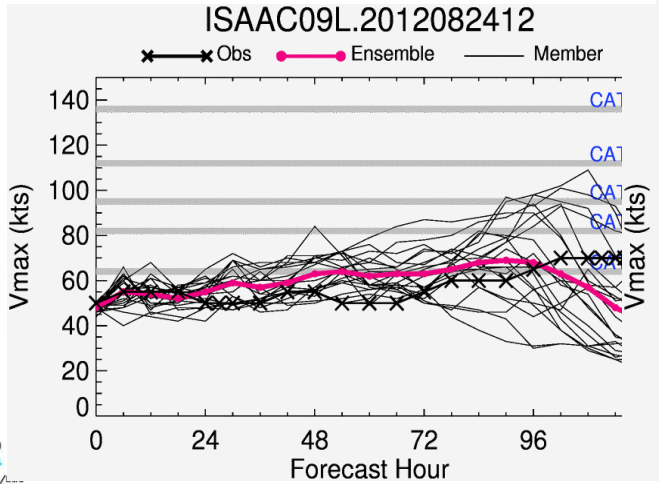
High-Resolution HWRF Ensembles for Real-Time HFIP Stream 1.5 Demo during 2013 Hurricane Season

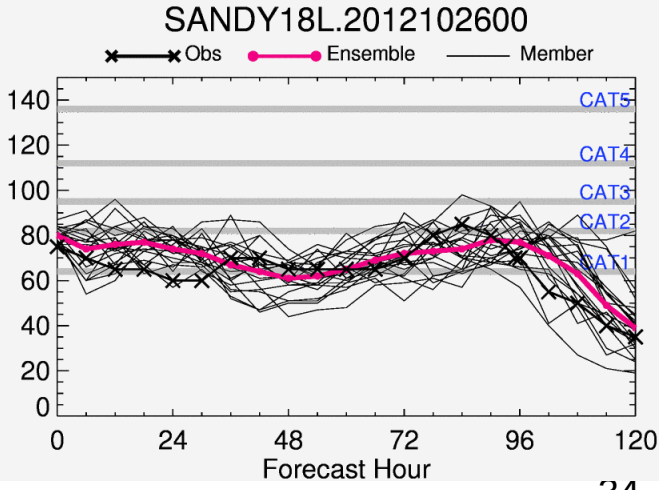
- Hurricane Ensemble Prediction System based on Stochastic Convective Trigger (vortex scale) and GEFS ETR initial conditions (large-scale) perturbations
- Based on latest FY2013 HWRF configuration (fully coupled system)
- Further improvements to track and intensity forecast skill
- High-Resolution Probabilistic Prediction Capability using NMME System (HWRF and COAMPS-TC)











Transitioning HWRF to NMM-B/NEMS Framework

Why NEMS/NMM-B?

- **Concept of Unified NOAA Modeling Framework**
- **Seamless expansion of current "storm-centric" approach to "global-to-local-scale" approach for hurricane prediction**
- **Take advantage of "in-house" expertise**

Three-Tier Developmental Path:

(a) put HWRF in NEMS Framework

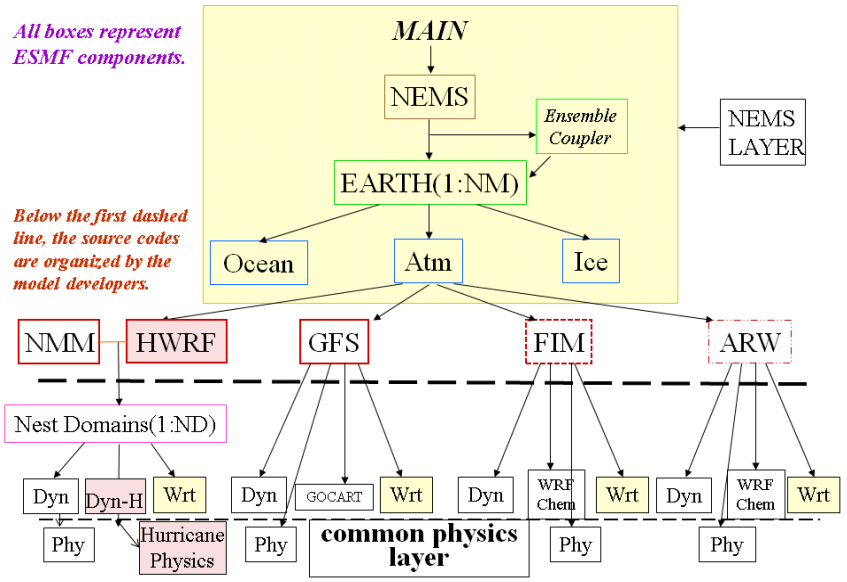
(b) Adopt NMM-B nests for hurricanes

(c) Global-to-local scale modeling system for hurricanes

3-year strategy for transitioning HWRF to NMM-B/NEMS framework:

1. **Transition existing operational HWRF capabilities**
2. **Transition basin-scale system with multiple moveable nests**
3. **Global-to-local scale modeling system for hurricanes in NMM-B global framework**

NEMS Component Structure

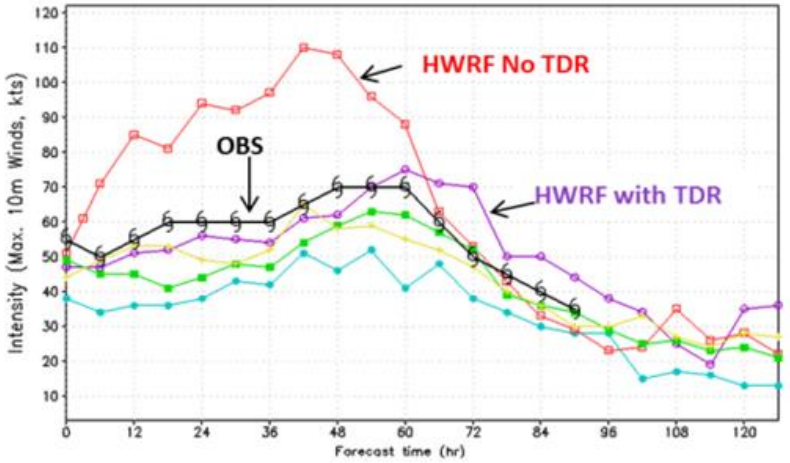


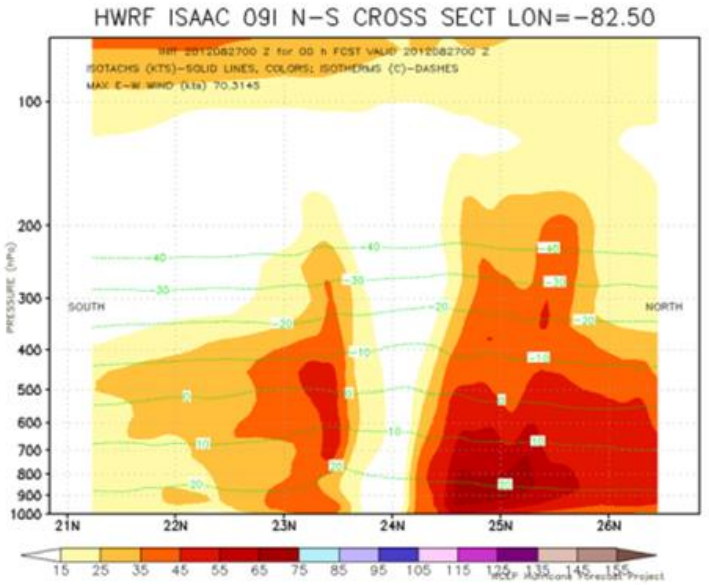
Resource requirements:

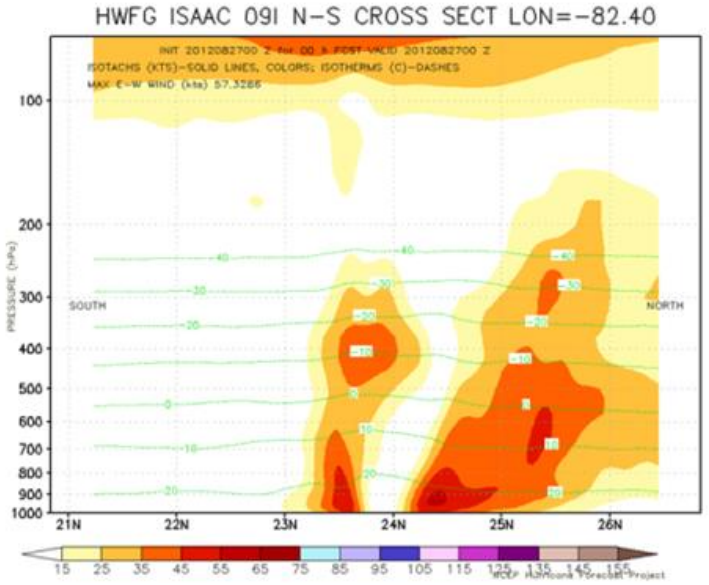
- Apart from computing resources, estimated human resources are of the order of 8 FTE for three years (includes transition and T&E) and sustained efforts then after.
- **Dual development strategy:**
  - Continue annual upgrades for HWRF until we have a stable, reliable and skillful hurricane model in NMM-B/NEMS framework
  - Requires extensive independent T&E setup specific to NMM-B/NEMS workflow

Impact of Radar Data

Hurricane Isaac with and without Tail Doppler Radar Data

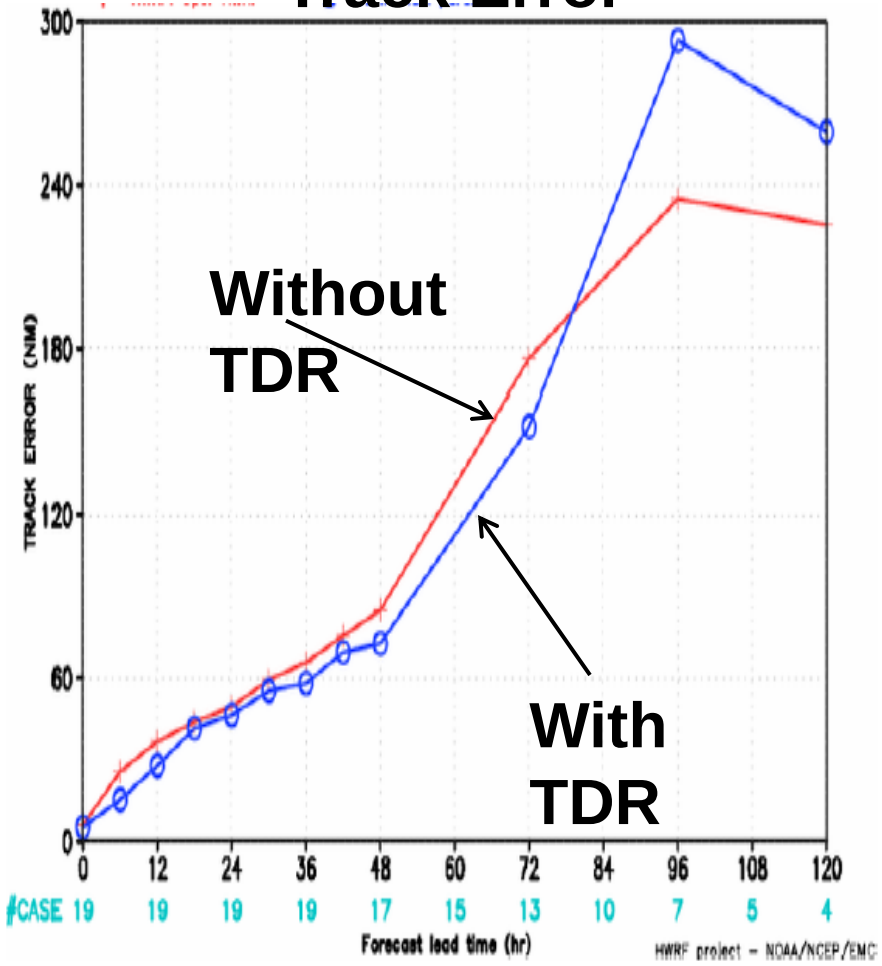




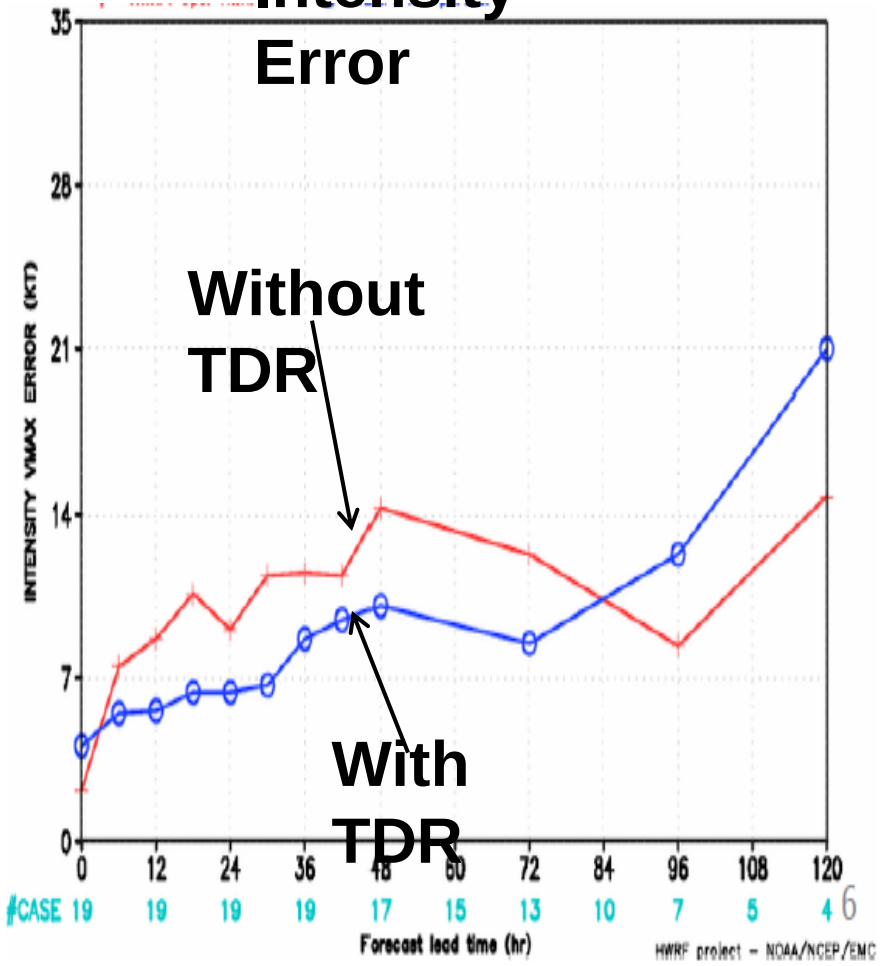


Impact of TDR Data In Operational HWRF

Track Error



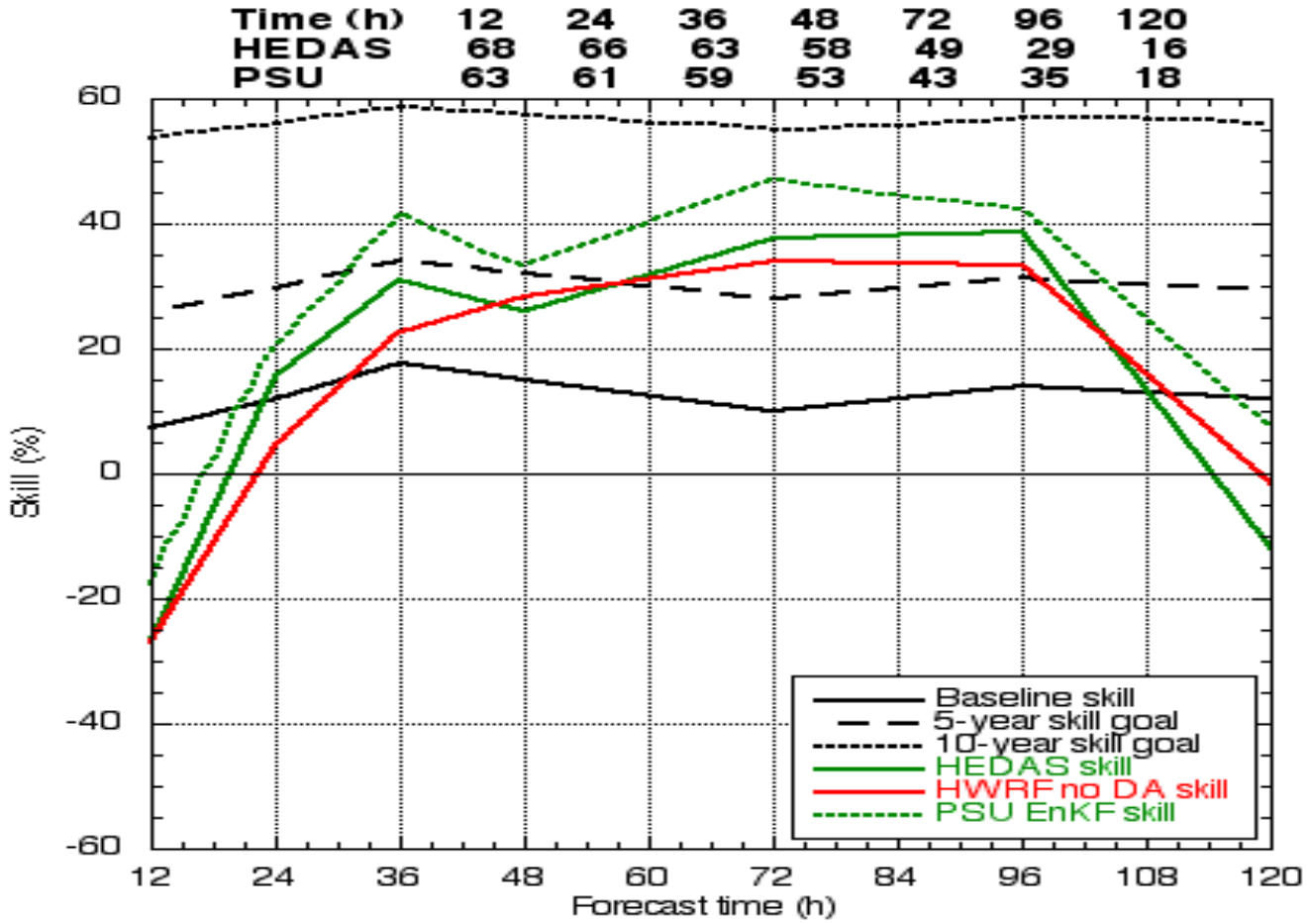
Intensity Error



Impact of Aircraft Data

(% improvement over Baseline (Skill))

All cases with radar data from 2008-2010 for ATL basin



Better Use of Satellite Data

Satellite Data
The hurricane initialization problem

- **HFIP has shown that high resolution data taken near the hurricane core and its near environment can significantly improve Intensity Forecasts.**
  - **This is particularly true for high resolution wind data (Tail Doppler Radar, TDR)**
  - **Flight level, dropsonde and SFMR surface wind data also important**
- **Currently available only when aircraft are within the Hurricane**
  - **Roughly only 10% of hurricane NWP initialization times**
  - **This is about 30% when storms are near the US coast**
- **Only other option for inner core data is Satellite data**
  - **Lower horizontal and vertical resolution than TDR**
- **Hurricane core is a highly challenging environment for satellite measurements**
  - **Heavy precipitation**
  - **Often completely overcast**
  - **Sharp gradients of cloudy and clear areas (e.g. eye wall) enhance probability of correlated errors and are often of the same horizontal scale as satellite footprints**

Satellite Data
Data Sources and Challenges

- **Goes Atmospheric Motion Vectors (AMV)**
  - **Height assignment is crude and significantly impacts data quality**
  - **Hourly time resolution may be useful with emerging 4-D hybrid assimilation**
  - **Probably the easiest to implement**
  - **Available all the time**

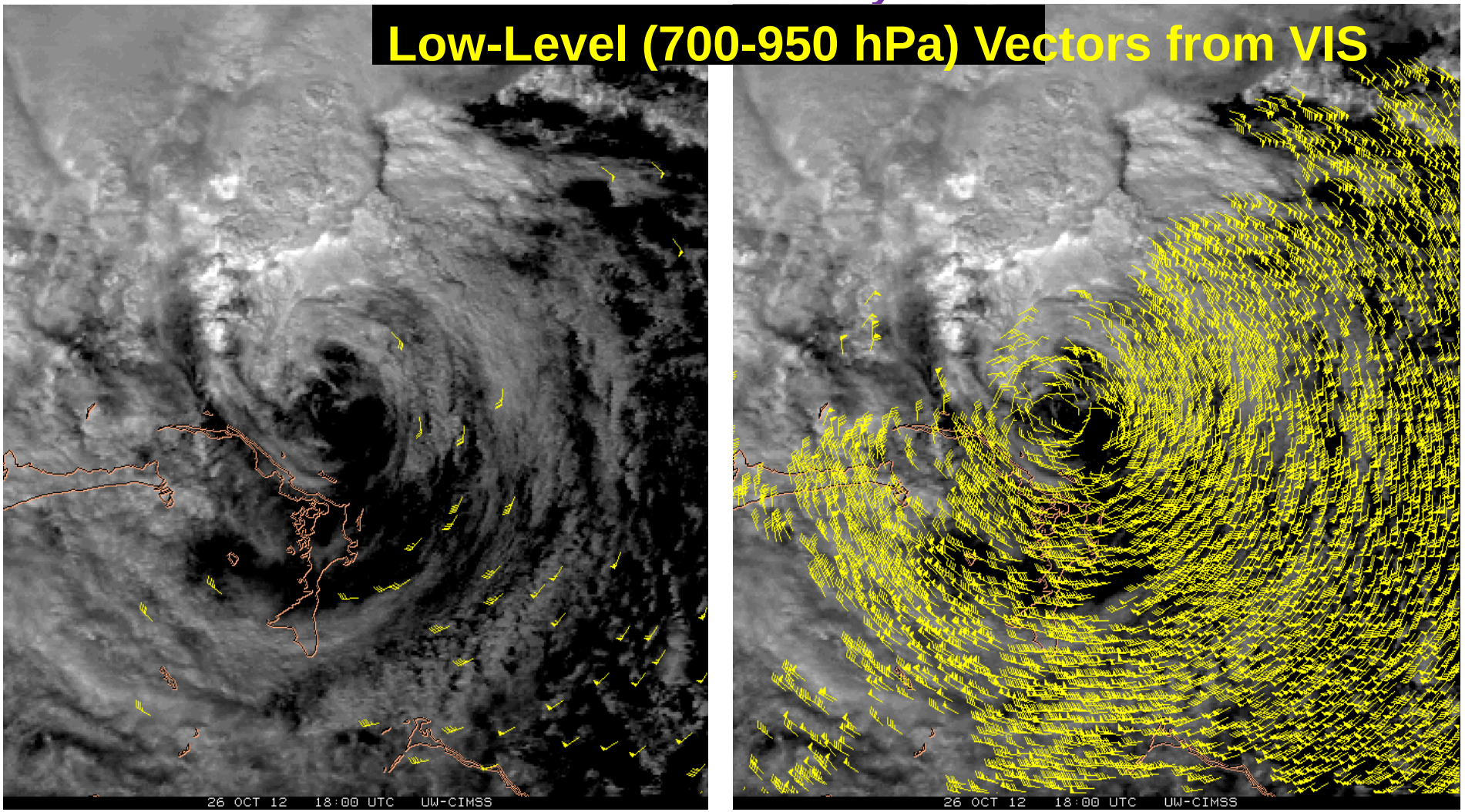
- **Scatterometer Surface Winds**
  - **From polar orbiters, not always available**
  - **Relatively easy to implement**

- **Microwave (MW) Sounders**
  - **From polar orbiters, not always available**
  - **Problems in heavy rain areas (absorption and scattering)**
  - **Some development required**

- **IR Sounders**
  - **Higher horizontal and vertical resolution than MW sounders**
  - **Works well in cloud free areas and above highest clouds**
  - **Much of hurricane region has significant clouds**
  - **HFIP has been working on use of this data in cloudy regions**
  - **This is a very difficult problem and will require considerable development**

Atmospheric Motion Vectors from GOES-R

Proxy: AMVs from special GOES-14 super-rapid-scan ops during *Hurricane Sandy*



AMVs from **15-min images** (routine **GOES** sampling)

AMVs from **1-min images** (meso **GOES-R** sampling)

1800 UTC 26 Oct. 2012

C. Velden (CIMSS)

Next Steps

HFIP Priorities 2013 - 2016

Operational Impact

- Continued development and demonstration of the Experimental Numerical Forecast System (real-time) during hurricane season on HFIP Boulder Jet System
- Determine the benefit from standard reconnaissance data (flight level, dropsondes, SFMR) and the addition of Doppler Radar
- Demonstrate Impact of Multi-model ensembles for Track and Intensity

Research and Development

- Best use of limited TDR flights operationally
- Improve use of Satellite data in hurricane DA
- HWRF Physics
- HWRF GSI hybrid DA
  - Basin scale HWRF
  - High resolution inner domain/vortex scale

Technical Advancements

- Convert HWRF to NMM and optimize code for application of accelerator technologies

Questions?

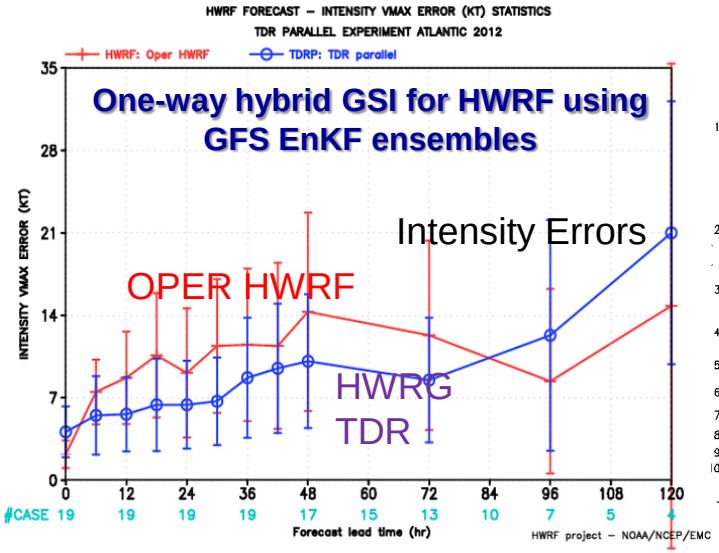
Backup Slides

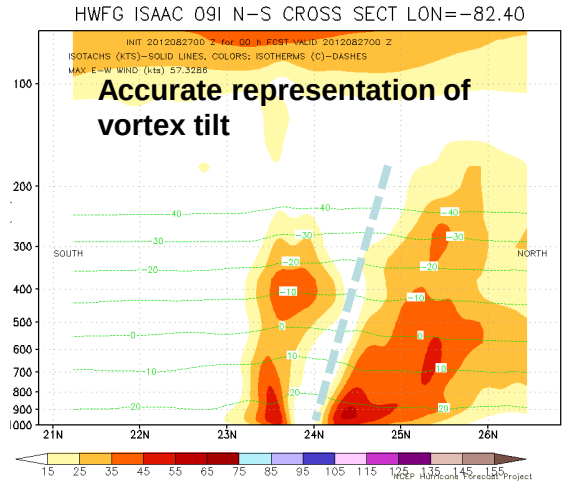
Recent HWRF Results

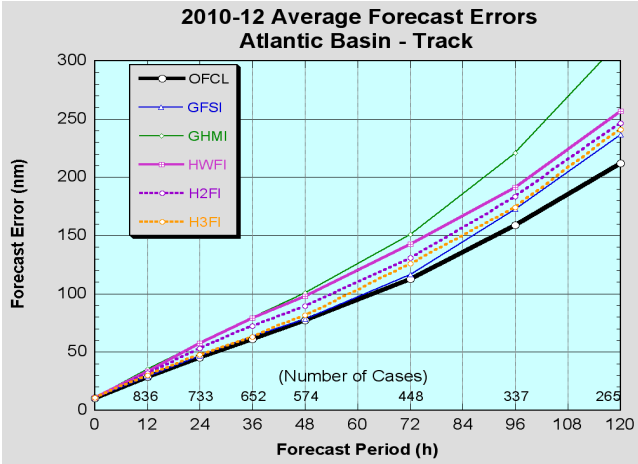
Further advancements to FY13 HWRF for improved track, intensity and structure forecasts

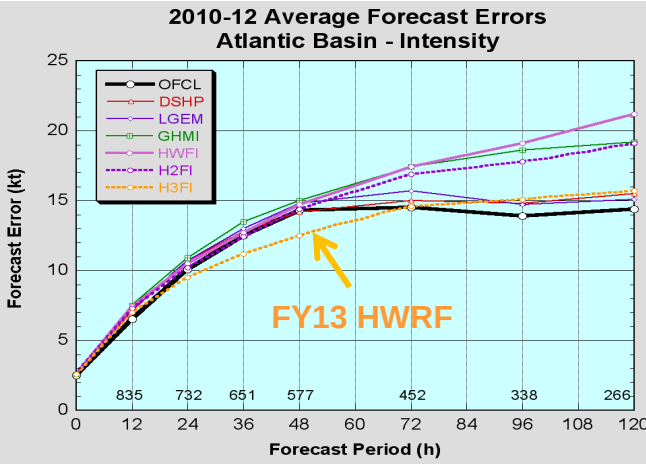
Advanced High resolution (3km)Triple Nested HWRF for 2013 Hurricane Season to be implemented on WCOSS

- Implementation of One-Way Hybrid Global EnKF-Regional 3DVAR GSI DA
- Improved vortex initialization, nest motion algorithm and nesting techniques
- Improved physics and air-sea interactions
- Improved product quality and enhanced synthetic satellite imagery
- Track Skill comparable to GFS, Intensity Skill superior to Official forecasts and statistical models



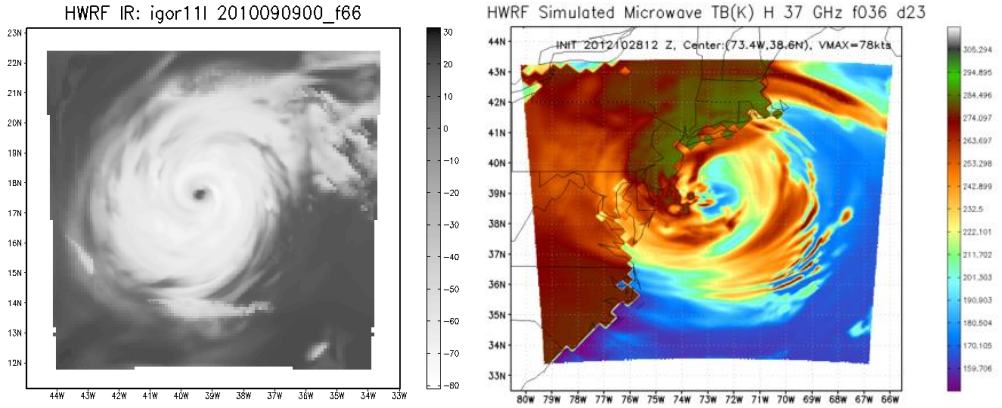






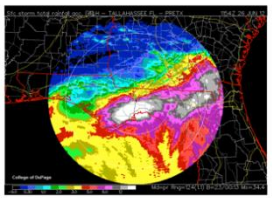
Advanced Real-Time Products from Operational HWRF

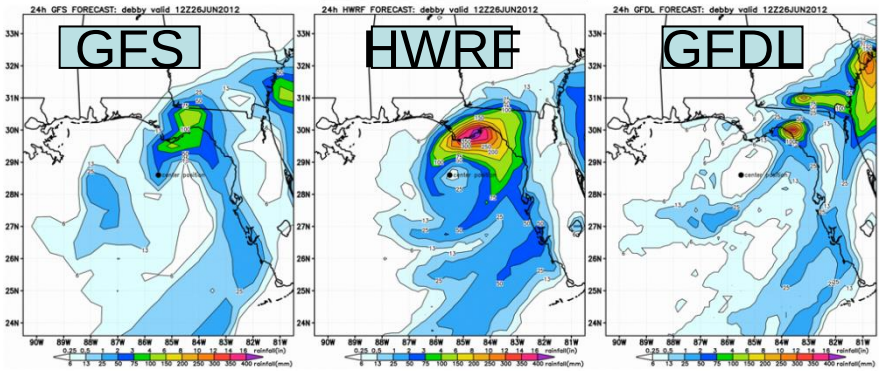
- High-Resolution synthetic satellite imagery (IR and Microwave)
- High temporal resolution track, intensity and structure forecasts
- Advanced inner core and large-scale diagnostics
- Swaths for maximum wind and rainfall, SHIPS predictors, 24-hr QPF, TPW, OHC, SST cooling
- Advanced verification tools to make use of all available observations (aircraft recon, TDR, AXBTs, buoy data and remote sensing satellite data)

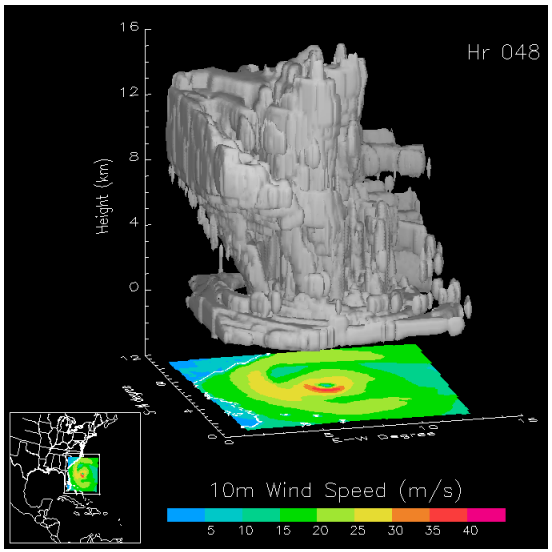


Research quality forecasts for real-time operations

NHC Rainfall Product (below), and verifying radar-estimated rainfall totals (right).



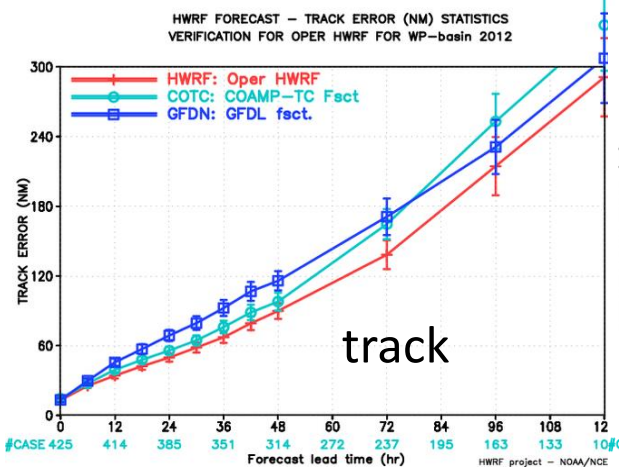


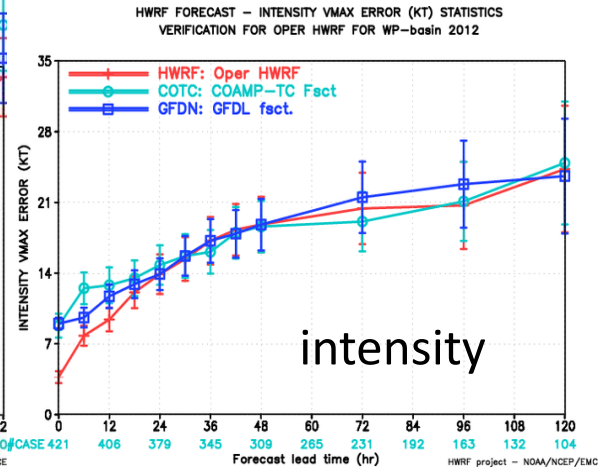


HWRF in the Western Pacific Basin in support of JTWC Operations (supported by HFIP)

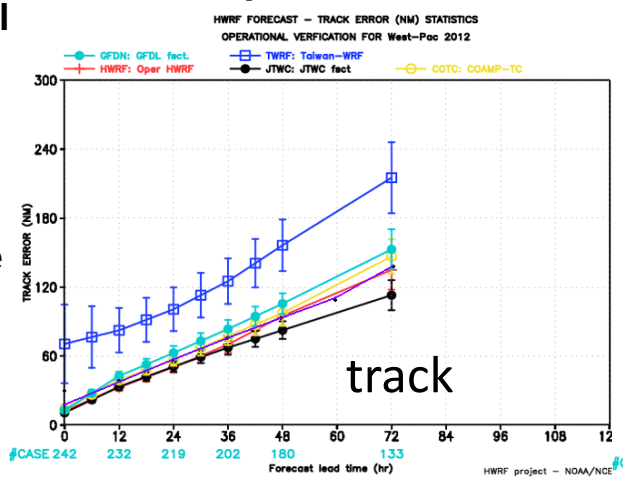
- HFIP's collaborations with JTWC to extend our emerging capabilities to other critical operational centers.
- For the first time, starting with 2012 typhoon season, EMC HWRF Team is delivering real-time guidance to JTWC forecasters for Western Pacific Typhoons using dedicated reservations on HFIP computing. Products delivered directly to JTWC and through EMC HWRF website.
- 85% on-time delivery of forecasts in a quasi-operational setting.
- FY12 HWRF for WPAC basin demonstrated superior forecast skill compared to other regional model guidance from FNMOC and other international agencies operating in that region.
- We will continue providing real-time guidance to JTWC, CPHC and NWS Pacific Region for 2013 season using upgraded FY13 HWRF.

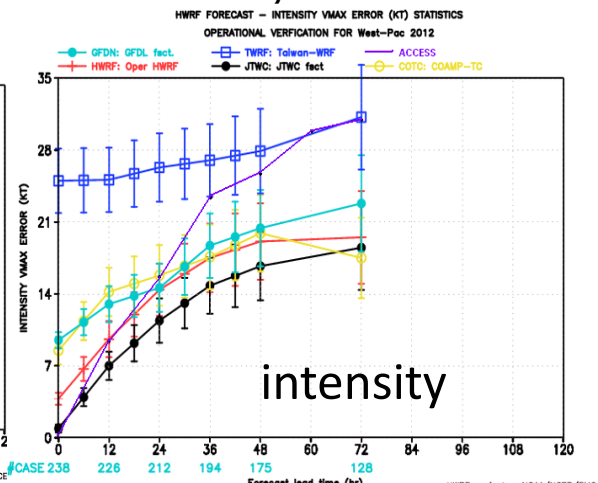
West-Pac HWRF compared to Navy Models (COAMPS-TC and GFDN)





West-Pac HWRF compared to other operational regional models (TWRF-Taiwan and ACCESS-TC, Australia

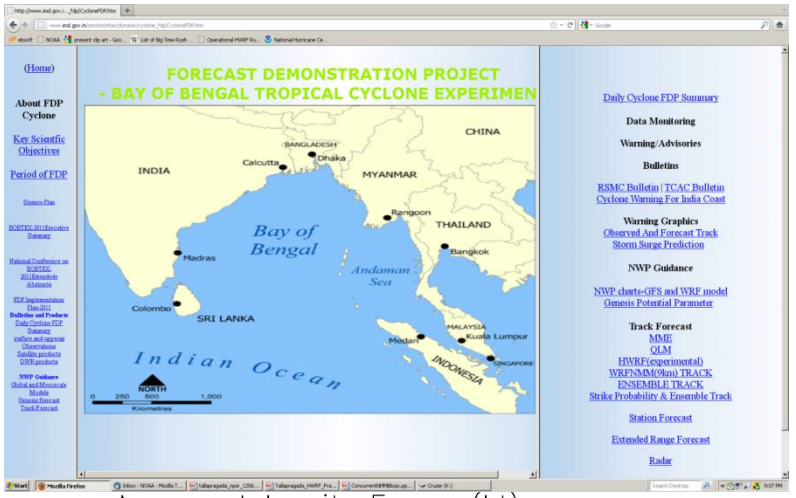


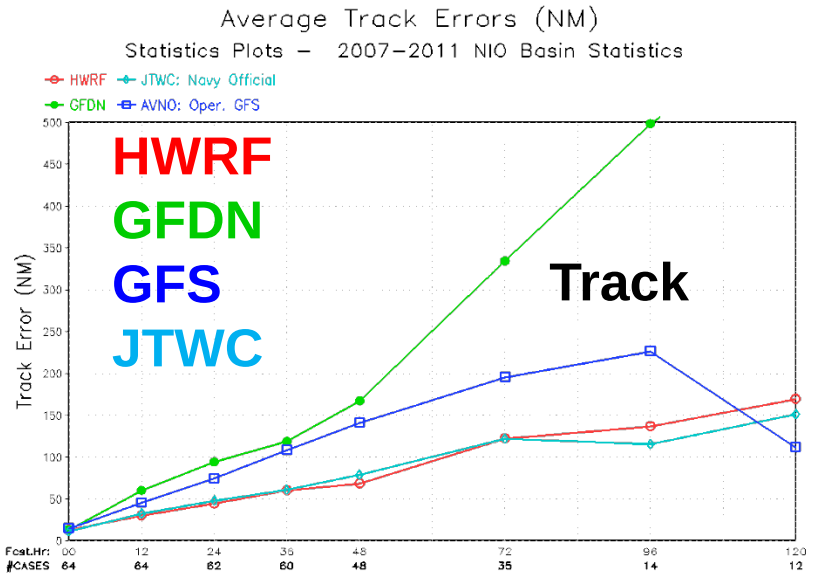


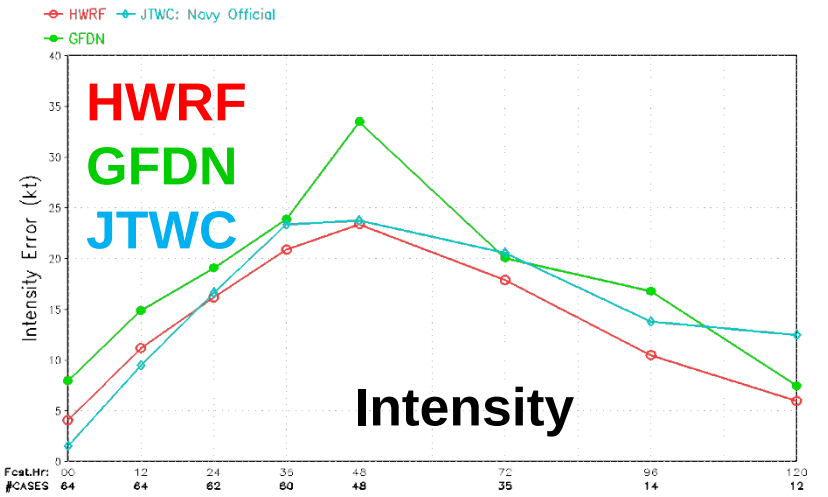
Expanding the scope of operational HWRF for World Oceanic Basins through International Collaborations

- HWRF operational in India for Tropical Cyclone Forecasts for the North Indian Ocean through support from Indo-US Science and Technology Forum and NOAA-MoES bilateral MoU and IA. Two IMD scientists to visit EMC this summer
- HWRF implemented at Shanghai Typhoon Institute, China for Western Pacific basin. STI sending a visiting scientist to EMC in May.
- HWRF implemented in Vietnam for Western Pacific basin
- HWRF will be implemented in Taiwan for real-time applications in 2013
- Oman expressed interest in HWRF for applications in the Arabian Sea

Operational implementation of HWRF by India Meteorological Department







Science Review Committee

HFIP Scientific Review Committee: Recommendations*

- Revisit Intensity Goals
  - Present intensity goals are unreachable and/or impossible; reduction of the largest error (e.g., 90th percentile) error values may be more meaningful
  - Consider metrics for defining size and shape of storm, and/or accuracy of the precipitation field structure

- Improve HFIP Model Physics and Initialization
  - Broaden capabilities in HWRF for idealized simulations
  - Improve model physics and vortex initialization focusing on microphysics, boundary layer structure, and turbulent mixing -- not ocean and air-sea coupled modeling
  - Develop a self-consistent, flow-dependent data assimilation system

- Further Integrate the HFIP and HWRF Efforts with Community
  - Initiate a visiting scientist program at NOAA laboratories
  - Be open minded, accept criticism, and willing to restructure modeling frameworks if necessary

* Response in development

Appropriation History
(2009-2014)

	FY09	FY10	FY11	FY12	FY13	FY14 (PB)
WCOSS PAC (HFIP	6.000M	3.000M	3.000M	4.000M	2.000M	4.000M
NWS ORF	*15.040*M	*14.040M	*14.044M	*14.044M *8.540M Due to NWS reprogramming	* **14.044M	* **14.044M
OAR ORF	6.100M	6.100M	6.100M	6.000M	5.800M	5.800M
TOTAL	**$*27.140M**	**$*23.140M**	**$*23.144M**	**$*18.540M**	**$*22.040M**	***24.044M**

** OMB Restored NOAA and DOC proposed reductions

NHC Endorsement

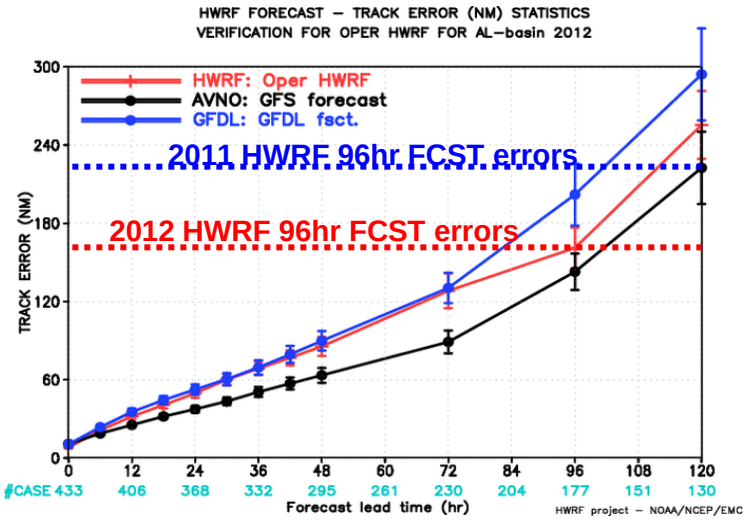
NHC has reviewed the performance of the proposed HWRF implementation for 2013. The model has been extensively tested on a three-year sample of cases with very impressive results. **For Atlantic basin track, the HWRF is improved by ~5-15% and now appears competitive with the GFS. For intensity, the model reduces errors by ~15%, has demonstrated skill greater than that of the NHC official forecast and greater than that of the statistical models. These are remarkable results and Rick has asked me to relay NHC's strong endorsement for implementation of the upgraded HWRF for the 2013 season**.

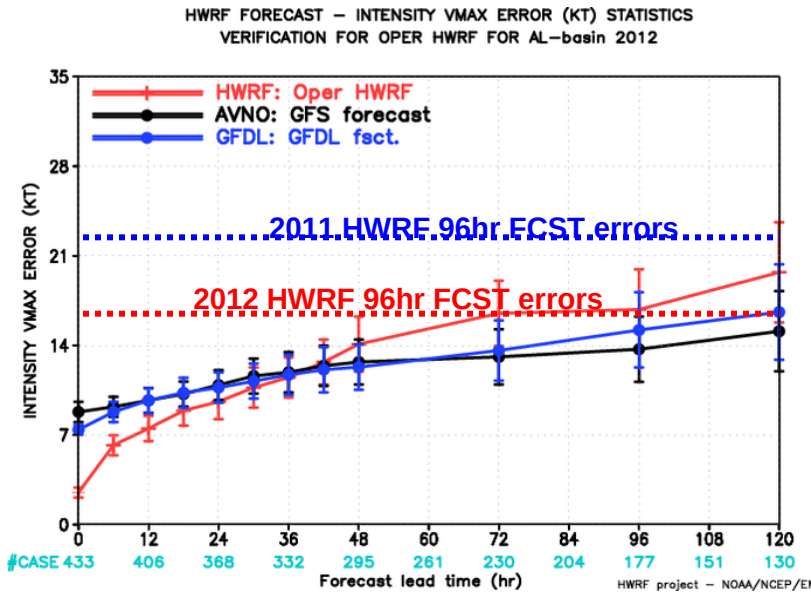
Congratulations on a tremendous effort. NHC is eager to see the new model in operations as soon as possible.

-- James Franklin

FY2012 Implementation of High-Resolution 3km Triple-Nested HWRF – Major Step towards improved forecasts

- ***For the first time, a high-resolution hurricane model operating at cloud-permitting 3km resolution implemented into NCEP operational system***
- **This upgrade is a result of multi-agency efforts supported by HFIP**
- ***EMC**: Computational efficiency, nest motion algorithm, physics improvements, 3km initialization and pre-implementation T&E*
- ***HRD/AOML**: nest motion algorithm, PBL upgrades, interpolation for initialization,*
- ***DTC/NCAR**: code management and repository, MPI profiling.* **Operational HWRF modeling system in the community framework supported by DTC since 2010.**
- ***ESRL**: Physics sensitivity tests*
- ***URI**: 1D ocean coupling in East Pac*
- ***GFDL**: Knowledge sharing, joint T&E*
- ***NHC**: Diagnostics and evaluation of the HWRF pre-implementation tests and real-time guidance*





Progress of Operational HWRF To-Date