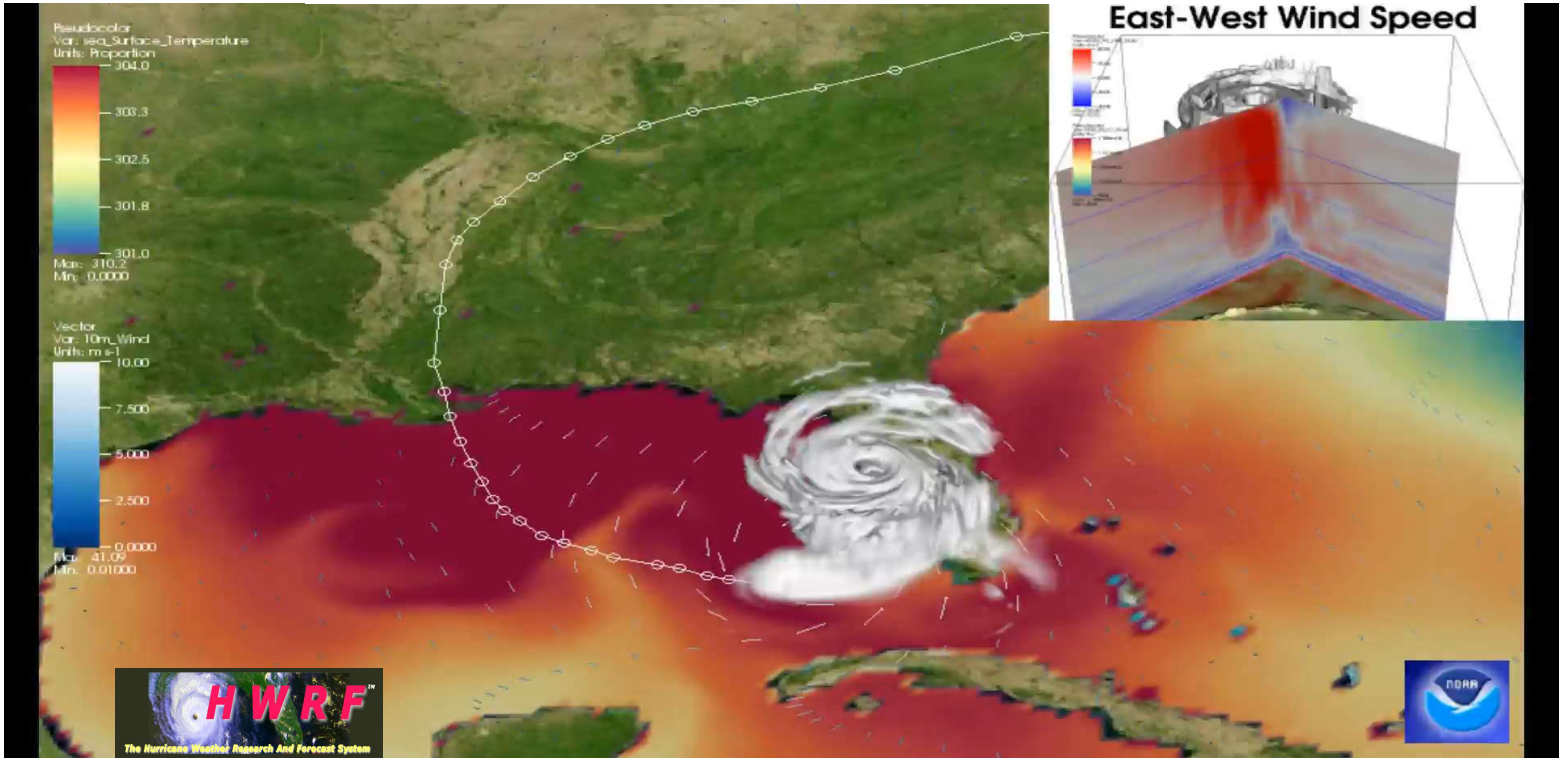
Advancements in Operational Tropical Cyclone Forecast Guidance from NOAA/NCEP' Operational Models: *Current Status and Future Plans*

NOAA HURRICANE FORECAST IMPROVEMENT PROJECT



Rapid Progress in Hurricane Intensity Forecast Improvements

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NCEP Operational Models for Tropical Cyclone Forecast Guidance

- Deterministic forecast guidance
  - Hurricane Weather Research and Forecast System (HWRF)
  - Geophysical Fluid Dynamics Laboratory Hurricane Model (GFDL)
  - Global Forecast System (GFS)

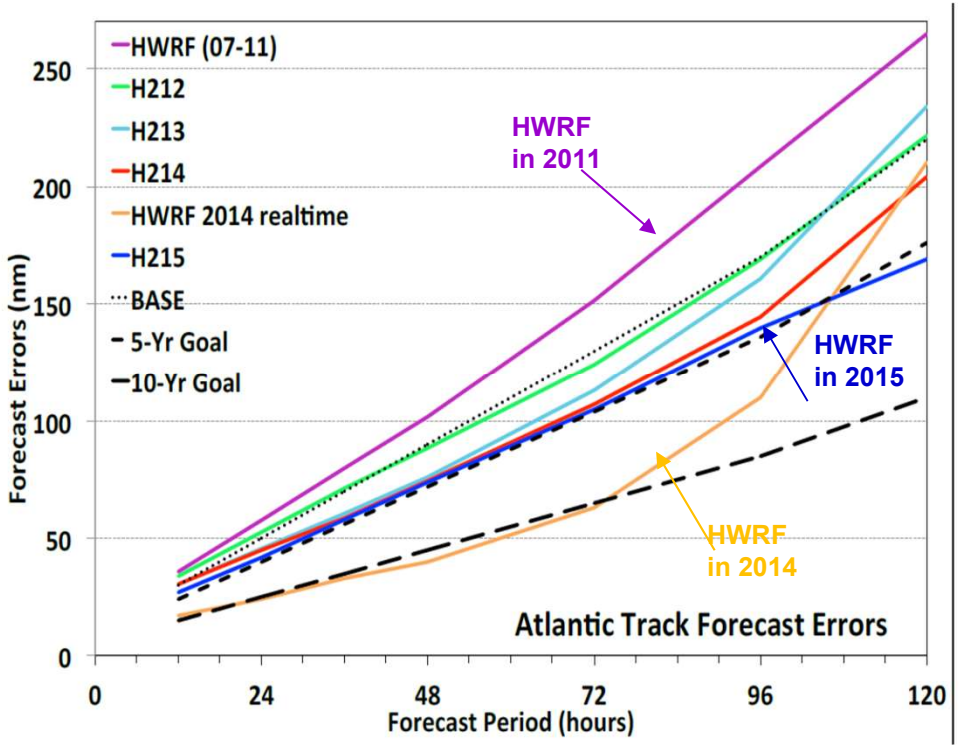
- Ensemble forecast guidance
  - Global Ensemble Forecast System (GEFS)

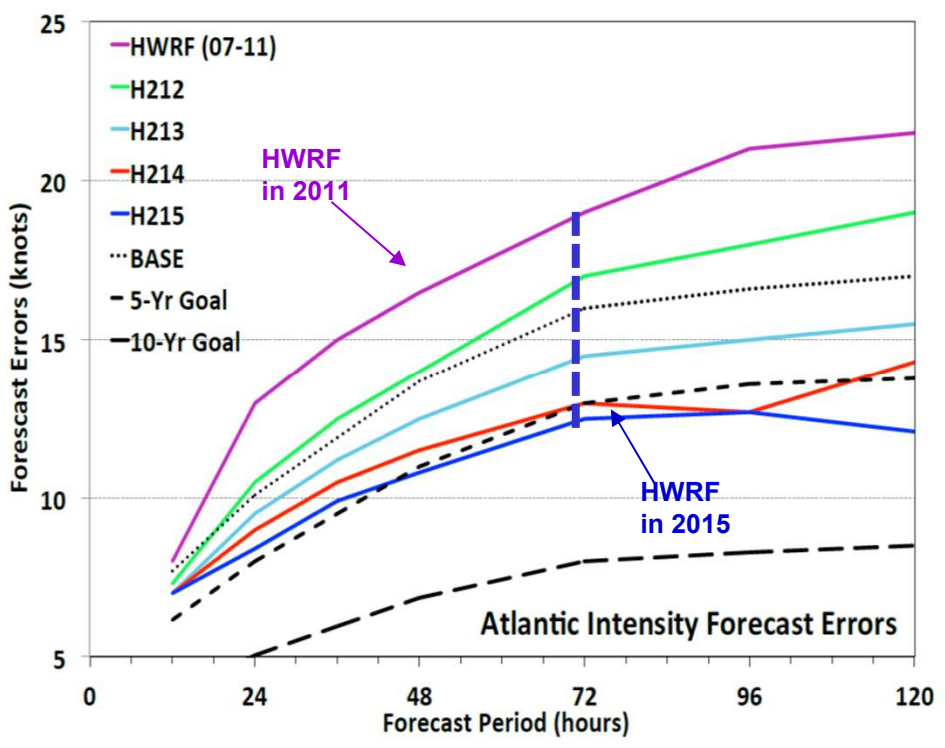
- HFIP supported NWP models
  - Experimental Multi-model High-Resolution Regional Ensemble System (20-member HWRF + 10-member COTC + 10-member GFDL)
  - Other experimental deterministic models: various versions of ARW and HWRF, GFDL, Univ. Wisconsin, COAMPS-TC

Hurricane Weather Research and Forecast (HWRF) Modeling System

- Unique regional model with global coverage
  - High-resolution triple nested atmosphere-ocean coupled system operating at 18/6/2 km providing 126-hr forecast guidance for all tropical cyclones in the world
  - On-demand modeling system run for as many as 7 storms including invests
  - Advanced vortex initialization and inner core data assimilation system ingesting many in-situ observations including NOAA P3 TDR and dropsondes from various reconnaissance aircrafts (NOAA P3, G-IV, AF-C130 and Global Hawk)
  - Annual upgrades focused on continuous advancements to the modeling system for improved TC track, intensity, structure, size and rainfall predictions with increased focus on Rapid Intensity forecasts
  - Special forecast products including synthetic satellite imagery, swaths of wind/rain and IC/BC for hurricane waves

Significant improvements in Atlantic Track & Intensity Forecasts





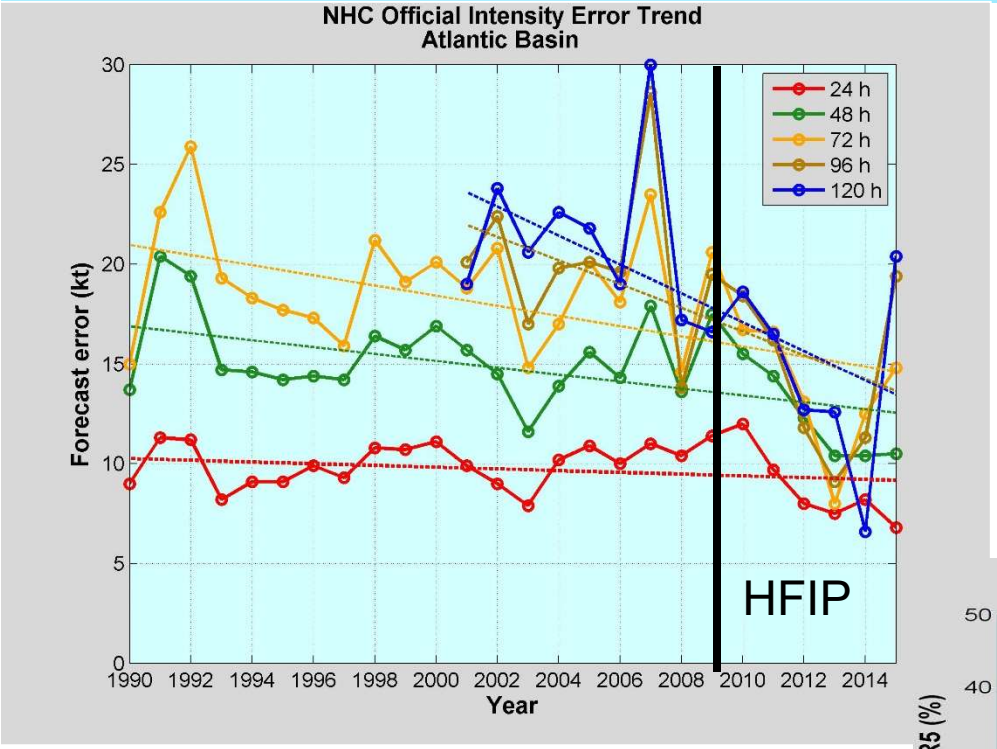
Improvements of the order of 10-15% each year since 2012

What it takes to improve the models and reduce forecast errors???

- **Physics**
- **Data Assimilation**
- **& Higher Resolution**

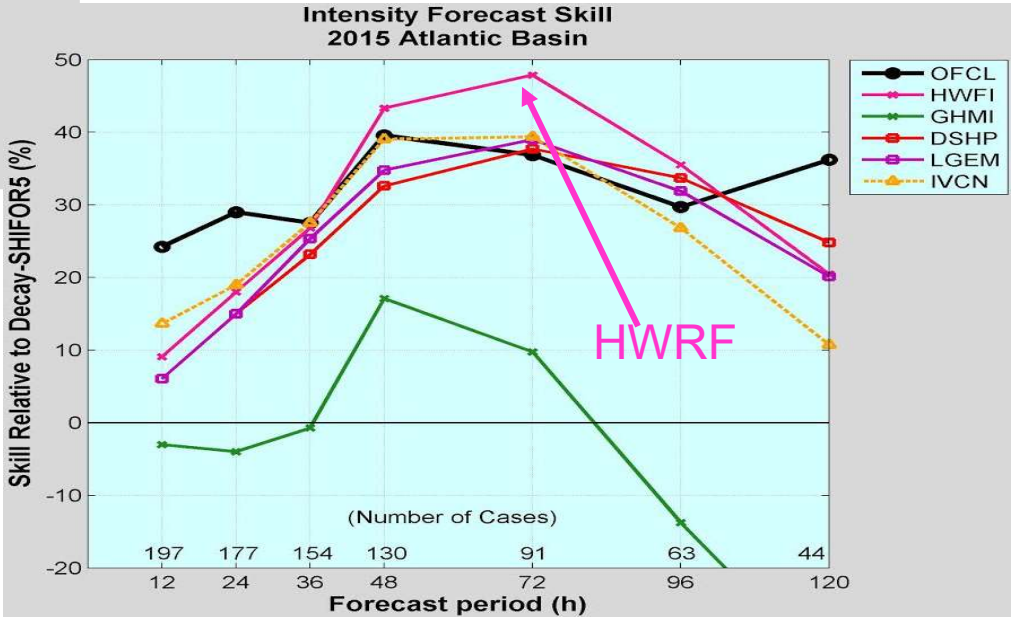
Targeted research and development in all areas of hurricane modeling

Highlights for 2015: Intensity forecast improvements realized in real-time from operational HWRF



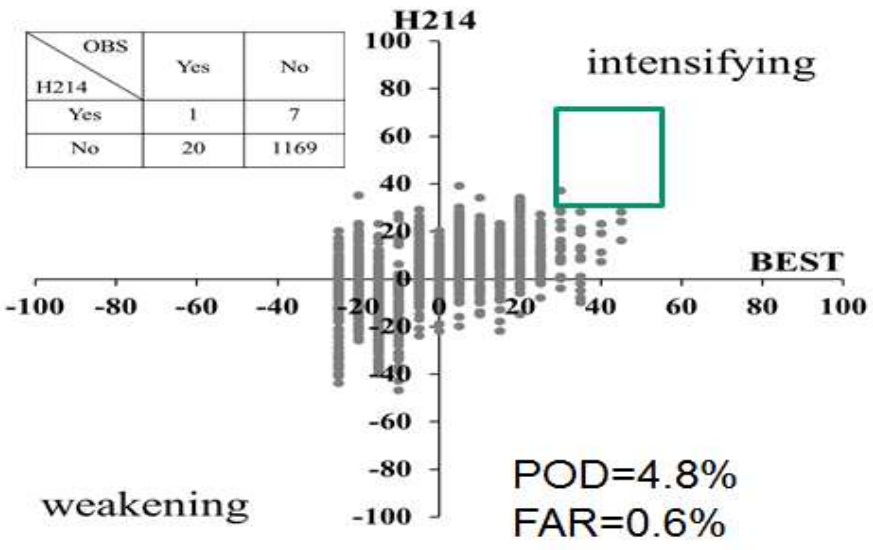
Long term trends show slow improvement in intensity forecasts.

HWRF intensity forecast skill highest among other model guidance for 2015

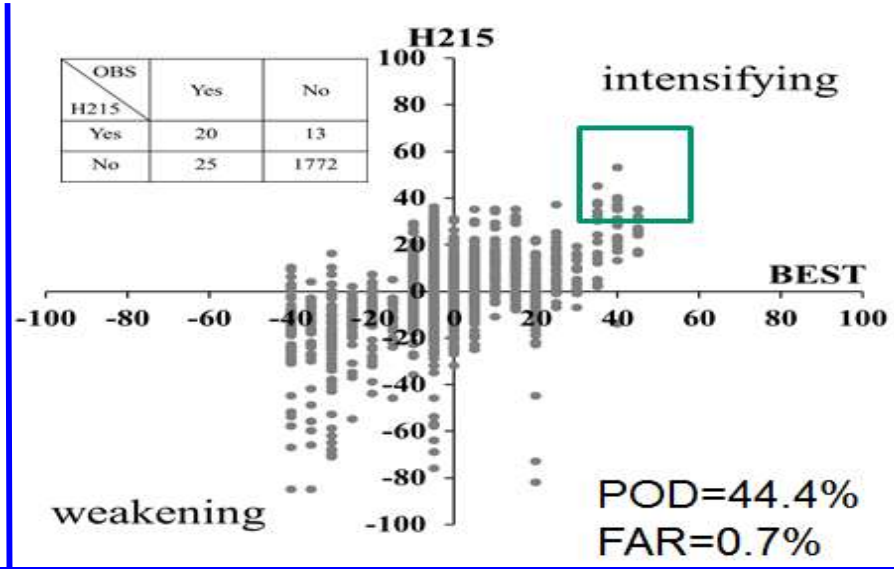


Courtesy: James Franklin & Eric Blake, NHC

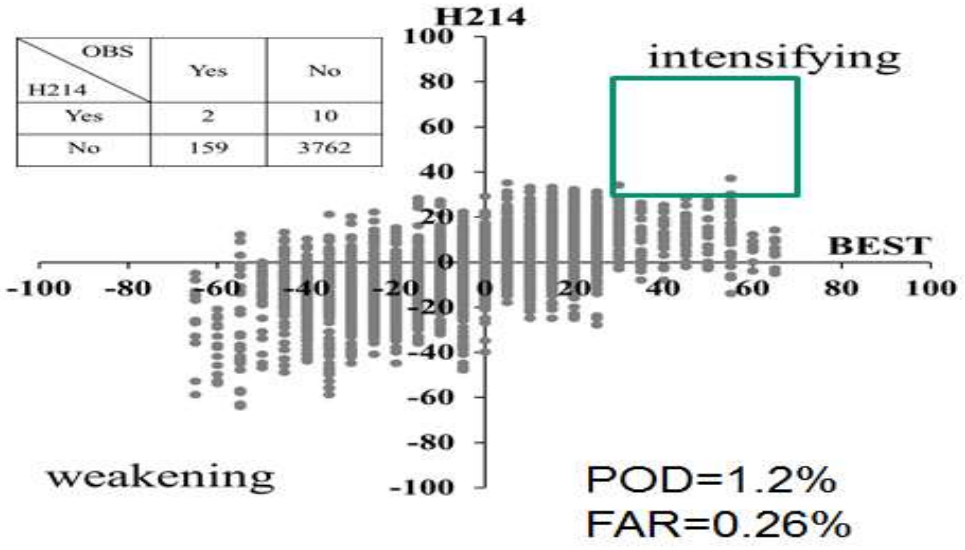
Improvement in RI Forecasts:
North Atlantic and Eastern Pacific Basins



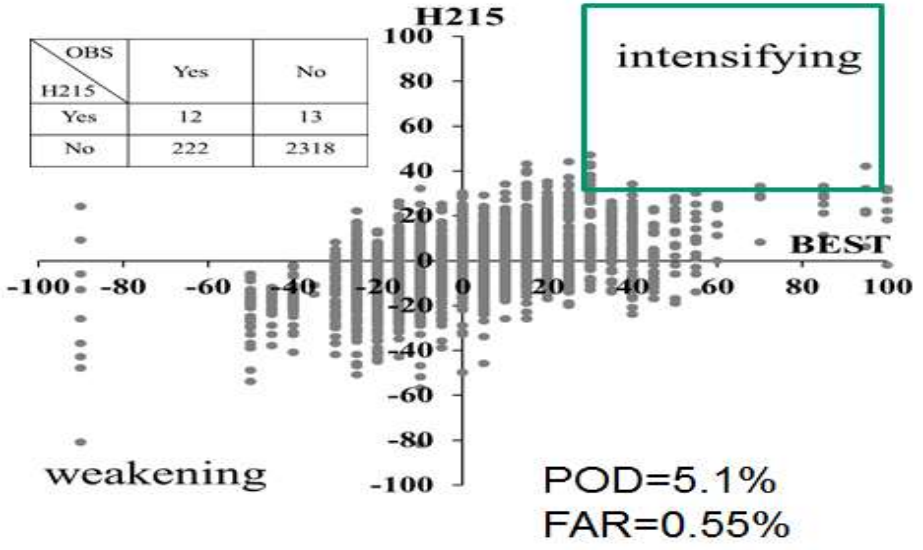
OBS / H214	Yes	No
Yes	1	7
No	20	1169



OBS / H215	Yes	No
Yes	20	13
No	25	1772



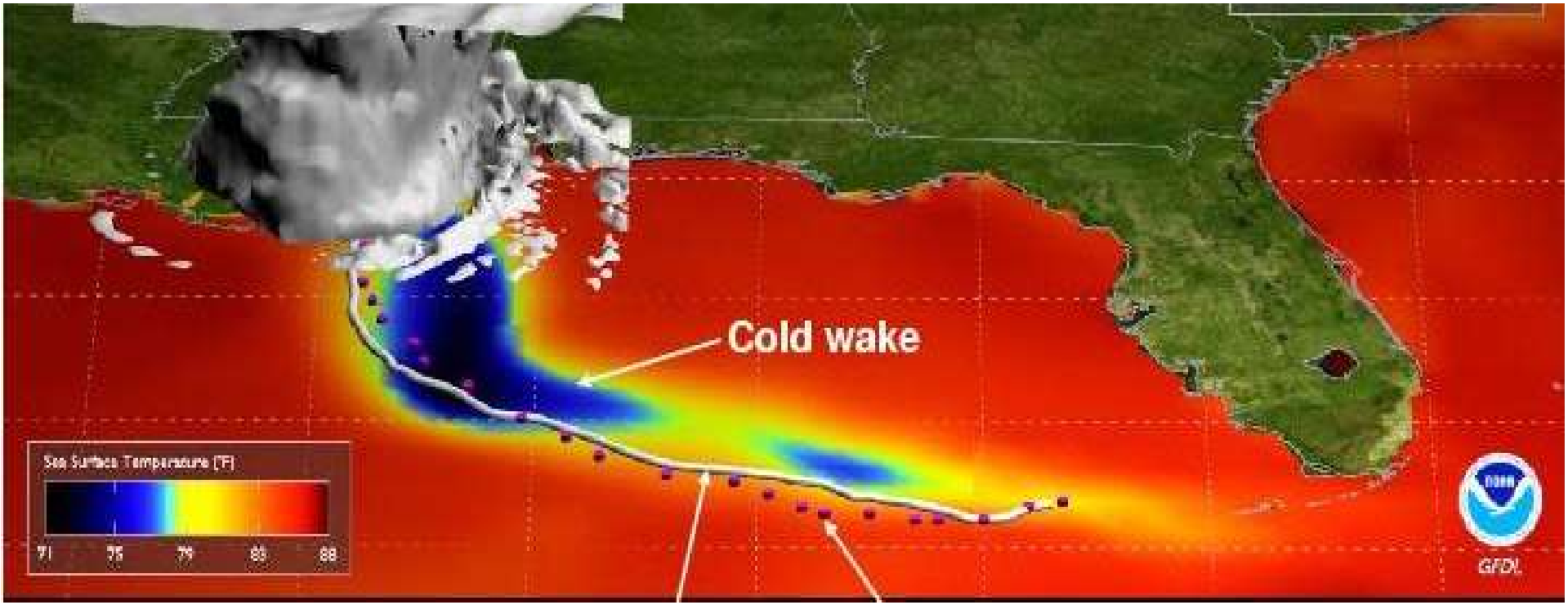
OBS / H214	Yes	No
Yes	2	10
No	159	3762



OBS / H215	Yes	No
Yes	12	13
No	222	2318

NWS GFDL Hurricane Forecast System

Morris Bender and Timothy Marchok NOAA/GFDL

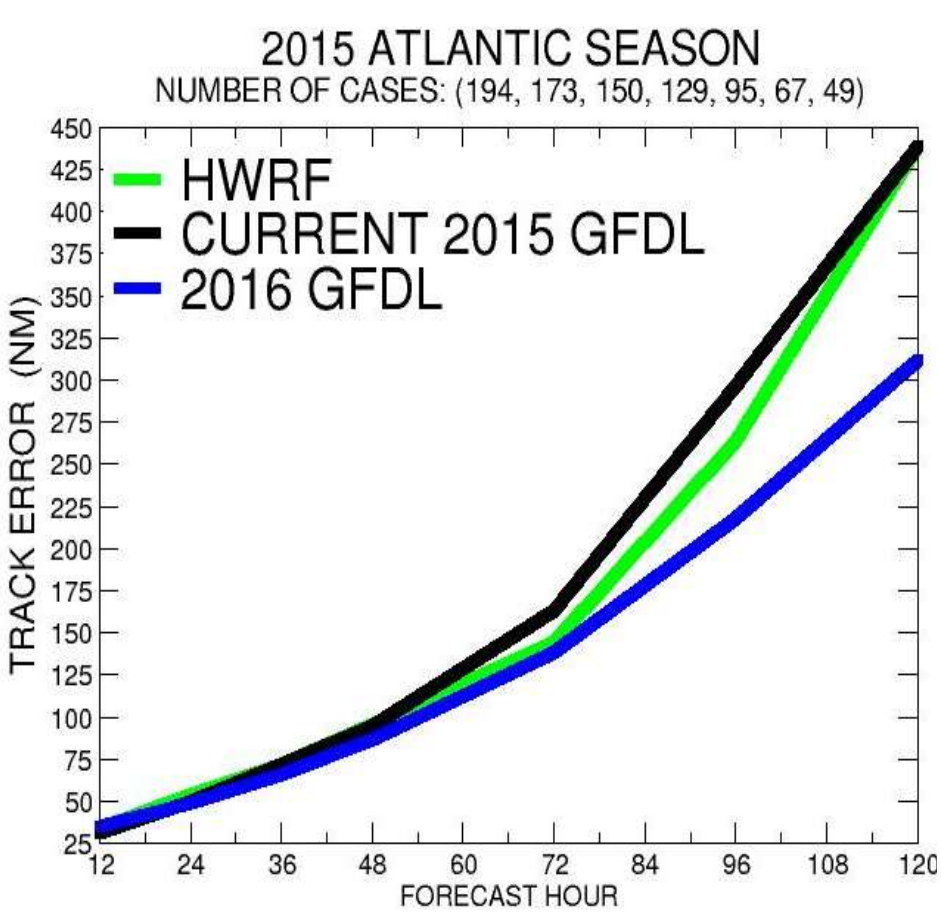


- Operational hurricane forecast model for over two decades serving NHC and JTWC
- Atmosphere-Ocean Coupled system operating at 18/6 km resolution
- Supported by JHT and HFIP to serve research and operations
- Participating in HFIP regional ensemble system

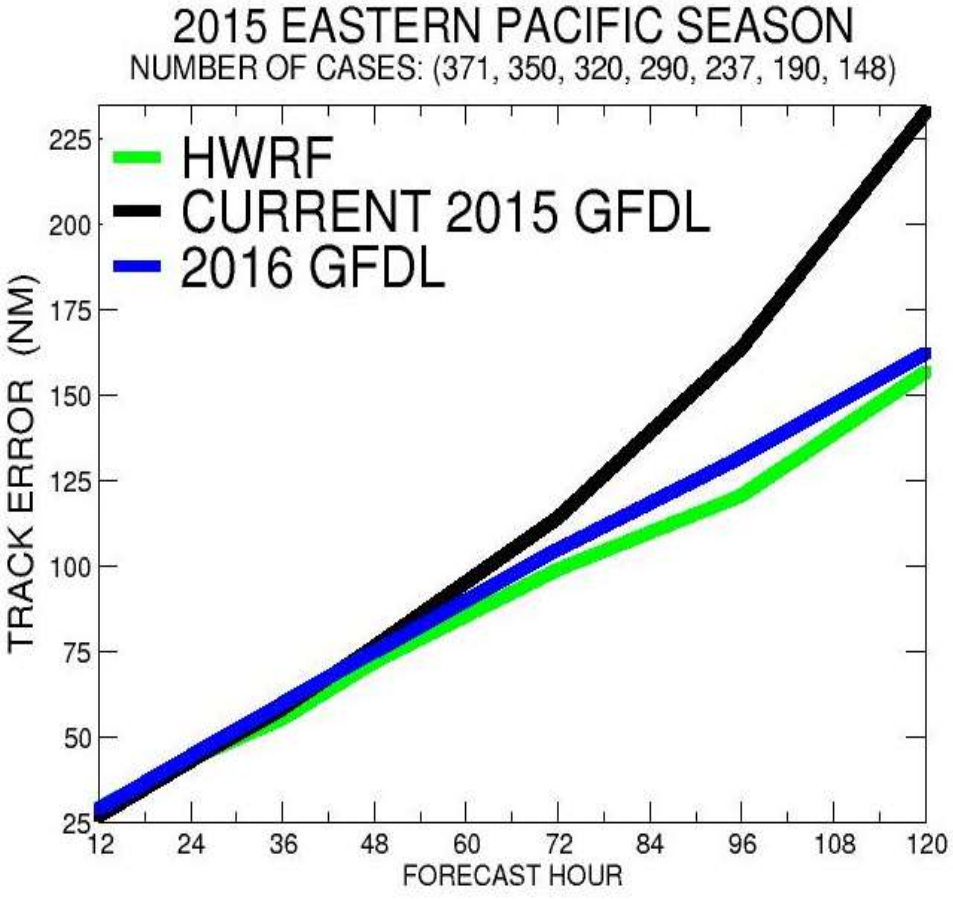
Upcoming changes to the GFDL Model:

Significantly Reduced Track Error in 3-5 day forecast lead times

2015 Atlantic



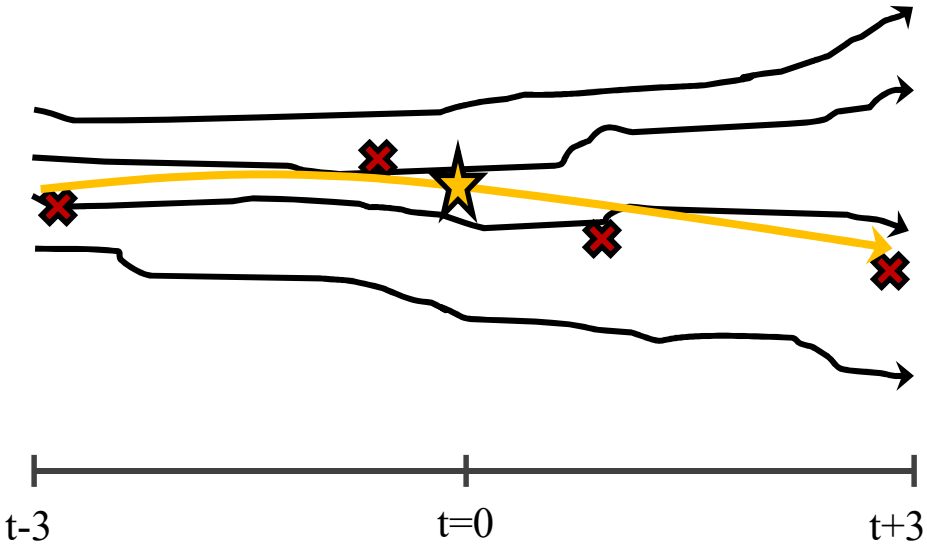
2015 Eastern Pacific



Next GFS/GDAS in 2016: The 4D Hybrid En-Var

- 4-D hybrid
- All-sky AMSU-A Radiances
- SATWND ob changes
- CRTM v2.2.1
- Aircraft ob changes
- Modified thinning/weight in time
- Bug fixes and optimization for GSI
- New ob monitoring
- Upgrade data assimilation monitoring package

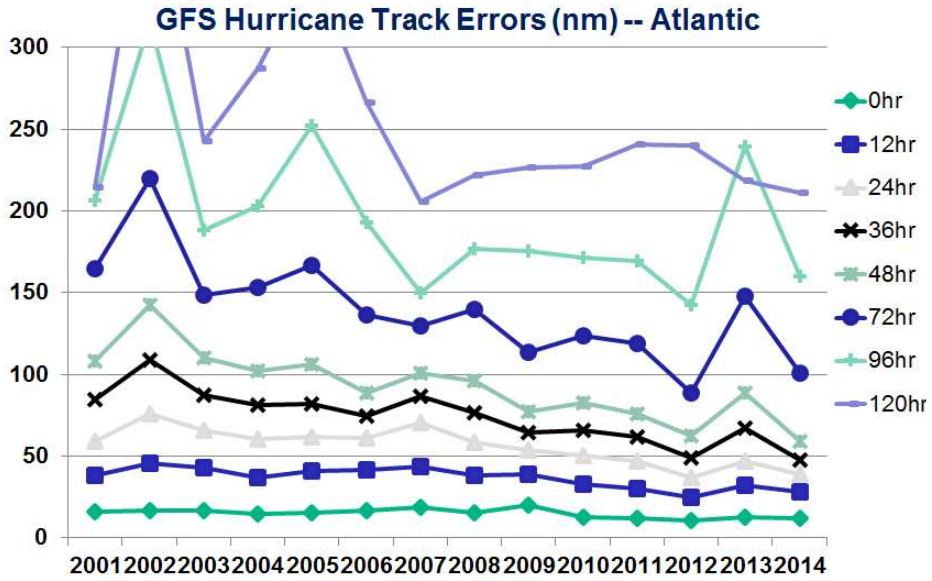
4D Schematic

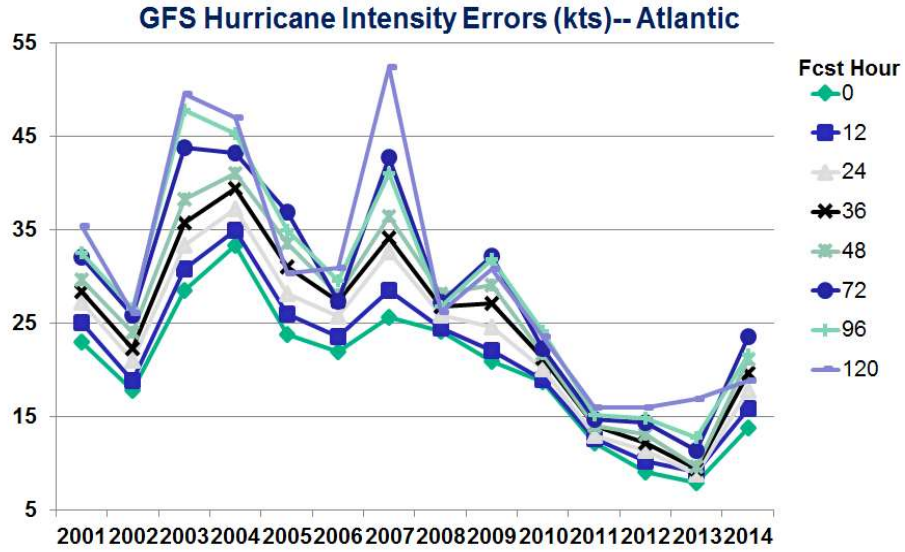


- 4D increment constructed by figuring out best combination of 4D ensemble perturbations
- Weights constant throughout window
- Use temporal correlations within each member to extract time information in obs

NCEP Global Forecast System (GFS)

Historical performance of GFS for Atlantic Hurricane Forecasts



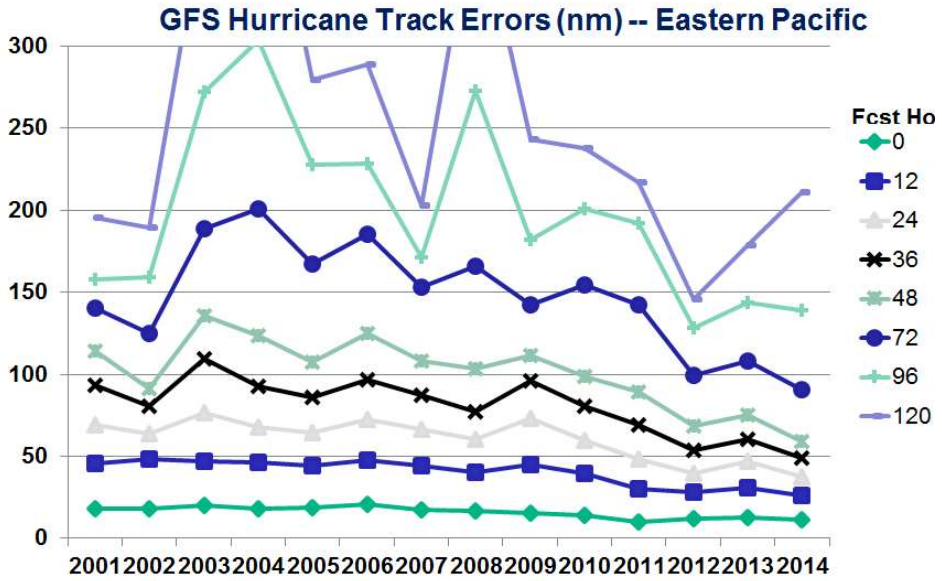


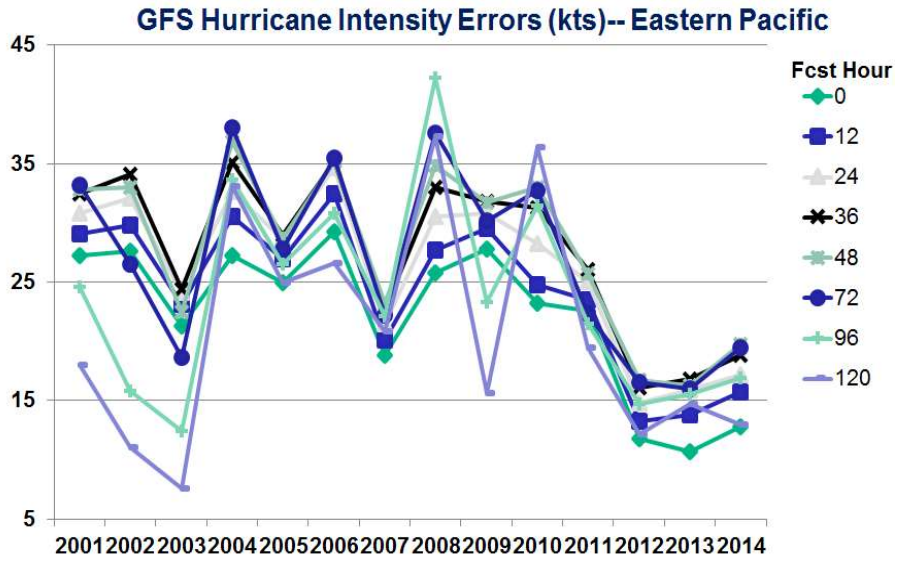
Tracks for all forecast lengths have been improved in the past 14 years; 72-hr track error reduced from 200nm to 100nm

Intensity improved in 2010 and 2011 due to GFS resolution increase from 35km to 23km; and in 2012 and 2013 due to ENKF-3DVAR GSI Implementation in May 2012

NCEP Global Forecast System (GFS)

Historical performance of GFS for Eastern Pacific Hurricane Forecasts



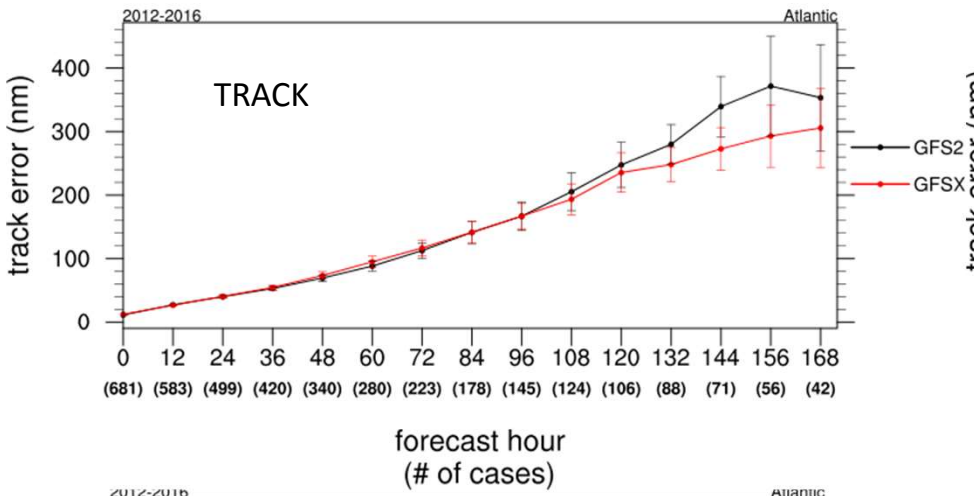


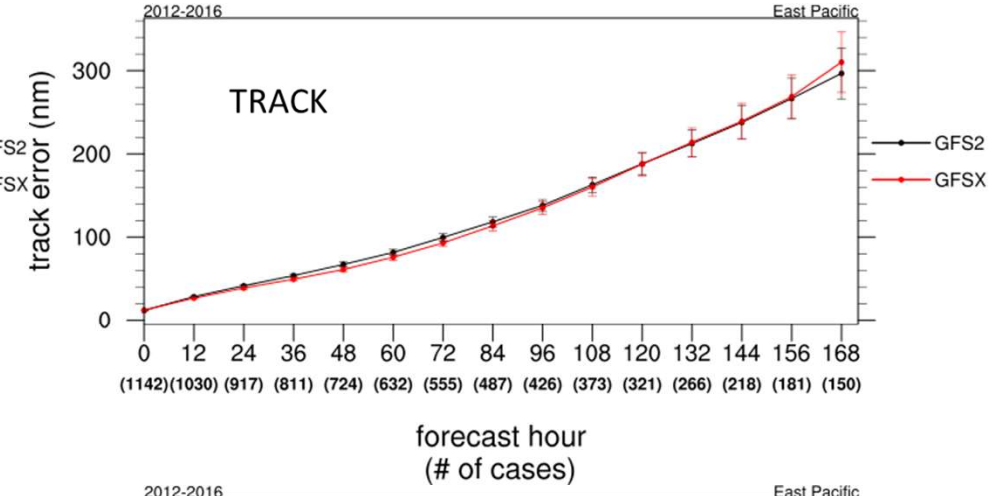
Significant track error reduction in the past 14 years. 36-hr track error reduced from 100nm to 50nm; 72-hr track reduced from 200 to 100 from 2004 to 2014 !

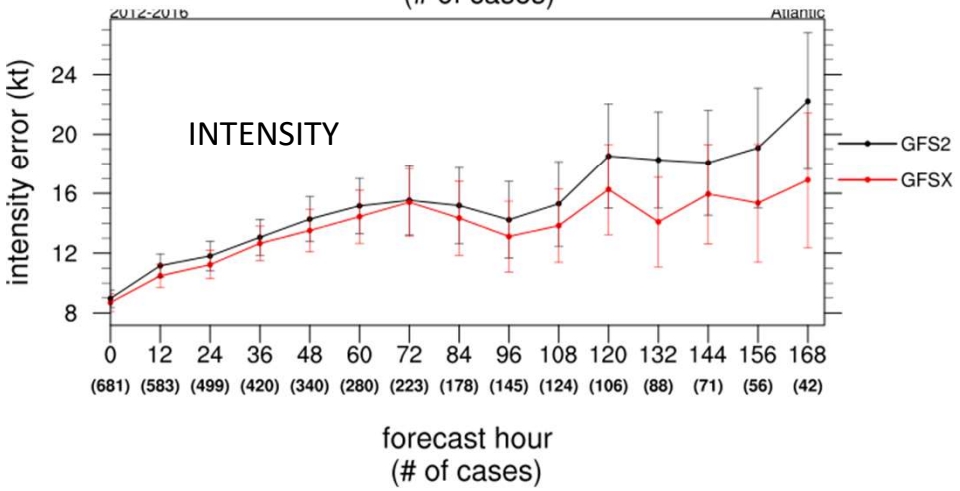
Significant intensity forecast improvements in 2012 stabilized to some extent…

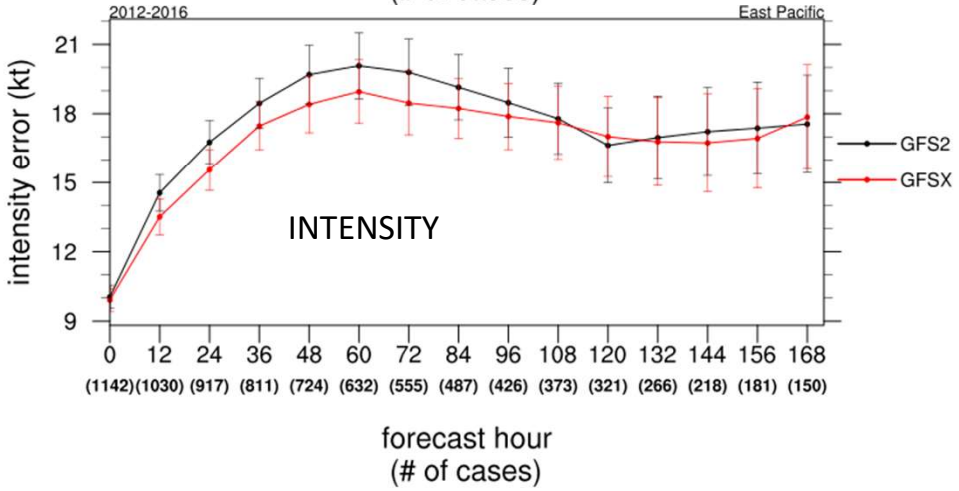
Impact on Hurricanes: NHC Evaluation of 2016 GFS

2012-2016 Atlantic **Track/Intensity Error** **East Pacific**



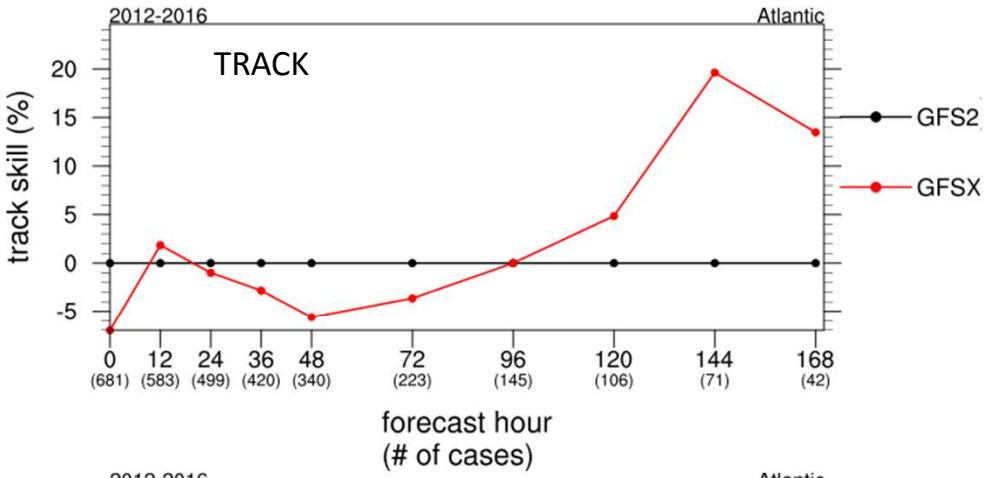


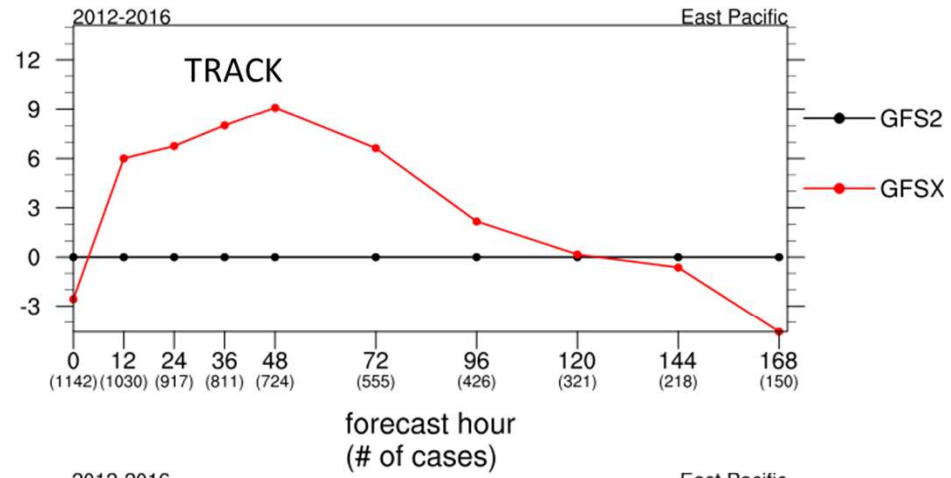


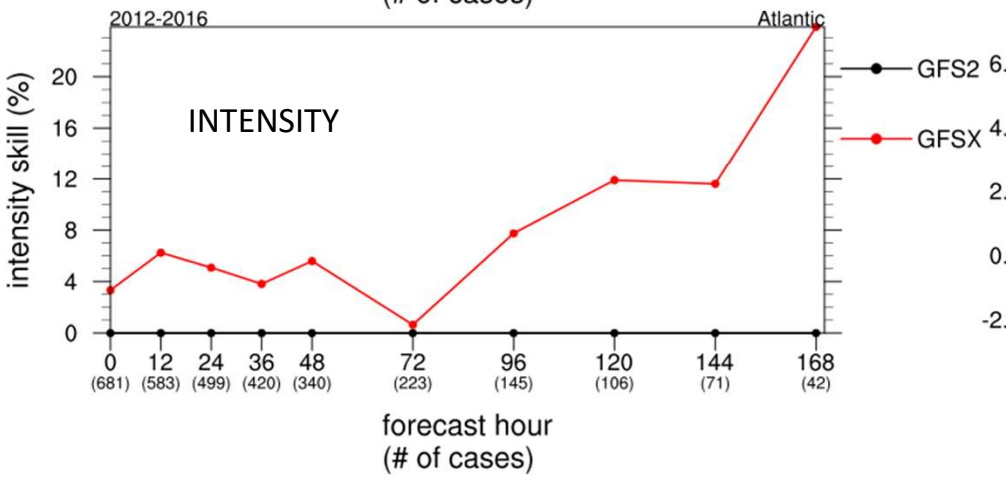


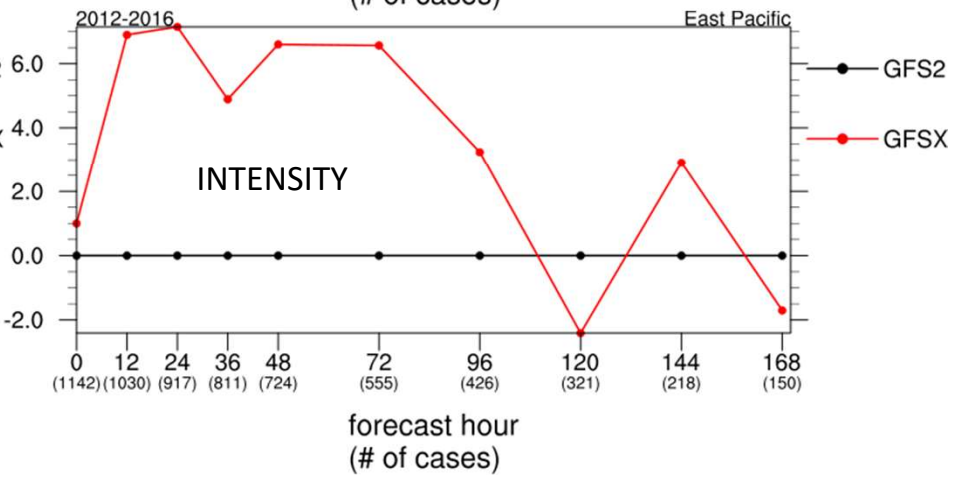
Impact on Hurricanes: NHC Evaluation of 2016 GFS

2012-2016 **Atlantic** **Track/Intensity Skill (with respect to GFS2)** **East Pacific**



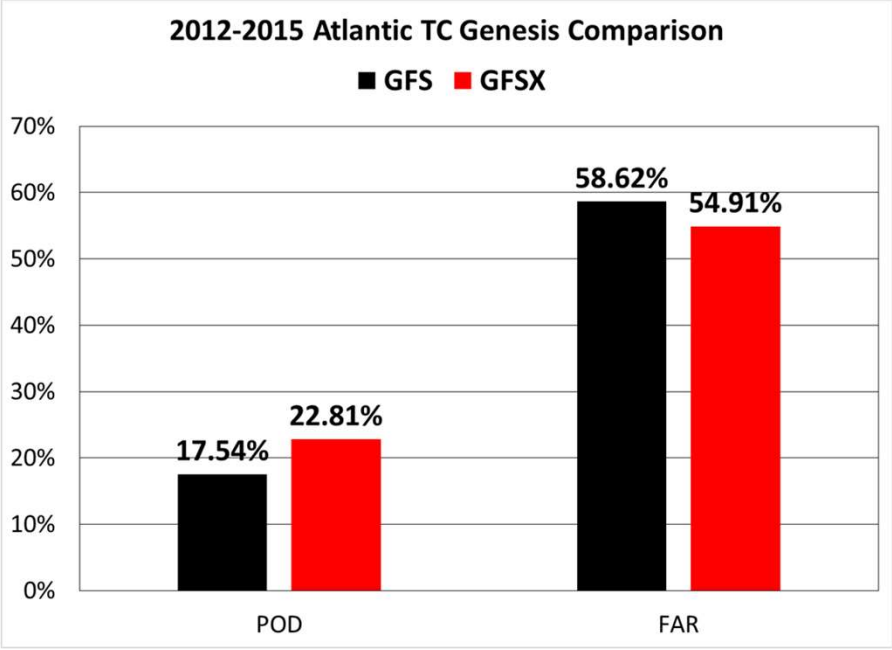


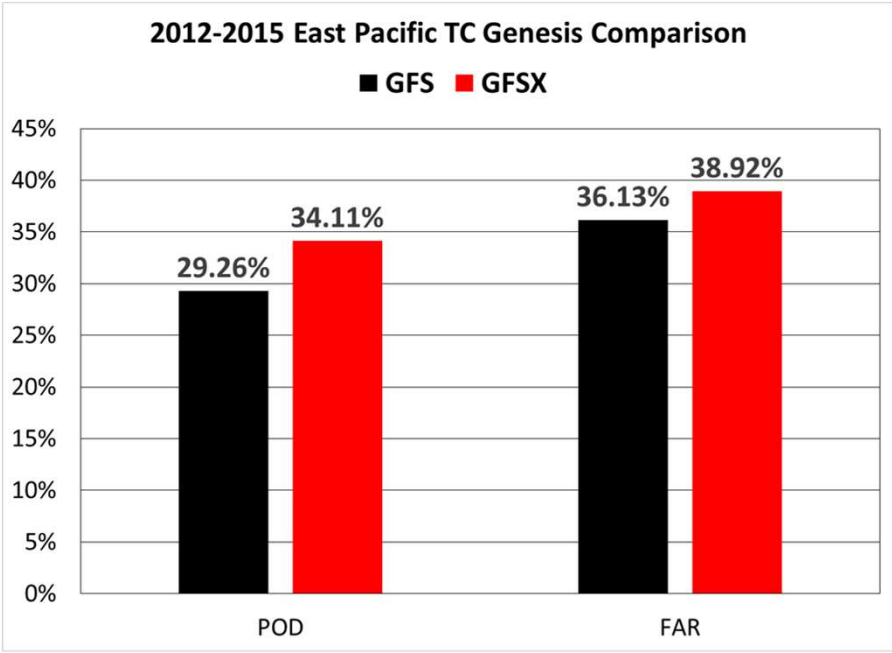




Impact on Hurricanes: NHC Evaluation of 2016 GFS

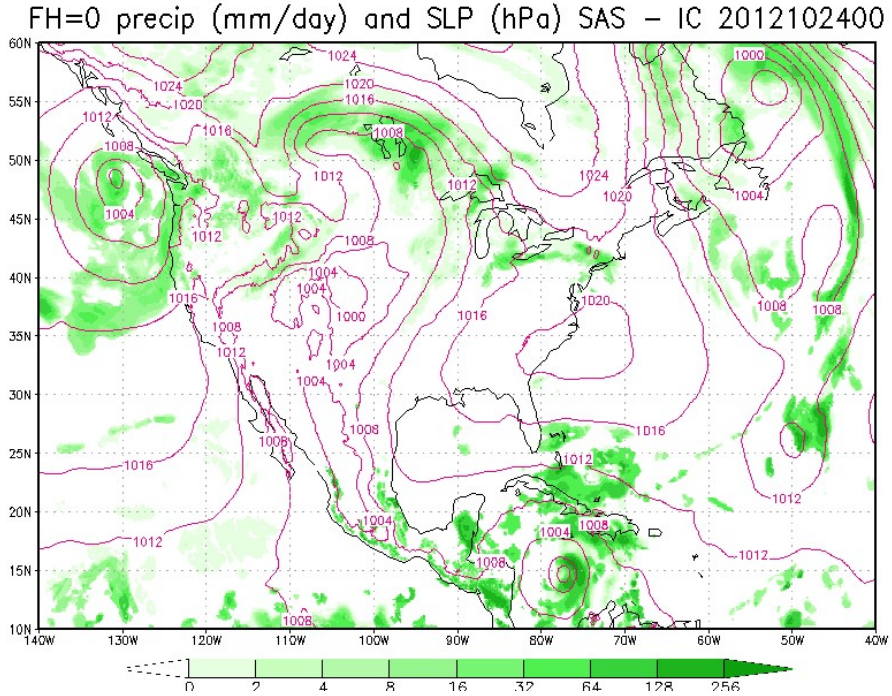
Verification of TC cyclogenesis in the GFSX – comparison to current and previous version of the GFS (courtesy of Dan Halperin and Bob Hart)



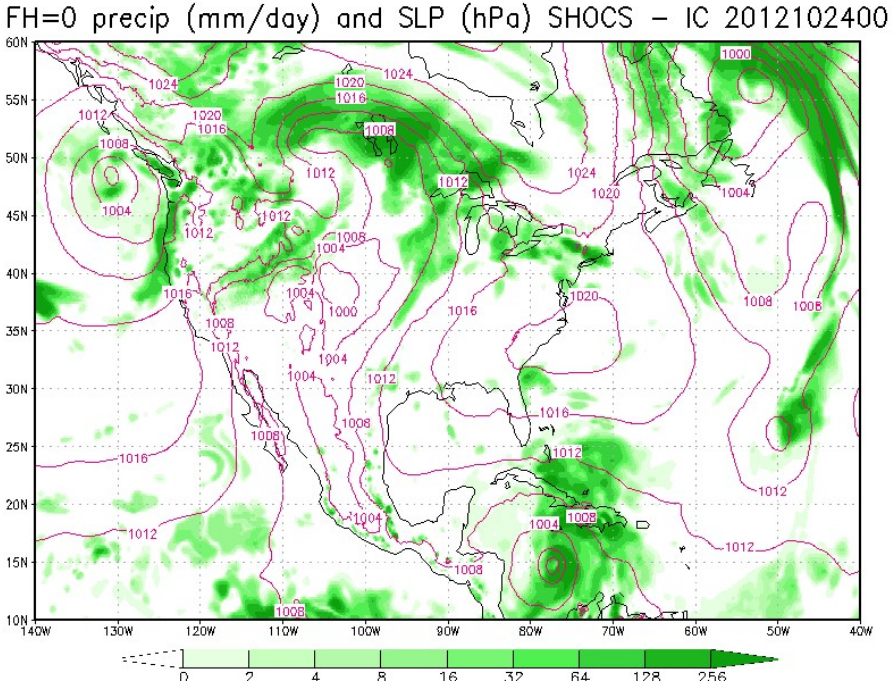


GFS in 2017/2018: Impact of resolution & physics

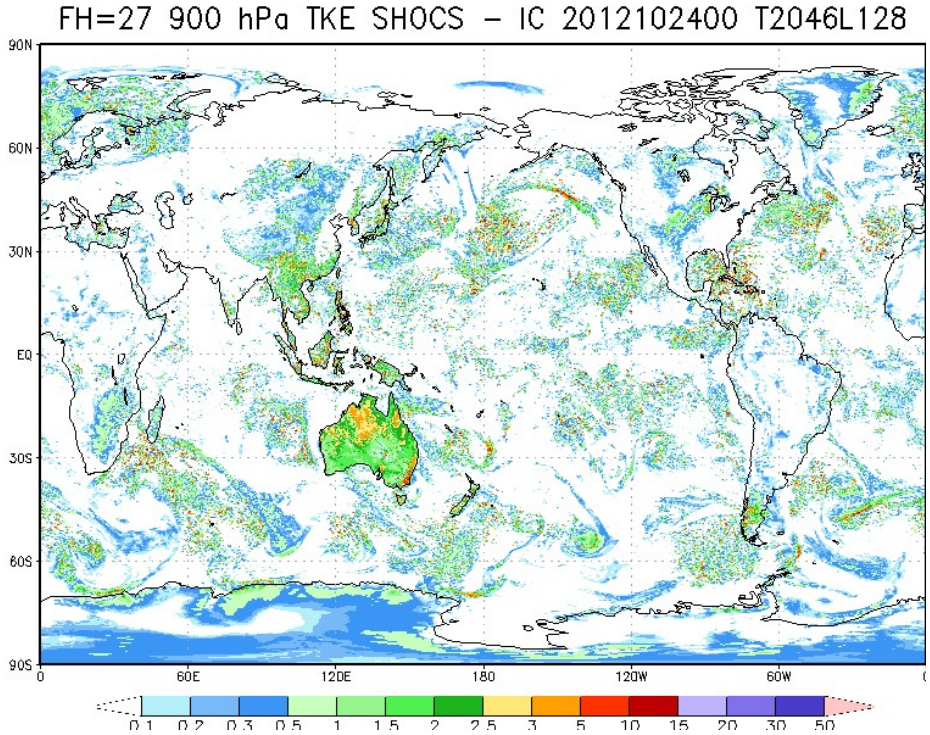
NEMS/GSM run at T2046: opr physics

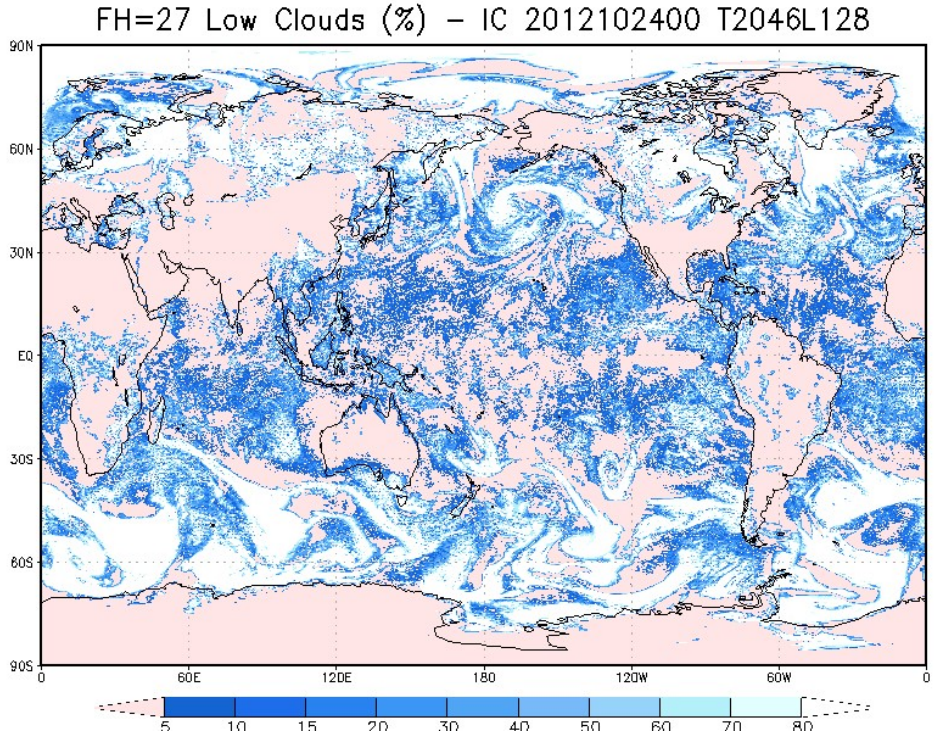


NEMS/GSM run at T2046: SHOC+CS



GFS in 2017/2018: Unified representation of Clouds, Convection, PBL and Microphysics





Future of Global Modeling at EMC: NGGPS

Multi-year NWS-led community effort to build and implement:

- Future global prediction system supporting multiple forecast applications at NCEP
- Community code development at EMC
- Unified modeling at NCEP
- Accelerate Forecast Performance Improvement through accelerated Research to Operations
- Extend forecast skill beyond 8 to 10 days
- Support development of weeks 3 and 4 products
- Overall system designed (re-architected) to take advantage of evolving HPC architectures (CPU/GPU Hybrid or Massively Integrated Cores (MIC))
- Highly scalable
- Adapt to continued evolution of HPC

Results from Phase 1 Testing

~~GSM-NH (EMC)~~
MPAS (NCAR)
FV3 (GFDL)
~~NIM (ESRL)~~
~~NEPTUNE (NRL)~~
~~NMMB-UJ (EMC)~~

GOAL: Global Weather Prediction: Becoming Second to None

Re-establish US as world's leader in Global Weather Prediction

NGGPS Dynamic Core Phase 2 Test Plan & Implementation Strategy

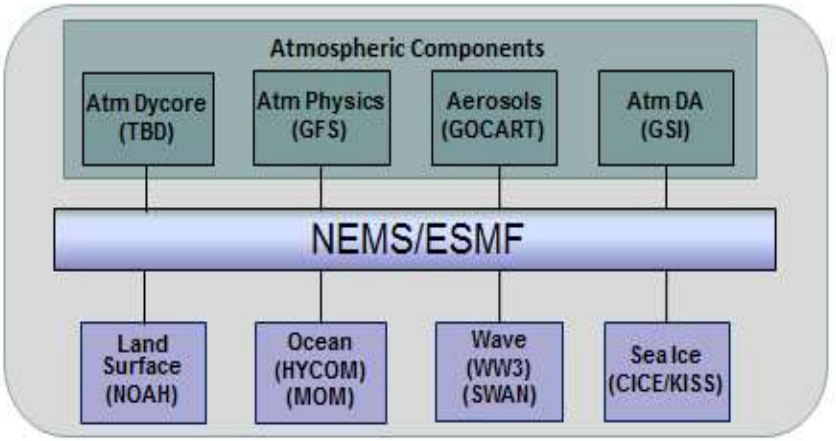
Testing plan drafted by the Test Manager (Jeff Whitaker) - DTG will assess plan

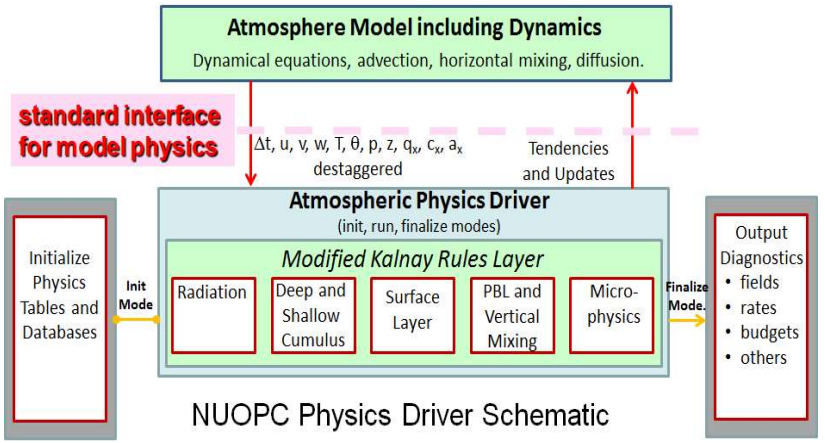
Planned Phase 2 Testing criteria:

- Deep atmosphere dynamics
- Conservation properties
- Untuned forecast skill and model robustness
- Model performance with physics
- Variable resolution/nesting
- Climate integration performance
- Adaptable to NEMS/ESMF

Phase 2 testing is being conducted with a stand-alone GFS based physics package using interoperable physics driver

NGGPS Design

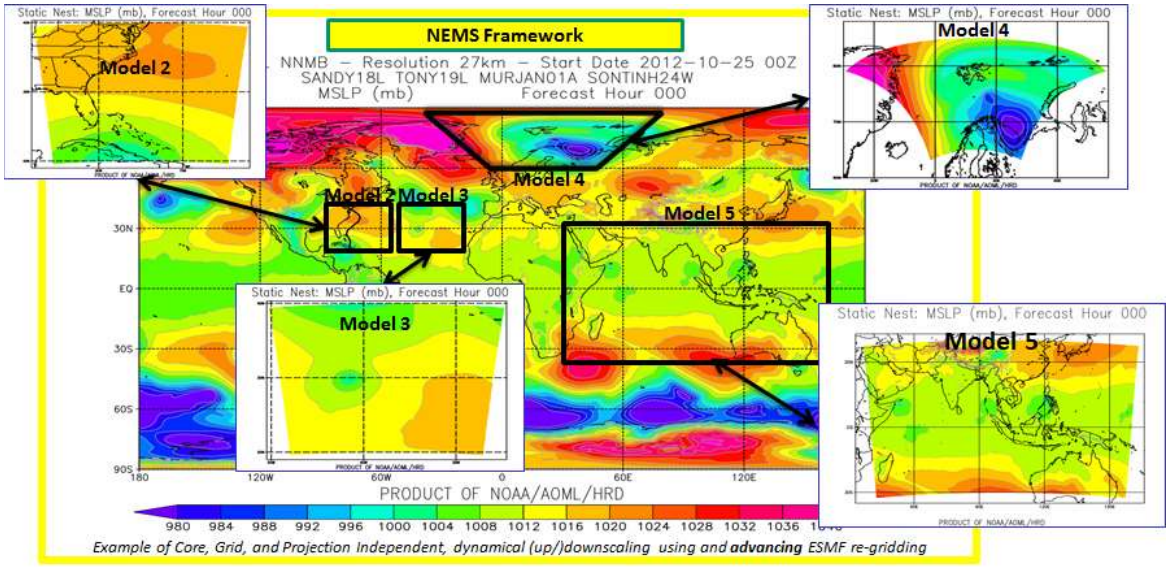


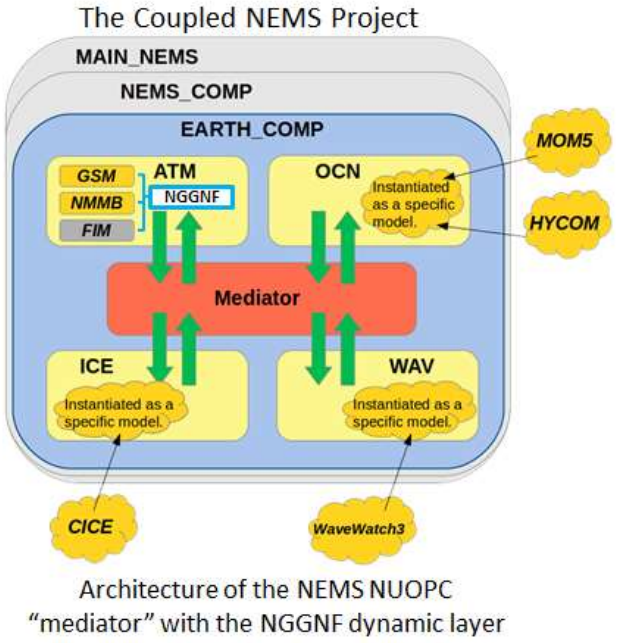


NUOPC Physics Driver Schematic

Generalized Nesting By Coupling

AOML in partnership with EMC and other OAR labs is building the Next Generation Generalized Nesting Framework (NGGNF) within NEMS to advance global-2-local scale modeling for hurricanes

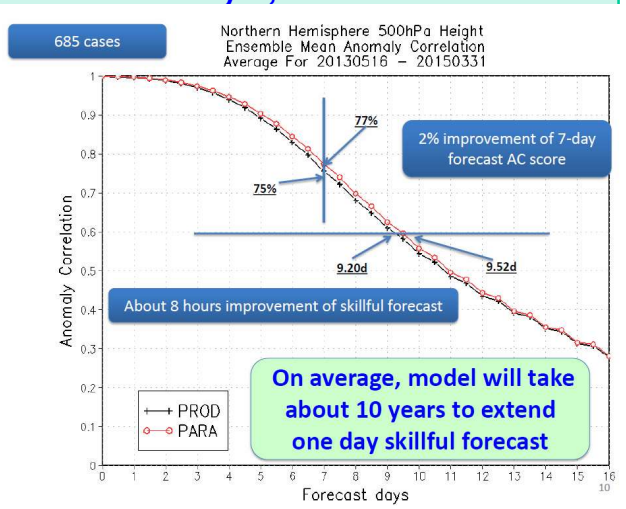




Architecture of the NEMS NUOPC "mediator" with the NGGNF dynamic layer

GEFS Changes (Dec. 2nd 2015)

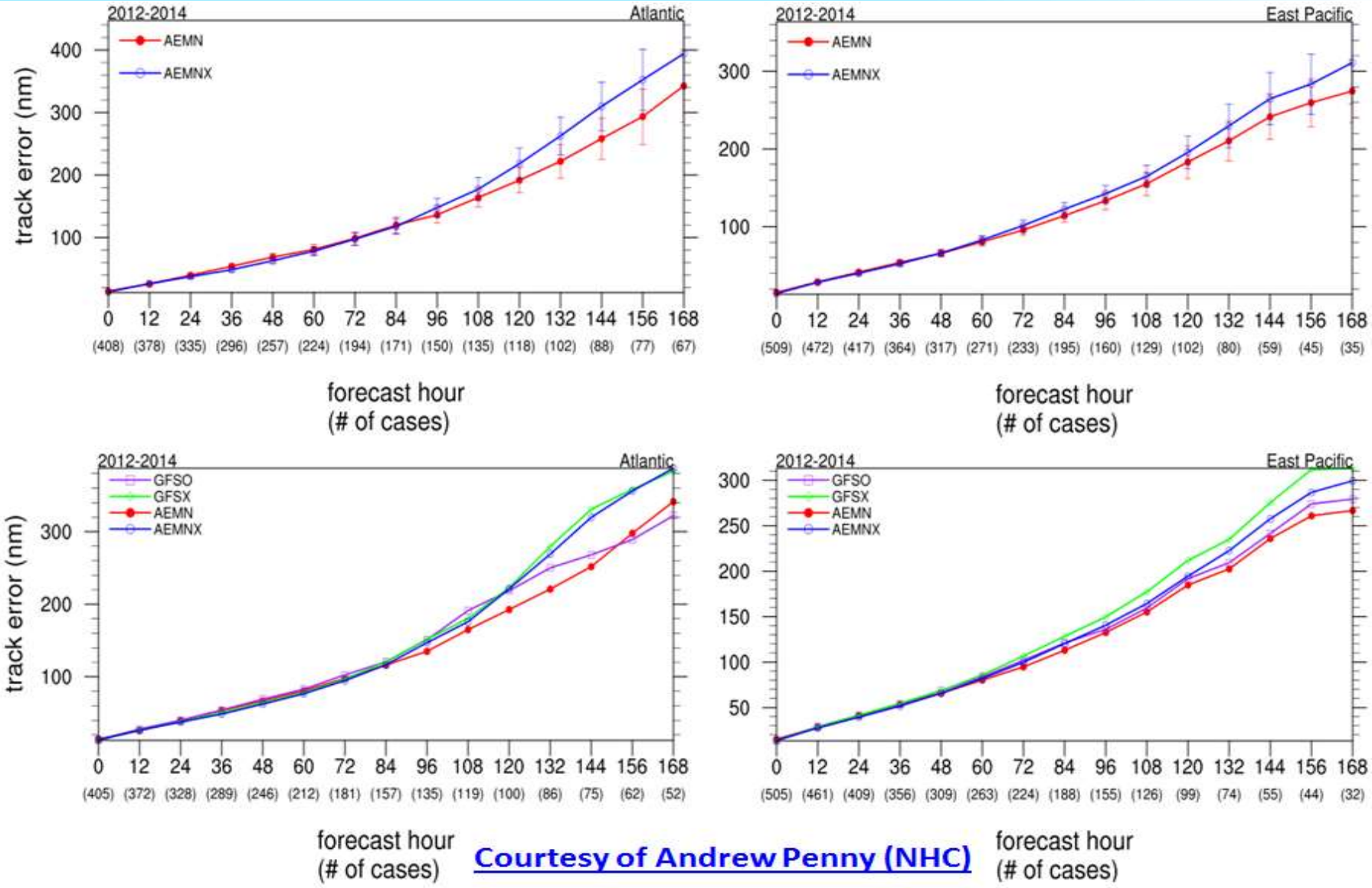
	V10.0.0	V11.0.0
GFS Model	Euler, 2012	Semi-Lagrangian, 2015
Resolution 0-192 h	T254 (52km) L42 (hybrid)	T_L574 (34km) L64 (hybrid)
Resolution 192-384 h	T190 (70km) L42 (hybrid)	T_L382 (52km) L64 (hybrid)
Output resolution	1^O x 1^O	0.5^O x 0.5^O and 1^O x 1^O
Output frequency	6h	3h the first 8 days; 6h the rest



- Moving from BV-ETR approach to EnKF
  - A major scientific shift
- Unification of DA and Ensemble Generation
  - Direct link to the hybrid 3D-Var EnKF DA systen
- Perturbations are 6h EnKF forecasts with adjustmen
  - Tropical Storm Relocation
  - Centering of the perts on the ensemble ctl analy
- Stochastic perturbation (STTP) upgrade
  - Fine-tune amplitude for changes in model and perturbation method
  - Turn off surface pressure perturbations for tropics
    - to reduce the spread growing of geopotential height

TC Track Forecast Performance from GEFS

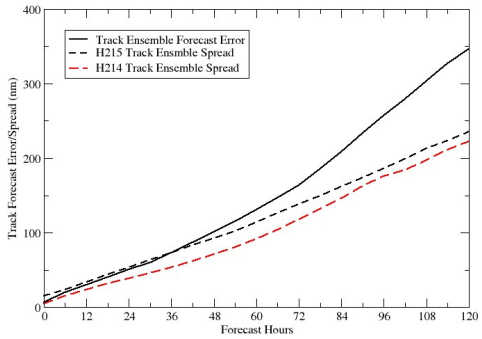
2012 - 2014

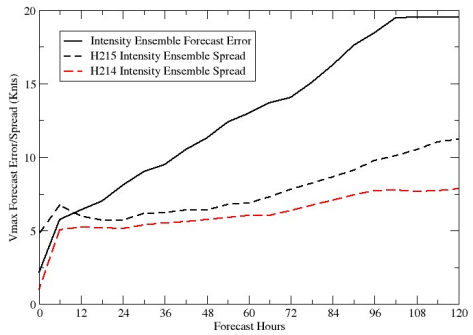


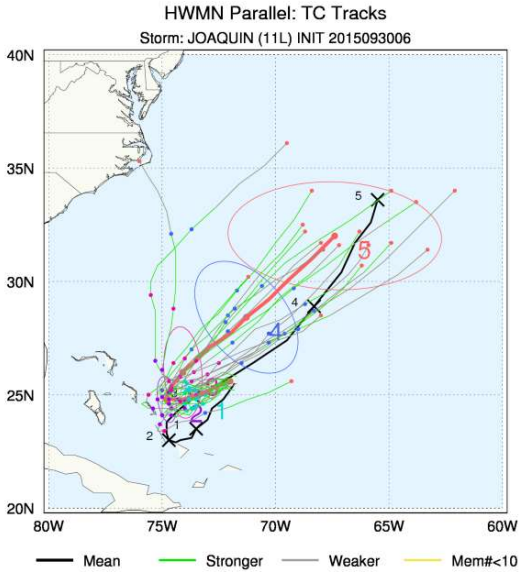
Courtesy of Andrew Penny (NHC)

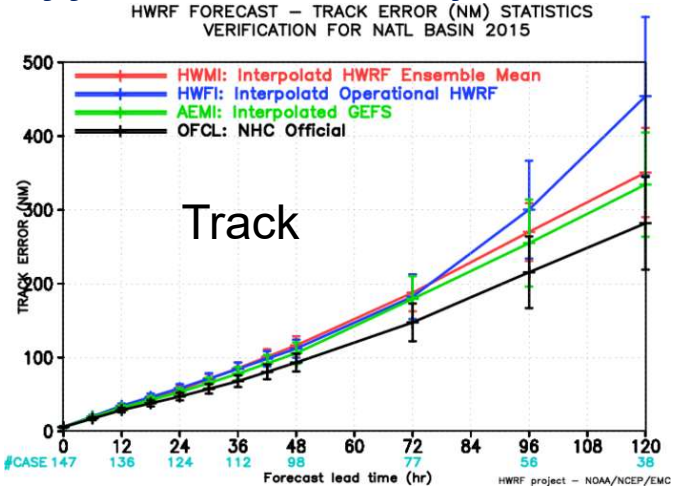
HFIP Experimental Regional Ensemble Prediction System

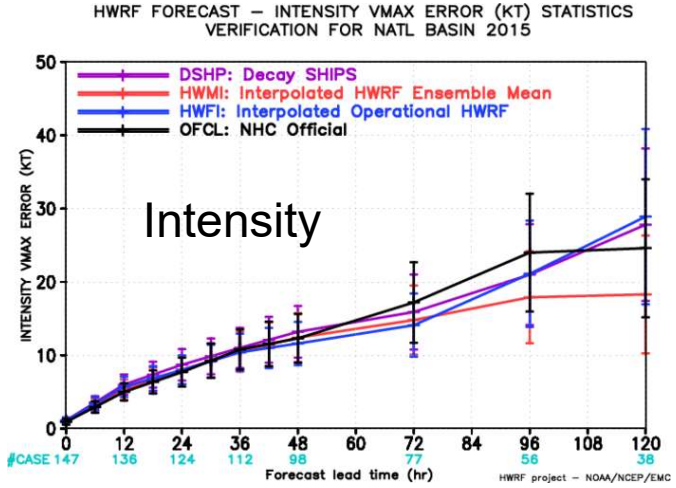
High-Resolution HWRF based Ensembles for Hurricane Forecasts at NATL
Advanced probabilistic guidance with representation of forecast uncertainty









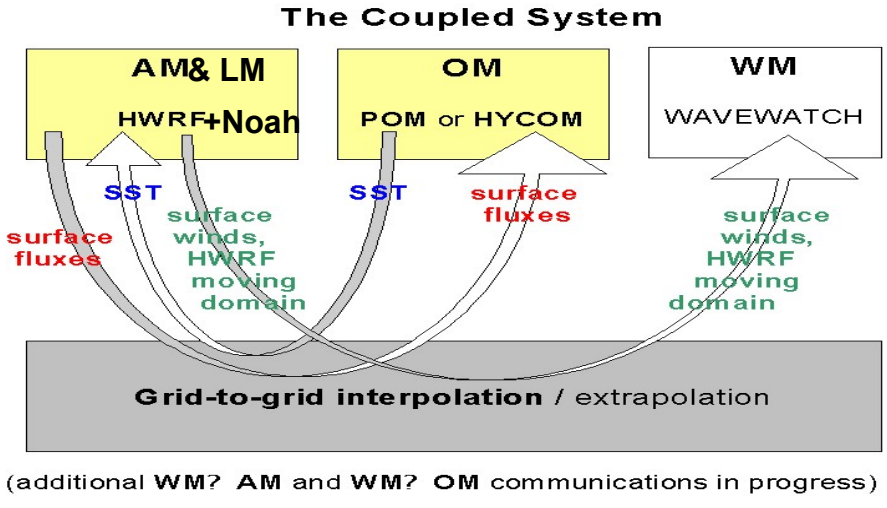


- ***20-member 3km HWRF ensembles driven by GEFS for IC/BC and stochastic convective and PBL perturbations***
- ***High-resolution probabilistic products provide forecast uncertainty in track, intensity, structure (size) and rainfall, along with ensemble mean products***

Long-Term Plans for Hurricane Modeling at NCEP

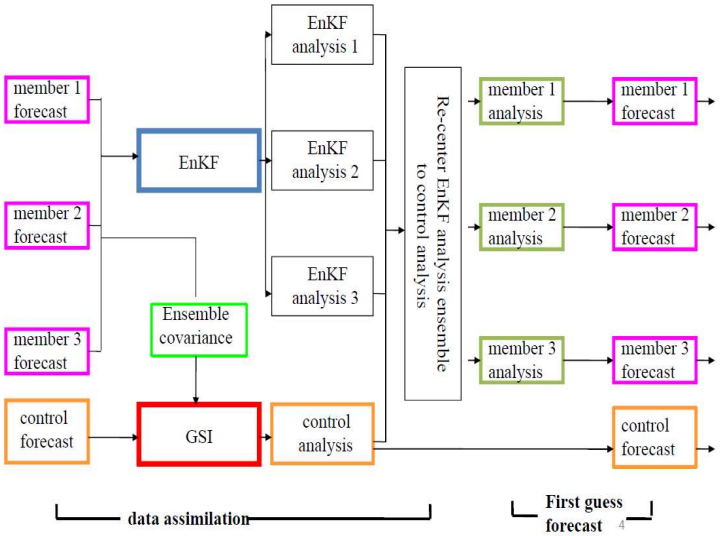
2016	2017	2018	2019	2020
GFDL ——— **HNMMB**		**10-member HWRF/ HNMMB Ensembles**	NEMS Global Nests (NGGPS)	
HWRF Operational Model Continues Followed by Ensembles				
Basin-Scale HWRF/NMMB———Tropical NMMB Domain				

Hurricane Models take over Hurricane Wave Forecasts



(additional WM? AM and WM? OM communications in progress)

Hybrid EnKF-GSI DA system: 2 way coupling



Summary

- NCEP is uniquely positioned to provide high-resolution deterministic and ensemble forecast guidance for tropical cyclones and high-impact weather associated with TCs
- Future plans are designed to further accelerate the improvements in forecast products through developing advanced NWP techniques supported by HFIP and NGGPS
- Community interactions through effective O2R/R2O/T2O strategies to address Next Generation Forecaster Needs

QUESTIONS?