



NCEP Operational Hurricane WRF (HWRF) Modeling System

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Overview

- **Development of HWRF at EMC**
- **Implementation Strategies**
- **HWRF Configuration and T&E requirements**
- **Future Advancements to operational HWRF**
- **Research to Operations**

Design of the Hurricane WRF Modeling System

The Hurricane Weather Research and Forecasting (HWRF) Model dynamical core is designed based on the WRF model using NCEP Non-Hydrostatic Mesoscale Model (NMM) core with a movable high-resolution nested grid (telescopic)

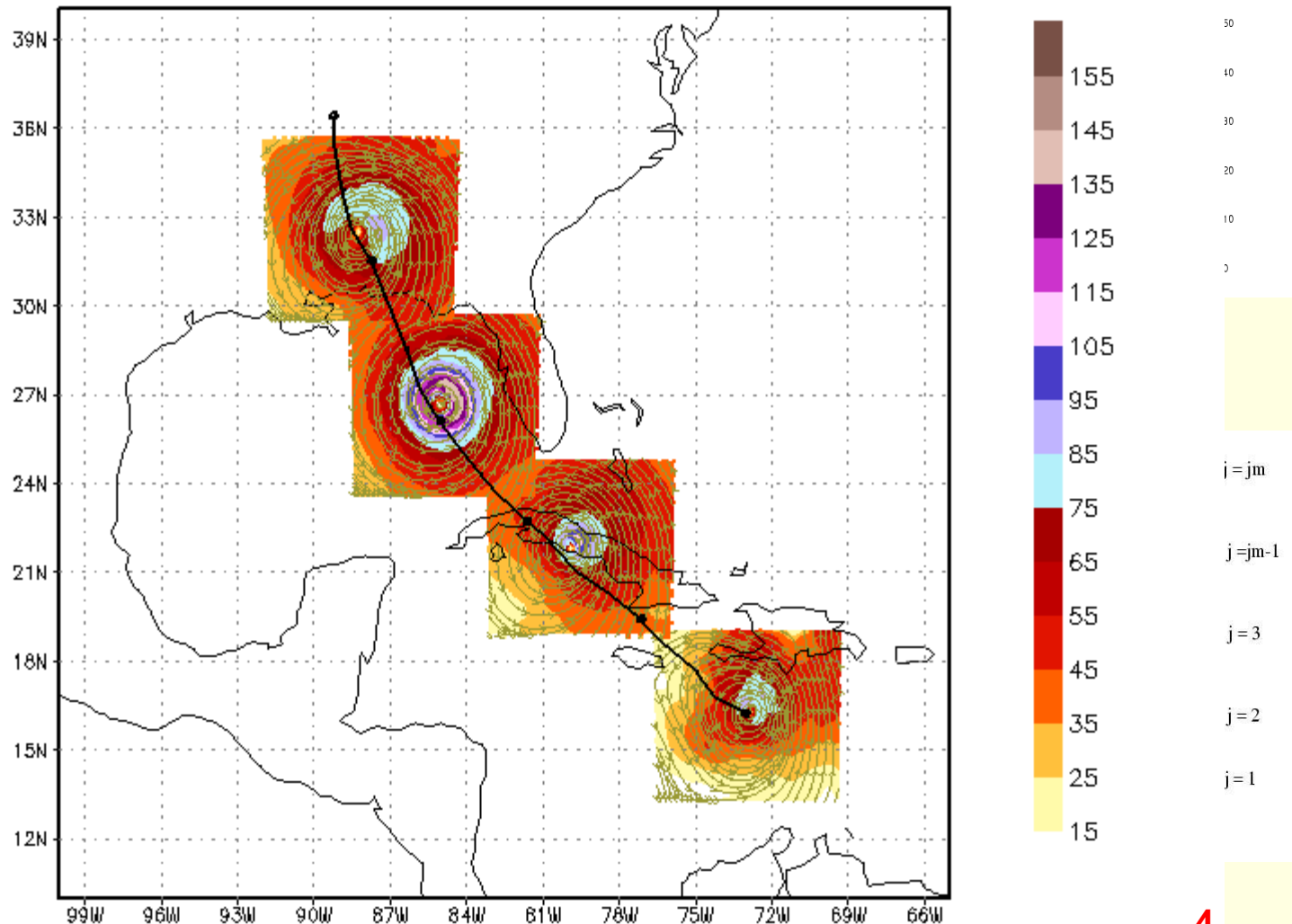
Regional-Scale, Moving Nest, Ocean-Atmosphere Coupled Modeling System. Horizontal resolution: 27 km outer grid, 9 km inner grid, 42 vertical levels

- **Non-Hydrostatic** system of equations formulated on a **rotated latitude-longitude**, Arakawa E-grid and a vertical, pressure **hybrid (sigma_p-P) coordinate**.
- Advanced HWRF 3D Variational analysis that includes **vortex relocation**, correction to winds, MSLP, temperature and moisture in the hurricane region and **adjustment to actual storm intensity**.
- Uses SAS convection scheme, GFS/GFDL surface, boundary layer physics, GFDL/GFS radiation and Ferrier Microphysical Scheme.
- **Ocean coupled** modeling system (POM/HYCOM).

Design of movable nest

JUL 07, 2005 00Z: 120-hr HWRP Forecast, Hurricane Dennis
(Winds at 850 hPa)

Plot of grid and subgrids

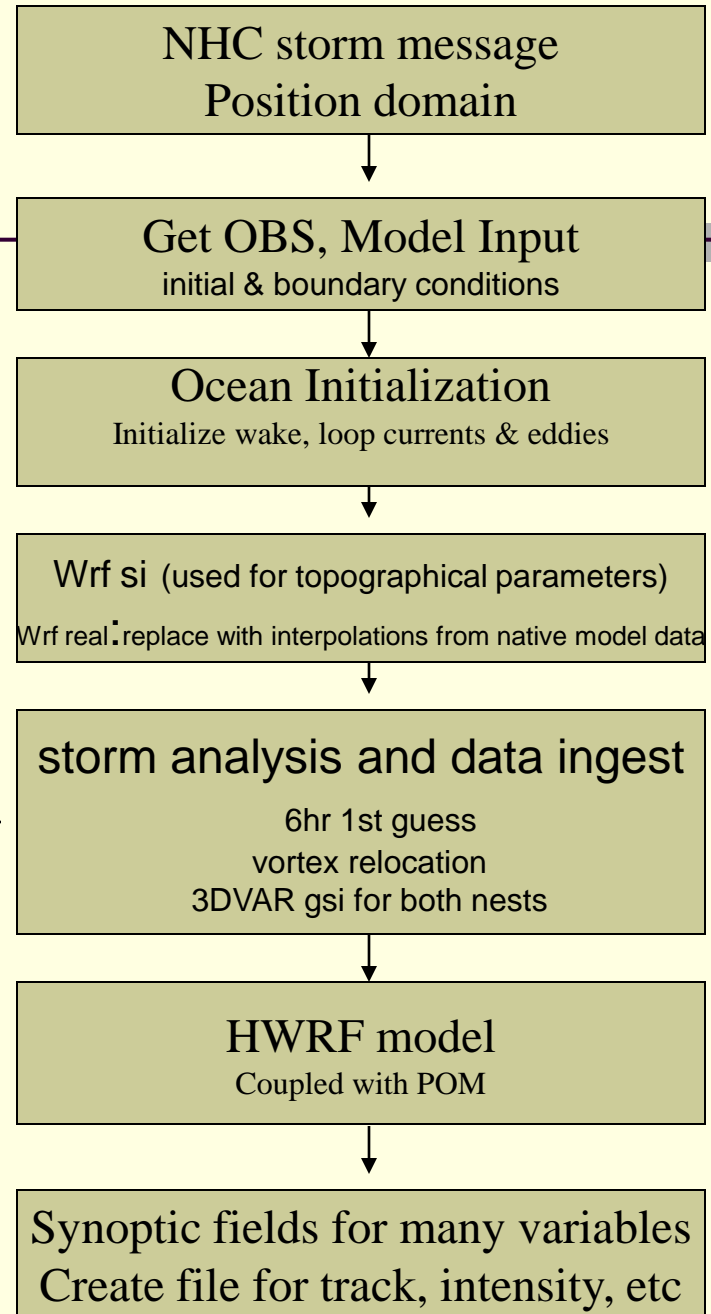


HWRF

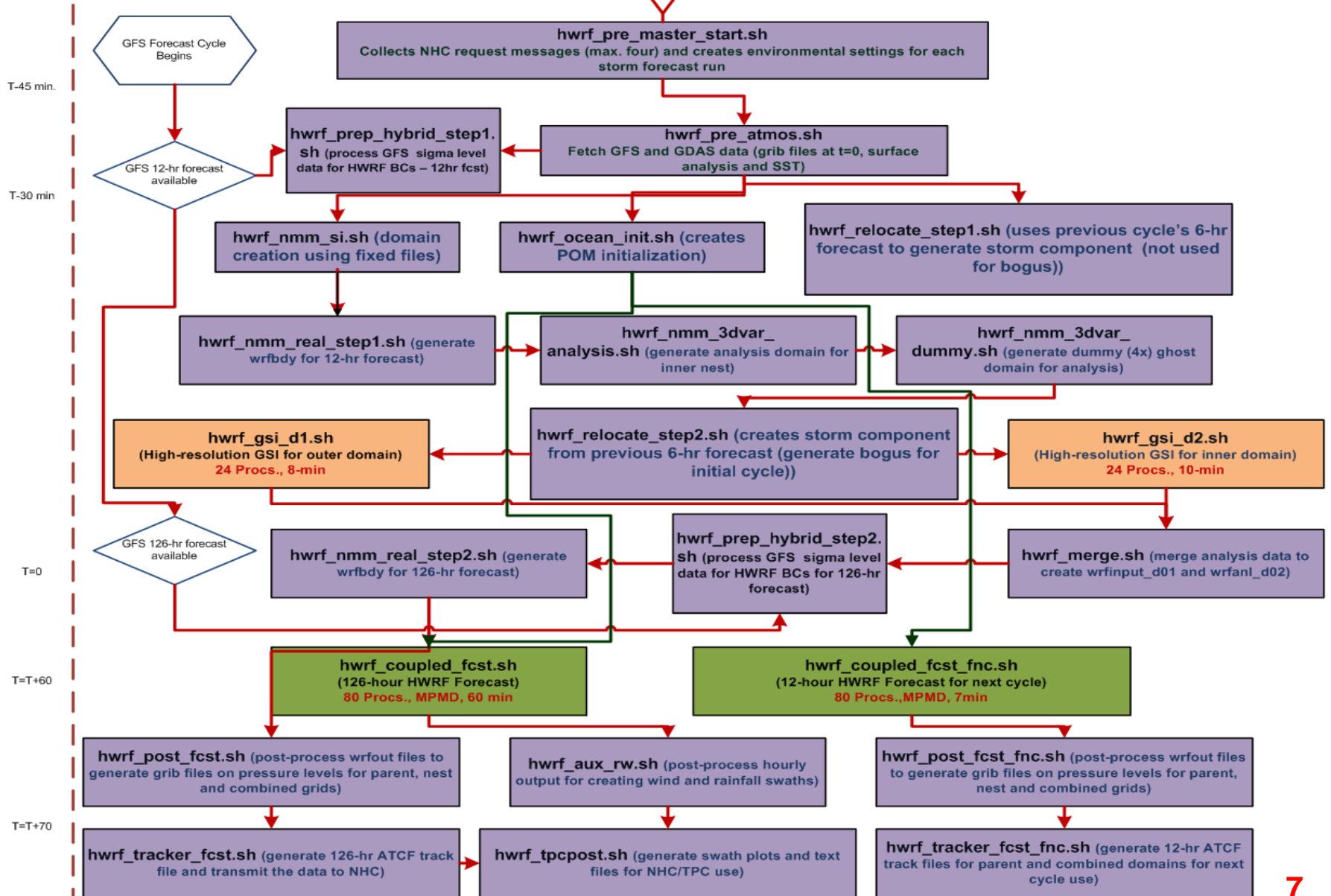
GFDL

Grid configuration	2-nests (coincident)	3-nests(not coincident)
Nesting	Force-feedback	Interaction thru intra-nest fluxes
Ocean coupling	POM (Atlantic only)	POM
Convective parameterization	SAS mom.mix.	SAS mom.mix.
Explicit condensation	Ferrier	Ferrier
Boundary layer	GFS non-local	GFS non-local
Surface layer	GFDL ..(Moon et. al.)	GFDL ..(Moon et. al.)
Land surface model	GFDL slab	GFDL slab
Dissipative heating	Based on D-L Zhang	Based on M-Y TKE 2.5
Radiation	GFDL (cloud differences)	GFDL
Gravity Wave Drag	YES	NO

HWRF Operational Hurricane Forecast System



NCEP Operational HWRF-POM Coupled Modeling System for Hurricane Forecasts



Hurricane Forecast System Requirements Document for T20

Requirements document co-written between EMC and TPC for transition to NCEP operations of a new candidate hurricane model...or for annual or periodic upgrades to an existing operational hurricane model for transition to NCEP operations.

Sets standards for:

Performance testing – case load, eval criteria

System functionality – initialization, coupling

Computational performance

HWRF Development (for initial implementation in 2007)

- CONDUCTED 27 EXPERIMENTS since 2002 , ie: 27 versions of the HWRF
- Tested each upgrade (numerics, physics, coupling) for clean comparisons - comprehensive testing (>200 runs)
- FINALIZED HWRF FOR '07 IMPLEMENTATION
- PERFORMED EXTENSIVE COMPARISONS BETWEEN GFDL AND HWRF FOR MULTIPLE SEASONS AND STORMS - **THREE SEASONS** ('04, '05, '06) for both ATL and EPAC basins

Note: **HWRF, 1745 runs**; GFDL 900 runs; **HWRF ran 4X/day**, GFDL 2X/day. Ran homogeneous comparison between HWRF and GFDL for 0Z and 12Z runs

- **NO TUNING OF HWRF** (tuning has a lot of impact on track and intensity skill)
- **NO OCEAN COUPLING IN EPAC**

Chronology of HWRF development (pre-implementation testing)

Initial HWRF (2002-2004)	Tests for moving nest, GFDL IC
H001 (2005)	GFS IC, near-real time testing
H002 (2005)	New GFDL Surface Physics
H003 (2005)	GFS PBL, GFDL Radiation
H004 (2006)	Two-way interactive nesting
H005/H006/H007/H009 (2006)	Varying physics time steps for radiation and convection
H008 (2006)	Tests with uncoupled GFDL IC
H010/H011 (2006/2007)	New vortex initialization (relocation, 3DVAR/GSI)

Chronology of HWRF development

Continued

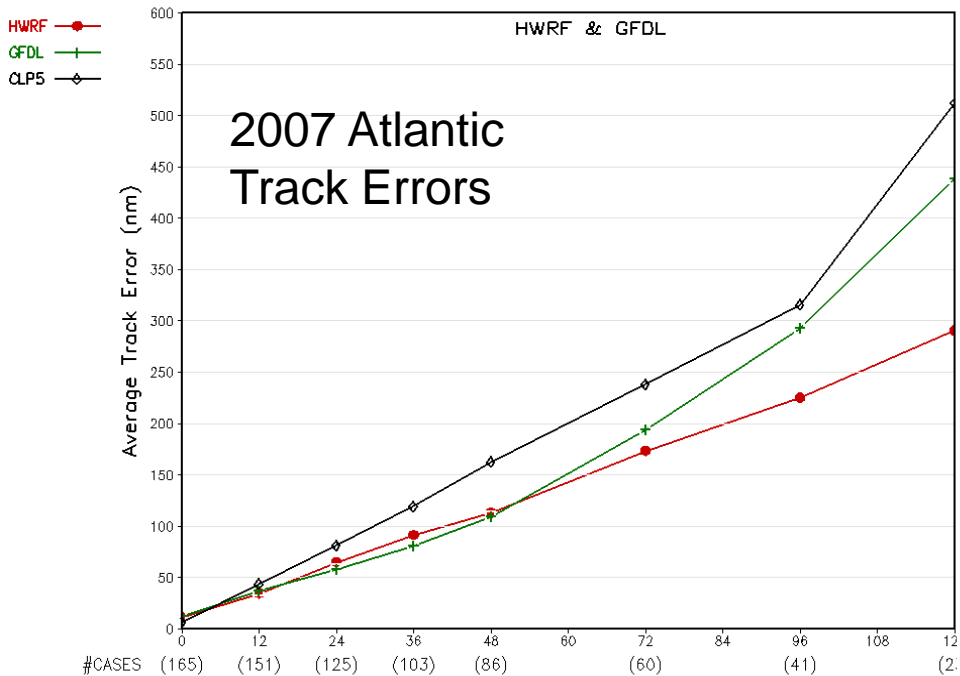
H012 (2006)	New random number for SAS
H013 (2006)	Ferrier Microphysics
H014 (2006)	Bogus vortex for cold start
H015/H016 (2006)	Further changes to vortex initialization
H017 (2006)	Dissipative heating, Surface physics
H018/H019 (2006)	Further changes to vortex initialization
H020 (2006)	Momentum mixing in SAS

Chronology of HWRF development

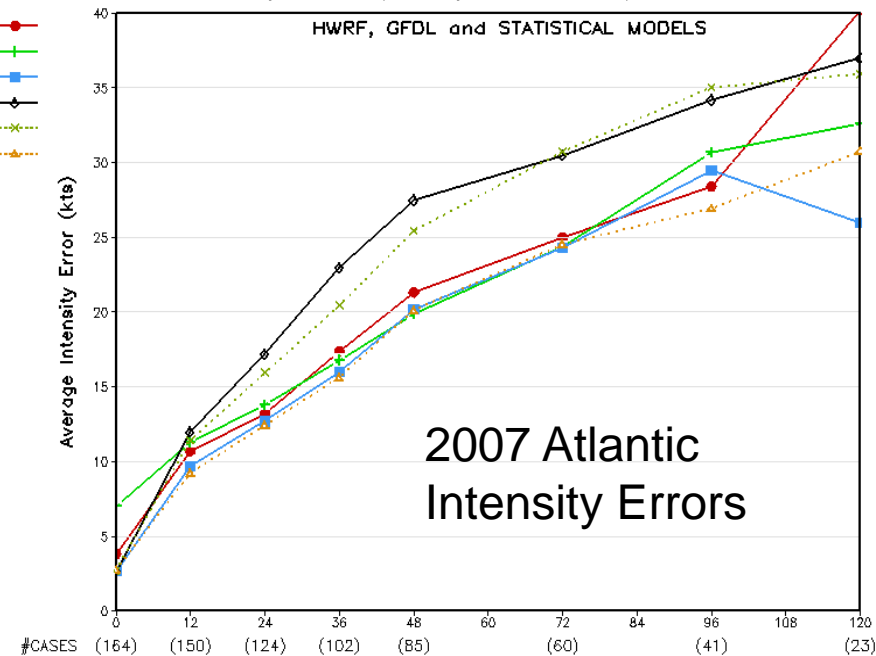
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H021 (2006)	Use of observed 10m winds for intensity adjustment
H022 (2006)	Adjustment to sea-level pressure
H023 (2006)	First end-to-end testing of stand-alone HWRF (~500 cases)
H024 (2007)	Coupling to POM (Atlantic) (outer domain)
H025 (2007)	Use of GFS spectral files for IC/BC
H026 (2007)	Coupling to POM (moving grid)
H027	Final configuration for 2007 implementation

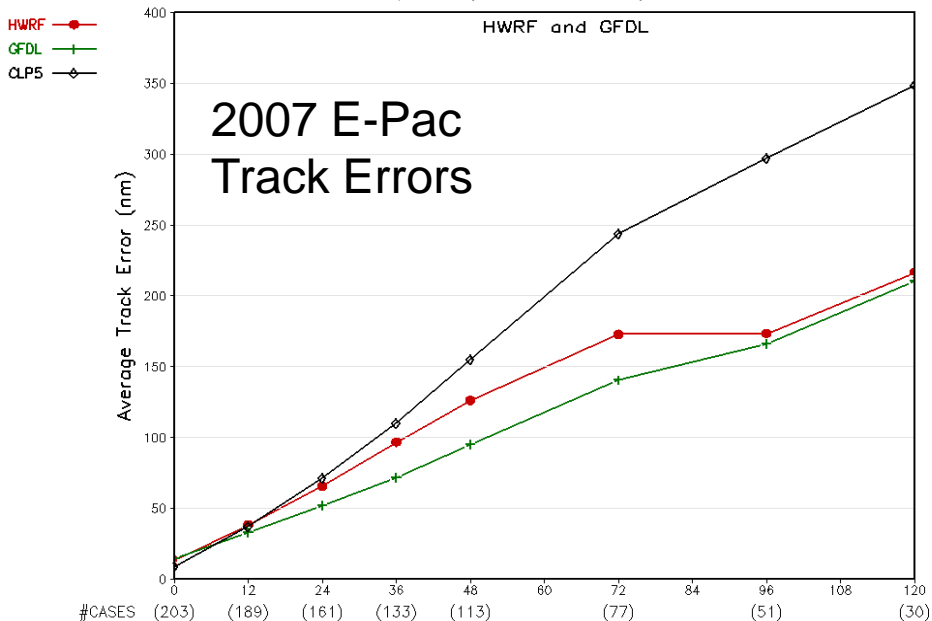
Track Error Comparison, Atlantic Hurricanes (2007)
Coupled HWRF (2007 Operational Version) NCO PROD



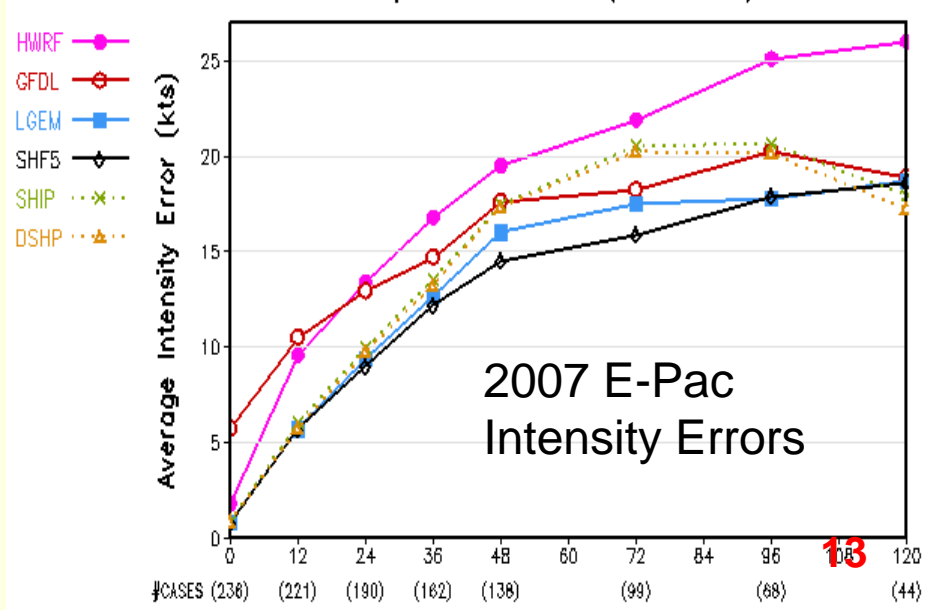
Intensity Error Comparison - Atlantic Hurricanes (2007)
Coupled HWRF (2007 Operational Version) NCO PROD



Track Error Comparison, East Pacific Hurricanes (2007)
HWRF (2007 Operational Version) NCO PROD



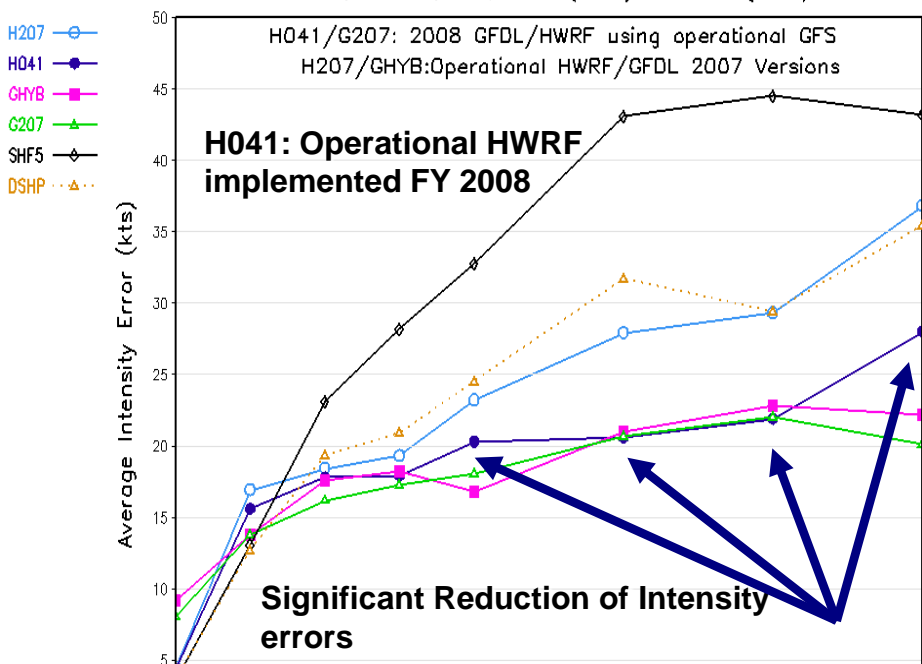
Intensity Error Comparison, EAST-PACIFIC HURRICANES, 2007
HWRF: Operational Model (NCO PROD)



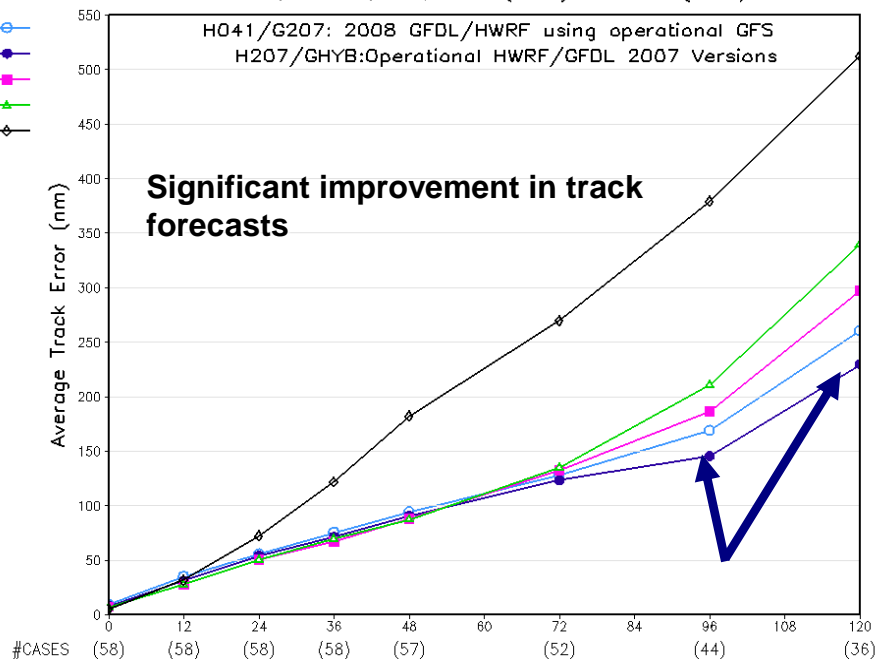
HWRF '08 implementation strategy

- **HWRF Analysis Changes:**
 - Weak storm treatment: The weak storm is a weighted blend of the guess and the composite storm. Weights are based on the observed storm intensity and the vertical structure of the guess storm.
 - Storm Balance: Instead of assuming gradient wind balance, surface pressure is treated as a function of non-linear gradient wind stream function. Once surface pressure is adjusted, vertical temperature fields are adjusted based on hydrostatic balance.
- **Changes to POM initialization:**
 - Feature based assimilation of meso-scale oceanic features
 - Assimilate more than one warm core rings as well as cold core rings
 - Rings can be assimilated close to the loop current
- **HWRF Physics changes / Bug fixes:**
 - Initialize TKE to zero (HWRF does not use TKE based PBL)
 - Adjustment of temperature and pressure fields after nest motion to remove noise at the lateral boundary of nest domain
- **HWRF Script Changes:**
 - Improved functionality of all HWRF scripts
 - HWRF scripts for EMC parallels are consistent with operational configuration.
- **13 Additional sets of experiments (H028 through H041)**

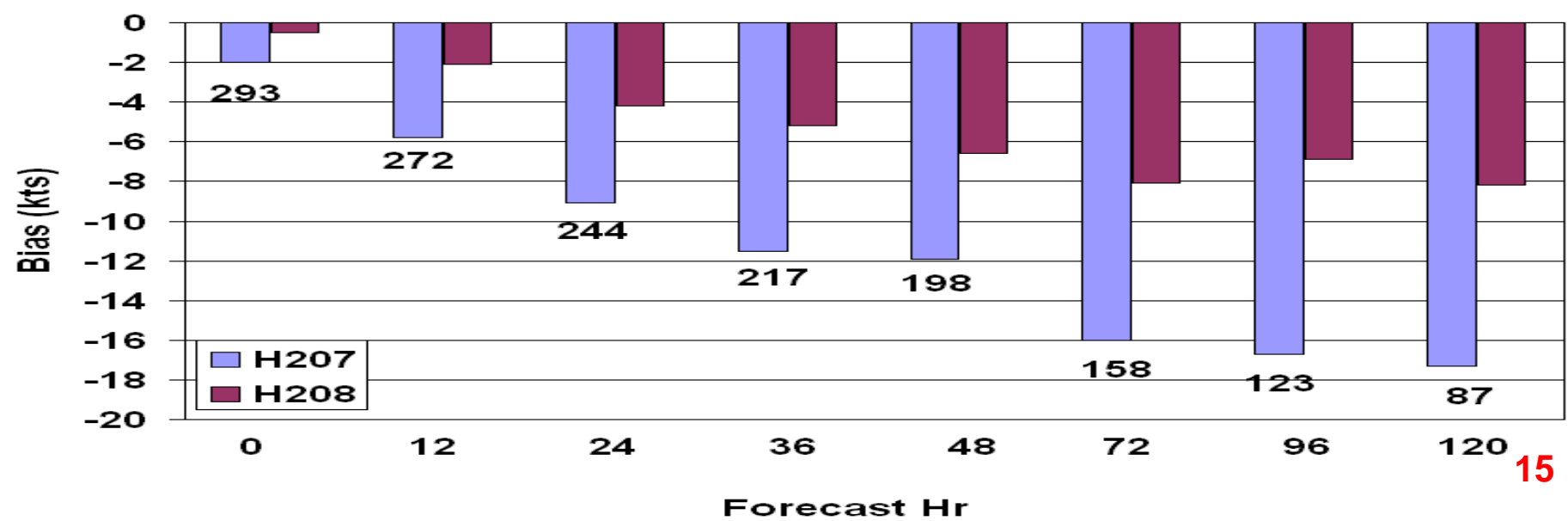
Intensity Error Comparison – Benchmark Atlantic Hurricanes
DENNIS, KATRINA, RITA, WILMA (2005) and DEAN (2007)



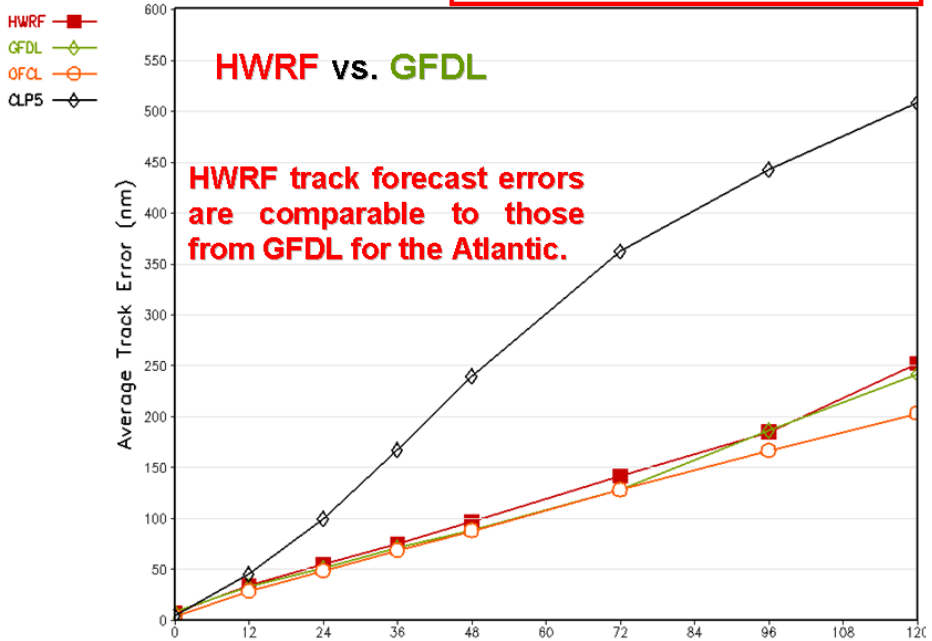
Track Error Comparison – Benchmark Atlantic Hurricanes
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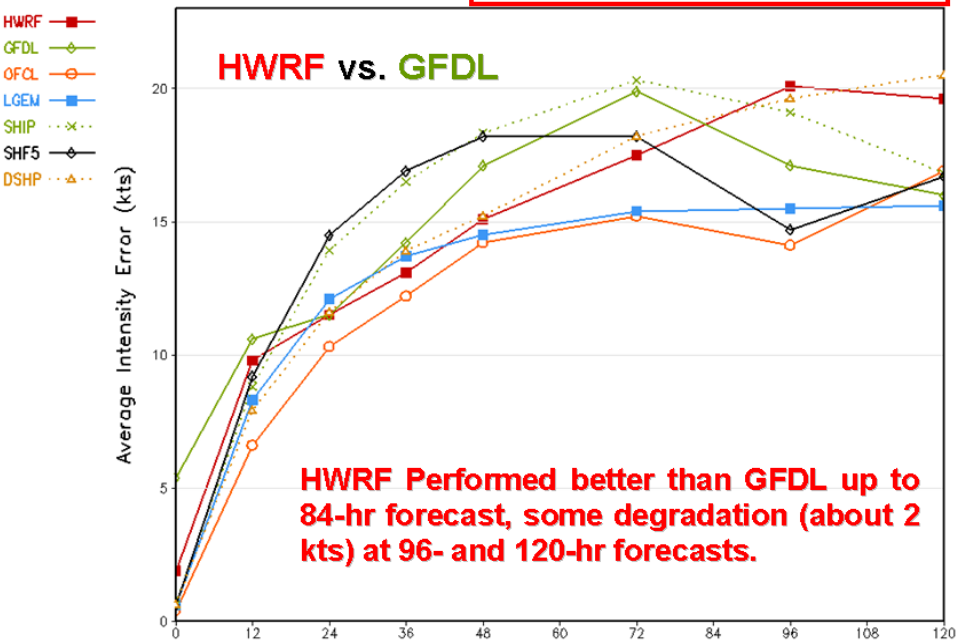
**Average Intensity Bias
Atlantic Hurricanes, 2005-2007**



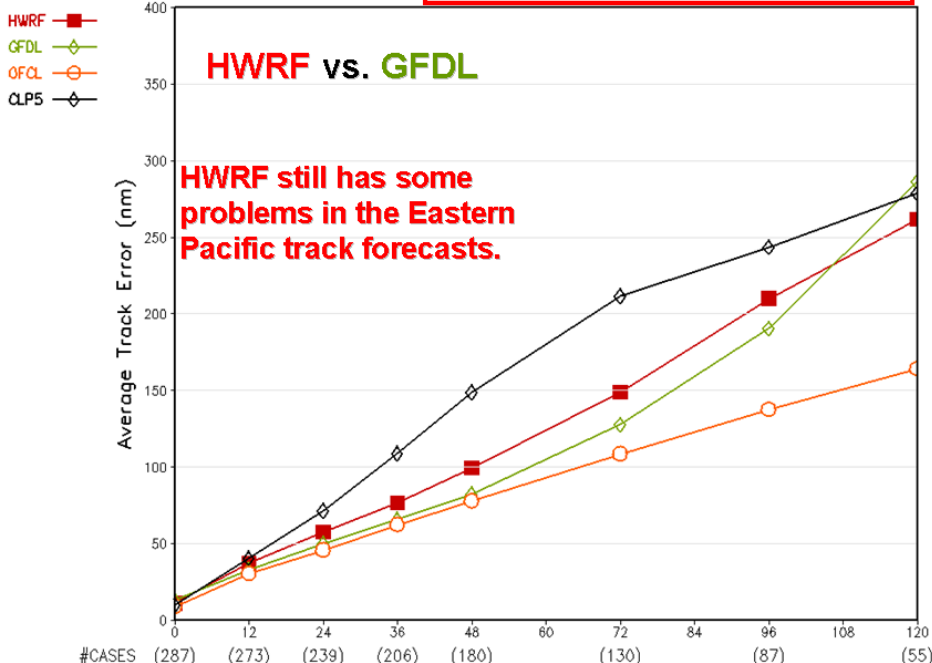
HWRf: Operational Coupled Hurricane WRF (NCO PROD)
Track Error Comparison, 2008 Atlantic Hurricanes (Arthur to Paloma)



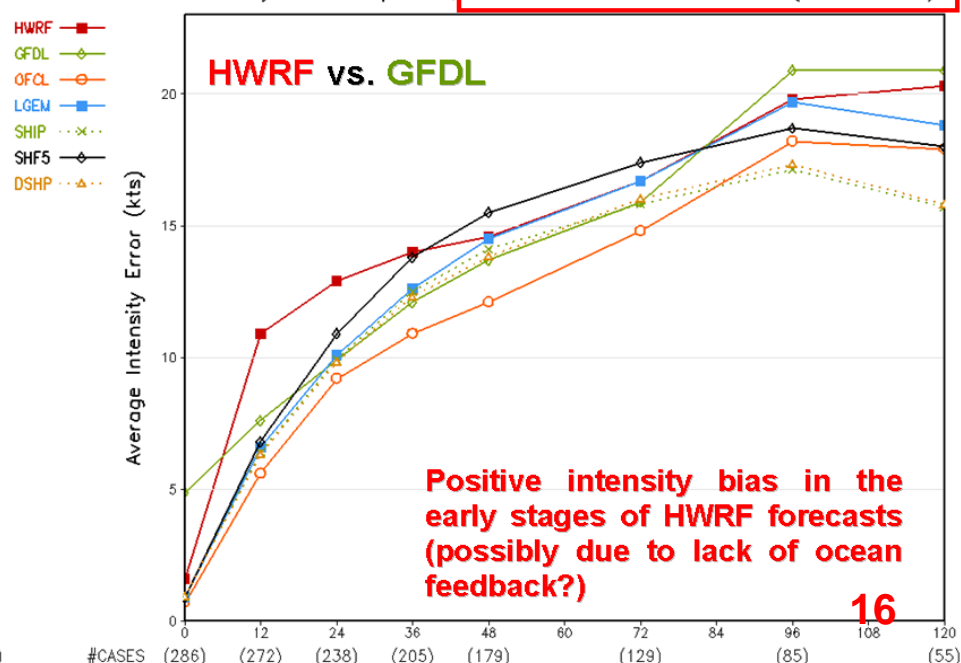
HWRf: Operational Coupled Hurricane WRF (NCO PROD)
Intensity Error Comparison, 2008 Atlantic Hurricanes (Arthur to Paloma)



HWRf: Operational Coupled Hurricane WRF (NCO PROD)
Track Error Comparison, 2008 Eastern Pacific Hurricanes (Alma to Polo)



HWRf: Operational Coupled Hurricane WRF (NCO PROD)
Intensity Error Comparison, 2008 Eastern Pacific Hurricanes (Alma to Polo)



2009 HWRF Implementation Strategy

- Gravity Wave Drag Parameterization
- Modified Initialization
- Bug fix for Land Surface Temperature
- Bug fix for solar radiation
- Bug fix for non-hydrostatic advection of vertical velocity
- Q2FY09 GSI/GFS for initial and boundary conditions
- Restart capability
- Unified scripting with advanced options for high-resolution, 3-way coupling with POM, HYCOM, Wave Watch III; genesis mode etc.
- **Conducted eight different sets of experiments (H042-H049)**
- Pre-implementation testing showed degradation of important 2008 storms after known bugs were removed
 - Initial testing (with bugs) showed neutral impact of physics changes in ATL, positive impact in EPAC
- TPC recommended not implementing bug removal and upgrades
- Porting 2008 HWRF to Cirrus (P6) consumed personnel resources that would otherwise have been used to mitigate bug removal and improve physics tuning

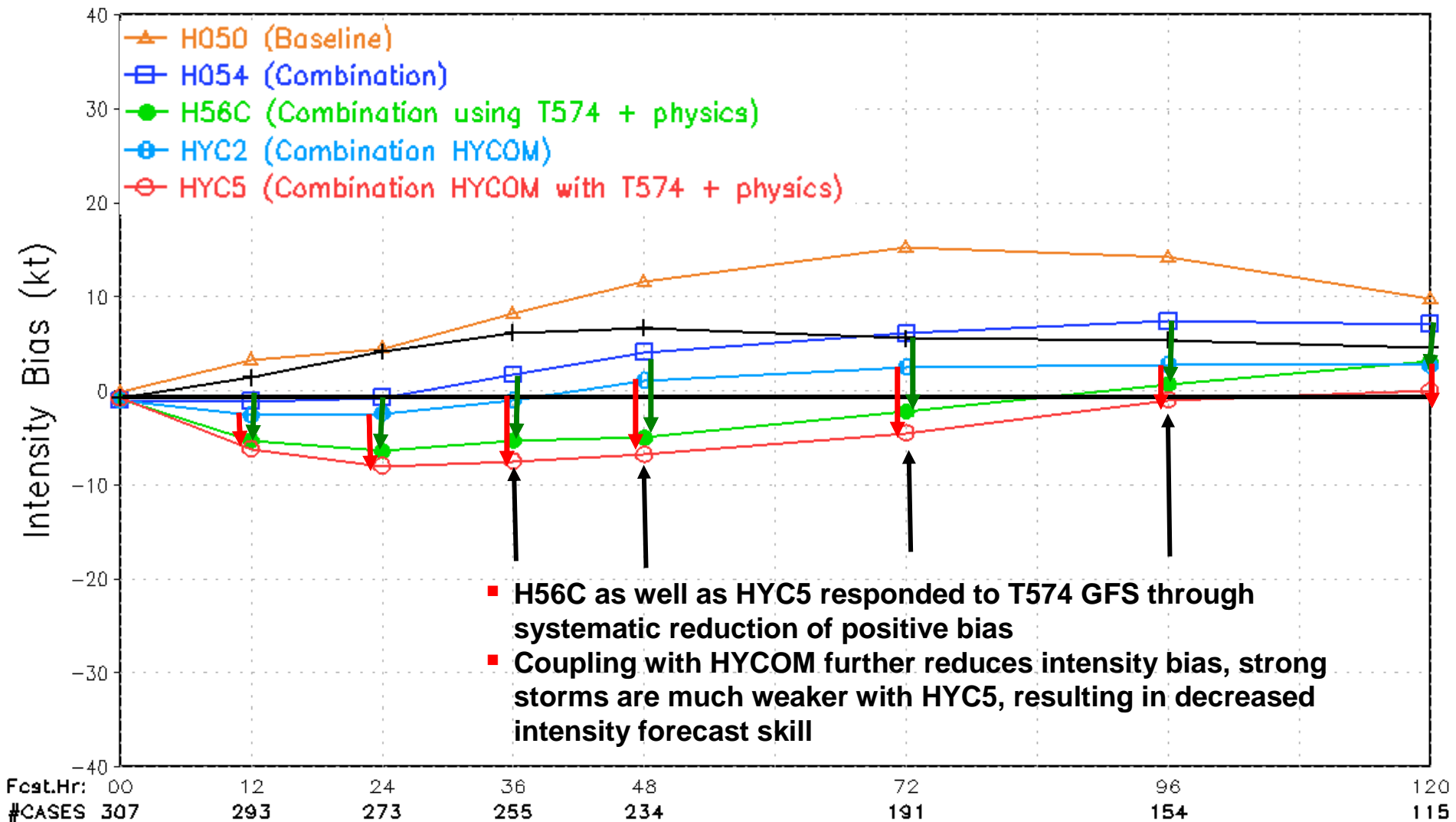
Withdrawn for 2009

HWRF 2010 Implementation Strategy

- Define new baseline (benchmark) (H050)
- Evaluate against benchmark H050:
 1. Changes to initialization (use of satellite data in 9km nest) (H051)
 2. New surface physics specification for Cd/Ch (H052)
 3. Gravity wave drag parameterization (H053)
 4. HYCOM Coupling for Atlantic (HYC1)*
- Combine (1), (2), (3) (HWRF-POM: H054) and (1), (2), (3) and (4) (HWRF-HYCOM: HYC2) for final pre-implementation testing
 - These combinations determine the final HWRF configuration for 2010 implementation.
- Test the combinations using proposed GFS (T574+physics upgrades) – one with HWRF-POM (H56C) and another with HWRF-HYCOM (HYC5).
- Performance for a selected set of priority test cases (about 230) were chosen to provide basis for decision-making.
 - If proven positive, continue these tests for entire set of 600 cases from 2008/2009 Atlantic and Eastern Pacific storms.
- Analyze the results in terms of track and intensity error statistics from each of these experiments

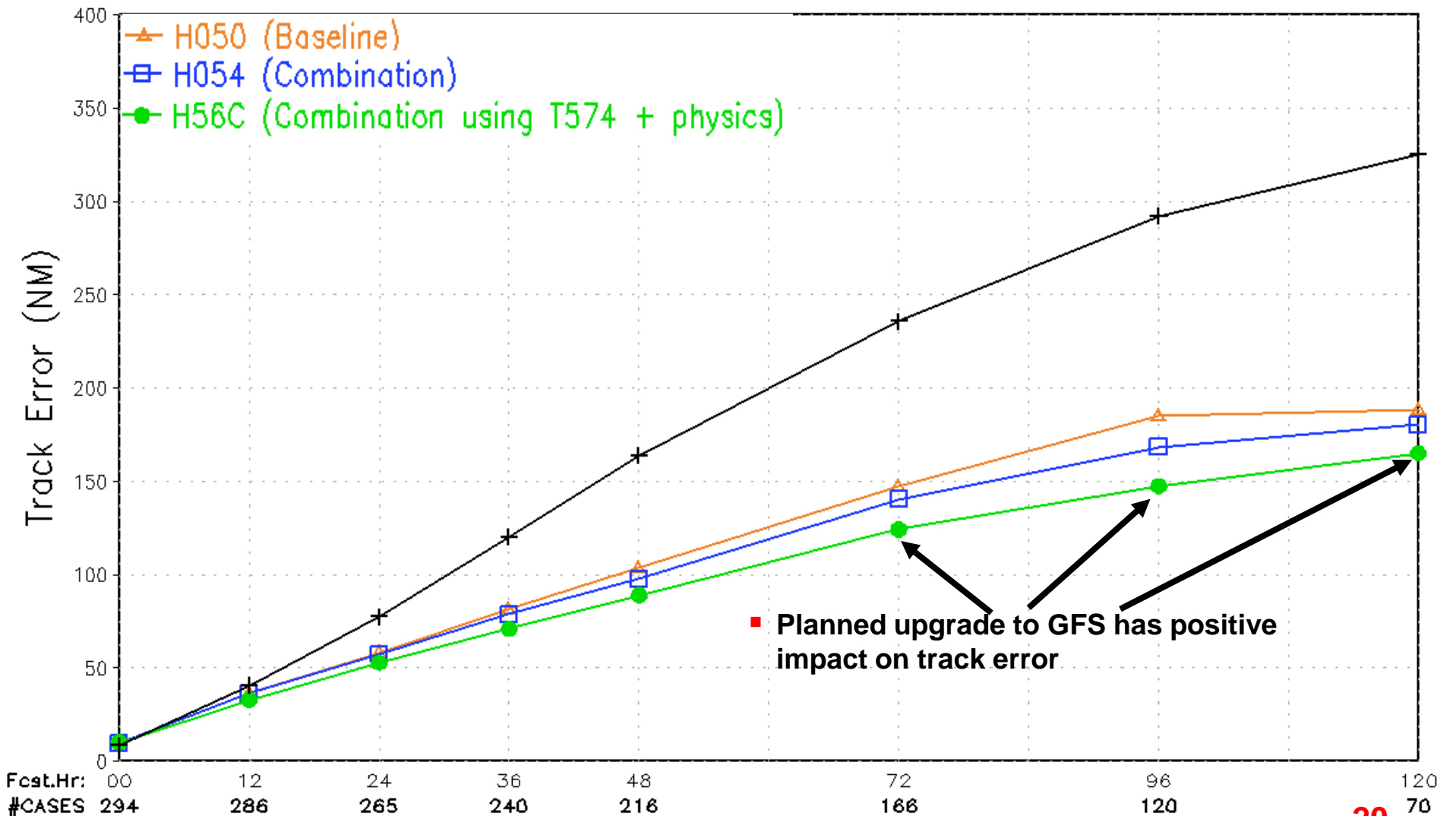
Set 4: HWRF-POM and HWRF-HYCOM with GFS @T574 & Upgraded Physics (Proposed GFS implementation)

Atlantic 2008-2009 Seasons – Intensity Bias



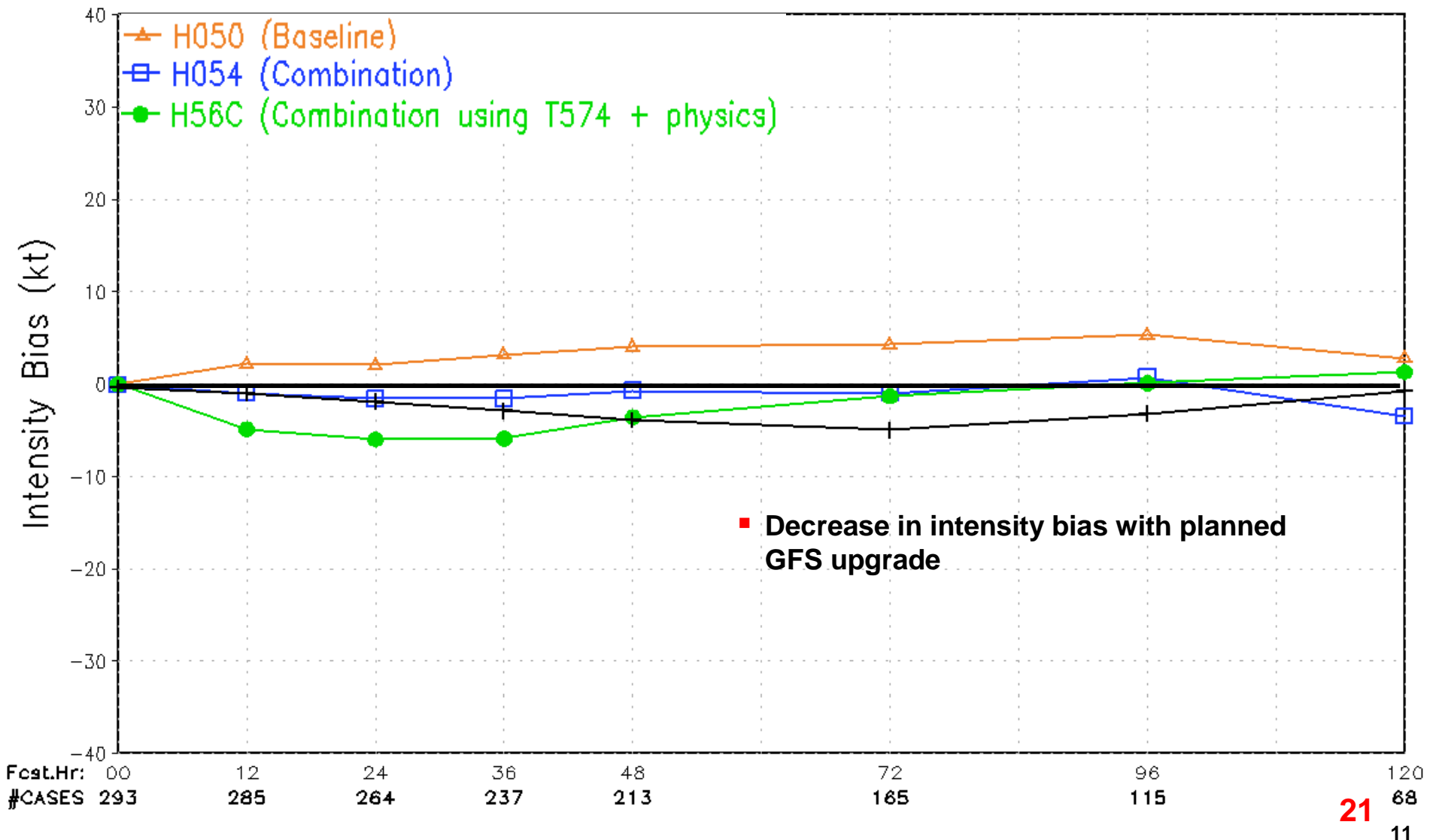
Set 6: HWRF with GFS @T574 & Upgraded Physics (Proposed GFS implementation)

Eastern Pacific 2008-2009 Seasons – Track Errors



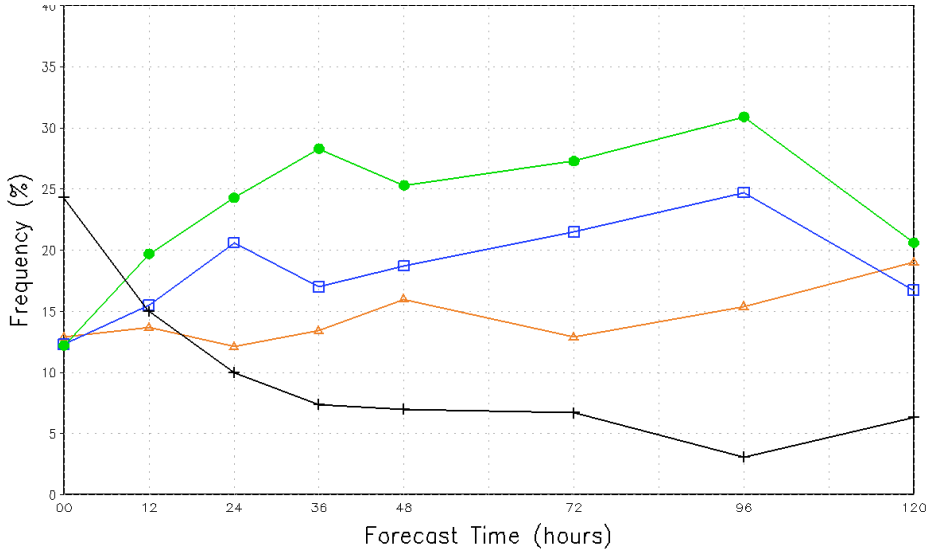
Set 6: HWRF with GFS @T574 & Upgraded Physics (Proposed GFS implementation)

Eastern Pacific 2008-2009 Seasons – Intensity Bias



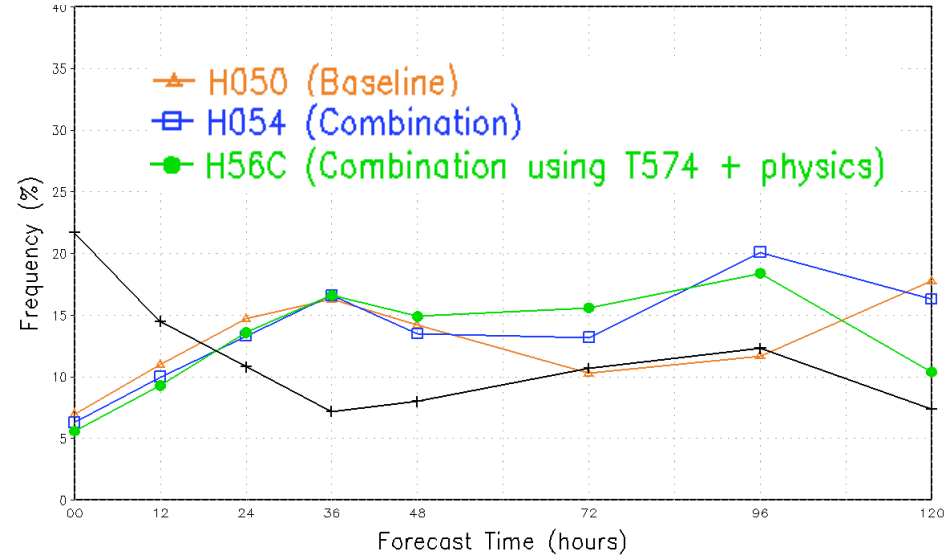
Frequency of superior performance

Atlantic Track Errors



NCEP Hurricane Forecast Project

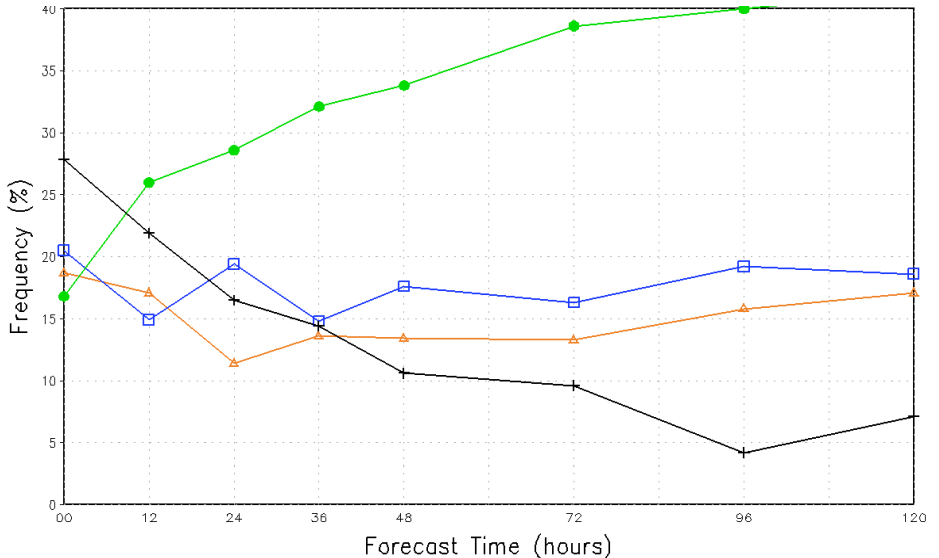
Atlantic Intensity Errors



NCEP Hurricane Forecast Project

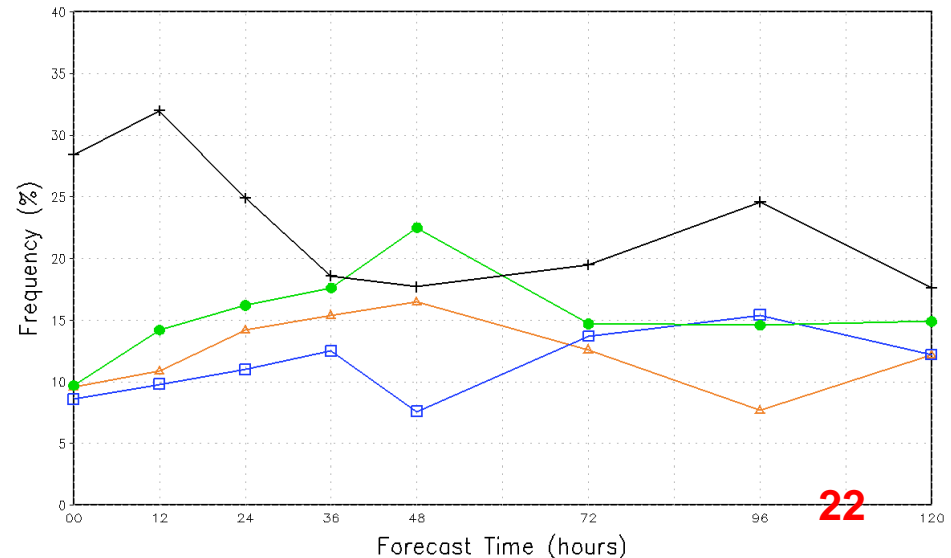
Frequency of superior performance

East-Pac Track Errors



NCEP Hurricane Forecast Project

East-Pac Intensity Errors



NCEP Hurricane Forecast Project

Near Term Tasks

- Implementation of HWRF FY2010 upgrades with H56C configuration. **06/01/2010**
 - **HWRF-HYCOM system to run in EMC parallel. ~ July 1 – Nov. 30**
- Two additional parallel experiments ~ **July 1 – Nov. 30**
 1. **Airborne Doppler radar data assimilation through modified GSI**
 2. **HWRF coupled to NOAA LSM.**
- Transitioning to HWRF V3.2 – R2O tests are in progress. V3.2 available for development by **June-July 2010.**
- High-resolution configurations are being designed (9:3 or 27:9:3) for real-time HFIP demo, in collaboration with HRD.

Technical advancements to HWRF (for high-resolution simulations)

Moving nest algorithm

Mathematically

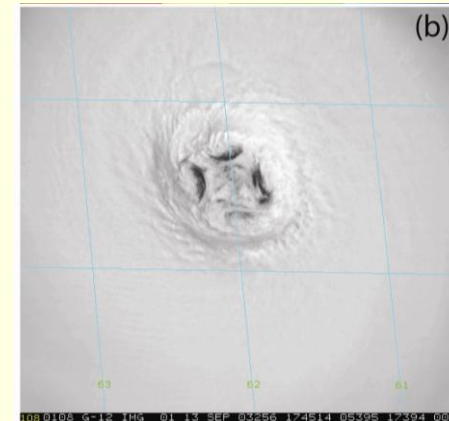
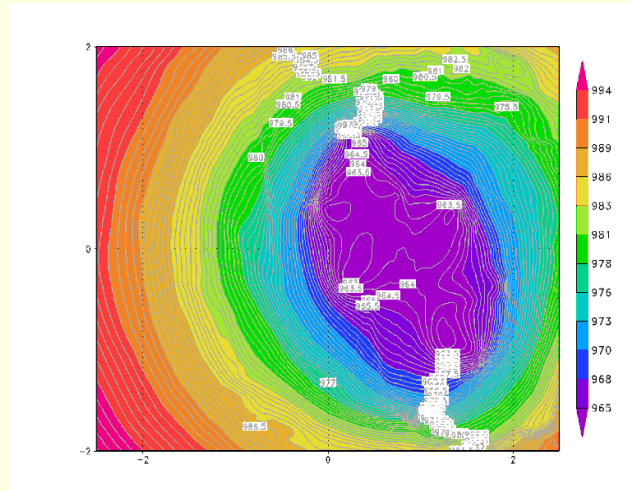
- Stable and unique storm center

Computationally

- Effective and efficient

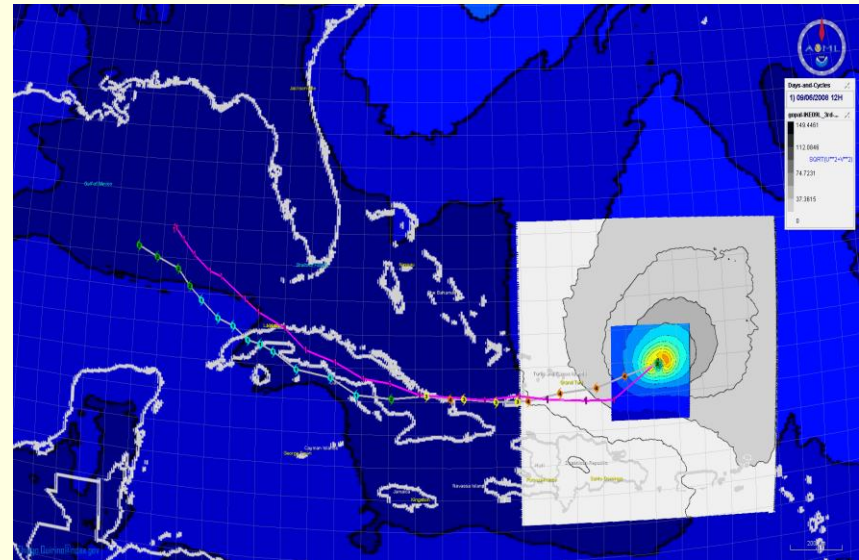
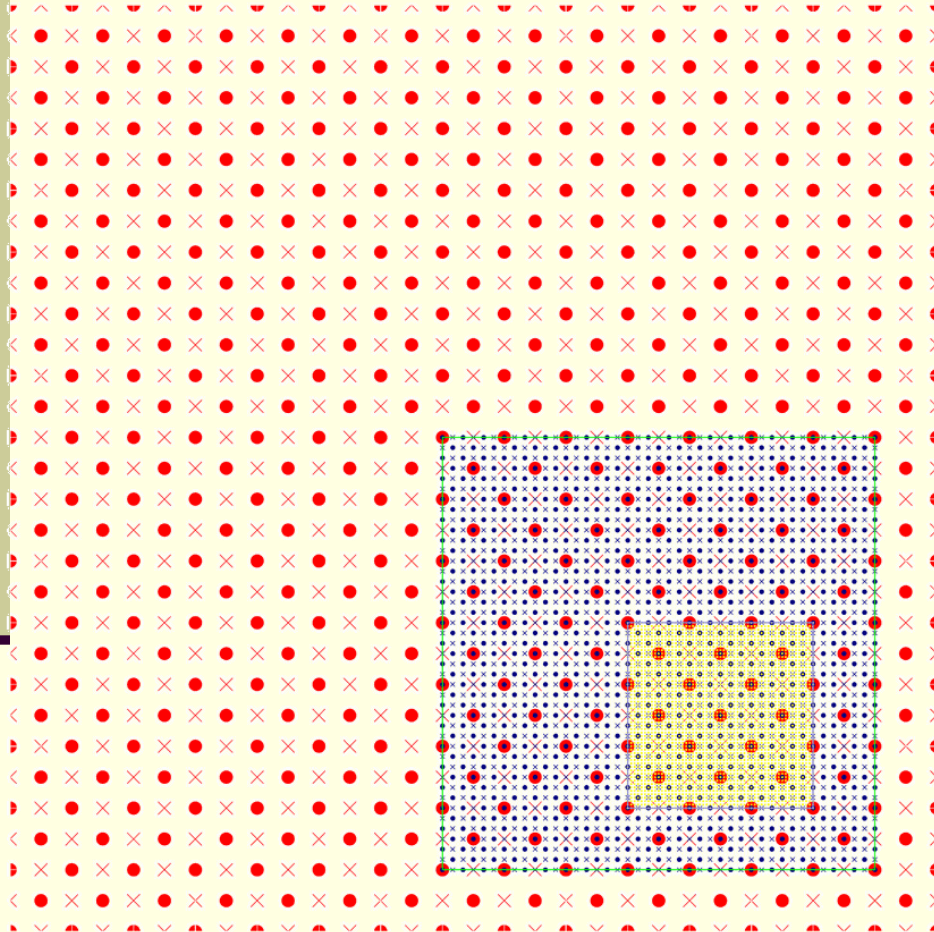
Solution

- Centroid MSLP
- Range limit to start moving (resolution dependent)



Difficulties in tracking a storm at high resolutions when there are multiple centers (or the storm is not well defined)

Example of triple-nested HWRf



Issues/Challenges

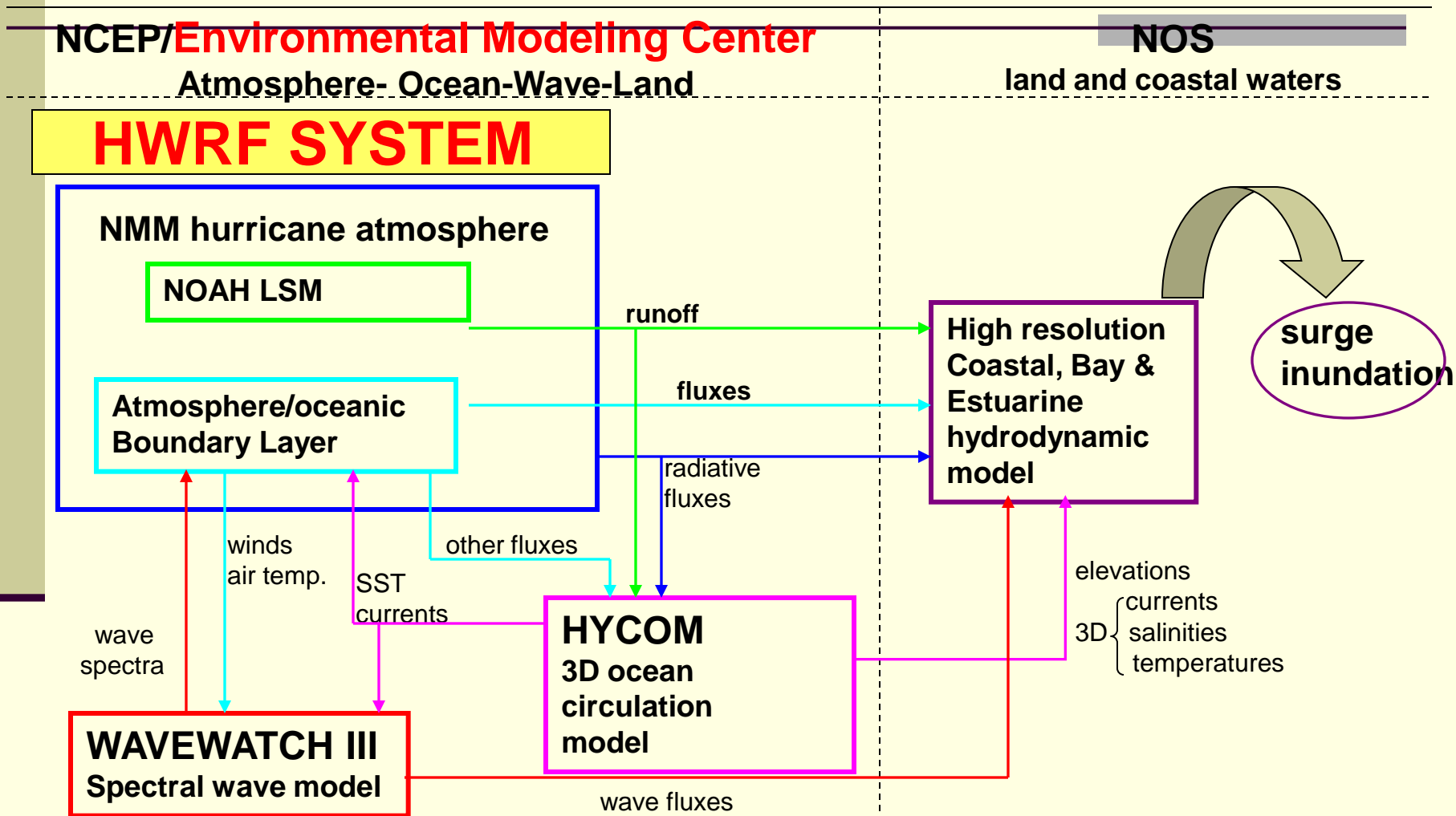


- **HWRF-HYCOM intensity forecast error/bias**
- **Rapid growth if initial intensity errors (initialization issues)**
- **Improvements to physics for high-resolution**
- **Model configuration (domain, physics, initialization, coupling, data assimilation) for higher resolution and multiple nests**
- **Additional data assimilation methods (Hybrid EnKF-GSI)**
- **Future advancements to HWRF modeling system (NEMS??)**
- **Regional model ensembles**

Model & Science Issues

- Resolution is simply the starting point for improving intensity predictions. Host of other issues need to be addressed
- **Mechanics of multiple movable nests**
- **Air Sea Interaction: Ocean Coupling down to 3 km**
- **Improved Surface Layer: Enthalpy and Momentum Fluxes**
- **Wave coupling**
- **Boundary Layer physics and influence of roll convection**
- **Advancing initialization for high resolutions (ENKF/hybrid methods)**

Hurricane-Wave-Ocean-Surge-Inundation Coupled Models



Moving forward....

■ **HWRF model Diagnostics**

- Evolution of large-scale flow in HWRF model
- Sensitivity of model storm to environmental shear
- Interactions of convection-clouds-radiation-microphysics
- Development of core diagnostics facility at DTC

■ **Scientific advancements**

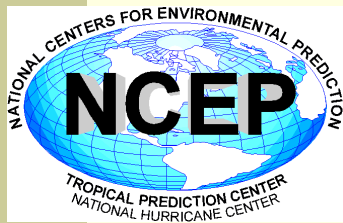
- Increased resolution, with the possibility of including 3rd nest (27/9/3)
- Coupling to HYCOM and Wave-WatchIII
- Improvements to PBL, radiation and microphysics
- Improvements to vortex initialization
- Advanced data-assimilation to include aircraft/radar observations

■ **Partnerships and collaborations**

- Move to more advanced (current) WRF infrastructure (V3.2) - DTC supported R2O – O2R mechanism
- Take advantage of HFIP funded research in improving operational HWRF system
- Active collaborations with DTC, HRD, ESRL, URI, FSU, CIRA, UMD/UMBC and others

DTC-EMC Collaboration

- EMC and DTC signed a code management document to coordinate R2O efforts
 - DTC will maintain operational HWRF as a reference configuration of general WRF repository
- DTC-EMC Efforts on R2O Test Plans
 - Multi-stage R2O tests to benchmark HWRF V3.2 performance comparable to FY2010 operational HWRF ~ June-Sep. 2010
 - HYCOM coupled to HWRF V3.2 ~ Oct-Nov. 2010
- EMC will provide
 - operational HWRF and HYCOM components and datasets
- DTC will conduct
 - weekly regression tests and monthly “mini” performance tests.
 - Planned synchronization of EMC branch with the DTC trunk
- EMC and DTC will coordinate test plans for HWRF FY2011 implementation and future upgrades, engaging research community to actively participate in improving the HWRF performance.



**THANK YOU FOR
YOUR ATTENTION...**

Questions???