High-Resolution Hurricane Model Development and Evaluation at NCEP/EMC – the Operational HWRF Model

Vijay Tallapragada
Hurricane Team Lead
Environmental Modeling Center, NCEP/NOAA/NWS
Camp Springs, MD 20746.

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Outline

- Current operational HWRF system
- Evolution of HWRF
- HWRF in FY2011
- Ongoing developments and FY2012 implementation strategies
- Collaborative efforts
- Challenges and Future developments

The HWRF Team at EMC

- **Vijay Tallapragada (Team Lead, EMC)**
- **Robert Tuleya***
- **Qingfu Liu**
- **Young Kwon**
- **Zhan Zhang**
- **Sam Trahan**
- **Eric Aligo^{+} , Weiguo Wang^{++}**
- **Janna O'Connor**
- **Chanh Kieu****
- **Xuyang Ge**
- **AOML/HRD Collaborators:**
  - Bob Atlas, Frank Marks, Gopalakrishnan, Xuejin Zhang,
  - Kevin Yeh, Thiago Quirino,
  - Lisa Bucci, Tomislava Vukicevic,
  - Bachir Annane, Stan Goldenberg,
  - Rob Rogers, Sim Aberson, Altug Aksoy, Shirley Murilo and many others

- **MMAB Collaborators**
  - Hyun-Sook Kim, Dan Iredell
- **DA Collaborators**
  - John Derber, Mingjing Tong
  - In-Hyuk Kwon, Emily Liu
- **GCWMB Collaborators**
  - Hua-Lu Pan, Dmitry Sheinin
  - Fanglin Yang
- **MMB Collaborators**
  - Dusan Jovic, Tom Black
  - Matt Pyle, Brad Ferrier
- **Ensemble Team**
  - Jiyayi Peng
- **NHC**
  - Richard Pasch, James Franklin
  - Wallace Hogsett, David Zelinsky,
- **DTC**
  - Ligia Bernardet, Shaowu Bao,
  - Don Stark, Tim Brown, Mrinal Biswas
- **CIRA**
  - Mark DeMaria and his team
- **URI**
  - Isaac Ginis, Rich Yablonsky, Biju Thomas
- **GFDL**
  - Morris Bender, Tim Marchok

Special Recognition to AOML, DTC, CIRA, NHC & other HFIP partnerships

Works from ODU; $^{+}$Moving to Mesoscale Branch, $^{++}$Moving from Mesoscale Branch, ** New Hire

Operational HWRF Modeling System

- Current operational HWRF
  - Regional-Scale Ocean-Atmosphere Coupled Modeling System specially designed to advance hurricane track and intensity forecasts.
  - Non-Hydrostatic system of equations formulated on a rotated latitude-longitude, Arakawa E-grid and a vertical, pressure hybrid (sigma-P) coordinate.
  - Based on WRF NMM V2.0 framework with movable, vortex following high-resolution nested grid
  - 27 km outer domain, 9 km inner domain, 42 vertical levels
- Advanced vortex initialization and GSI/3DVAR data assimilation
  - Advanced vortex initialization and GSI/3DVAR data assimilation consisting of Vortex relocation, Storm size and intensity correction based on tcvitals, and combination of bogus (synthetic) vortex and six-hour cycling
  - Assimilation of satellite radiance datasets in the hurricane environment
- Coupled to Princeton Ocean Model (POM) in the Atlantic
  - Feature based initialization of cold wake, loop current, warm and cold core eddies
- Physical parameterizations designed for tropical environment
  - GFS/GFDL SAS Convection and PBL
  - GFDL Surface Physics, Radiation, Ferrier Microphysics

Design of high-resolution movable nest

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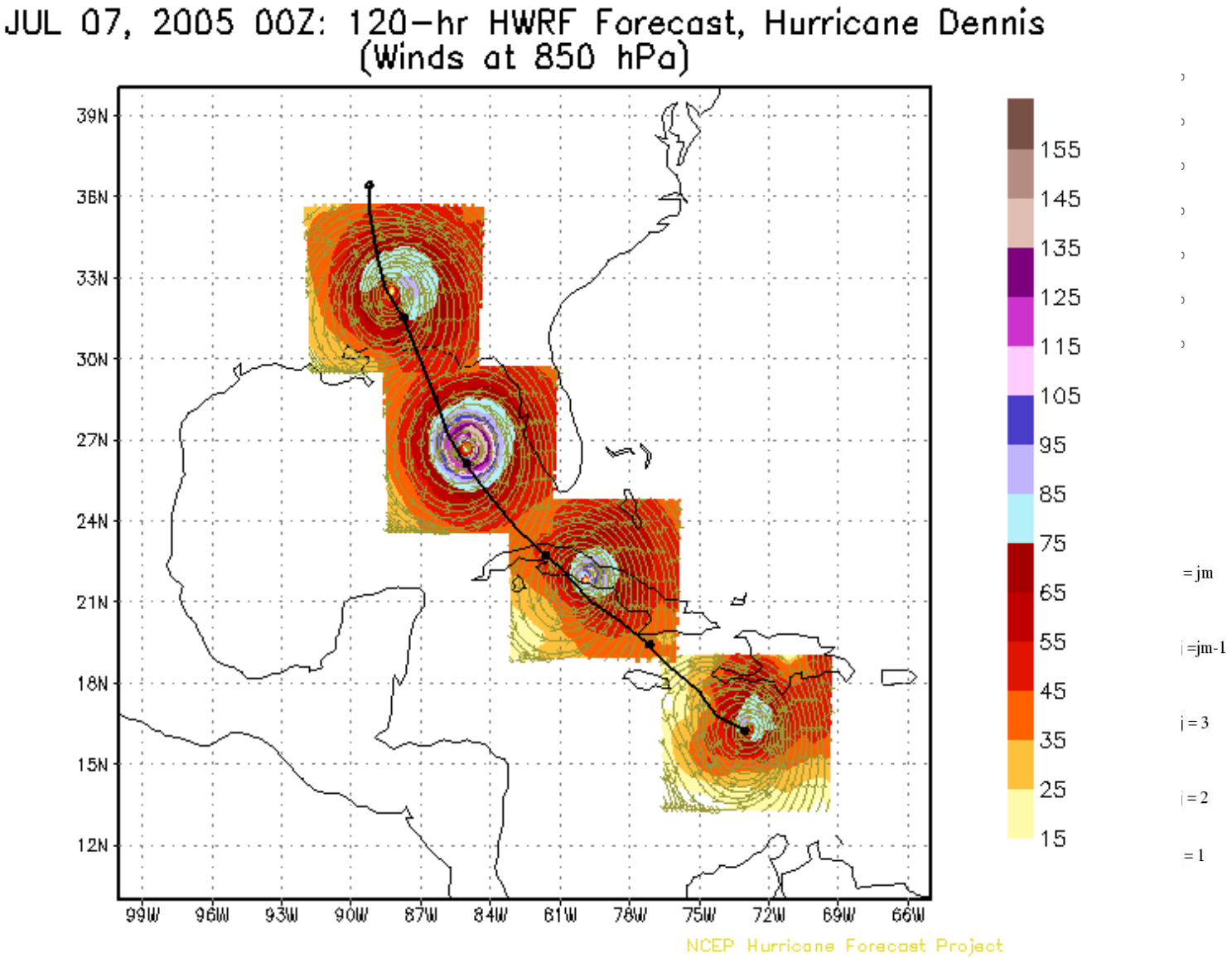
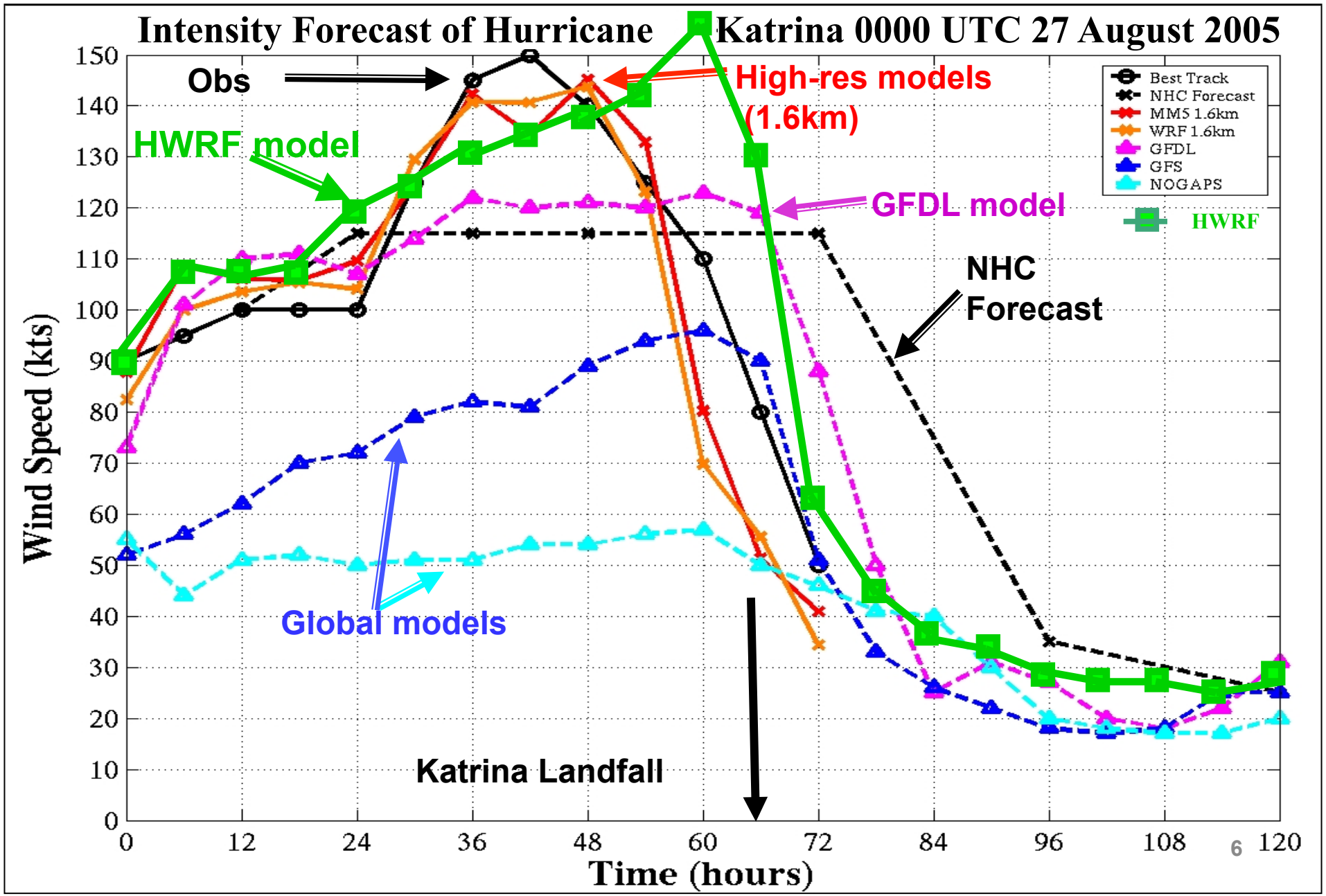
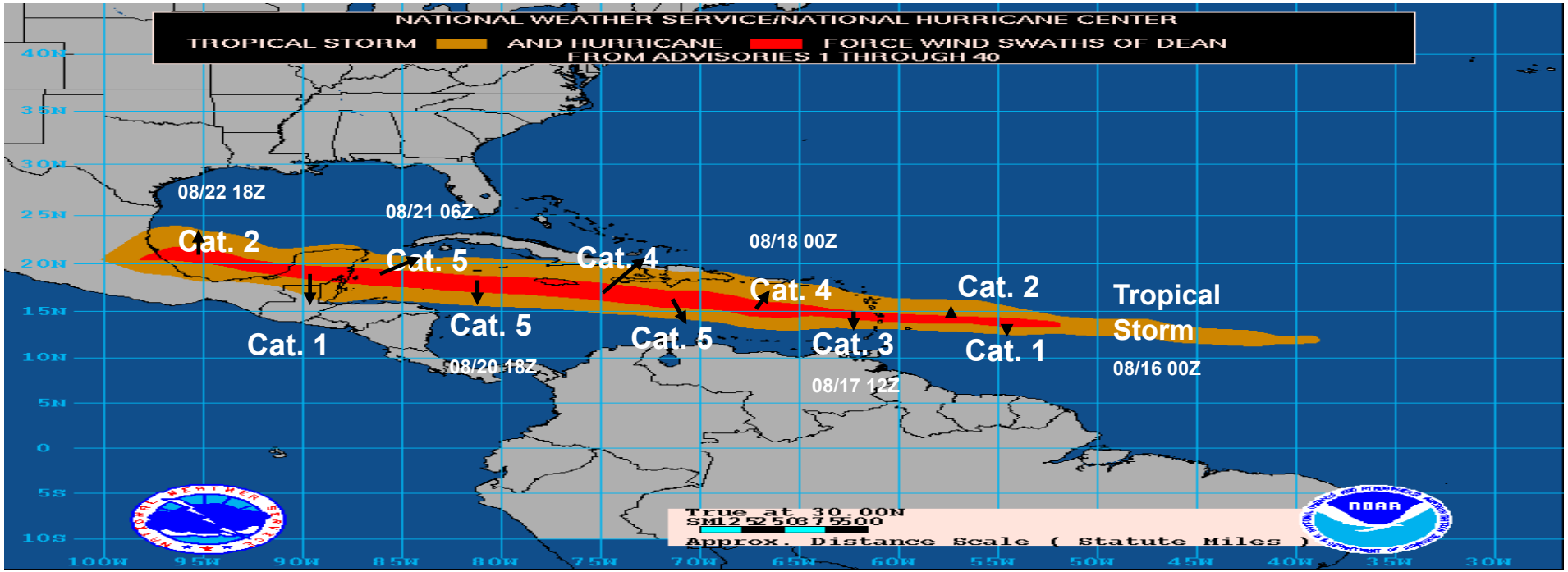
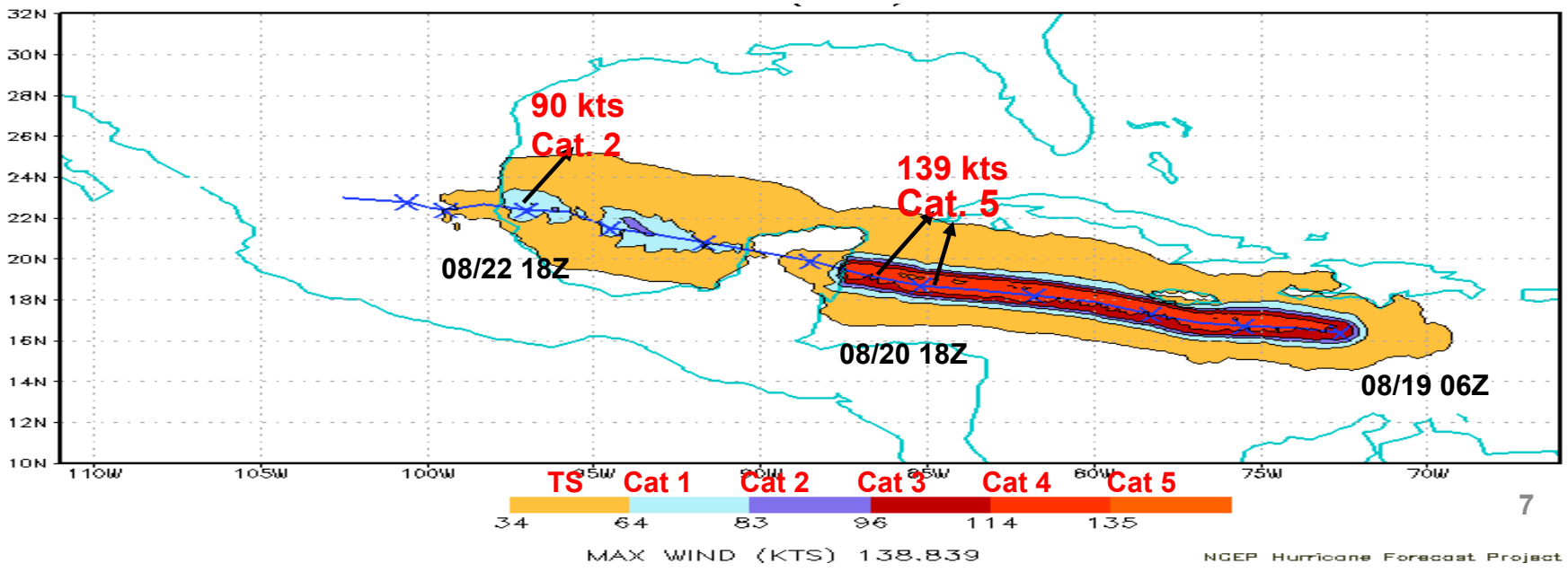


Research model forecasts of storm intensity for Hurricane Katrina showing benefit of high (1.6km) resolution (S. Chen)





Hurricane Dean 5 day forecasts of maximum winds starting from 8/19/06Z

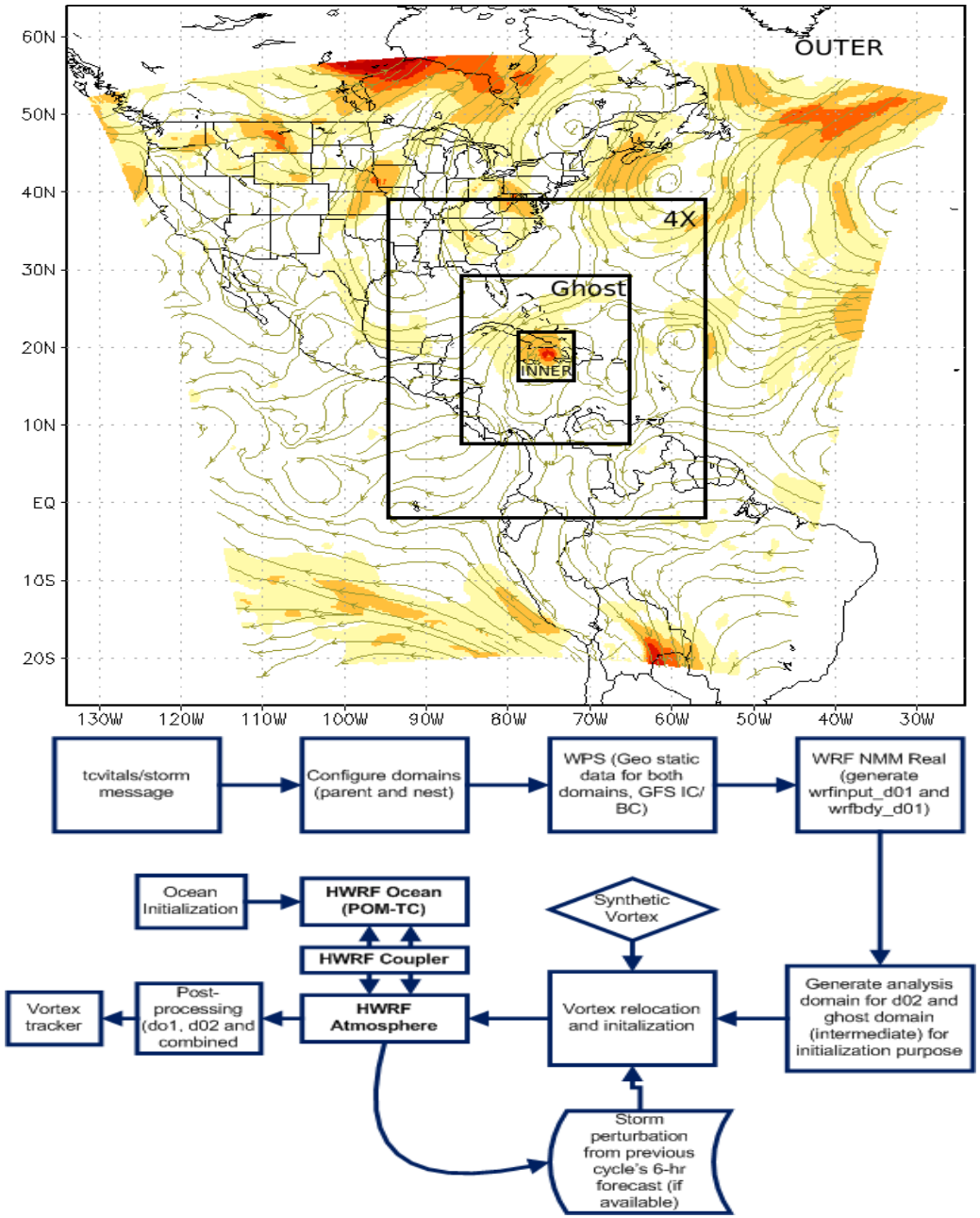


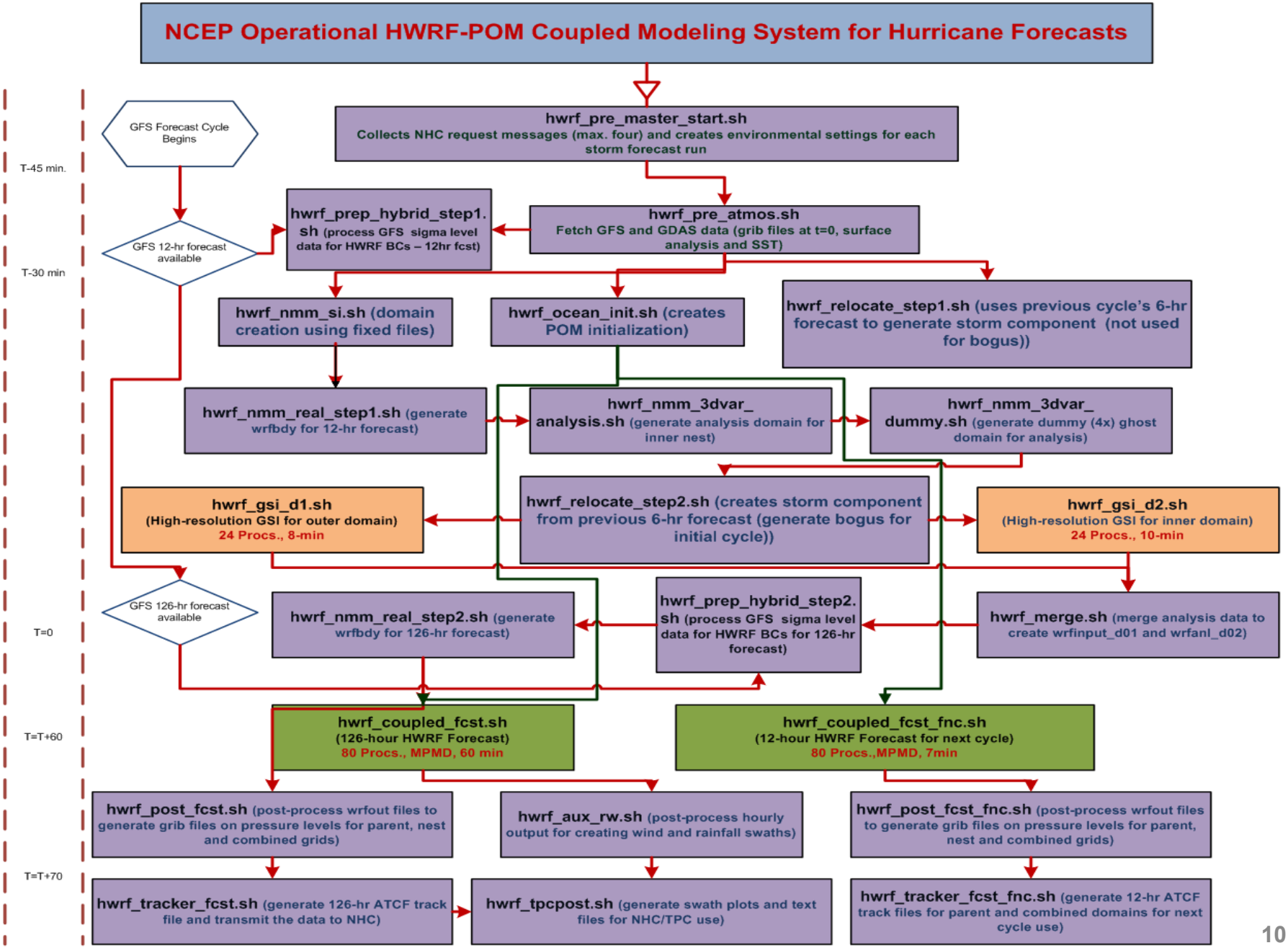
Evolution of HWRF

- **Initial implementation in 2007 hurricane season**
  - Model design and development of movable nested grid started in 2002
  - Initial HWRF workshop at NSF in 2004
  - 28 different configurations tested individually (each with about 200 simulations) before initial implementation
  - Extensive 3-season (2004-2006) pre-implementation testing of HWRF for all storms in the Atlantic and Eastern Pacific basins
- **Vortex initialization upgrades in 2008**
  - Address intensity bias for weaker systems, modifications to storm balance
- **Infrastructure upgrade and transition to P6 in 2009**
  - Capability enhancements to allow coupling to HyCOM and Wave Watch-III
  - Script enhancements (identical scripts for NCO operations and EMC parallels)
- **Physics and initialization upgrades in 2010 to improve the forecast skill.**
  - New baseline version with several bug fixes, modified surface physics formulation and use of Gravity Wave Drag parameterization, Addition of satellite radiance data assimilation in the hurricane environment, Focus on reducing intensity bias
- **Transition to community modeling framework HWRF V3.2 and scientific upgrades in 2011**

Overview of the Operational HWRF

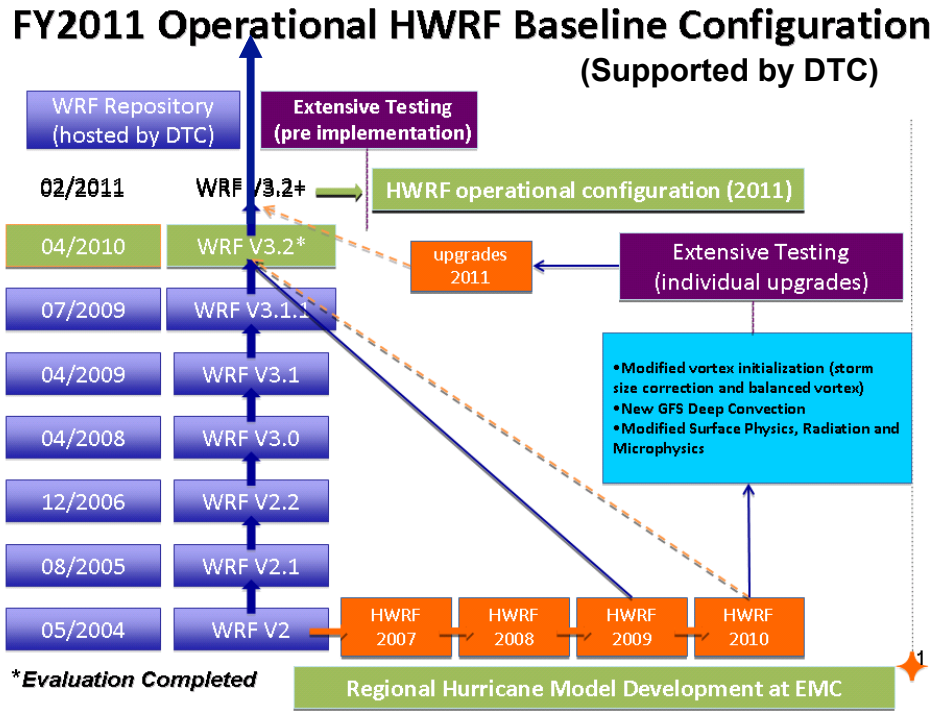
- **HWRF Atmosphere**
  - Movable, two-way nested vortex following grid
  - 9km inner domain and 27km outer domain), 42 vertical layers
  - Advanced physics from GFDL/GFS
  - Advanced vortex initialization with GSI/3DVAR
- **HWRF Ocean**
  - Coupled to Princeton Ocean Model (POM) in the Atlantic Basin
  - Feature based initialization of loop current and warm/cold core rings, cold wake specification during spin-up phase
- **Operational HWRF products**
  - Numerical guidance on 6-hrly hurricane track and intensity for as many as five storms (both Atlantic and Eastern Pacific)
  - High-resolution swaths (hourly, 10th of a degree) for wind and precipitation along the projected storm path
  - Simulated GOES synthetic satellite imagery (IR, VIS and WV) and radar reflectivity
- **Five years into operations, since 2007**

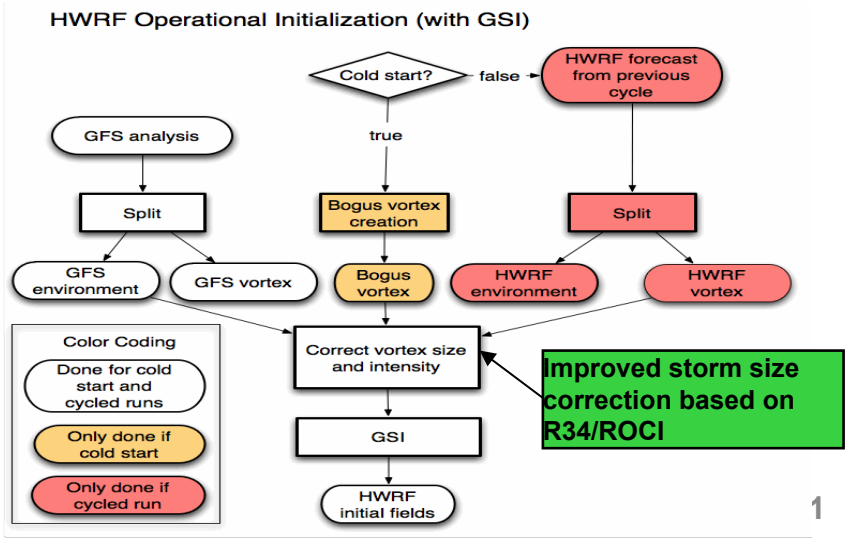



NCEP Operational HWRF-POM Coupled Modeling System for Hurricane Forecasts
GFS Forecast Cycle Begins
hwrf_pre_master_start.sh
Collects NHC request messages (max. four) and creates environmental settings for each storm forecast run
T-45 min.
GFS 12-hr forecast available
hwrf_prep_hybrid_step1.sh (process GFS sigma level data for HWRF BCs – 12hr fcst)
hwrf_pre_atmos.sh
Fetch GFS and GDAS data (grib files at t=0, surface analysis and SST)
T-30 min
hwrf_nmm_si.sh (domain creation using fixed files)
hwrf_ocean_init.sh (creates POM initialization)
hwrf_relocate_step1.sh (uses previous cycle's 6-hr forecast to generate storm component (not used for bogus))
hwrf_nmm_real_step1.sh (generate wrfbdy for 12-hr forecast)
hwrf_nmm_3dvar_analysis.sh (generate analysis domain for inner nest)
hwrf_nmm_3dvar_dummy.sh (generate dummy (4x) ghost domain for analysis)
hwrf_gsi_d1.sh
(High-resolution GSI for outer domain)
24 Procs., 8-min
hwrf_relocate_step2.sh (creates storm component from previous 6-hr forecast (generate bogus for initial cycle))
hwrf_gsi_d2.sh
(High-resolution GSI for inner domain)
24 Procs., 10-min
GFS 126-hr forecast available
T=0
hwrf_nmm_real_step2.sh (generate wrfbdy for 126-hr forecast)
hwrf_prep_hybrid_step2.sh (process GFS sigma level data for HWRF BCs for 126-hr forecast)
hwrf_merge.sh (merge analysis data to create wrfinput_d01 and wrfanl_d02)
T=T+60
hwrf_coupled_fcst.sh
(126-hour HWRF Forecast)
80 Procs., MPMD, 60 min
hwrf_coupled_fcst_fnc.sh
(12-hour HWRF Forecast for next cycle)
80 Procs.,MPMD, 7min
hwrf_post_fcst.sh (post-process wrfout files to generate grib files on pressure levels for parent, nest and combined grids)
hwrf_aux_rw.sh (post-process hourly output for creating wind and rainfall swaths)
hwrf_post_fcst_fnc.sh (post-process wrfout files to generate grib files on pressure levels for parent, nest and combined grids)
T=T+70
hwrf_tracker_fcst.sh (generate 126-hr ATCF track file and transmit the data to NHC)
hwrf_tpcpost.sh (generate swath plots and text files for NHC/TPC use)
hwrf_tracker_fcst_fnc.sh (generate 12-hr ATCF track files for parent and combined domains for next cycle use)

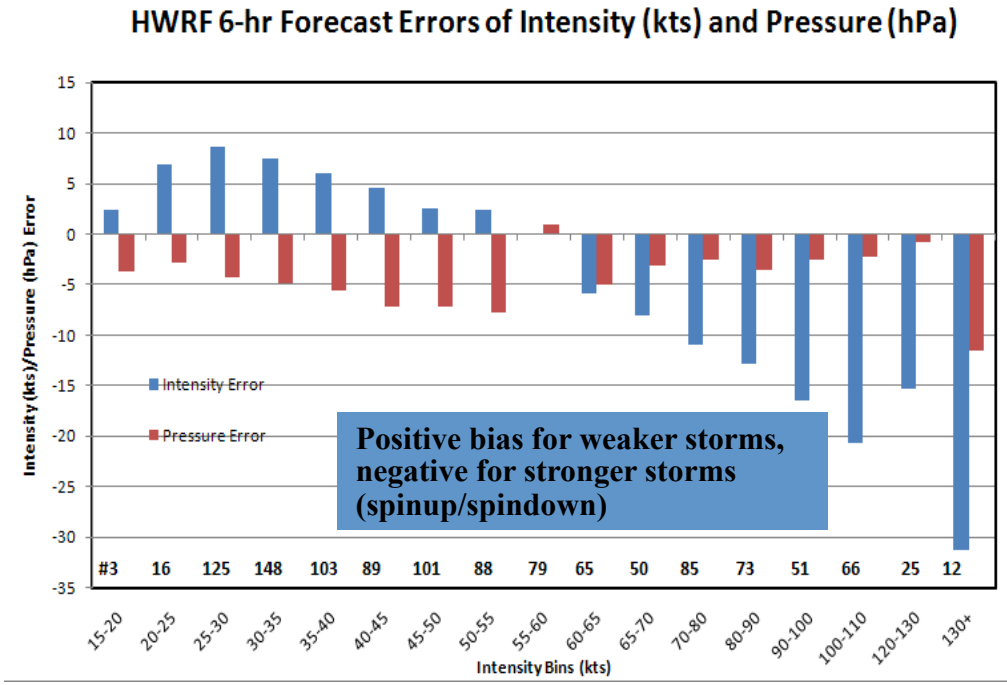
HWRF Upgrades FY2011

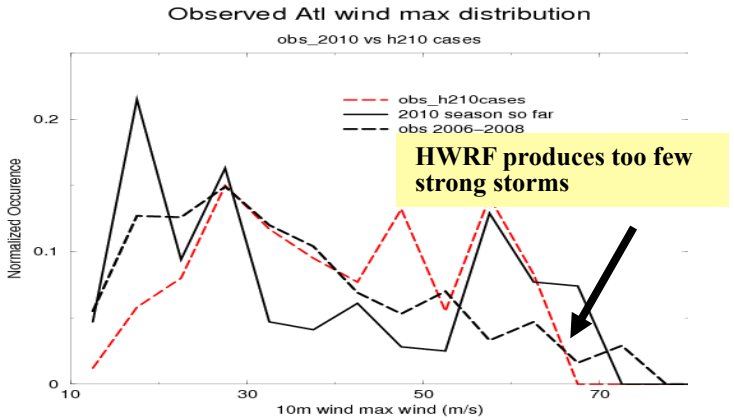
- **Model Upgrades (Atmosphere)**
  - Upgrade dynamical core to NMM community version V3.2 (EMC-DTC Collaboration)
  - New GFS Deep Convection, Improved surface physics, and new FY2011 GSI/GFS IC/BC (EMC- GFDL Collaboration)
- **Vortex initialization upgrades**
  - Improved storm size correction based on radius of 34 kt winds or ROCI and dynamical mass-wind consistency of the initial vortex (EMC-HRD collaboration)
  - Modification of synthetic storm and its application in the initialization (vortex cycling)
  - Upgrade HWRF GSI to V2.5 (community code)
- **Operational HWRF product enhancements**
  - Satellite angle corrections for simulated GOES WV and IR imagery, additional simulated microwave products
  - New enhanced HWRF website for product display and navigation
  - High-frequency output (3 hourly) and additional derived variables for diagnostics (EMC-NHC-CIRA Collaboration)
- **Mid-Season major bug fix in SAS deep convection (array out of bounds)**





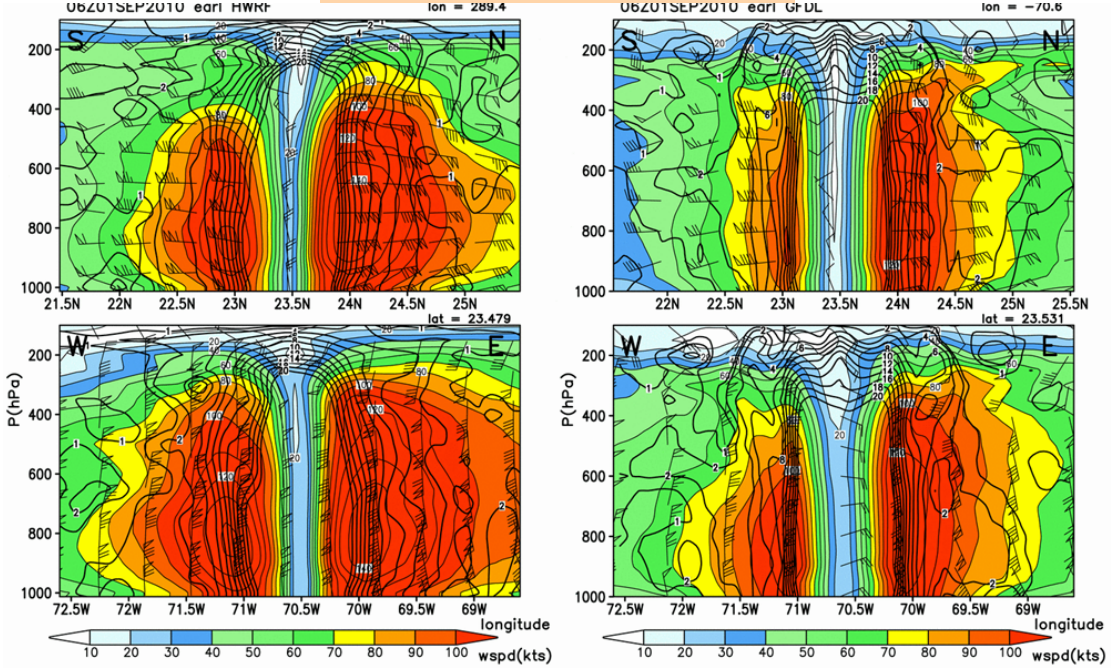
Vortex Initialization Issues/Challenges

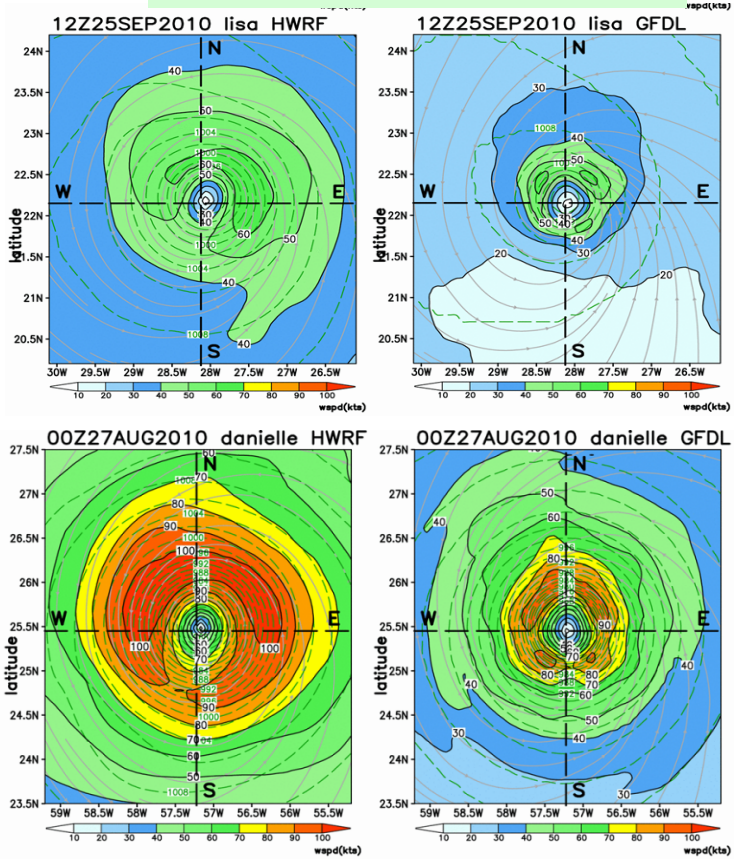


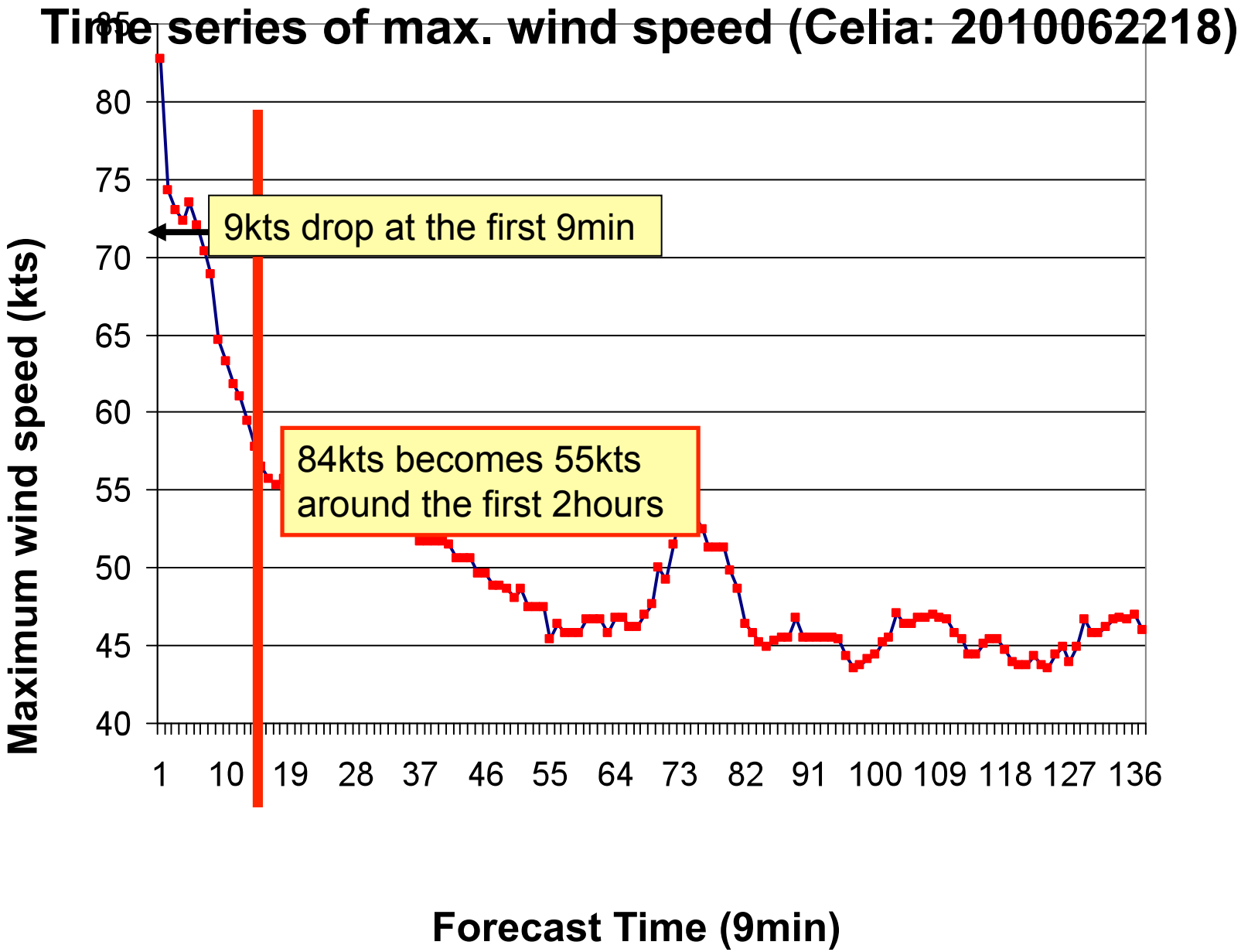


Insufficient vortex size correction

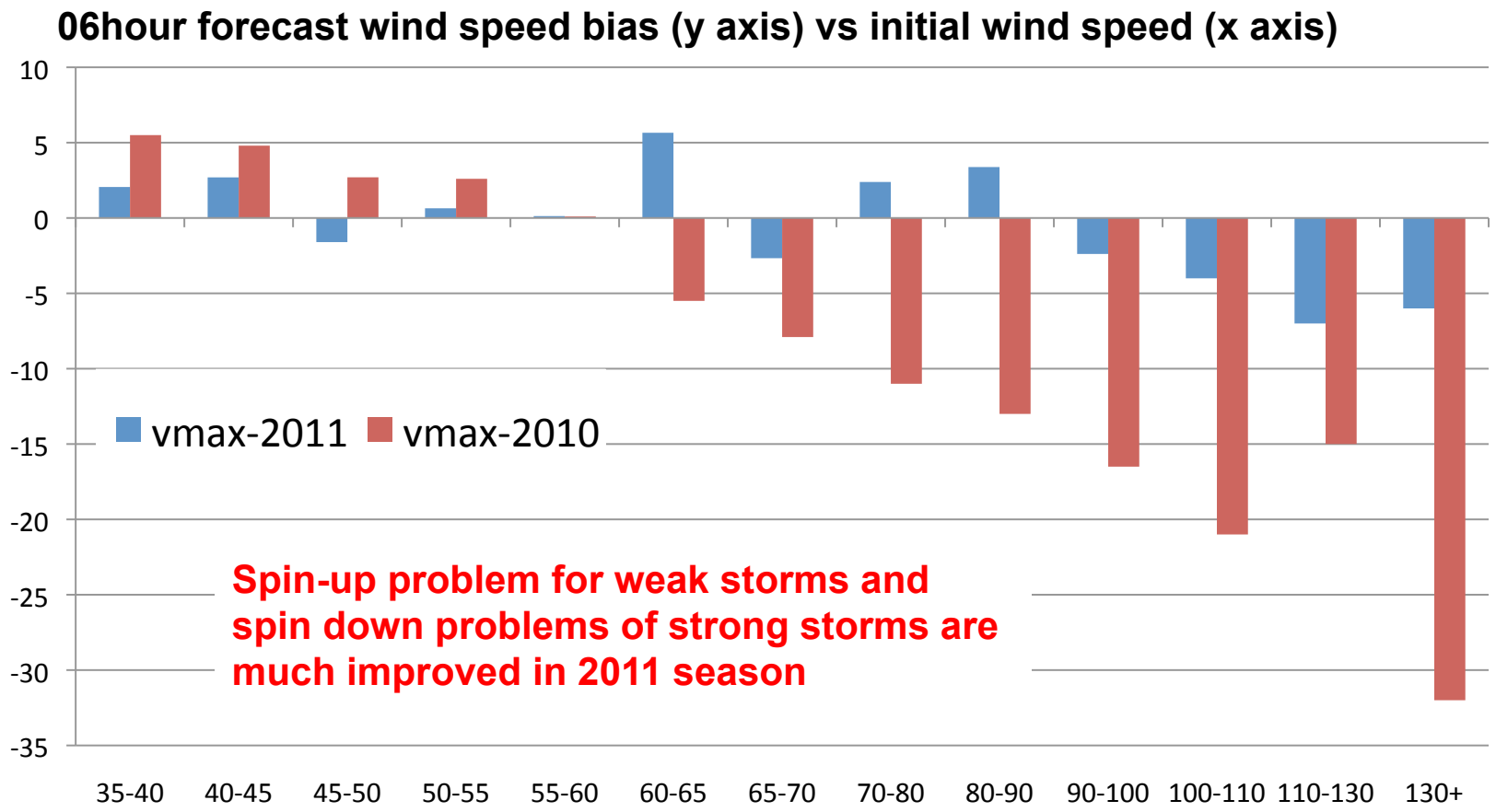
Broad initial vertical structure






Time series of max. wind speed (Celia: 2010062218)
Maximum wind speed (kts)
85
80
75
70
65
60
55
50
45
40
9kts drop at the first 9min
84kts becomes 55kts
around the first 2hours
1
10
19
28
37
46
55
64
73
82
91
100
109
118
127
136
Forecast Time (9min)

Impact of upgraded vortex initialization scheme in 2011 HWRF (EMC-HRD)



1. Vortex size correction

- Instead of matching only RMW but also matching outer radii such as ROCI or R34kt

2. Less use of the composite storms for weak storms

- Preventing the rapid spin-up of weak storms

3. Matching the maximum 10m wind speed but not forcing the minimum SLP

- With more balanced vortex, rapid spin-down of strong storm is much reduced

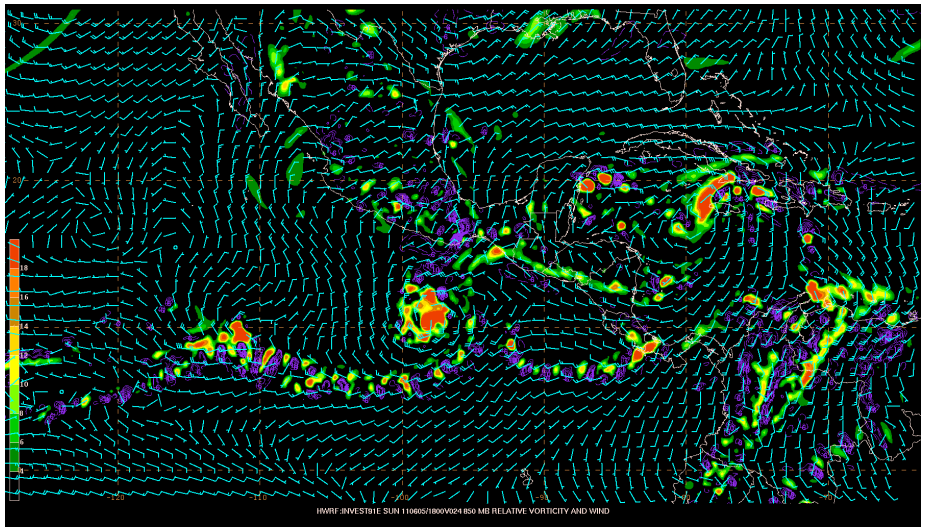
*** Modified initialization significantly improve the intensity skill of HWRF model (especially 0-48hr)**

12,24,48 hour forecast wind speed bias (y axis) vs initial wind speed (x axis)

24-hr and beyond, HWRF tends to over-intensify the storms (very few samples)

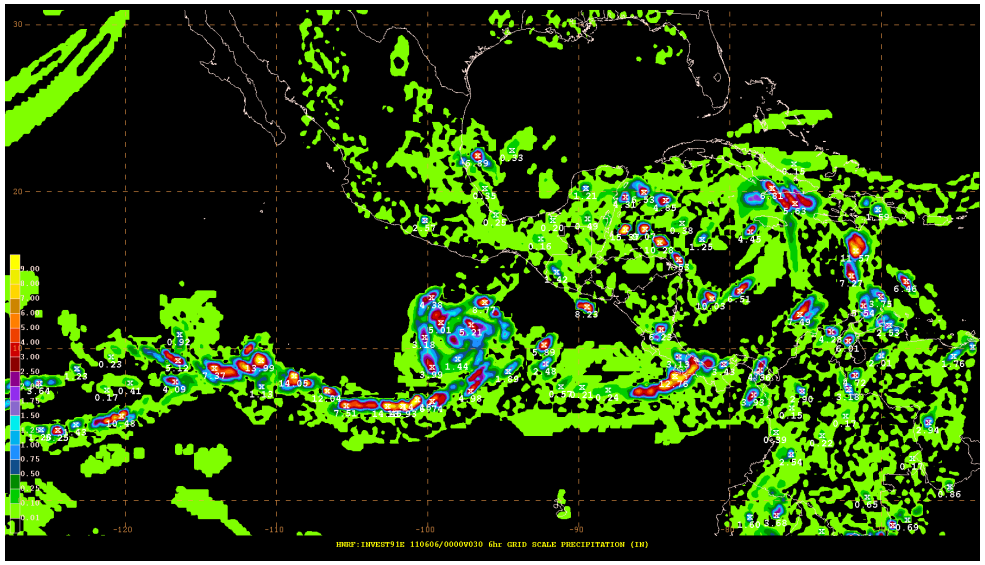
Operational Challenges

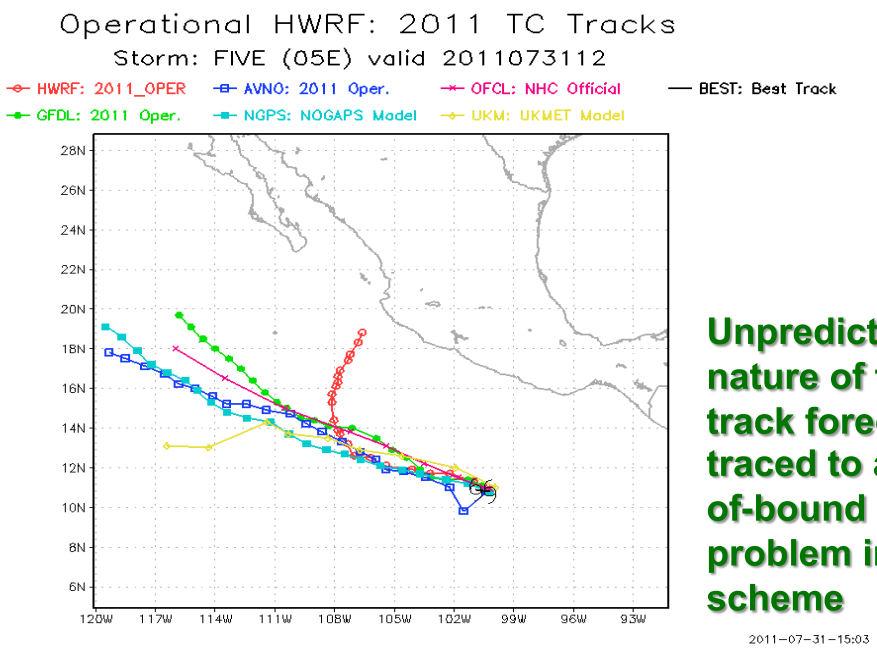
Initial observations from Mike Brennan (NHC): 18 to 24 hours into the HWRF model run the low-level vortex associated with the invest appears to break down. The model shows a patchwork pattern of low-level vorticity maxima and minima in association with the invest, along the ITCZ, and in the high terrain of Mexico. This appears to be due to very large amounts of grid-scale precipitation, in some areas exceeding 5 or even 10 inches in a 6-h period across much of the domain. Interestingly, the precip amounts produced by the convective scheme are quite small (generally < 1 inch in a 6-h period).



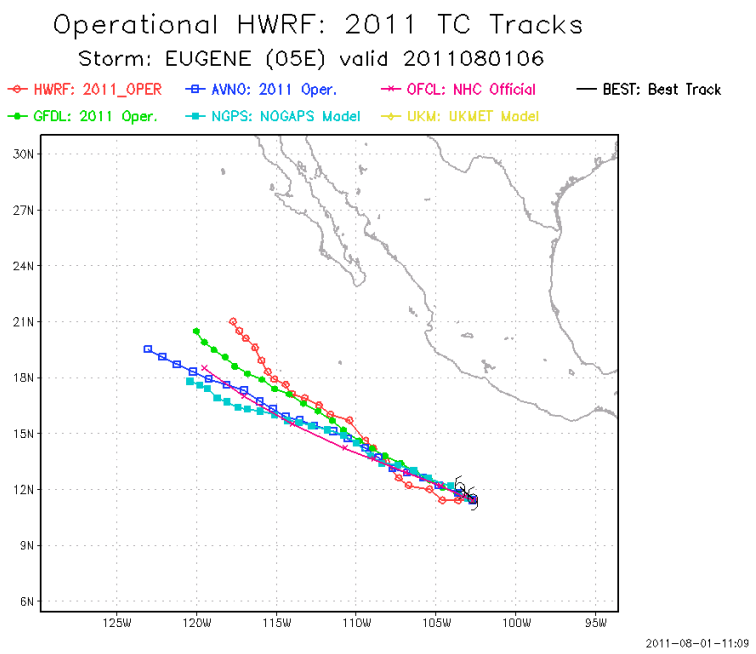
850 hPa Vorticity

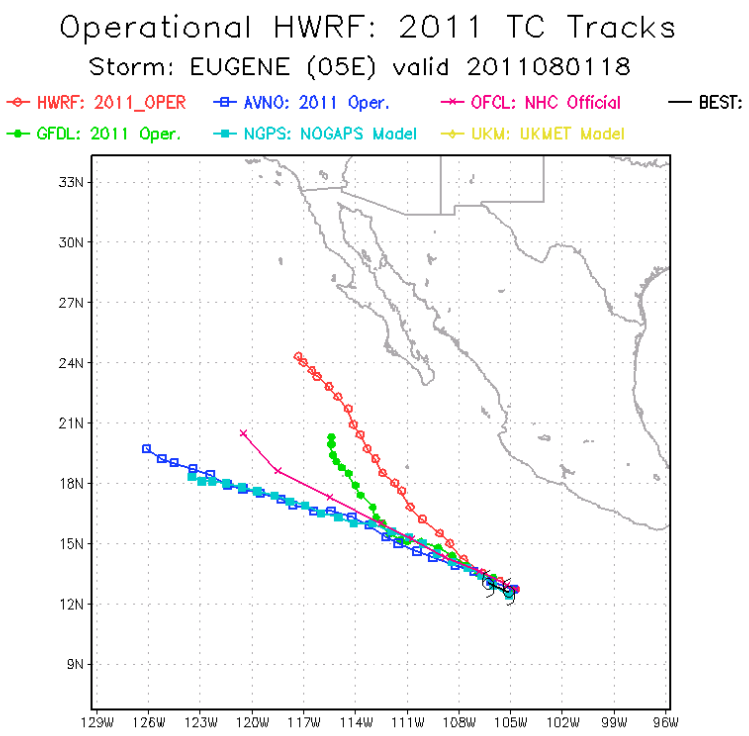
Grid-Scale Precipitation

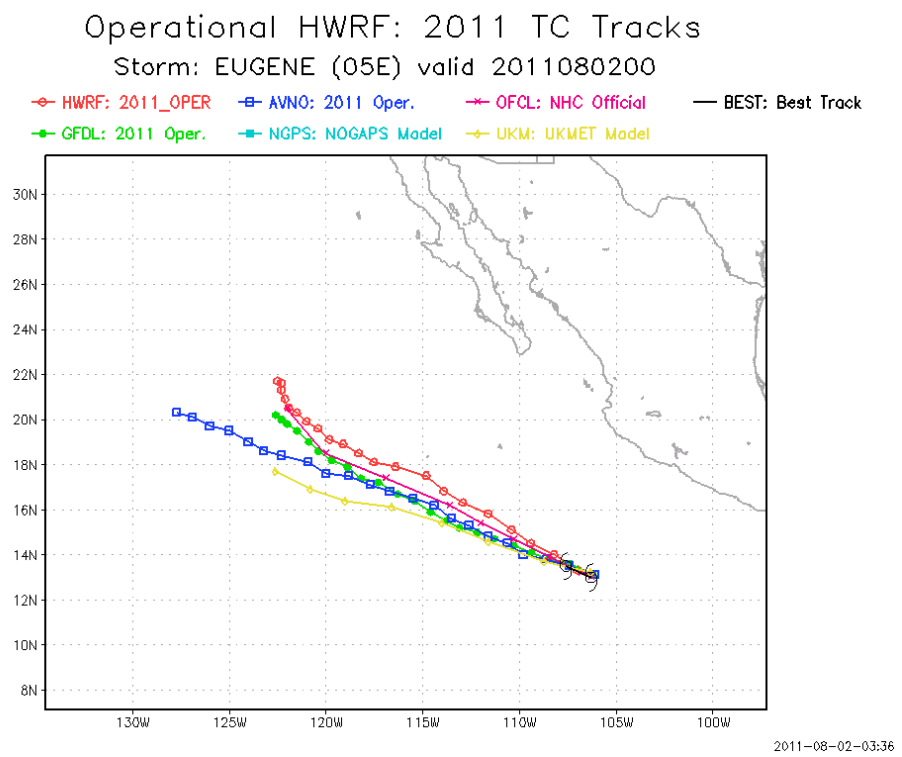




Unpredictable nature of the track forecasts – traced to an out-of-bound array problem in SAS scheme

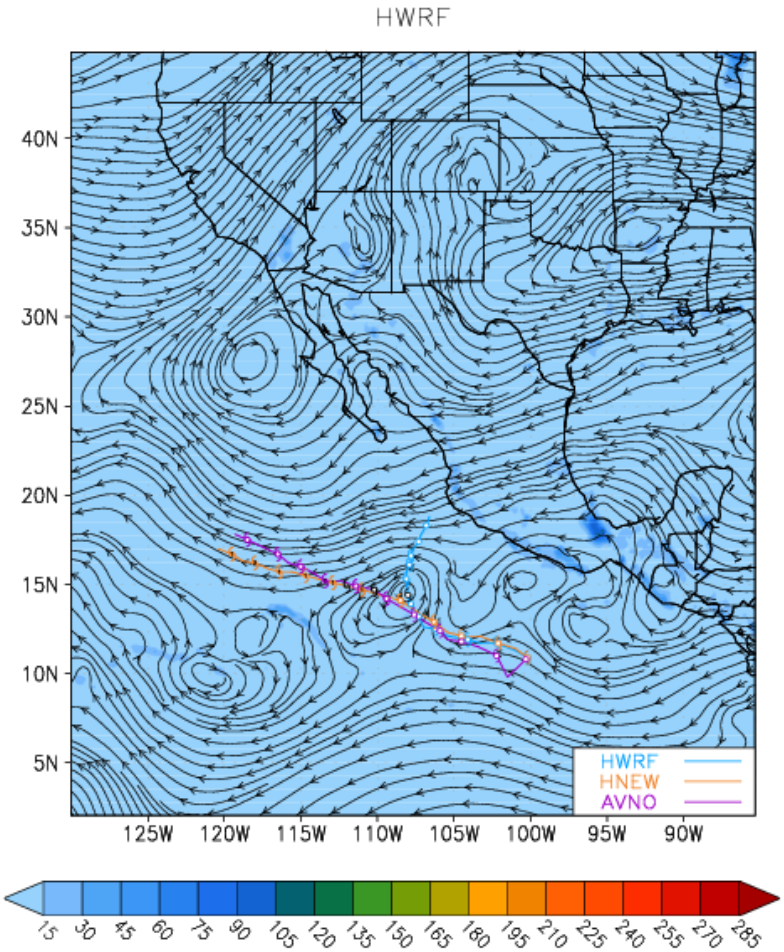


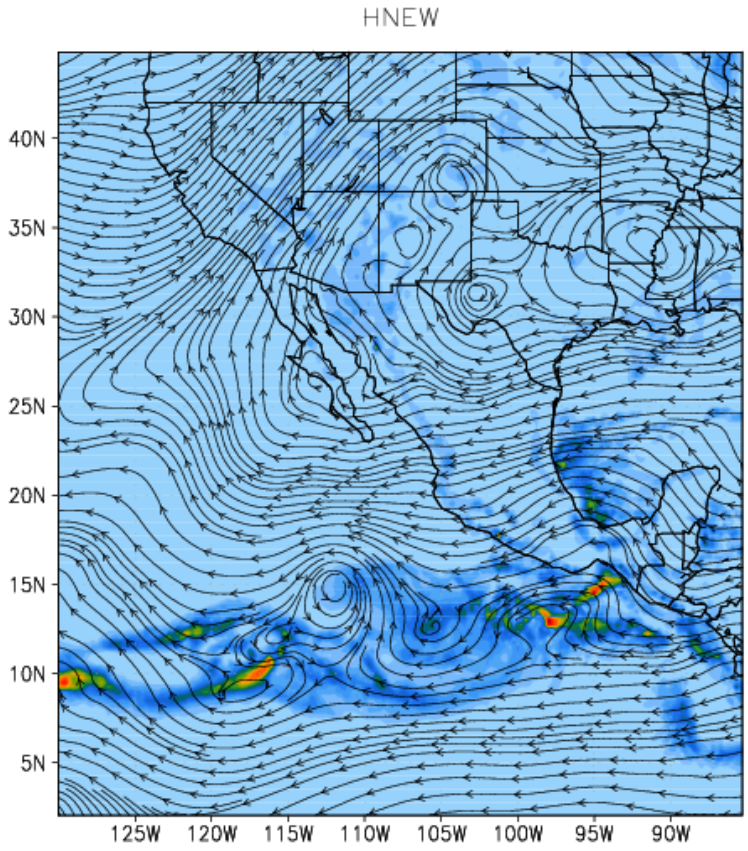




Data Set #1 : HWRF PARENT GRID – FIVE05e
Data Set #2 : HNEW PARENT GRID – FIVE05e
it: 2011073112 vt: 2011080306 (66h)

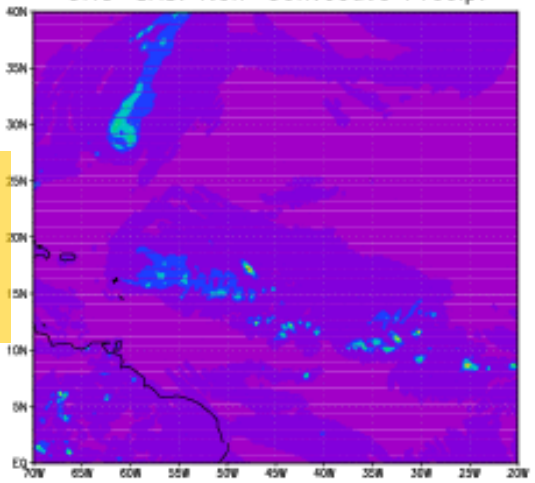
surface convective precip (shaded, kg/m^2)
850–200 mb mean wind (streamlines,)



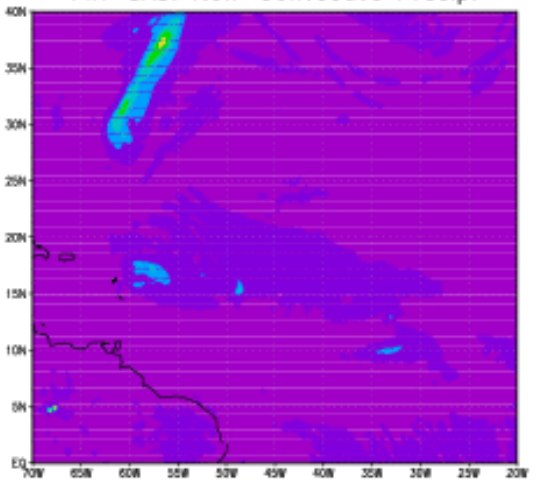


Convective and non-Convective Precip. related to SAS bug
Hurricane Earl:2010082800 t=48Hr (Parent Domain)

ORG-SAS: Non-Convective Precip.

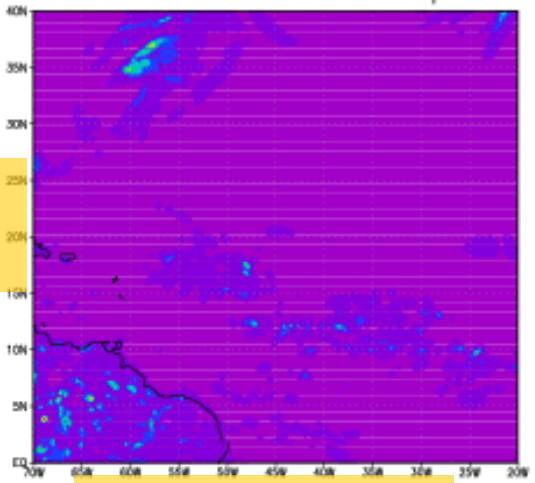


FIX-SAS: Non-Convective Precip.

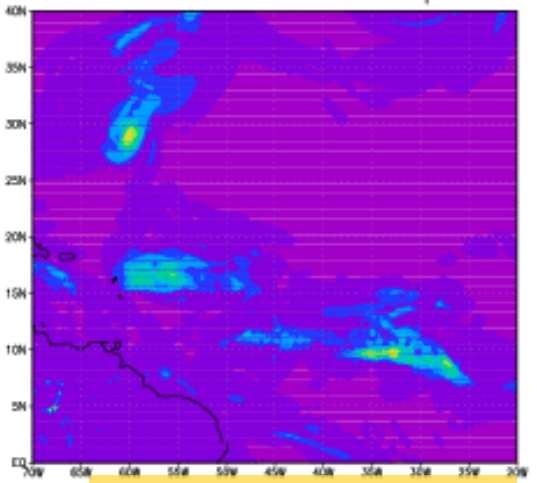


Large-scale precip

ORG-SAS: Convective Precip.



FIX-SAS: Convective Precip.

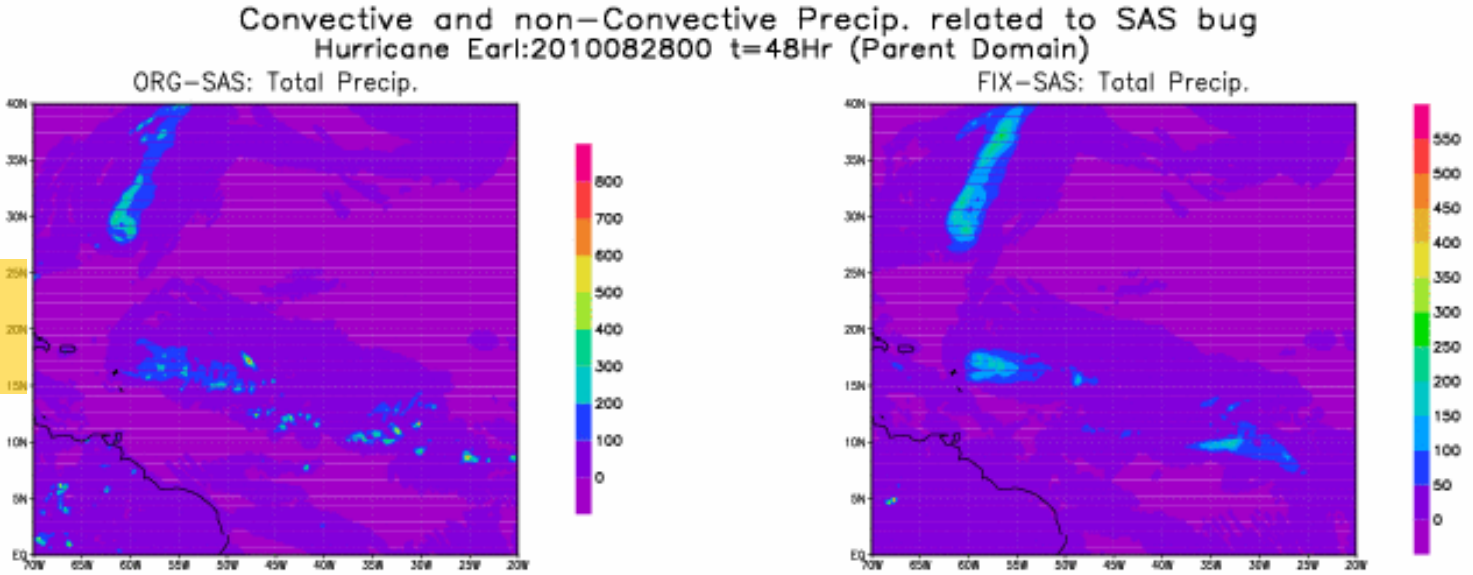


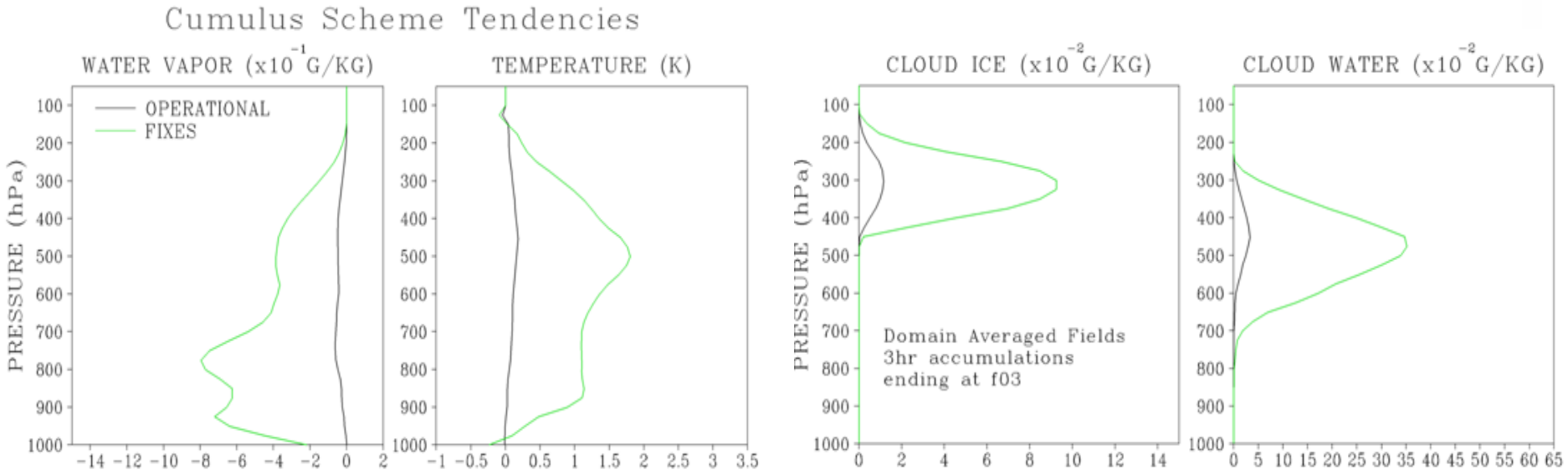
Conv. precip

Original SAS

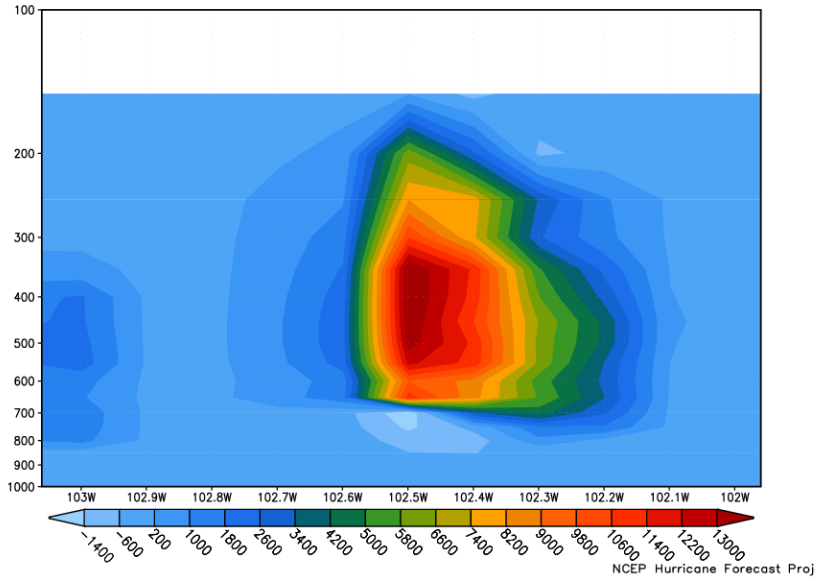
Bug-fixed SAS

Total precip

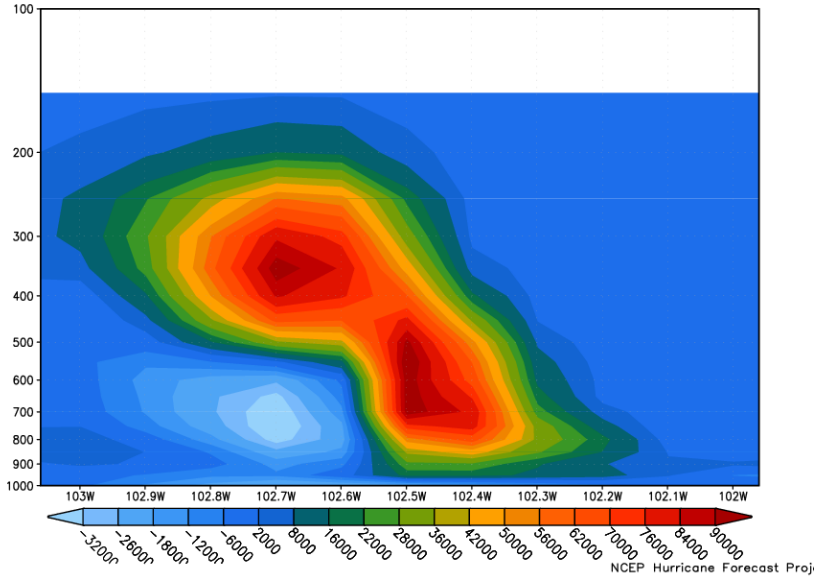




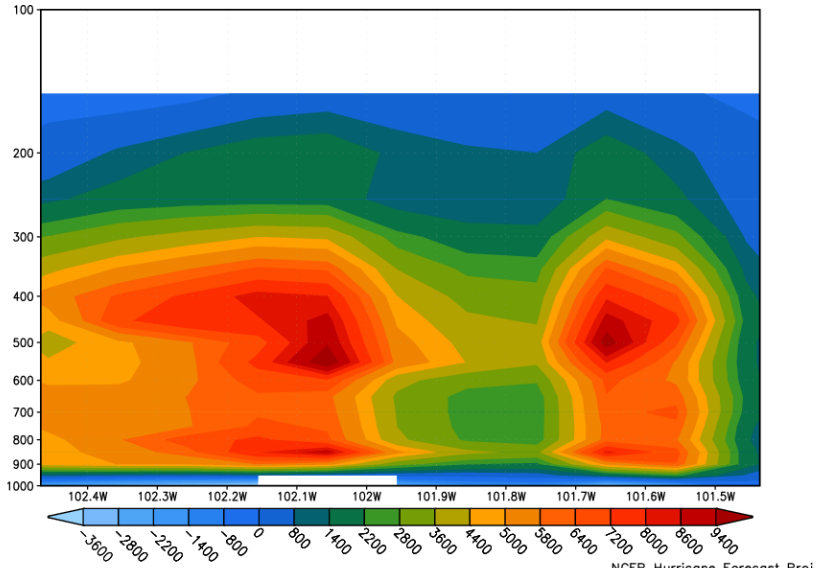
HWRF NEST GRID – FIVE05e convective heating (shaded, Kdy⁻¹)
it: 2011073112 vt: 2011080100 (12h)
x–sect: E–W at 11.32N



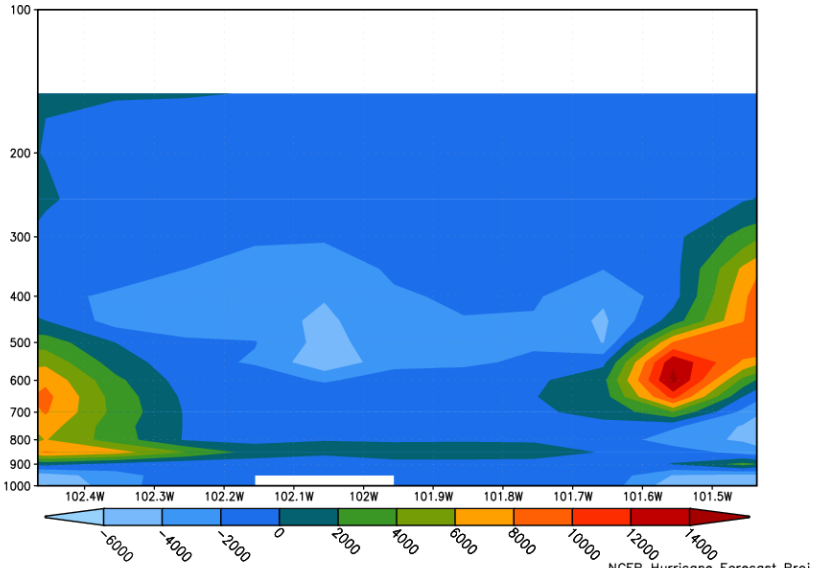
HWRF NEST GRID – FIVE05e lg. scl. heating (shaded, Kdy⁻¹)
it: 2011073112 vt: 2011080100 (12h)
x–sect: E–W at 11.32N

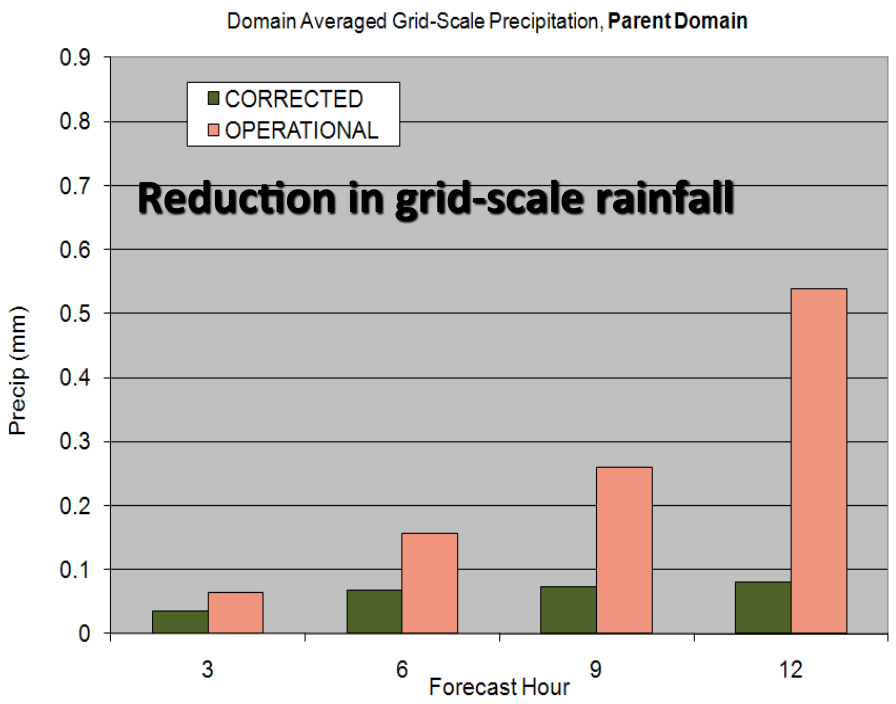


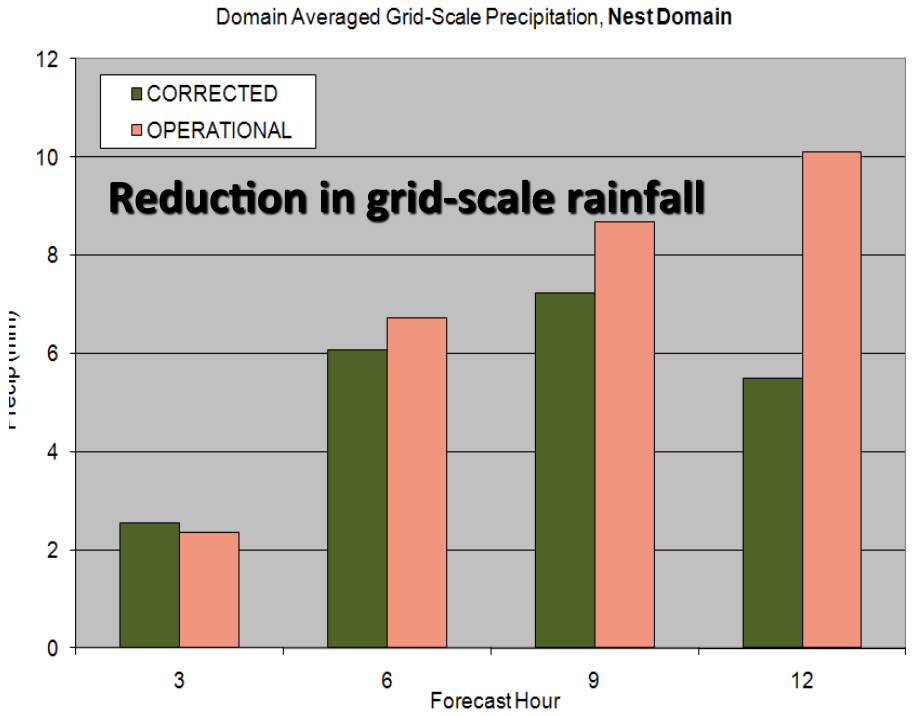
HNEW NEST GRID – FIVE05e convective heating (shaded, Kdy⁻¹)
it: 2011073112 vt: 2011080100 (12h)
x–sect: E–W at 11.98N

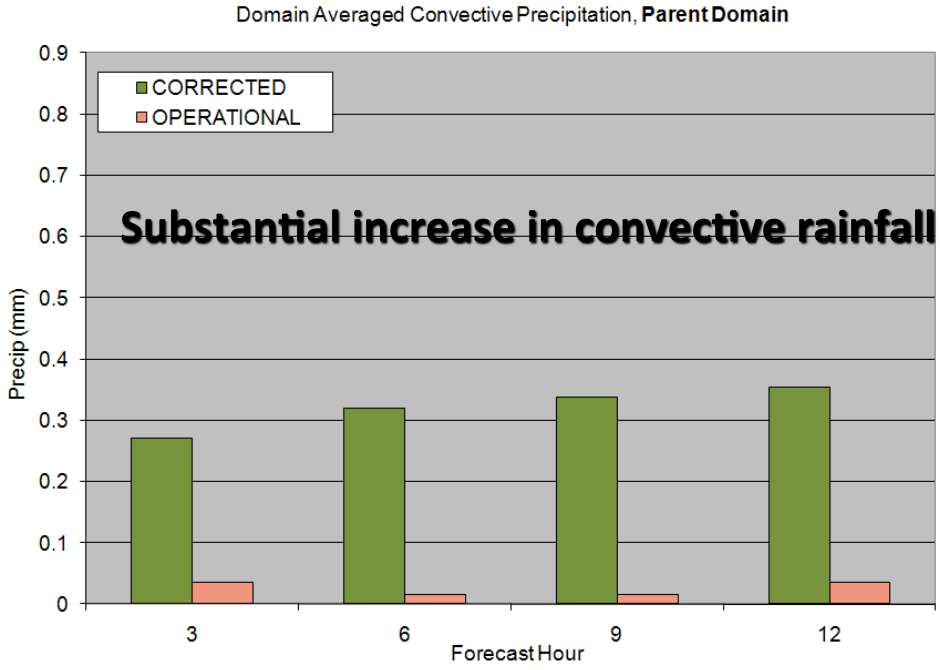


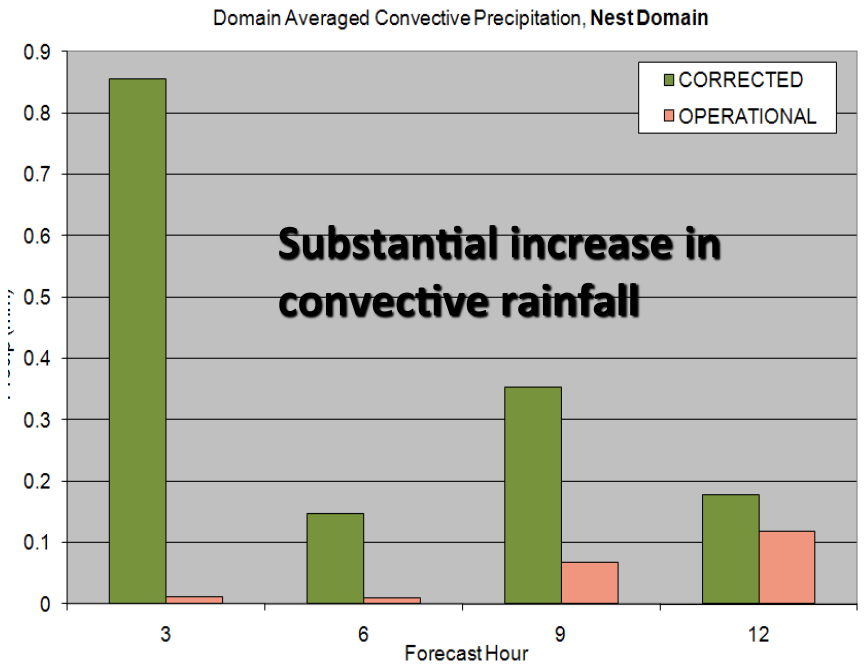
HNEW NEST GRID – FIVE05e lg. scl. heating (shaded, Kdy⁻¹)
it: 2011073112 vt: 2011080100 (12h)
x–sect: E–W at 11.98N



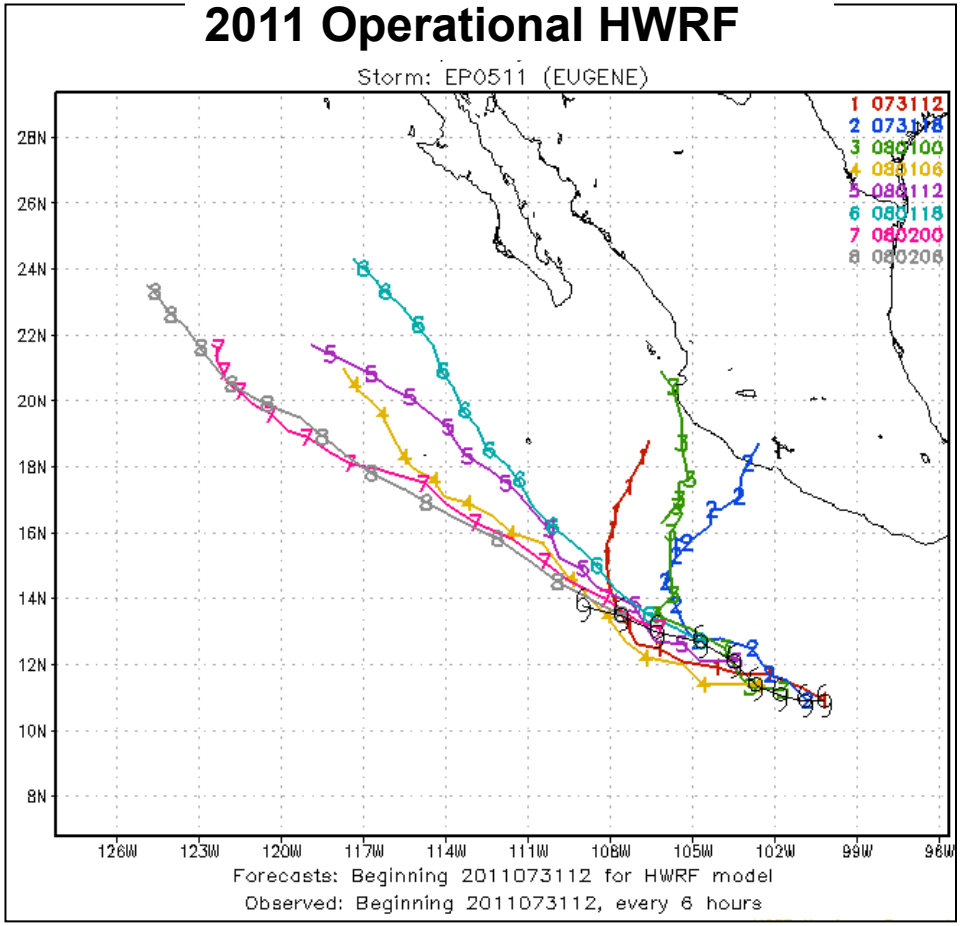

Domain Averaged Grid-Scale Precipitation, Parent Domain
CORRECTED
OPERATIONAL
Reduction in grid-scale rainfall
Precip (mm)
0.9
0.8
0.7
0.6
0.5
0.4
0.3
0.2
0.1
0
3
6
9
12
Forecast Hour


Domain Averaged Grid-Scale Precipitation, Nest Domain
CORRECTED
OPERATIONAL
Reduction in grid-scale rainfall
12
10
8
6
4
2
0
3
6
9
12
Forecast Hour

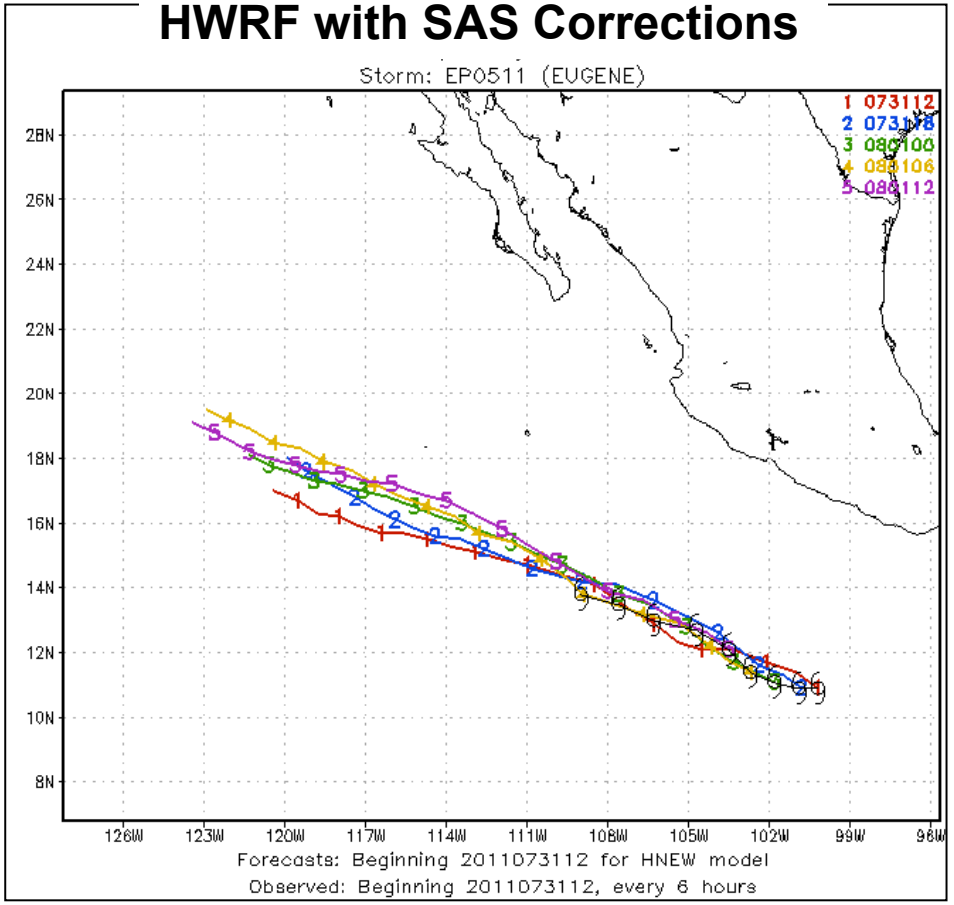

Domain Averaged Convective Precipitation, Parent Domain
CORRECTED
OPERATIONAL
Substantial increase in convective rainfall
Precip (mm)
0.9
0.8
0.7
0.6
0.5
0.4
0.3
0.2
0.1
0
3
6
9
12
Forecast Hour


Domain Averaged Convective Precipitation, Nest Domain
CORRECTED
OPERATIONAL
Substantial increase in convective rainfall
0.9
0.8
0.7
0.6
0.5
0.4
0.3
0.2
0.1
0
3
6
9
12
Forecast Hour

2011 Operational HWRF

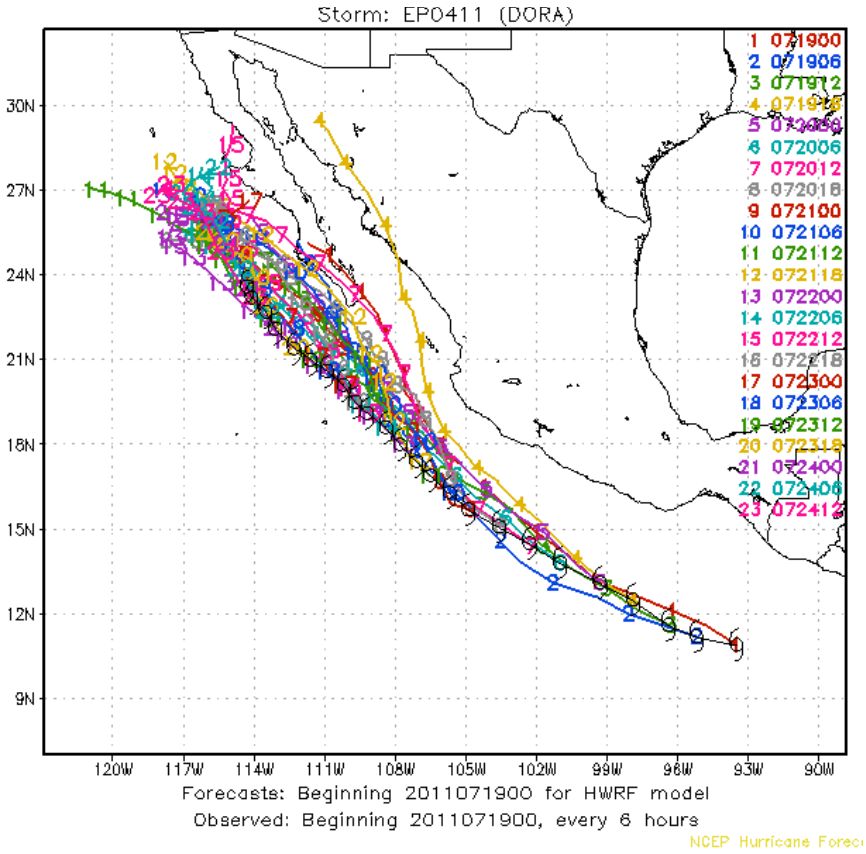


HWRF with SAS Corrections

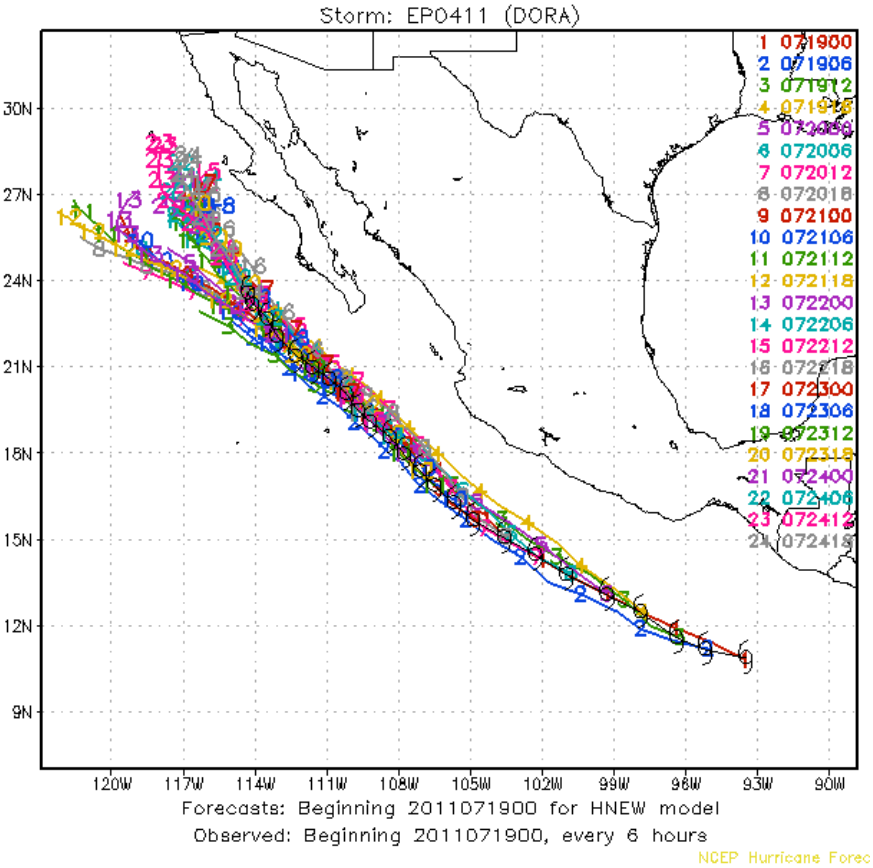


Hurricane Eugene, 2011

2011 Operational HWRF

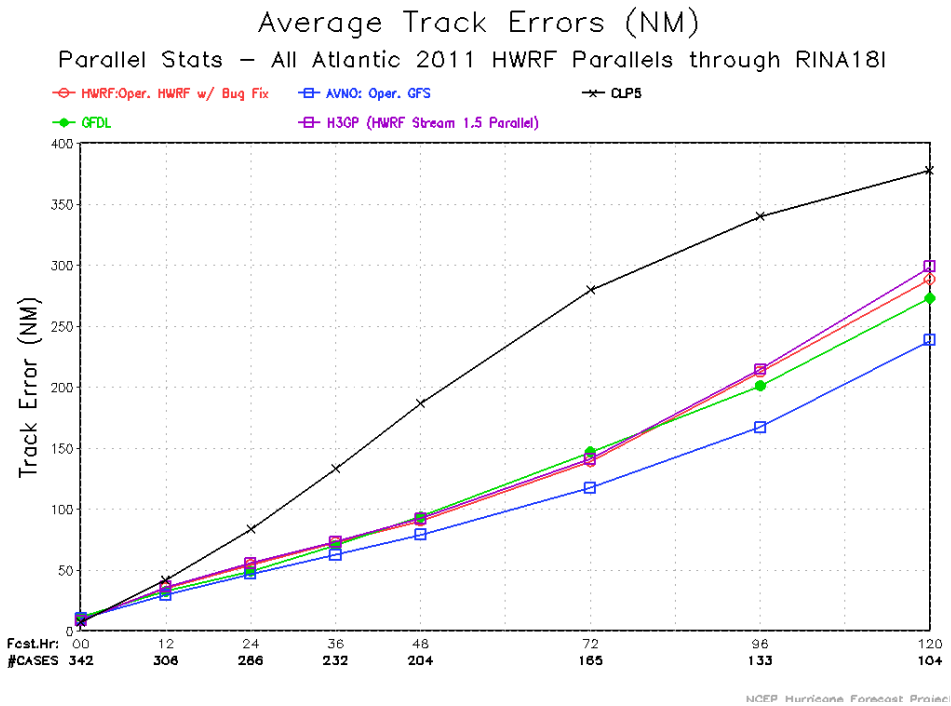


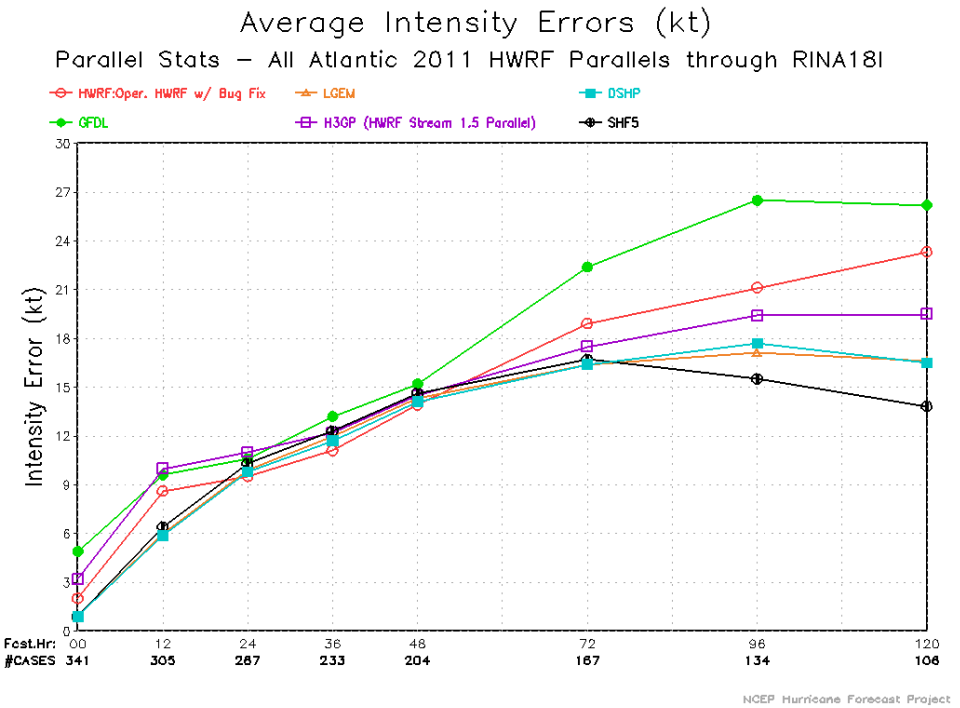
HWRF with SAS Corrections



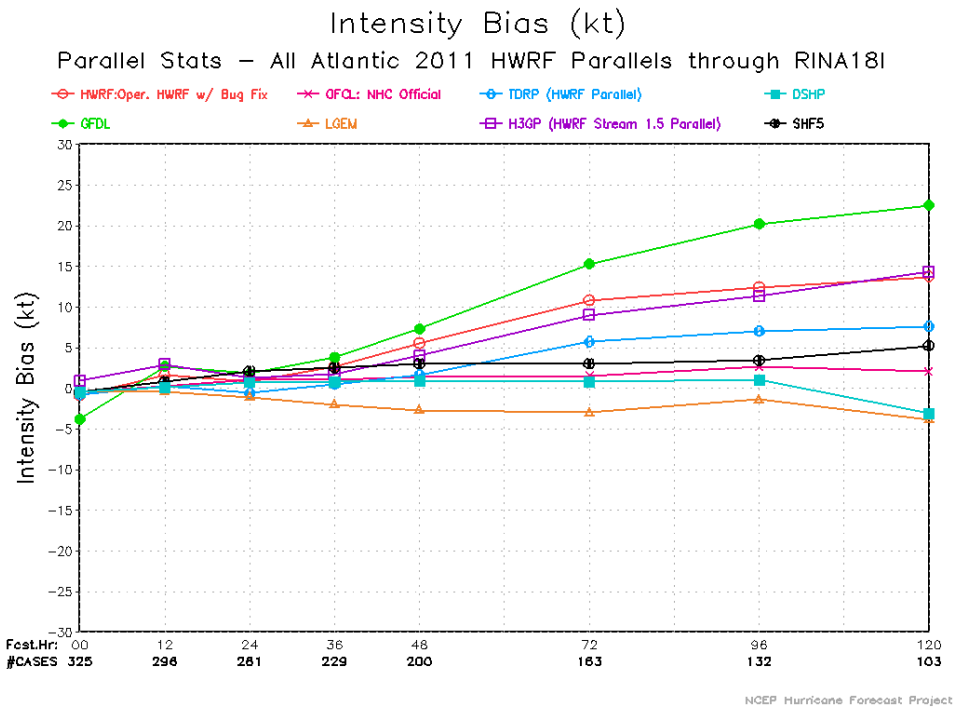
Hurricane Dora, 2011

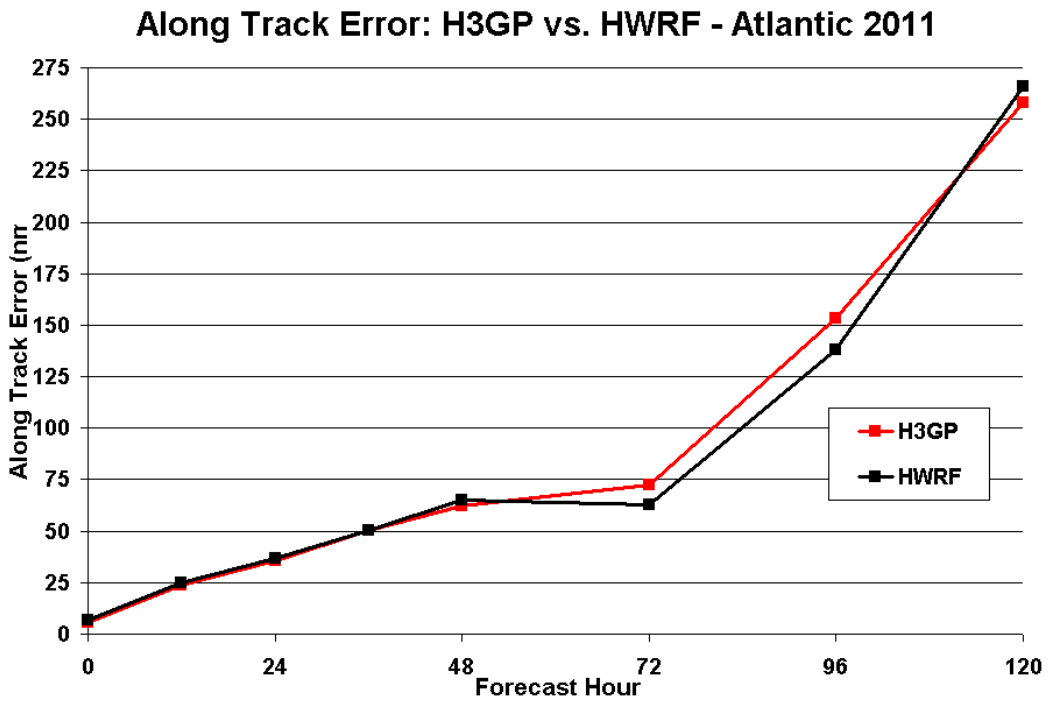
Performance of operational HWRF in 2011



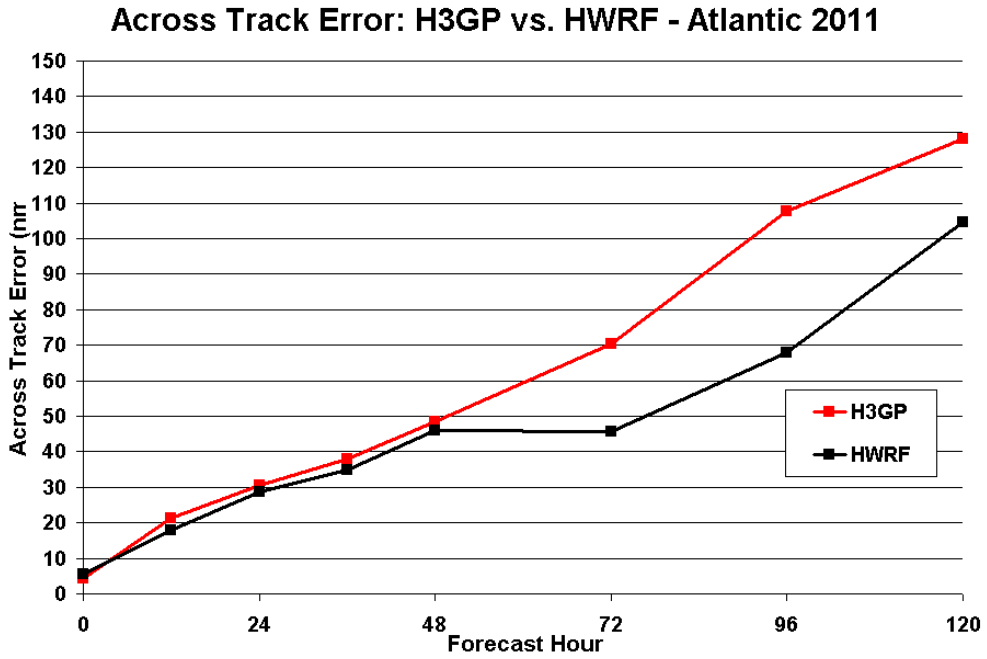


HWRF and High-Res (3km) HWRF in 2011 Atlantic

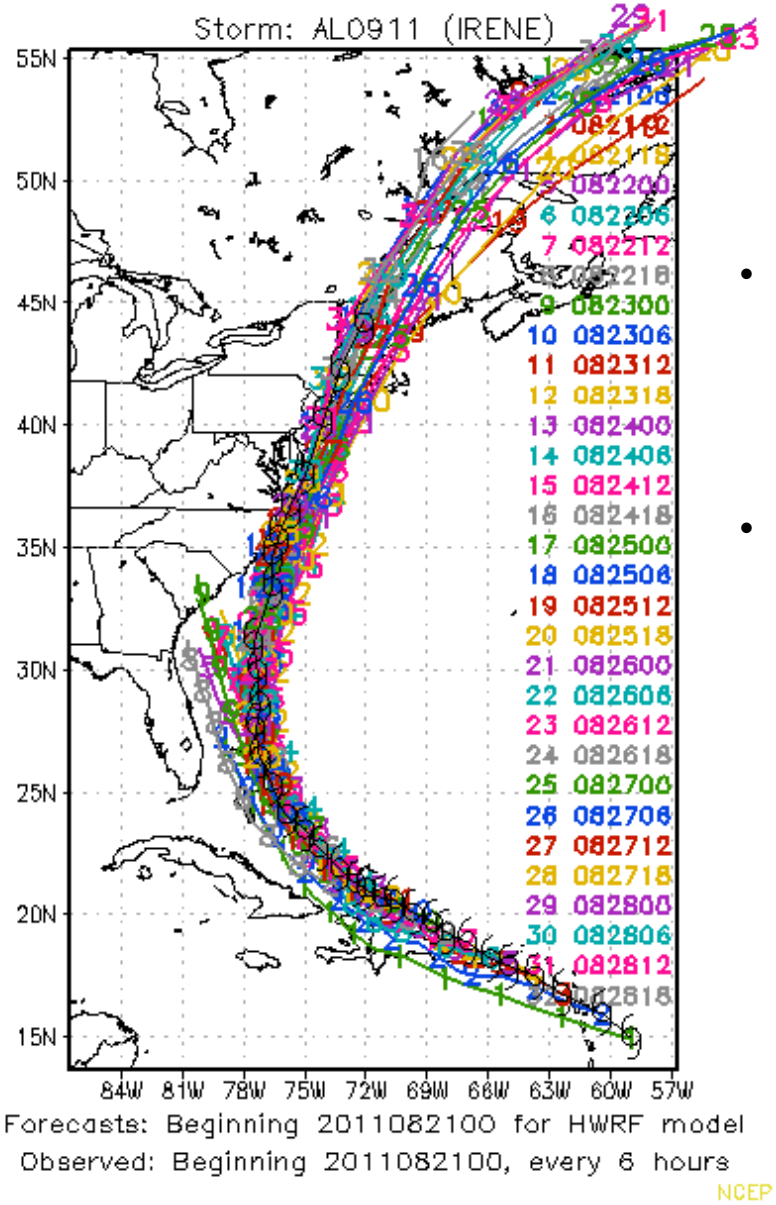




Along track and cross track errors increased after 72 hrs

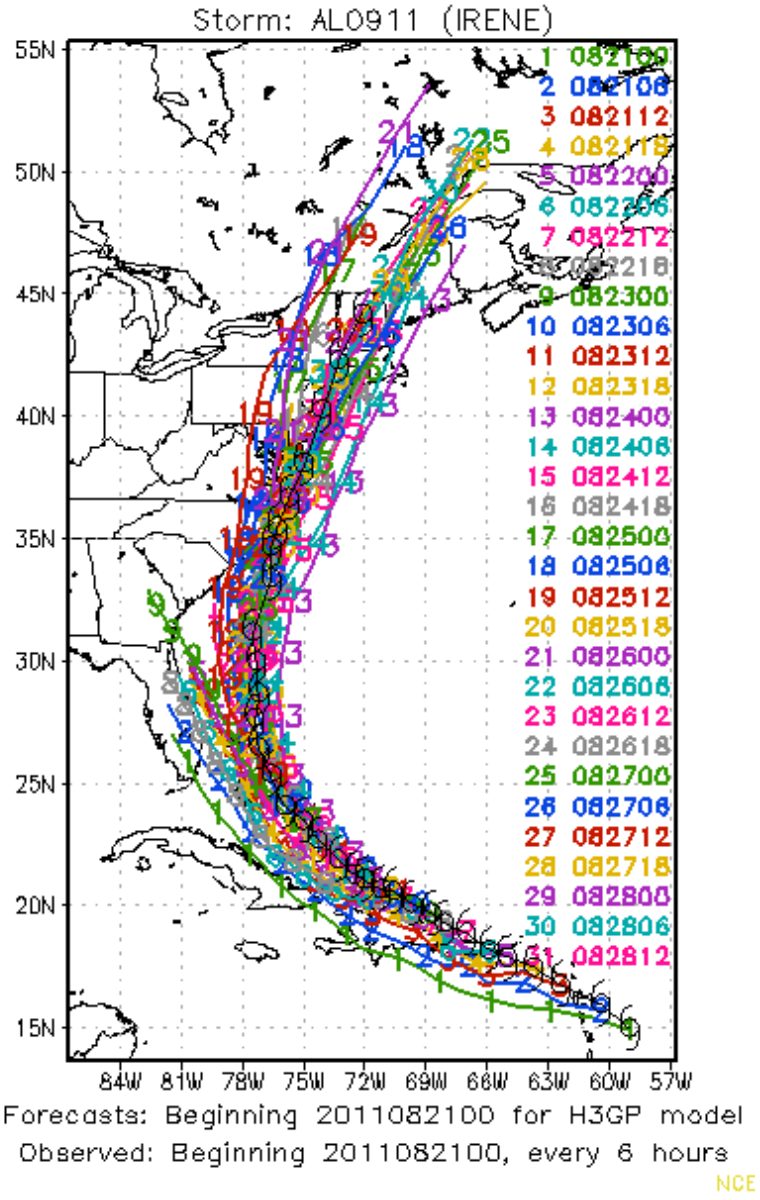


Track Forecasts for Hurricane Irene



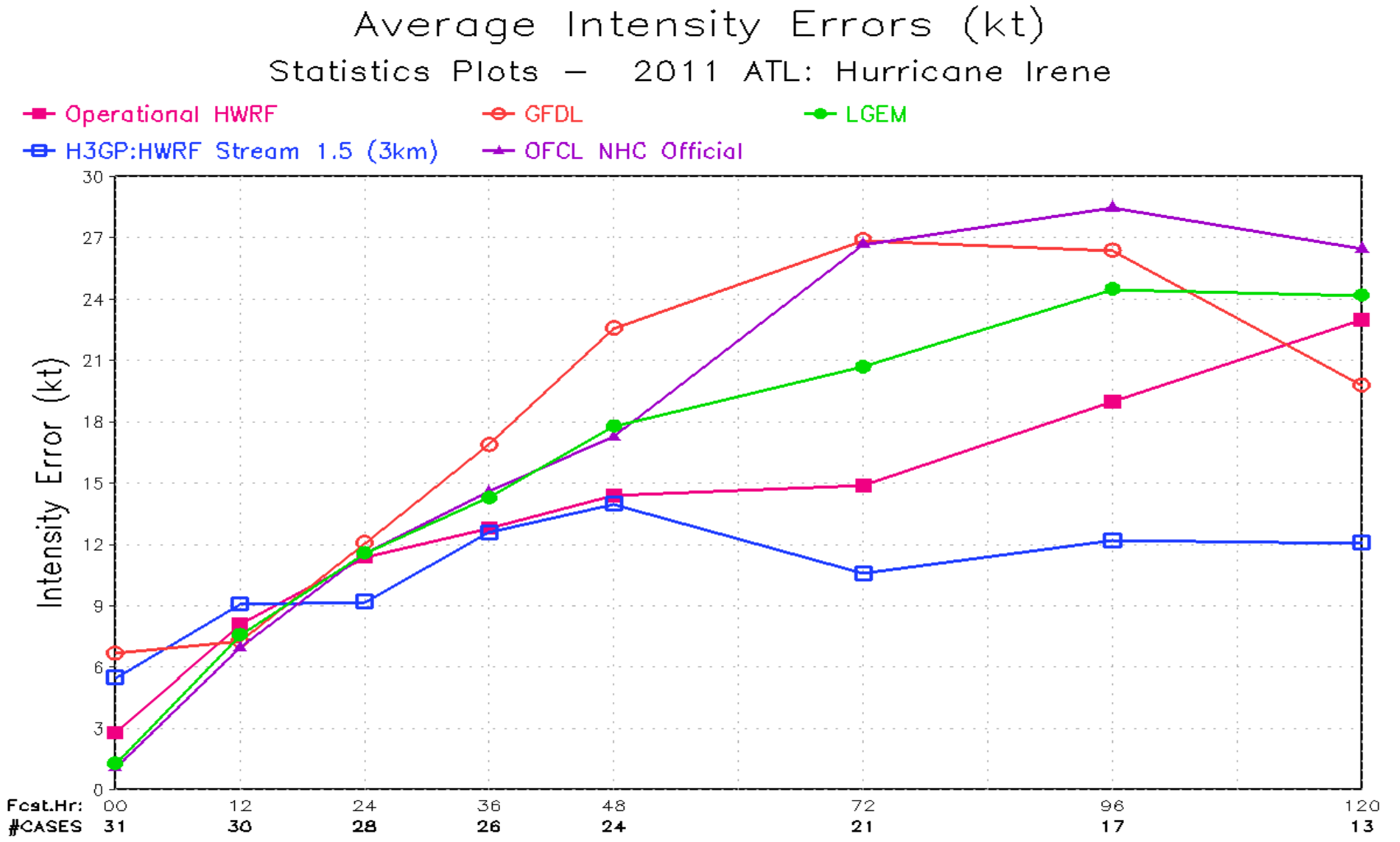
Operational HWRF

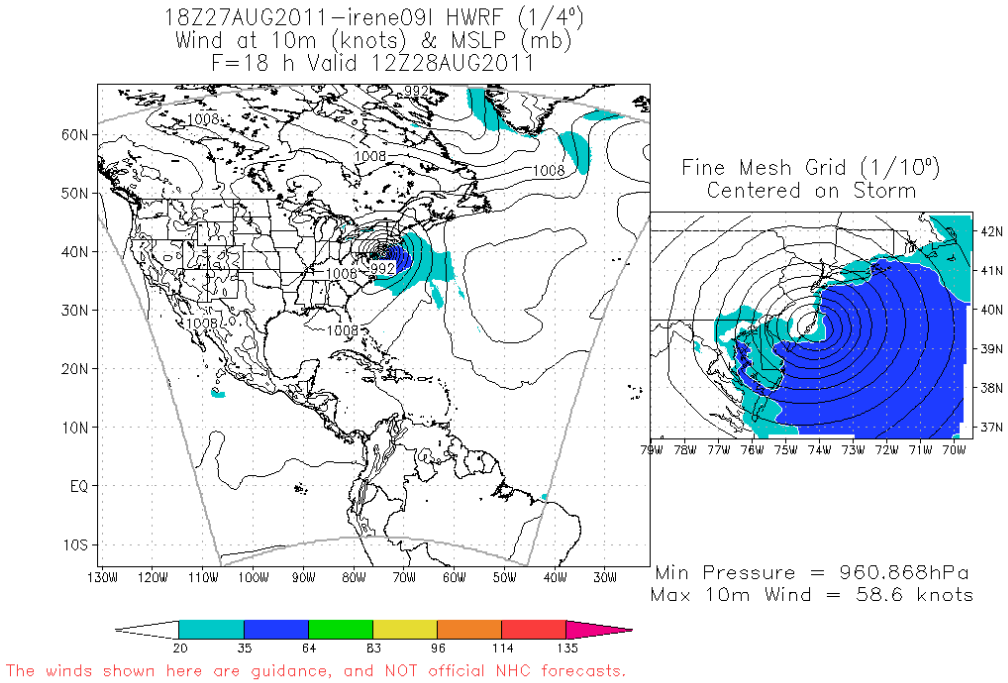
- More consistent track forecasts from operational HWRF
- Very little "west" bias compared to H3GP forecasts.



HFIP Stream 1.5 HWRF (H3GP)

Mean Intensity Errors for Hurricane Irene: H3GP (real-time HFIP Stream 1.5 3km version of HWRF) extremely impressive, with skill improvements of the order of 30 – 50% over the operational HWRF at 72 hr and beyond.





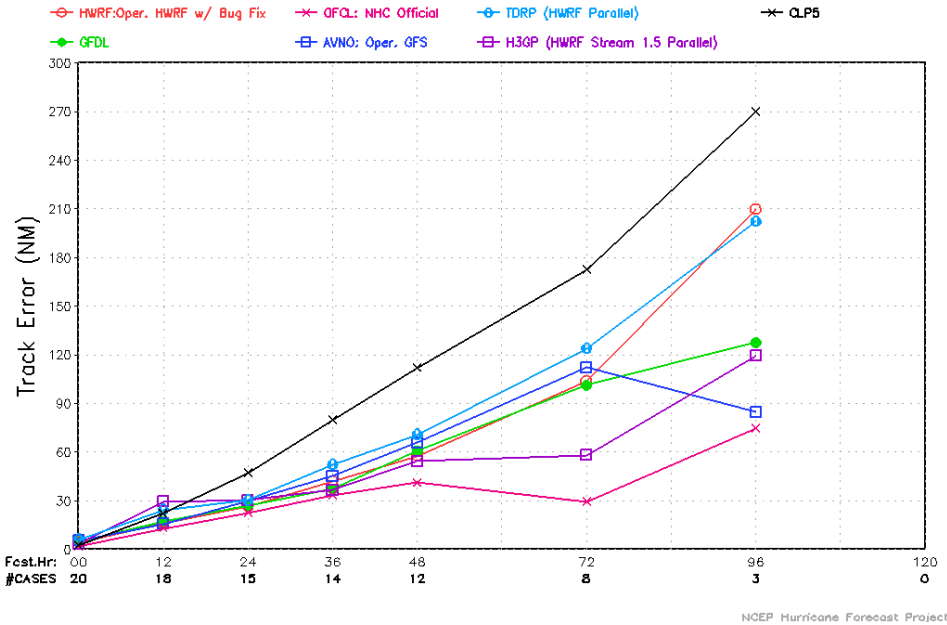
"The HWRF did, in my opinion, a fantastic job representing the radii of stronger winds as Irene made landfall in NC and in forecasting what they would be as Irene moved up to the NJ/NY area.... that is, keeping sustained TS winds for the most part away from NJ/Manhattan." **---- Matthew Greenstein, MAP mailing list**

"I am watching with great interest the performance of the HWRF models (operational and 3 km parallel) and other HFIP models this year, and look forwards to seeing how well they do this year in post-analysis.

Anyway, with respect to Irene, the models were indispensible with respect to me being able to communicate to my audience that we had a high-confidence track forecast. The intensity forecasts weren't very useful, though. The ECMWF was particulary dissapointing in its intensity forecasting, as it predicted Irene would intensify into a 920 mb storm off of Cape Hatteras at the time Irene's eyewall was in the process of collapsing." **---- Jeff Masters, Weather Underground**

Forecast Errors (NM) For RINA 18L 2011

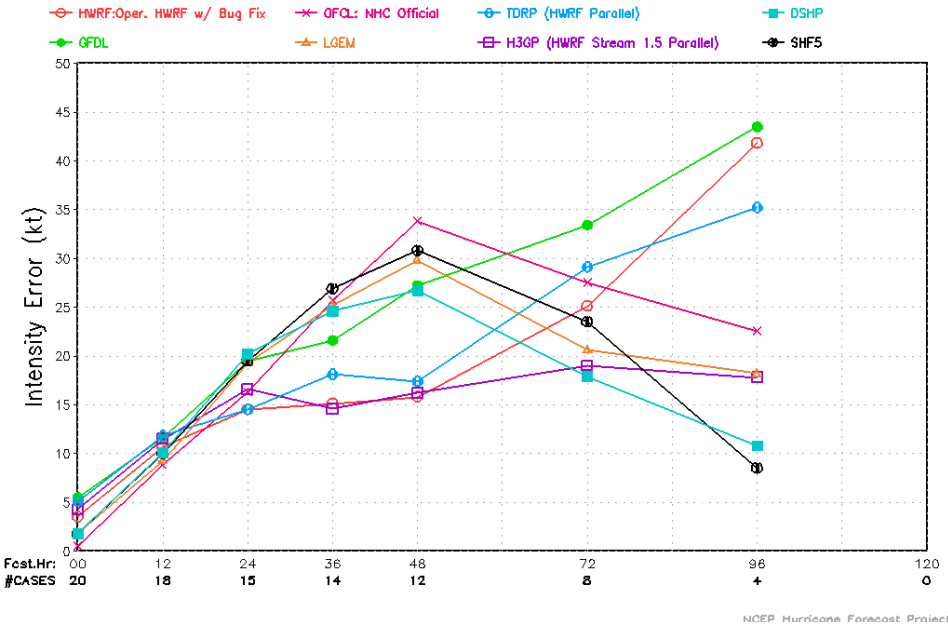
Parallel Stats – All Atlantic 2011 HWRF Parallels through RINA18l



NCEP Hurricane Forecast Project

Forecast Errors (kt) For RINA 18L 2011

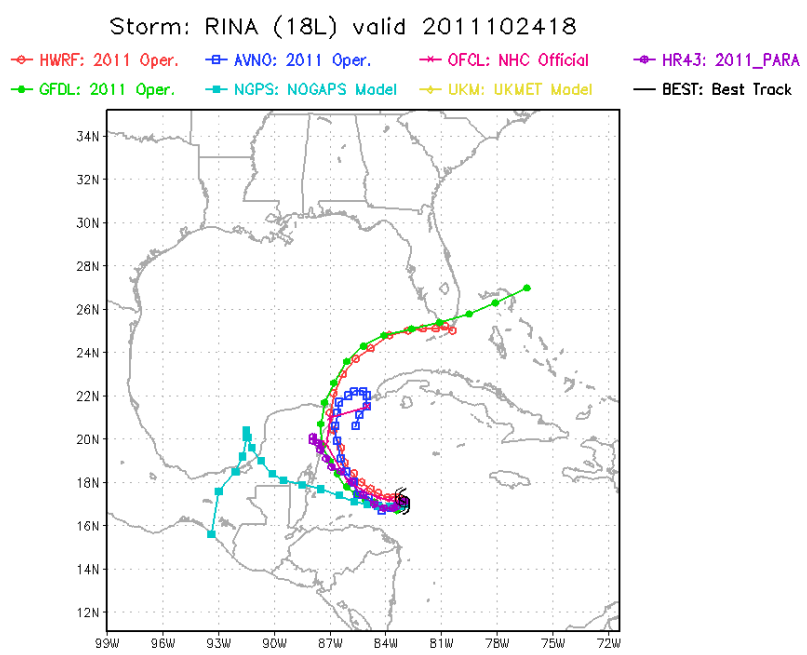
Parallel Stats – All Atlantic 2011 HWRF Parallels through RINA18l



NCEP Hurricane Forecast Project

HR43 HWRF Parallel: 2011 TC Tracks

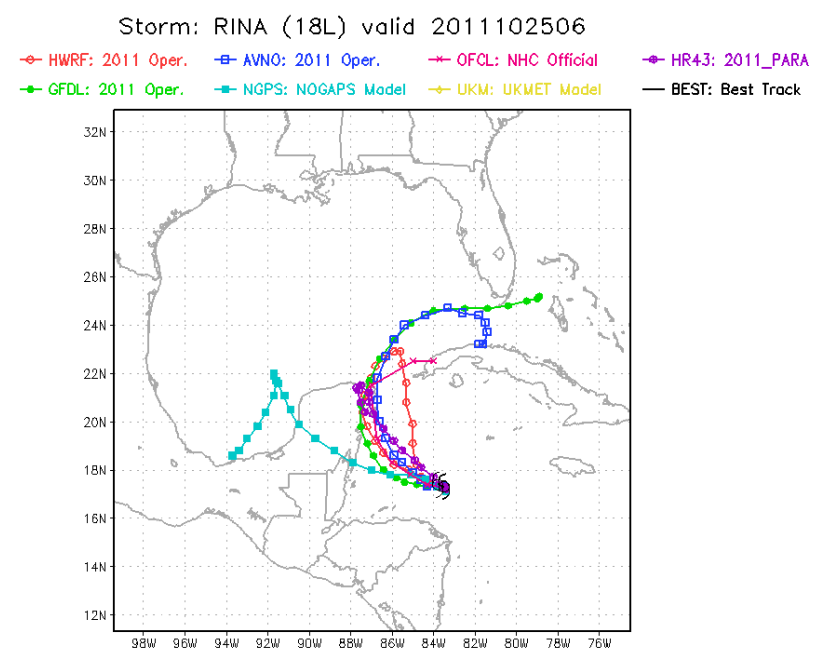
Storm: RINA (18L) valid 2011102418



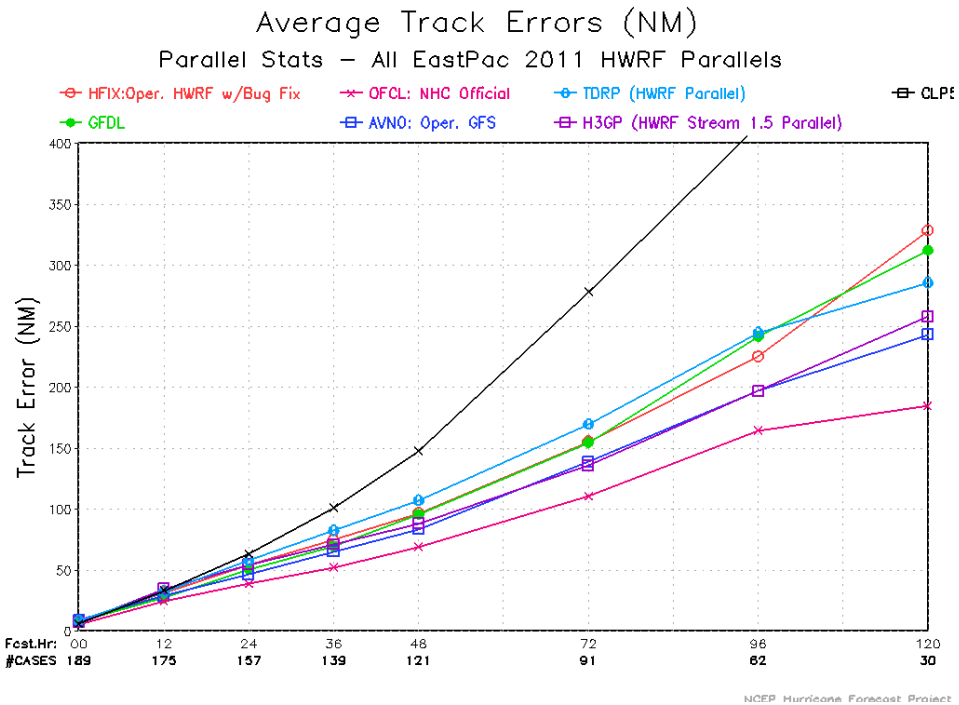
2011-10-25-00:09

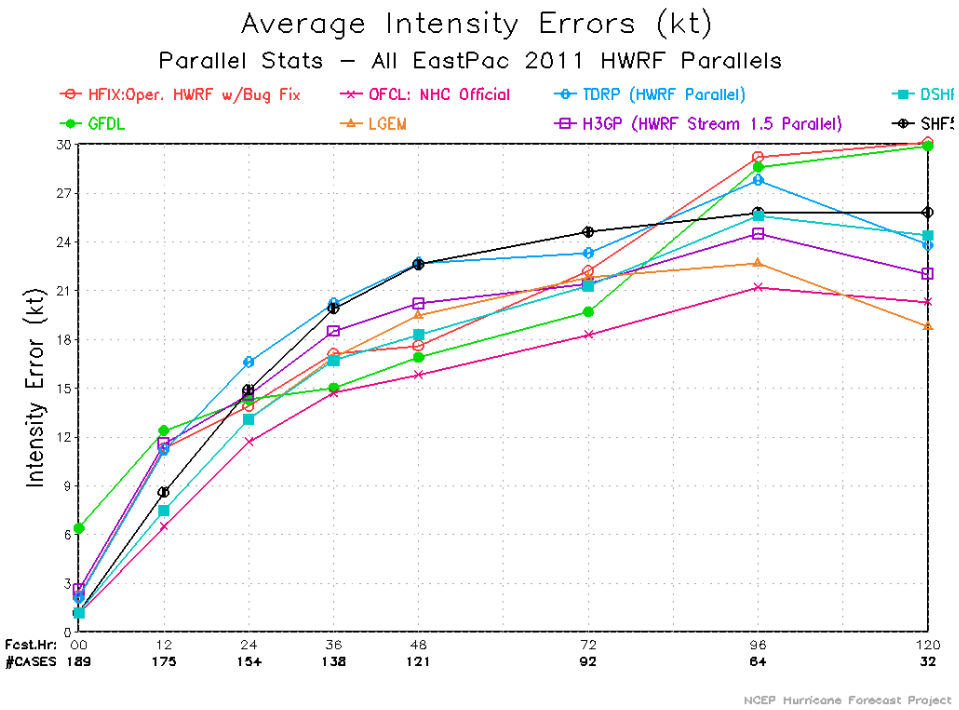
HR43 HWRF Parallel: 2011 TC Tracks

Storm: RINA (18L) valid 2011102506



2011-10-25-12:10

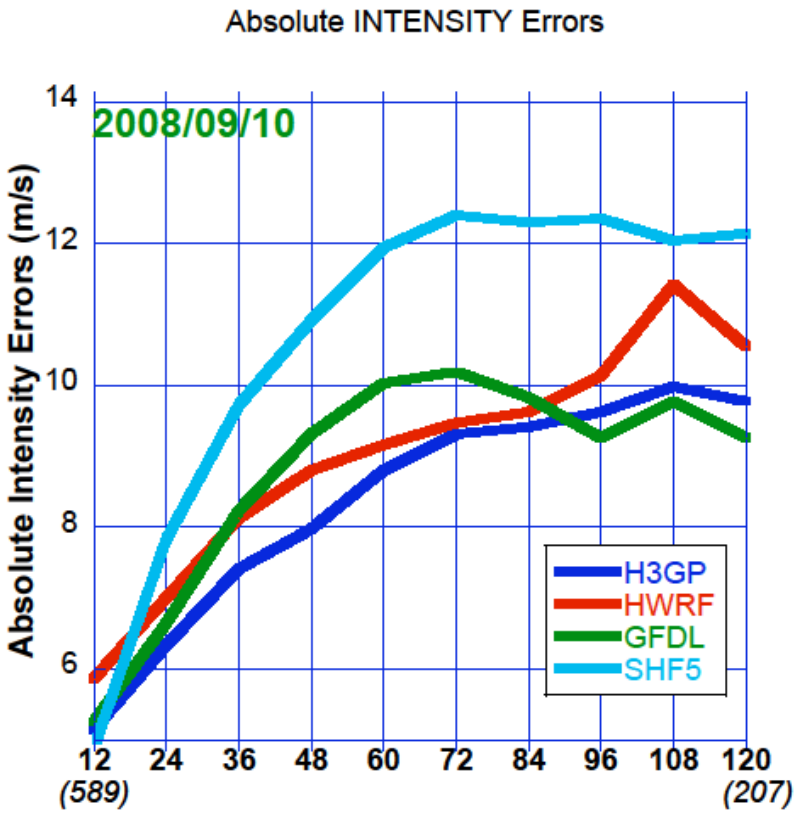


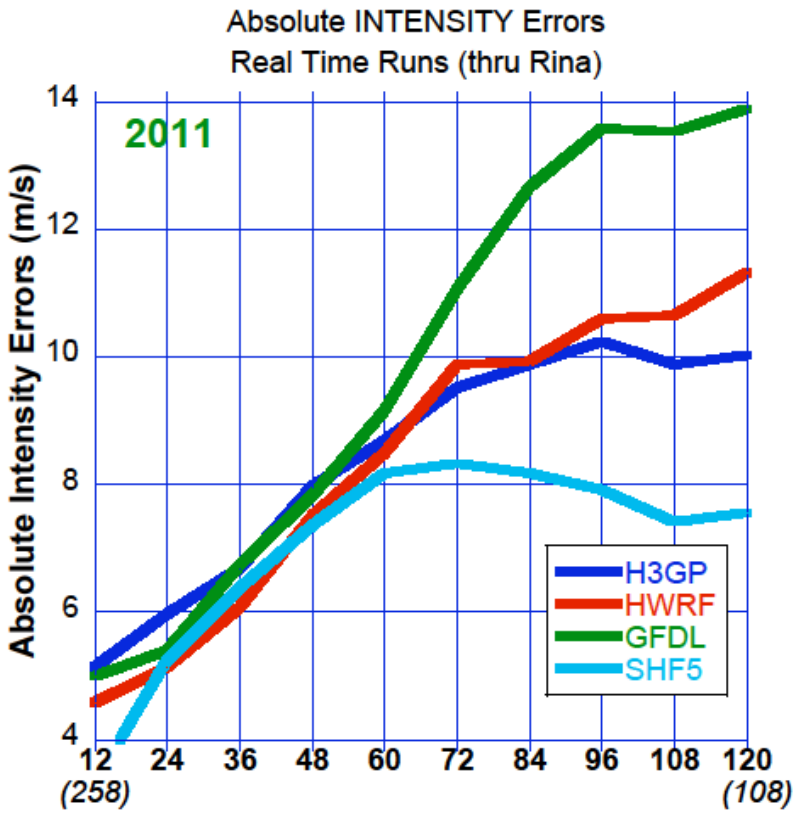


HWRF and High-Res (3km) HWRF in 2011 East-Pacific

H3GP has Track forecast skill as good as GFS, intensity skill better than operational HWRF at day-4 and day-5

Tell Tale for the 2011 Season



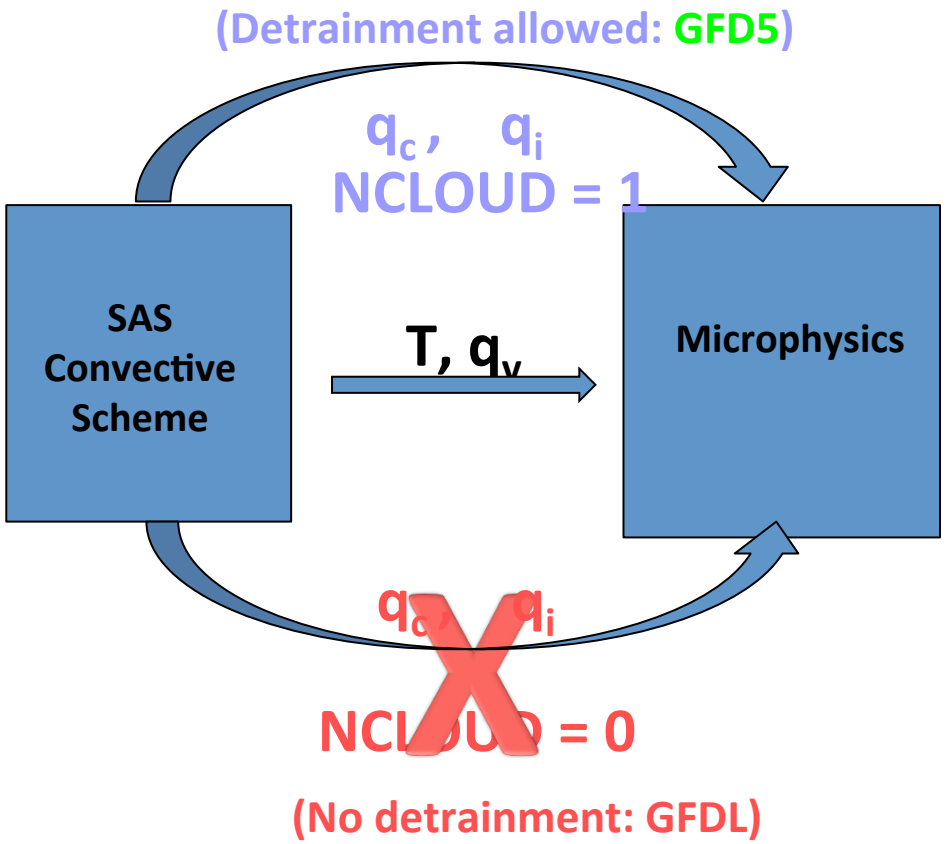


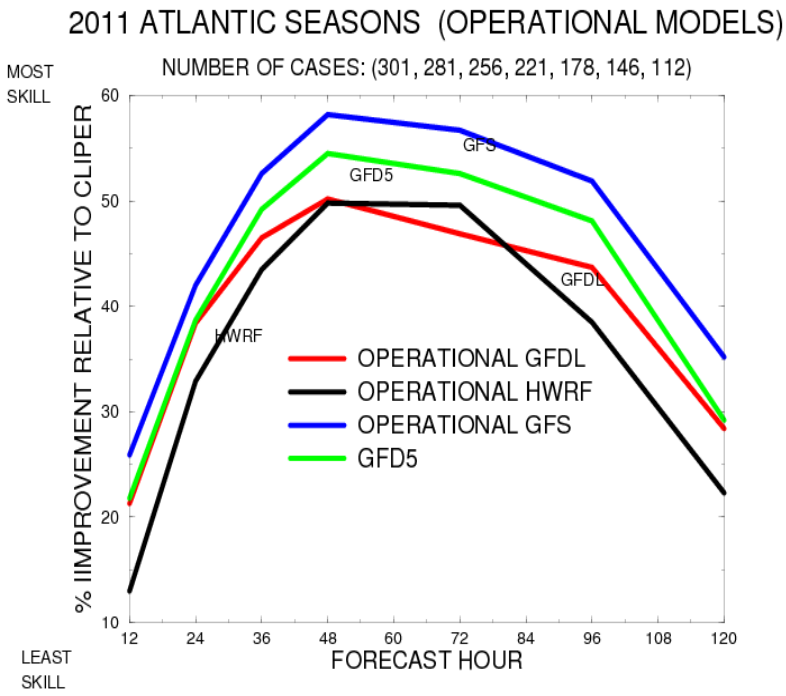
Thanks to Stanley Goldenberg, HRD/AOML

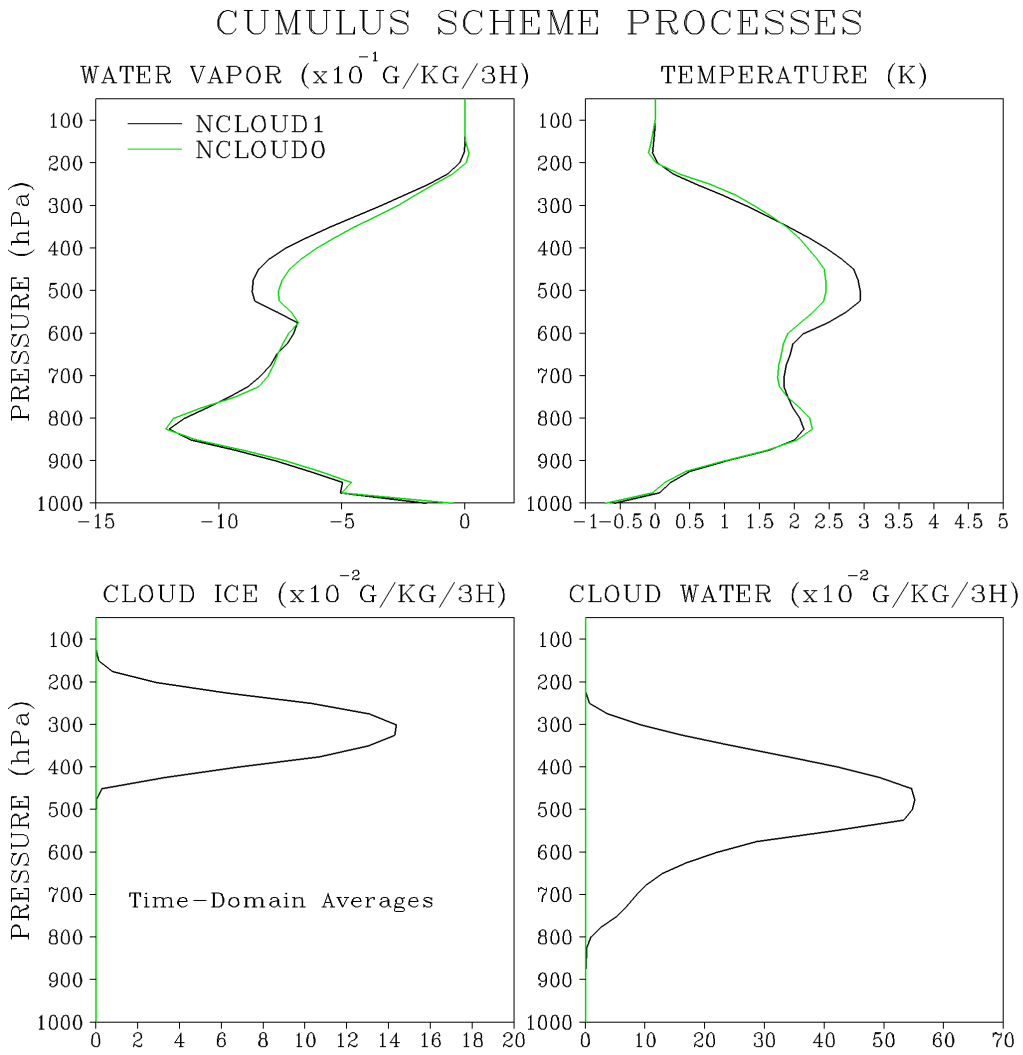
Hurricane Model Evaluation

- Traditionally, performance metrics for operational models are confined to improved track and intensity skills.
- Model improvements need higher-order evaluation and verifcation.
- Assessment of scientific upgrades require application of advanced diagnostics for both large-scale environment and inner core structure.
- Each season, each storm and each forecast poses it's own challenge for evaluation purpose.
- Structure evaluation becomes more important at very high resolutions.
- We are just in the beginning stage of evaluating high-resolution model forecasts with help from observational and diagnostic teams.
- Structure prediction and forecast of rapid intensity changes are an order of magnitude more difficult than intensity prediction.
- Understanding the relationship between track and intensity is another area that requires more attention.

Physics Sensitivities: Importance of Microphysics and Microphysics-Cumulus interactions (GFDL)

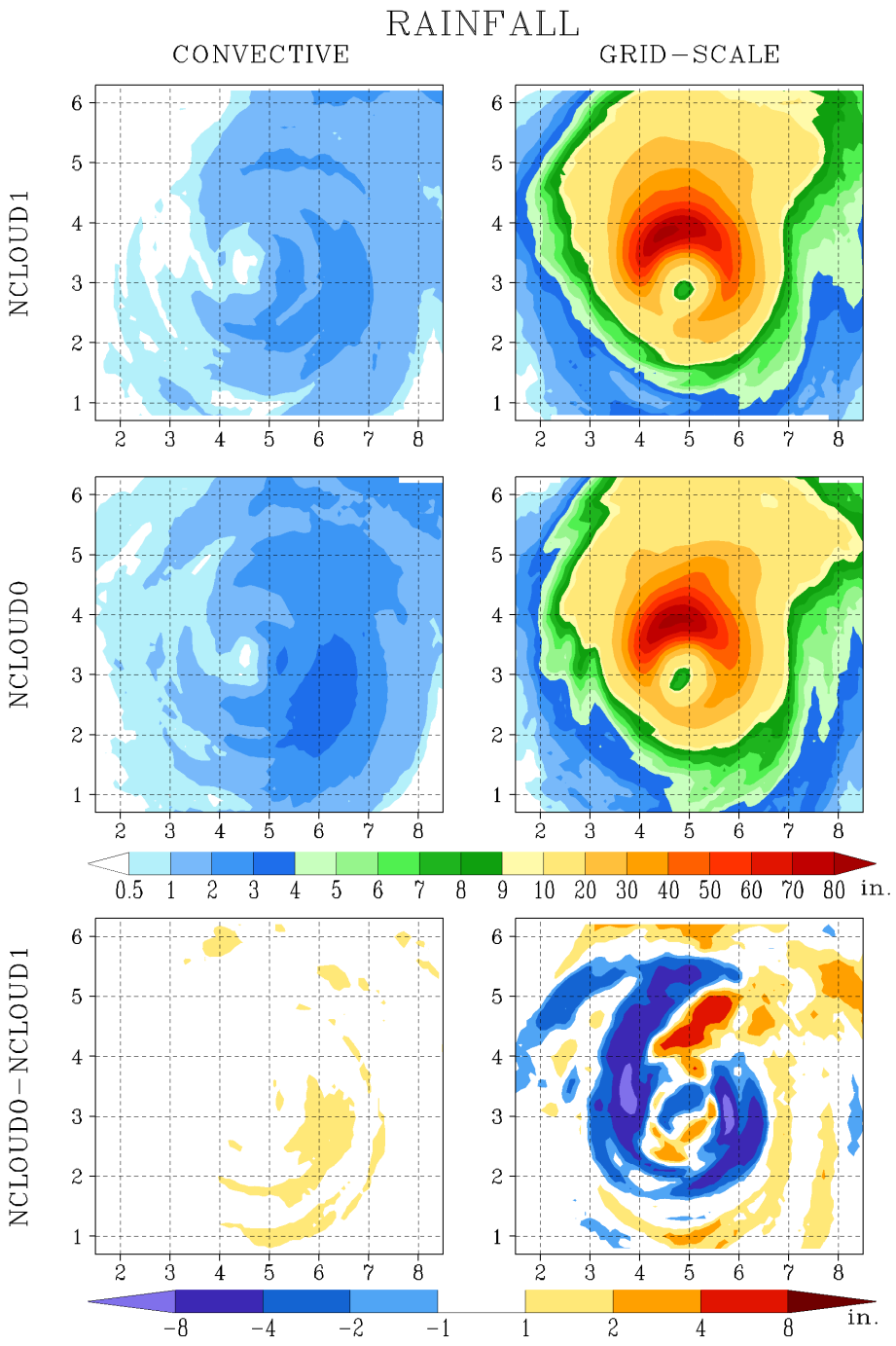






KATIA 2011083106

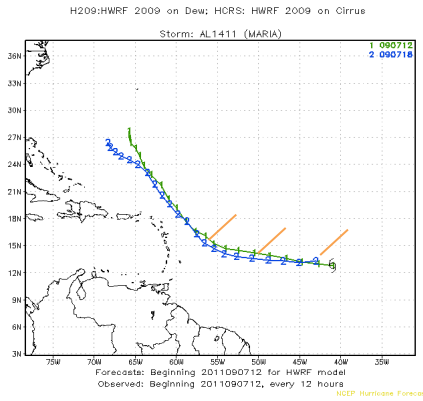
- More drying and warming with ncloud=1
- Same patterns in two other cases evaluated

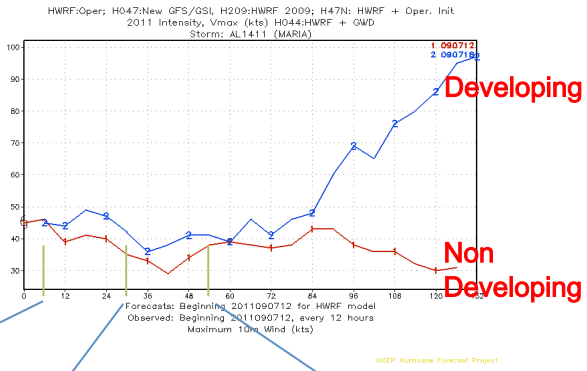


IRENE 2011082518 f00-f90

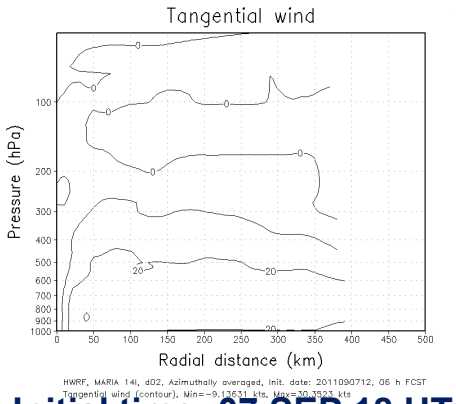
- 25 times more grid-scale than convective rainfall
- Heaviest grid-scale rainfall in eye wall region
- Up to 1” more convective rainfall with ncloud=0
- 4-8” less grid-scale rainfall in eye wall region with ncloud=0

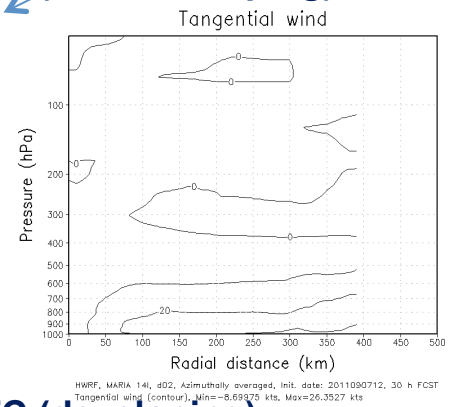
HWRF forecast results (07 SEP 12 UTC and 18 UTC) – Hurricane Maria

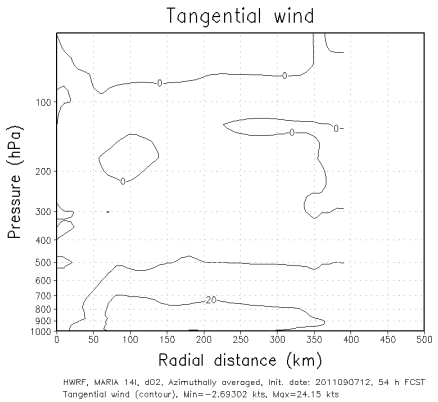




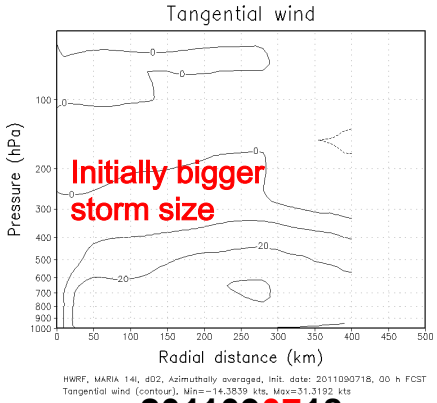
Initial time: 07 SEP 12 UTC (non developing)



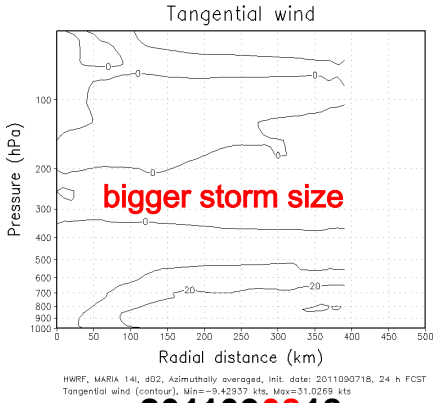




Initial time: 07 SEP 18 UTC (developing)



2011090718



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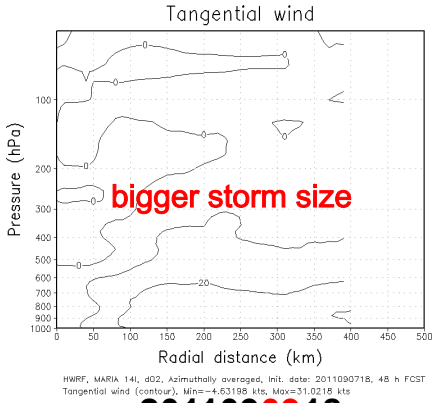
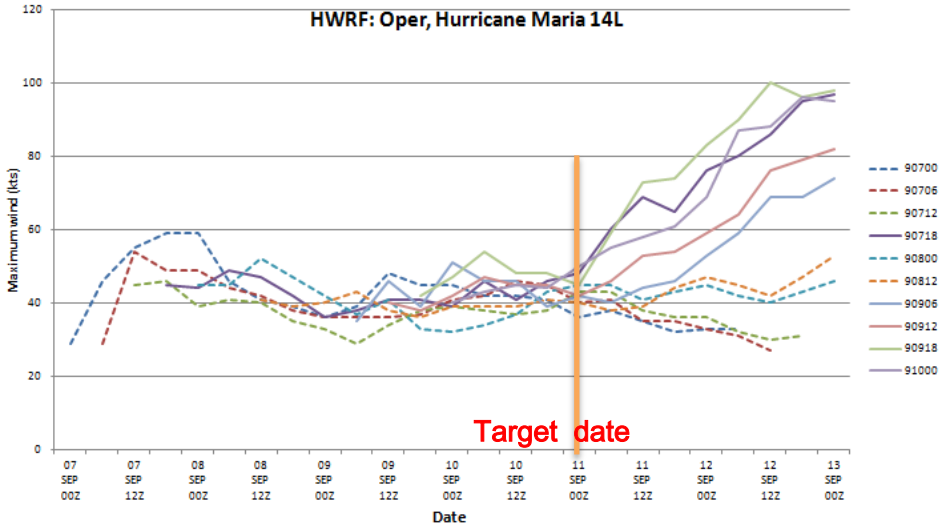


2011090918

Developing system has the bigger storm size at initial.

It keeps the bigger size during the whole forecast period

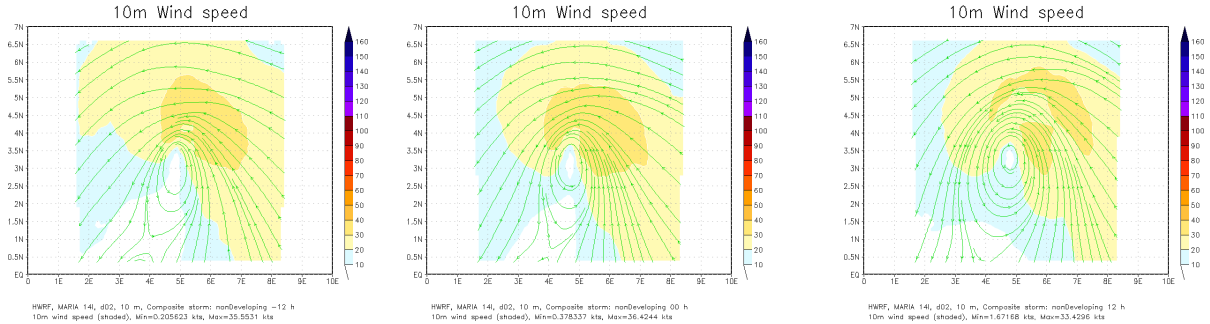
Composite storm study



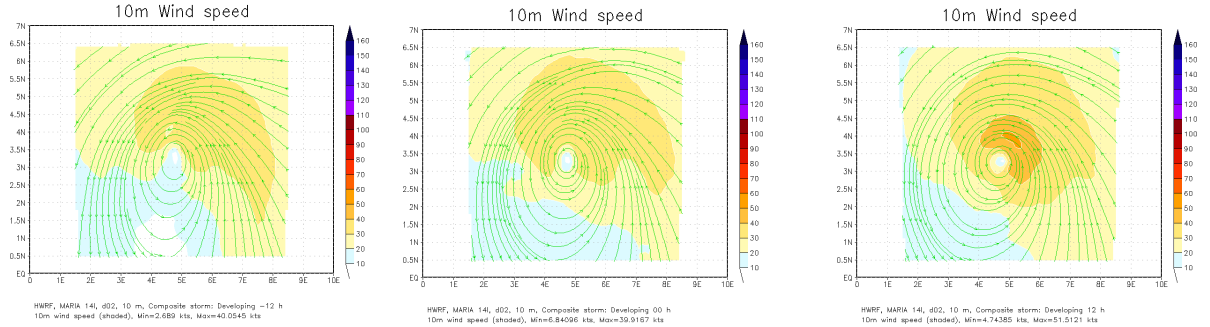
5 storms for developing

5 storms for non developing

Non developing



Developing



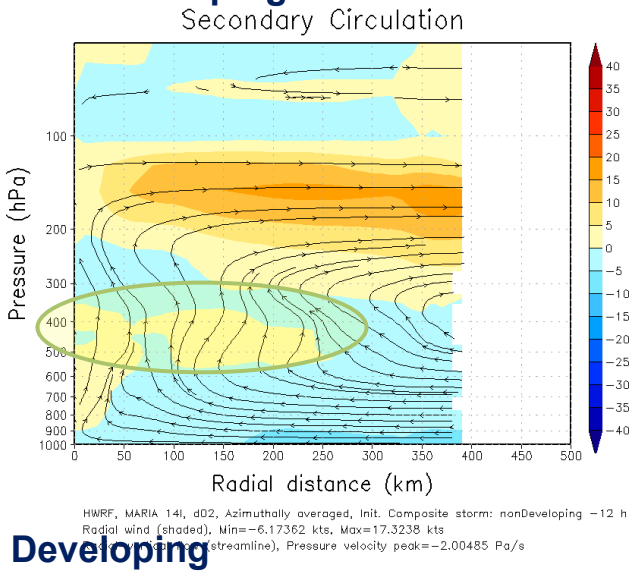
-12 h **Target date (2011091100)** **+12 h**

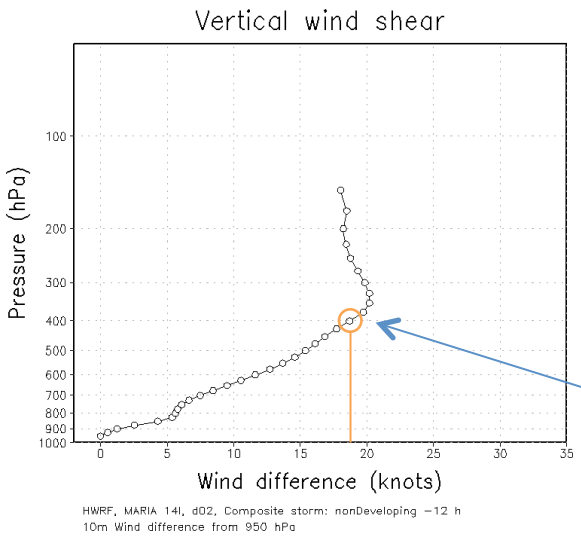
Bigger storm size

More axisymmetric wind distribution.

Composite storm structure at 11 SEP 00 UTC (target date -12h)

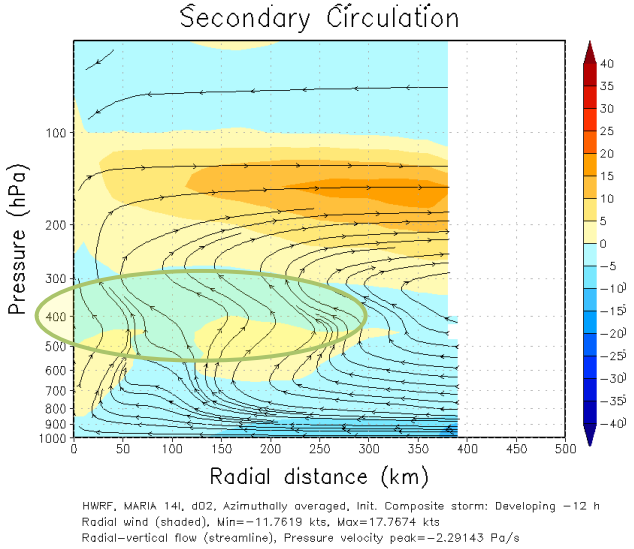
Non developing

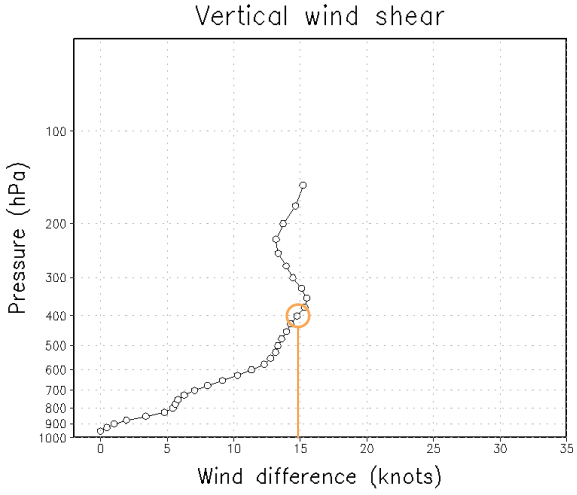




Averaged wind differences between the specific level and 950 hPa in the nest domain

Developing



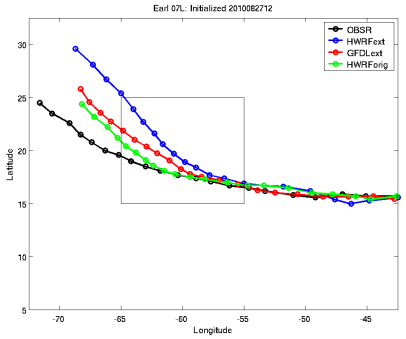


Non developing system has the bigger vertical wind shear between 400 hPa -950 hPa.

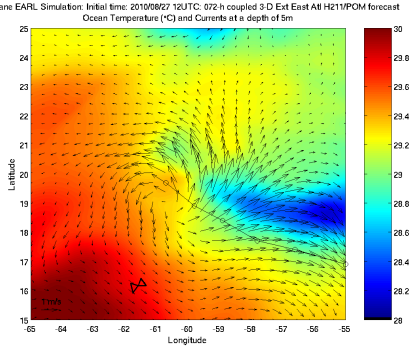
Middle level wind shear suppresses the vertical storm development

Hurricane Earl (20100827/12Z): HWRF ocean, intensity, and RMW

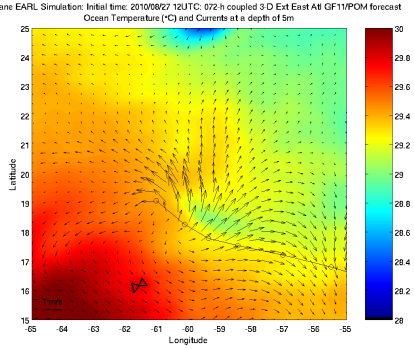
Tracks



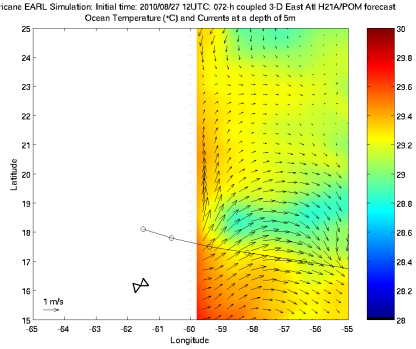
72-h SST: HWRF ext



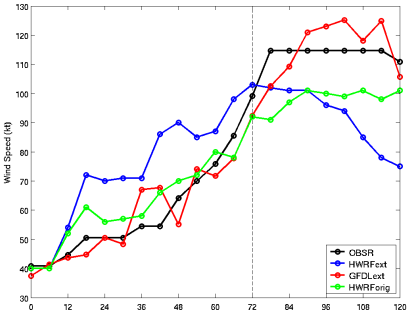
72-h SST: GFDL ext



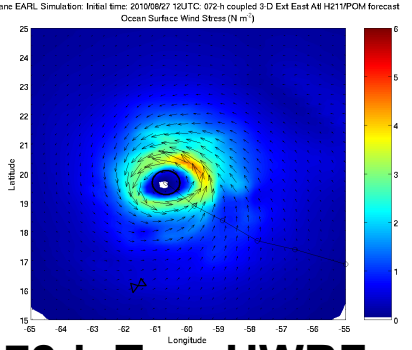
72-h SST: HWRF orig



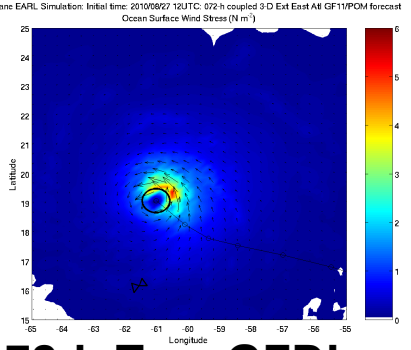
Intensities



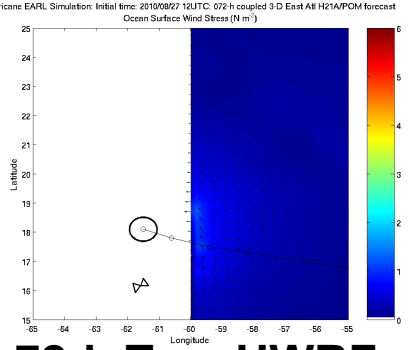
72-h Tau: HWRF ext



72-h Tau: GFDL ext

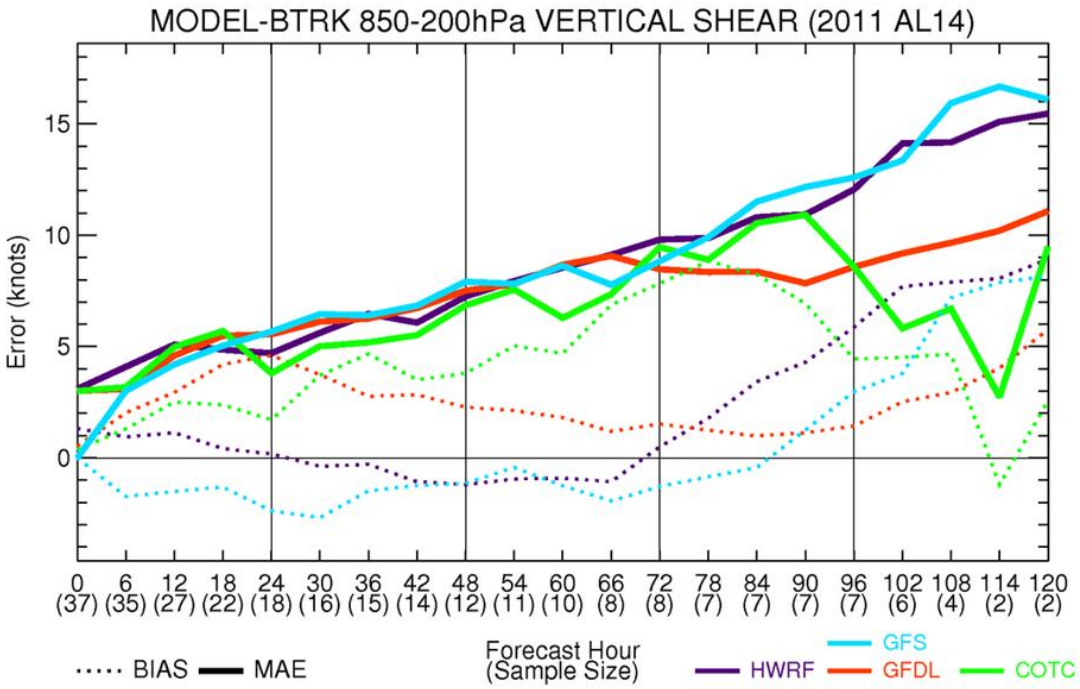


72-h Tau: HWRF orig



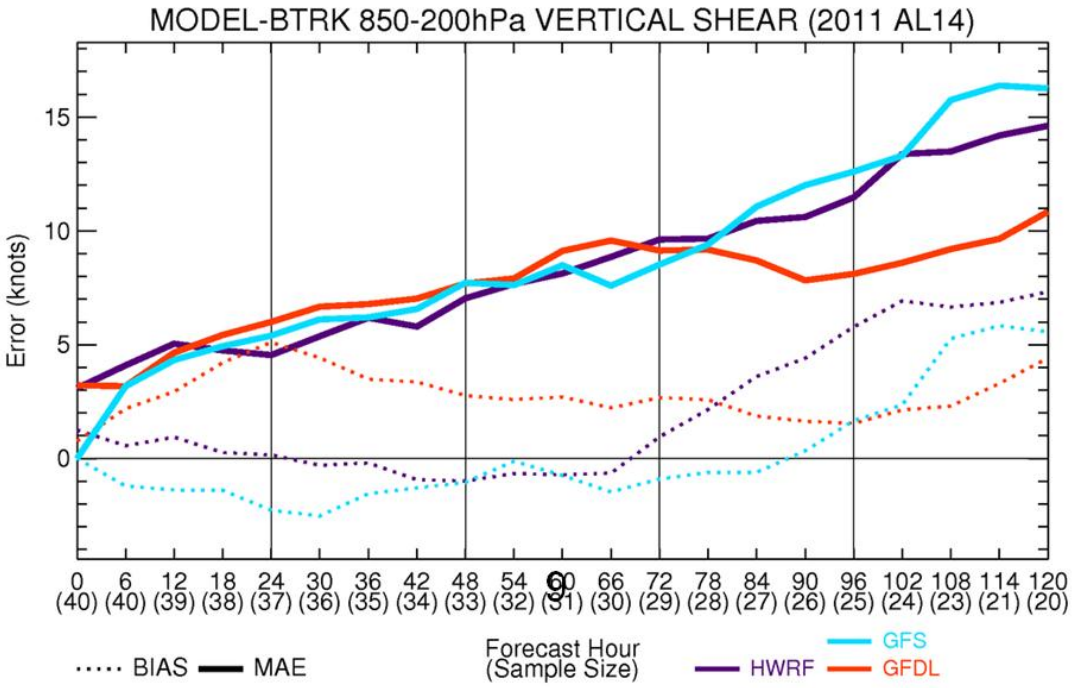
- **Ext domain prevents loss of ocean coupling but degrades HWRF intensity forecast**
- **Anomalously large HWRF RMW → excessive ocean cooling → erroneous weakening**
- **Ext domain produces accurate intensity forecast in GFDL, which has accurate storm size**

Courtesy: Rich Yablonsky

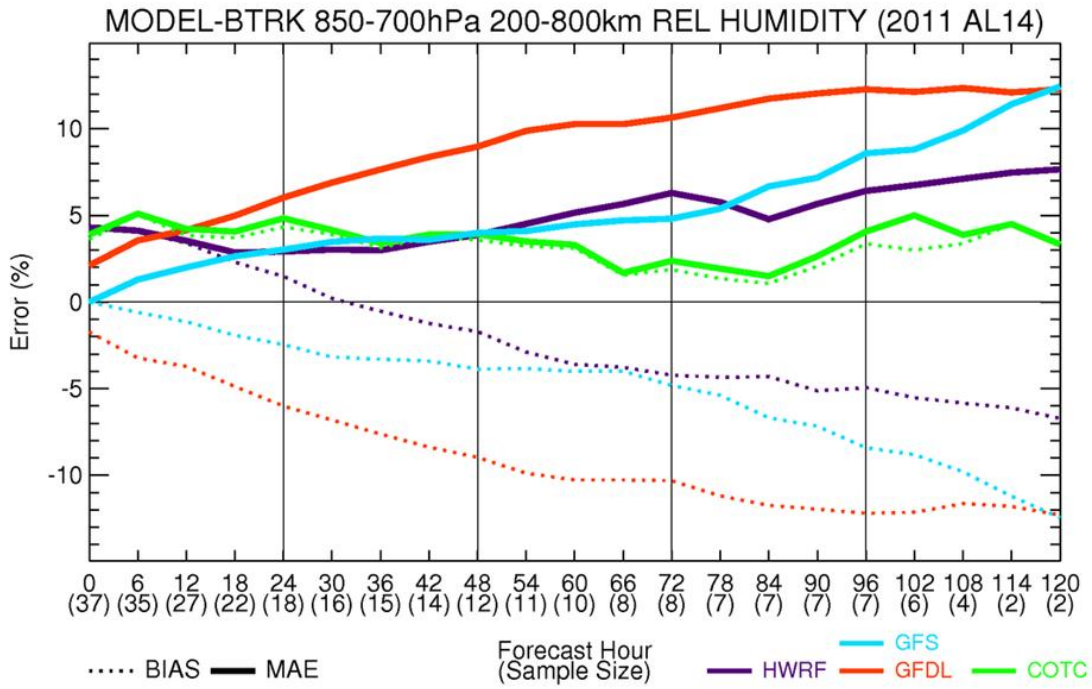


Shear

Excluding COTC

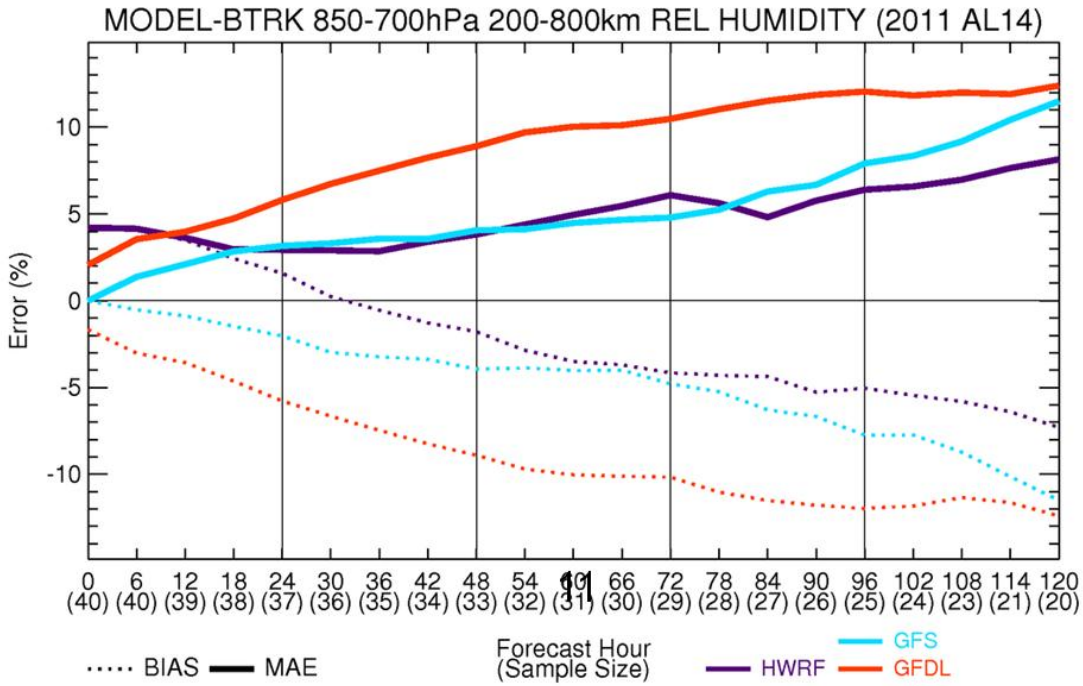


Courtesy: Mark DeMaria

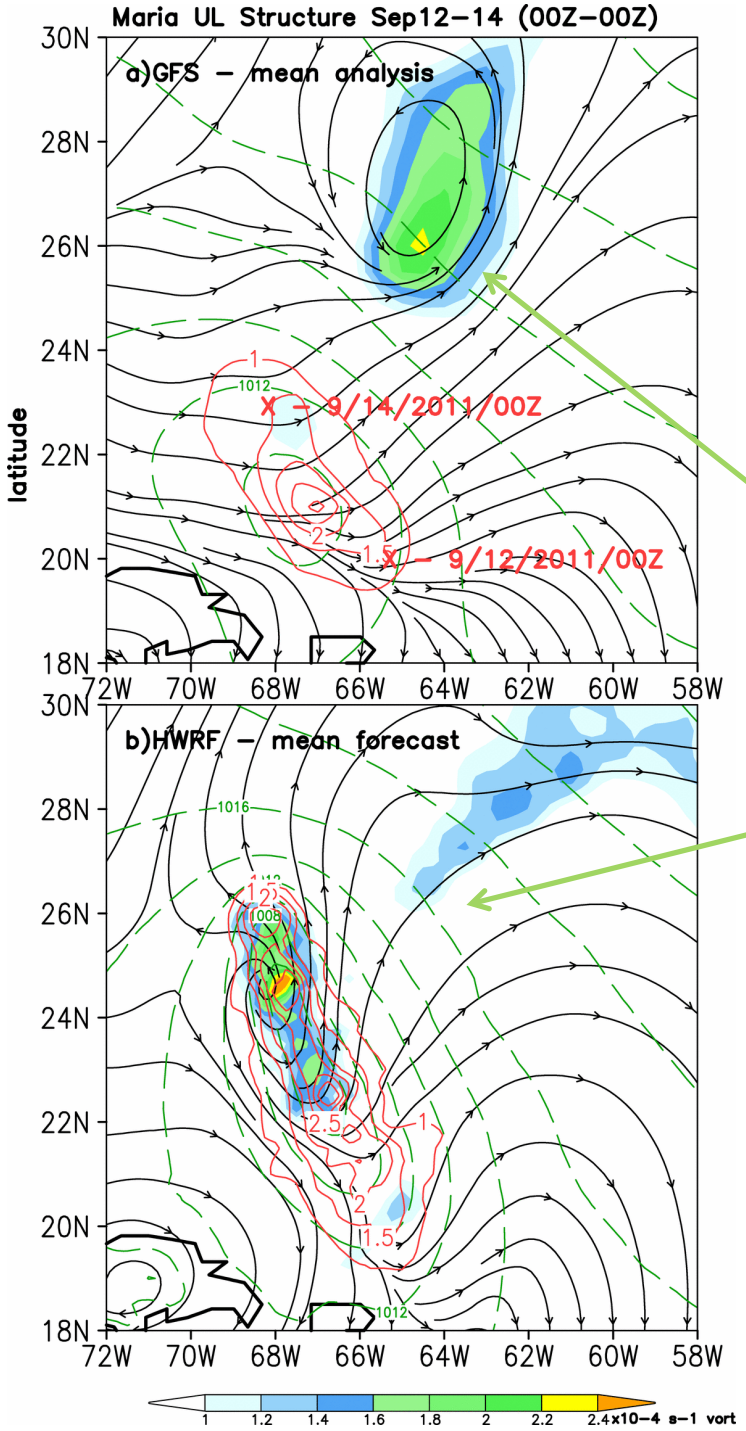


RH

Excluding COTC



Courtesy: Mark DeMaria



Maria – 12-14 Sep

The mean synoptic pattern consisted of an upper-level low north of Maria and associated westerly flow above Maria.

The GFS analyzed:

1. **A persistent 200mb low,**
2. **200mb westerlies above Maria**

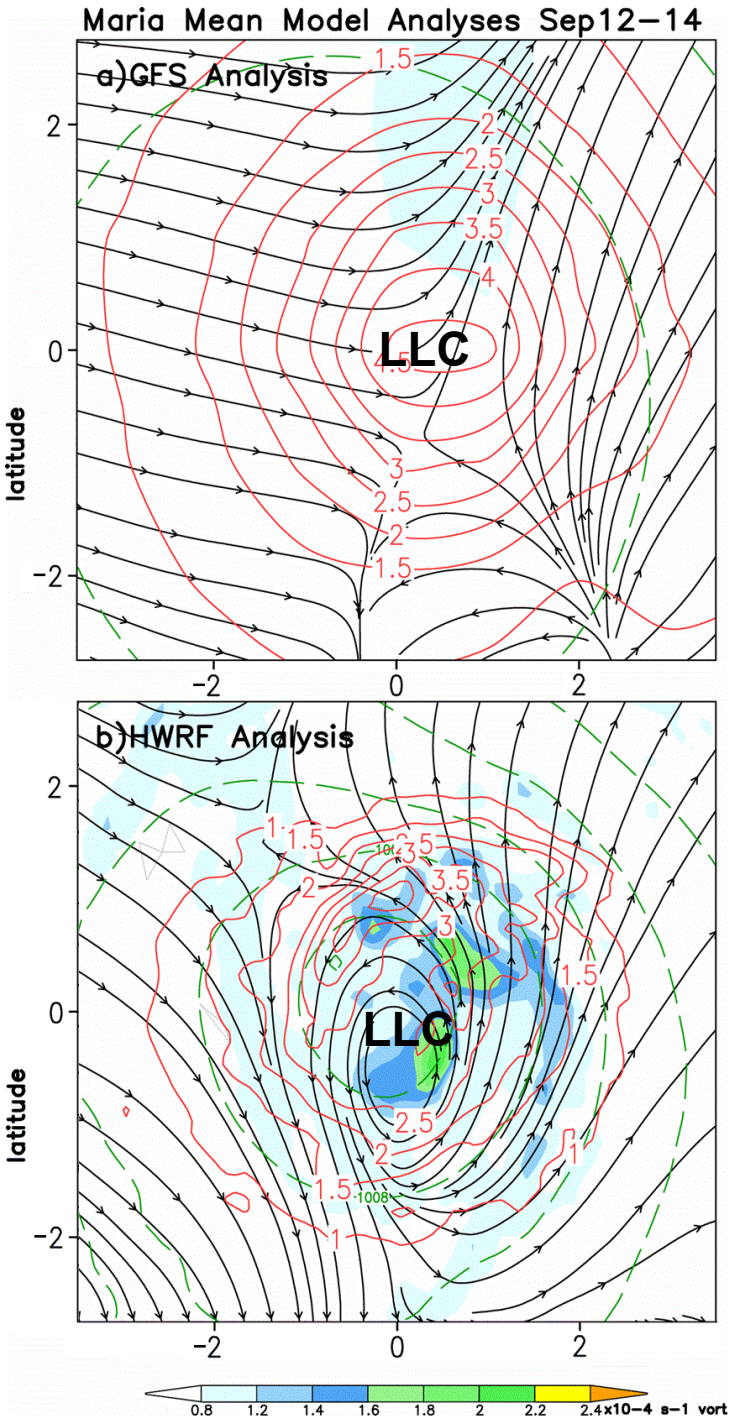
The 12Sep00Z HWRF forecasted:

1. **200mb upper low dissipation,**
2. **Southerlies extending north of Maria,**
3. **Maria to a hurricane with deep vortex**

Why does HWRF over-intensify Maria?

Courtesy: Wallace Hogsett

Left: 48h-mean 200mb vorticity (shaded), 200mb streamlines, 850mb vorticity (contoured, red), and MSLP (contoured, green), from the GFS analysis (top) and the 12Sep00Z (f00-f48) HWRF forecast.



Mean analyses 12-14 Sep

Before looking into the forecast fields, here we analyze the mean vortex structure in the GFS (top) and HWRF (bottom) .

The mean GFS analysis depicts:

1. **Confluent 200mb flow above the LLC,**
2. **No closed 200mb vortex**

The mean HWRF analysis depicts:

1. **Closed 200mb vortex directly above the LLC,**
2. **Well-defined outflow pattern north and east of Maria**

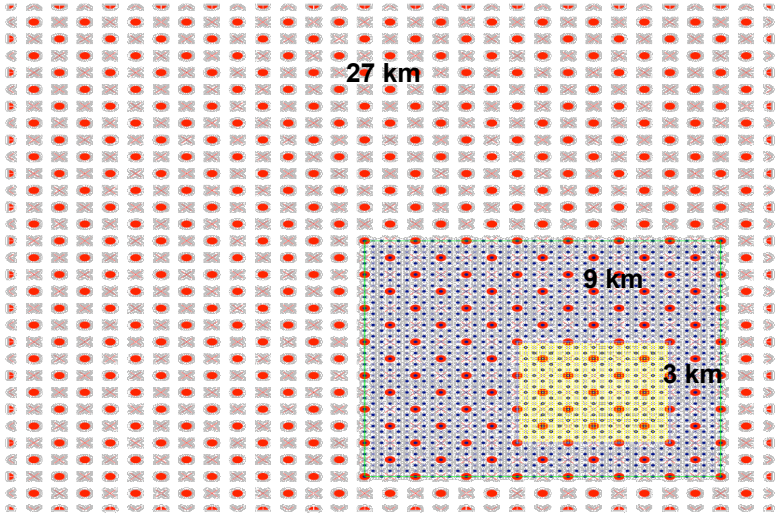
Courtesy: Wallace Hogsett

Left: 200mb vorticity (shaded), 200mb streamlines, and 850mb vorticity (contoured), averaged over nine model analyses (00Z 12 Sep – 00Z 14 Sep 2011).

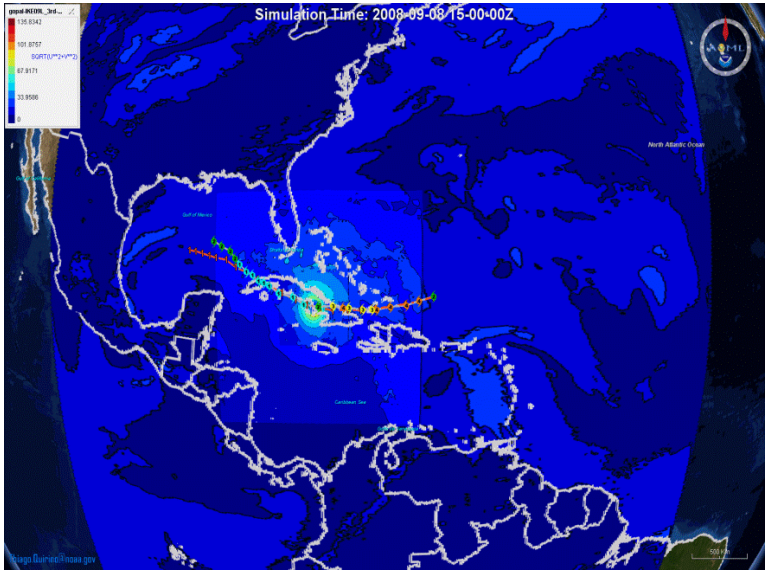
HWRF in 2012

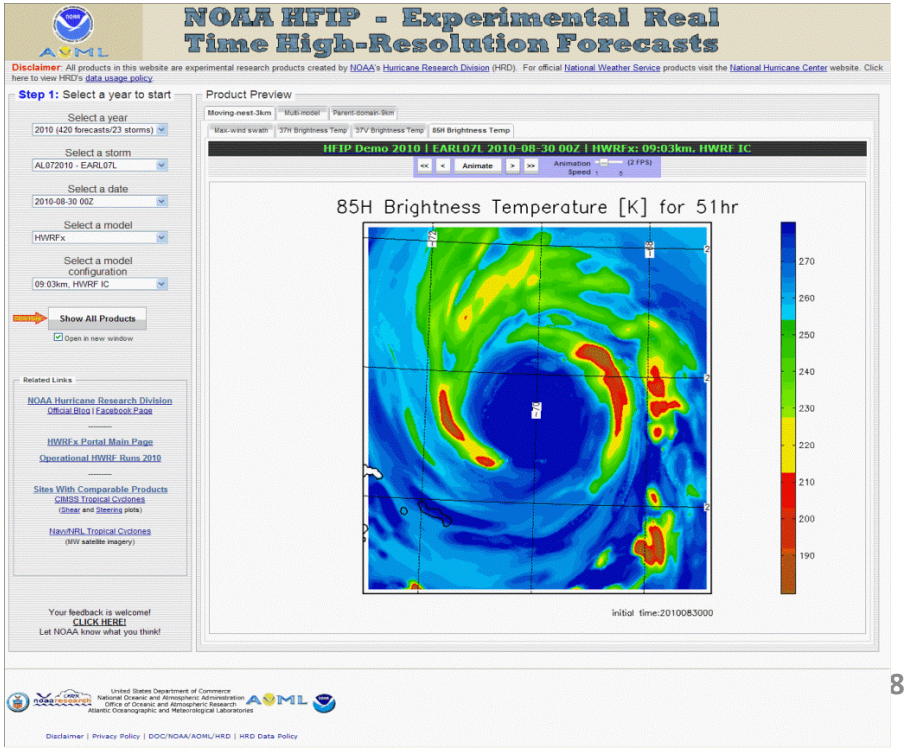
Towards High-Resolution HWRF implementation for FY2012

- Further advancements to the HWRF coupled modeling system (EMC & HRD)
- Code management and community support (EMC, DTC)
- Advanced vortex initialization (EMC & HRD)
- Improved physics (EMC & HRD)



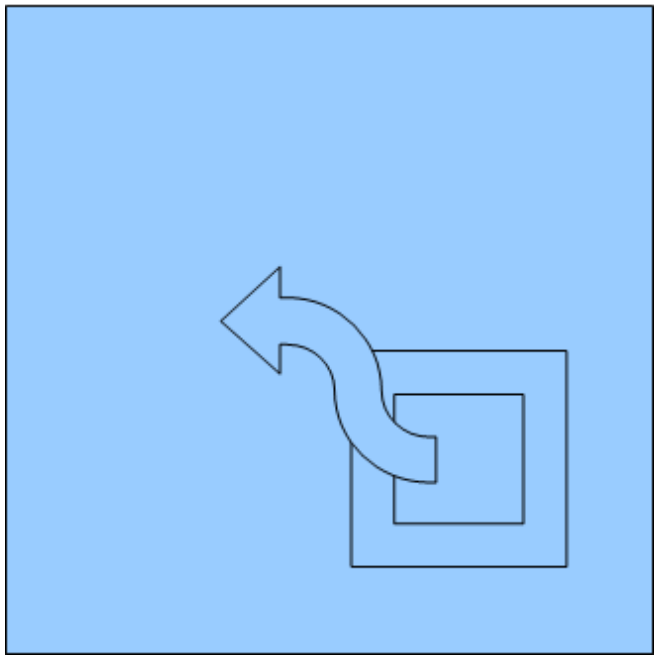
HWRF real-time demo simulations (https://storm.aoml.noaa.gov/realtime/)





Planned 2012 Operational HWRF System (EMC-HRD)

- Three atmospheric telescoping nested domains:
  - 27km resolution 75x75 degree domain
  - 9km resolution ~11x10 degree storm-following
  - 3km resolution ~6x5 degree storm-following
- Include new nest motion algorithm and other dynamics improvements tested in real-time during 2011 season in collaboration with HRD
- Coupled with POM ocean model.
- New coupler and modified HWRF vortex initialization for third nest
- Changes to HWRF physics appropriate for 3 km resolution



Code Optimization of Triple Nested HWRF System

- Triple nested HWRF system (27-9-3) has been running parallel for 2011 hurricane season ;
- The system is stable and produces comparable or better track/ intensity forecasts with current operational HWRF;
- The bottleneck for the system to be implemented into operation is the run time: it costs about 2 hours and 20 minutes for 126 hours forecast;
- Several possible ways to further reduce the model run time, including:
  - IO Servers configuration (identical results);
  - Reducing HALO width (identical results);
  - Increasing model time steps and physics calling frequencies;
  - Adding one more node; Reducing model print statements;
  - Reducing model domain; Loadleveler environment configuration;
- 3 dedicated nodes – thanks to vapor helpdesk.
- End Result: Triple Nested HWRF system can run in 75 minutes with four nodes

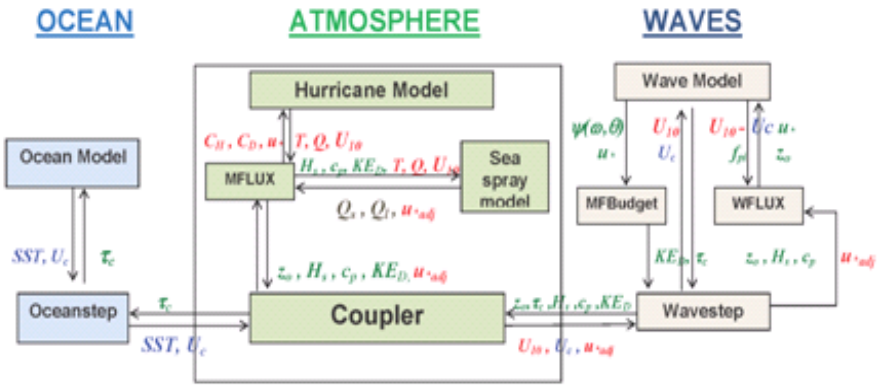
HWRF T&E for 2012 Implementation

HR12	H061	H062	H063	HWRFV6.0.0
New Baseline (Control)	GFS Shallow convection and new PBL	Tuning of Microphysics parameters (NCW, NLImax, fall speed and so on)	Q3FY12 GFS (Hybrid GSI, prd12q3k)	H061+ H062+H063
Triple nested HWRF (27-9-3km)	Uses GFS shallow convection and PBL scheme implemented in July 2010	Tune some microphysics parameters suggested by Eric and Brad	Create another baseline with proposed Q3FY12 Hybrid GSI/GFS	Combination of shallow convection, PBL and Microphysics and Q3FY12 GSI/GFS
Test cases: All 2011 cases in ALT and EP (about 600 cases)	Priority cases	Priority cases	All 2011 cases in ALT and EP (about 600 cases)	All 2011 cases in ALT and EP (about 600 cases)
Dec. 15, 2011	Jan. 31, 2012	Jan. 31, 2012	Feb. 28, 2012	Feb. 28, 2012

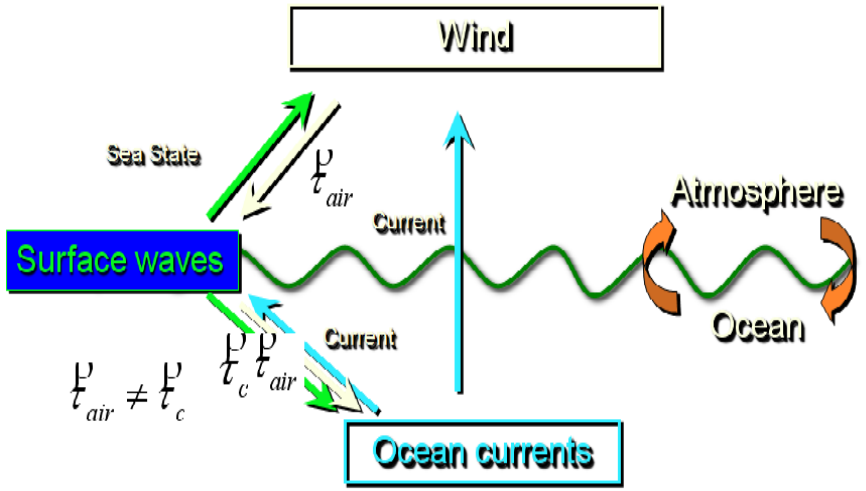
Future Developments

- **HWRF Physics (URI, GFDL, ESRL,HRD)**
  - Surface fluxes, sea spray and wave coupling
  - Physics for high-resolution (convection, micro physics, PBL, LSM)
- **HWRF Diagnostics (HFIP, EMC, NHC, FSU, CIRA, HRD, UMBC/UMD)**
  - Identifying forecast errors from different components of model physics and dynamics
  - Hurricane model diagnostics, evaluation and verification
  - Develop a common and comprehensive diagnostics framework and tools to integrate model output with available observations for verification
  - Enhanced real-time product display and navigation
- **HWRF Ensembles**
  - Large Scale Flow Perturbations;
  - Initial Storm Structure Perturbations;
  - Physics-Based Perturbations
- **High-Resolution HWRF and other parallels**
  - Real-time demo of triple nested (27/9/3) HWRF (HFIP Stream 1.5)
  - Real-time demo of high-resolution 9:3 HWRF (HFIP Stream 2)
  - Real-time demo of Doppler Radar DA experiments
  - Real-time demo of NOAH LSM Coupled HWRF

Three-way Atmosphere-Ocean-Wave Coupled System



Wind-Wave-Current Interaction

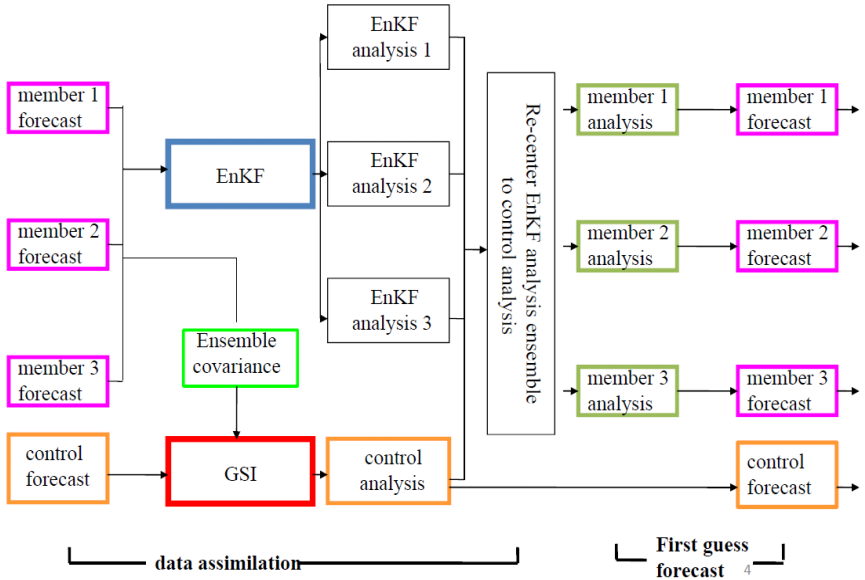


Improved Vortex Initialization and Inner Core Data Assimilation

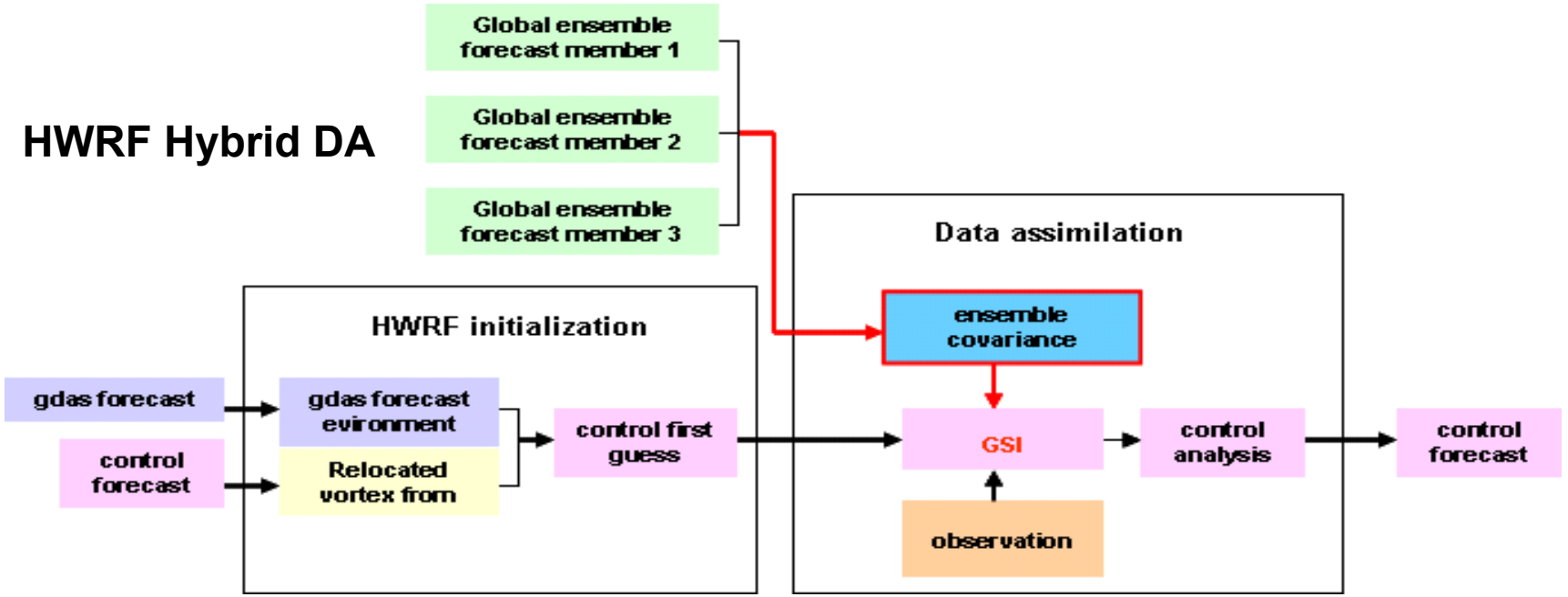
Data assimilation and vortex initialization (EMC, ESRL, OU, AOML)

- Real-time transmission of the P3 TDR data flow from aircraft to NCO/TOC/AOC and assimilation using advanced GSI.
- Improved vortex initialization (model consistent 3-D balanced vortex)
- Ensemble data assimilation - hybrid EnKF (ESRL, OU , AOML)
- Planned Demo during 2011 hurricane season (HFIP Stream 2)

Hybrid EnKF-GSI DA system: 2 way coupling

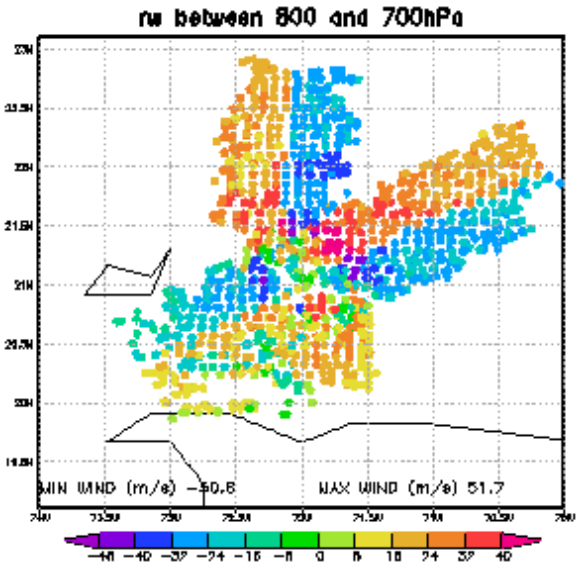


HWRF Hybrid DA

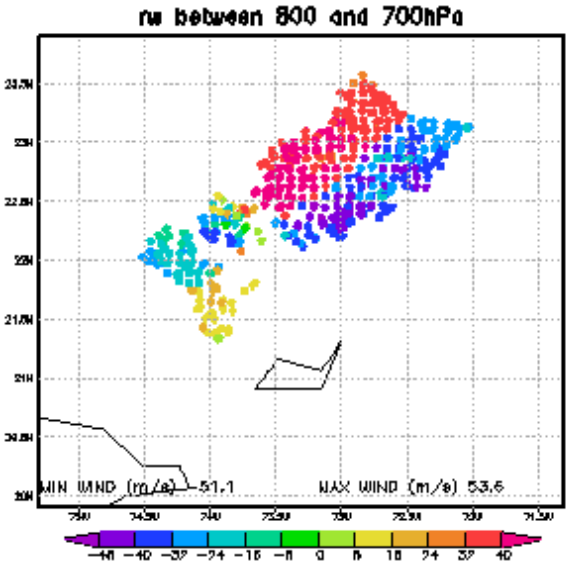


TDR radial velocity data assimilated in inner analysis domain

2011.08.24 00 UTC

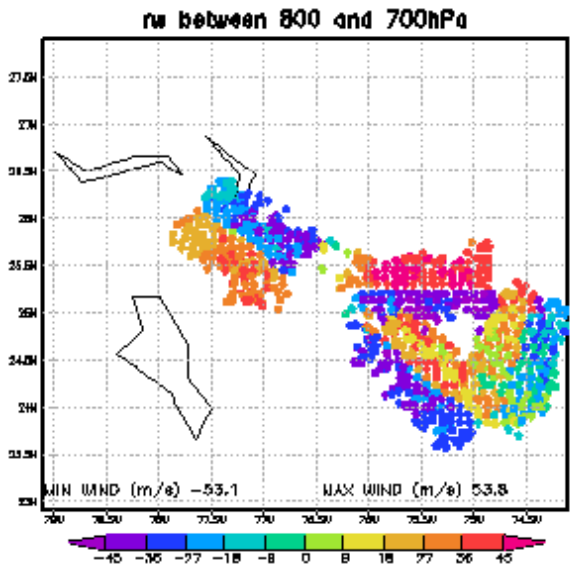


2011.08.24. 12 UTC

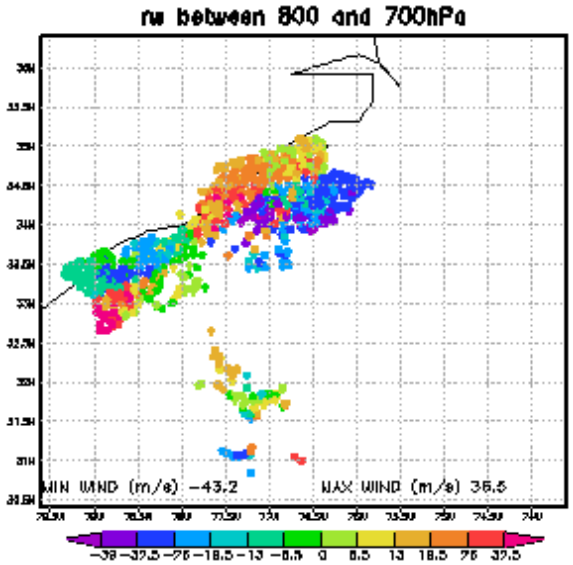


TDR radial velocity data assimilated in inner analysis domain

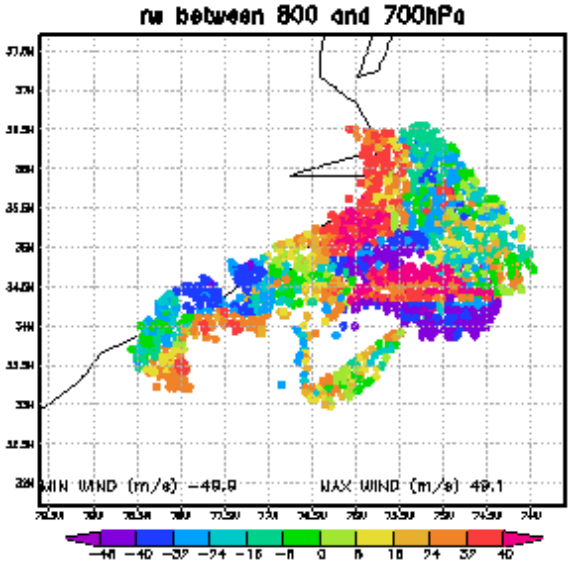
2011.08.25 12 UTC



2011.08.27. 00 UTC



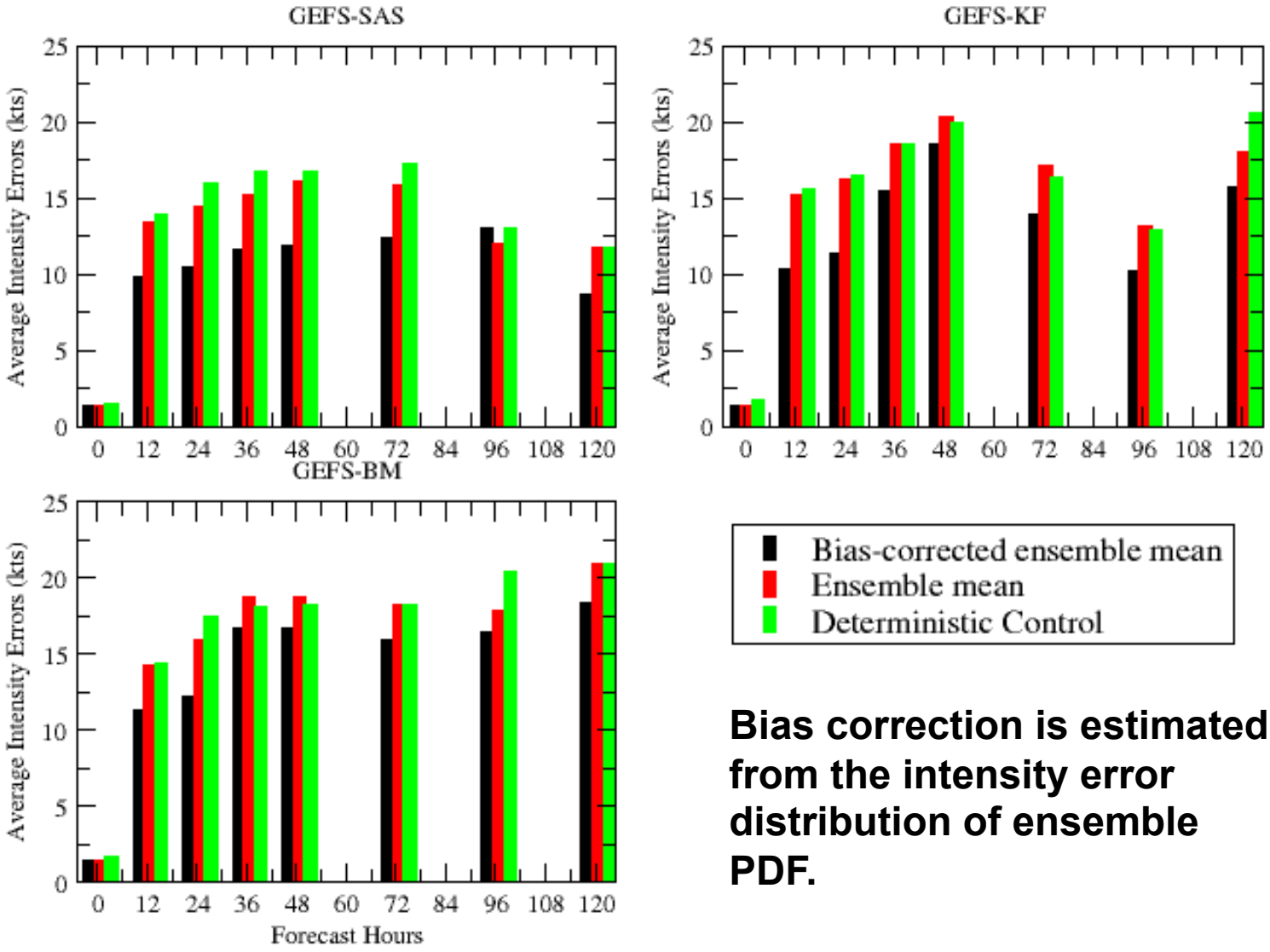
2011.08.27 12 UTC



HWRF ensembles

- Mainly focused on better estimation of hurricane intensity forecasts from EPS.
- Single model, multi-initial condition ensembles.
    1) GEFS-based HWRF ensembles with three cumulus convection schemes: Simplified Arakawa-Schubert (SAS), Kain-Fritsh (KF), and Batts-Miller (BM); Each includes 21 members.
    2) Error distribution-based model bias correction method was developed.
    3) Intensity forecast skills are greatly improved by the bias correction method, compared to simple ensemble average method (See Figure).
- Multi-model, multi-physics ensembles.
    1) Ensemble members include GFDL, high resolution (27-9-3) HWRF, HWRF with various cumulus convection schemes, PBL schemes;
    2) Mode analysis was developed using PDF kernel density estimation method
    3) Results showed that the intensity forecast skills are further improved by using mode analysis, compared to the arithmetic ensemble mean.

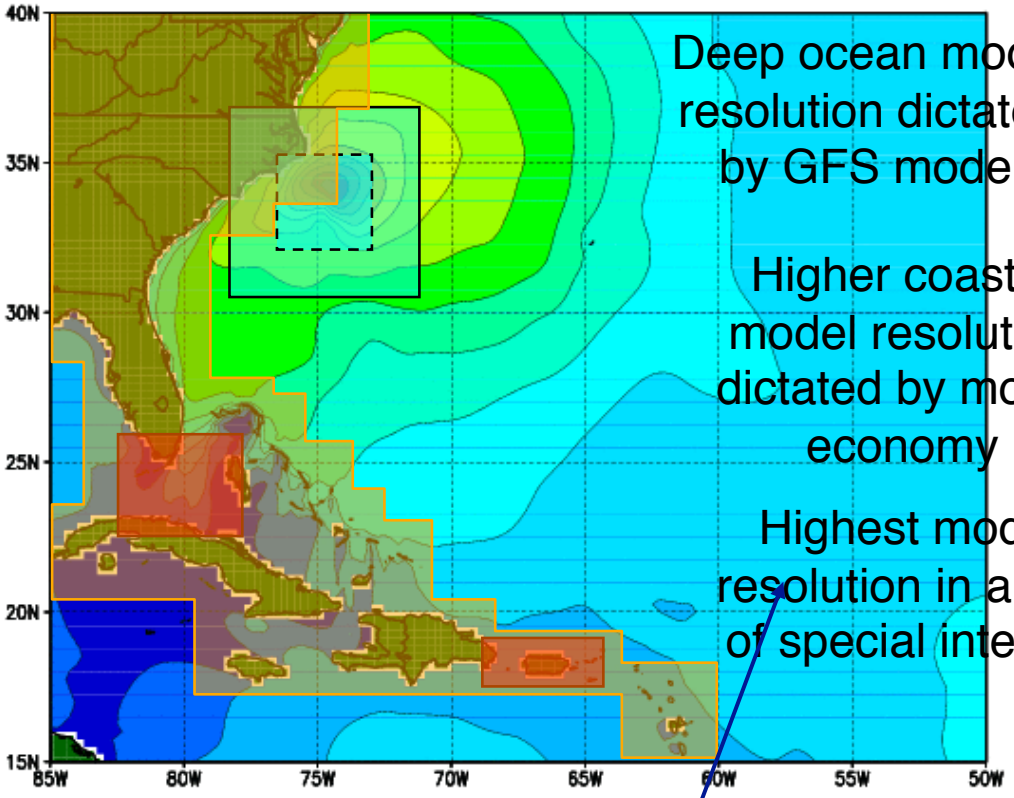
Comparison of Average Intensity Errors
Hurricane Earl (Total Sample: 40)



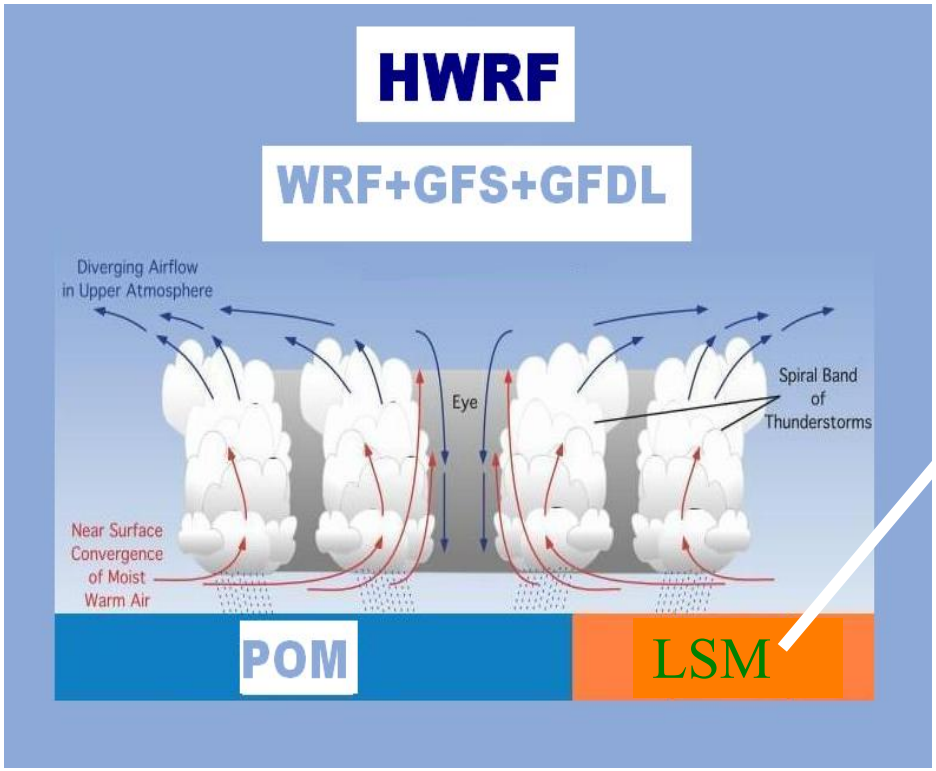
Bias correction is estimated from the intensity error distribution of ensemble PDF.

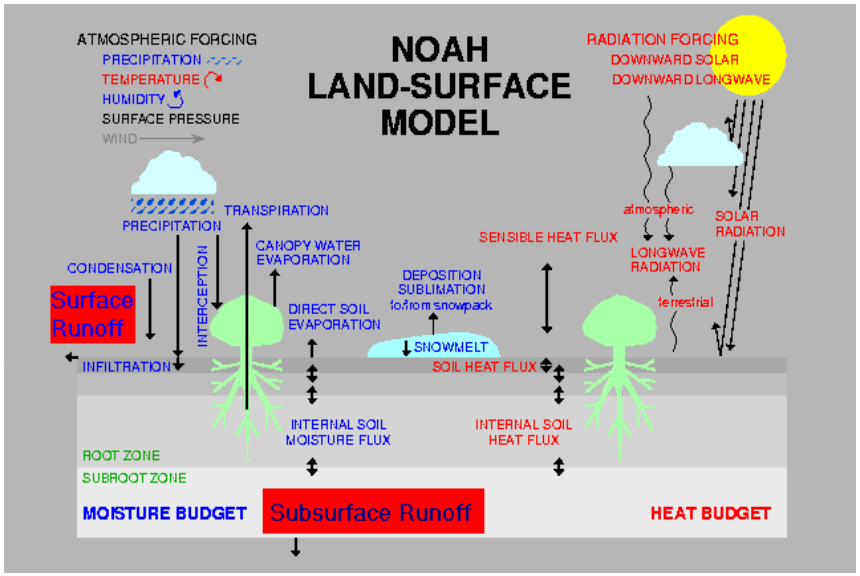
Coupling to Wave-Watch III

- **NOAA/NCEP in-house wave model, based on WAM.**
- **Operational global and (nested) regional model.**
- **Specialized Atlantic and Pacific hurricane wave models with blended winds from GFS and GFDL model.**
- **WAVEWATCH III will be coupled to HWRF**

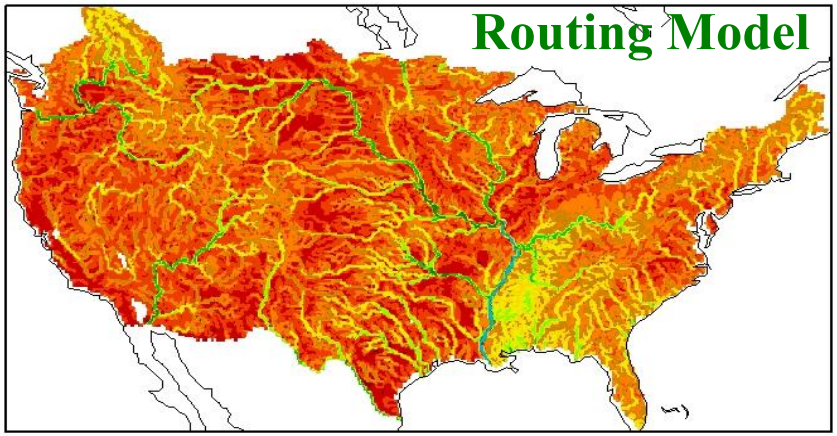


Coupling to Land Surface Model





www.emc.ncep.noaa.gov/HWRF

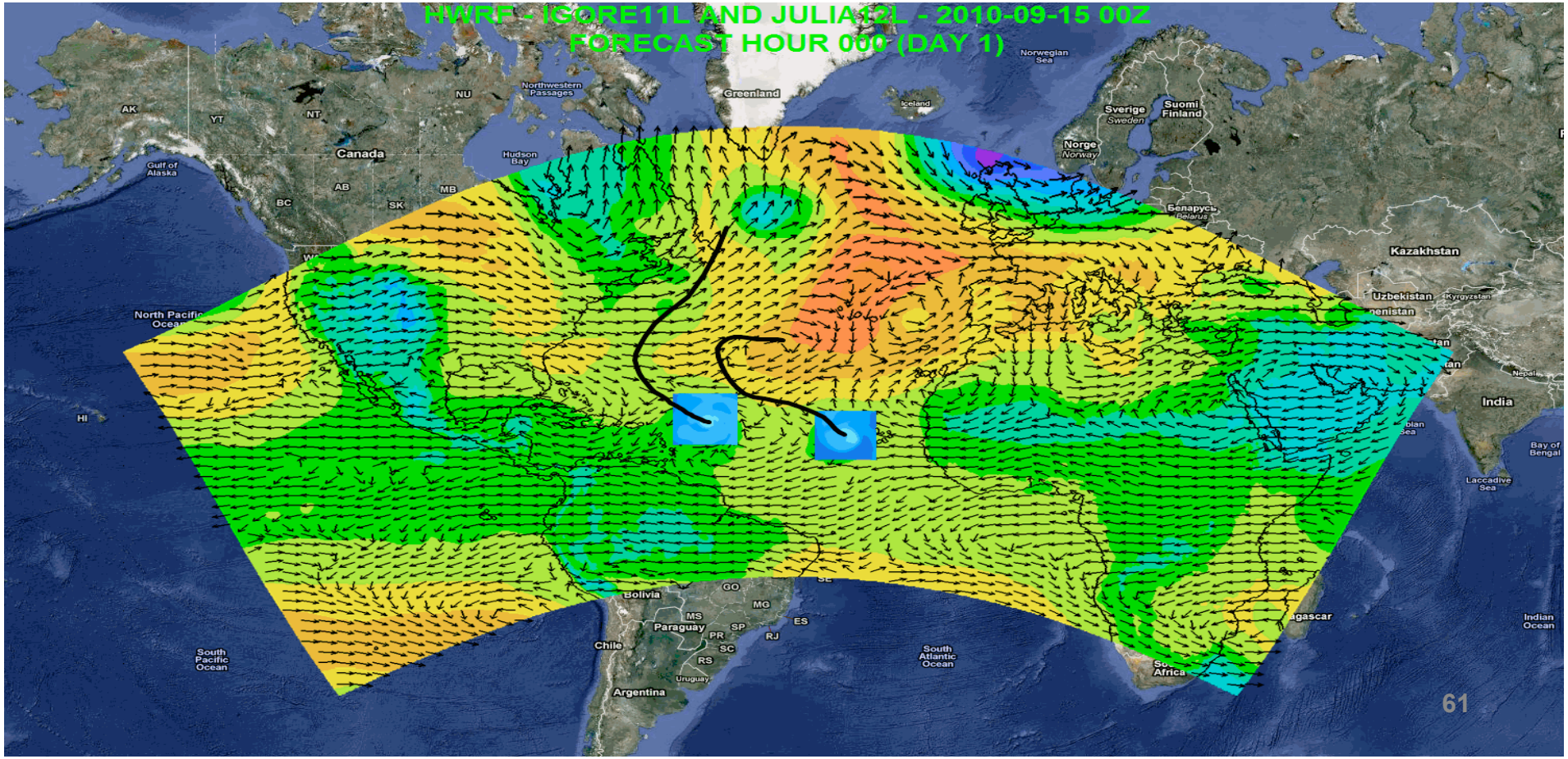


Driving Forcing: Surface runoff and baseflow

HWRF Domain With Multiple Moving Nests

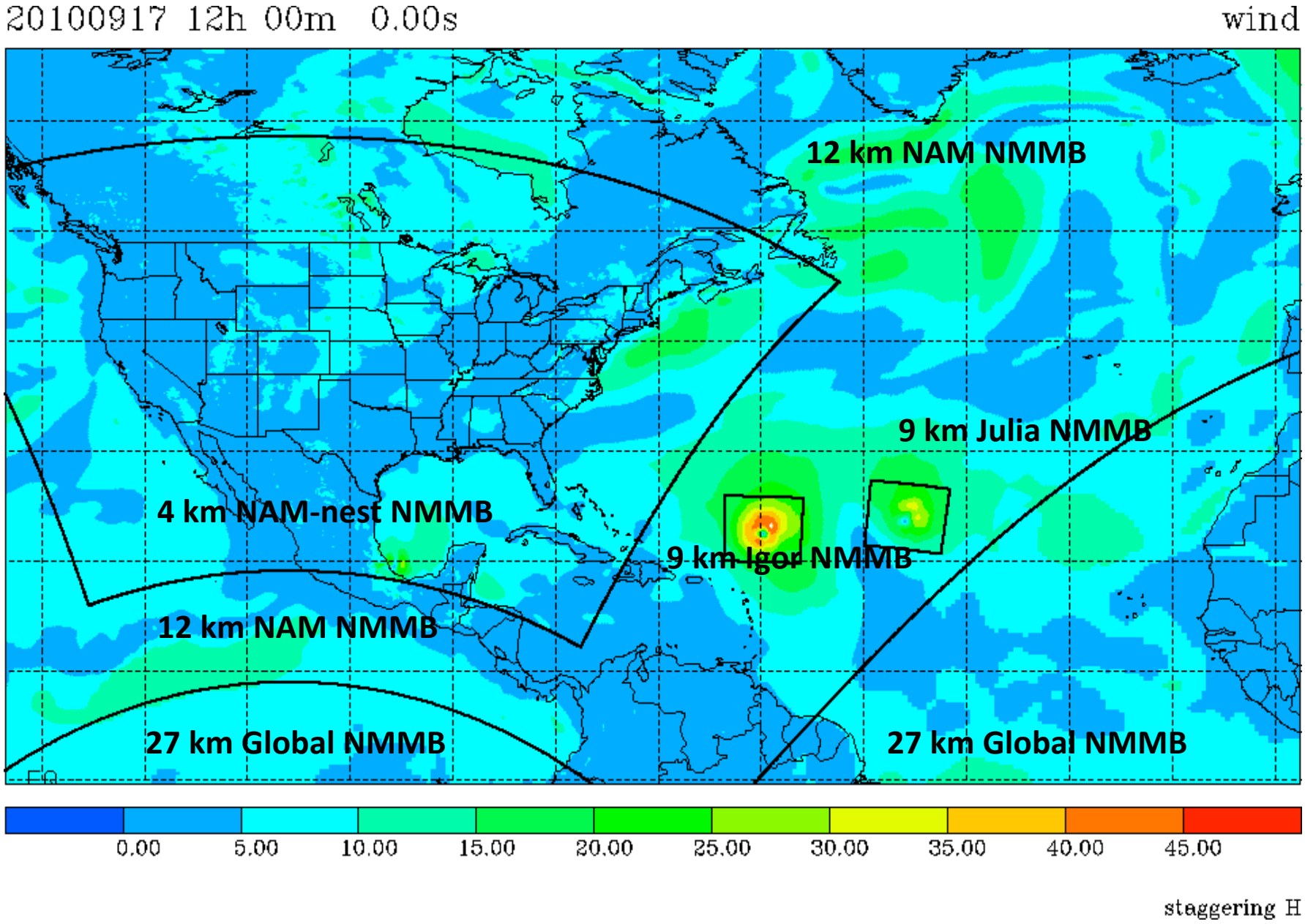
- Basin scale domain
- 7 days forecast
- SDA and cycling

- Regional ensembles/products
- Daily Tropical Outlook/genesis
- Computational Efficiency (27:9;about 2 h; 168 CPUs)



Hypothetical NMMB Simultaneous Run

Global [with Igor & Julia] and NAM [with CONUS nest]



Lessons learned so far…..

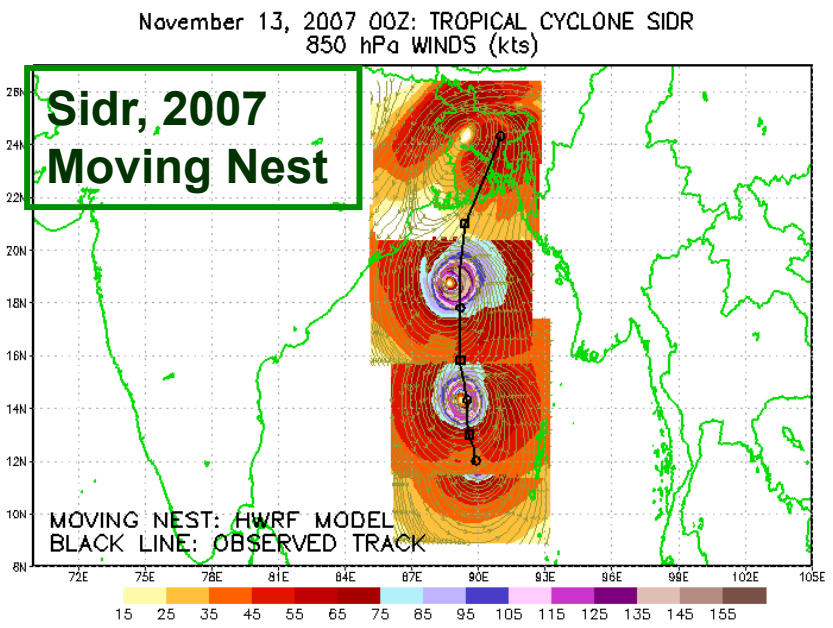
- Higher resolution alone is not enough. We need physics appropriate for high resolution. We started seeing better structure of tropical cyclones from high-res runs.
- Vortex initialization requires several changes (we may be able to resolve RMW, eye and eye-wall appropriately). We should explore inner core DA with available obs.
- Providing high-resolution capability within the operational framework allows developers to test new and innovative methods to improve forecast skill.
- We are focusing only on **TRACK** and **INTENSITY**, and just started looking into the **STRUCTURE**. More work needed to evaluate **Precipitation, Inland Flooding, Storm Surge** and other related landfall features from these models.

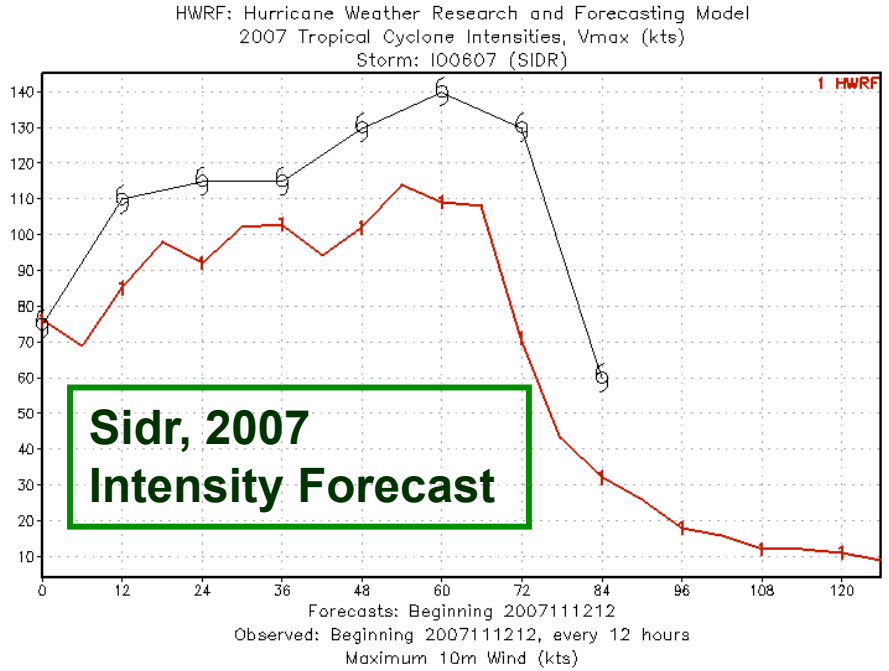
Expanding the scope and application of HWRF for World Oceans

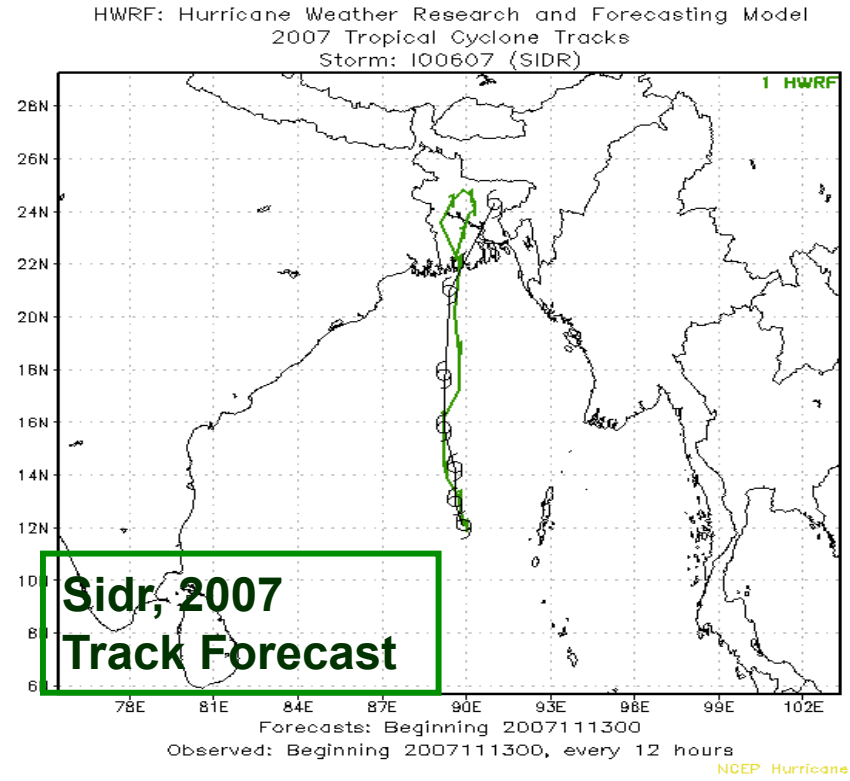
Operational implementation of
HWRF in India

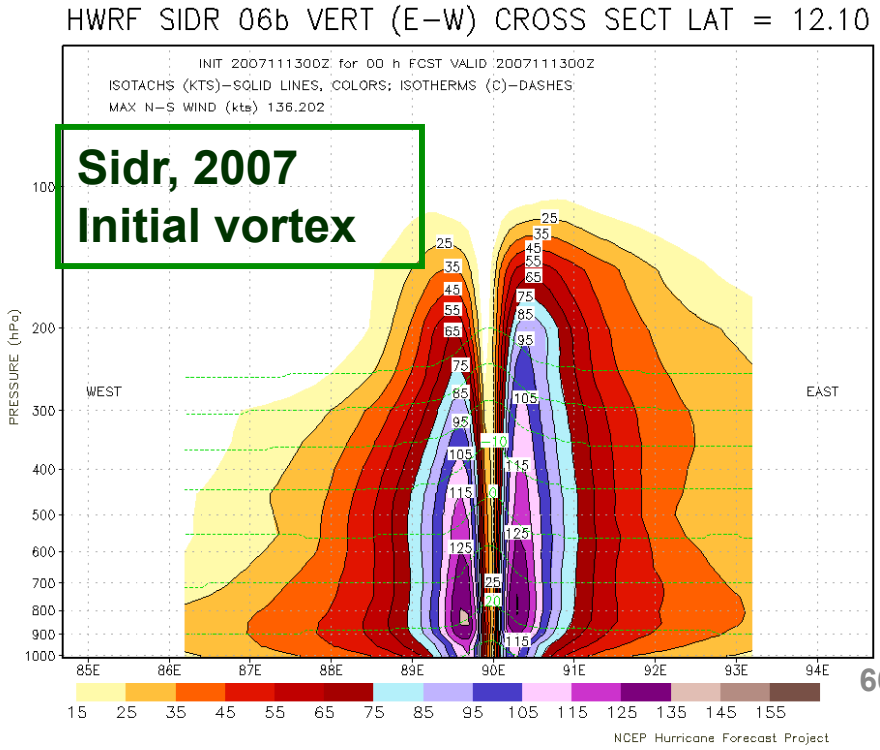
Applications of HWRF Modeling System for Tropical Cyclones of the Indian Ocean and Typhoons of the Western Pacific Ocean

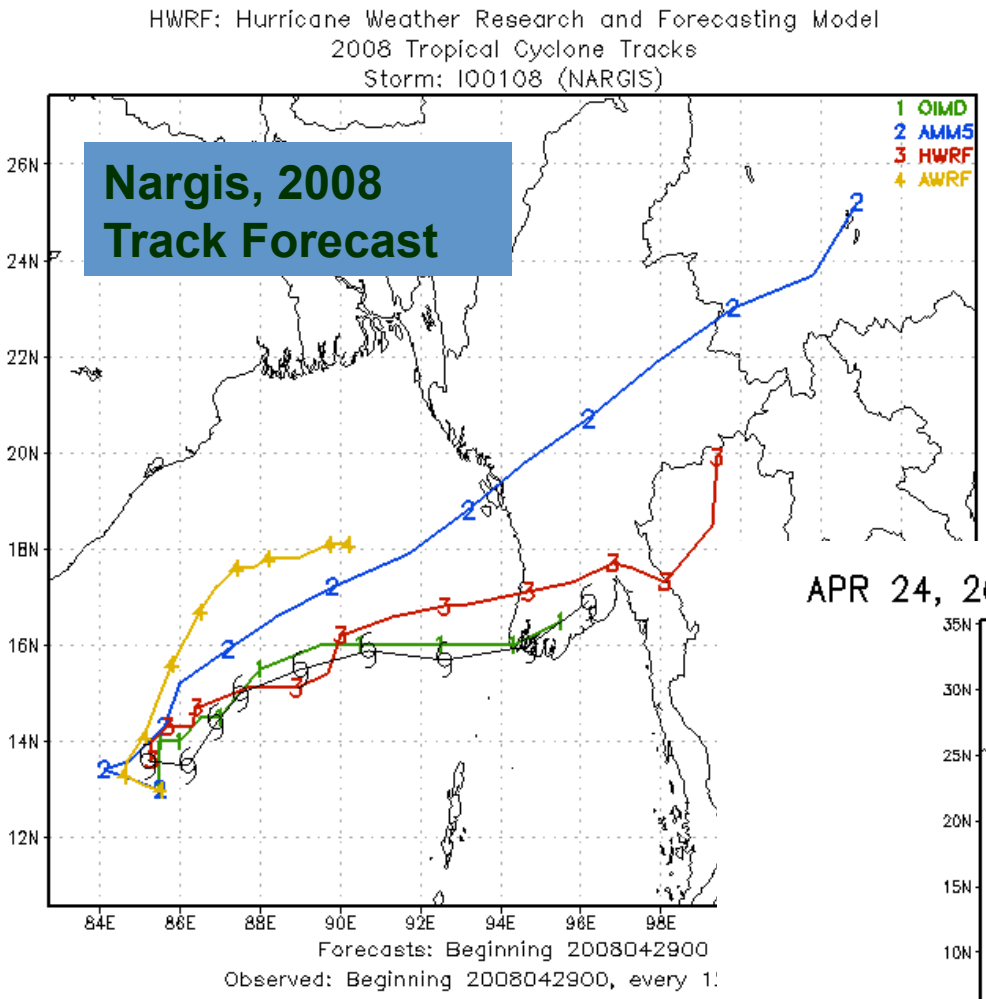
- Unified community HWRF modeling system provides a unique opportunity to expand its applications for tropical cyclone forecasts over the world.
- NOAA has signed an MoU with India (MoES) for improved tropical cyclone predictions over the Indian region.
- We started looking into performance of the HWRF model for Western Pacific typhoons.
- JTWC expressed interest in having HWRF run for all TC basins including Southern Pacific (Australia) region.

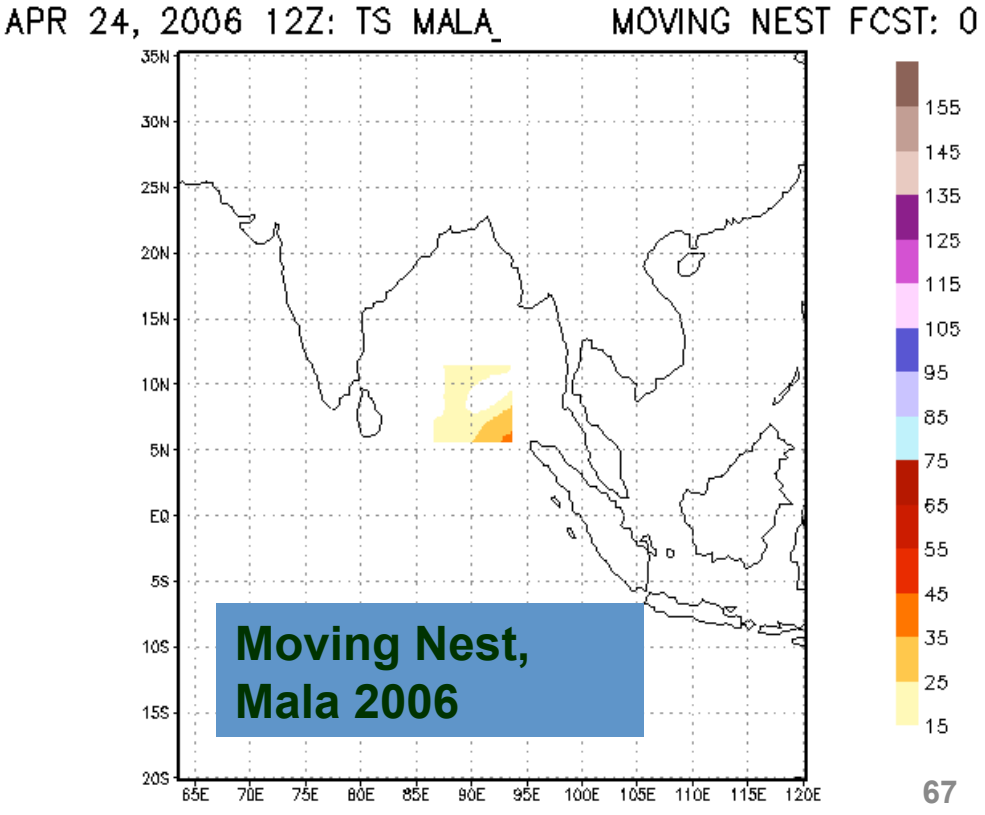

November 13, 2007 00Z: TROPICAL CYCLONE SIDR
850 hPa WINDS (kts)
Sidr, 2007
Moving Nest
MOVING NEST: HWRF MODEL
BLACK LINE: OBSERVED TRACK


HWRF: Hurricane Weather Research and Forecasting Model
2007 Tropical Cyclone Intensities, Vmax (kts)
Storm: I00607 (SIDR)
Sidr, 2007
Intensity Forecast
Forecasts: Beginning 2007111212
Observed: Beginning 2007111212, every 12 hours
Maximum 10m Wind (kts)


HWRF: Hurricane Weather Research and Forecasting Model
2007 Tropical Cyclone Tracks
Storm: I00607 (SIDR)
Sidr, 2007
Track Forecast
Forecasts: Beginning 2007111300
Observed: Beginning 2007111300, every 12 hours

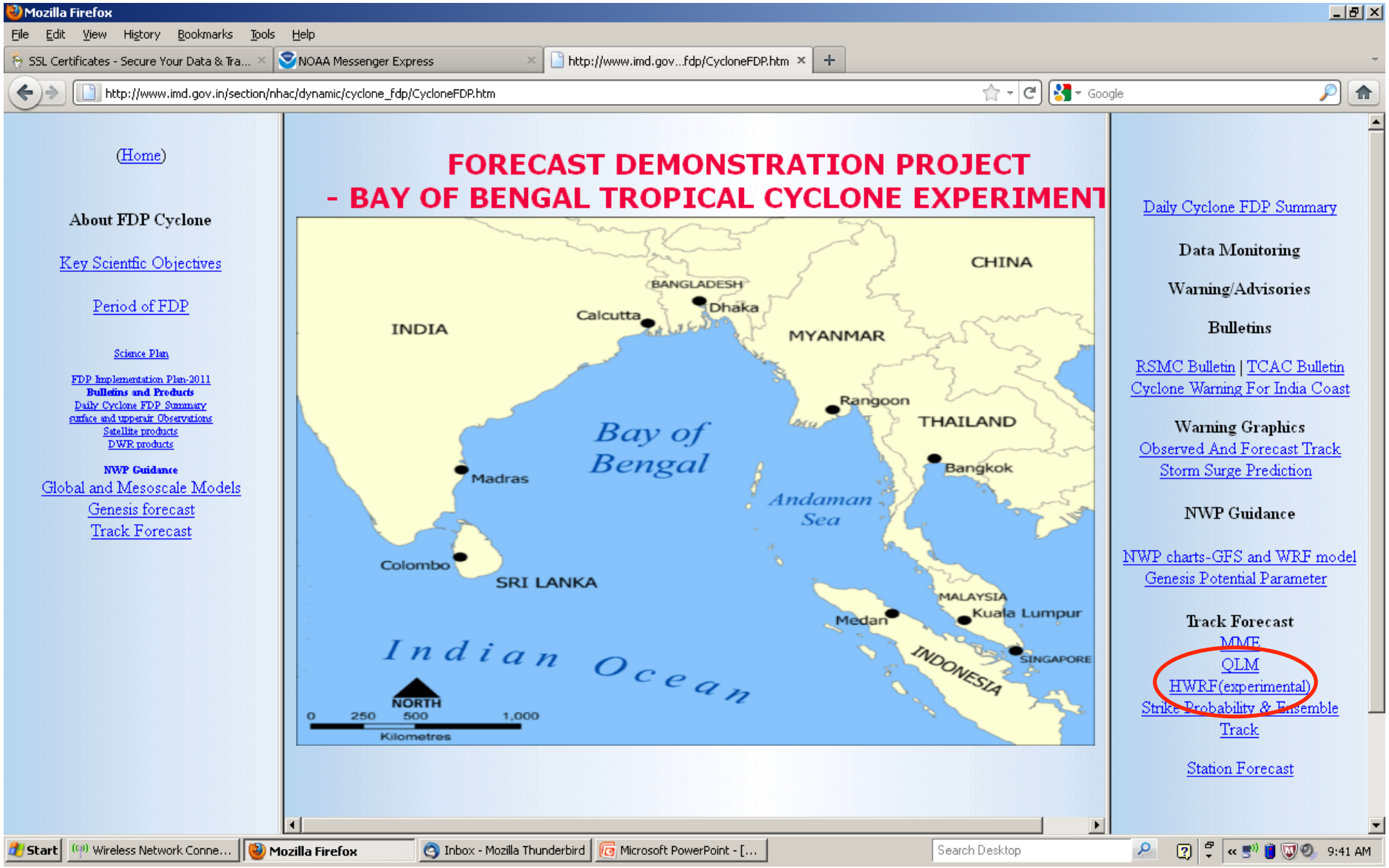

HWRF SIDR 06b VERT (E-W) CROSS SECT LAT = 12.10
Sidr, 2007
Initial vortex
WEST
EAST
PRESSURE (hPa)
NCEP Hurricane Forecast Project





GrADS: COLA/IGES

2006-06-01-00:38


Mozilla Firefox
File Edit View History Bookmarks Tools Help
SSL Certificates - Secure Your Data & Tra...
NOAA Messenger Express
http://www.imd.gov...fdp/CycloneFDP.htm
http://www.imd.gov.in/section/nhac/dynamic/cyclone_fdp/CycloneFDP.htm
Google
(Home)
About FDP Cyclone
Key Scientfic Objectives
Period of FDP
Science Plan
FDP Implementation Plan-2011
Bulletins and Products
Daily Cyclone FDP Summary
surface and upperair Observations
Satellite products
DWR products
NWP Guidance
Global and Mesoscale Models
Genesis forecast
Track Forecast
FORECAST DEMONSTRATION PROJECT
- BAY OF BENGAL TROPICAL CYCLONE EXPERIMENT
CHINA
BANGLADESH
Dhaka
Calcutta
INDIA
MYANMAR
Rangoon
THAILAND
Bay of Bengal
Bangkok
Madras
Andaman Sea
Colombo
SRI LANKA
MALAYSIA
Kuala Lumpur
Medan
SINGAPORE
INDONESIA
Indian Ocean
NORTH
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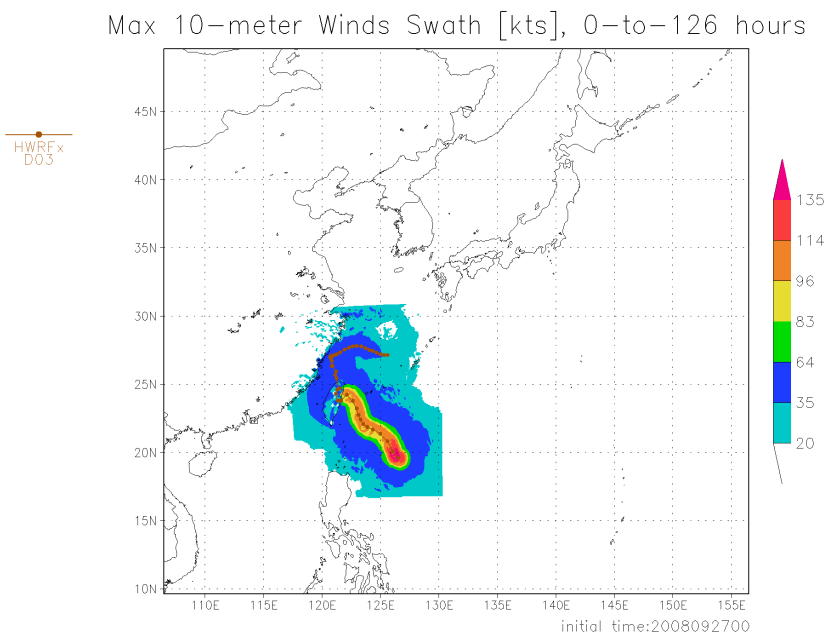
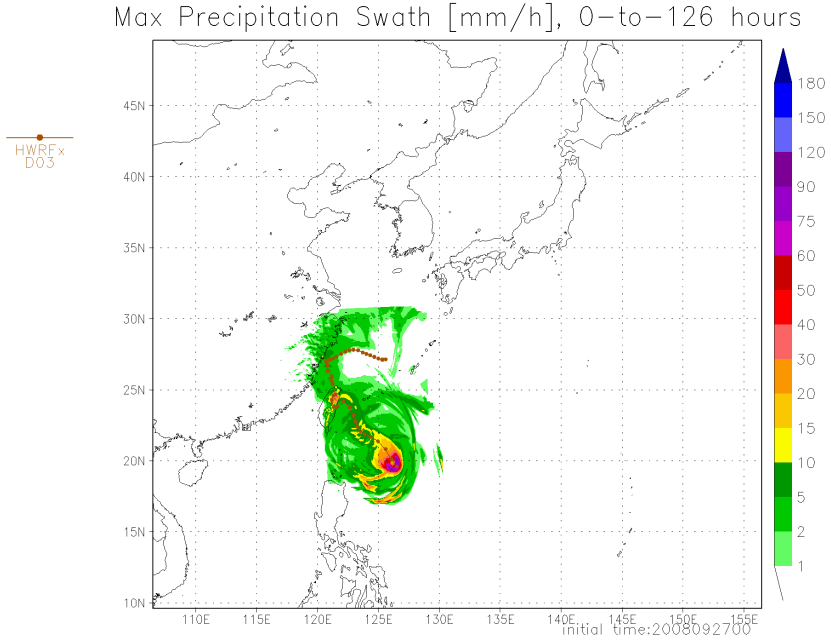
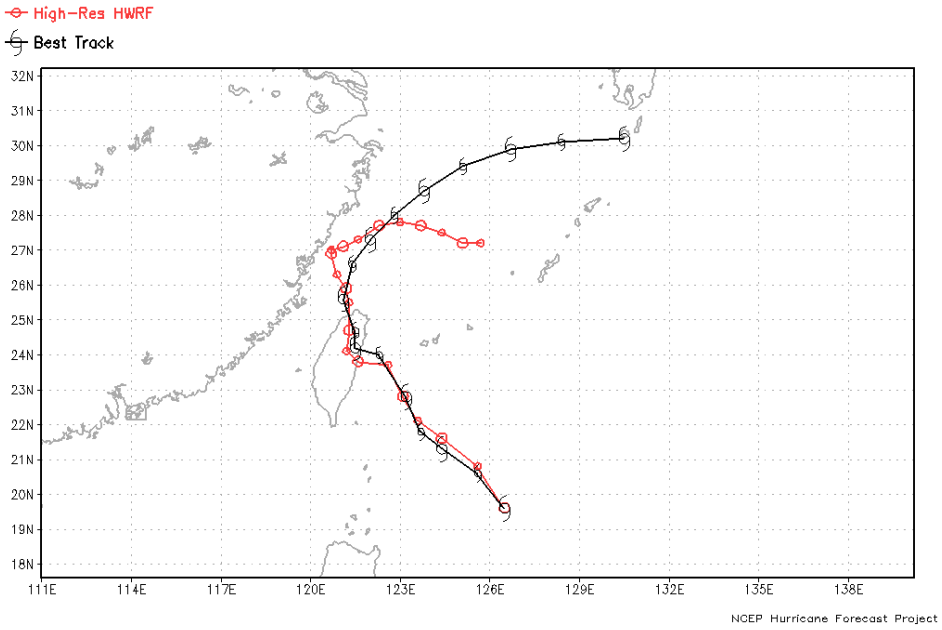
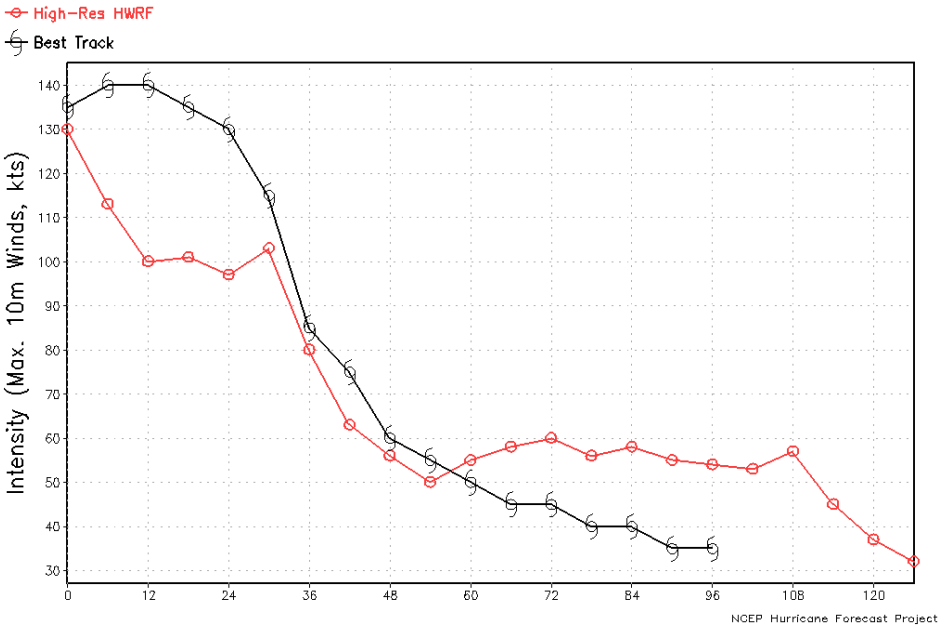
Kilometres
Daily Cyclone FDP Summary
Data Monitoring
Warning/Advisories
Bulletins
RSMC Bulletin | TCAC Bulletin
Cyclone Warning For India Coast
Warning Graphics
Observed And Forecast Track
Storm Surge Prediction
NWP Guidance
NWP charts-GFS and WRF model
Genesis Potential Parameter
Track Forecast
MME
QLM
HWRF(experimental)
Strike Probability & Ensemble Track
Station Forecast
Start
Wireless Network Conne...
Mozilla Firefox
Inbox - Mozilla Thunderbird
Microsoft PowerPoint - [...
Search Desktop
9:41 AM



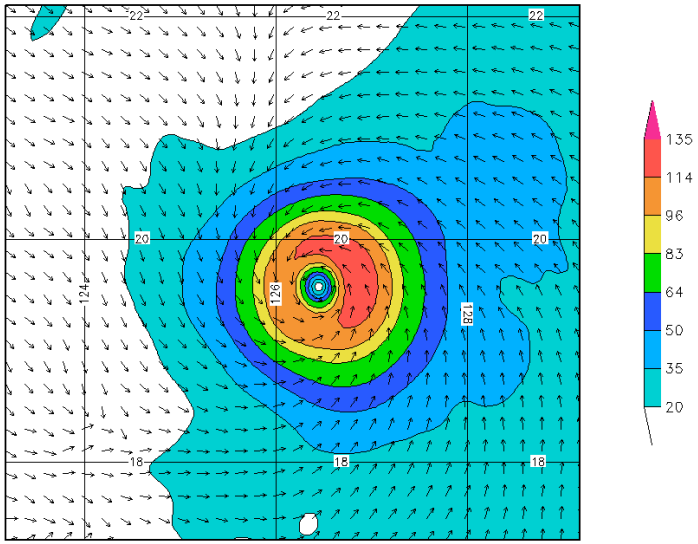


HWRF Forecasts for Typhoon Jangmi (19W), IC 2008092700



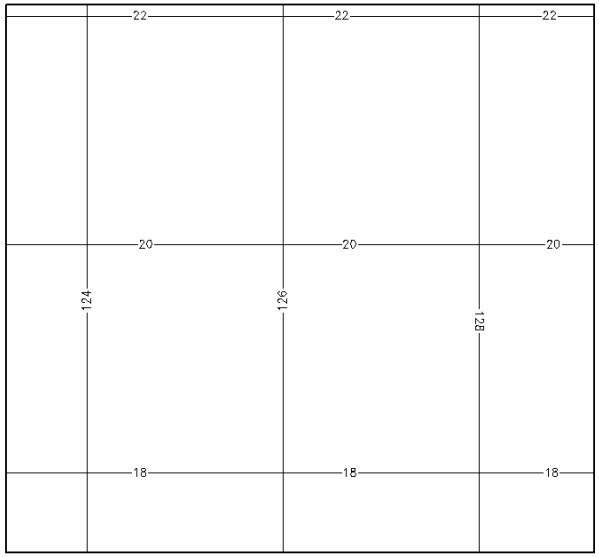


10M wind−speed [kts] 0hr



initial time:2008092700

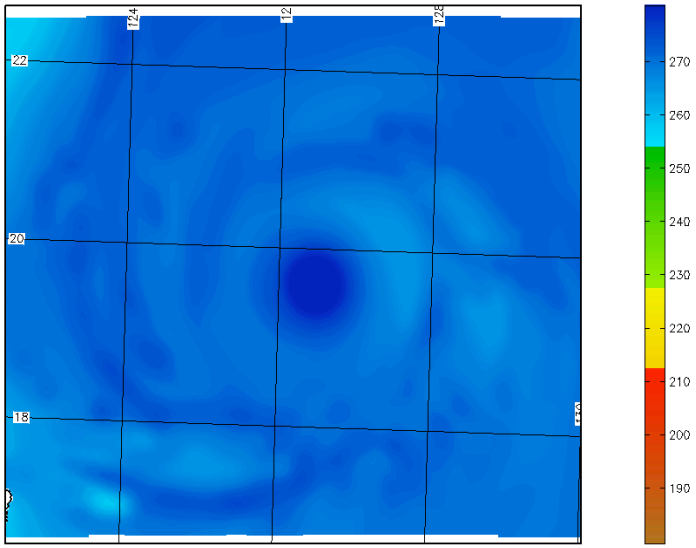
Precipitation Rate [mm/hr] for 0hr



initial time:2008092700

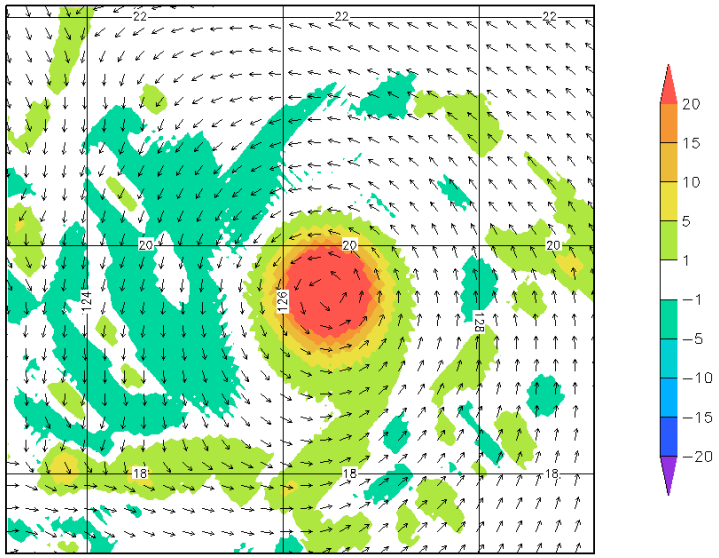
HWRF Forecasts for Typhoon Jangmi (19W), IC 2008092700

85H Brightness Temperature [K] for 0hr



initial time:2008092700

850mb vorticity [x 10^−4 S^−1] for 0hr



initial time:2008092700

SUMMARY

There has been lot of progress advancing the hurricane modeling capabilities at EMC, thanks to active collaboration between research and operations.

Improving intensity/structure forecasts are orders of magnitude more difficult than was for track forecasts.

Requires substantial effort between research and operational hurricane communities

With improved track, intensity and structure, it is possible to provide improved guidance on rainfall, storm surge, flooding and inundation.

Real-time Model Diagnostics

- Initial vortex diagnostics of HWRF/GFDL/GFS
- HWRF Synthetic satellite imagery for GOES (IR and WV) and Microwave (37 and 85 GHz)
- SHIPS diagnostics parameters (HWRF/GFDL/GFS/H3GP)
- Dissemination of products through various channels:
  - HWRF website (http://www.emc.ncep.noaa.gov/gc_wmb/vxt/)
  - FSU website (http://moe.met.fsu.edu/tcgengifs/)
  - AOML website (http://storm.aoml.noaa.gov/realtime/)
  - HFIP website (http://www.ral.ucar.edu/projects/hfip/d2011/forecasts/index.php)
  - Extensive discussion of HWRF/GFDL/GFS/H3GP forecasts in the tropical community, blogs and e-mail lists

Real-time and pre-implementation T&E HWRF products:

http://www.emc.ncep.noaa.gov/gc_wmb/vxt/index.html

Thanks for your attention

Questions?

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