High-Resolution Tropical Cyclone Forecasting Using NCEP Operational HWRF Model

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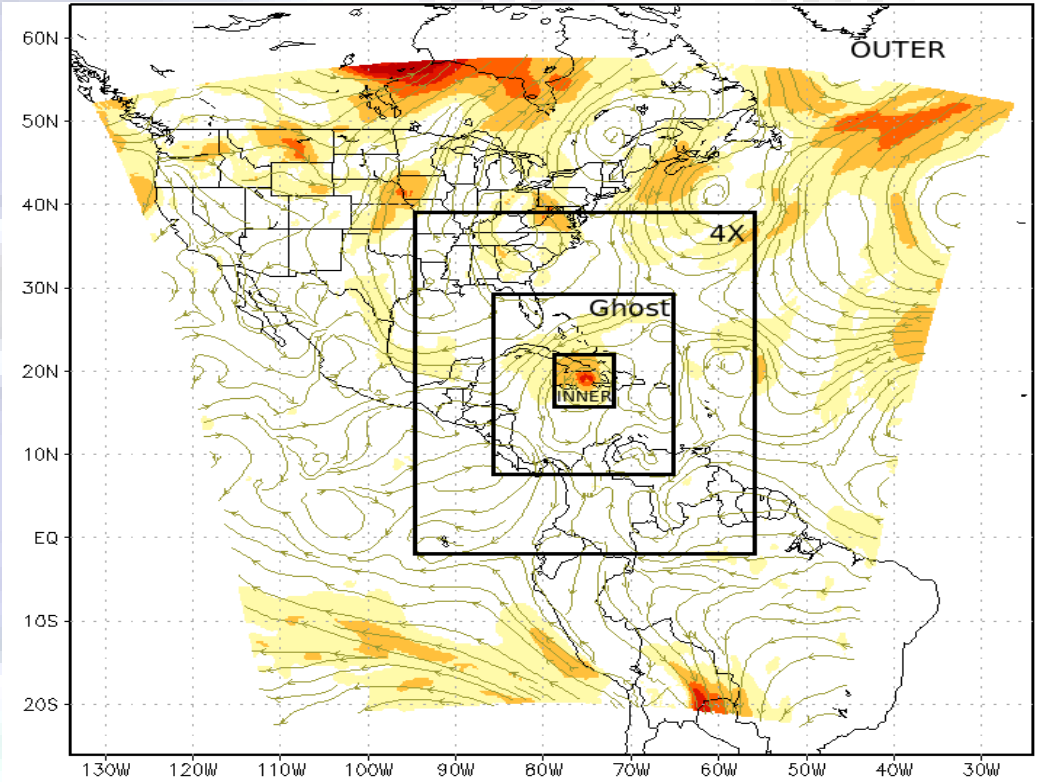
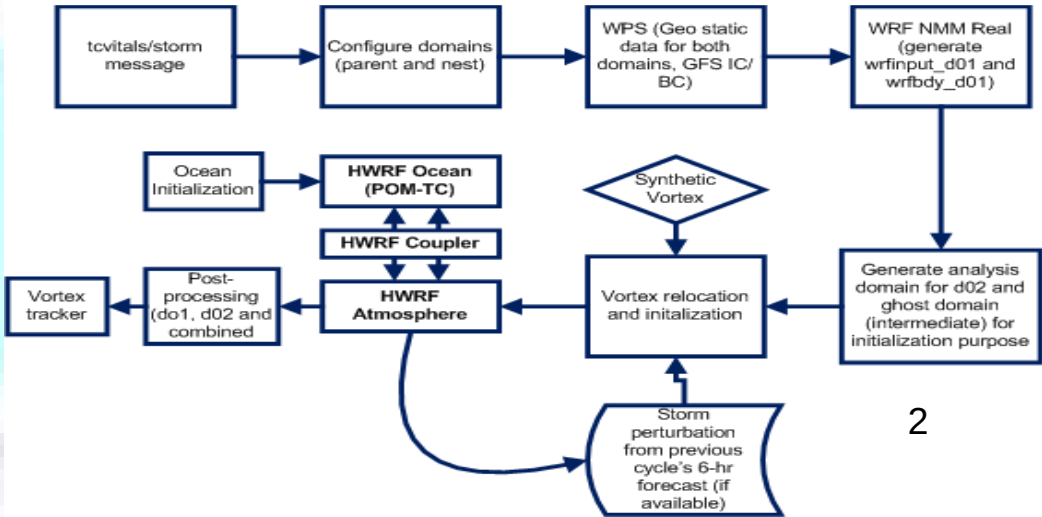
Overview of the Operational HWRF

- **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
- **Four years into operations, since 2007**





Design of high-resolution movable nest

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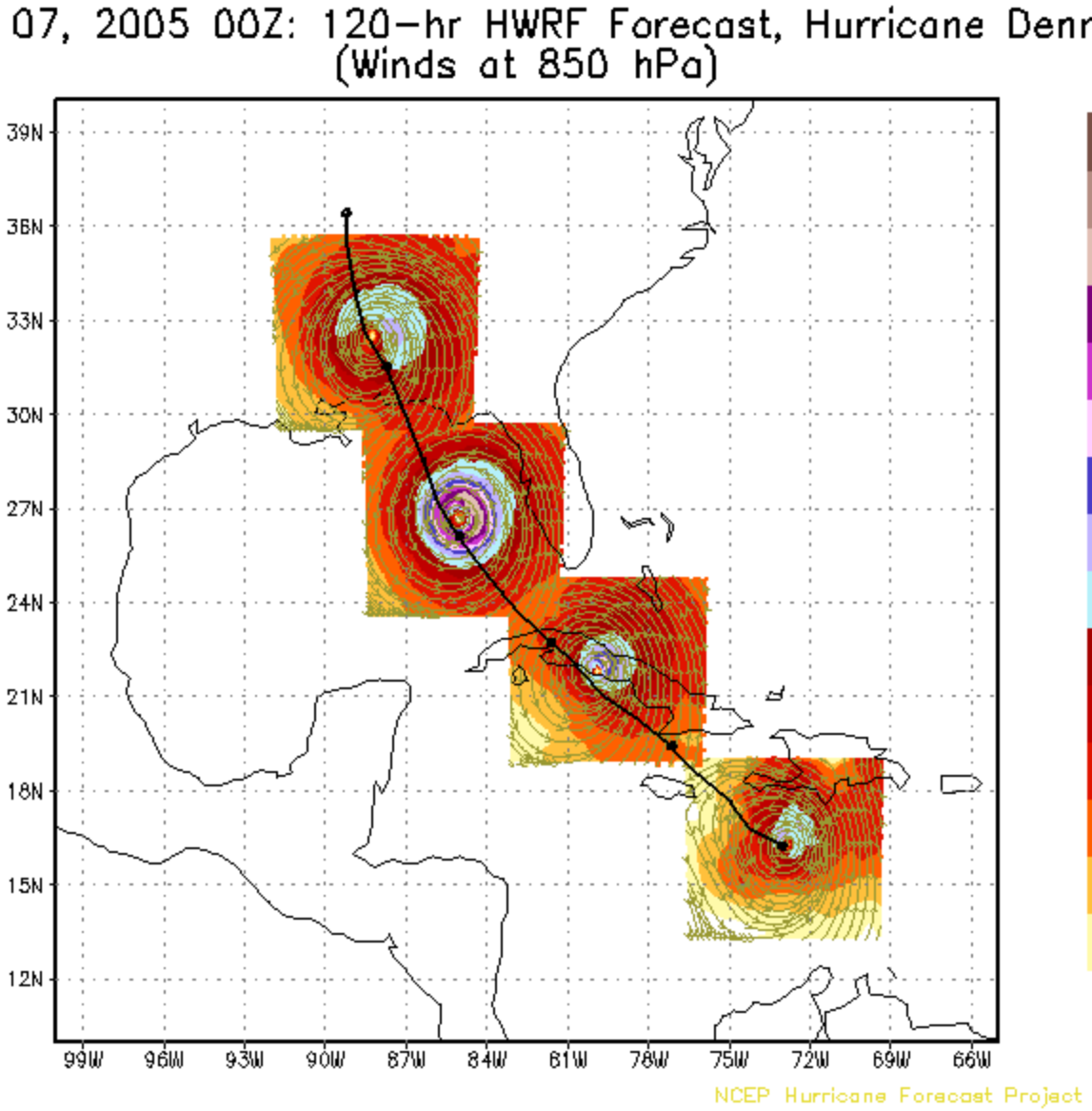
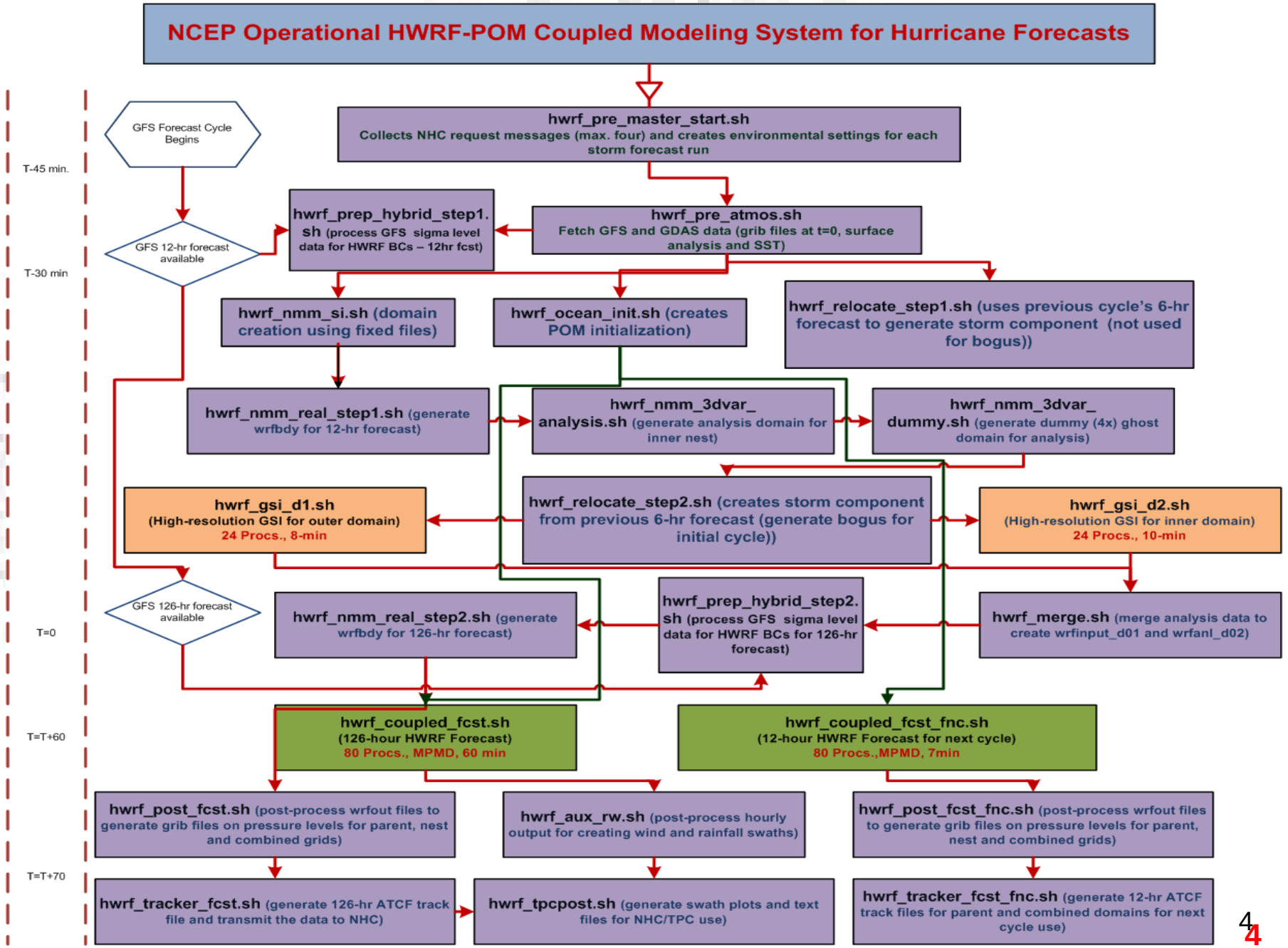
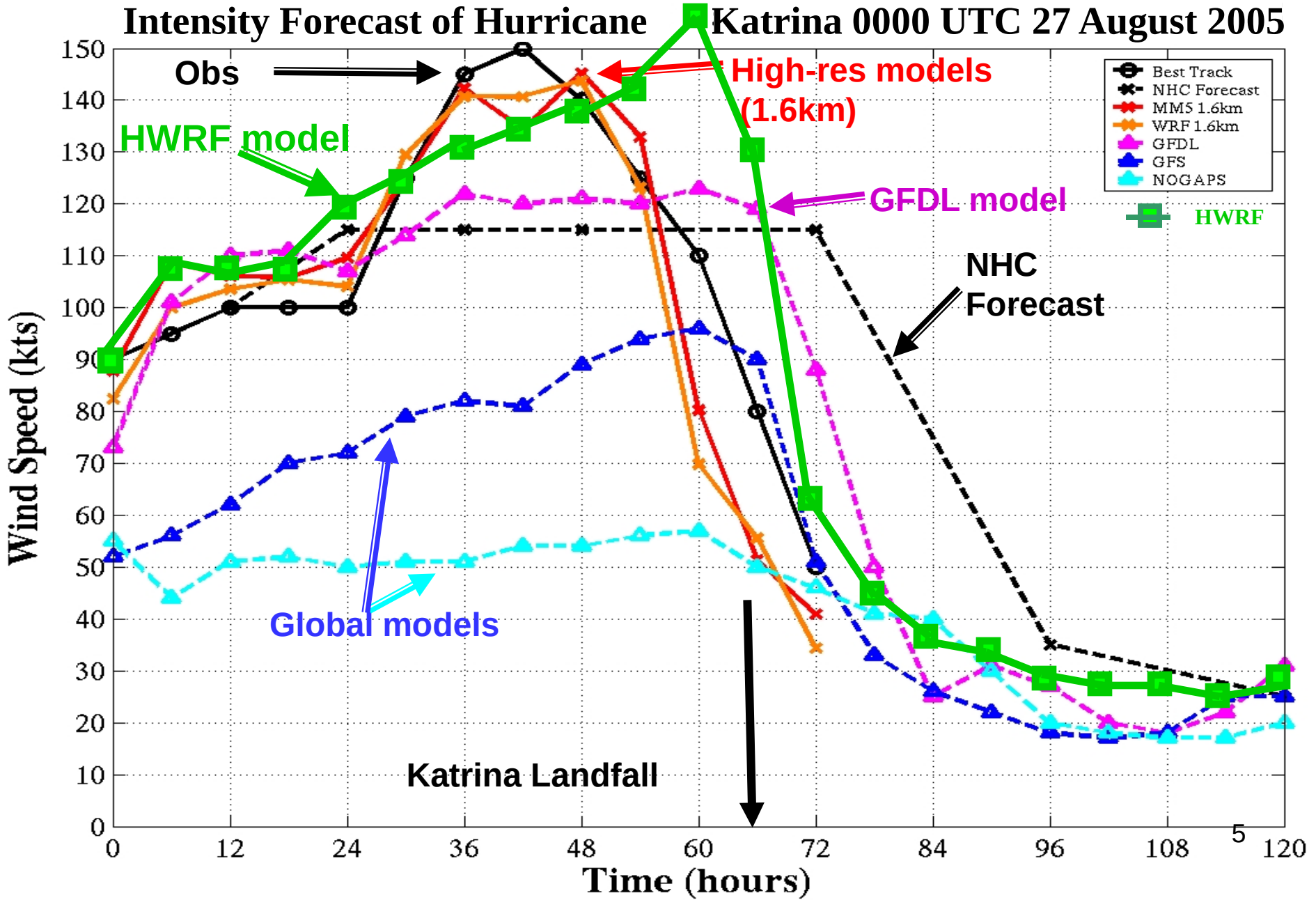
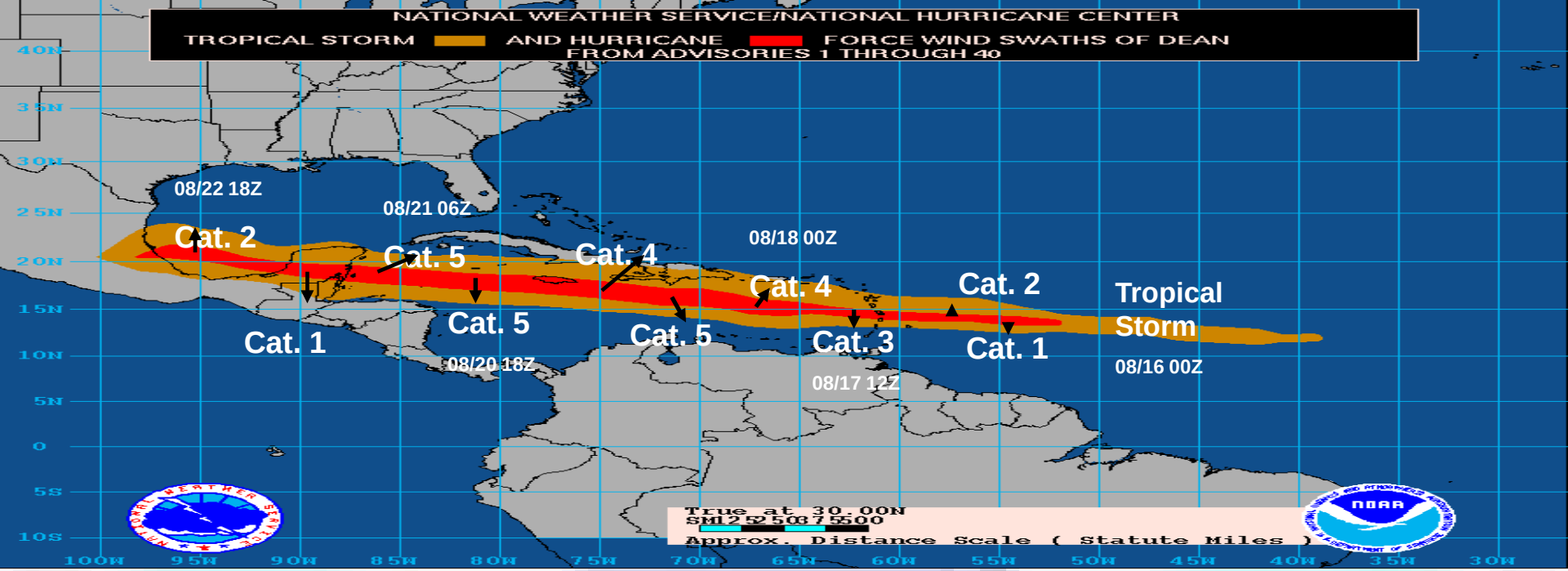


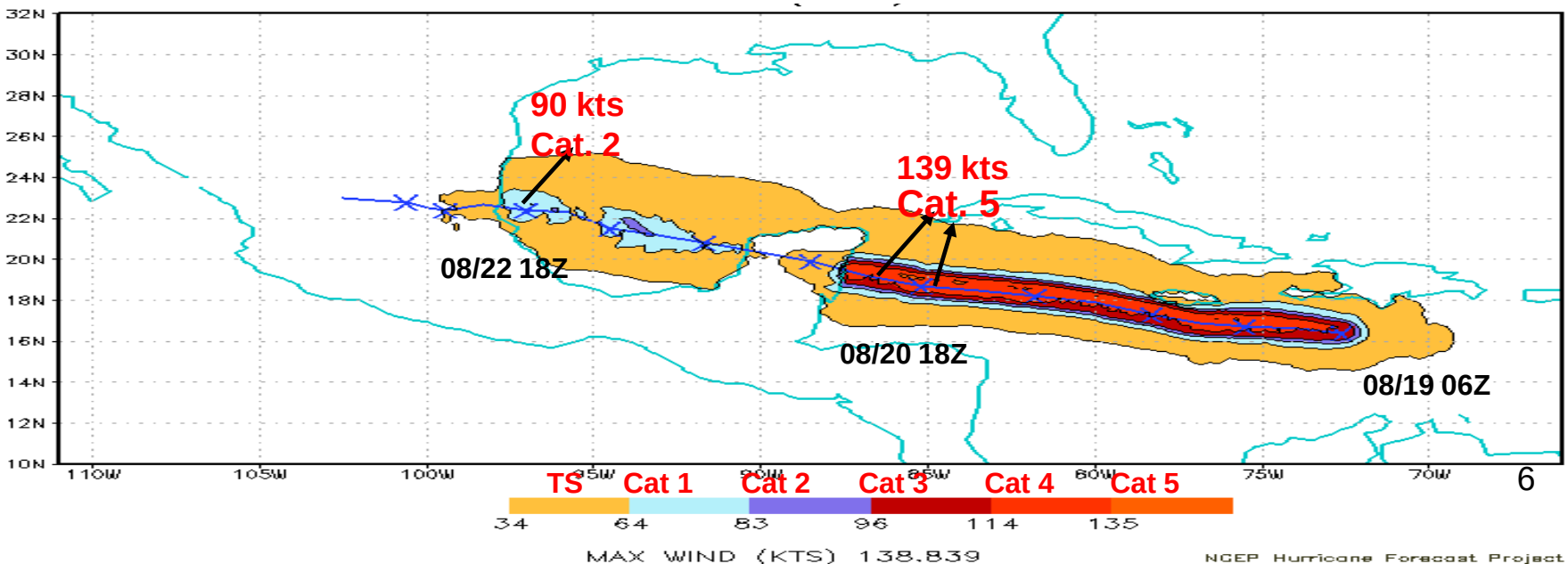

NCEP Operational HWRF-POM Coupled Modeling System for Hurricane Forecasts
GFS Forecast Cycle Begins
hwrf_pre_master_start.sh
Collects NHC request messages (max. four) and creates environmental settings for each storm forecast run
T-45 min.
GFS 12-hr forecast available
hwrf_prep_hybrid_step1.sh (process 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)

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



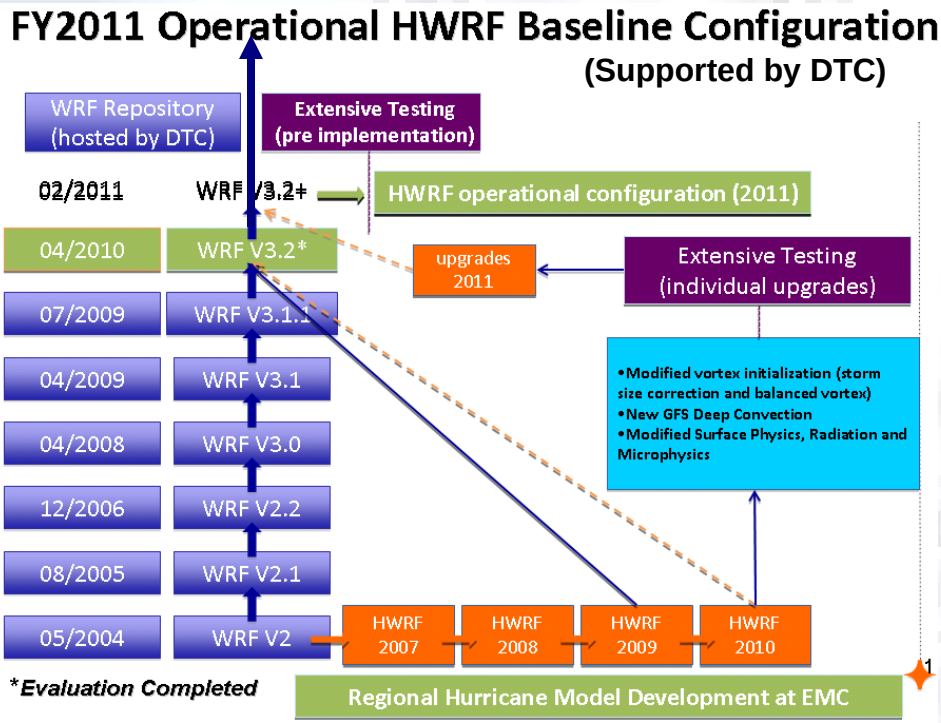


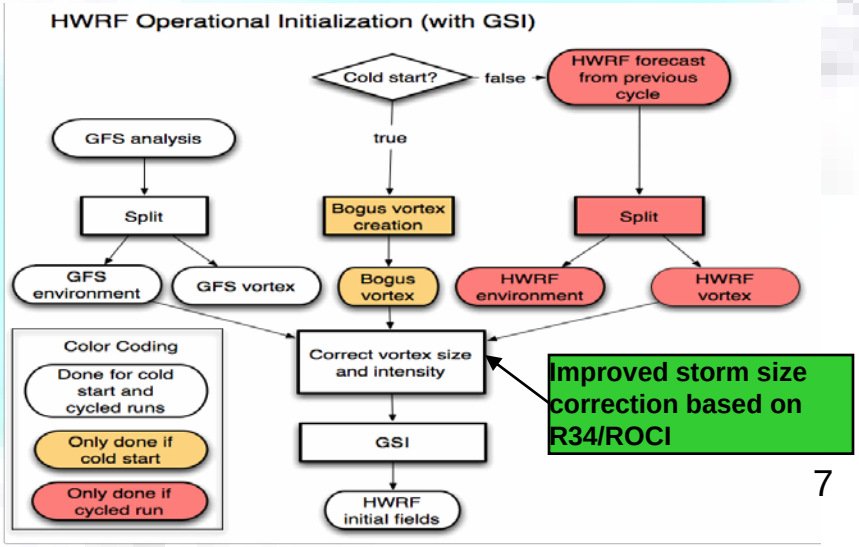
Hurricane Dean 5 day forecasts of maximum winds starting from 8/19/06Z



HWRF Upgrades FY2011 (05/24/2011)

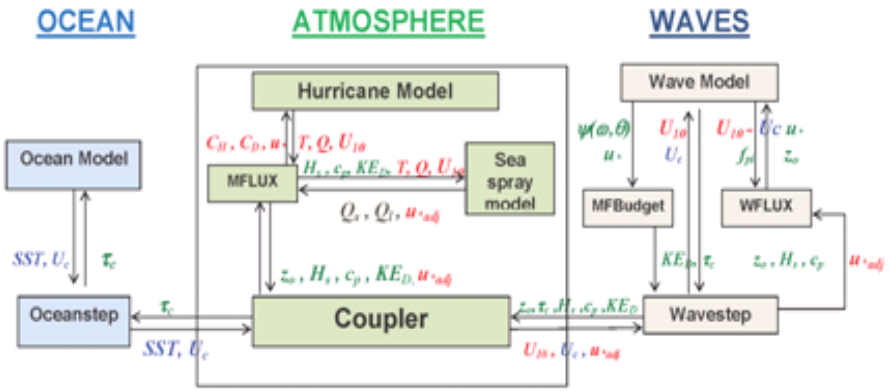
- **Model Upgrades (Atmosphere)**
  - Upgrade dynamical core to NMM community version V3.2 (EMC-DTC Collaboration)
  - New GFS Deep Convection, Improved surface physics, and new FY2011 GSI/GFS IC/BC (EMC- GFDL Collaboration)
- **Vortex initialization upgrades**
  - Improved storm size correction based 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)
- **Ocean Upgrades**
  - Coupling to HYCOM Ocean Model (*Withdrawn from 2011 implementation plans, will be tested in parallel)
- **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)



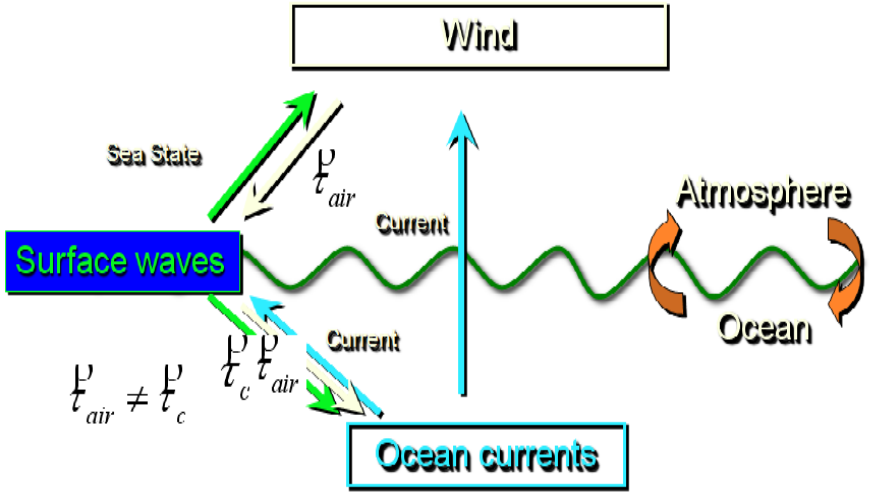


- **HWRF Physics (URI, GFDL, ESRL,HRD)**
  - Surface fluxes, sea spray and wave coupling
  - Physics for high-resolution (convection, micro physics, PBL, LSM)
- **HWRF Diagnostics (HFIP, EMC, NHC, FSU, CIRA, HRD, UMBC/UMD)**
  - Identifying forecast errors from different components of model physics and 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

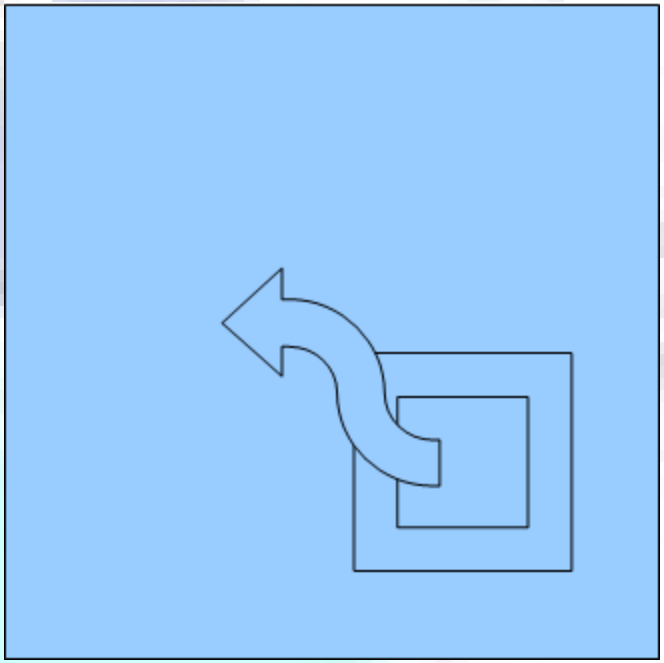


Lessons learned so far…..

- 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, Flooding, Storm Surge** and other related landfall features from these models.

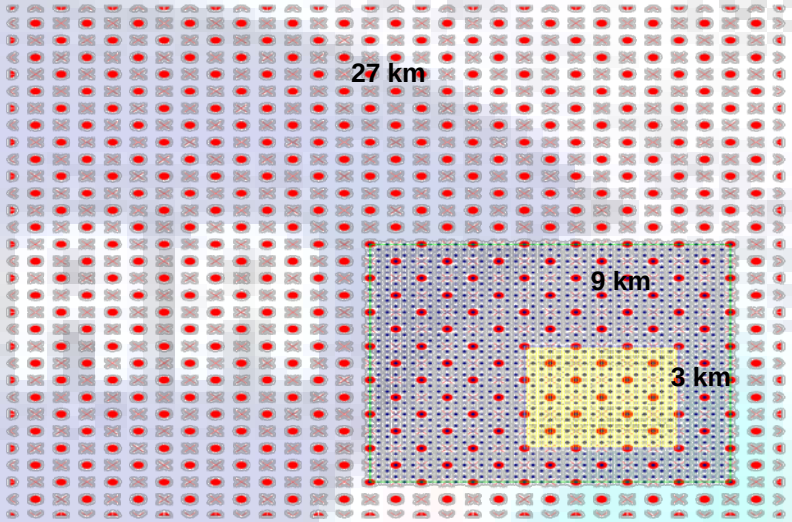
Planned 2012 Operational HWRF System

- Three atmospheric telescoping nested domains:
  - 27km resolution 75x75 degree domain
  - 9km resolution ~10x10 degree storm-following
  - 3km resolution ~5x5 degree storm-following
- Include new nest motion algorithm and other dynamics improvements from HRD's developmental version of HWRF
- Coupled with POM/HyCOM ocean model.
- New coupler and modified HWRF vortex initialization for third nest
- Changes to HWRF physics appropriate for 3 km resolution

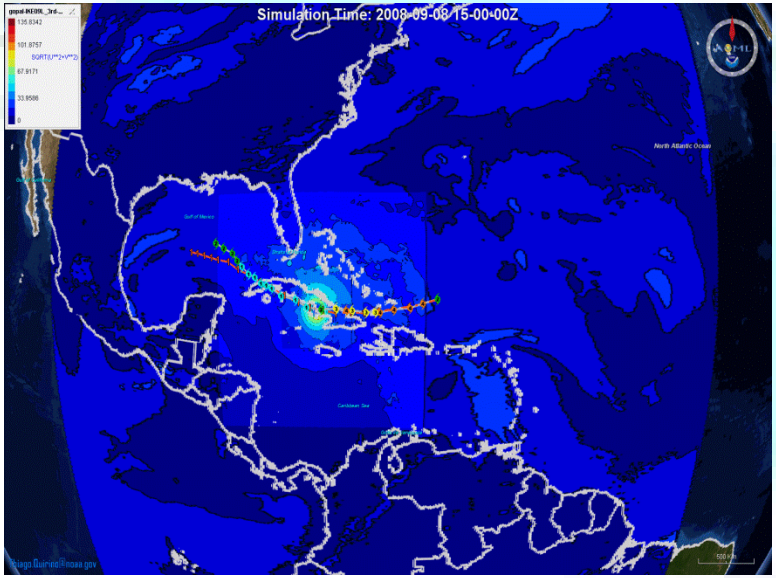


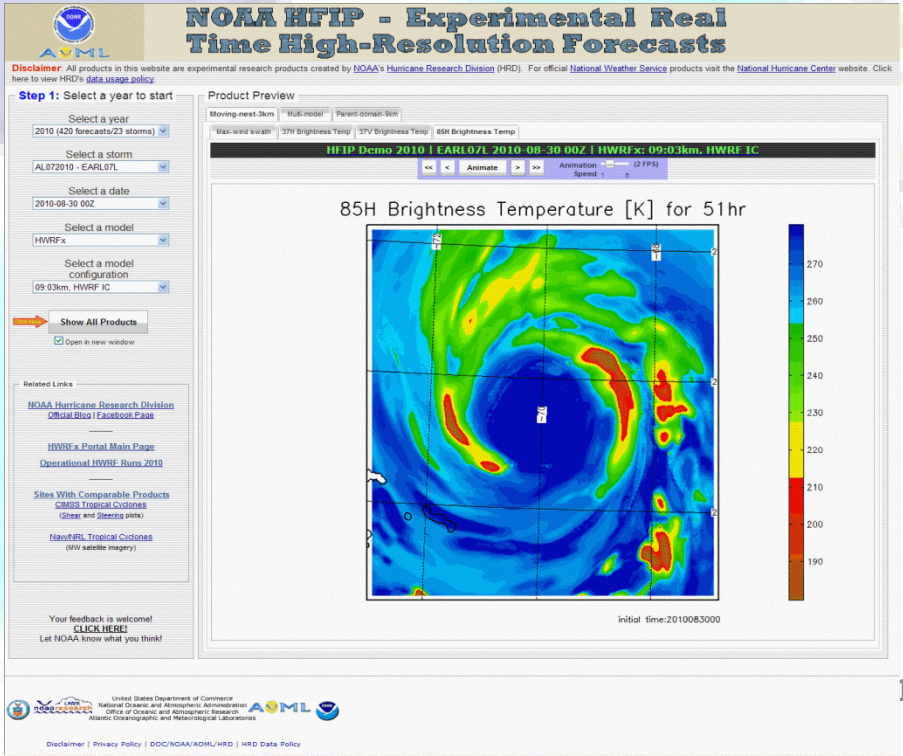
Ongoing Model development & collaborative efforts for FY2012 Season

- **Further advancements to the HWRF modeling system (EMC, HRD, URI)**
- **Code management and community support (EMC, DTC)**
- **Advanced Data Assimilation (EMC, ESRL, OU & HRD)**



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

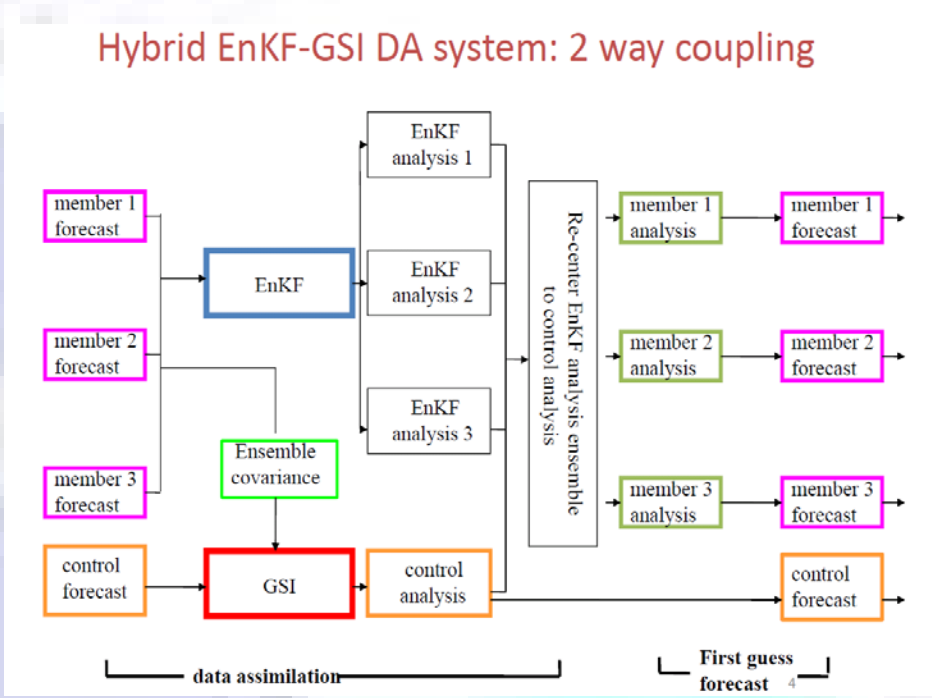




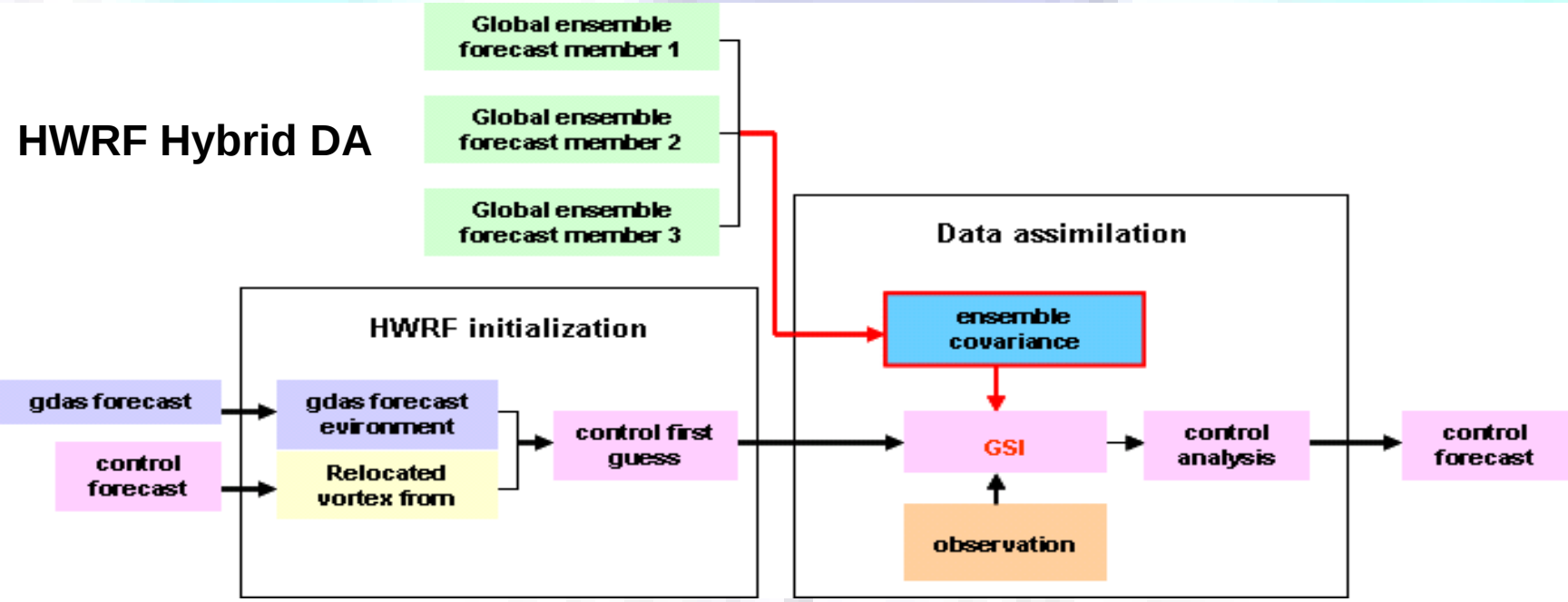
Improved Vortex Initialization and Inner Core Data Assimilation

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)

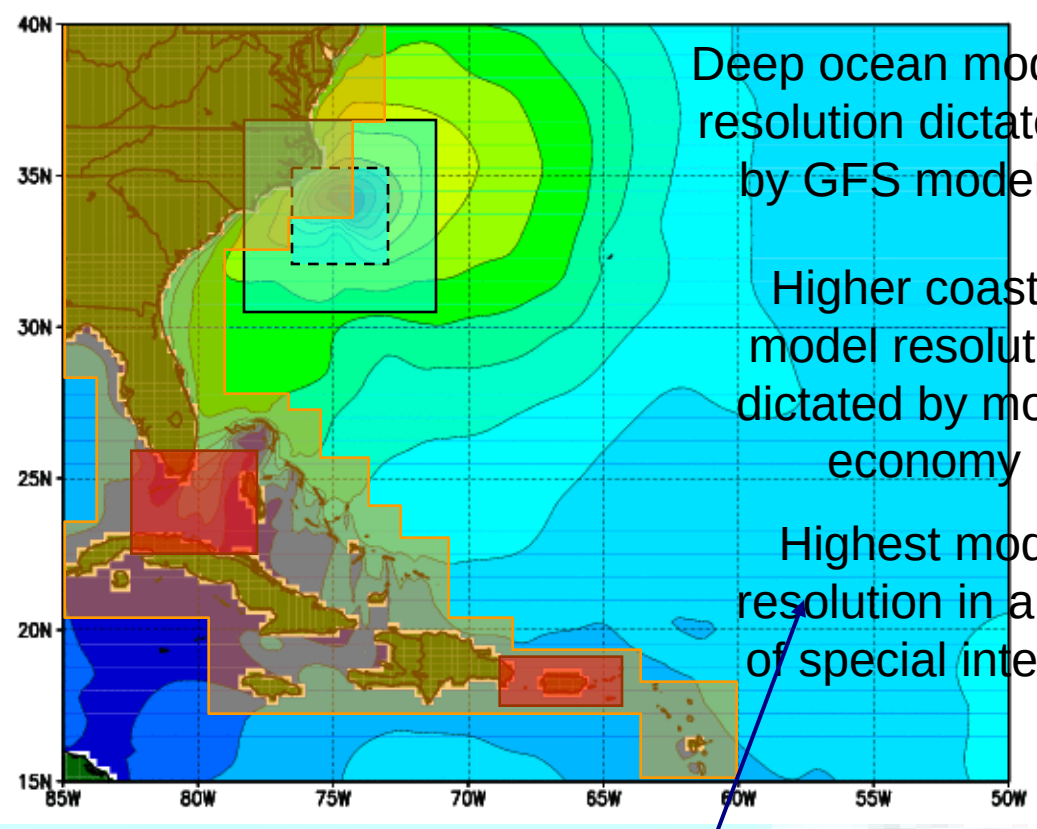


HWRF Hybrid DA

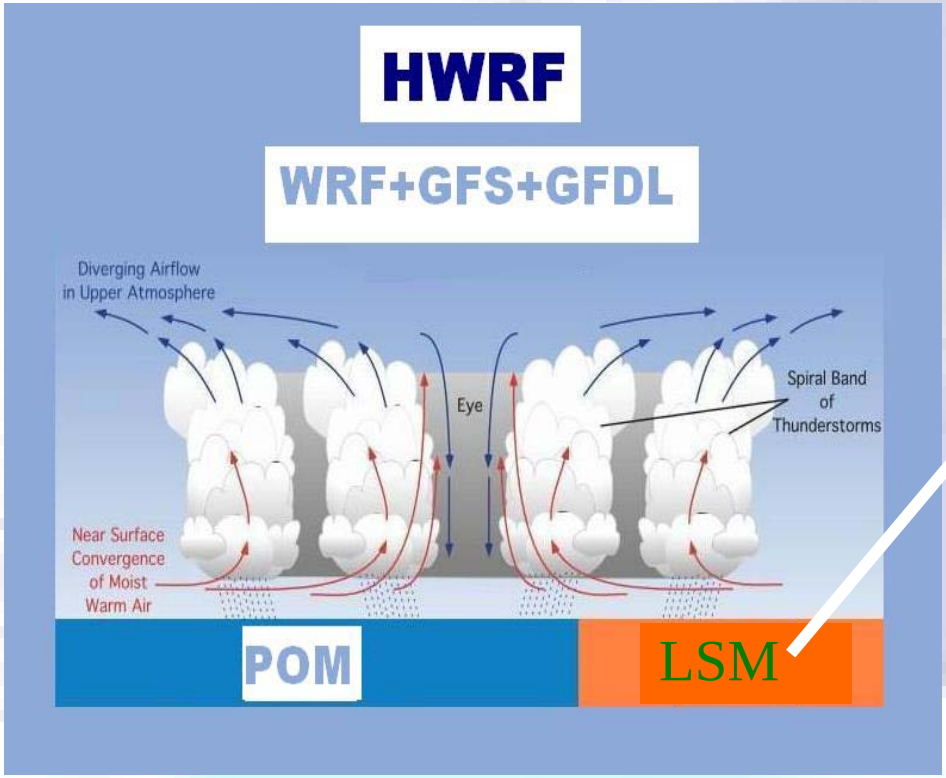


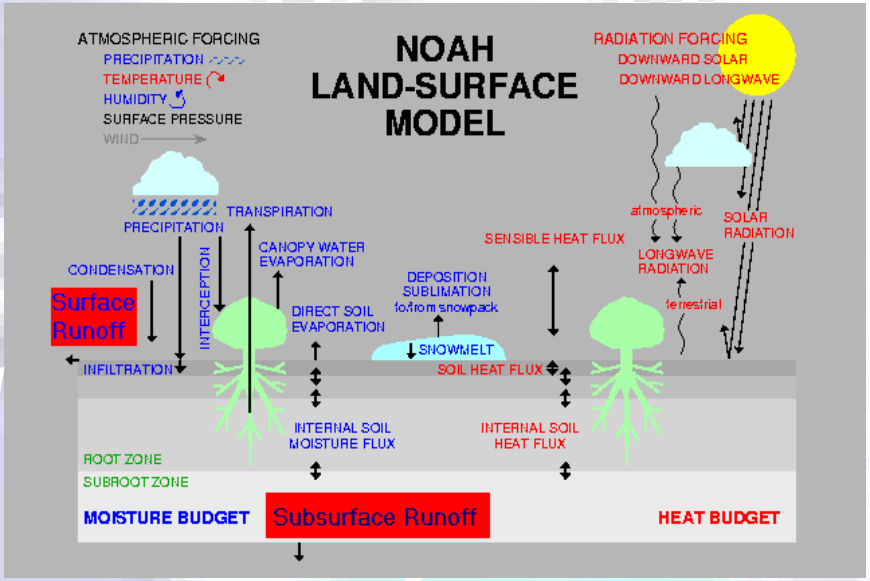
Coupling to Wave-Watch III

- **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**

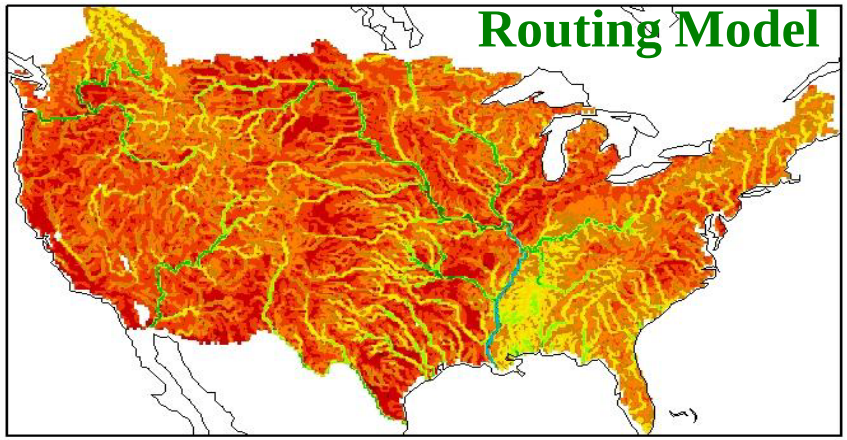


Coupling to Land Surface Model





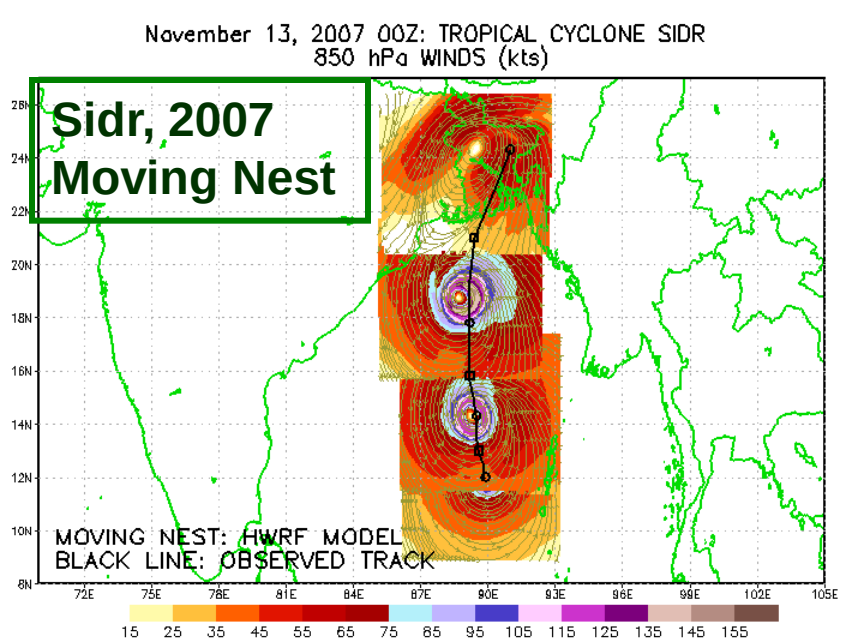
www.emc.ncep.noaa.gov/HWRF

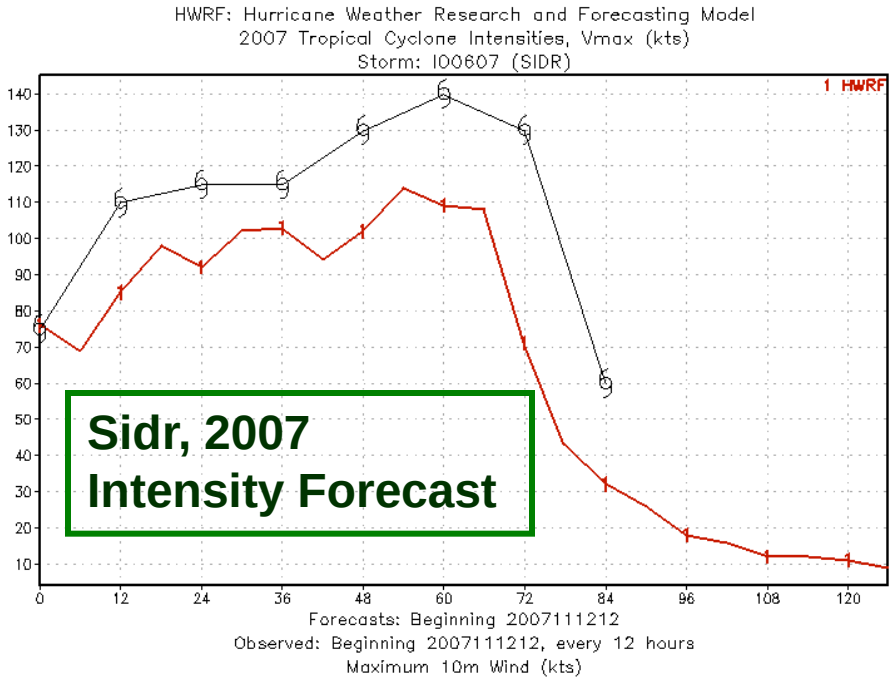


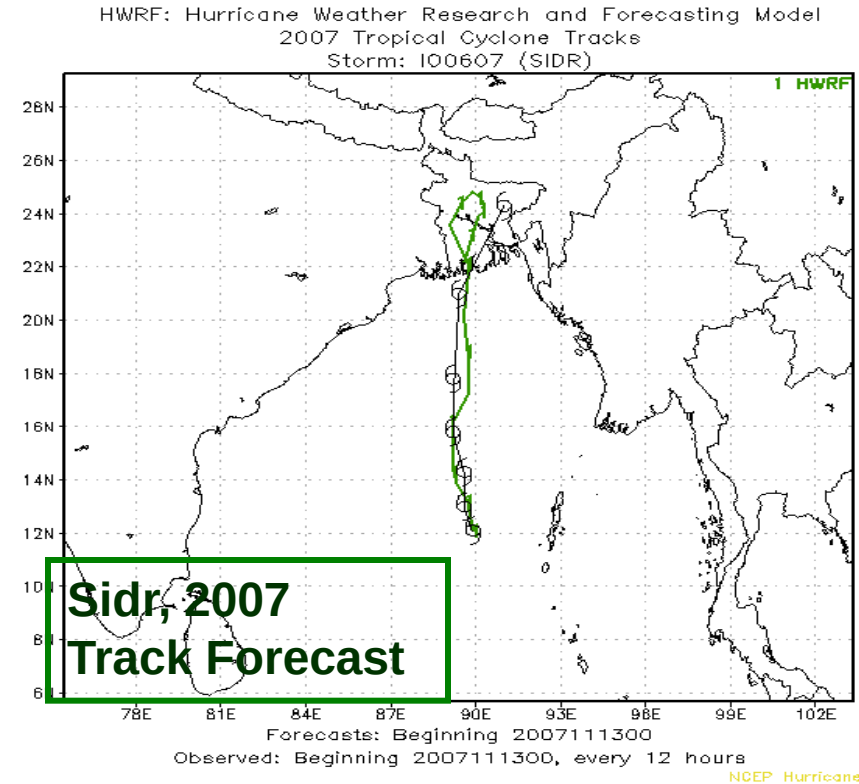
Driving Forcing: Surface runoff and baseflow

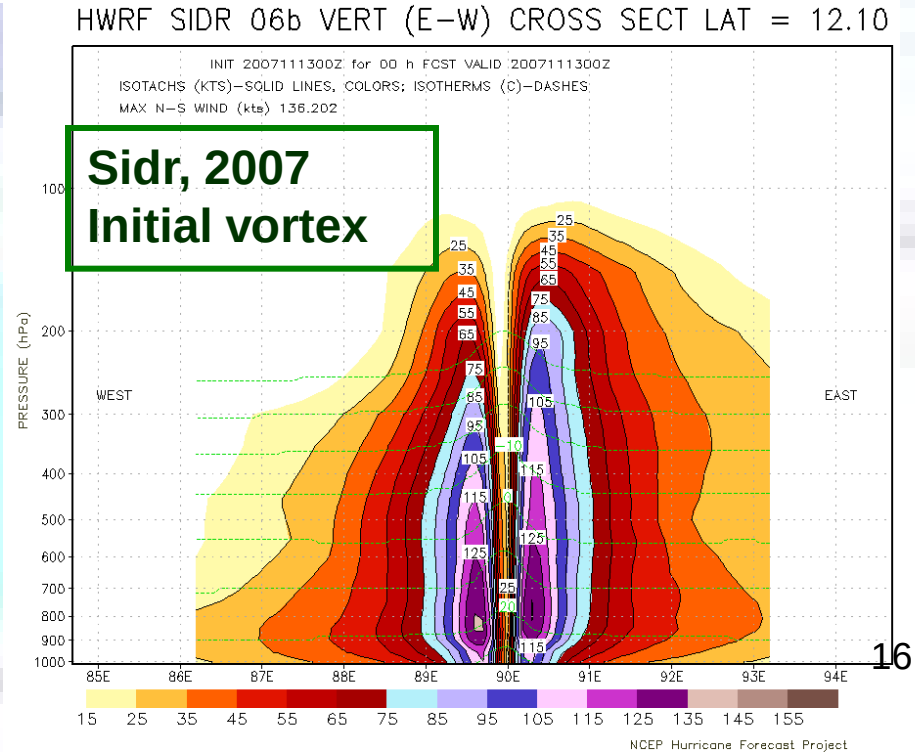
Applications of HWRF Modeling System for Tropical Cyclones of the Indian Ocean and Typhoons of the Western Pacific Ocean

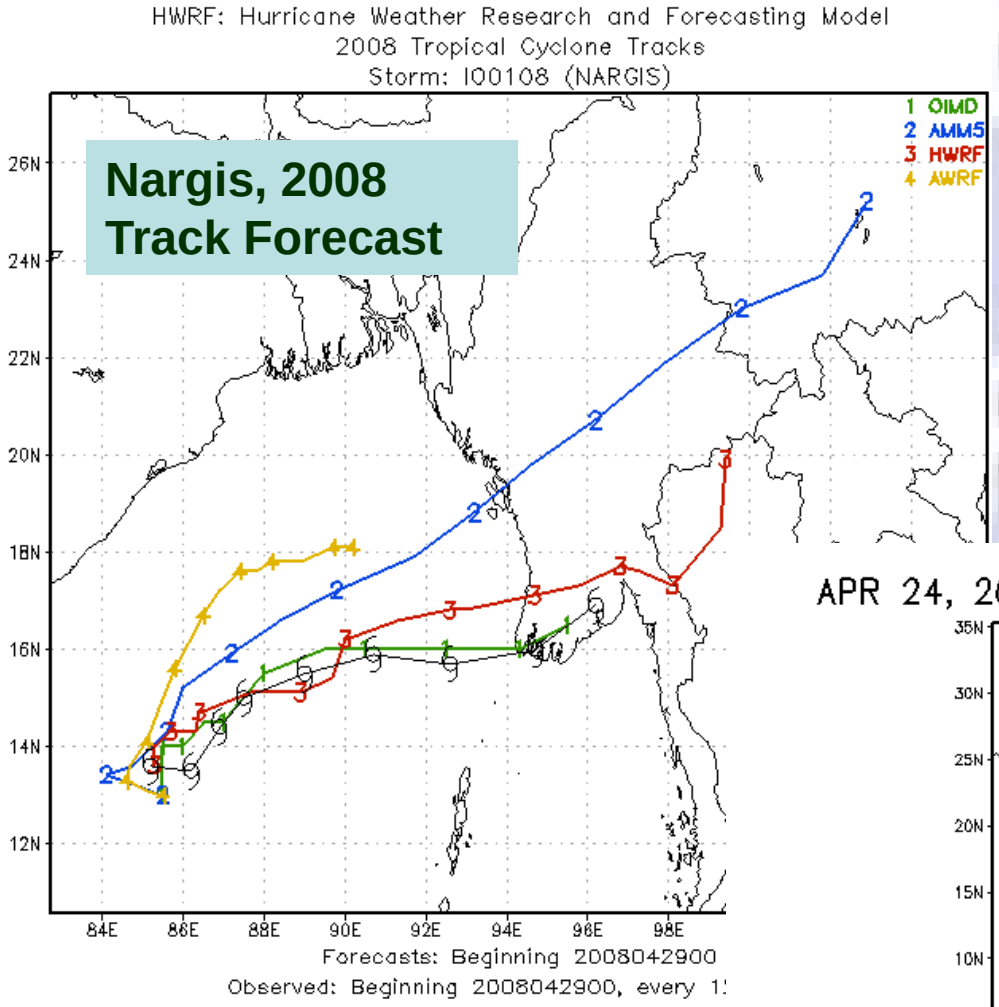
- Unified community HWRF modeling system provides a unique opportunity to expand its applications for tropical cyclone forecasts over the world.
- NOAA has signed an MoU with India (MoES) for improved tropical cyclone predictions over the Indian region.
- We started looking into performance of the HWRF 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
15 25 35 45 55 65 75 85 95 105 115 125 135 145 155

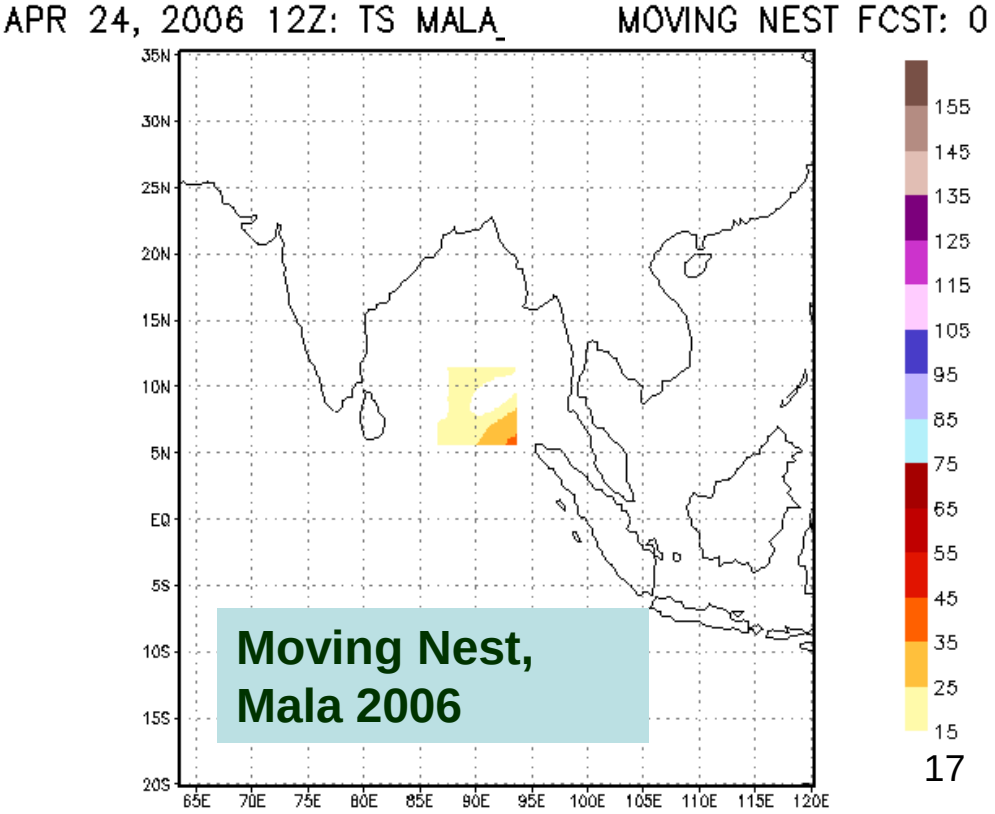

HWRF: Hurricane Weather Research and Forecasting Model
2007 Tropical Cyclone Intensities, Vmax (kts)
Storm: I00607 (SIDR)
1 HWRF
Sidr, 2007
Intensity Forecast
Forecasts: Beginning 2007111212
Observed: Beginning 2007111212, every 12 hours
Maximum 10m Wind (kts)


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


HWRF SIDR 06b VERT (E-W) CROSS SECT LAT = 12.10
INIT 2007111300Z for 00 h FCST VALID 2007111300Z
ISOTACHS (KTS)-SOLID LINES, COLORS; ISOTHERMS (C)-DASHES
MAX N-S WIND (kts) 136.202
Sidr, 2007
Initial vortex
PRESSURE (hPa)
WEST
EAST
15 25 35 45 55 65 75 85 95 105 115 125 135 145 155
NCEP Hurricane Forecast Project



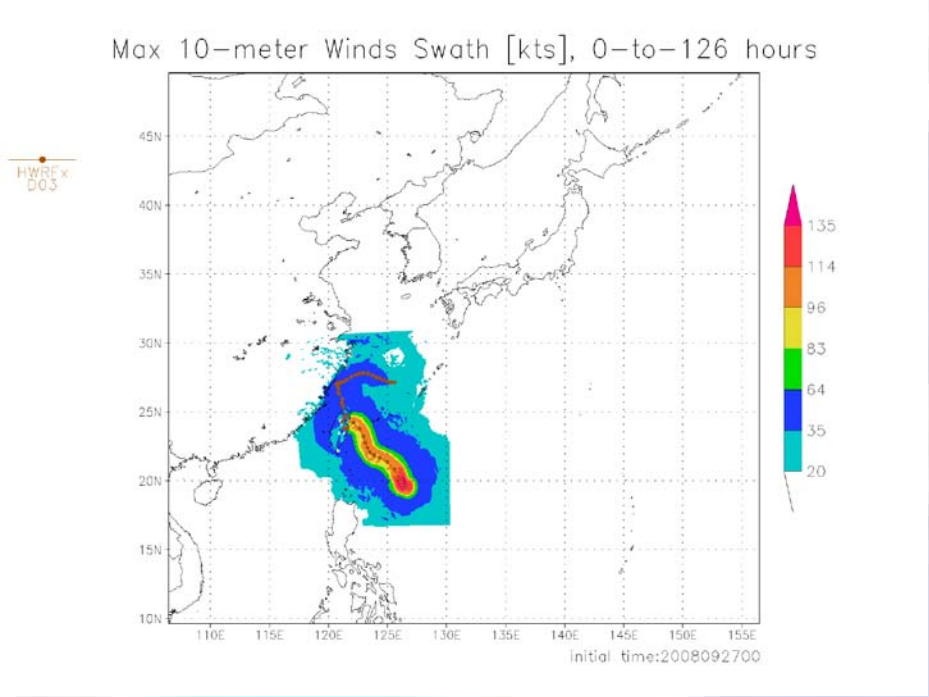
Nargis, 2008
Track Forecast

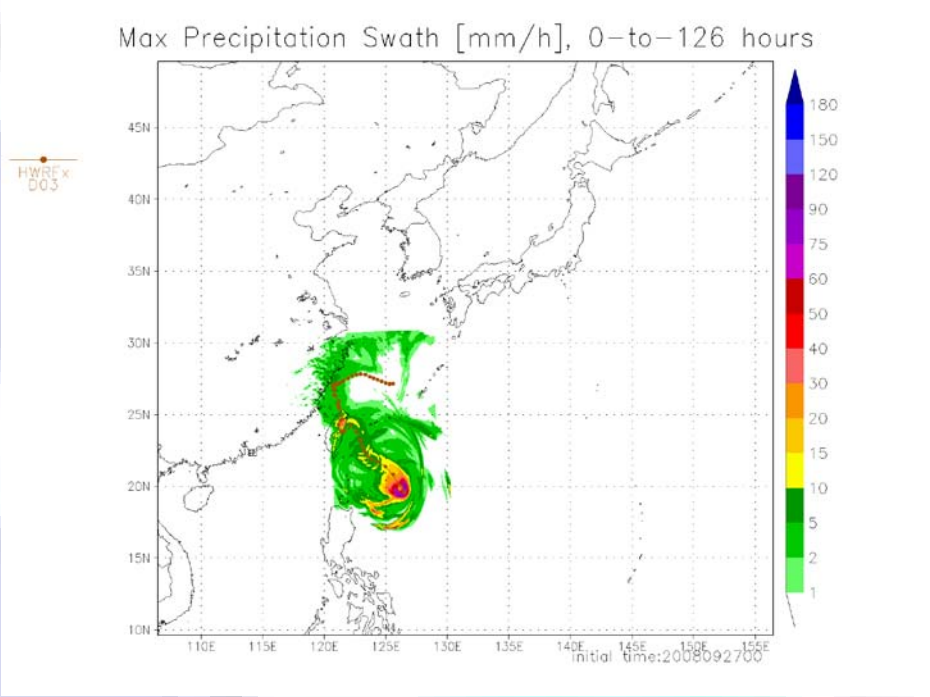


Moving Nest,
Mala 2006

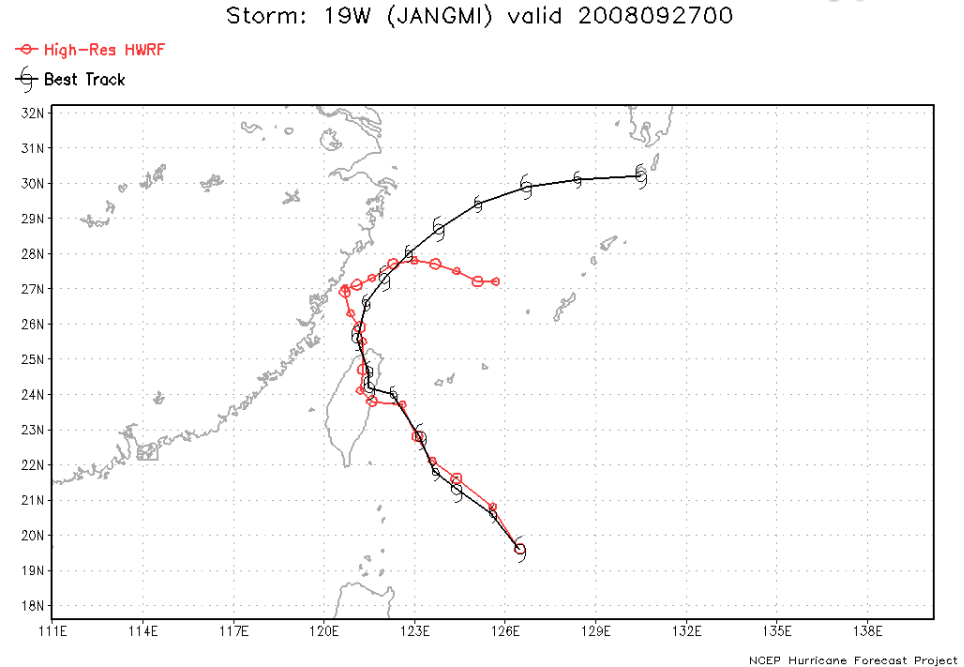
GrADS: COLA/IGES

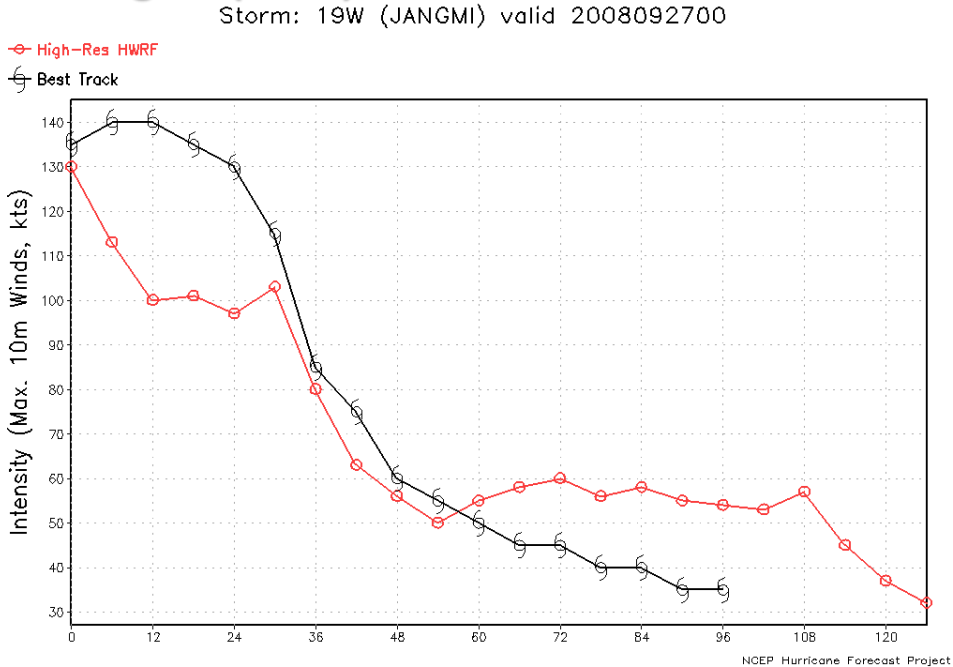
2008-06-01-00:38



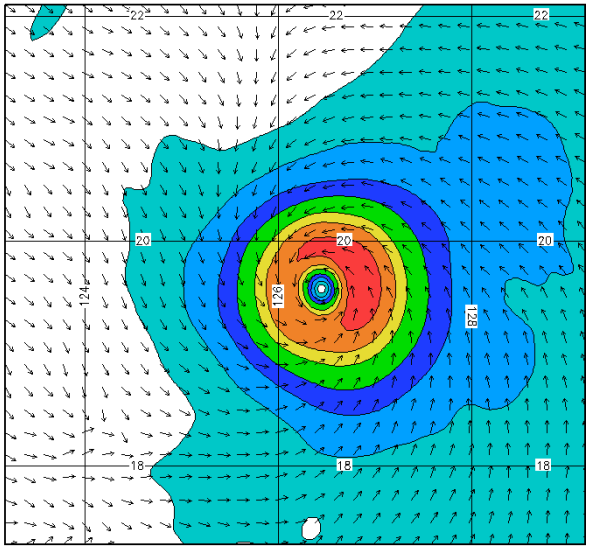


HWRF Forecasts for Typhoon Jangmi (19W), IC 2008092700



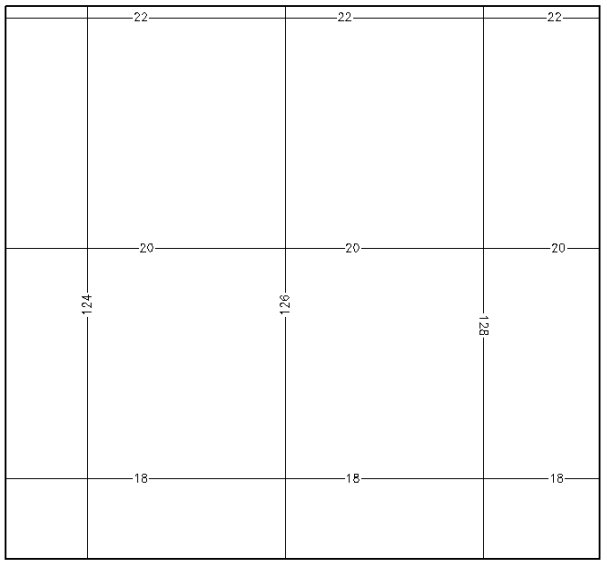


10M wind-speed [kts] 0hr



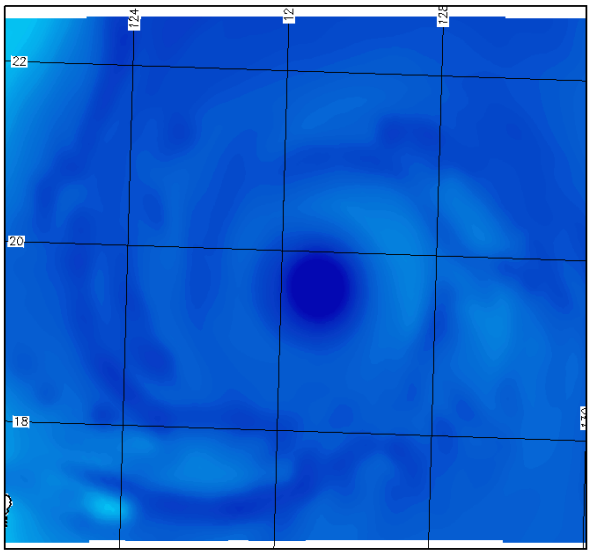
initial time:2008092700

Precipitation Rate [mm/hr] for 0hr



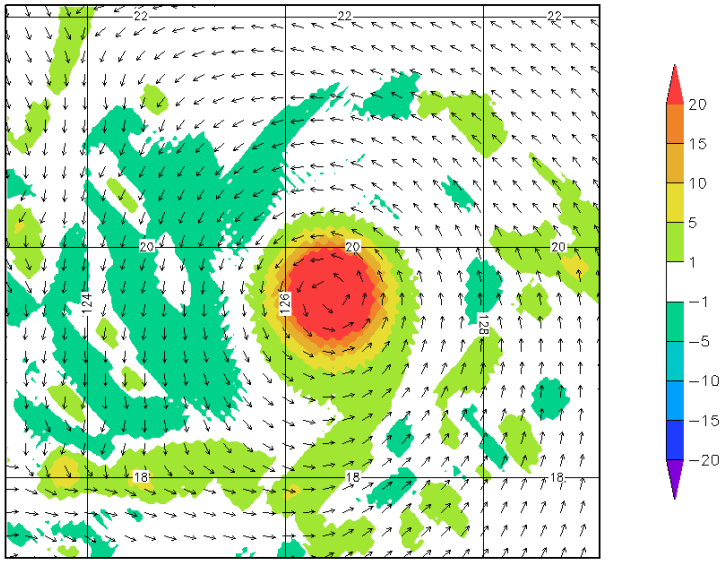
initial time:2008092700

85H Brightness Temperature [K] for 0hr



initial time:2008092700

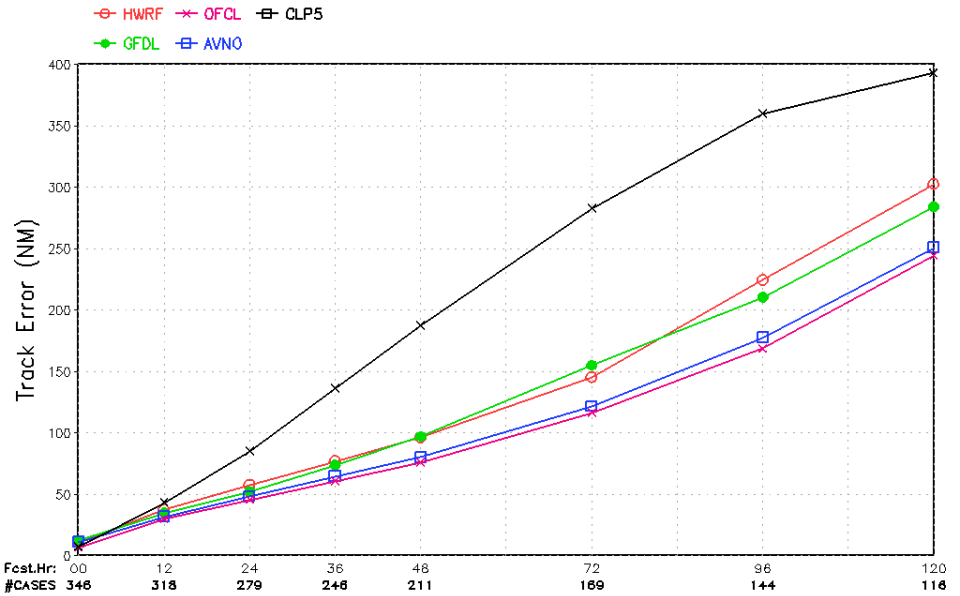
850mb vorticity [x 10^-4 S^-1] for 0hr



initial time:2008092700

Average Track Errors (NM)

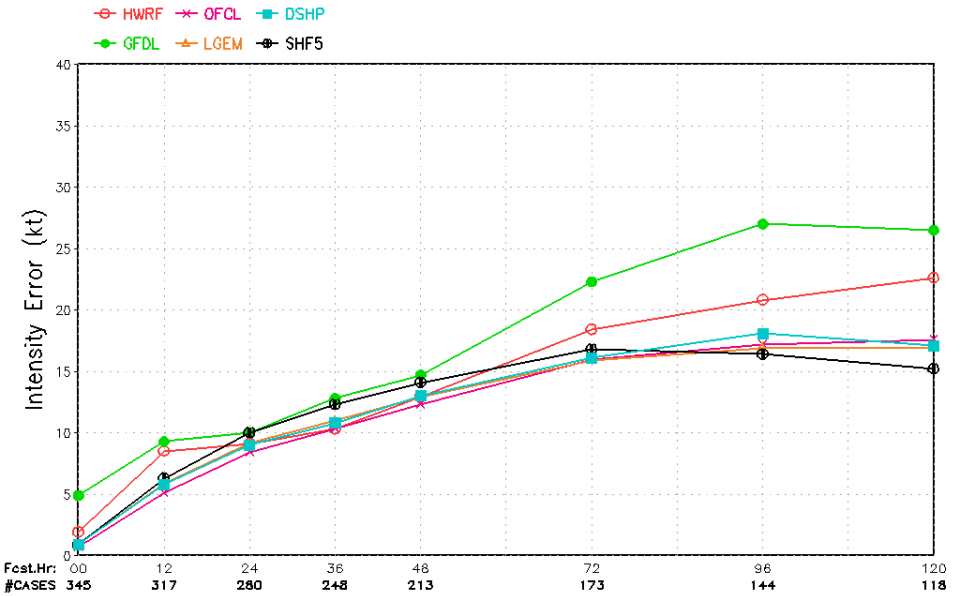
Operational Statistics Plots – ALL 2011 ATLANTIC through PHILIPPE17L



NCEP Hurricane Forecast Project

Average Intensity Errors (kt)

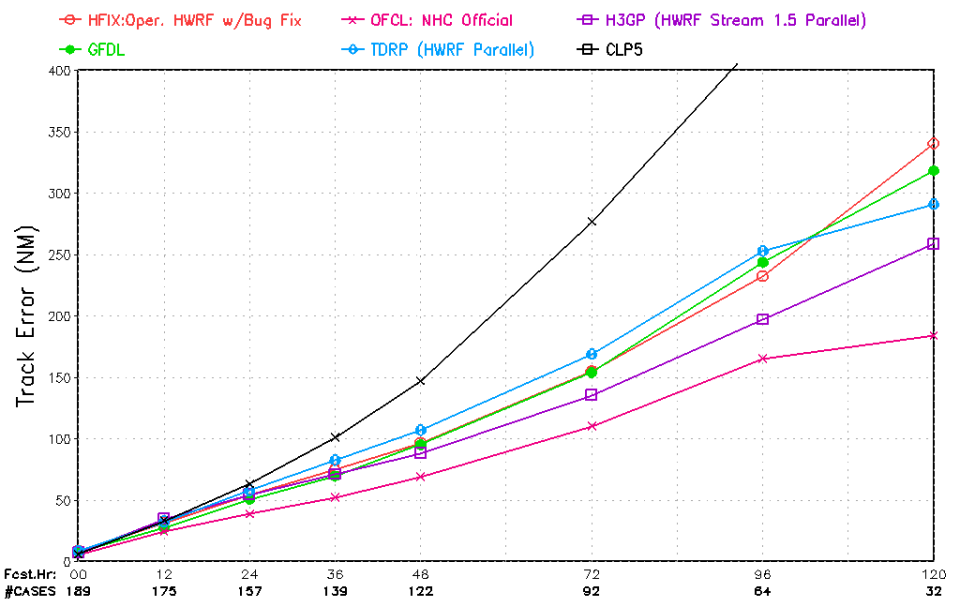
Operational Statistics Plots – ALL 2011 ATLANTIC through PHILIPPE17L



NCEP Hurricane Forecast Project

Average Track Errors (NM)

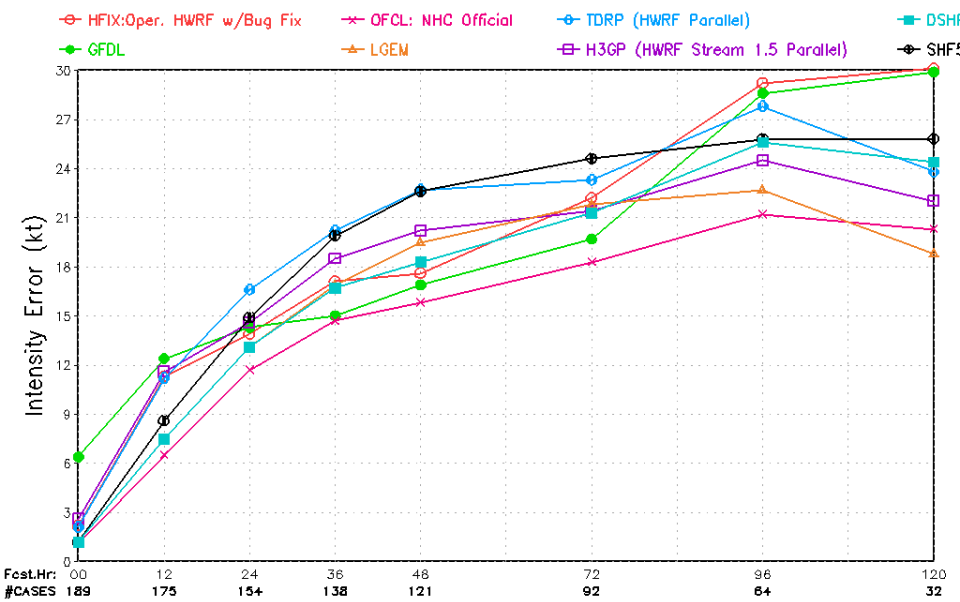
Parallel Stats – All EastPac 2011 HWRF Parallels



NCEP Hurricane Forecast Project

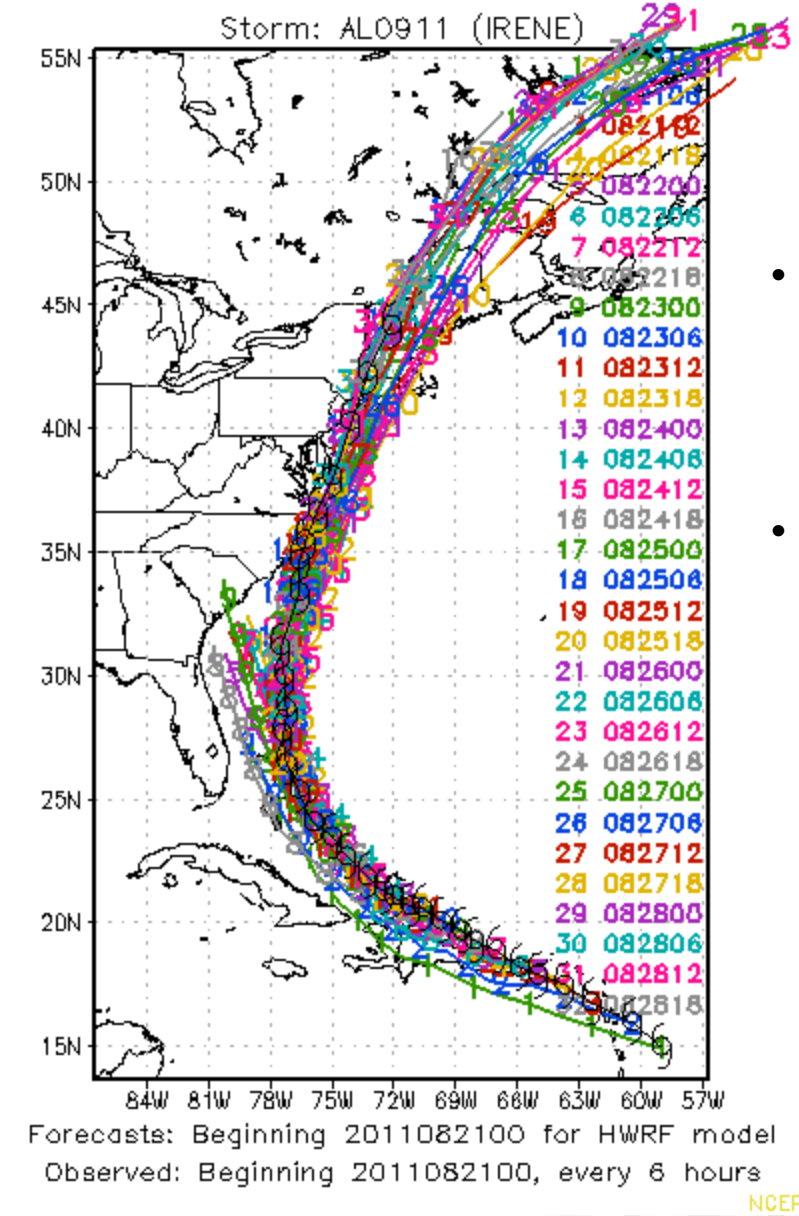
Average Intensity Errors (kt)

Parallel Stats – All EastPac 2011 HWRF Parallels

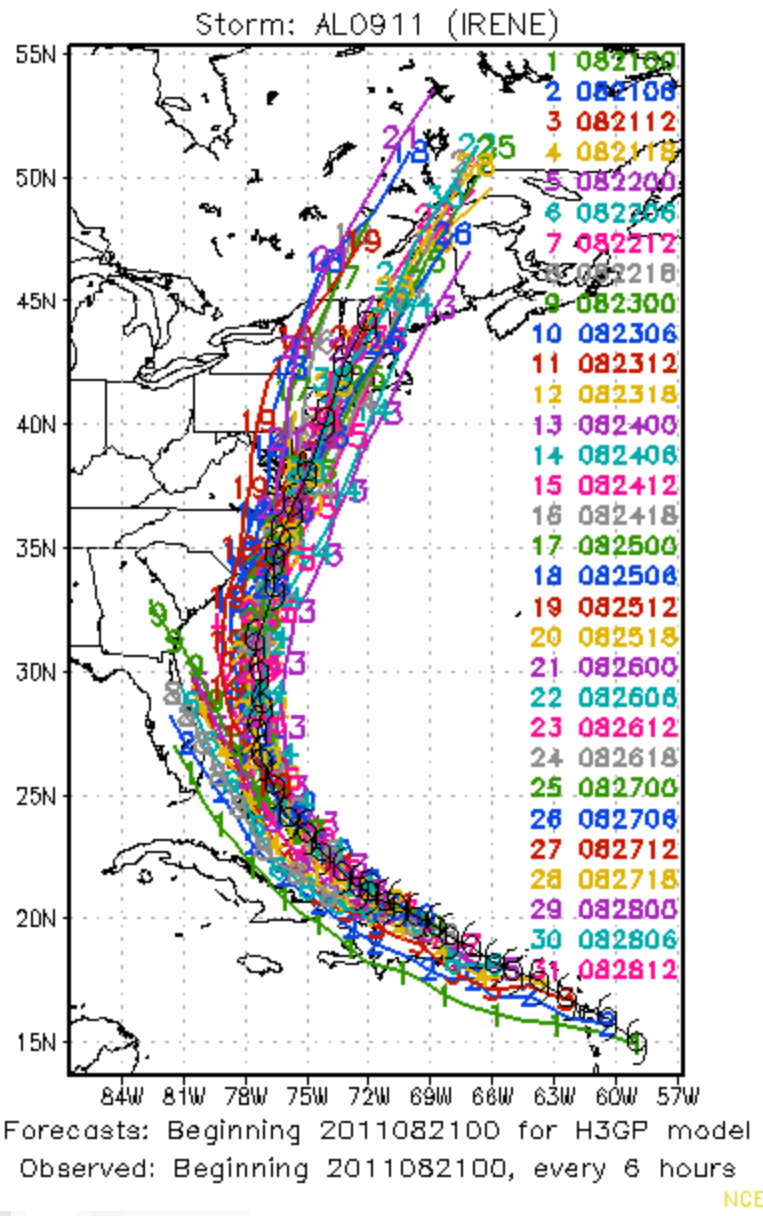


NCEP Hurricane Forecast Project

Track Forecasts for Hurricane Irene



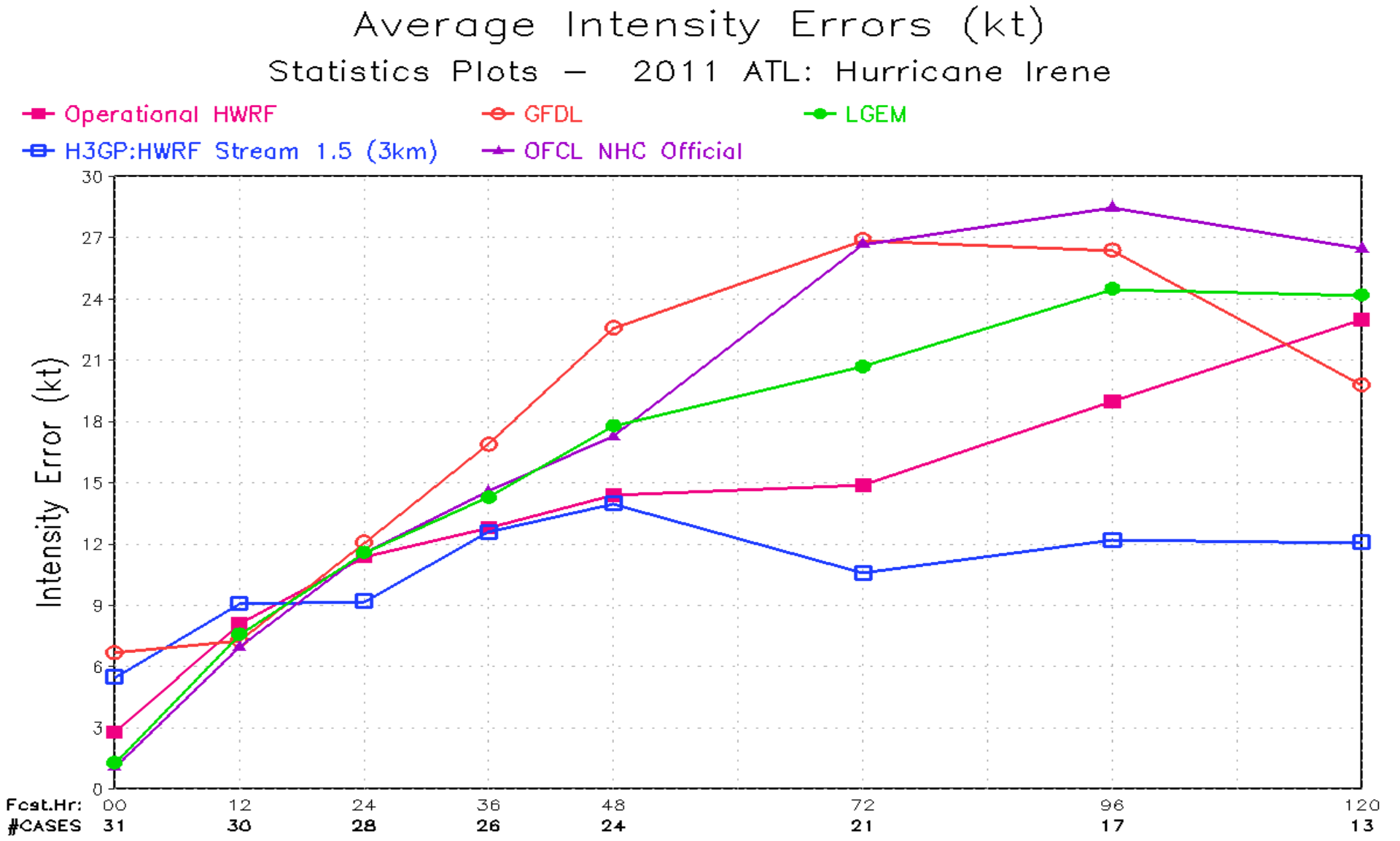
- **More consistent track forecasts from operational HWRF**
- **Very little "west" bias compared to H3GP forecasts.**



Operational HWRF

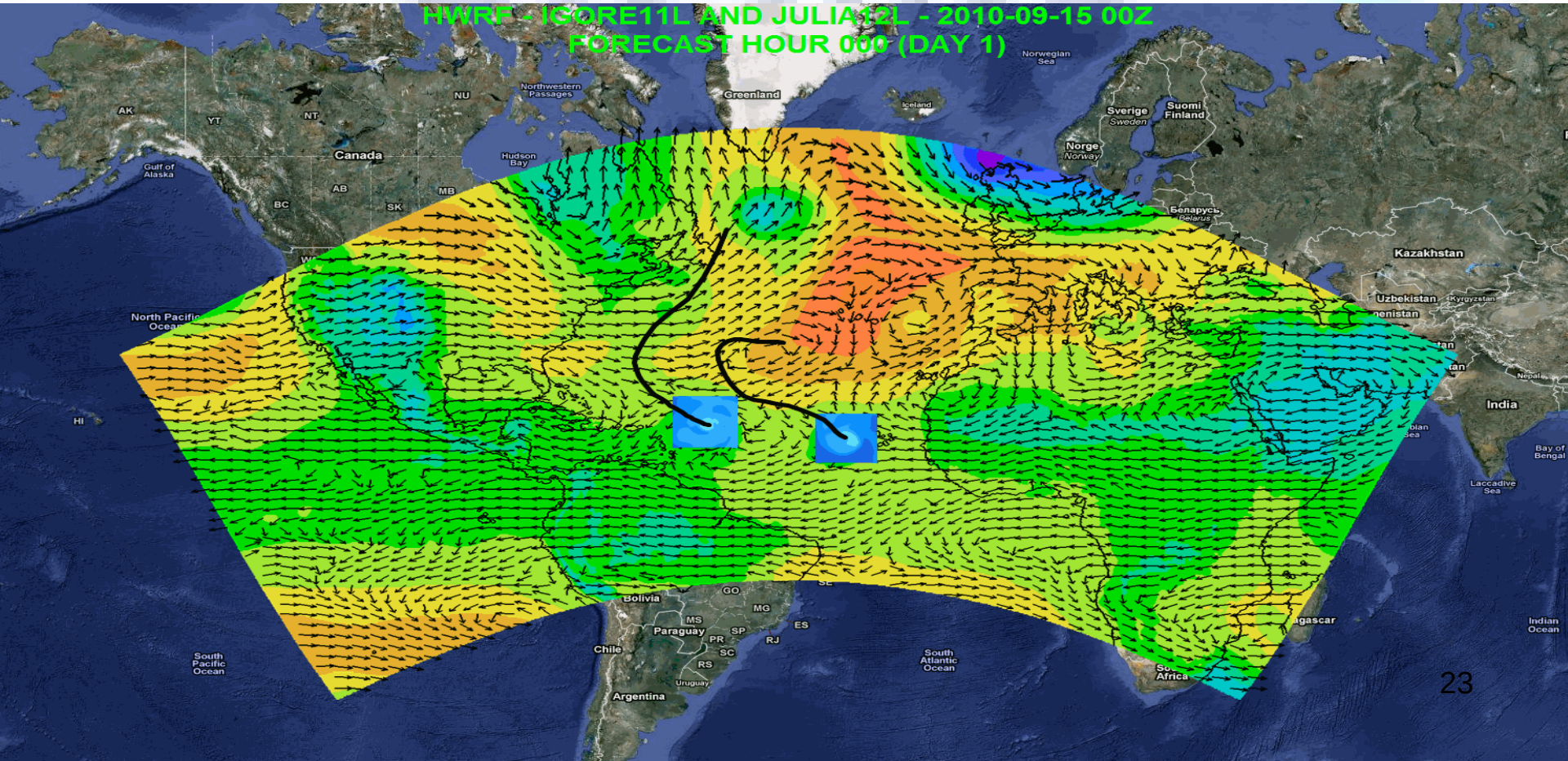
HFIP Stream 1.5 HWRF (H3GP)

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



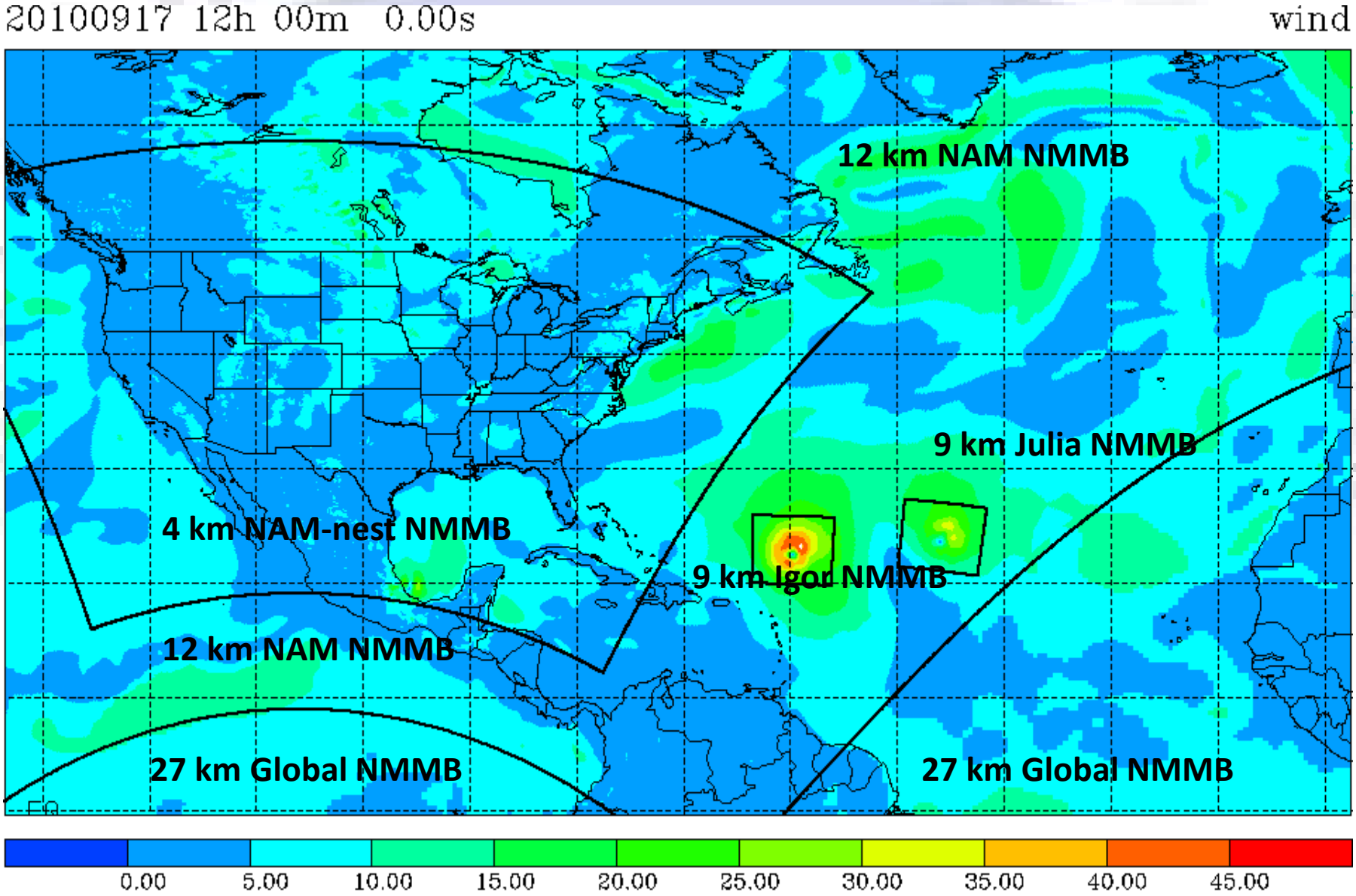
HWRF Domain With Multiple Moving Nests

- 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]



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.

We are looking for partners from operational and academic communities to tackle these scientific challenges.

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?

Acknowledgements:

HWRF team at EMC

EMC and HFIP Management

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