Introduction to Hurricane WRF

Mrinal Biswas

Developmental Testbed Center (DTC)

National Center for Atmospheric Research

Boulder

What is the Hurricane WRF?

- A US NWS operational model to provide numerical forecast guidance of track, intensity, and structure to the National Hurricane Center (NHC) for the North Atlantic and Eastern North Pacific basins
- The Weather Research and Forecasting for Hurricanes (HWRF) was designed and developed by NCEP/EMC utilizing the community WRF software infrastructure to rapidly advance hurricane forecast skills for operational needs.
- HWRF became operational in the year 2007 and has been constantly improved to increase the forecast skill for track, intensity and structure of Atlantic and Eastern Pacific hurricanes.
- Starting in 2011, the operational coupled HWRF-POM modeling system became a community tropical cyclone modeling system supported through Developmental Testbed Center (DTC). The use of same code by research and operations was accomplished through dedicated subversion based code management and community support, facilitating accelerated Operations to Research (O2R) and Research to Operations (R2O).

Overview of the HWRF system

- Regional-scale, moving nest, Ocean-Atmosphere coupled modeling system specially designed to advance hurricane forecasts.
- Non-hydrostatic system of equations within the WRF modeling infrastructure and framework
  - rotated latitude-longitude, Arakawa E-grid
  - vertical pressure hybrid (sigma-P) coordinate
- NMM dynamics modified for inclusion of
  - movable nested grids, coupling to ocean model (MPIPOM-TC/HYCOM)
- HWRF vortex initialization includes
  - vortex relocation, correction to winds, MSLP, temperature and moisture in the hurricane region
  - adjustment to actual storm size and intensity
  - assimilation of conventional observations and clear-sky radiance datasets using community GSI (one-way hybrid EnKF-3DVAR data assimilation since 2013)
- Physical parameterization schemes designed and tested for tropical cyclones
- Ocean coupled modeling system using an advanced NCEP coupler

What's new in 2015 HWRF?

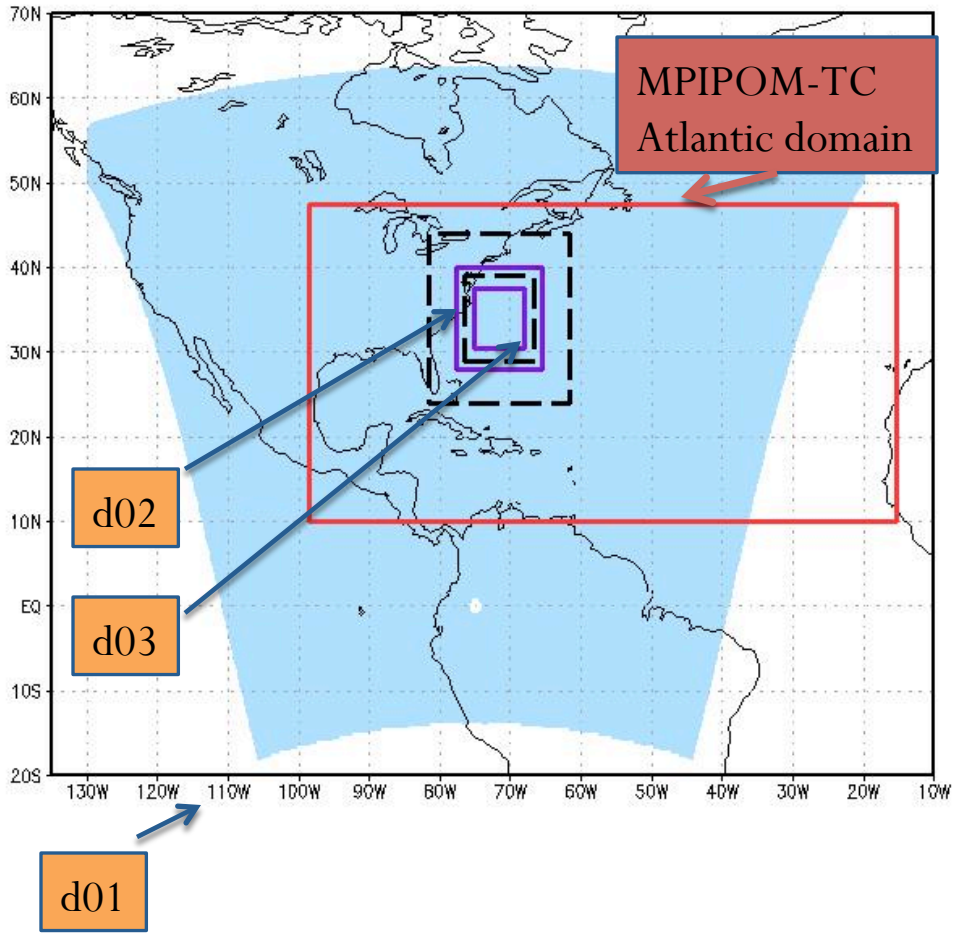
- Increase the horizontal resolution of the atmospheric model from **27/9/3** km to **18/6/2** km.

- Upgrade Data Assimilation System with hybrid 40-member HWRF-based high-resolution ensembles and GSI system. This is not supported through the public release.

- Upgrade Micro-physics process (**Ferrier-Aligo**); replace GFDL radiation with **RRTMG scheme including sub-grid scale partial cloudiness**; Upgrade surface physics and PBL, replace current GFDL slab model to more advanced **NOAH LSM**.

- Expand HWRF capabilities to all global (including WP/SH/IO) basins.

HWRF 2015 grid configuration



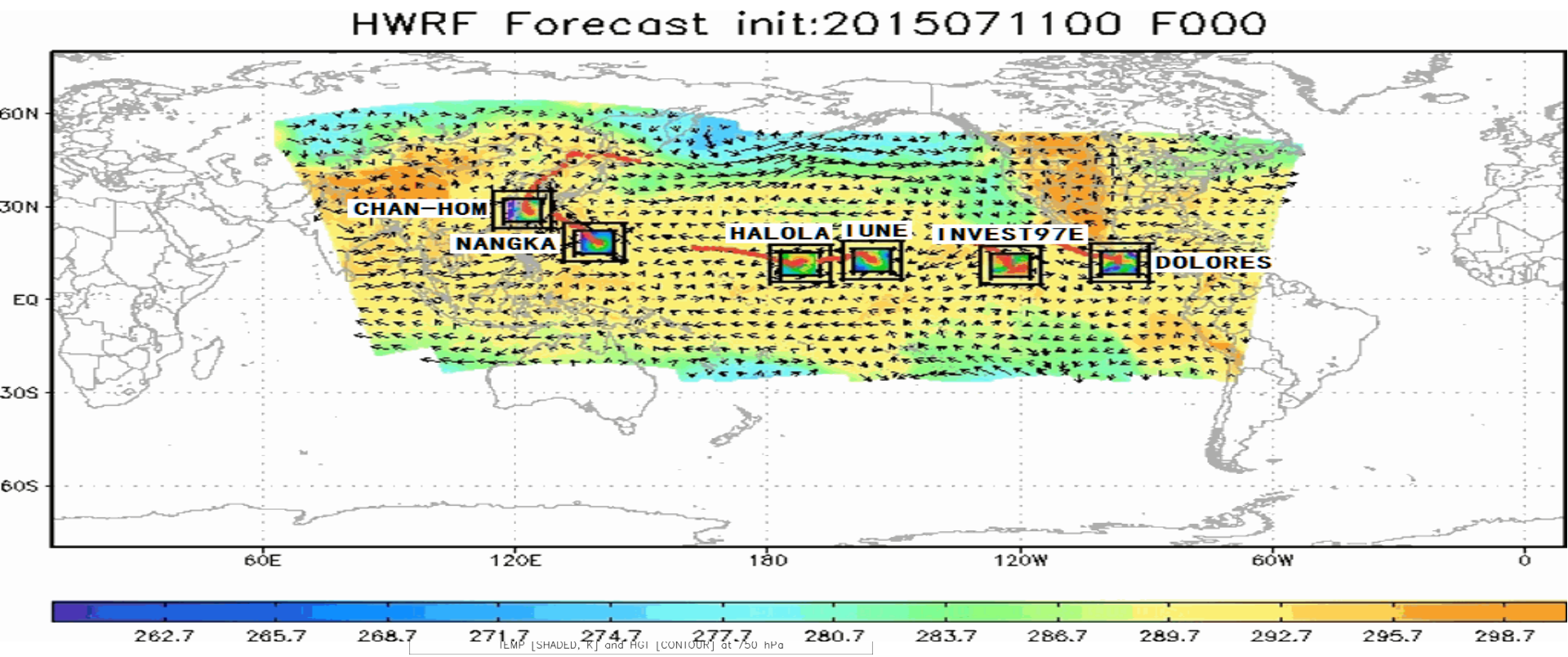
Atmospheric configuration

- Horizontal grid spacing: 18, 6, 2 km
- Inner nests move to follow storm
- Domain location vary from run to run depending on storm location
- 61 vertical levels; top at 2 hPa

Oceanic configuration – MPIPOM-TC

- Horizontal grid spacing: 1/12 deg (~9km)
- Location of grid depends of location of storm
- Atlantic and N. Eastern Pacific
  - 3-D model
  - 23 vertical levels

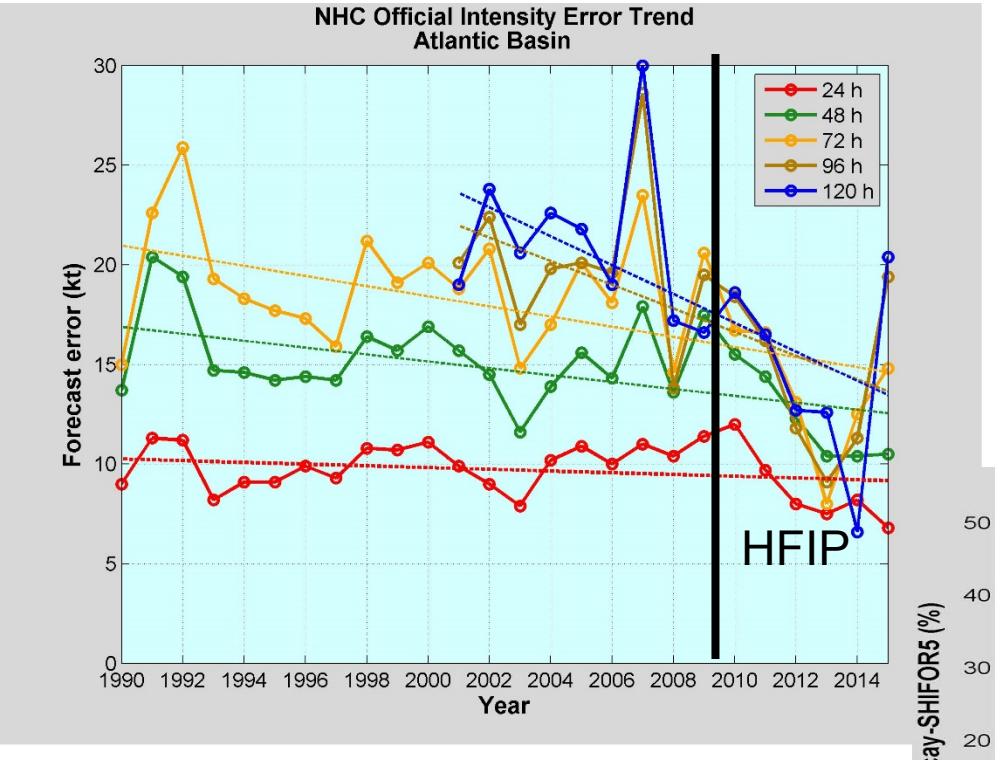
Real-time Operational Configuration for 2015 HWRF



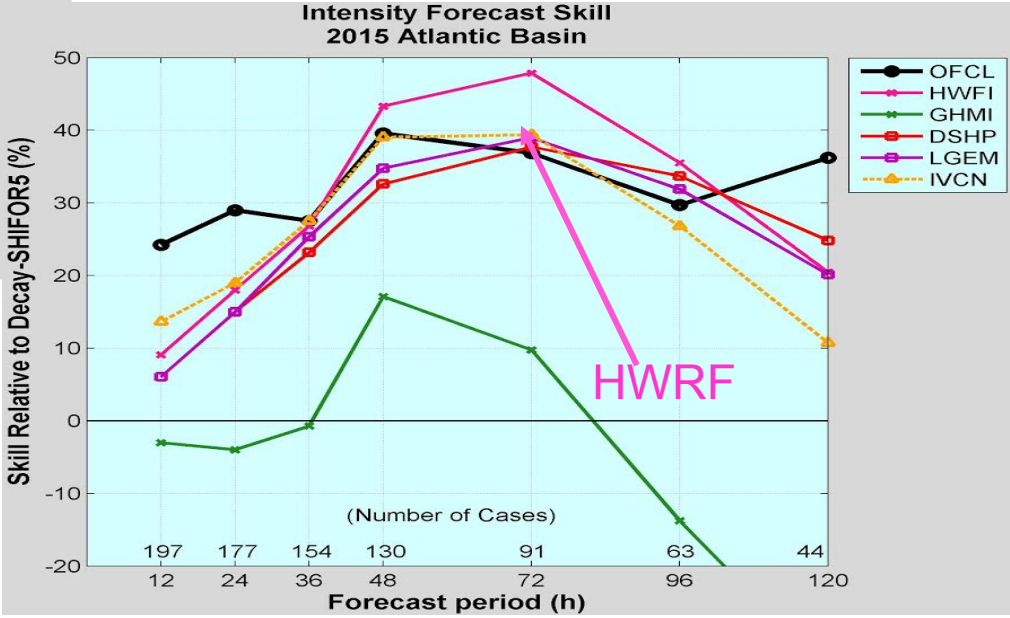
Slide adapted from Vijay Tallapragada, 2016 NCWCP HWRF tutorial

Developmental Testbed Center

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



Long term trends show slow improvement in intensity forecasts.

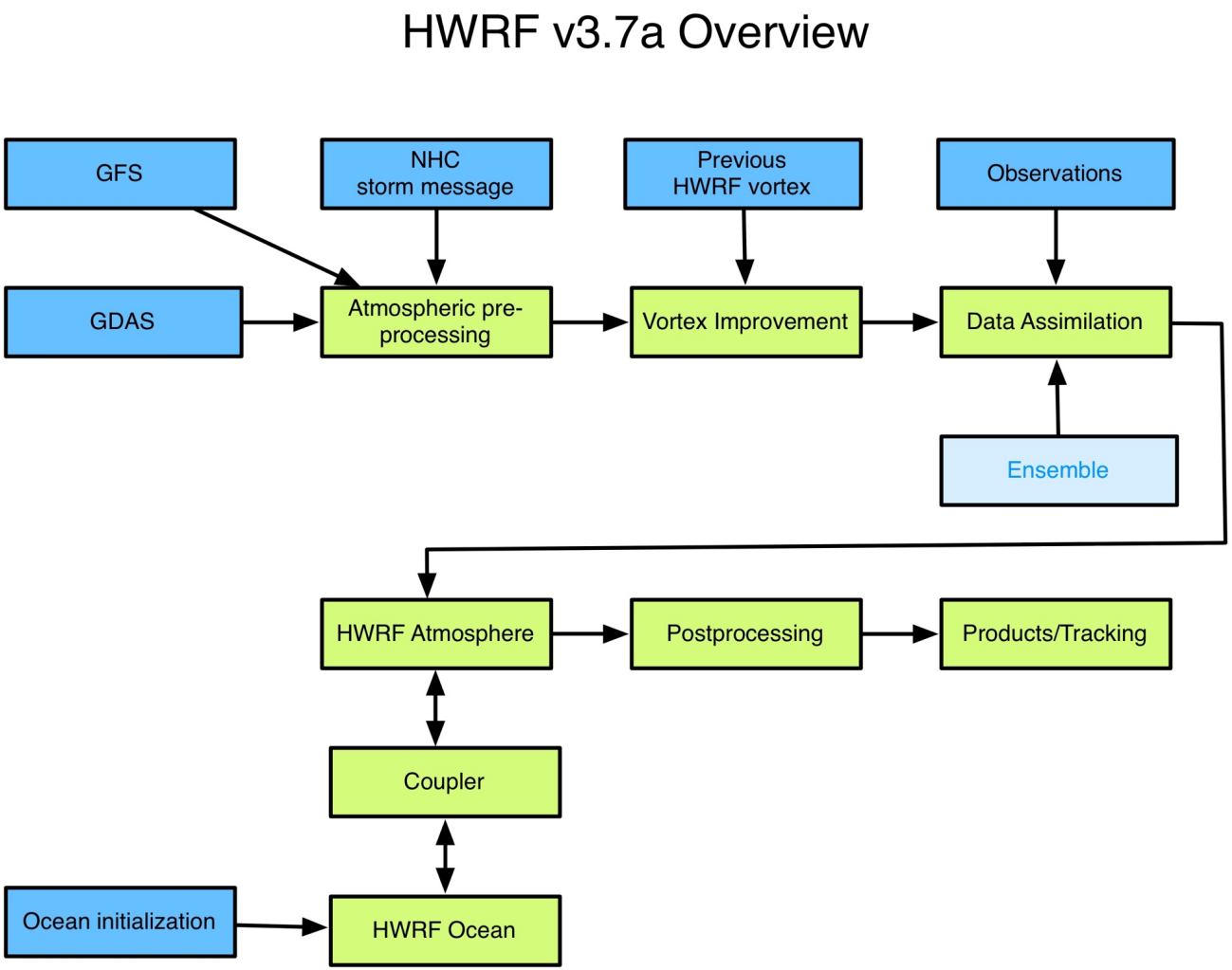


HWRF intensity forecast skill highest among other model guidance for 2015

Courtesy: James Franklin & Eric Blake, NHC

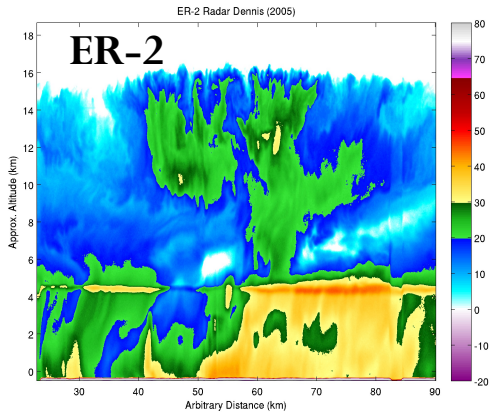
Slide adapted from Vijay Tallapragada, 2016 NCWCP HWRF tutorial

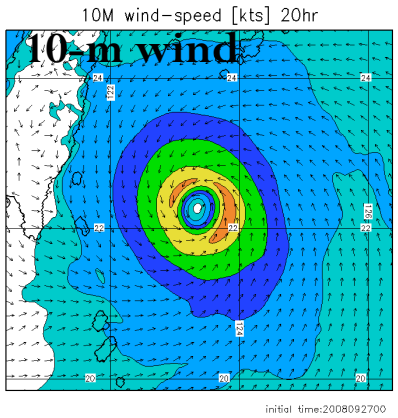
HWRF has many components

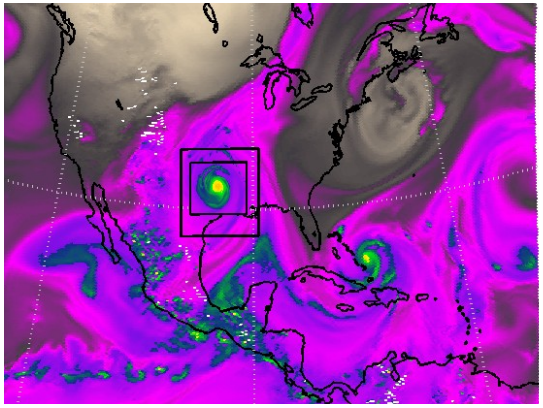


Why nesting is needed?

- Tropical cyclone forecasting needs high resolution
  - <5km to represent wind maxima and resolve meso-vortices
  - <3km to resolve clouds
- Running the model with 2 km everywhere is expensive
- Some areas are more important than others
  - Need to resolve small scale features to determine intensity and structure







Courtesy Sam Trahan, EMC

HWRF 2015 Initialization

Challenges

- Initializing a 2-km grid from a lower-resolution global model
  - Storm has wrong place, size and/or structure
  - Weak storm may dissipate in hurricane model

Solutions

- Use a vortex relocation and correction algorithm
  - Use current global GFS for first guess for parent domain and 6-hr GDAS forecast from previous cycle for nests
  - Remove vortex from GDAS forecasts
  - Insert a corrected vortex
    - Usually 6-h forecast from HWRF previous cycle
    - Vortex location, intensity, and structure corrected using observations

GSI 3D-Var/Ensemble- hybrid

$$J_{3DVAR}(\mathbf{x}') = \frac{1}{2}(\mathbf{x}')^{T}\mathbf{B}_{\mathbf{f}}^{-1}(\mathbf{x}') + \frac{1}{2}(\mathbf{H}\mathbf{x}' - \mathbf{y}')^{T}\mathbf{R}^{-1}(\mathbf{H}\mathbf{x}' - \mathbf{y}')$$

Fit to background Fit to observations

$$\mathbf{J}_{\mathbf{hybrid}}(\mathbf{x}') = \frac{\beta_1}{2}(\mathbf{x}')^{T}\mathbf{B}_{\mathbf{f}}^{-1}(\mathbf{x}') + \frac{\beta_2}{2}(\mathbf{x}')^{T}\mathbf{B}_{ens}^{-1}(\mathbf{x}') + \frac{1}{2}(\mathbf{H}\mathbf{x}' - \mathbf{y}')^{T}\mathbf{R}^{-1}(\mathbf{H}\mathbf{x}' - \mathbf{y}')$$

x' : Analysis increment ($\mathbf{x}^a - \mathbf{x}^b$), where $\mathbf{x}^b$ is a background

$\mathbf{B_f}$: (Fixed) Background error covariance (estimated offline)

H : Observations (forward) operator

$\mathbf{B_f}$: (Fixed) background-error covariance (estimated offline)

R : Observation error covariance (Instrument + representativeness)

$\mathbf{B_{ens}}$: (Flow-dependent) background-error covariance (estimated from ensemble), where $\mathbf{y}^o$ are the observations

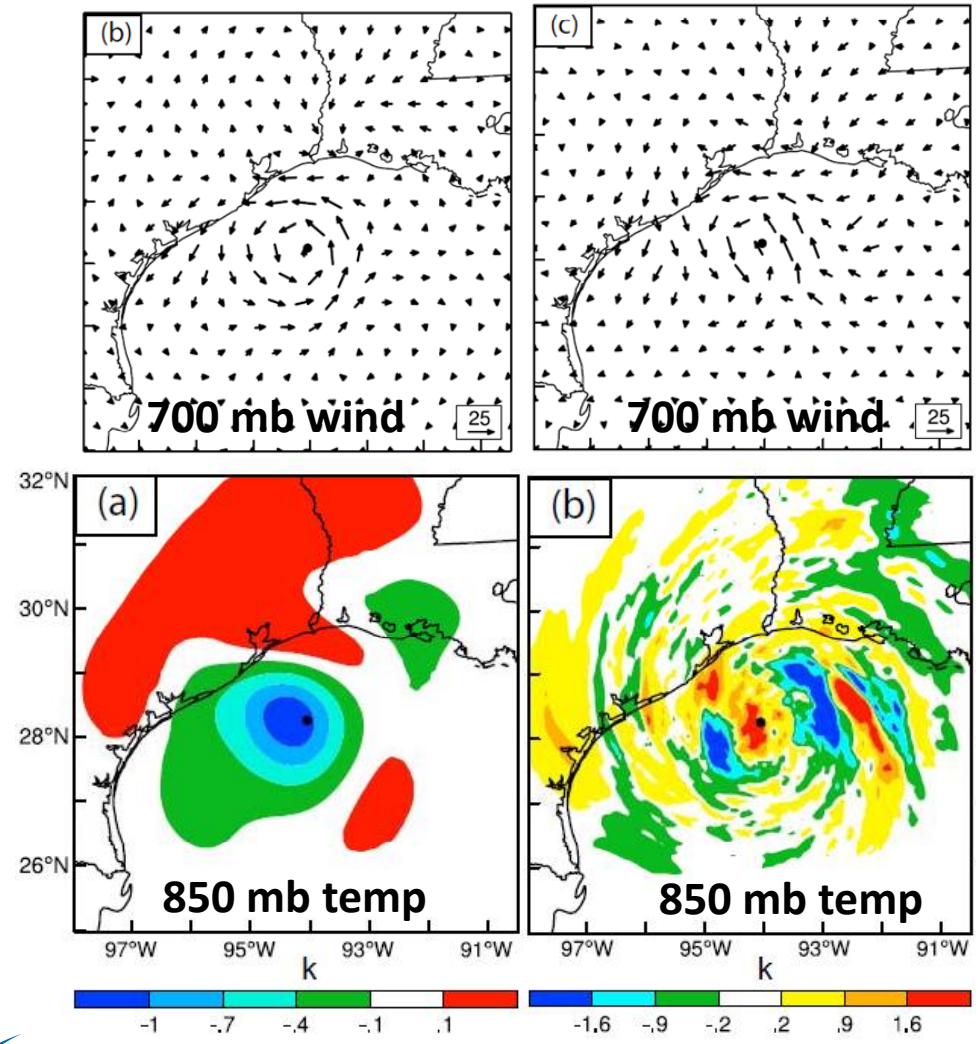
b: Weighting factor (0.25 means total **B** is ¾ ensemble).

Cost function (*J*) is minimized to find solution, $\mathbf{x}'$ [$\mathbf{x}^a = \mathbf{x}^b + \mathbf{x}'$]

(Courtesy from Jeff Whitaker, GSI Tutorial, 2012)

Why hybrid assimilation is beneficial

3DVAR hybrid



- Hurricane IKE 2008
- WRF ARW: Δx=5km
- Observations: radial velocity from two WSR88D radars (KHGX, KLCH)
- WRFVAR hybrid DA system (Wang et al. 2008ab, MWR)

Li et al., 2012, MWR

Courtesy: Xuguang Wang, HFIP Telecon

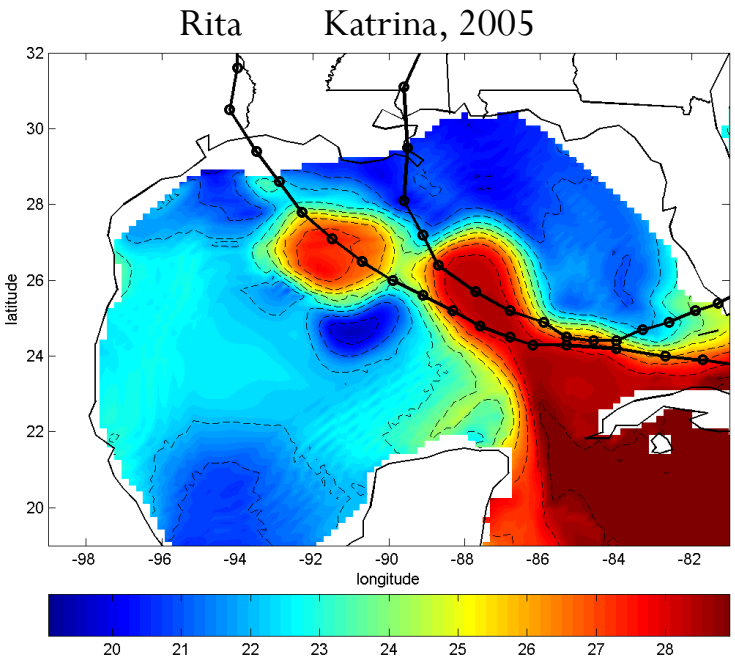
HWRF 2015 operational physics

Physics	Parameterization	Option
Cumulus (only d01 & d02)	SAS deep and shallow convection	84
Microphysics	Ferrier-Aligo	5
Planetary Boundary Layer	GFS (modified Hong & Pan 1996)	3
Surface Layer	GFDL (modified)	88
Land Surface Model	Noah LSM	2
Radiation	RRTMG	4

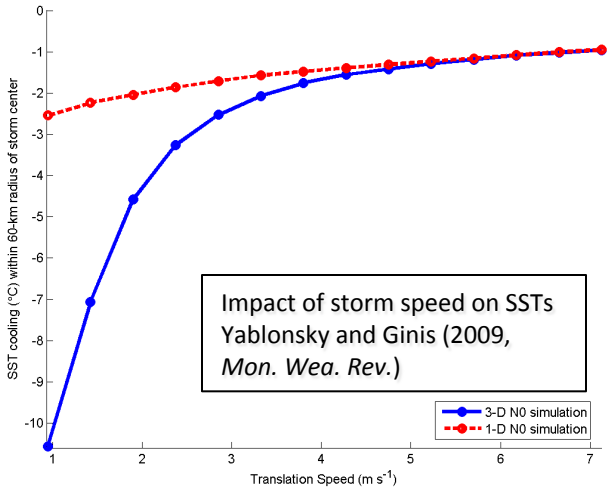
Cumulus parameterization: only on d01 (18 km) and d02 (6 km).
In d03 (2 km), microphysical parameterization explicitly resolves clouds.

HWRF Ocean Component

- Message Passing Interface Princeton Ocean Model for Tropical Cyclones (MPIPOM-TC)
- MPIPOM-TC creates an accurate sea-surface-temperature (SST) field that **evolves** during the model run
- Moisture/heat fluxes from the ocean provide energy for hurricanes



75-m depth temperature
Courtesy R. Yablonsky (URI)



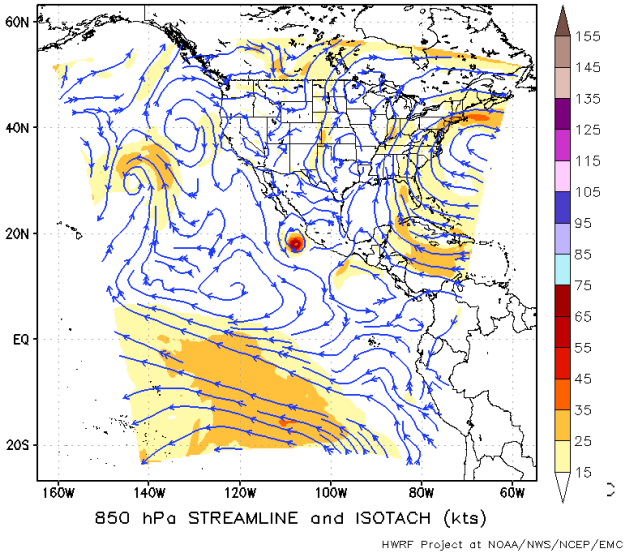
Impact of storm speed on SSTs
Yablonsky and Ginis (2009, *Mon. Wea. Rev.*)

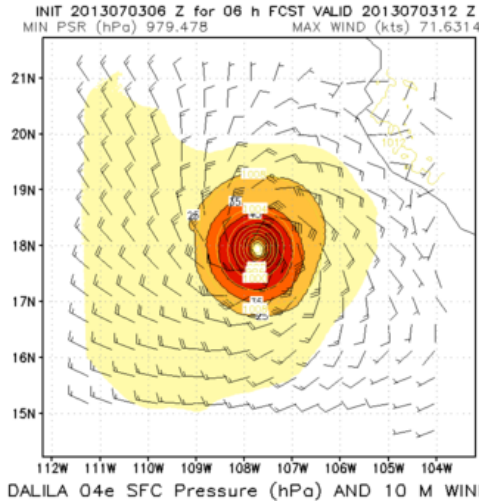
Includes feature based initialization for warm and cold core rings

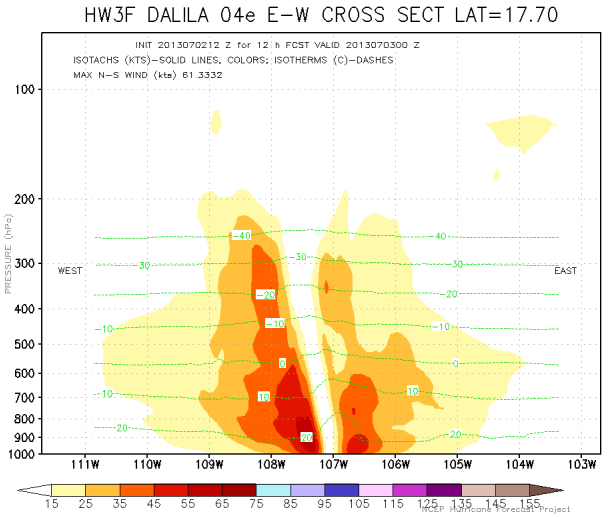
HWRF Post-Processing

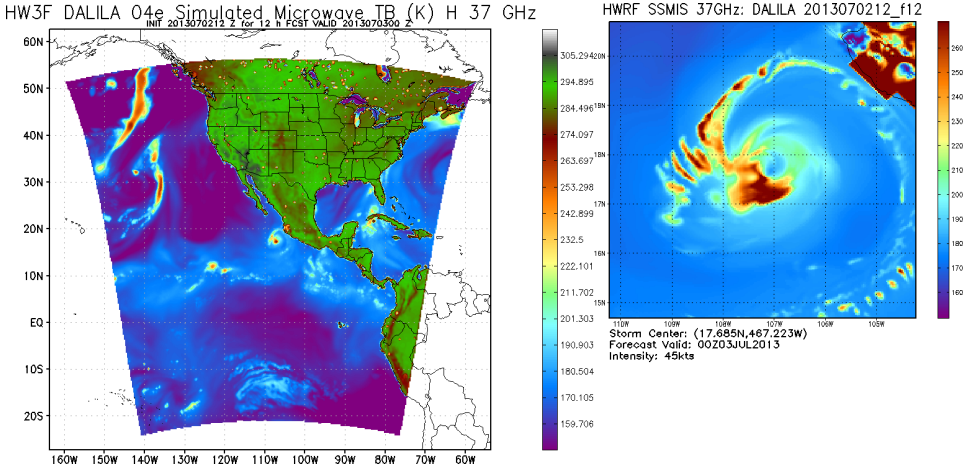
- Uses the Unified post-processor (UPP)
  - Interpolates the forecast
    - Horizontally from the WRF native grid to a lat-lon grid
    - Vertically from WRF native levels to isobaric levels
  - Generates output in GRIB format
  - Computes derived variables
- Domains processed separately, then combined
- Output is used for
  - Graphics
  - Running the external vortex tracker

Surface or isobaric fields

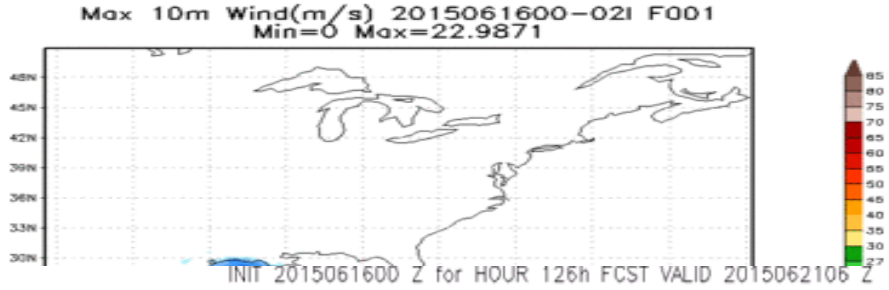


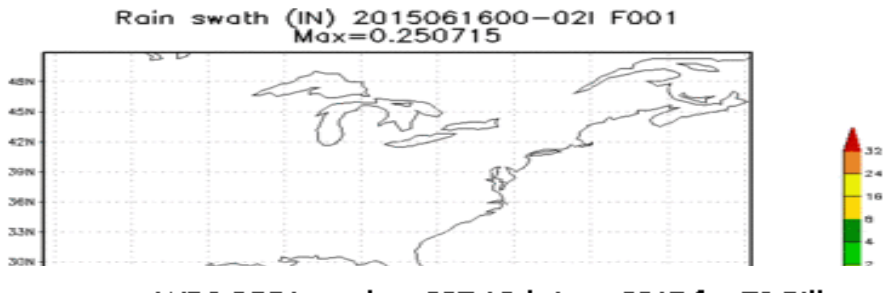




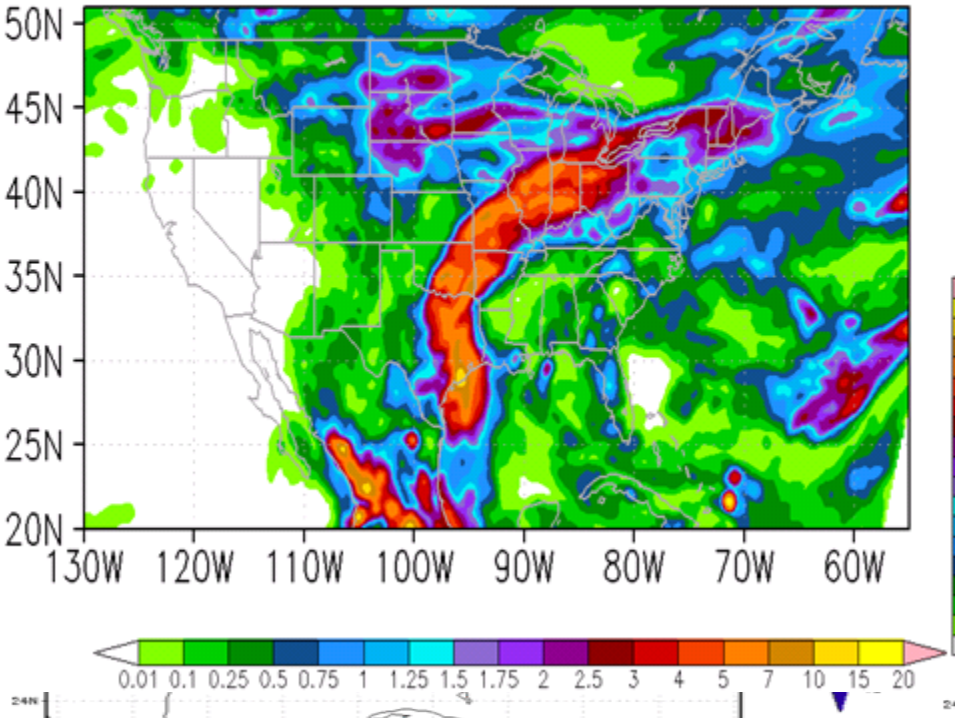


New Products from 2015 HWRF

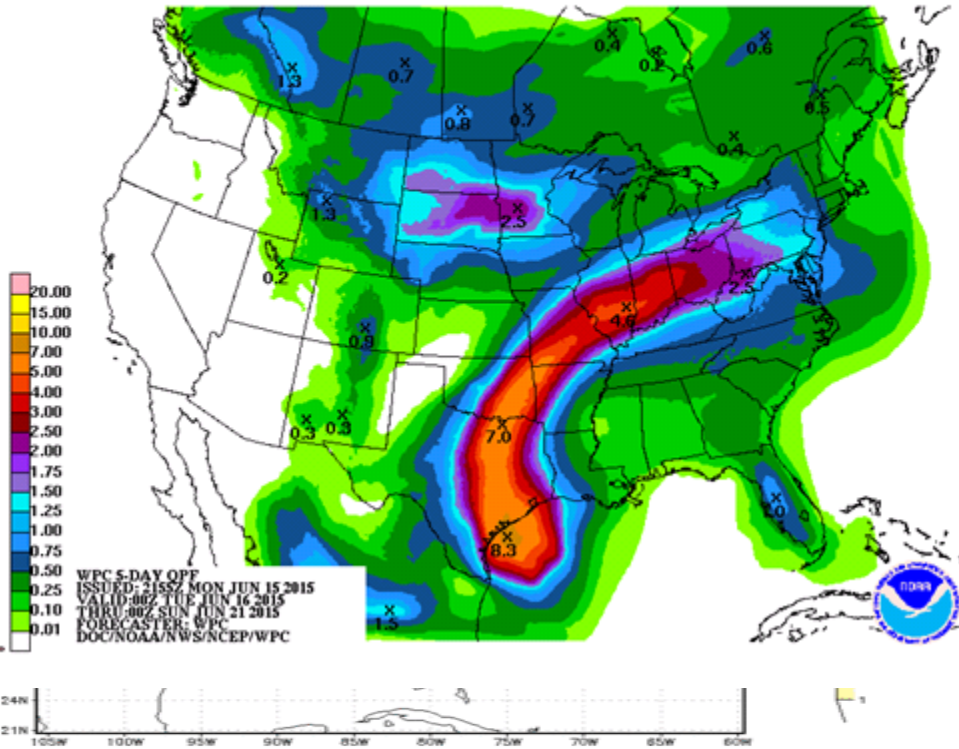




HWRF TOTAL RAINFALL(IN) STORM

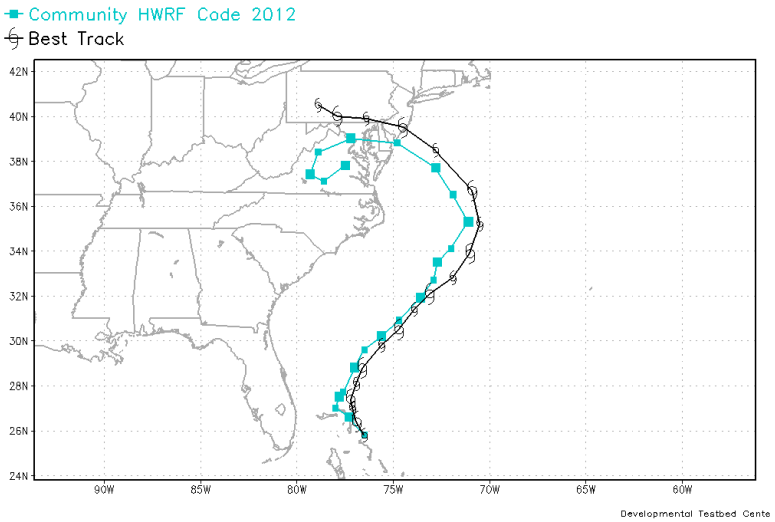


WPC QPF Issued on 00Z 16th June 2015 for TS Bill



GFDL External Vortex Tracker

- Extracts storm properties from the 3D forecast fields
  - Location, intensity, structure
- Outputs text file which can be used for plotting
- Can be used for HWRF or any other model, as long as proper files are provided in GRIB1 format



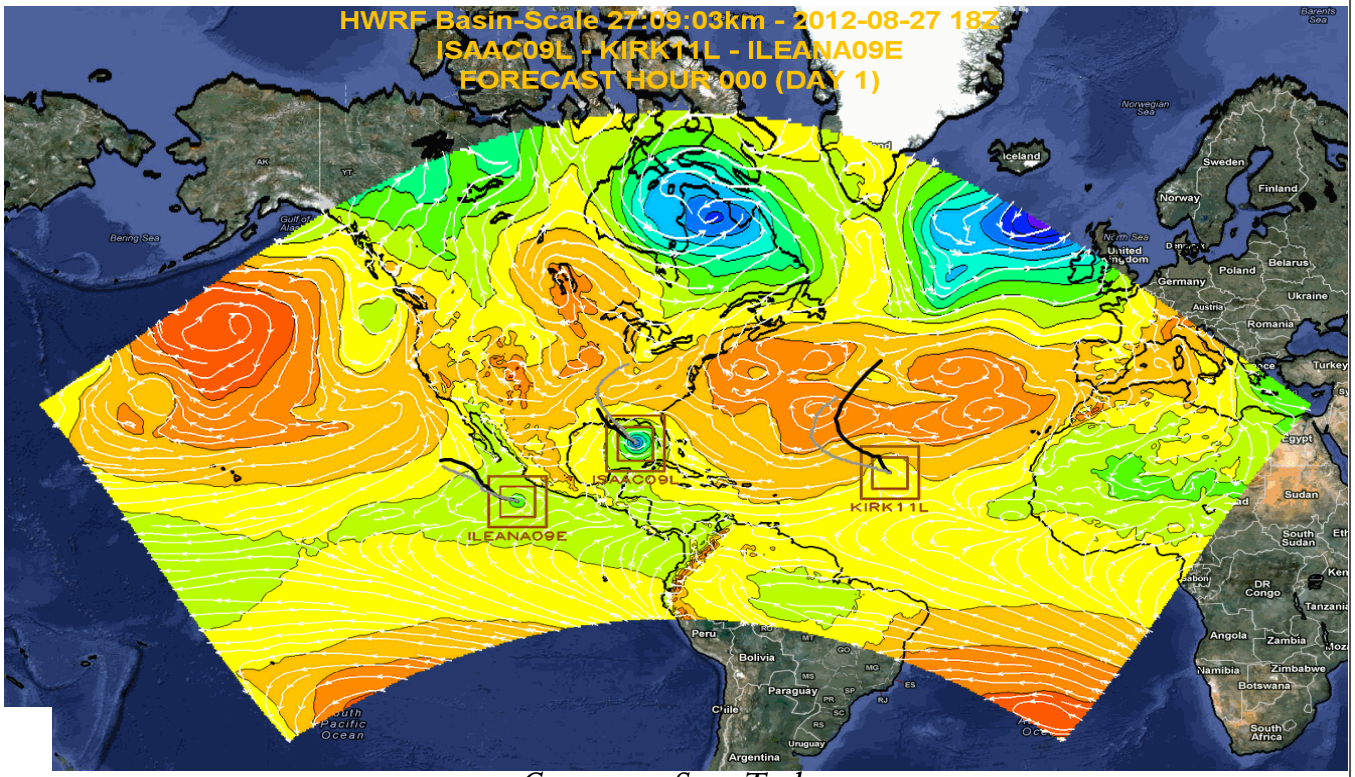
Sandy 2012: Sample of Community HWRF runs by DTC

Expanded capabilities

- Idealized hurricane simulation included in the public release
  - Great research tool for testing the sensitivity of model forecasts for various forcings, physics options, time steps
  - Uncoupled, no DA, no vortex initialization
- Basin-scale HWRF with multiple moving nests is now integrated with the HWRF modeling system, and will be included in the next public release
- Upcoming upgrades include three-way ocean-wave-atmosphere coupled system (not currently supported)

Basin-Scale HWRF Model

- Large domain, multiple storms within, facilitates storm-storm interactions.
- Will be included in 2016 public release



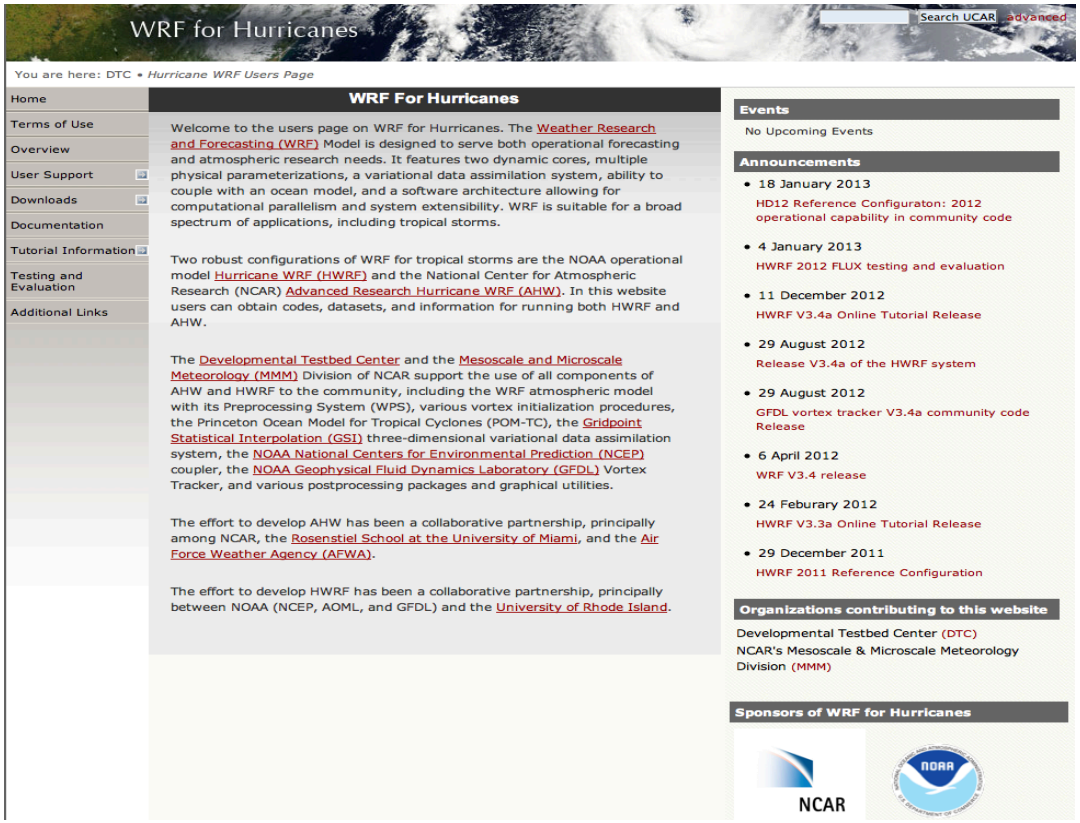
Courtesy: Sam Trahan

HWRF codes and scripts

- Python based scripts
- Configuration of the HWRF system for user needs can be done through .conf files
  - use_gsi?
  - use GFS spectral?
  - use_ocean?
  - ….
- Supported wrappers scripts to run different modules of the system

www.dtcenter.org/HurrWRF/users

Community support



Code downloads, datasets, documentation, online tutorial, helpdesk

1000+ registered users

Yearly releases corresponding to operational model of the year

Stable, tested code

Current release: HWRF v3.7a (2015 operational)

Online tutorial: http://www.dtcenter.org/HurrWRF/users/tutorial/2016_NCWCP_tutorial/practical_def/

HWRF: A collaborative effort

- HWRF is developed under the coordination of NOAA/NWS/NCEP/EMC
- Besides EMC, many groups participate in HWRF development
- Many receive funding from NOAA Hurricane Forecast Improvement Project

Institution	Role
NOAA NWS Natl Hurricane Center	Main customer, evaluation, diagnostics
NOAA NWS/NCEP/EMC	Coordination and overall development
NOAA Research AOML/ESRL/GFDL	Nesting, physics, initialization, vortex tracking, diagnostics
NCAR	WRF model infrastructure
University of Rhode Island	Ocean component (POM-TC)
Developmental Testbed Center	Code management, community support, testing
Your institution!	**You could be the next HWRF user and developer**

Thank you!

- Questions?
  - http://www.dtcenter.org/HurrWRF/users
  - biswas@ucar.edu
  - hwrf-help@ucar.edu

Dennis, 7/10/2005