Introduction to Hurricane WRF

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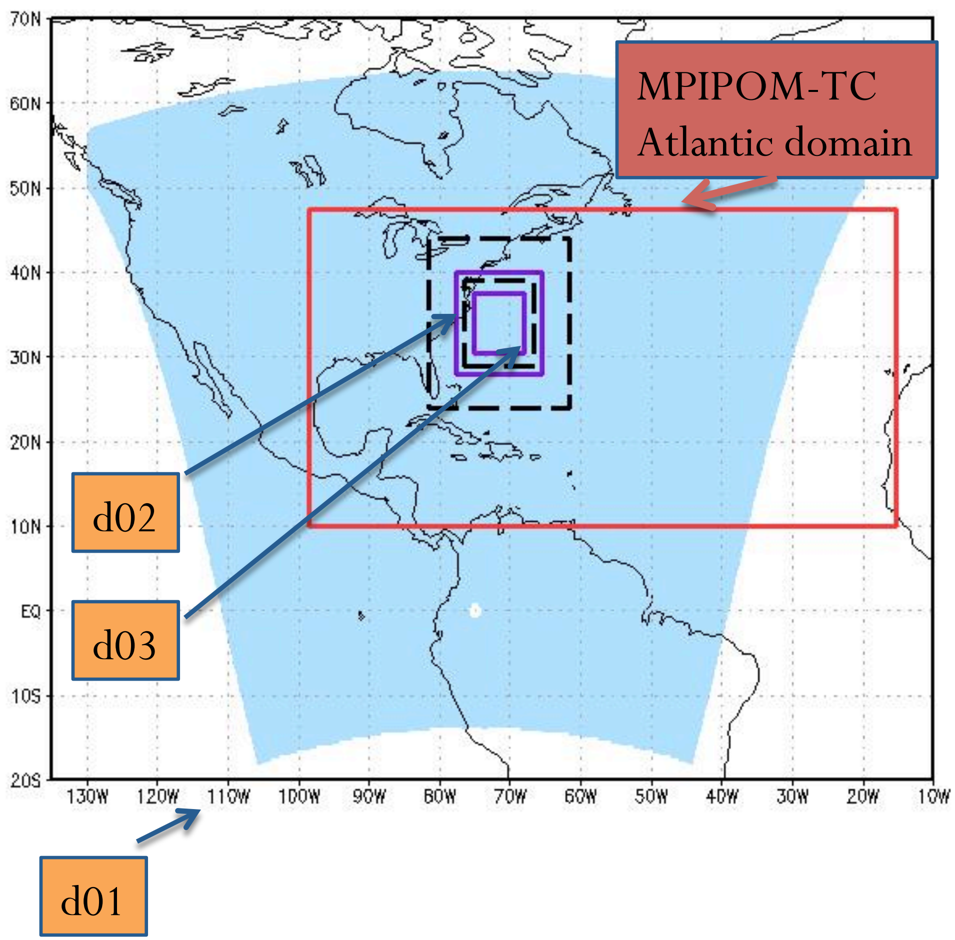
What is the Hurricane WRF?

- 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 tropical cyclones
- Starting in 2011, the operational HWRF modeling system became a community model 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.
- 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

HWRF 2015 grid configuration



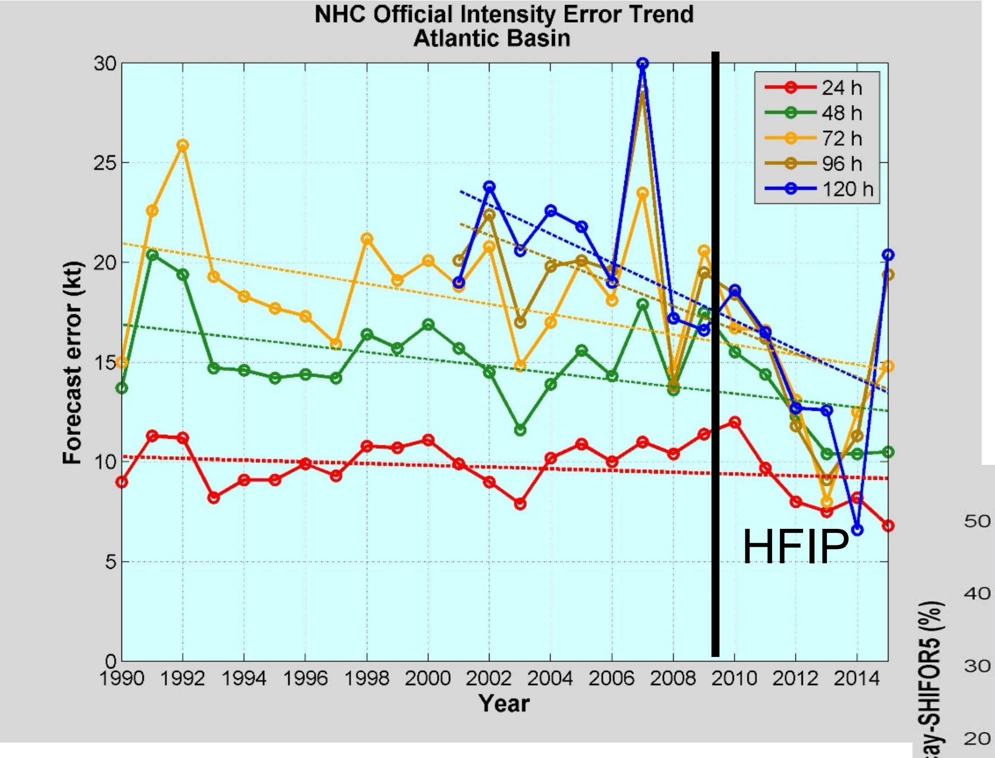
Atmospheric configuration

- 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

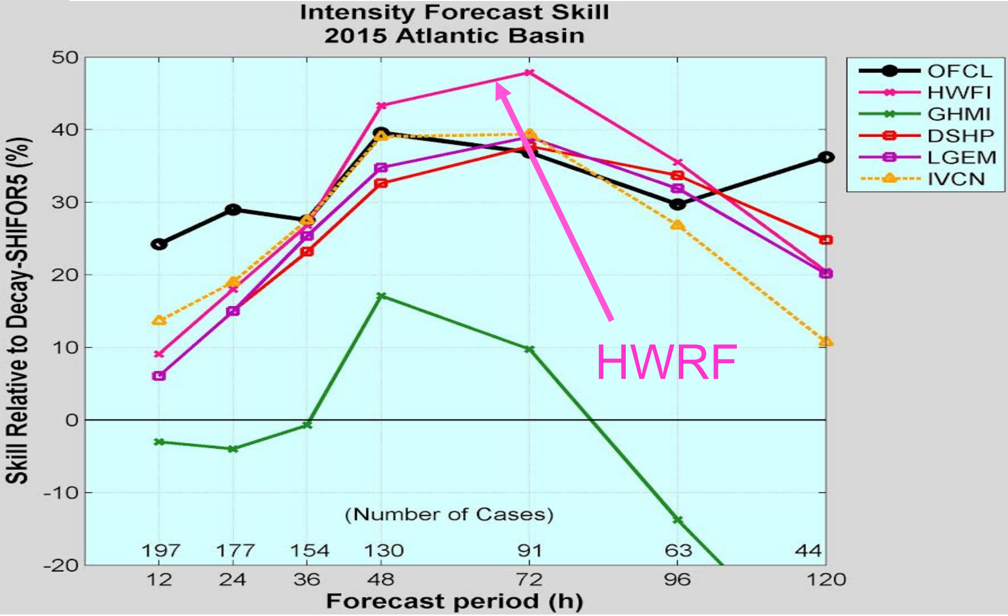
Oceanic configuration – MPIPOM-TC

- 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

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



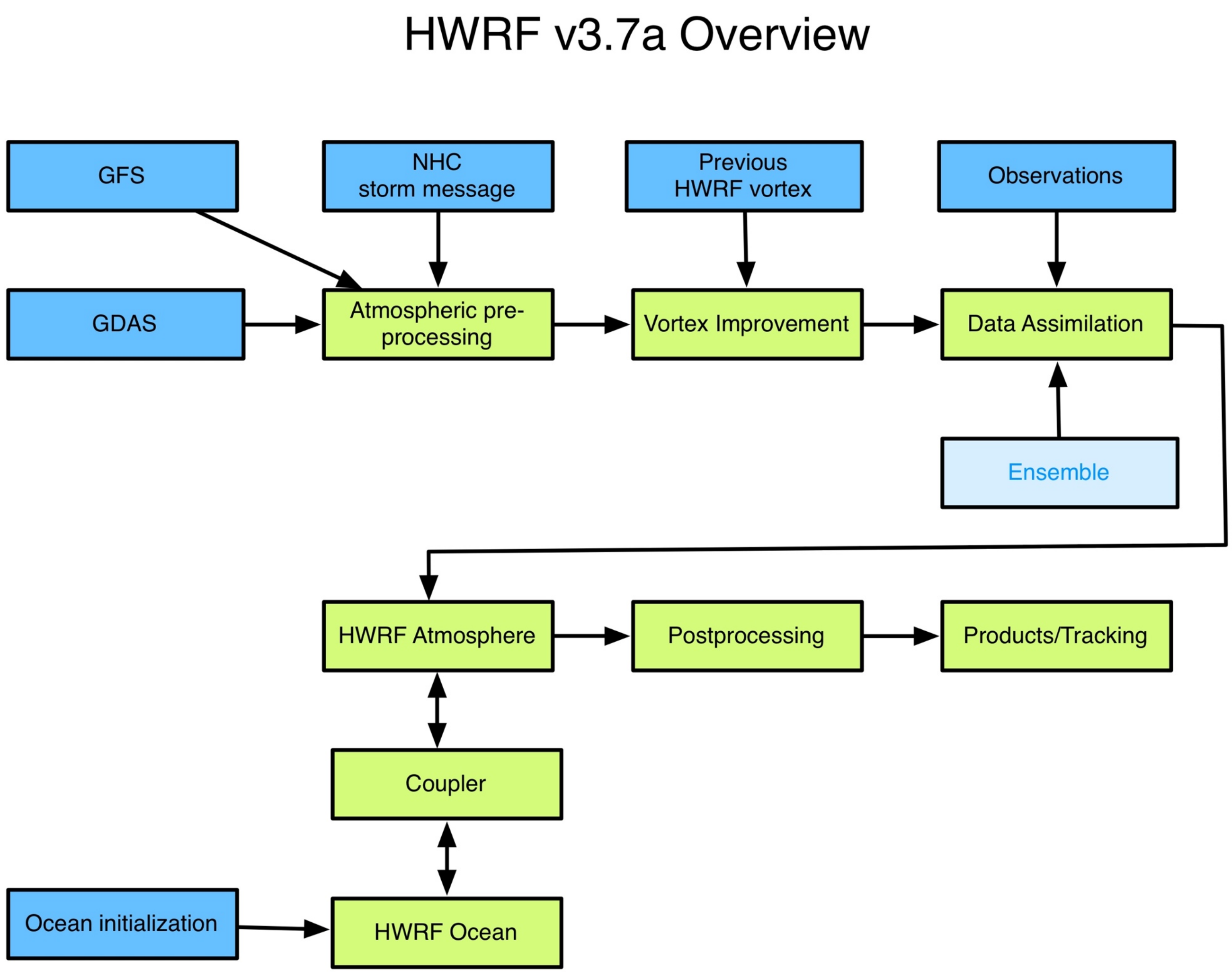
Long term trends show slow improvement in intensity forecasts.



HWRF intensity forecast skill highest among other model guidance for 2015

Courtesy: James Franklin & Eric Blake, NHC

HWRF has many components



HWRF Initialization

- Requirement
  - TC forecasting needs high resolution
  - <3km to resolve clouds

- Challenges
  - Initializing a 2-km grid from a lower-resolution global model
  - Storm is in wrong place, incorrect size and/or structure
  - Weak storm may dissipate in hurricane model
  - Running the model with 2 km everywhere is expensive

HWRF Initialization Contd..

Solution

- 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 based on observations

GSI 3D-Var/Ensemble- hybrid

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

Fit to background   Fit to observations

$$\mathbf{J}_{\mathbf{hybrid}}(\mathbf{x}') = \frac{\beta}{2}(\mathbf{x}')^T \mathbf{B}_f^{-1}(\mathbf{x}') + \frac{\beta}{2}(\mathbf{x}')^T \mathbf{B}_{ens}^{-1}(\mathbf{x}') + \frac{1}{2}(\mathbf{Hx}' - \mathbf{y}')^T \mathbf{R}^{-1}(\mathbf{Hx}' - \mathbf{y}')$$

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

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

$\mathbf{H}$: Observations (forward) operator

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

$\mathbf{R}$: Observation error covariance (Instrument + representativeness)

$\mathbf{B}_{ens}$: (Flow-dependent) background-error covariance (estimated from ensemble)

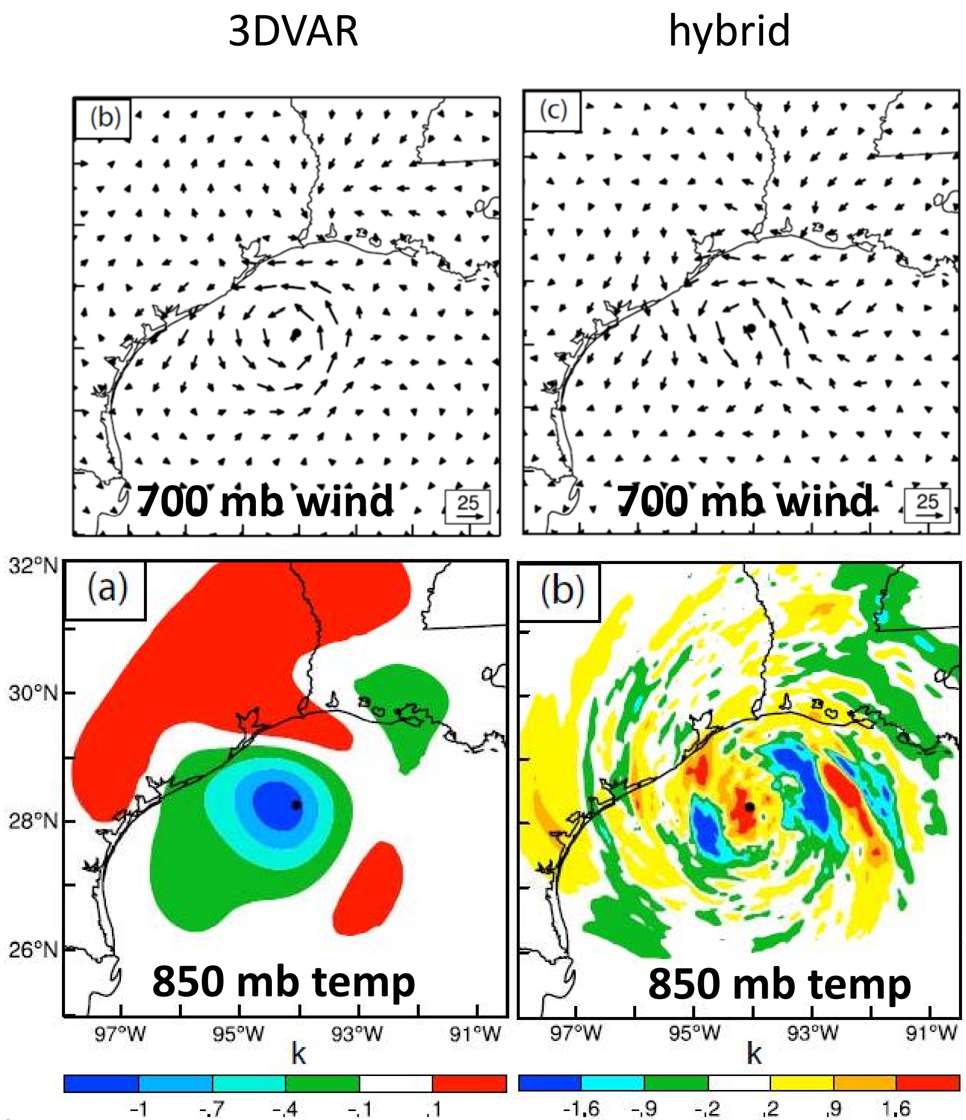
, where $\mathbf{y}^o$ are the observations

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



- 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

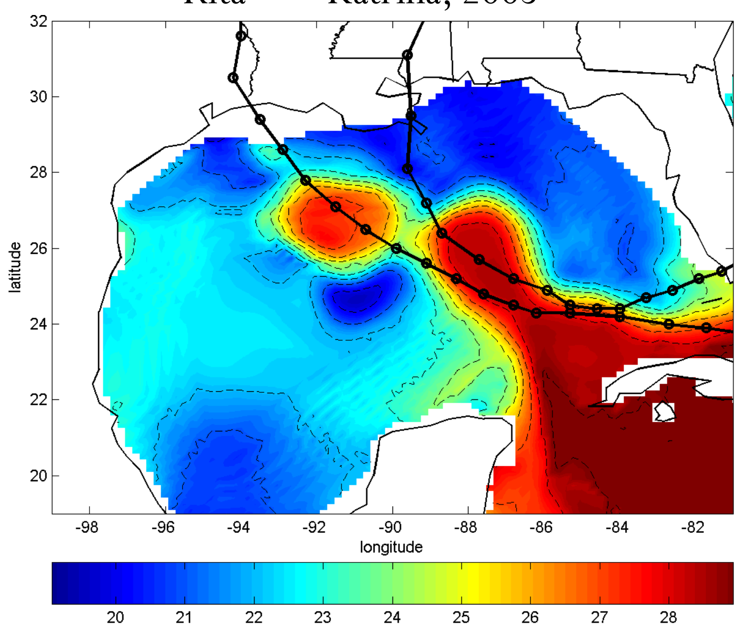
Physics	Parameterization	Option
Cumulus (only d01 & d02)	SAS deep and shallow convection	84
Microphysics	Ferrier-Aligo	5
Planetary Boundary Layer	GFS (modified Hong & Pan 1996)	3
Surface Layer	GFDL (modified)	88
Land Surface Model	Noah LSM	2
Radiation	RRTMG with partial cloudiness	4

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

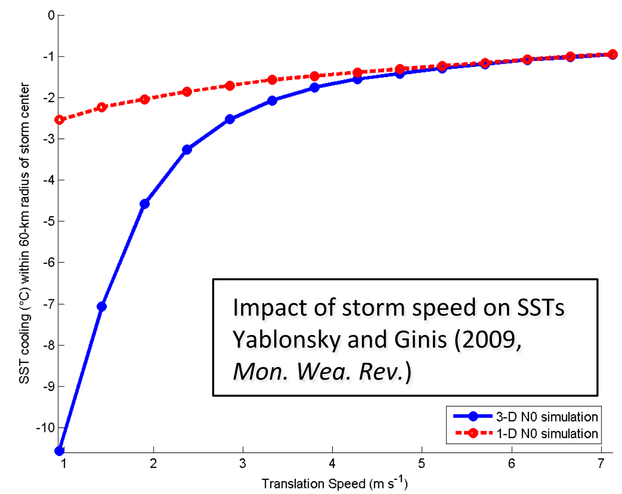
HWRF Ocean Component

- 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

Rita Katrina, 2005



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

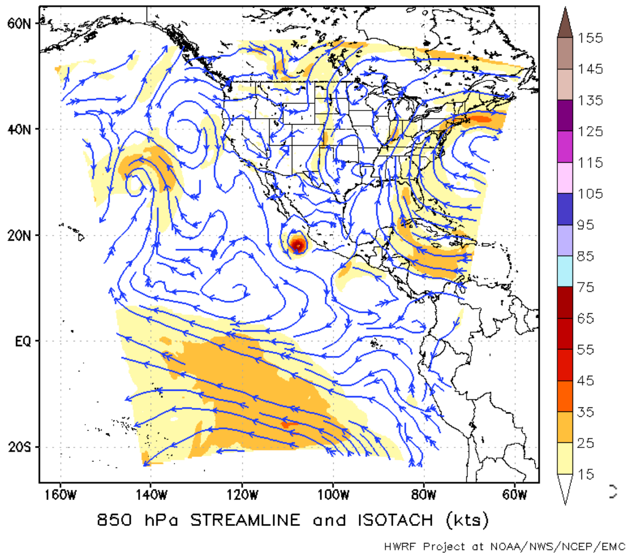


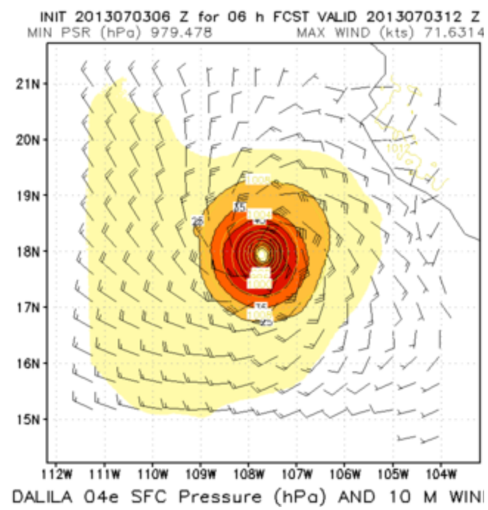
Includes feature based initialization for warm and cold core rings

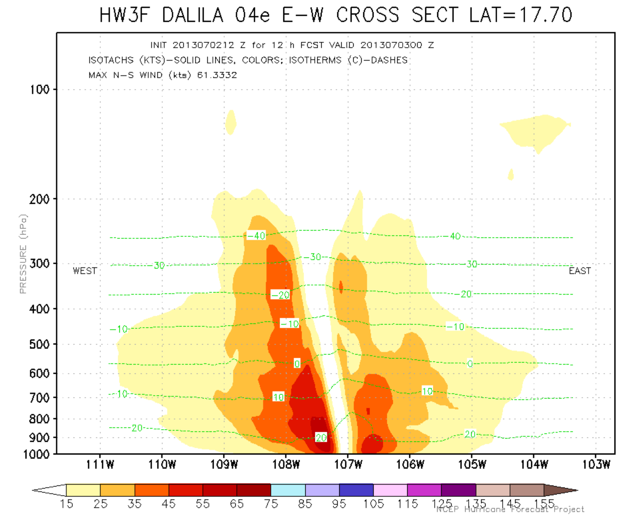
HWRF Post-Processing

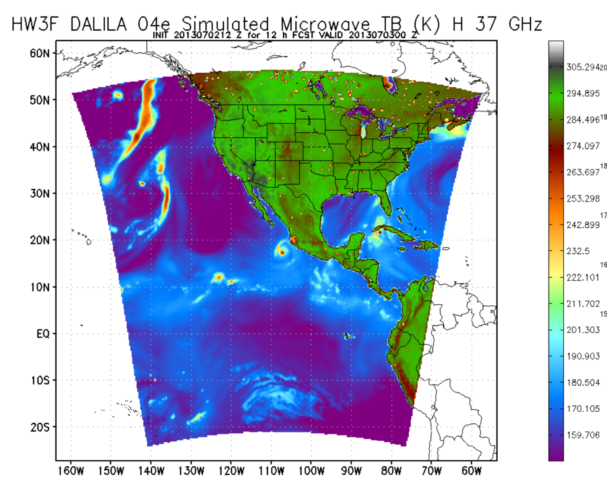
- Uses the Unified post-processor (UPP)
  - Interpolates the forecast
    - Horizontally from the WRF native grid to a lat-lon grid
    - Vertically from WRF native levels to isobaric levels
  - Generates output in GRIB format
  - Computes derived variables
- Domains processed separately, then combined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

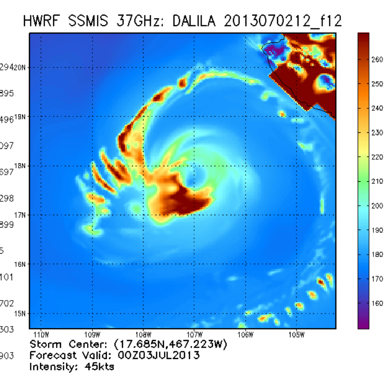
Surface or isobaric fields





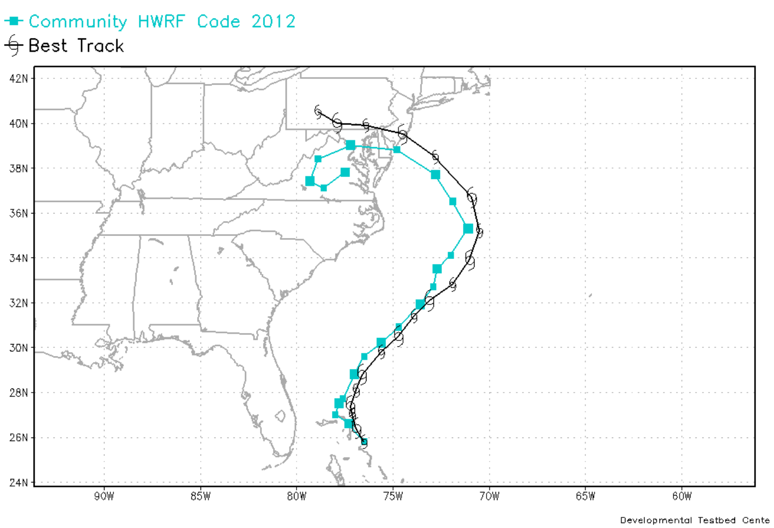






GFDL Vortex Tracker

- 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

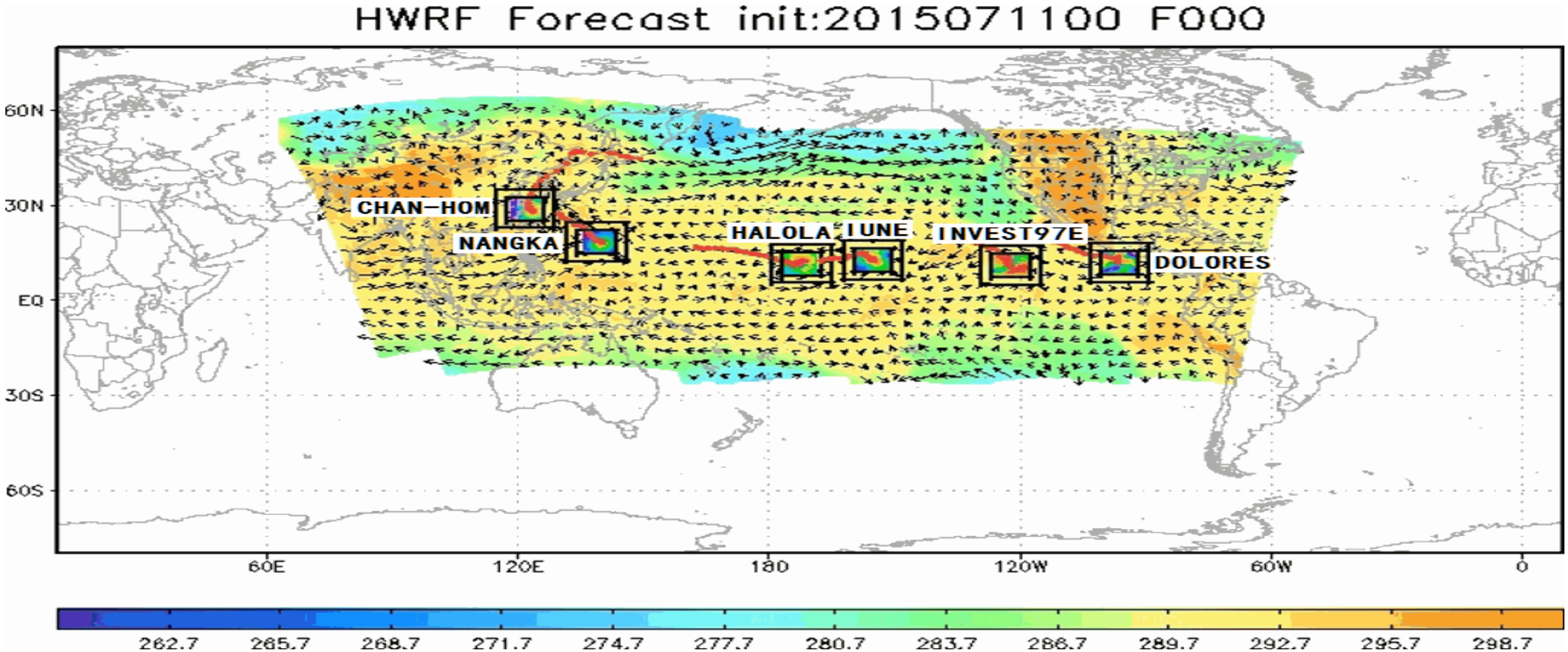


Sandy 2012: Sample of Community HWRF runs by DTC

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
- Ocean coupling supported for all ocean basins

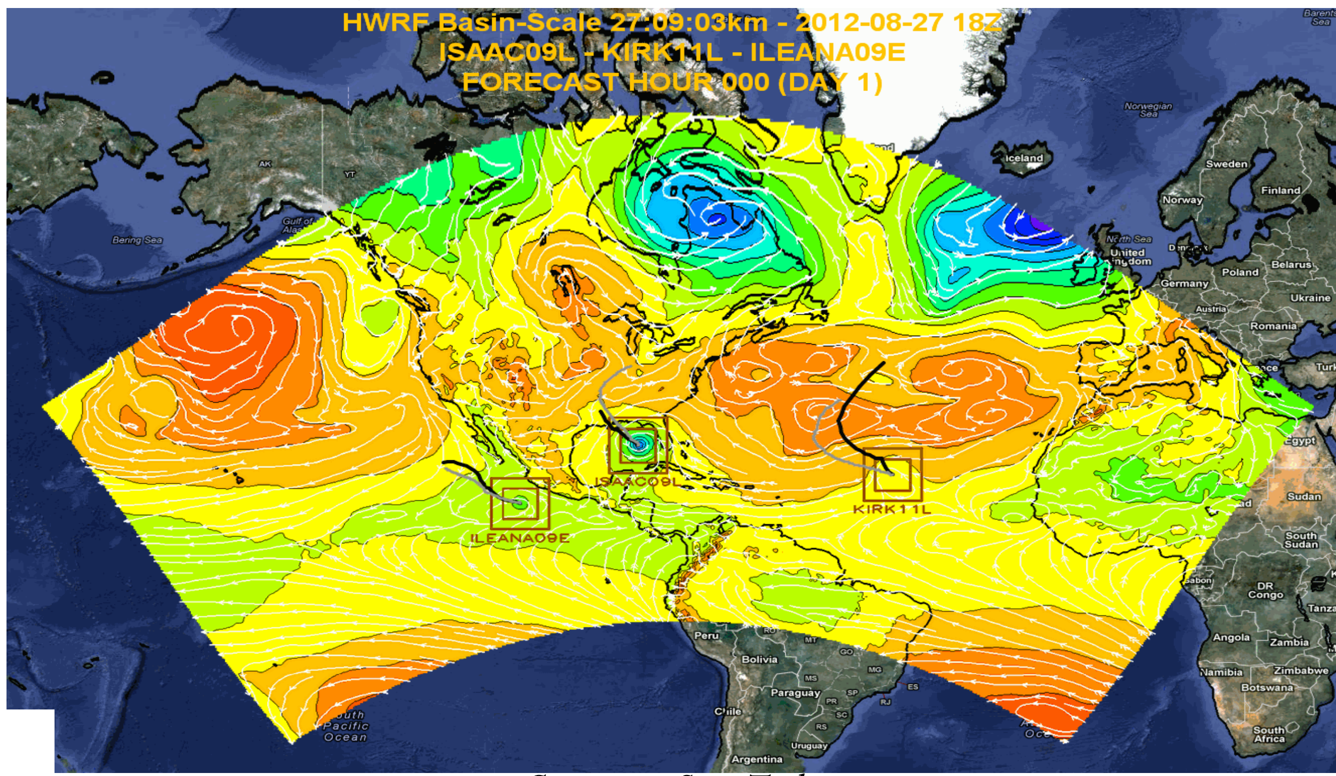
Ocean coupling for all ocean basins



Slide adapted from Vijay Tallapragada, 2016 NCWCP HWRF tutorial

Basin-Scale HWRF Model

- Large domain, multiple storms within, facilitates storm-storm interactions.
- Available as research capability, not included in public release



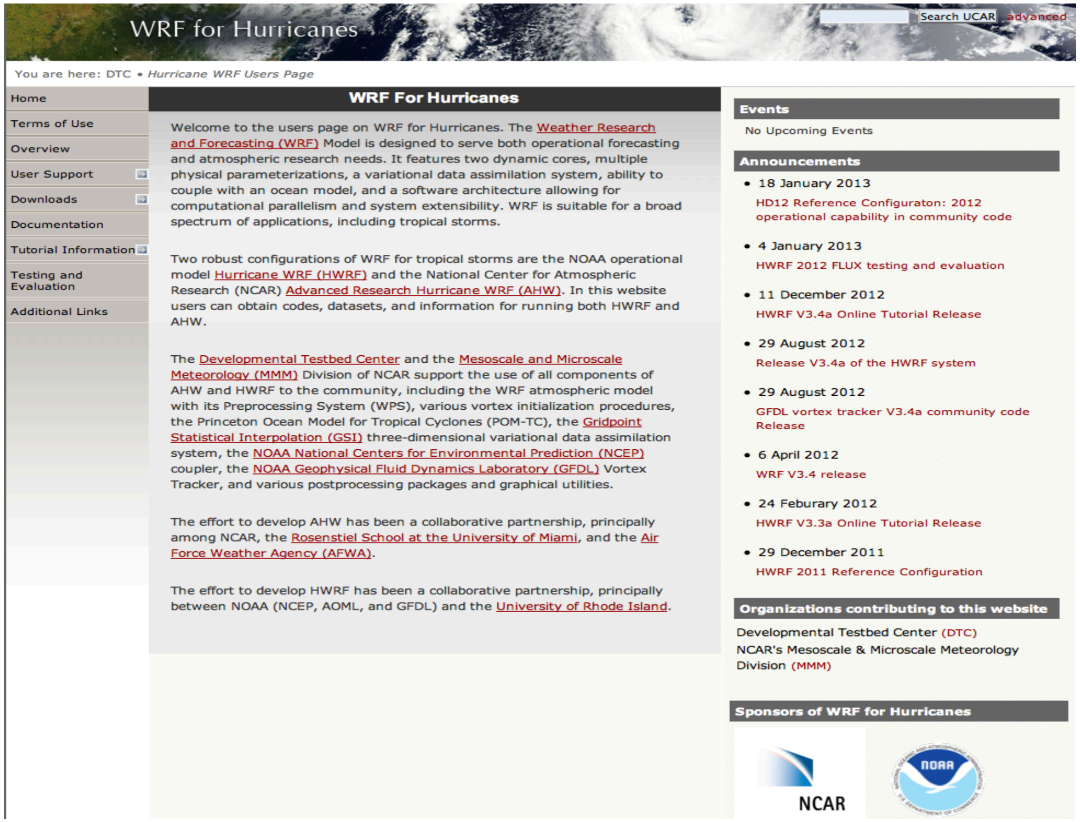
Courtesy: Sam Trahan

HWRF codes and scripts

- Python based scripts
- Configuration of the HWRF system for user needs can be done through .conf files
  - use_gsi? yes/no
  - use GFS spectral? yes/no
  - use_ocean? yes/no
  - ….
- Supported wrappers scripts to run different modules of the system

www.dtcenter.org/HurrWRF/users

Community support


WRF for Hurricanes

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WRF For Hurricanes

Welcome to the users page on WRF for Hurricanes. The Weather Research and Forecasting (WRF) Model is designed to serve both operational forecasting and atmospheric research needs. It features two dynamic cores, multiple physical parameterizations, a variational data assimilation system, ability to couple with an ocean model, and a software architecture allowing for computational parallelism and system extensibility. WRF is suitable for a broad spectrum of applications, including tropical storms.

Two robust configurations of WRF for tropical storms are the NOAA operational model Hurricane WRF (HWRF) and the National Center for Atmospheric Research (NCAR) Advanced Research Hurricane WRF (AHW). In this website users can obtain codes, datasets, and information for running both HWRF and AHW.

The Developmental Testbed Center and the Mesoscale and Microscale Meteorology (MMM) Division of NCAR support the use of all components of AHW and HWRF to the community, including the WRF atmospheric model with its Preprocessing System (WPS), various vortex initialization procedures, the Princeton Ocean Model for Tropical Cyclones (POM-TC), the Gridpoint Statistical Interpolation (GSI) three-dimensional variational data assimilation system, the NOAA National Centers for Environmental Prediction (NCEP) coupler, the NOAA Geophysical Fluid Dynamics Laboratory (GFDL) Vortex Tracker, and various postprocessing packages and graphical utilities.

The effort to develop AHW has been a collaborative partnership, principally among NCAR, the Rosenstiel School at the University of Miami, and the Air Force Weather Agency (AFWA).

The effort to develop HWRF has been a collaborative partnership, principally between NOAA (NCEP, AOML, and GFDL) and the University of Rhode Island.

Events

No Upcoming Events

Announcements

- 18 January 2013
  HD12 Reference Configuraton: 2012 operational capability in community code
- 4 January 2013
  HWRF 2012 FLUX testing and evaluation
- 11 December 2012
  HWRF V3.4a Online Tutorial Release
- 29 August 2012
  Release V3.4a of the HWRF system
- 29 August 2012
  GFDL vortex tracker V3.4a community code Release
- 6 April 2012
  WRF V3.4 release
- 24 Feburary 2012
  HWRF V3.3a Online Tutorial Release
- 29 December 2011
  HWRF 2011 Reference Configuration

Organizations contributing to this website

Developmental Testbed Center (DTC)
NCAR's Mesoscale & Microscale Meteorology Division (MMM)

Sponsors of WRF for Hurricanes

NCAR
NOAA

Code downloads, datasets, documentation, online tutorial, helpdesk

1200+ 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

Hurricane Odile HWRF Simulation

14-20 September 2014

NCAR