Introduction to Hurricane WRF

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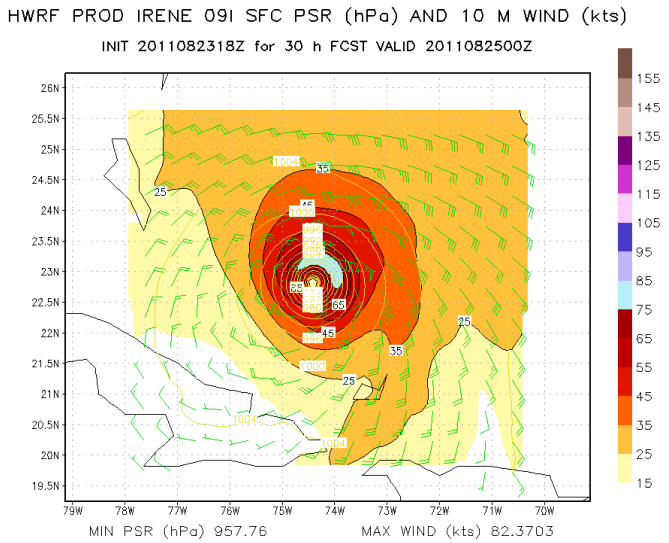
Outline for Introduction to HWRF

- What is the Hurricane WRF
- HWRF domains
- Overview of components
- Dynamic core
- Moving nest
- Initialization and data assimilation
- Physics
- Ocean and coupler
- Post-processor and tracker
- User support
- New in 2015 and future development

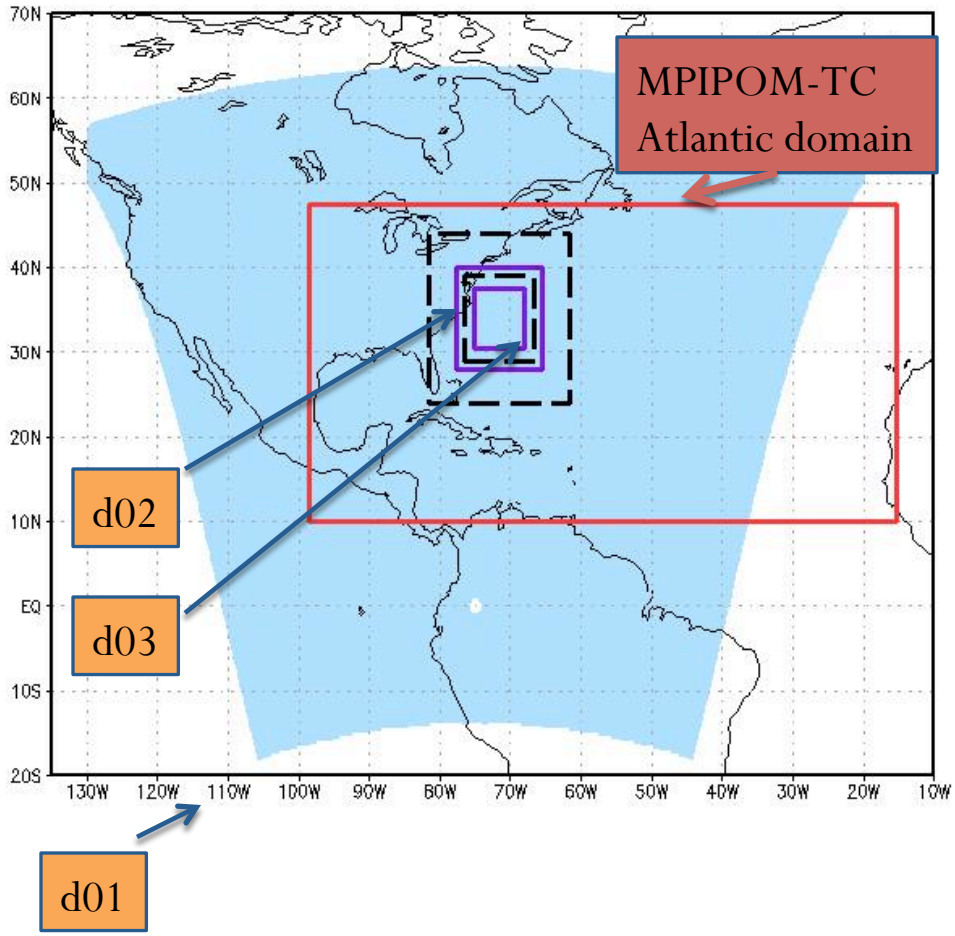


What is the Hurricane WRF?

- A US NWS operational model used 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
- A model that can be run for all Northern and Southern Hemisphere basins and that contains an idealized tropical cyclone capability
- A community supported code
- A model that is always evolving and improving: new operational implementations of HWRF occur every year in the beginning of the hurricane season
- This talk focuses on 2014 HWRF (some info on 2015 operational implementation and upcoming public release is provided)

Operational forecasts
http://www.emc.ncep.noaa.gov/gc_wmb/vxt/

HWRF 2014 grid configuration



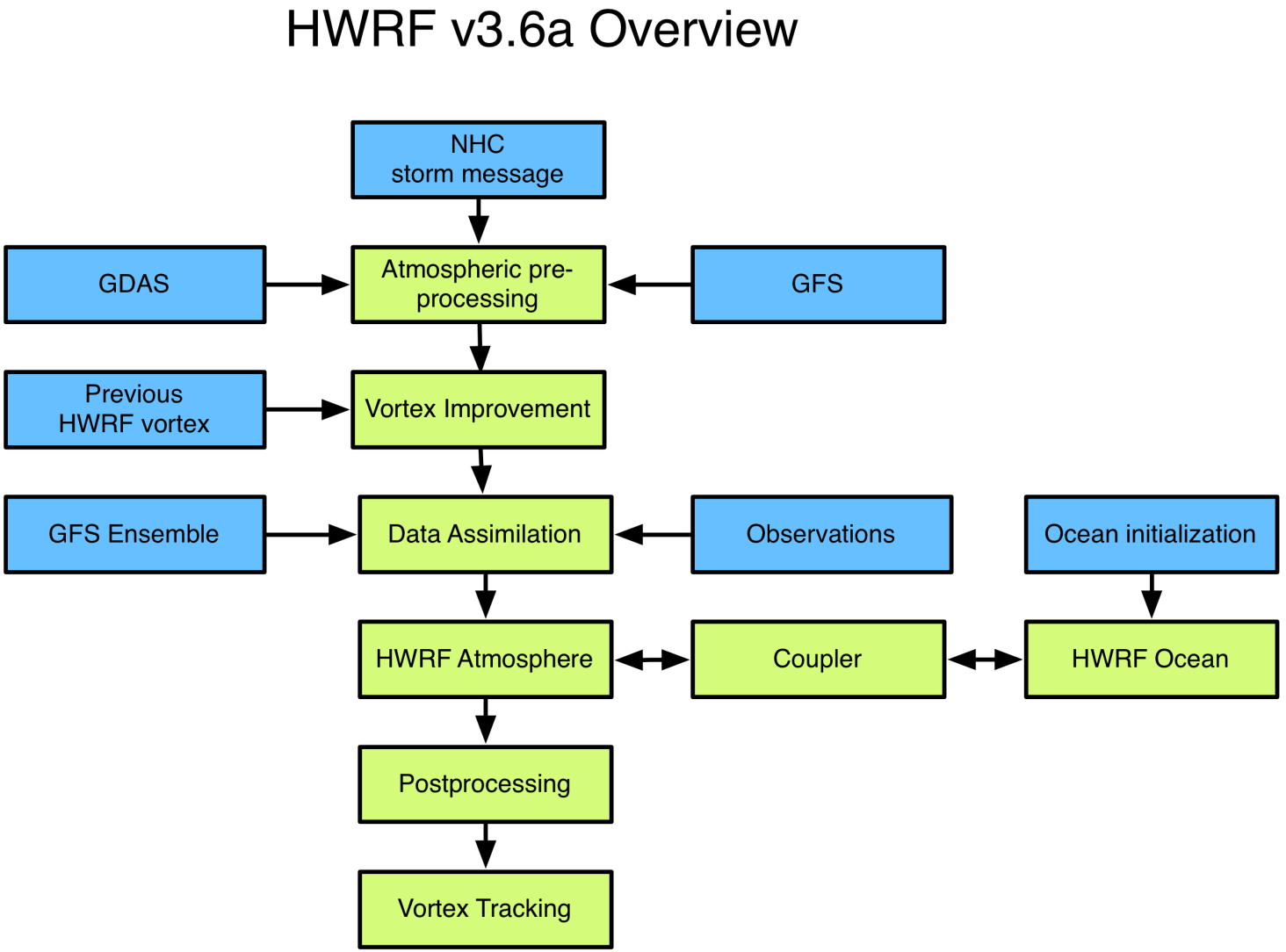
Atmospheric configuration

- Horizontal grid spacing: 27, 9, 3 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

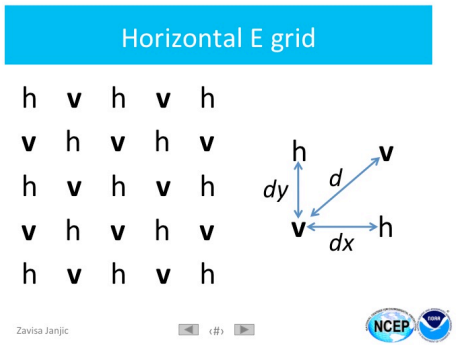
- Horizontal grid spacing: 1/12 deg (~9km)
- Location of grid depends of location of storm
- Atlantic and Pacific
  - 3-D model
  - 23 vertical levels

HWRF has many components

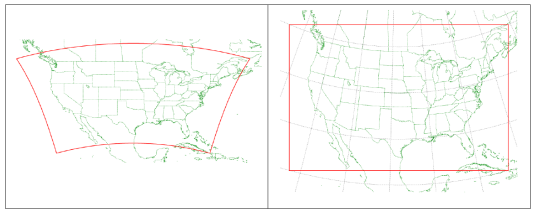


HWRF dynamical core

- WRF has two dynamic cores: ARW and NMM (Non-Hydrostatic Mesoscale Model)
- The dynamic core encompasses the grid projection, grid staggering, system of equations for solving the equations of motion and thermodynamics, the numerical methods, and the nesting mechanisms
- This Tutorial only covered the ARW core. For NMM core, refer to
  - WRF-NMM website: http://www.dtcenter.org/wrf-nmm/users/
  - Presentation about WRF-NMM in 2012 WRF tutorial http://www.mmm.ucar.edu/wrf/users/tutorial/201201/NMM_Dynamics_jan2012_tut_cnvsym.pptx.pdf
  - Scientific Documentation for the NMM Solver http://opensky.library.ucar.edu/collections/TECH-NOTE-000-000-000-845



Sample rotated lat-lon domain

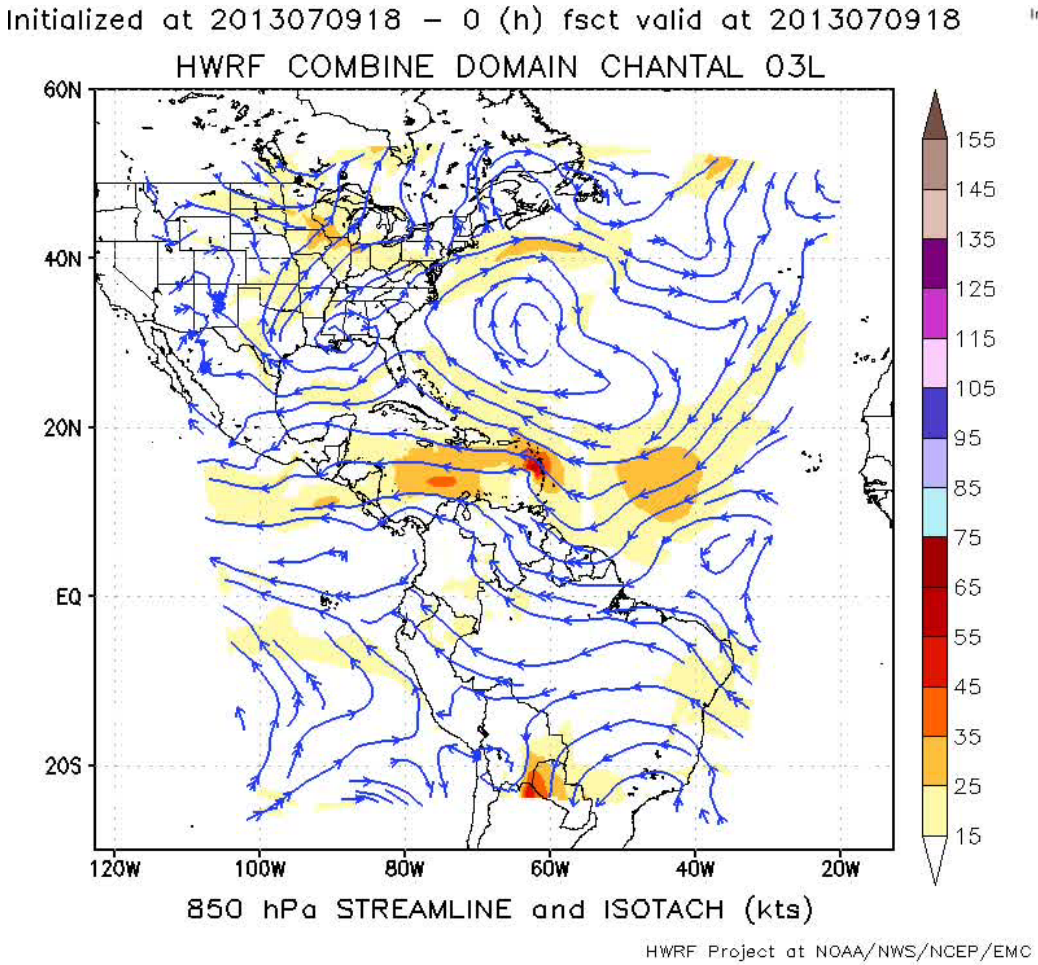


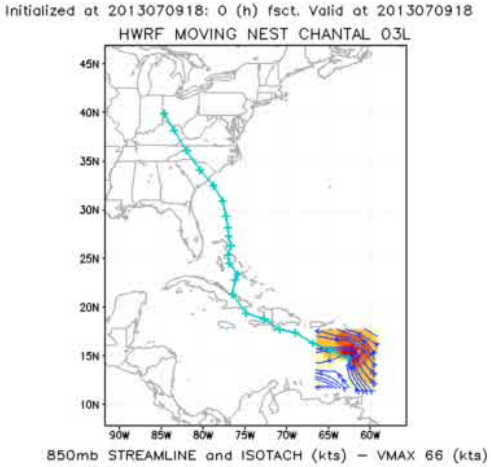
On a regular lat-lon map background

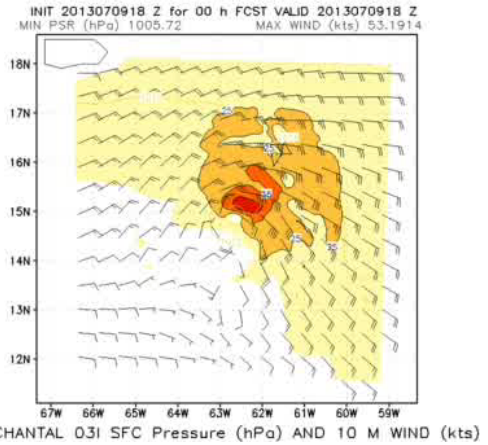
On a rotated lat-lon map background (same rotation as model grid).

Courtesy: Z. Janjic NOAA/NCEP/EMC

HWRF Moving Nests

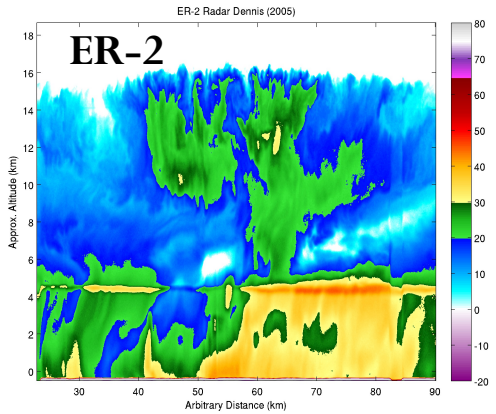


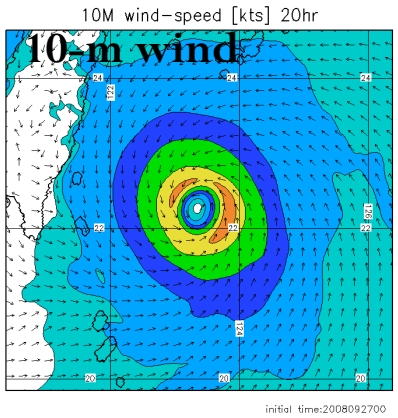


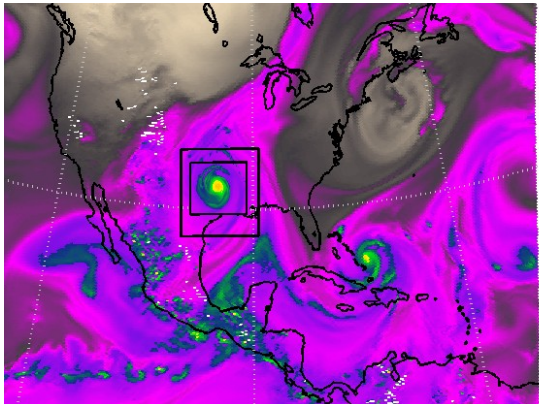


Why nesting is needed?

- Tropical cyclone forecasting needs high resolution
  - <5km to represent wind maxima and resolve meso-vortices
  - <3km to resolve clouds
- Running the model with 3km 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 2014 Initialization

Challenges

- Initializing a 3-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

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

Fit to background Fit to observations

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

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

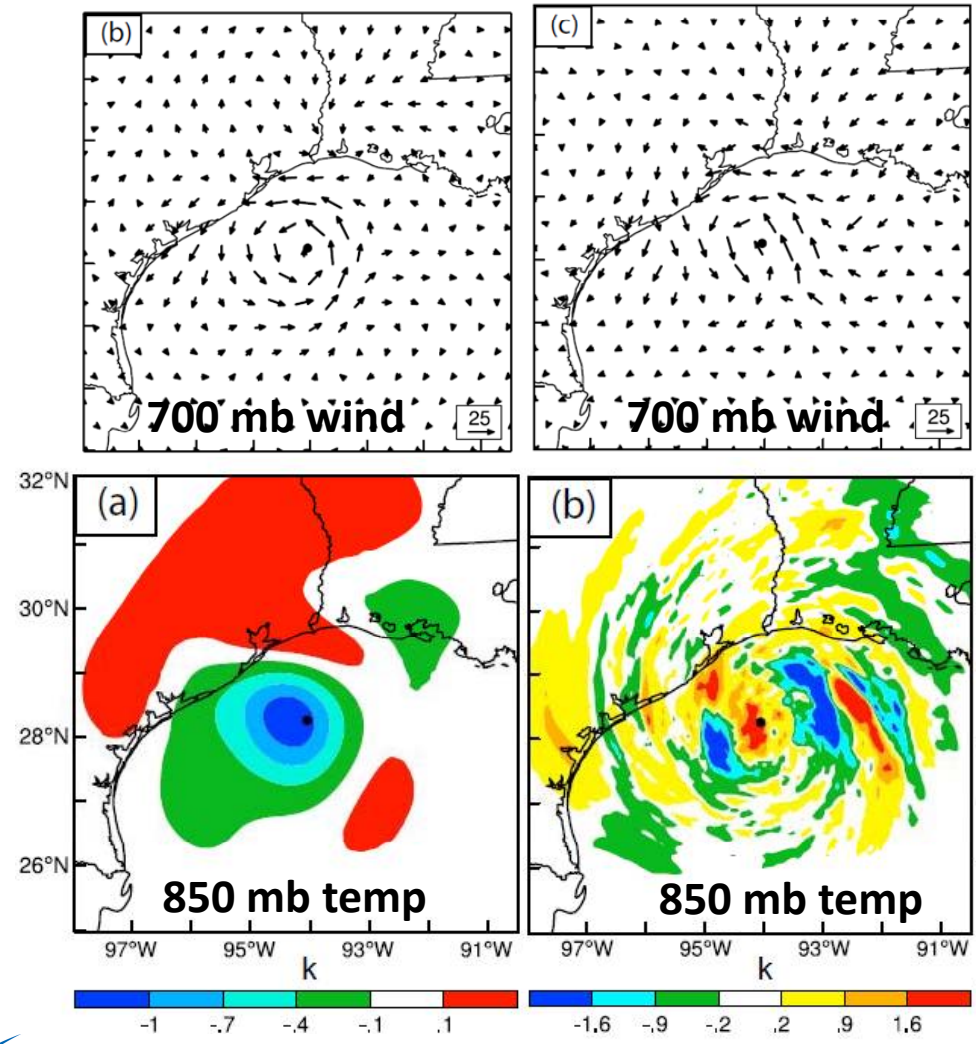
β: Weighting factor (0.25 means total **B** is ¾ ensemble).

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

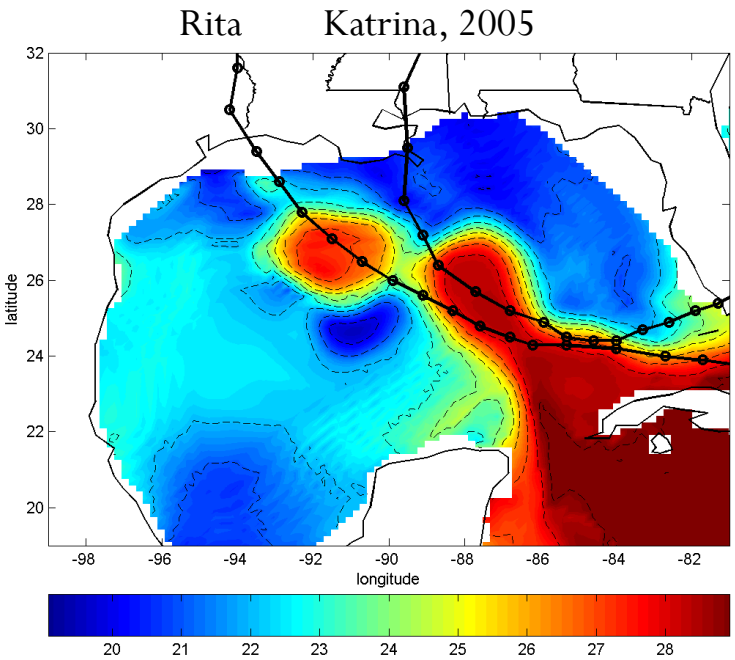
HWRF 2014 operational physics

Physics	Parameterization	Option
Cumulus (only d01 & d02)	SAS deep and shallow convection	84
Microphysics	Ferrier for the tropics	85
Planetary Boundary Layer	GFS (modified Hong & Pan 1996)	3
Surface Layer	GFDL (modified)	88
Land Surface Model	GFDL slab model	88
Radiation	GFDL	98

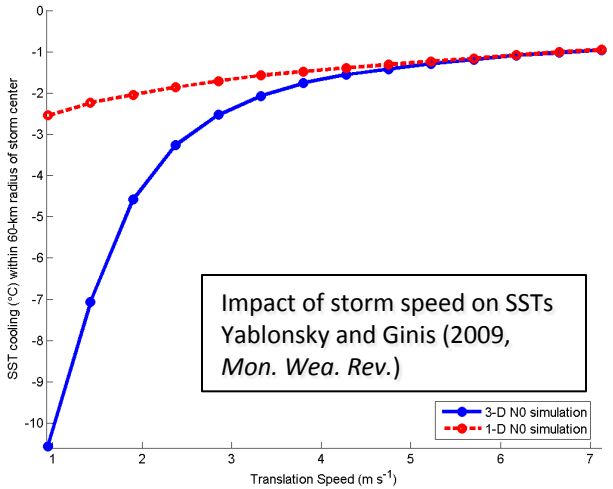
Cumulus parameterization: only on d01 (27 km) and d02 (9 km).
In d03 (3 km), microphysical parameterization explicitly resolves clouds.

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



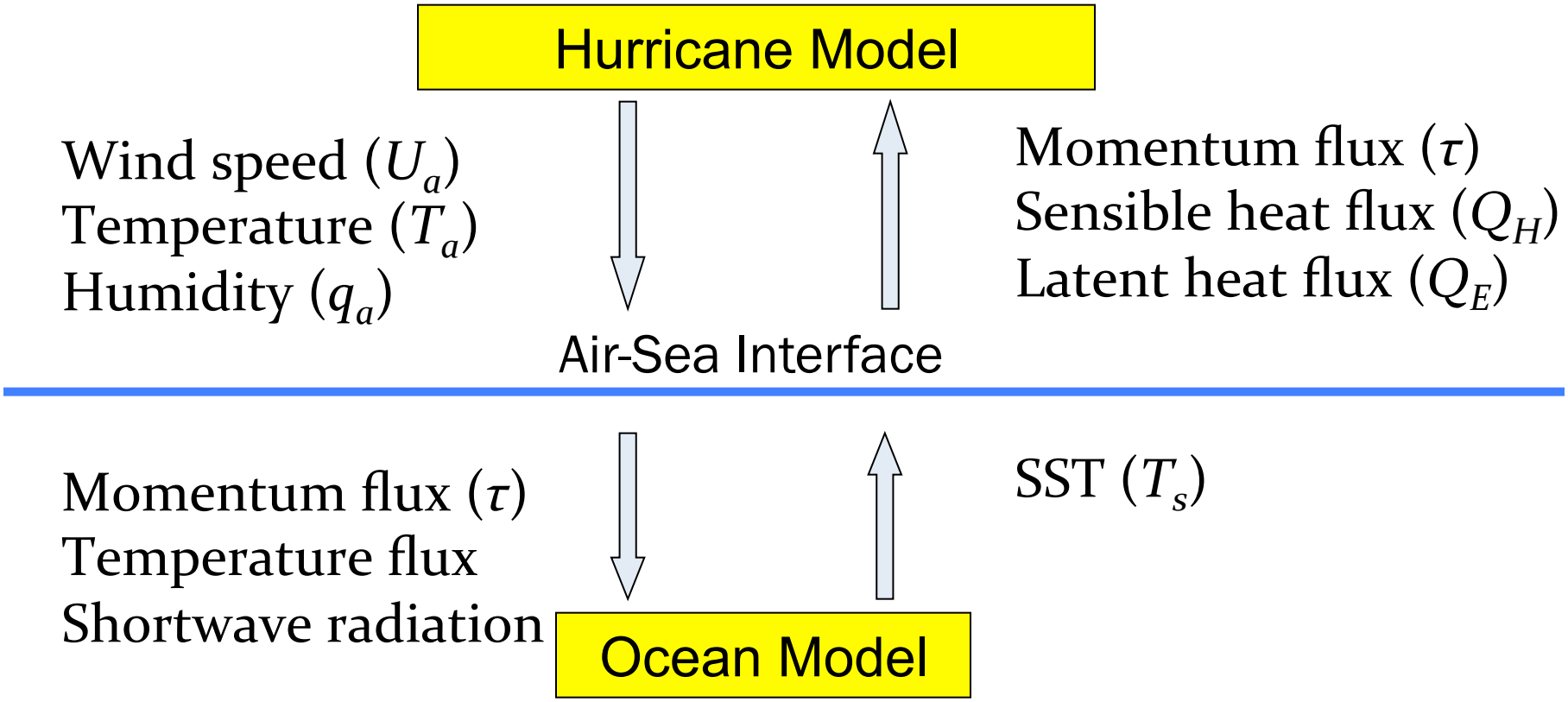
75-m depth temperature
Courtesy R. Yablonsky (URI)



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

Includes feature based initialization for warm and cold core rings

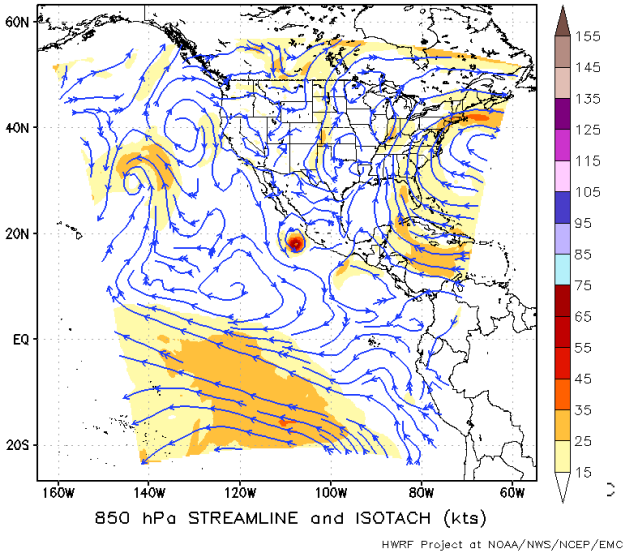
NCEP coupler handles communication between WRF and MPIPOM-TC

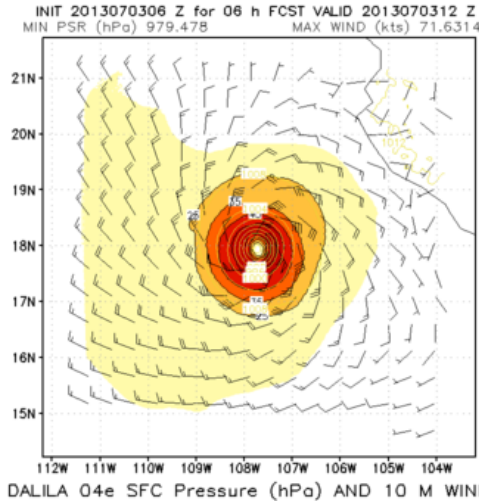


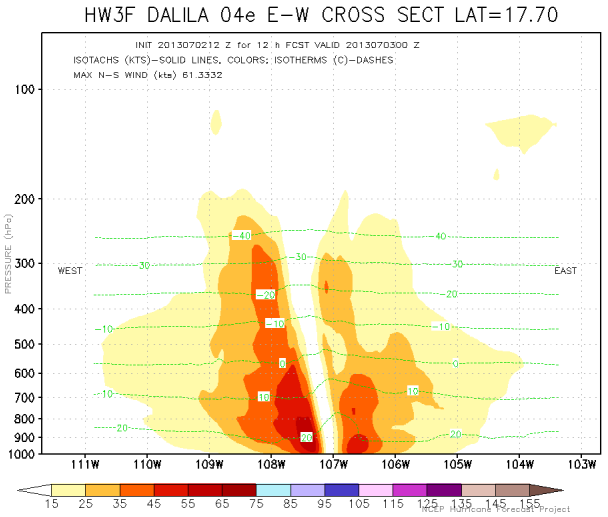
HWRF Post-Processing

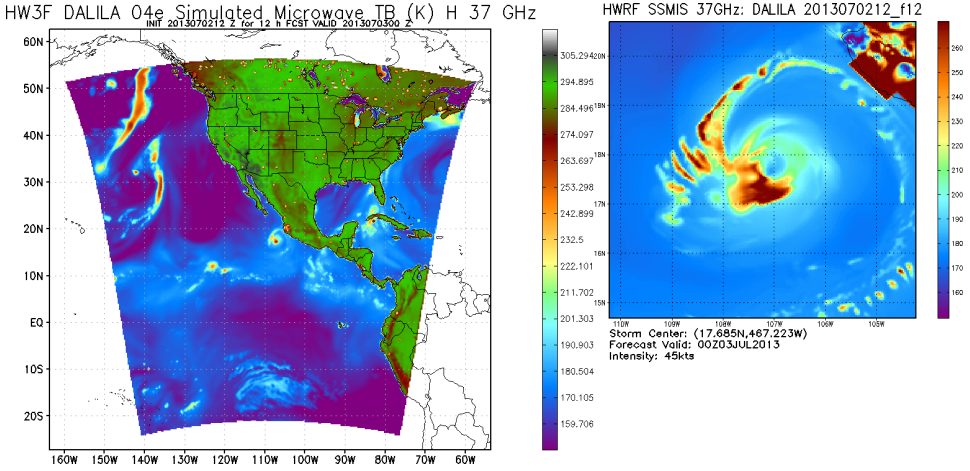
- Uses the Unified post-processor (UPP)
  - Interpolates the forecast
    - Horizontally from the WRF native grid to a lat-lon grid
    - Vertically from WRF native levels to isobaric levels
  - Generates output in GRIB format
  - Computes derived variables
- Domains processed separately, then combined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

Surface or isobaric fields



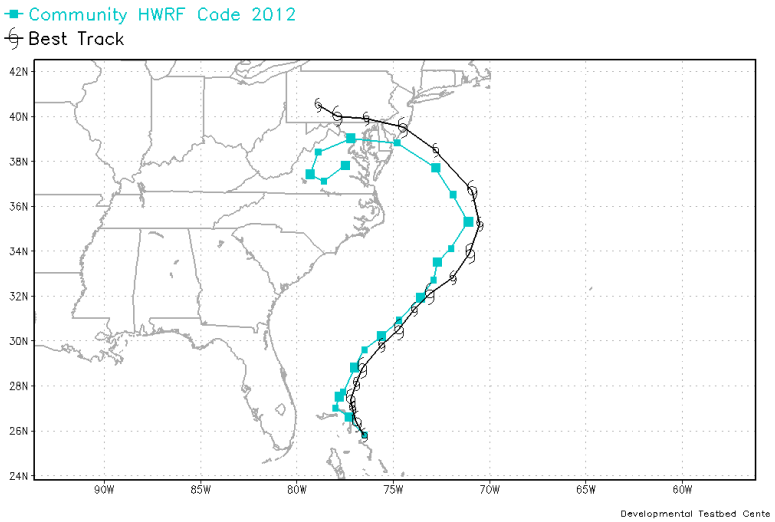






GFDL External Vortex Tracker

- 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

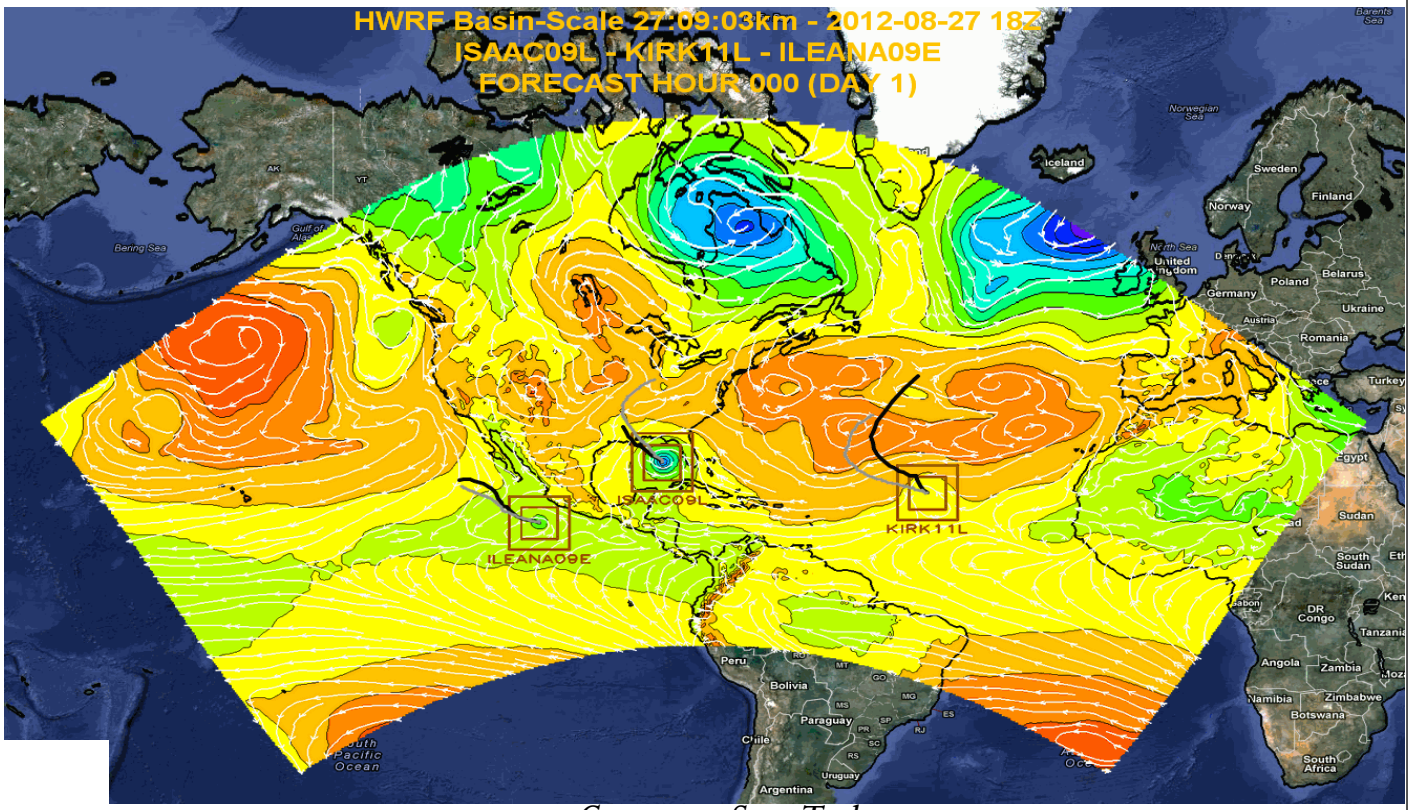
FY15 HWRF Upgrades

- **System & Resolution Enhancements**
  - Pure Python scripting system, identical to DTC public release.
  - GFS model upgrades significantly degraded TC forecasting skill
  - *Increase HWRF atmospheric horizontal resolution from 27/9/3 to 18/6/2 km.*
- **Initialization/Data Assimilation Improvements**
  - Upgrade and improve HWRF vortex initialization scheme.
  - Upgrade Data Assimilation System: Hybrid HWRF-based EnKF and GSI system.
    - *40 member 6hr forecast ensemble for forecast error covariances (TDR only)*
- **Physics Advancements**
  - Upgrade microphysics: Ferrier-Aligo
  - Upgrade GFDL radiation to RRTMG scheme
    - Partial sub-gridscale cloudiness and space-time varying ozone.
  - Upgrade surface physics and PBL, momentum exchange coefficient (Cd)
  - Upgrade current GFDL slab model to NOAH LSM.
- **First time in 2015….**
  - *Run HWRF in all TC basins worldwide*

Courtesy: Sam Trahan

Basin-Scale HWRF Model

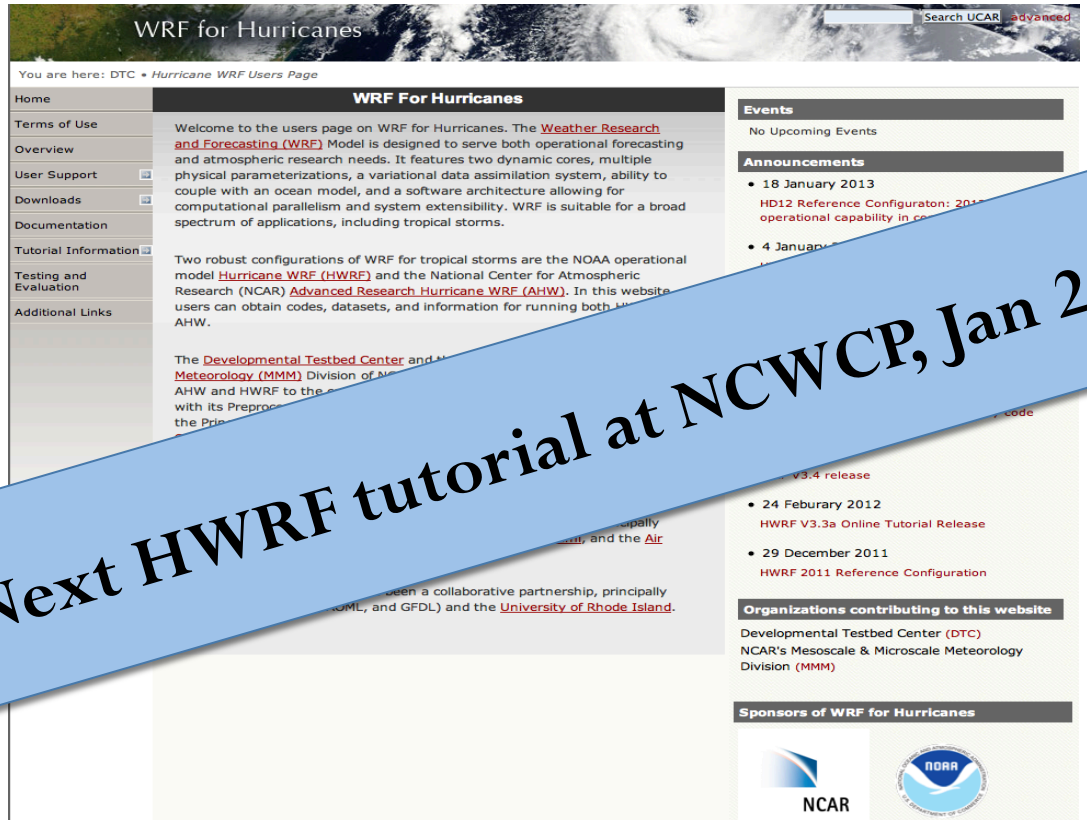
- Large domain, multiple storms within.
- Expect improved track after system is fully developed



Courtesy: Sam Trahan

www.dtcenter.org/HurrWRF/users

Community support



Next HWRF tutorial at NCWCP, Jan 25-27, 2016

Code downloads, datasets, documenta[illegible], online [illegible]sk

[illegible]egistered users

Yearly releases corresponding to operational model of the year

Stable, tested code

Current release: HWRF v3.6a (2014 operational)

Upcoming release August, 2015: HWRF v3.7a (2015 operational)

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

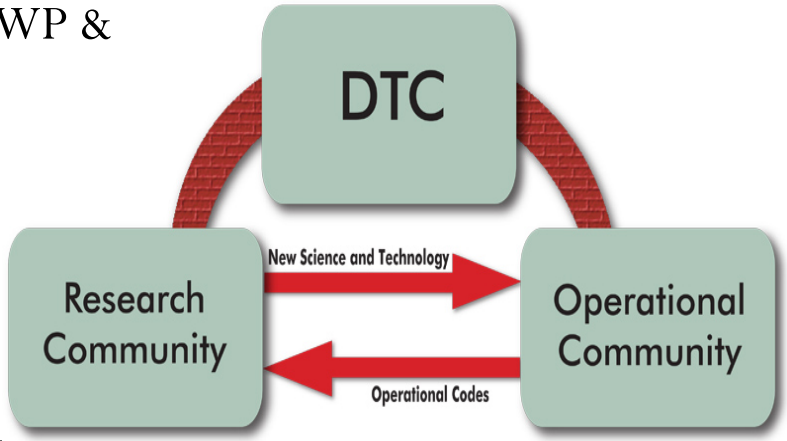
Institution	Role
NOAA NWS Natl Hurricane Center	Main customer, evaluation, diagnostics
NOAA NWS/NCEP/EMC	Coordination and overall development
NOAA Research AOML/ESRL/GFDL	Nesting, physics, initialization, vortex tracking, diagnostics
NCAR	WRF model infrastructure
University of Rhode Island	Ocean component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

DTC (NOAA, Air Force, NSF, & NCAR)

The purpose of the DTC is to facilitate the interaction & transition of NWP technology between research & operations. DTC facilitates:

- R2O transition by performing testing & evaluation of new NWP innovations over an extended period and moving them for possible operational implmentation
- O2R transition by making the operational NWP systems available to the research community & providing user support (WRF, HWRF etc.)

- Interaction between research & operations through the organization of community workshops on NWP & hosting DTC Visitor Program



Thank you!

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

Dennis, 7/10/2005