Introduction to Hurricane WRF

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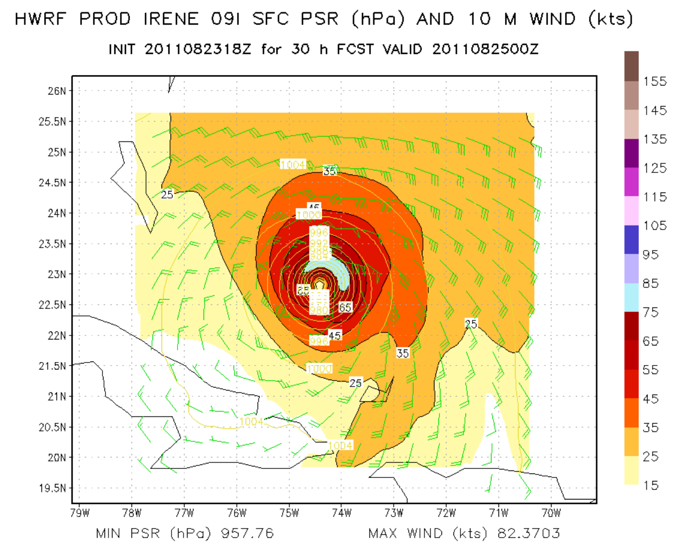
Outline for Introduction to HWRF

- 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

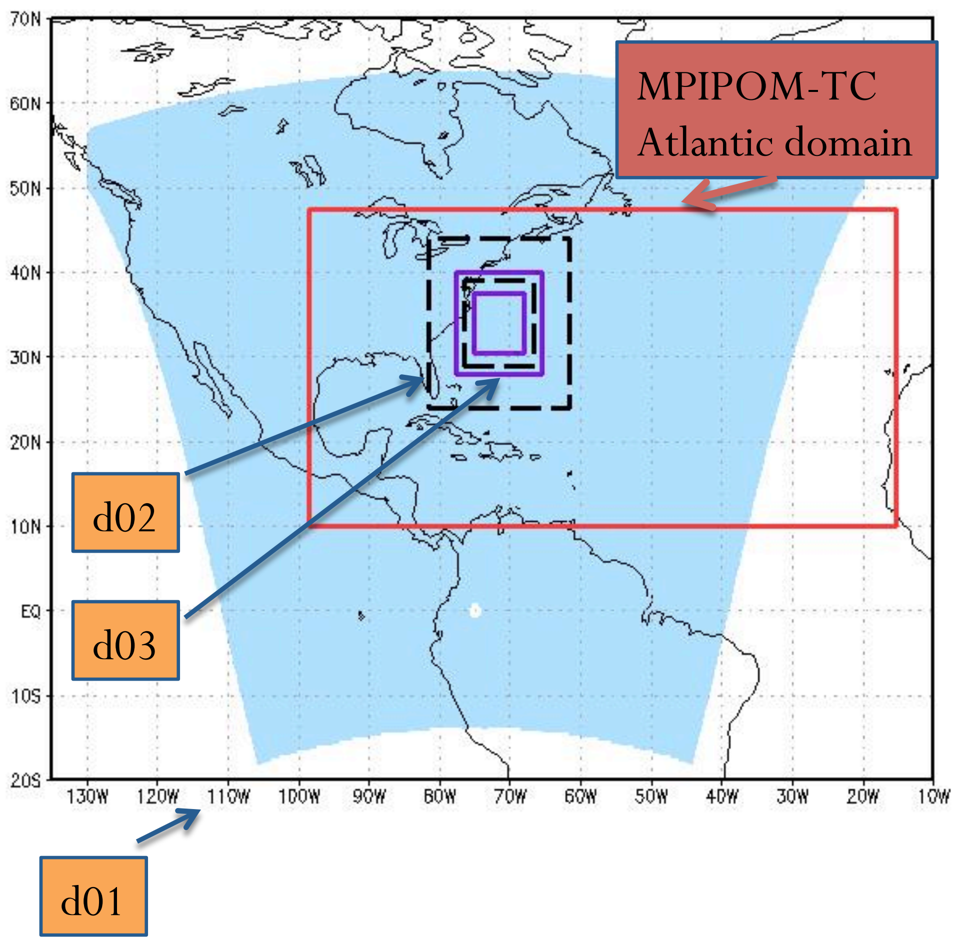


What is the Hurricane WRF?

- 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 (coupled only in AL and EP) 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 plans for future provided)

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

HWRF 2014 grid configuration



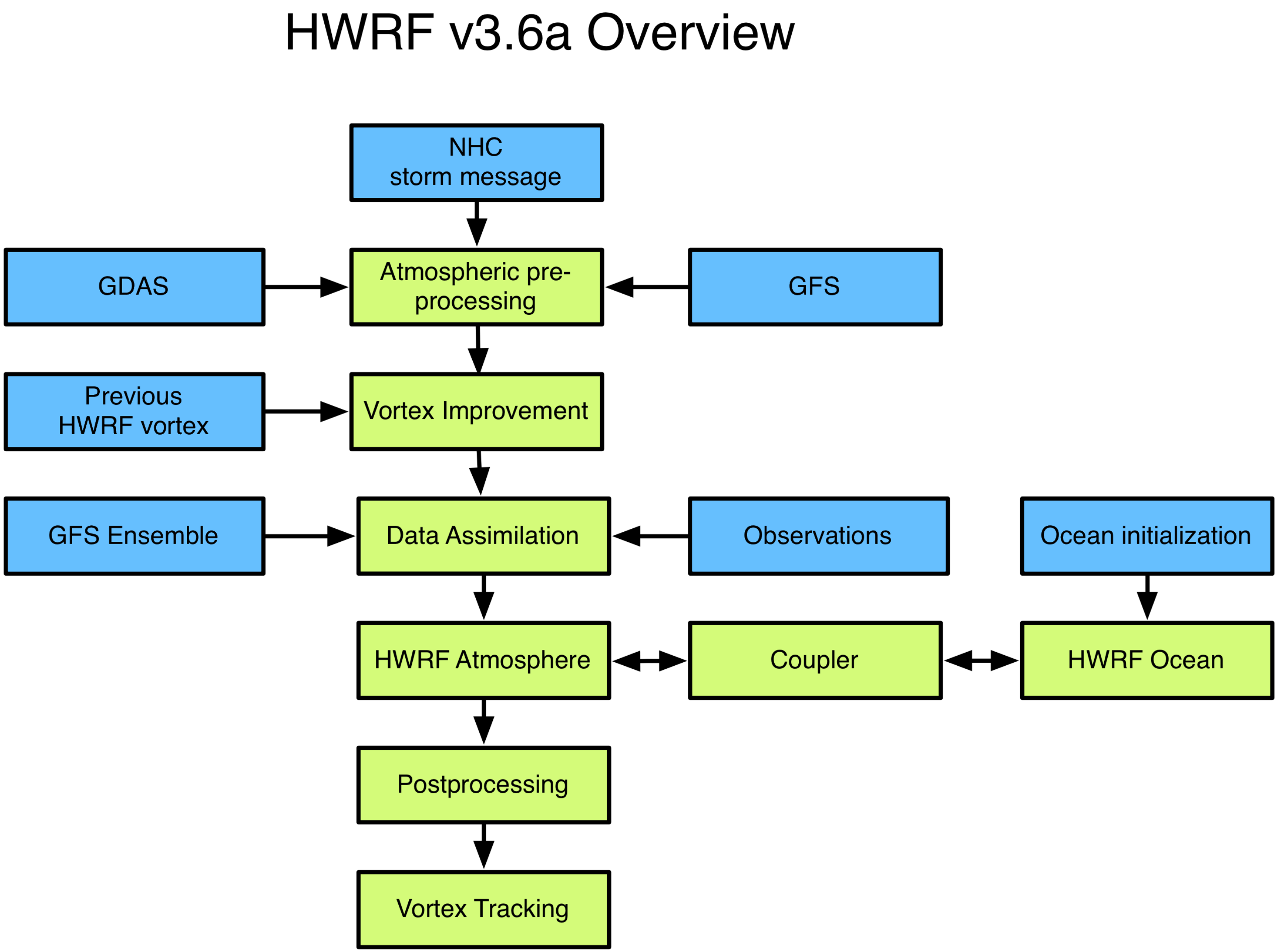
Atmospheric configuration

- 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

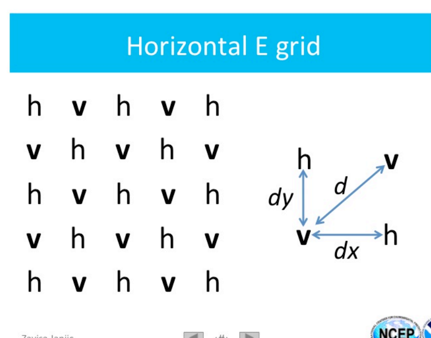
- Horizontal grid spacing: 1/12 deg (~9km)
- Location of grid depends of location of storm
- Atlantic and Pacific
    - 3-D model
    - 23 vertical levels

HWRF has many components

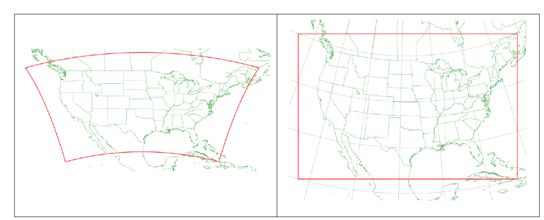


HWRF dynamical core

- 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

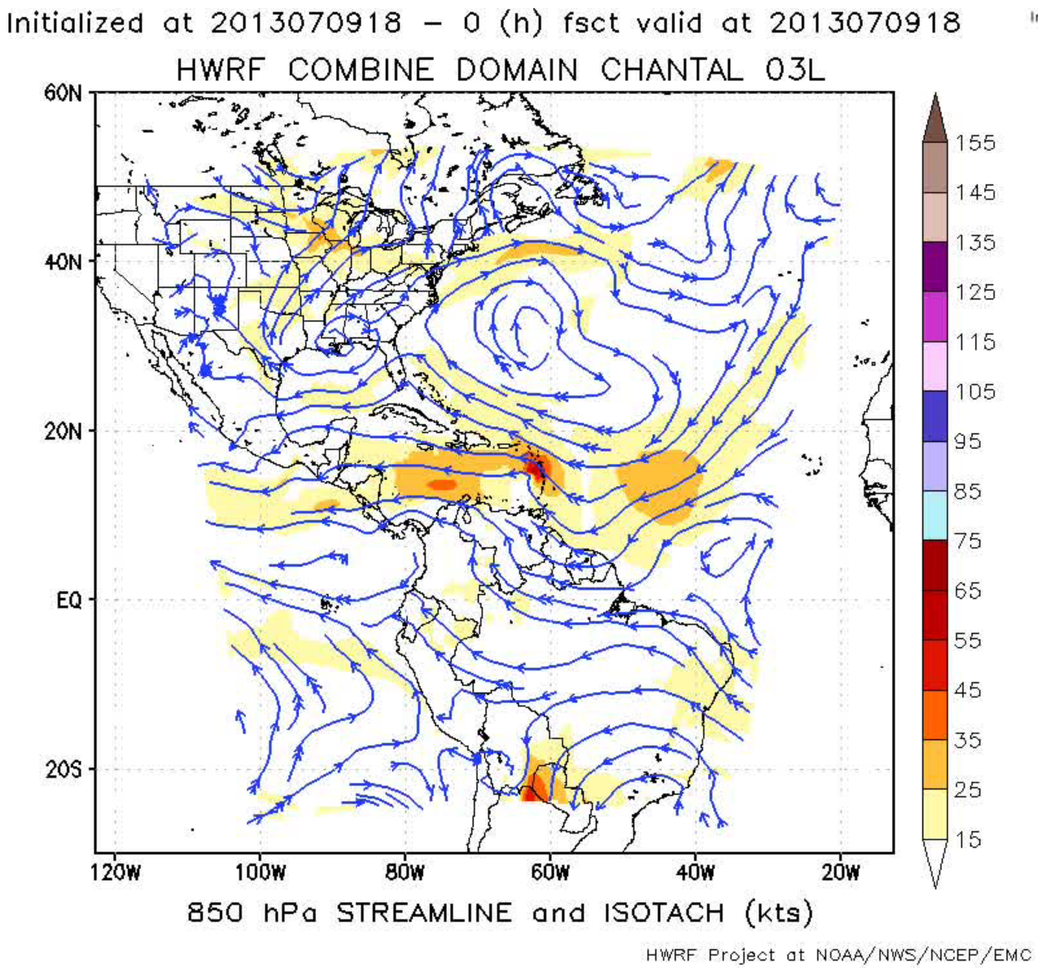


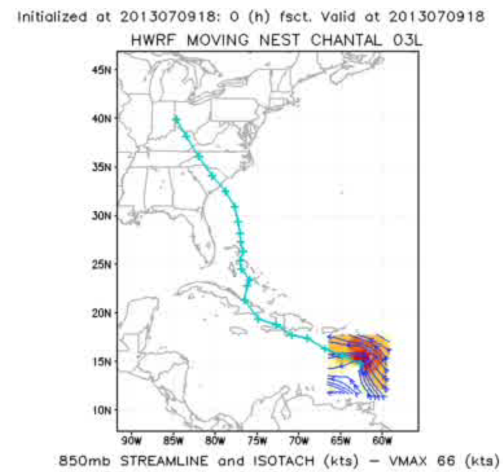
On a regular lat-lon map background

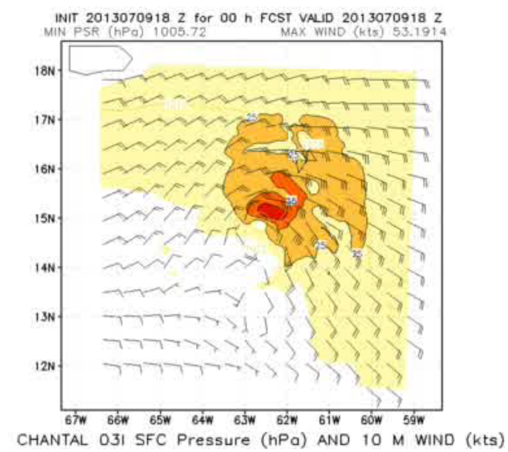
On a rotated lat-lon map background (same rotation as model grid).

Courtesy: Z. Janjic NOAA/NCEP/EMC

HWRF Moving Nests

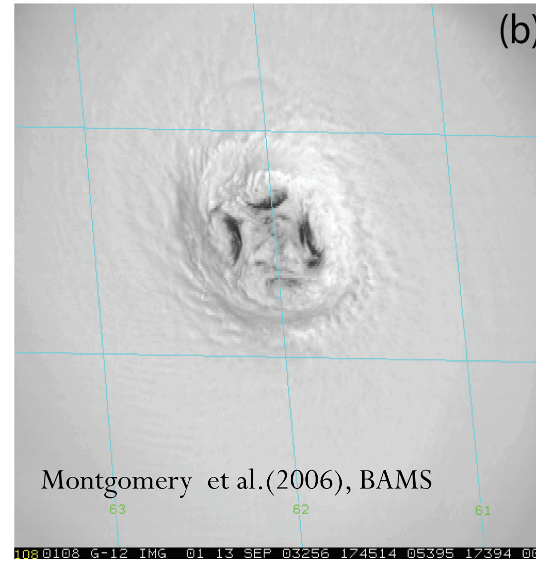






Inner nest follows the vortex

- Why nests: need high-resolution to resolve convection in hurricane but cannot afford it everywhere in domain
- 27-km parent domain does not move during a run
- 9-km domain moves following the 3-km domain, which follows storm center
- A vortex tracking algorithm is used to track the center of the storm and automatically move the nest
- The storm center is determined based on surface p, winds and 850/700 hPa geopotential/winds
- Straight forward for well-defined vortices
- Challenge: following disorganized TS and mesovortices, so tracking algorithm is sophisticated



Montgomery et al.(2006), BAMS

Chantal, 7/8/2013

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/Hybrid Ensemble

$$J_{3DVAR}(\mathbf{x}') = \underbrace{\frac{1}{2}(\mathbf{x}')^{\mathbf{T}}\mathbf{B}_{\mathbf{f}}^{-1}(\mathbf{x}')}_{\text{Fit to background}} + \underbrace{\frac{1}{2}(\mathbf{Hx}' - \mathbf{y}')^{\mathbf{T}}\mathbf{R}^{-1}(\mathbf{Hx}' - \mathbf{y}')}_{\text{Fit to observations}}$$

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

$\mathbf{x}'$: 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

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

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

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

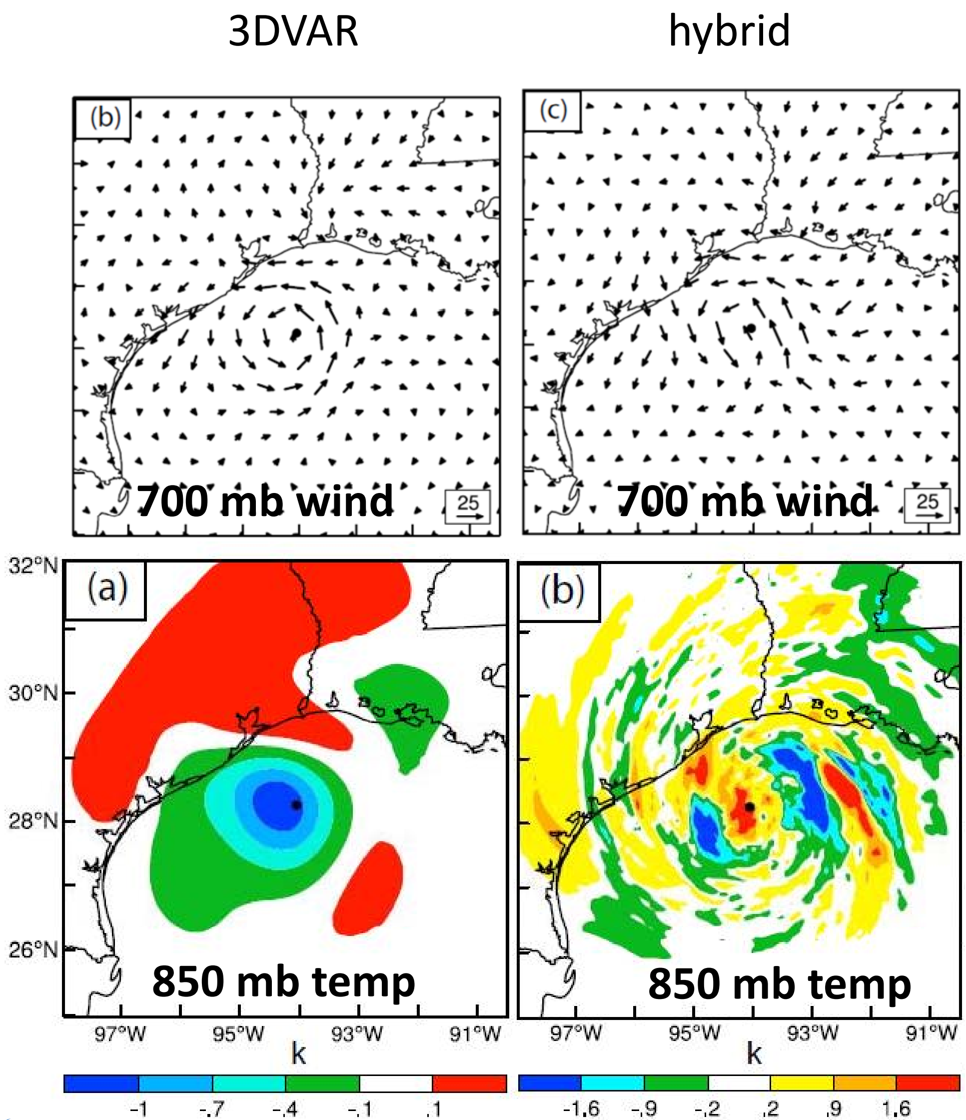
$\mathbf{B}_f$: (Fixed) background-error covariance (estimated offline)

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

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

(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 2014 operational physics

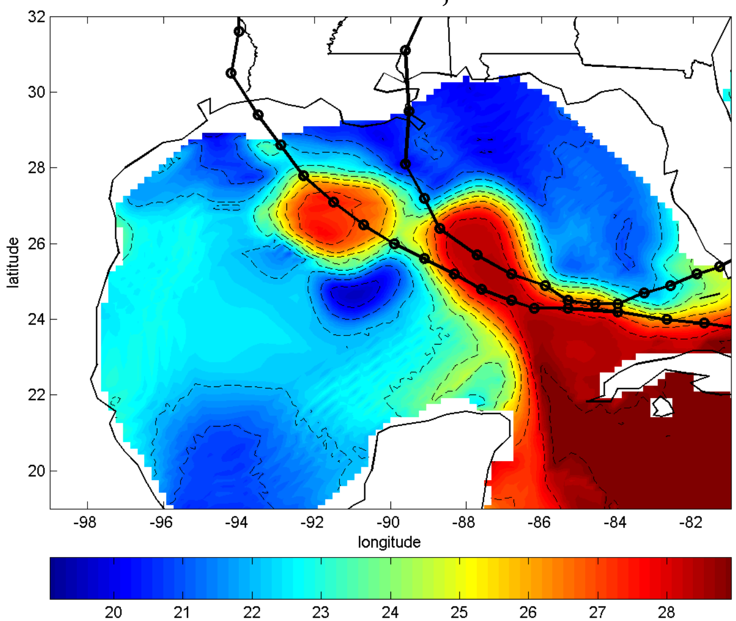
Physics	Parameterization	Option
Cumulus (only d01 & d02)	SAS deep and shallow convection	84
Microphysics	Ferrier for the tropics	85
Planetary Boundary Layer	GFS (modified Hong & Pan 1996)	3
Surface Layer	GFDL (modified)	88
Land Surface Model	GFDL slab model	88
Radiation	GFDL	98

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

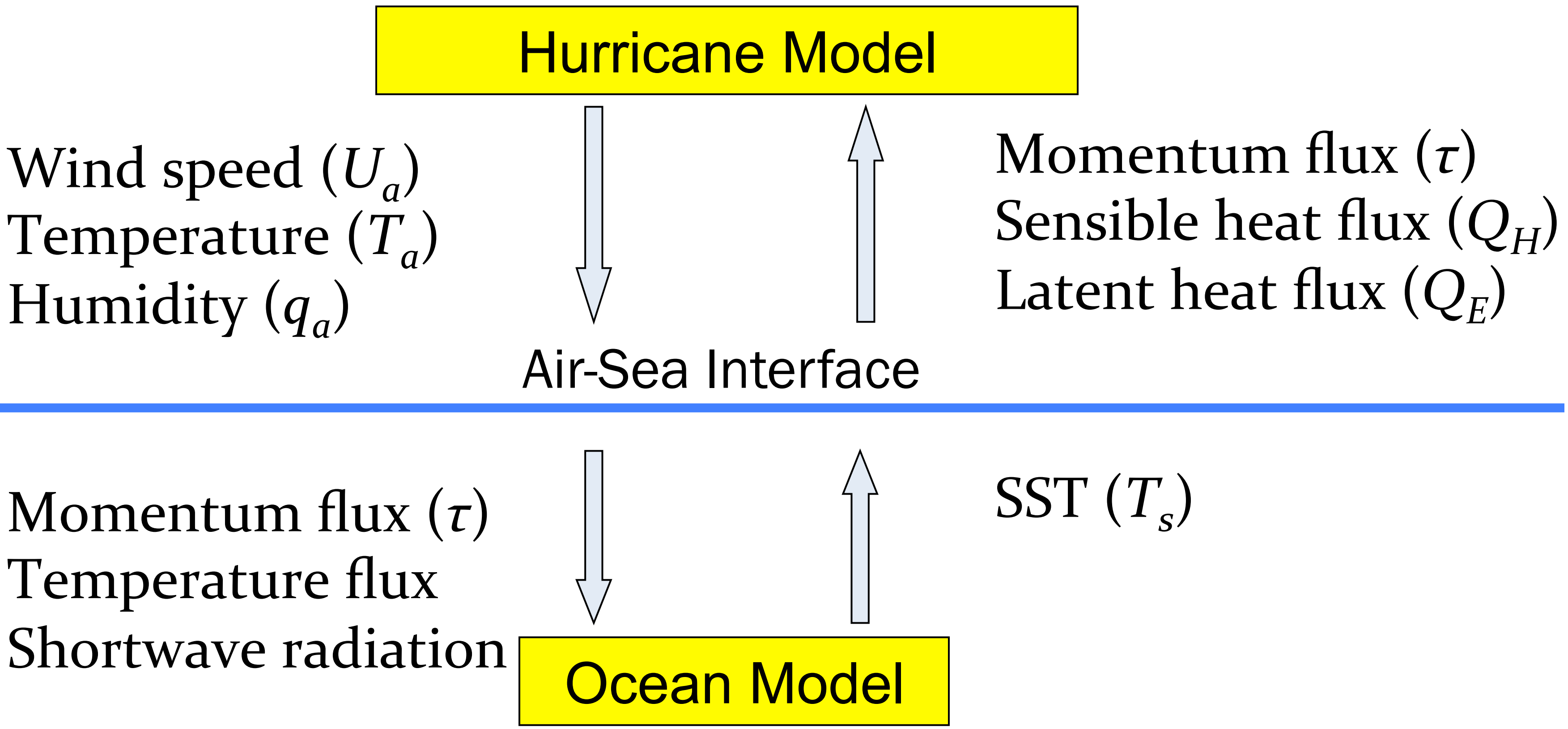
Rita Katrina, 2005



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

Warmer ocean leads to more intense storms

NCEP coupler handles communication between WRF and POM-TC

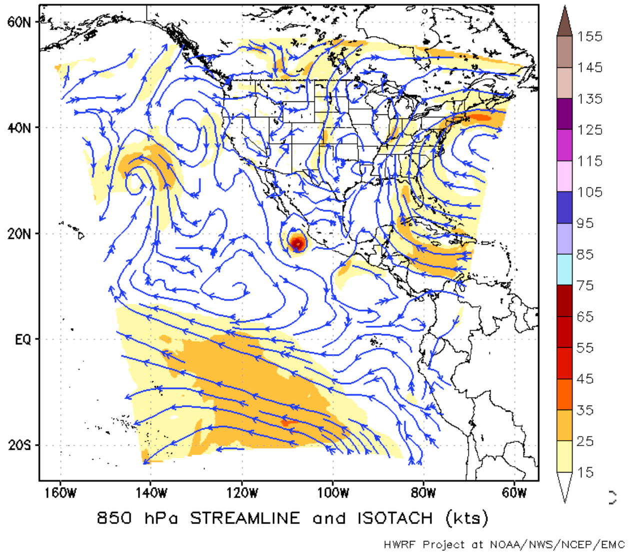


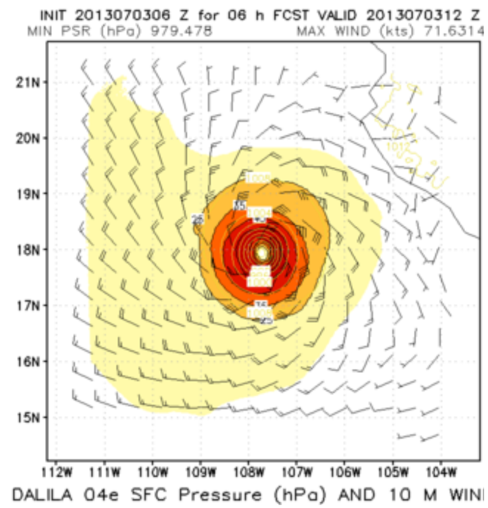
$$\tau = \rho_a C_D U_a U_a \qquad Q_H = C_H U_a \left(T_a - T_s\right) \qquad Q_E = \frac{L_V}{C_P} C_E U_a \left(q_a - q_s\right)$$

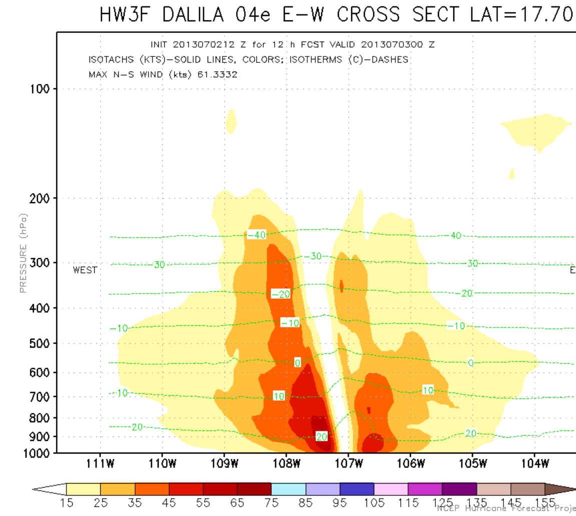
HWRF Post-Processing

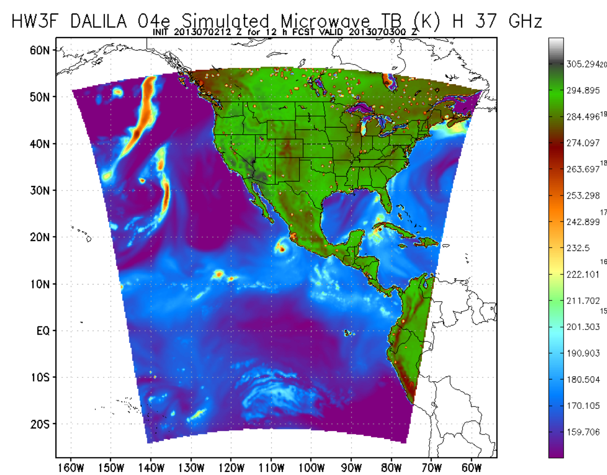
- Uses the Unified post-processor (UPP)
  - Computes derived variables
  - Interpolates the forecast
    - Horizontally from the WRF native grid to a lat-lon grid
    - Vertically from WRF native levels to isobaric levels
  - Generates output in GRIB format
- Domains processed separately, then combined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

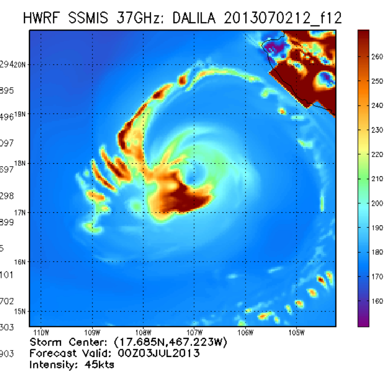
Surface or isobaric fields





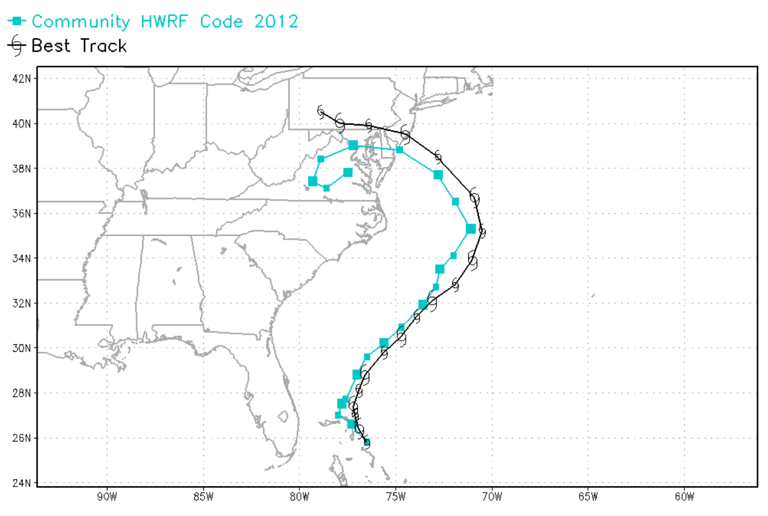


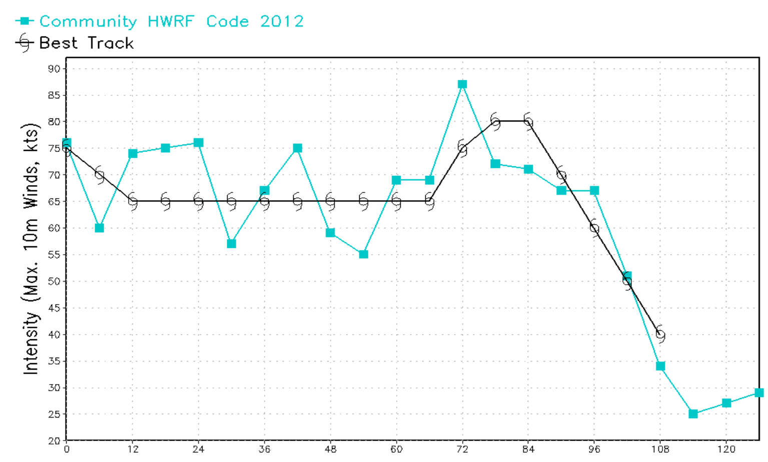




GFDL External Vortex Tracker

- 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



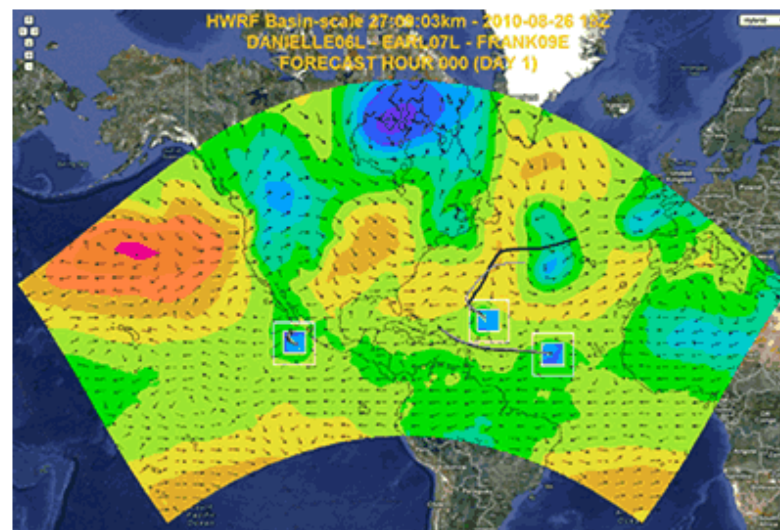


Sandy 2012: Sample of Community HWRF runs by DTC

DTC
Developmental Testbed Center

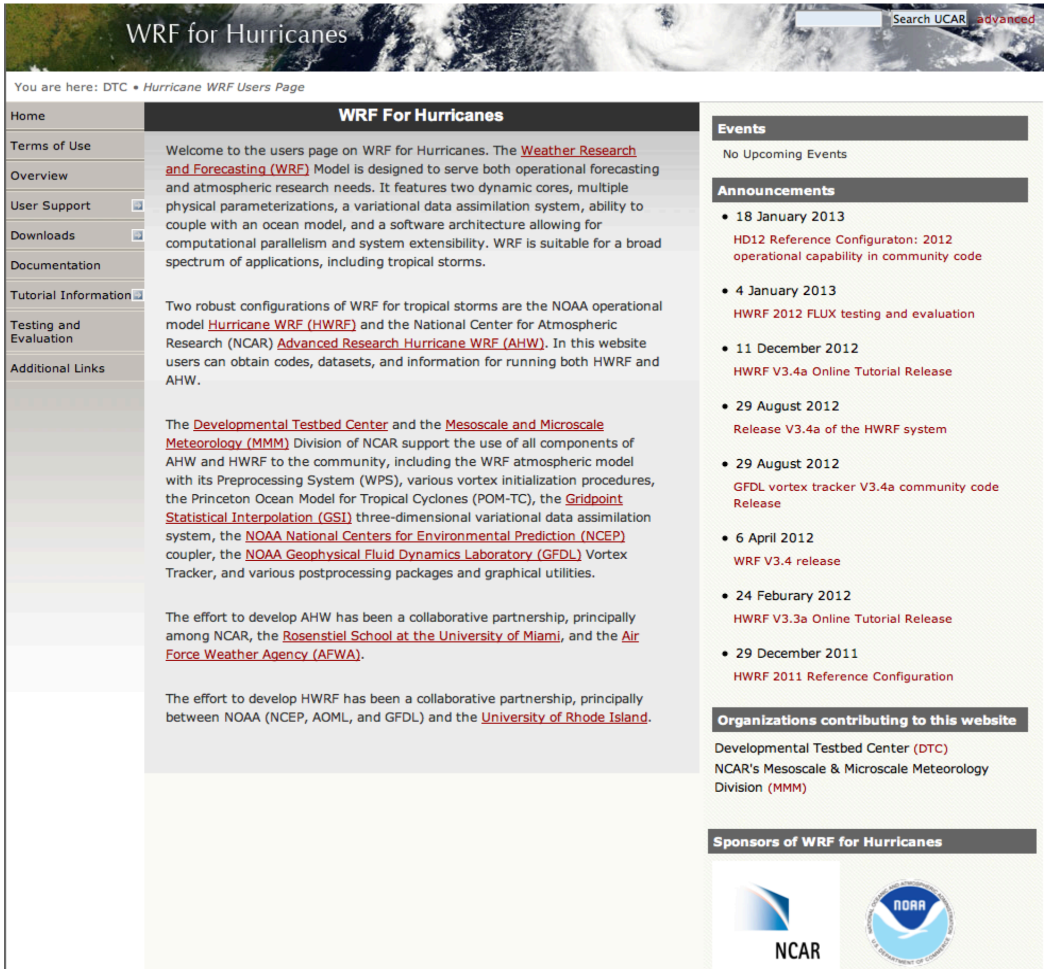
Challenges and ongoing work for 2015 and beyond

- **Increased resolution:** Going to 18/6/2 km, use of T1534 GFS
- **Global application:** Coupling of MPIPOM-TC for all ocean basins
- **Ocean:** HYCOM
- **Ensemble**: Data assimilation to include 40 member HWRF ensemble for inner-core DA
- **Physics:** radiation (RRTMG), PBL, NOAH LSM, MP (Ferrier-Aligo), convection, sea spray
- **Coupling**: wave model, storm surge, inundation
- **Configuration:** larger grids with multiple moving nests



www.dtcenter.org/HurrWRF/users

Community support



WRF for Hurricanes

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- Tutorial Information
- Testing and Evaluation
- Additional Links

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

800 registered users

Yearly releases corresponding to operational model of the year

Stable, tested code

Current release: HWRF v3.6a (2014 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

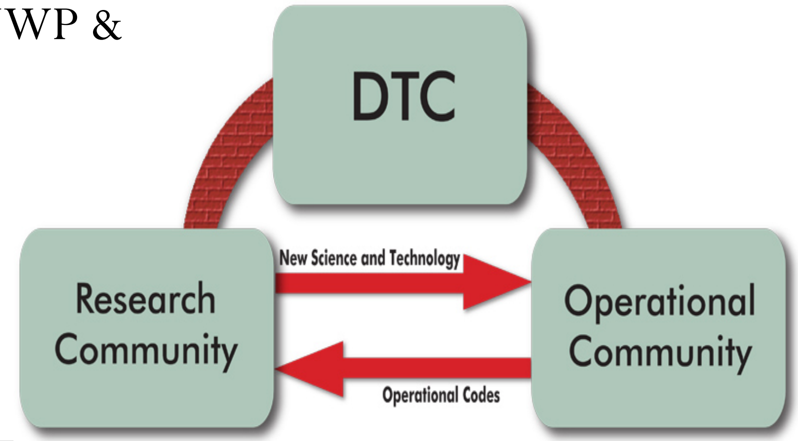
Institution	Role
NOAA NWS Natl Hurricane Center	Main customer, evaluation, diagnostics
NOAA NWS/NCEP/EMC	Coordination and overall development
NOAA Research AOML/ESRL/GFDL	Nesting, physics, initialization, vortex tracking, diagnostics
NCAR	WRF model infrastructure
University of Rhode Island	Ocean component (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