Hurricane WRF: 2016 Operational Implementation and Community Support

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HWRF Overview

- HWRF is the NCEP operational hurricane model providing model guidance to global tropical cyclones
- It is an air-sea coupled system specialized for hurricane forecasting
- Built within WRF infrastructure
- Based on WRF-NMM dynamic core
 - Rotated lat-lon
 - Arakawa E-grid
 - Hybrid sigma-pressure coordinate
 - Triple nested vortex following domains



HWRF Forecast SANDY18L INIT:2012102518 at 000 h

Triple nested (18-6-2km) domains



Highlights of FY2016 HWRF Upgrades

- Infrastructure Enhancements
 - Upgrade dynamic core from WRF3.6a to WRF3.7.1a (with bug fixes)
 - Increase the size of nested domains and reduce the time step (dt=30 s vs. 38 4/7 s)
 - T&E with new 2016 4D-Hybrid GDAS/GFS IC/BC
- Vortex Initialization/Data Assimilation Improvements
 - Turn off blending of vortex initialization and GSI analysis for weak storms (Vmax < 50 kts)
 - GSI upgrades with new data sets (CrIS, SSMI/S, METOP-B changes)
 - Turn on DA for all storms in the EPAC basin (along with the NATL basin)

Physics Advancements

- Implement new GFS-EDMF PBL scheme with observation based K profile
- Upgrade to new scale-aware SAS convection scheme for all domains
- Update surface scheme with modified momentum and enthalpy exchange coefficients (Cd/Ch)

• Air-Sea Interaction and Coupling

- Enable ocean coupling for CPAC, WPAC and NIO (all NH basins)
- Utilize RTOFS (instead of GDEM climatology) data for POM initialization for EPAC basin
- Implement one-way coupling to wave model (Hurricane Wave Model)
- Post-Processing and Product Upgrades
 - Include additional simulated synthetic imagery from different satellite sensors
 - Update HWRF website with new graphics (e.g., radar reflectivity, oceanic and surface wave parameters, etc.)



2016 HWRF Infrastructure Enhancements

Larger nested domains and smaller time steps

size (deg) dt (sec)	18 km	6 km	2 km
2015	75x75	12x12	6.5x7
HWRF	38 4/7	12 6/7	4 2/7
2016	75x75	25x25	8.3x8.3
HWRF	<mark>30</mark>	10	3 1/3

2015 HWRF 6km Domain





2016 HWRF 6km Domain



2016 HWRF Vortex Initialization and Data Assimilation Upgrades

- Turn on DA for all storms in the EPAC basin (along with the NATL basin)
- Turn off blending of vortex initialization and GSI analysis for weak storms (Vmax < 50 kts)
- Enable satellite DA on ghost d03
- Satellite data usage changes:
 - Adding assimilation of CrIS (JPSS), SSMIS, Metop-B AMSU-A, Metop-B MHS and IASI
 - Change from assimilation to monitor: NOAA 19 AMSU-A Channel 7;
 NOAA 18 AMSU-B Channel 5, 8; NOAA 19 HIRS4; NOAA 19 MHS channel 3; GOES sounder; SEVIRI Meteosat-10
 - Modified channels used for cloud detection: NOAA 15 AMSU-A; Metop-A AMSU-A; NOAA 18 AMSU-B; HIRS/3; HIRS/4; AQUA AMSU-A; ATMS; GOES sounder; IASI



2016 HWRF Physics Upgrades

	2015	2016	Improvements
Microphysics	Ferrier-Aligo	Ferrier-Aligo	
Convection	SAS in d01 & d02	Scale-aware SAS	Scale-aware SAS deep/shallow convection scheme in all domains
PBL	GFS PBL with K profile adjustment	GFS EDMF PBL with adjusted K profile	Observation based and height- dependent K profile in PBL Fix the discontinuity of K near surface Better wind profile in PBL
Radiation	RRTMG	RRTMG	
LSM	Noah LSM	Noah LSM	
Surface	GFDL surface layer with 2015 Cd/Ch	GFDL surface layer with 2016 Cd/Ch	Independent of lowest model level height Better low level winds
Horizontal diffusion	COAC values of 0.75, 3, 4	COAC values of 0.75, 1, 1.2	Reduce horizontal length scale to be more consistent with higher resolution



2016 HWRF Configurations for Different TC Basins

Basin	Ocean Cpling	Wave Cpling	Data Assimilation	Ensemble DA	Vertical	Тор
NATL	3D POM GDEM	WW3 1-way	Always	TDR Only	61 level	2 mb
EPAC	3D POM RTOFS	WW3 1-way	Always	TDR Only	61 level	2 mb
CPAC	3D POM GDEM	None	None	None	61 level	2 mb
WPAC	3D POM GDEM	None	None	None	43 level	50 mb
NIO	3D POM GDEM	None	None	None	43 level	50 mb
SIO	None	None	None	None	43 level	50 mb
SPAC	None	None	None	None	43 level	50 mb

- Enable ocean coupling for CPAC, WPAC and NIO (all NH basins)
- Utilize daily RTOFS (instead of GDEM climatology) data for POM initialization for EPAC basin
- Implement one-way coupling to wave model (intend to replace the standard-alone hurricane wave model)
- Turn on DA for all EPAC storms



POM RTOFS Initialization for EPAC Blanca 02E2015





HWRF: POM Forecast for BLANCA02E Init: 2015060218 F000



EQ

135w 130w 125w 120w 115w 110w 105w 100w 95w

9ÓW

2016 HWRF for Blanca 02E2015 Impact of POM RTOFS Initialization





2016 HWRF One-Way Coupling to WW3 Edouard 06L2014

HWRF: WW3 Forecast for EDOUARD06L Init: 2014091300 F000





Evaluation of 2016 HWRF for NATL (2013-2015 storms and 2012 Sandy)



HWRF FORECAST – TRACK FORECAST SKILL (%) STATISTICS VERIFICATION FOR NATL BASIN 2013-2015



HWRF FORECAST - INTENSITY RELATIVE SKILL (%) STATISTICS VERIFICATION FOR NATL BASIN 2013-2015





Evaluation of 2016 HWRF for EPAC (2014-2015)



HWRF FORECAST - TRACK FORECAST SKILL (%) STATISTICS VERIFICATION FOR EPAC BASIN 2014-2015



HWRF FORECAST - INTENSITY RELATIVE SKILL (%) STATISTICS VERIFICATION FOR EPAC BASIN 2014-2015



2016 HWRF Performance for Rapid

Intensification Storms in EPAC





NNAF

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- For RI storms in EPAC, DA and ٠ POM RTOFS initialization gave improved performance for intensity skill (both error and bias)
- Impact on track is neutral
- Results very similar to GFDL model



Evaluation of 2016 HWRF for WPAC (13-25W2015)



Impacts of 2016 HWRF upgrades with ocean coupling







Impact of Ocean Coupling for Soudelor (13W2015, 2015080112Z)

H215 no ocean coupling

H216 with ocean coupling

HWRF: POM Forecast for SOUDELOR13W Init: 2015080112 F000

HWRF forecast for SOUDELOR (13W) at 2015080112





HWRF: POM Forecast for SOUDELOR13W Init: 2015080112 F000





SST (Celsius degree)



H216 forecast: SOUDELOR (wp132015) Maximum 10-m wind time series



8 10 12 14 16 18 20 22 24 26 27 28 29 30 31 32 6



Successful R2O in FY2016 HWRF Upgrades

- This upgrade is a result of multi-agency R2O efforts supported by HFIP.
- <u>EMC/NCEP</u>: Key model physics upgrades, including GFS-EDMF PBL scheme, eddy diffusivity K adjustment, scale-aware convection scheme; computational efficiency; and pre-implementation T&E
- <u>DTC/NCAR</u>: Community support including code management; Thompson microphysics experiment; icloud=3 bug fix
- <u>HRD/AOML</u>: Help in adjusting surface exchange coefficients and eddy diffusivity K profile in PBL
- <u>URI</u>: RTOFS initialization for EPAC basin; ocean coupling for NH basin storms; one-way wave coupling
- **<u>GFDL</u>**: Knowledge sharing
- <u>NHC/CPHC/JTWC/NWS-PR</u>: Diagnostics and evaluation of the HWRF pre-implementation tests and real-time guidance



Developmental Testbed Center Support

www.dtcenter.org/HurrWRF/users



You are here: DTC • Hurricane WRF Users Page

Home	WRF For Hurricanes	Events	
Terms of Use	Welcome to the users page on WRF for Hurricanes. The Weather Research		
Overview	and Forecasting (WRF) Model is designed to serve both operational forecasting and atmospheric research needs. It features two dynamic cores	16th WRF Users Workshop 06.27.2016 to 07.01.2016	
User Support	multiple physical parameterizations, a variational data assimilation system,	Location: NCAR Center Green Campus, Boulder, Colorado	
Downloads 🔤	ability to couple with an ocean model, and a software architecture allowing for computational parallelism and system extensibility. WRF is suitable for a		
Documentation	broad spectrum of applications, including tropical storms.	Announcements	
Idealized		31 August 2015 Release v3 Za of the HWRE system	
Tutorials & Workshops	operational model <u>Hurricane WRF (HWRF)</u> and the National Center for	Release vs.va or the HWRE System	
Testing and	Atmospheric Research (NCAR) Advanced Research Hurricane WRF (AHW). In	Organizations contributing to this website	
Evaluation	both HWRF and AHW.	Developmental Testbed Center (DTC)	
HWRF Developers Info		NCAR's Mesoscale & Microscale Meteorology	
Additional Links	The <u>Developmental Testbed Center</u> and the <u>Mesoscale and Microscale</u>		
	AHW and HWRF to the community, including the WRF atmospheric model	Sponsors of WRF for Hurricanes	
	with its Preprocessing System (WPS), various vortex initialization procedures, the Princeton Ocean Model for Tropical Cyclones (MPIPOM-TC)		
	the <u>Gridpoint Statistical Interpolation (GSI)</u> three-dimensional ensemble-		
	variational data assimilation system, the <u>NOAA National Centers for</u> Environmental Prediction (NCEP) coupler, the NOAA Geophysical Fluid		
	Dynamics Laboratory (GFDL) Vortex Tracker, and various postprocessing	NCAR	
	and products utilities.	And Sector of Co.	
	The effort to develop AHW has been a collaborative partnership, principally	National Center for National Oceanic and	
	among NCAR, the <u>Rosenstiel School at the University of Miami</u> , and the	(NCAR) (NOAA)	

Yearly releases, code downloads, datasets, documentation, online tutorial, helpdesk

1200+ registered users

Stable, tested code

Benchmarks available

Support to HWRF developers in code management



Current release: HWRF v3.7a (2015 operational) August 2015 **Next release:** HWRF v3.8a (2016 operational) August 2016

Developmental Testbed Center



HWRF community code

HWRF public release

- End-to-end atmosphere-ocean coupled HWRF system corresponding to operational model of the year
 - Freely available and fully supported
- Additional research capabilities
 - Idealized tropical cyclone
 - 27/9/3 domain configuration
 - Alternate physics schemes



P74: Biswas et al.

HWRF developer support

DTC provides specialized support for HWRF developers using repository code

Streamlines transition of new developments to the HWRF model

DTC visitor program

The DTC is interested in engaging with the community about new developments that could be evaluated for HWRF

http://www.dtcenter.org/visitors/

P75: Bernardet et al.

2016 HWRF Forecast Website

<u>http://www.emc.ncep.noaa.gov/HWRF</u> - HWRF forecast guidance, all year round

Will be updated in Mid July together with the 2016 HWRF implementation





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25

23

22

22 🔚

21 21

15

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146 Pageviews: 198,375 Flags Collected: 151

24

23 23 More than 198,000 page views from more than 150 regions all over the world, since last May

MCINCEP



Summary of FY2016 HWRF Upgrades

- Triple-nested storm-following domains based on WRF infrastructure with increased size for the two nested domains and reduced model time step
- Hybrid ENKF-3DVAR data assimilation for both NATL and EPAC storms
- Further improvements to model physics:
 - EDMF based GFS PBL with observation based K profile
 - Scale-aware SAS convection for all domains
 - Improved surface physics with new Cd/Ch
- Ocean coupling for storms in CPAC, WPAC and NIO (all NH basins)
- POM RTOFS initialization for EPAC instead of GDEM climatology
- One-way coupling to WW3 for NATL and EPAC basins



Thank you!

Real-time operational HWRF model guidance for global TCs

http://www.emc.ncep.noaa.gov/HWRF



Summary of 2016 HWRF Evaluation

- Total H216 retrospective evaluation of 2012-2015 hurricane seasons (total 571 verifiable cycles in NATL, 888 in EPAC, 211 in CPAC, 353 in WPAC, 52 in NIO) demonstrated improved track/intensity forecasts compared to FY15 operational HWRF (H215)
- Results from H216 for the Atlantic basin and the Central Pacific suggested additional 5-10% improvement compared to H215.
- Results from H216 for the Eastern Pacific basin suggested a modest (~5%) improvement in intensity forecasts is shown possible from 2015 operational HWRF. Use of DA and RTOFS for ocean initialization should help in RI cases.
- Results from H216 for the West Pacific basin suggested additional 5-10% improvement for track forecasts, more than 20% improvement in intensity forecasts, compared to H215;
- Results from H216 for the Northern Indian basin suggested average of ~23% improvement in track forecasts from 2015 operational HWRF, and neutral impact before 72h and degradation at day 4 and 5 in intensity forecasts with limited sample size.



2016 HWRF: Continuing the Trend of Improving NATL Intensity Forecast



Latest version GFS PBL EDMF

 $w'\phi' = local flux + non local flux$

HWRF2015

$$\overline{w'\phi'} = -K\left(\frac{\partial\overline{\phi}}{\partial z} - \gamma\right)$$

Counter-gradient method to represent nonlocal flux

Mass Flux

HWRF2016

$$\overline{w'\phi'} = -K\frac{\partial\phi}{\partial z} + M(\phi_u - \overline{\phi})$$

Local Eddy

Also, TKE-based dissipation heating



K adjustment

- Observations based
- Constant (with z) adjustment, simply multiply K by a coefficient, discontinuous K, big impact on low-level wind.
- Fix: height-dependent adjustment so that K is continuous.

Scale-aware SAS convection scheme

For cumulus convection, a scale-aware parameterization will be necessary for the grid sizes of $500m \sim 10$ km where the strong updrafts are partially resolved.

$$m'_b = (1 - \sigma_u)^2 m_b$$
 Scale function

Based on Arakawa & Wu (2013): $\overline{w'\psi'} = (1 - \sigma_u)^2 \overline{(w'\psi')}_E$

 σ_u : updraft area fraction (0~1.0)

 m_b : original cloud base mass flux from AS quasi-equilibrium closure m'_b : updated cloud base mass flux with a finite σ_u



Surface-layer Cd and Ch

- Reduce Cd for wind > 20 m/
 s
- ✓ Ch is reduced by 5%
- More consistent with
 Observations-derived Cd,
 Ch.
- ✓ Modify current Z0 ~ wind function; Use the standard 10m wind to compute Cd, Ch through Zo.



HWRF VS OBSERVED WIND PROFILES

Upgraded HWRF generates more physically sensible structure.

2016 HWRF for WPAC Storms RI Probability of Detection (13-25W2015)



POD = 0.28 FAR = 0.67

POD = 0.24 FAR = 0.63

HWRF Initialization



Coupled Atmosphere-Wave-Ocean HWRF System



Courtesy to I. Ginis et al. from URI