Hurricane WRF: 2016 Operational Implementation and Community Support

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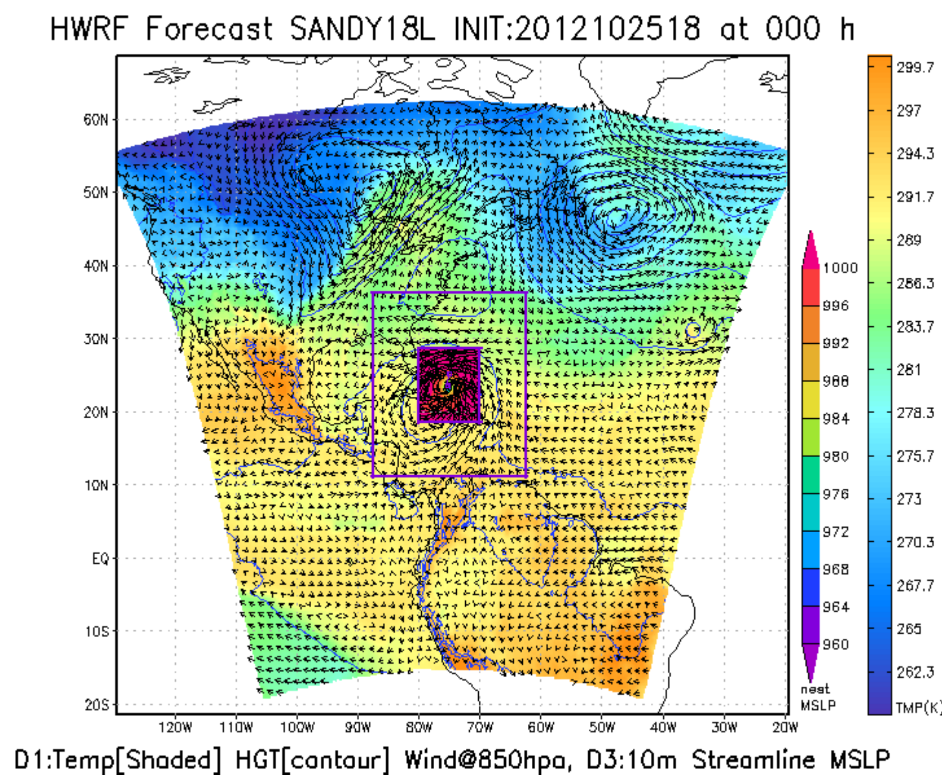
17th WRF Users Workshop, June 27-July 1, 2016

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



Triple nested (18-6-2km) domains

Highlights of FY2016 HWRF Upgrades

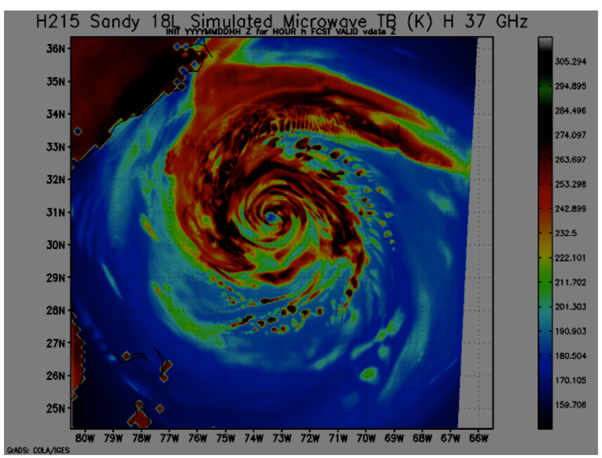
- Infrastructure Enhancements
  - Upgrade dynamic core from WRF3.6a to WRF3.7.1a (with bug fixes)
  - Increase the size of nested domains and reduce the time step (dt=30 s vs. 38 4/7 s)
  - T&E with new 2016 4D-Hybrid GDAS/GFS IC/BC
- Vortex Initialization/Data Assimilation Improvements
  - Turn off 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.)

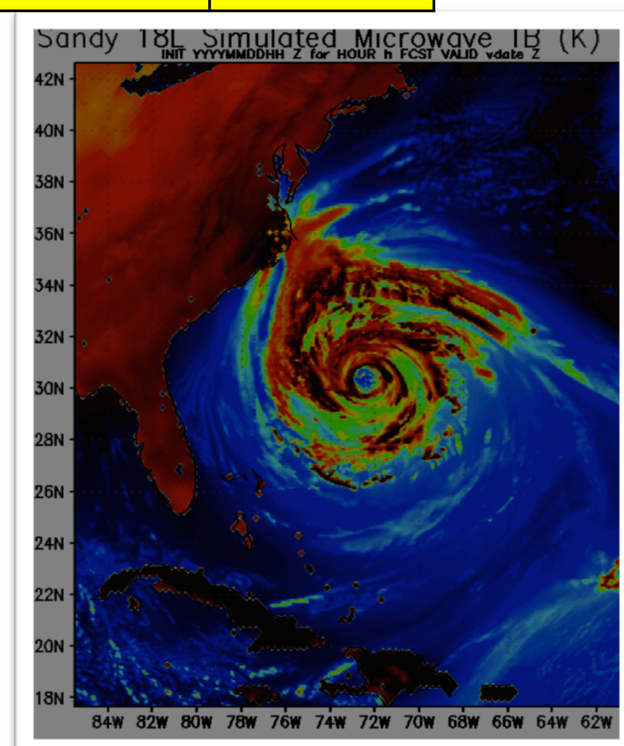
2016 HWRF Infrastructure Enhancements

Larger nested domains and smaller time steps

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

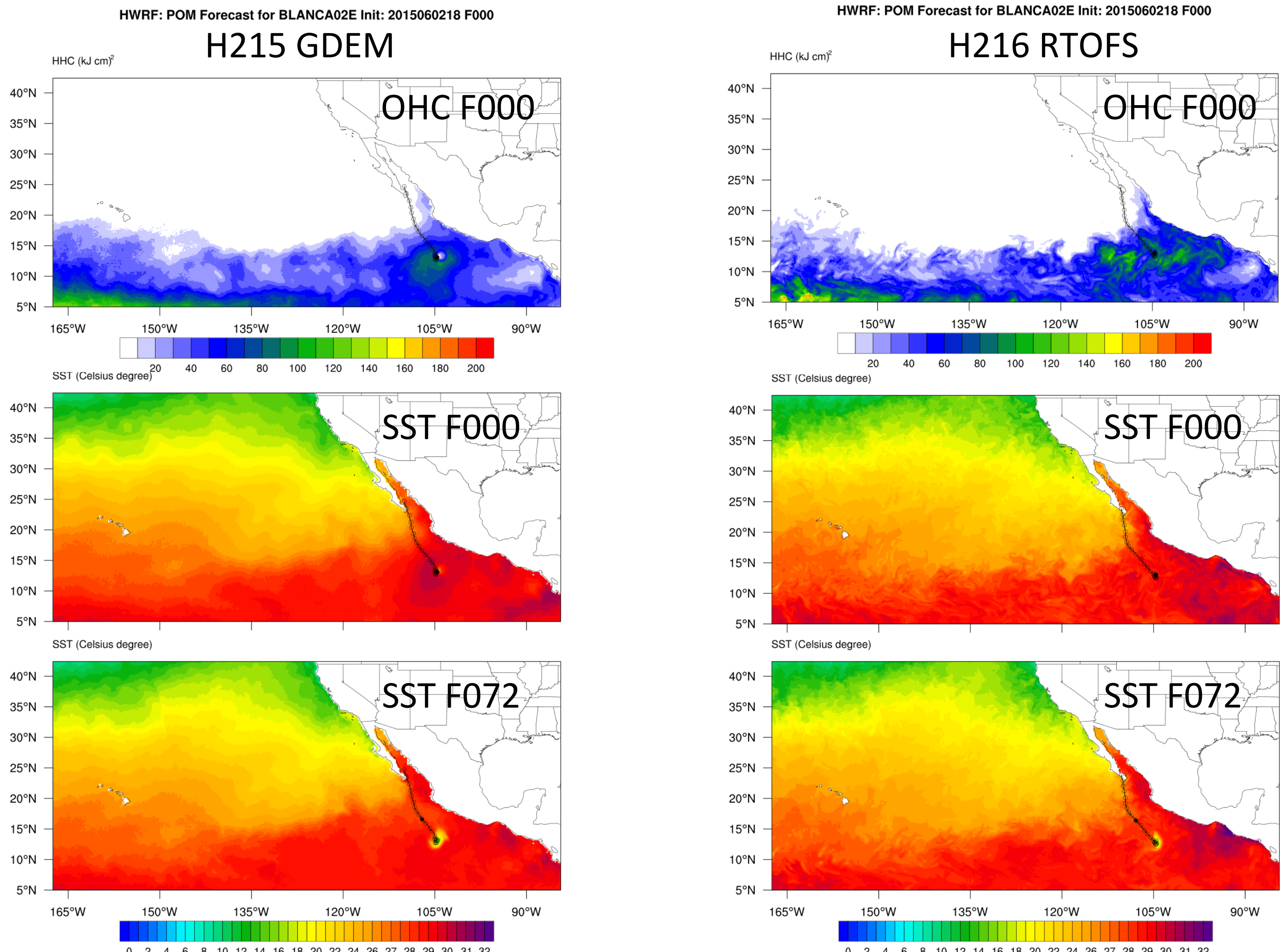
	2015	2016	Improvements
Microphysics	Ferrier-Aligo	Ferrier-Aligo	
Convection	SAS in d01 & d02	Scale-aware SAS	Scale-aware SAS deep/shallow convection scheme in all domains
PBL	GFS PBL with K profile adjustment	GFS EDMF PBL with adjusted K profile	Observation based and height-dependent K profile in PBL 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

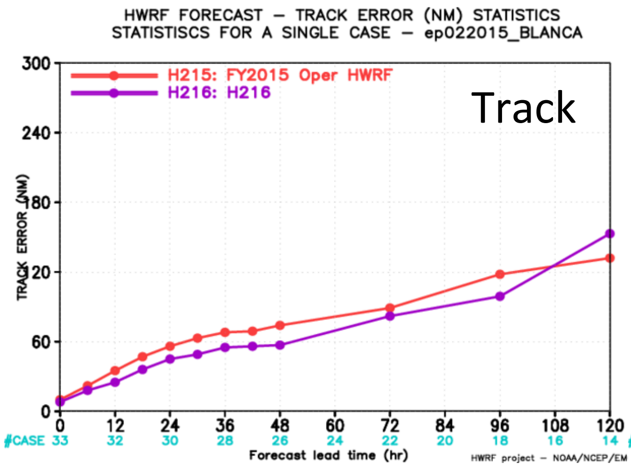
Basin	Ocean Cpling	Wave Cpling	Data Assimilation	Ensemble DA	Vertical	Top
NATL	3D POM GDEM	WW3 1-way	Always	TDR Only	61 level	2 mb
EPAC	3D POM RTOFS	WW3 1-way	Always	TDR Only	61 level	2 mb
CPAC	3D POM GDEM	None	None	None	61 level	2 mb
WPAC	3D POM GDEM	None	None	None	43 level	50 mb
NIO	3D POM GDEM	None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

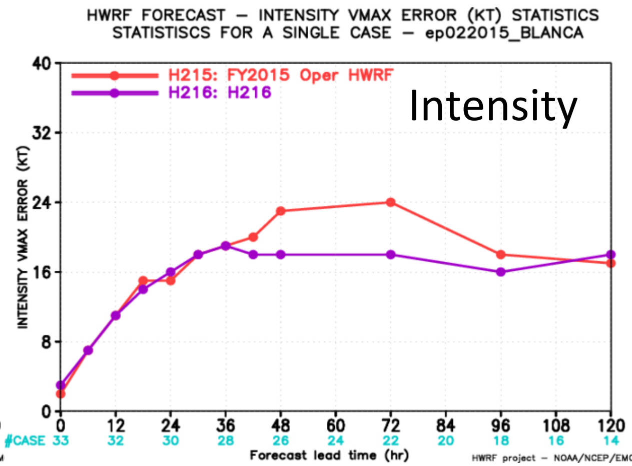
- Enable ocean coupling for CPAC, WPAC and NIO (all NH basins)
- Utilize daily RTOFS (instead of GDEM climatology) data for POM initialization for EPAC basin
- Implement one-way coupling to wave model (intend to replace the standard-alone hurricane wave model)
- Turn on DA for all EPAC storms

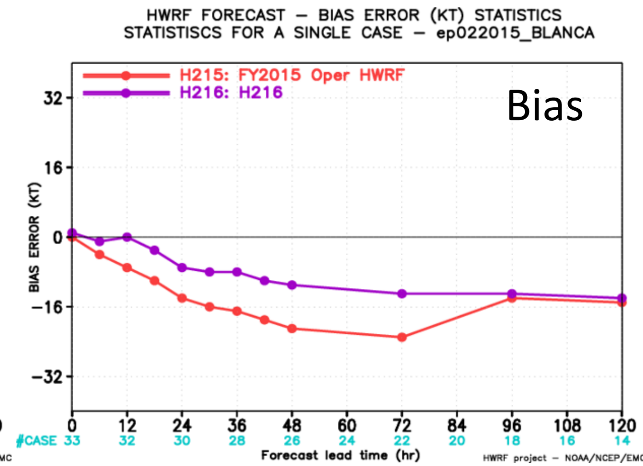
POM RTOFS Initialization for EPAC
Blanca 02E2015

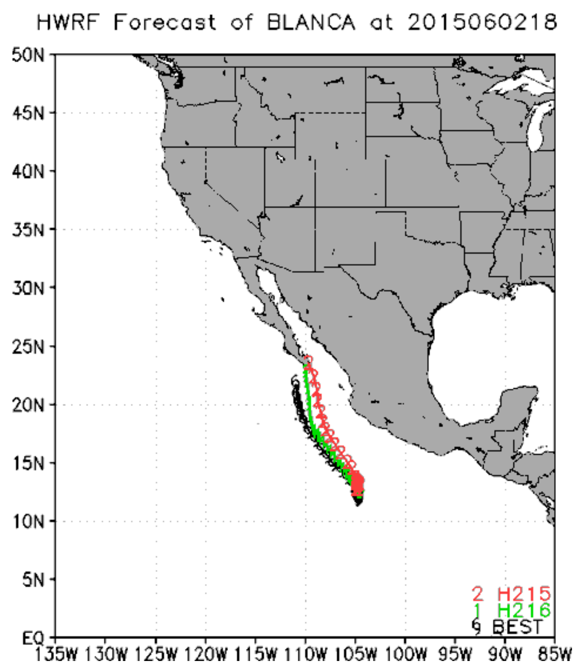


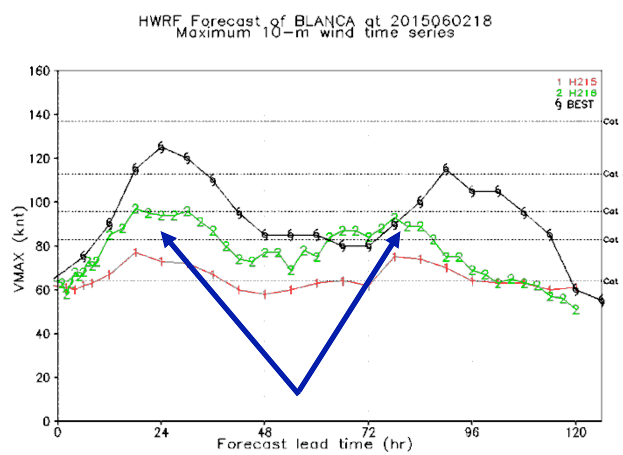
2016 HWRF for Blanca 02E2015
Impact of POM RTOFS Initialization

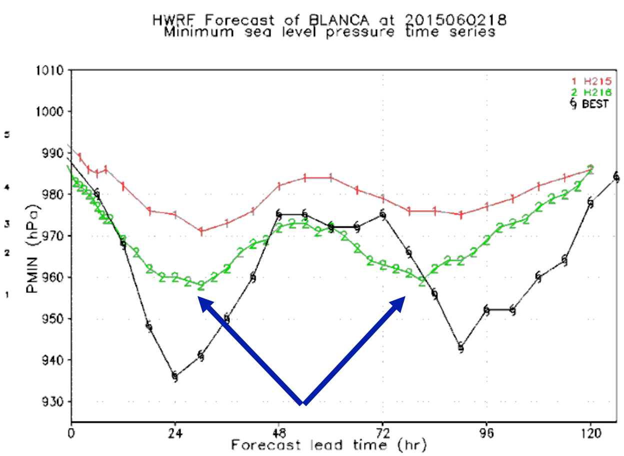




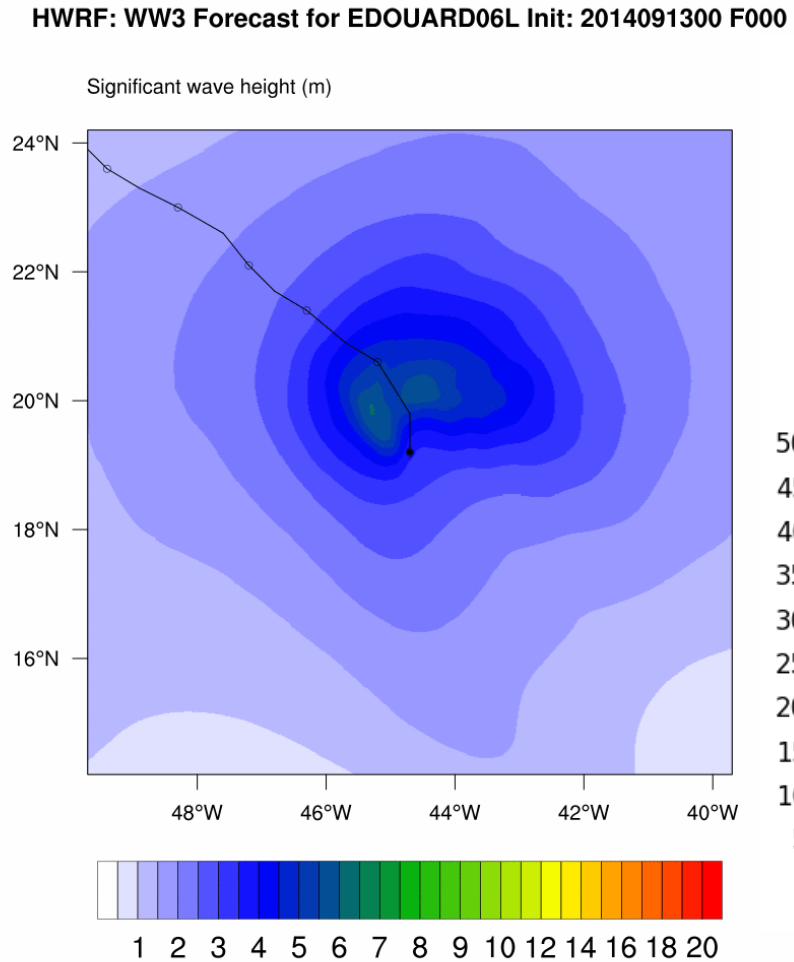


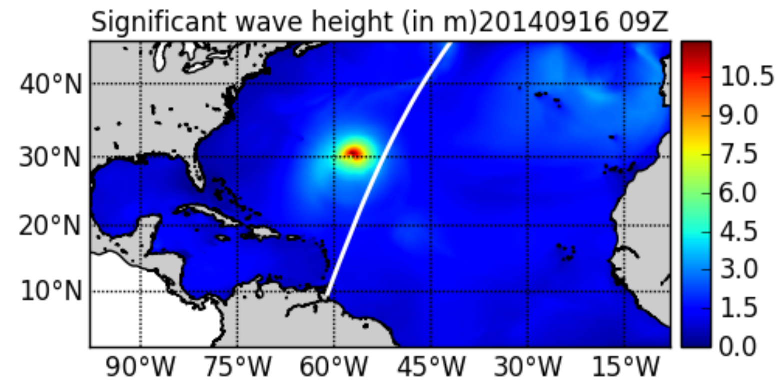


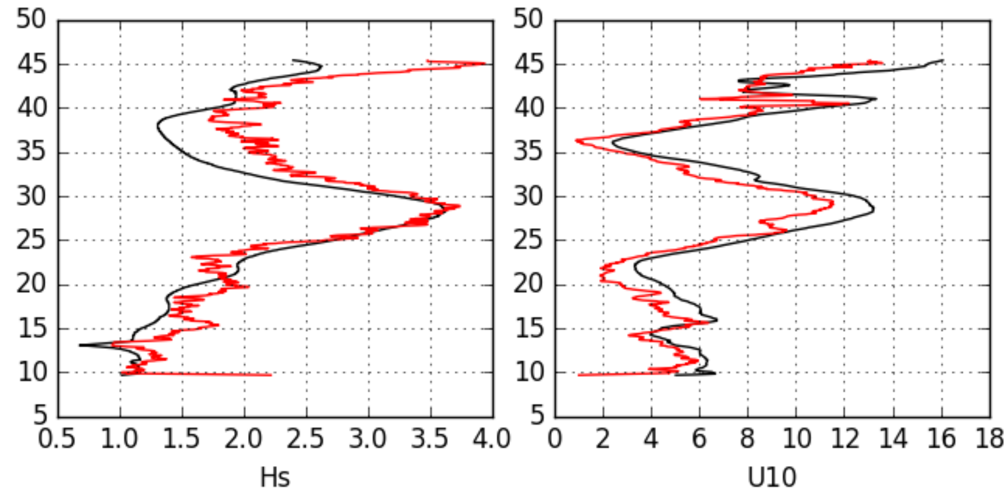




2016 HWRF One-Way Coupling to WW3
Edouard 06L2014

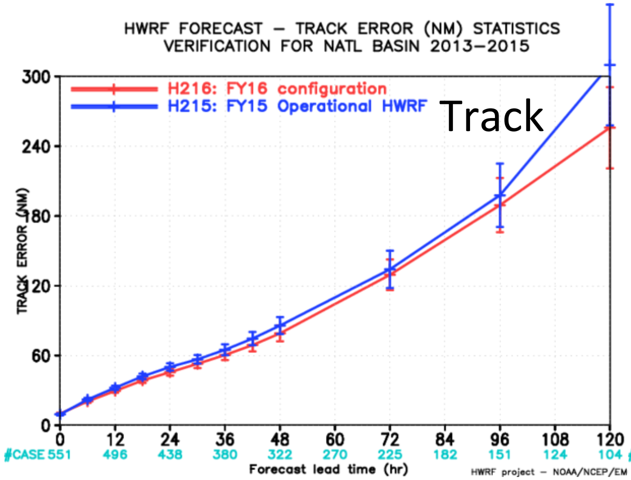


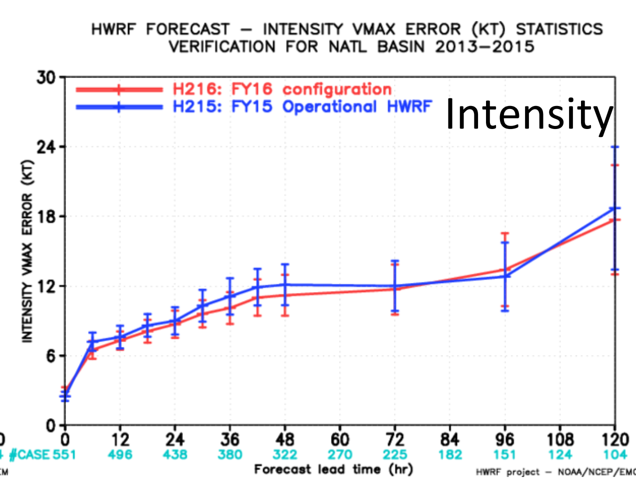


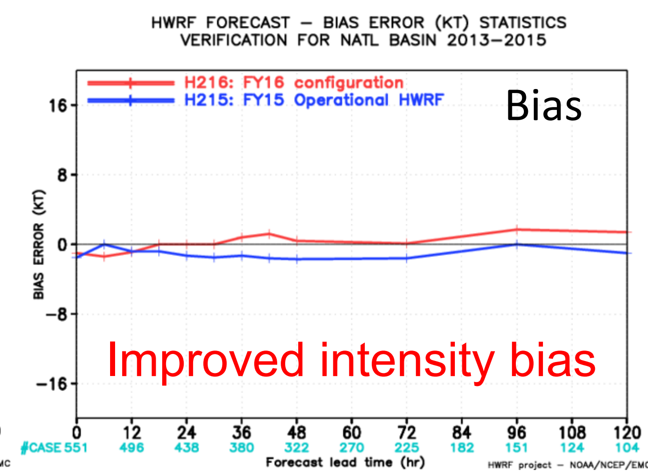


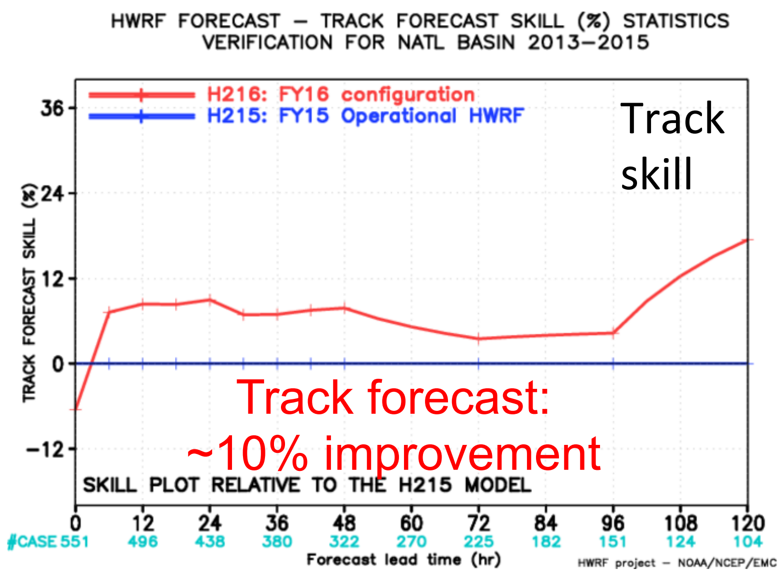
Red – Jason2 Black – HWRF WW3

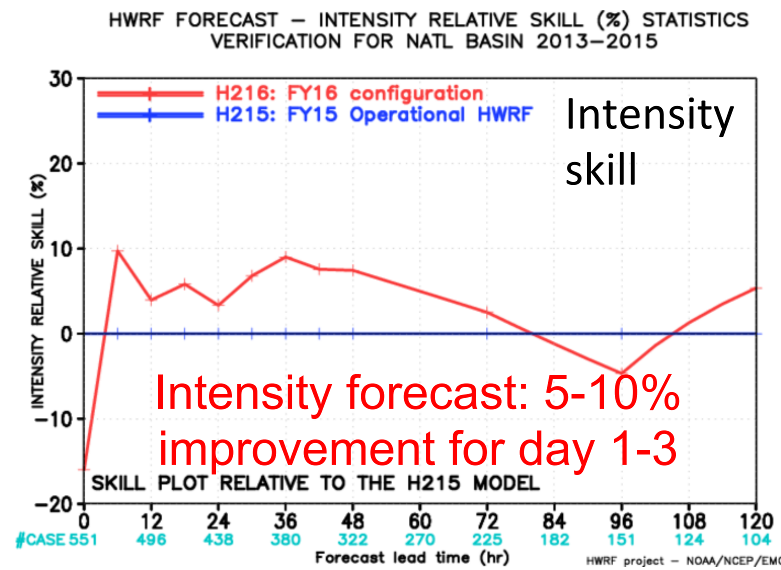
Evaluation of 2016 HWRF for NATL
(2013-2015 storms and 2012 Sandy)



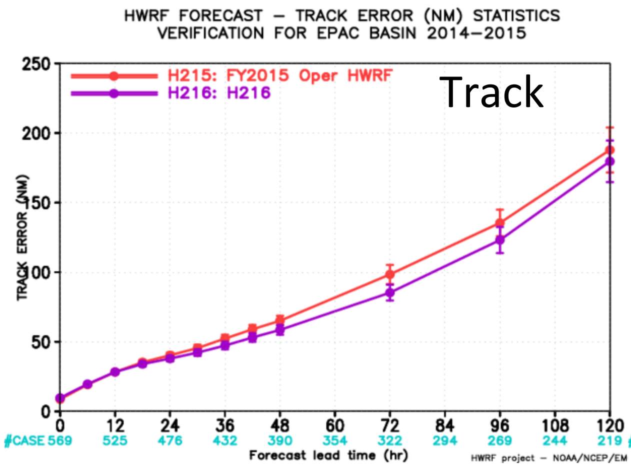


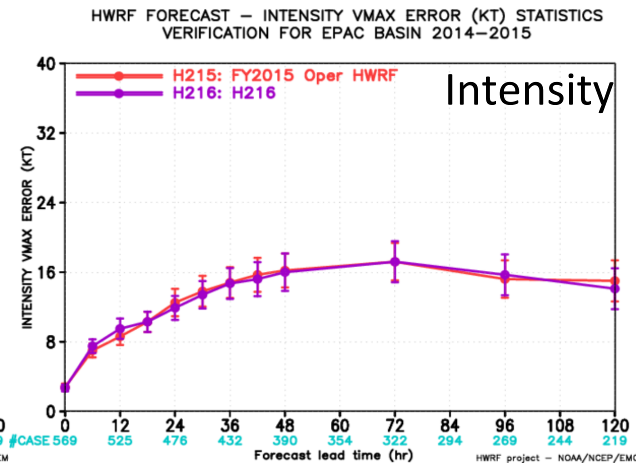


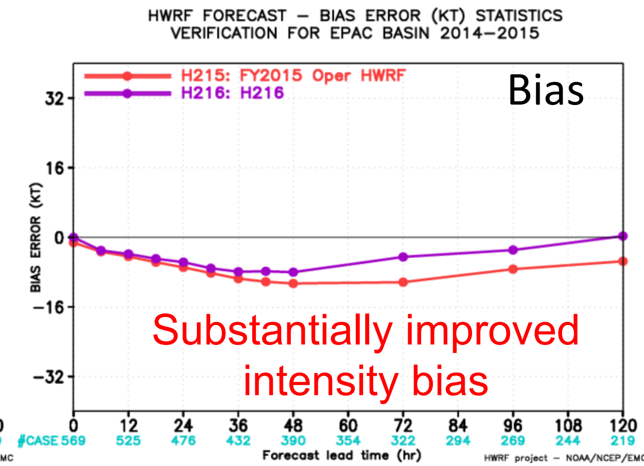


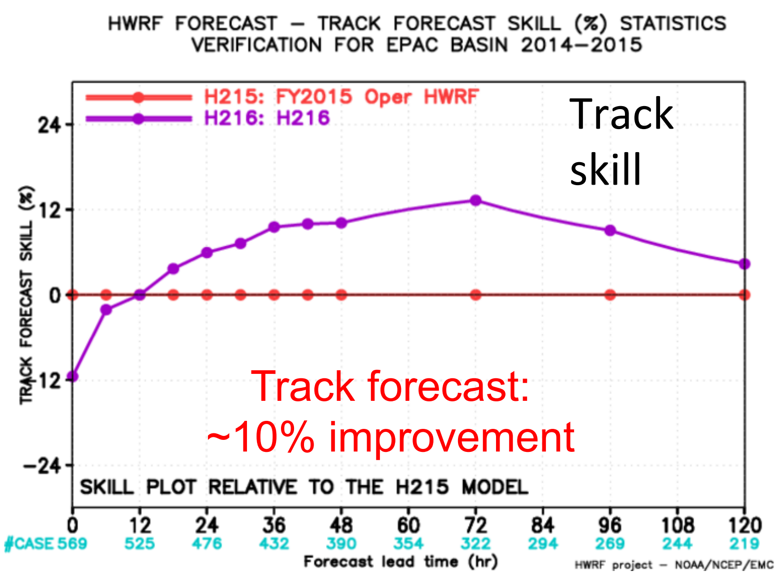


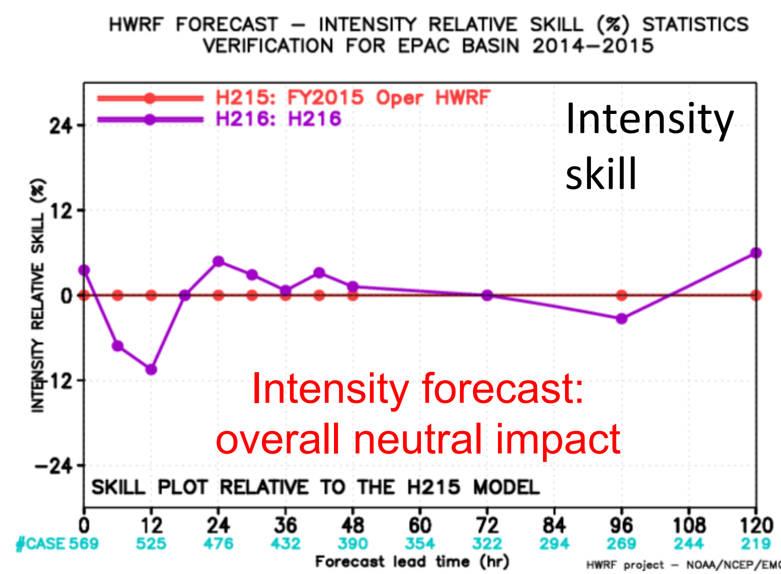
Evaluation of 2016 HWRF for EPAC (2014-2015)



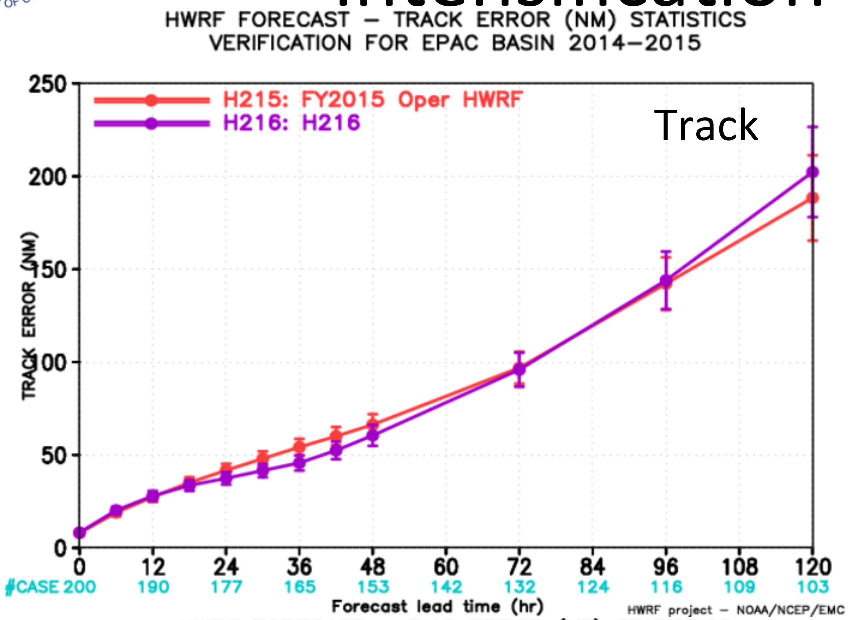


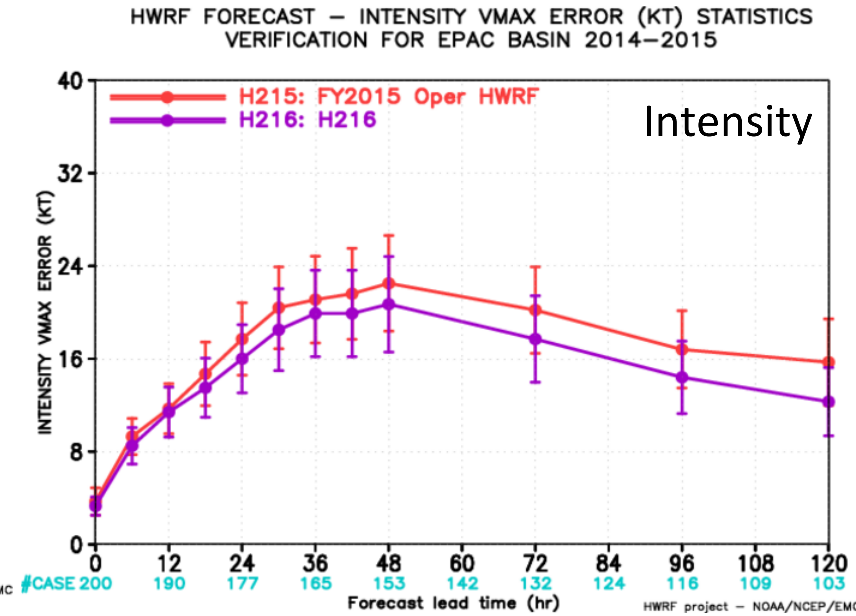


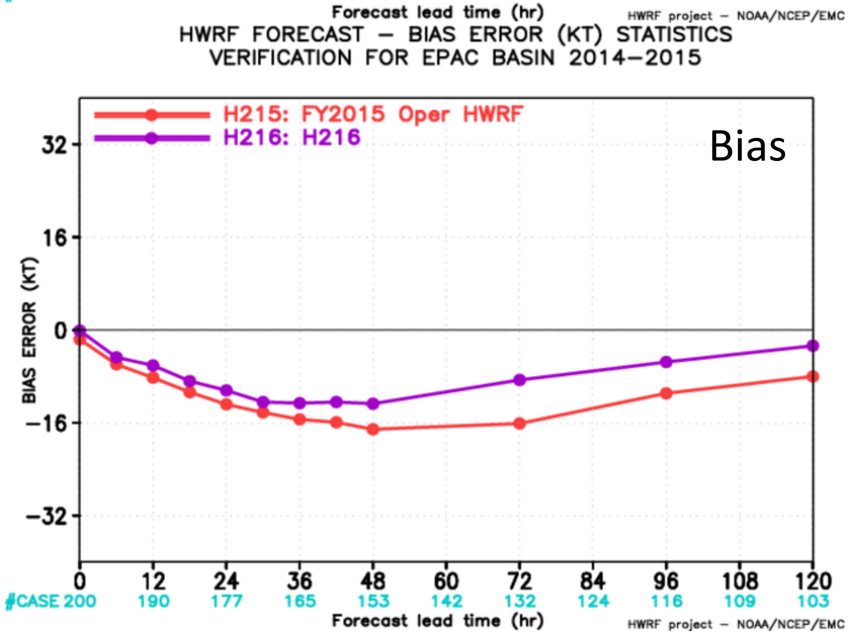




2016 HWRF Performance for Rapid Intensification Storms in EPAC

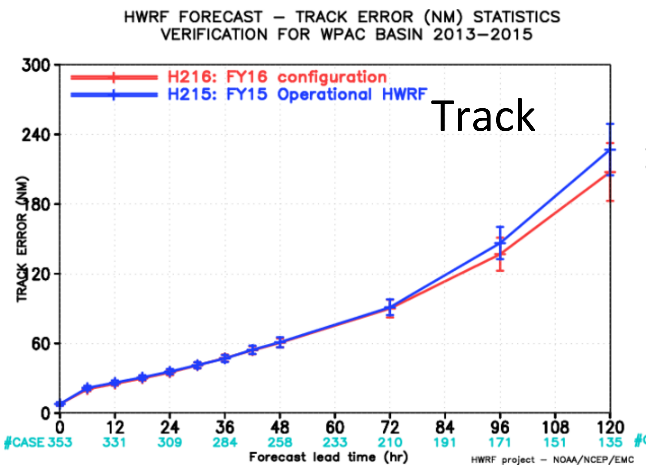


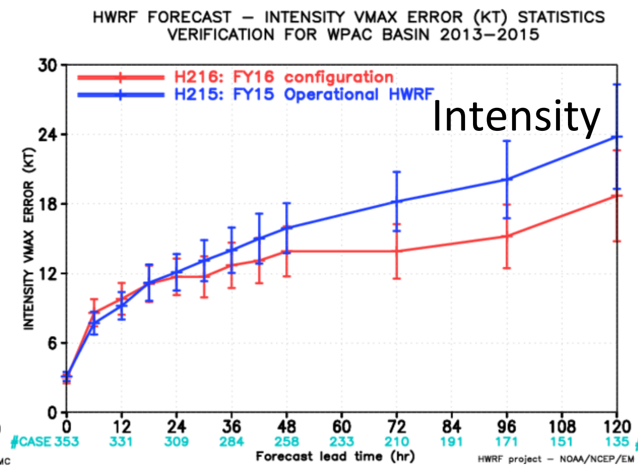


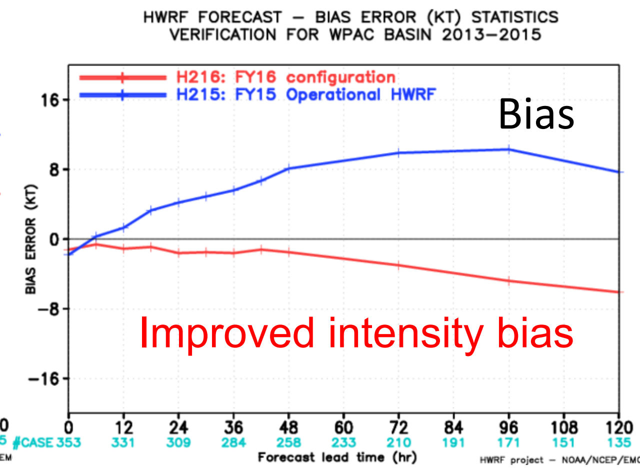


- For RI storms in EPAC, DA and POM RTOFS initialization gave improved performance for intensity skill (both error and bias)
- Impact on track is neutral
- Results very similar to GFDL model

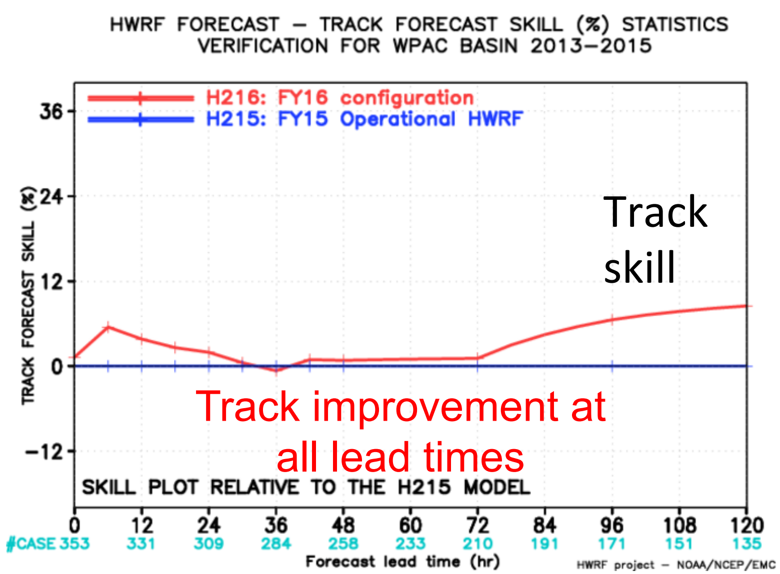
Evaluation of 2016 HWRF for WPAC (13-25W2015)

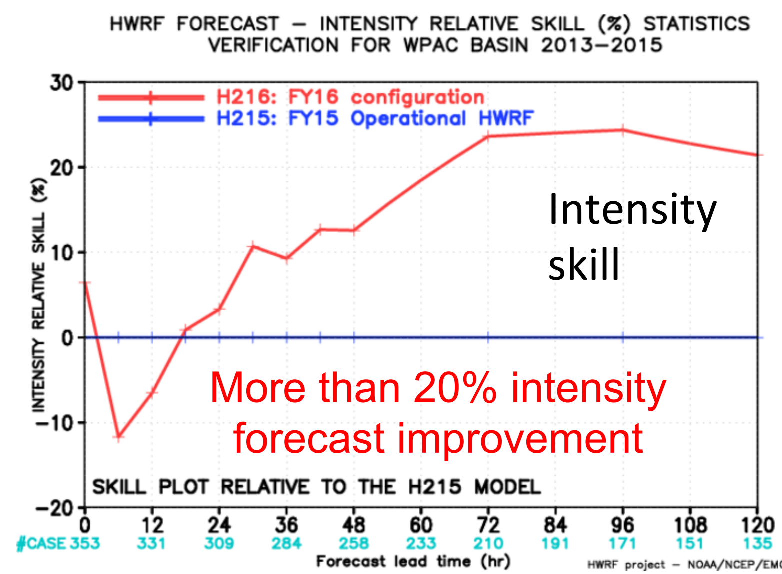






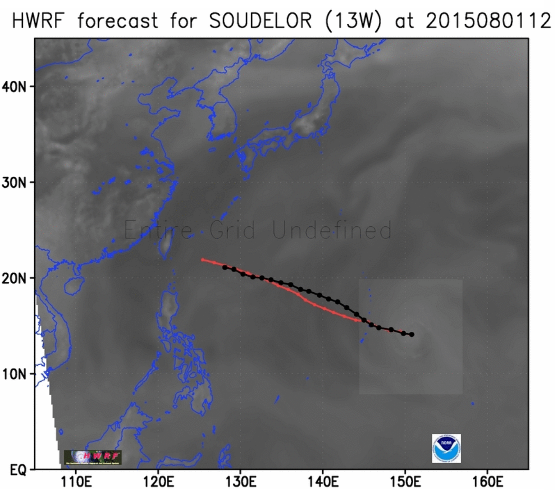
Impacts of 2016 HWRF upgrades with ocean coupling

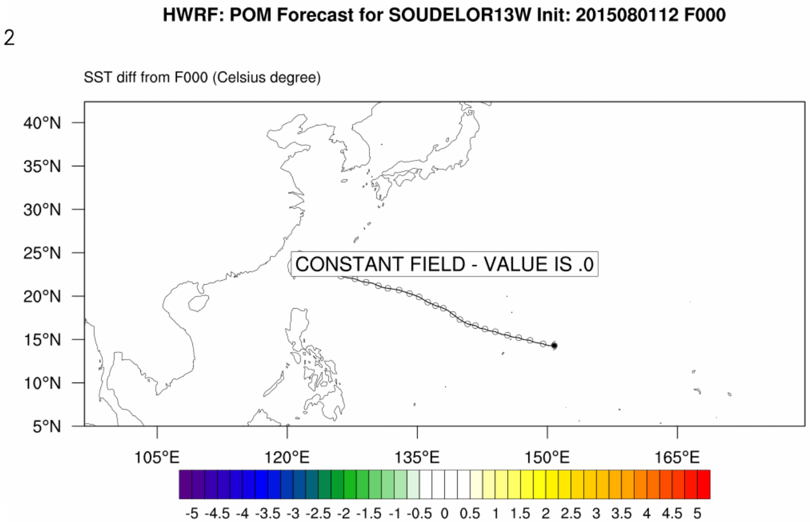




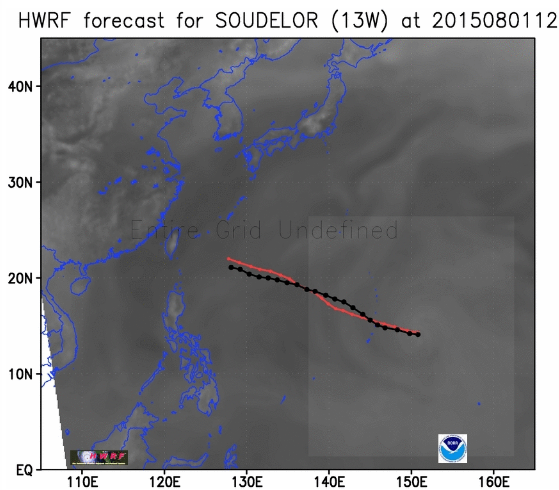
Impact of Ocean Coupling for Soudelor (13W2015, 2015080112Z)

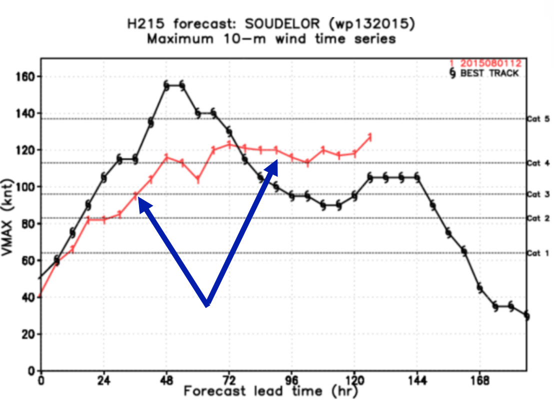
H215 no ocean coupling

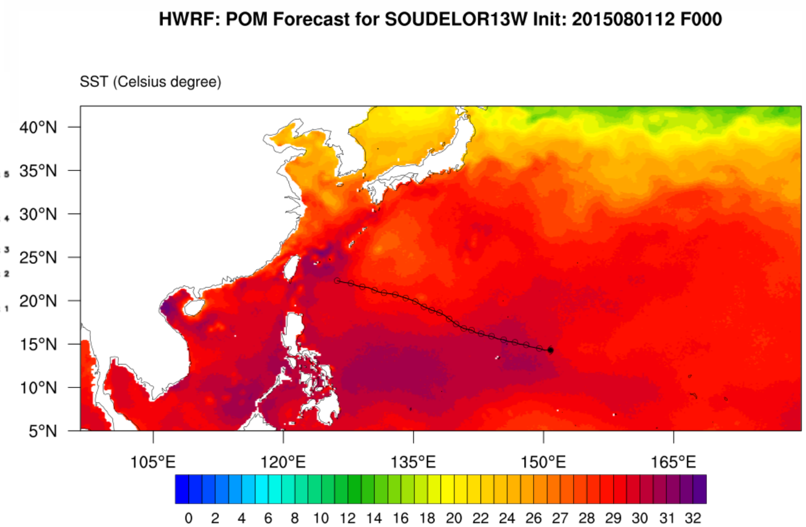


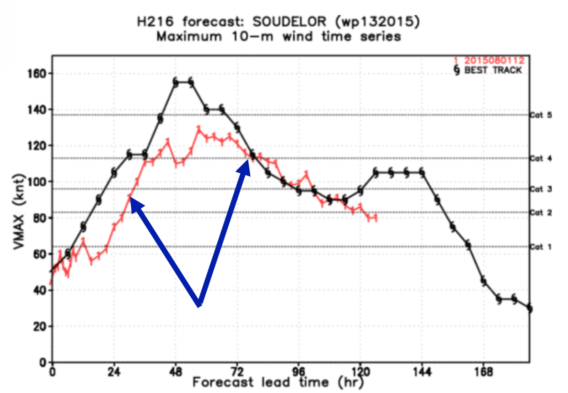


H216 with ocean coupling







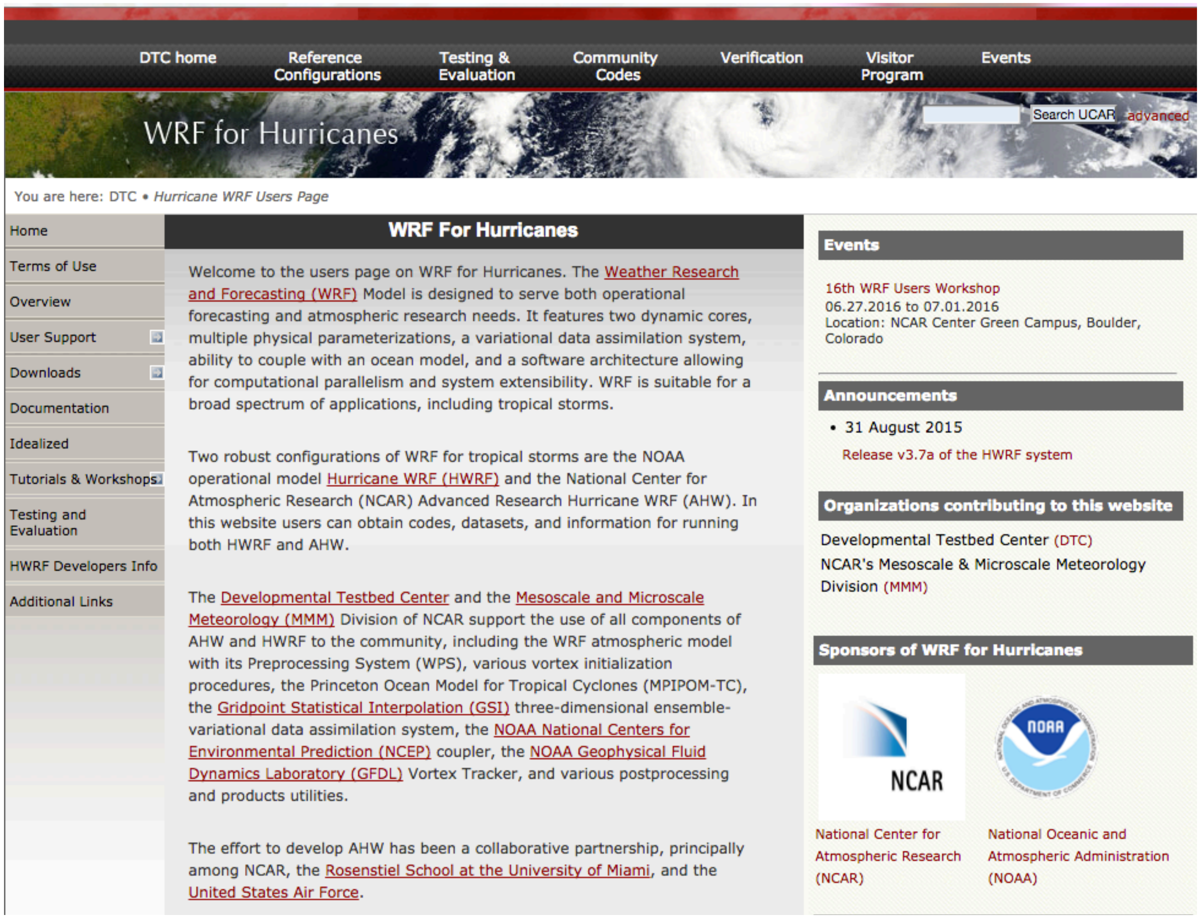


Successful R2O in FY2016 HWRF Upgrades

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

Developmental Testbed Center Support

www.dtcenter.org/HurrWRF/users



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

1200+ registered users

Stable, tested code

Benchmarks available

Support to HWRF developers in code management

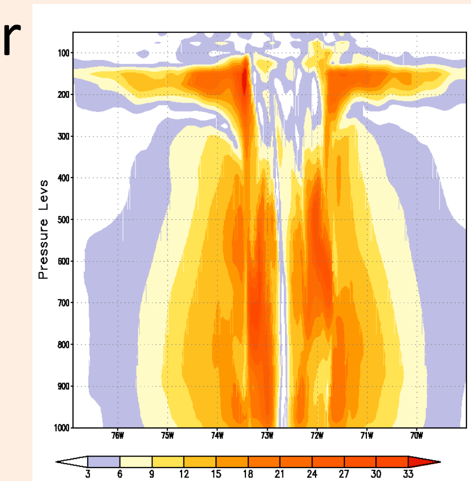
Current release: HWRF v3.7a (2015 operational) August 2015
Next release: HWRF v3.8a (2016 operational) August 2016

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

P75: Bernardet et al.

DTC visitor program

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

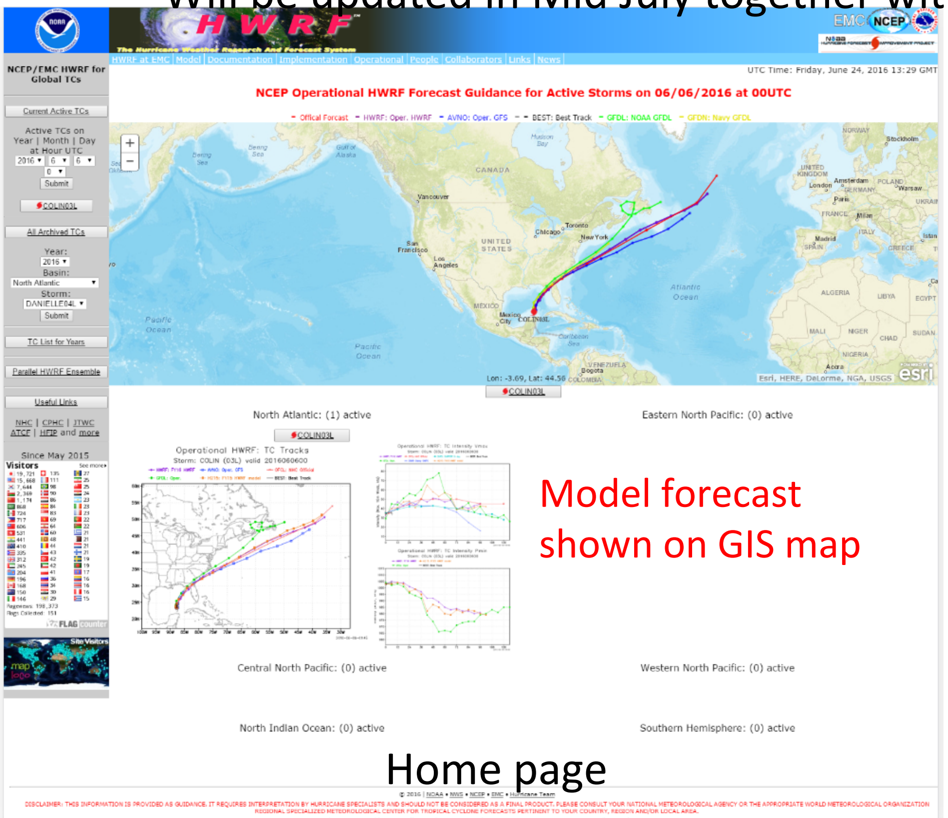
http://www.dtcenter.org/visitors/

9.8: Nance et al.

2016 HWRF Forecast Website

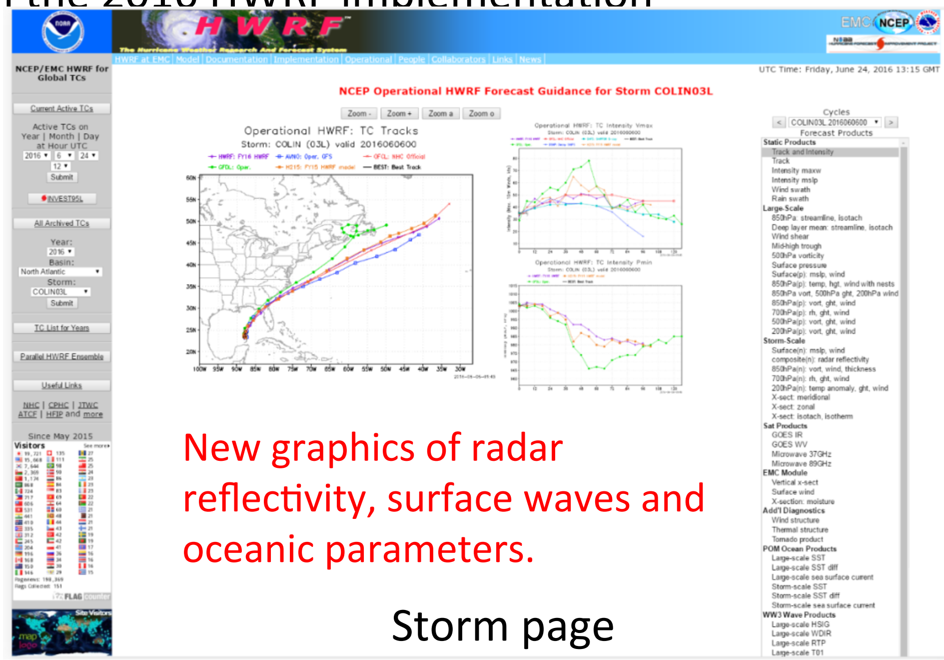
http://www.emc.ncep.noaa.gov/HWRF - HWRF forecast guidance, all year round

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



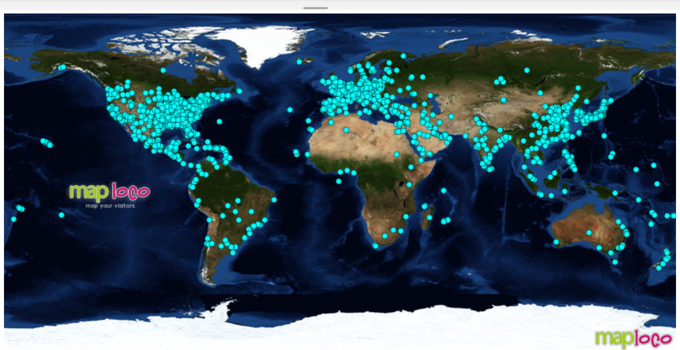
Model forecast shown on GIS map

Home page



New graphics of radar reflectivity, surface waves and oceanic parameters.

Storm page



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

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!

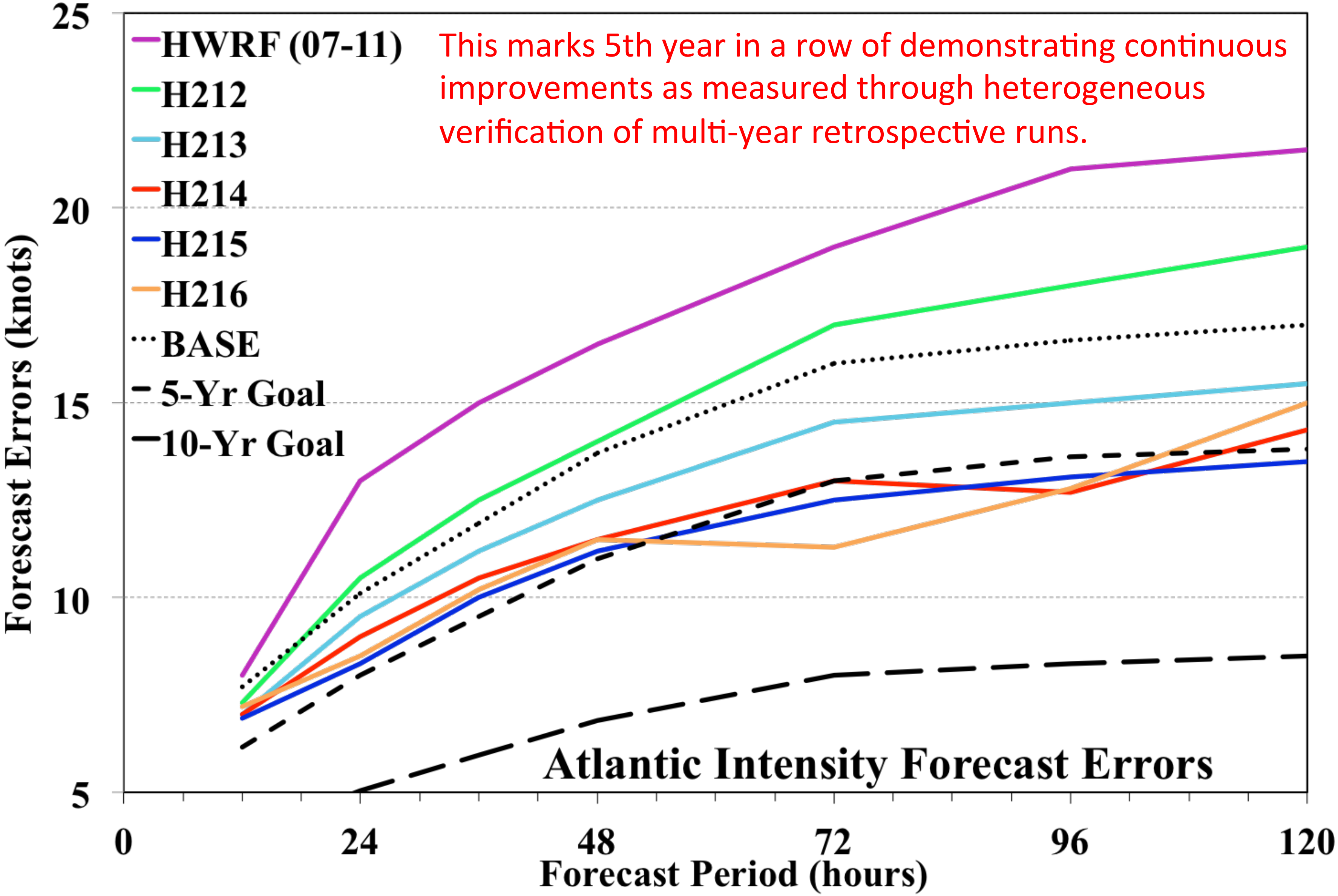
Real-time operational HWRF model guidance for global TCs

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



2016 Physics Upgrades

Latest version GFS PBL EDMF

$$\overline{w'\phi'} = local\ flux + non\ local\ flux$$

HWRF2015

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

Counter-gradient method to represent nonlocal flux

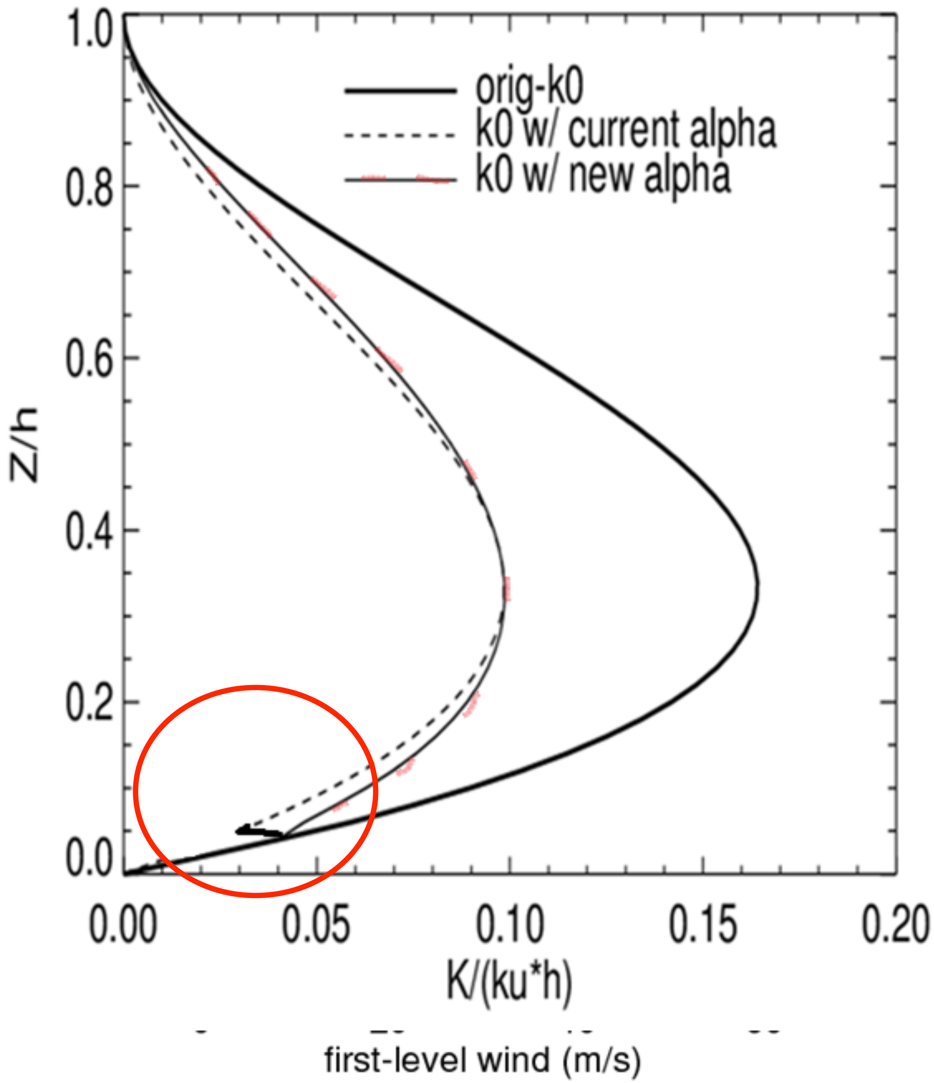
HWRF2016

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

Local Eddy **Mass Flux**

Also, TKE-based dissipation heating

2016 Physics Upgrades



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.

2016 Physics Upgrades

Scale-aware SAS convection scheme

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

$$m_b' = (1 - \sigma_u)^2 m_b$$

Scale function

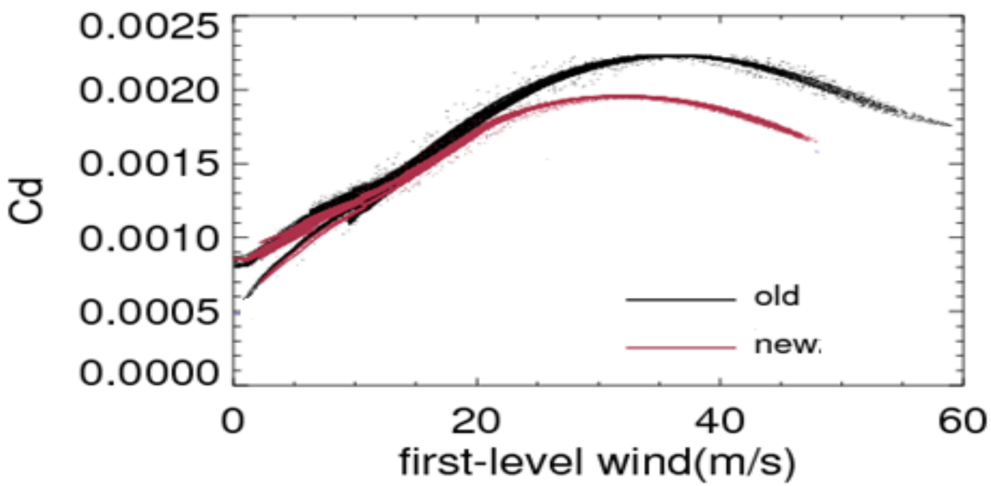
Based on Arakawa & Wu (2013): $\overline{w'\psi'} = (1 - \sigma_u)^2 \left(\overline{w'\psi'}\right)_E$

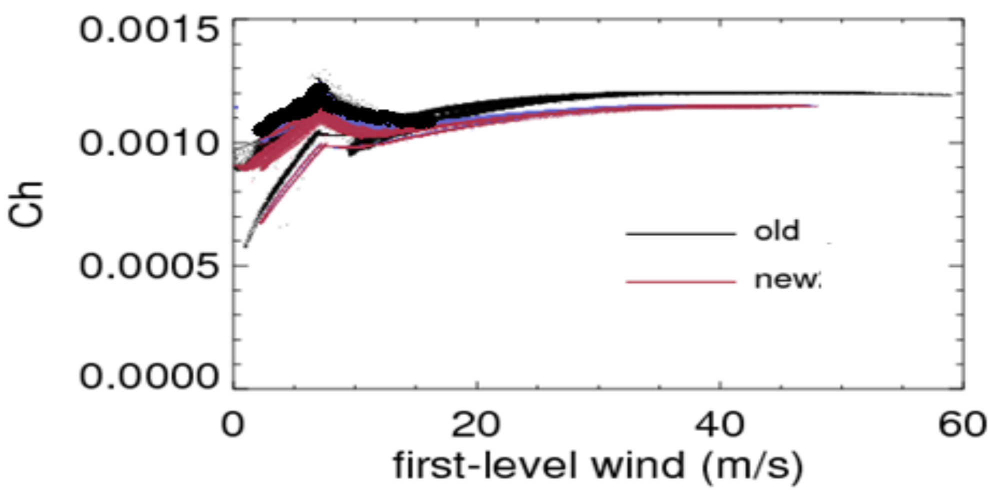
σ_u: updraft area fraction (0~1.0)

m_b : original cloud base mass flux from AS quasi-equilibrium closure

m_b' : updated cloud base mass flux with a finite σ_u

2016 Physics Upgrades

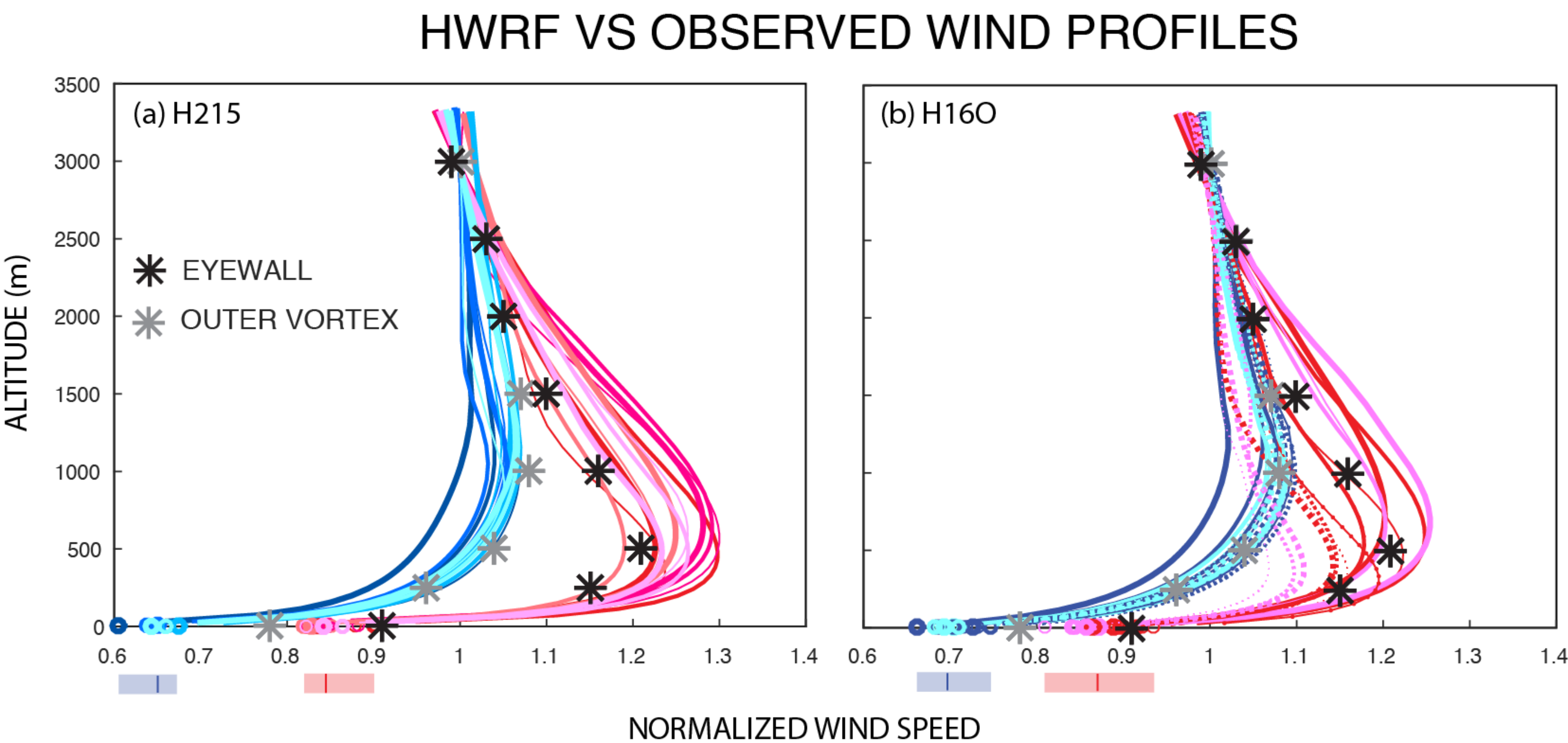




Surface-layer Cd and Ch

- ✓ 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.

2016 Physics Upgrades

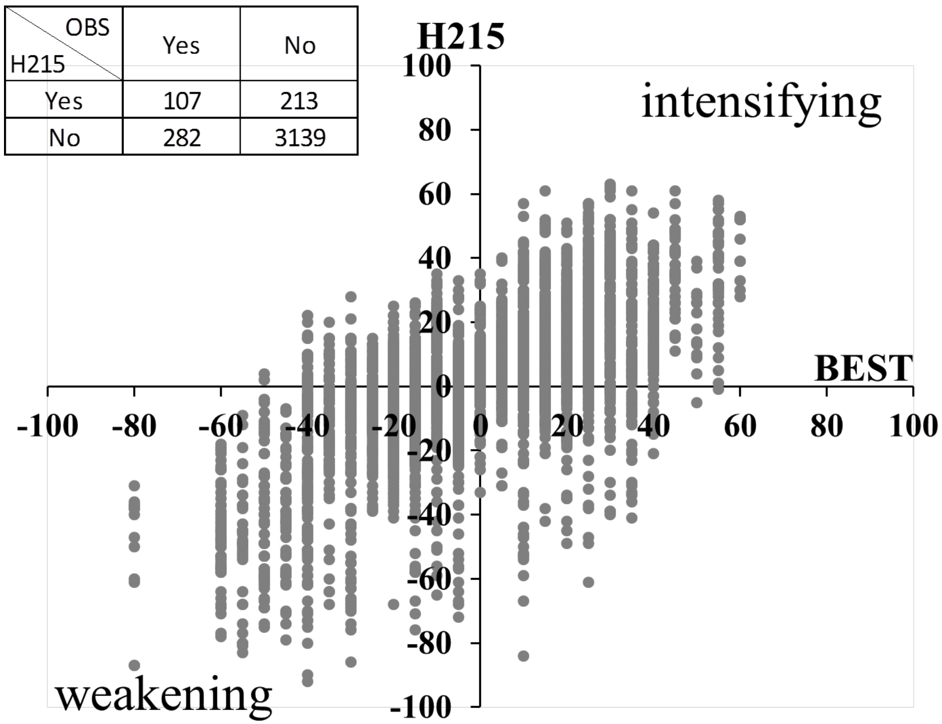


Upgraded HWRF generates more physically sensible structure.

2016 HWRF for WPAC Storms

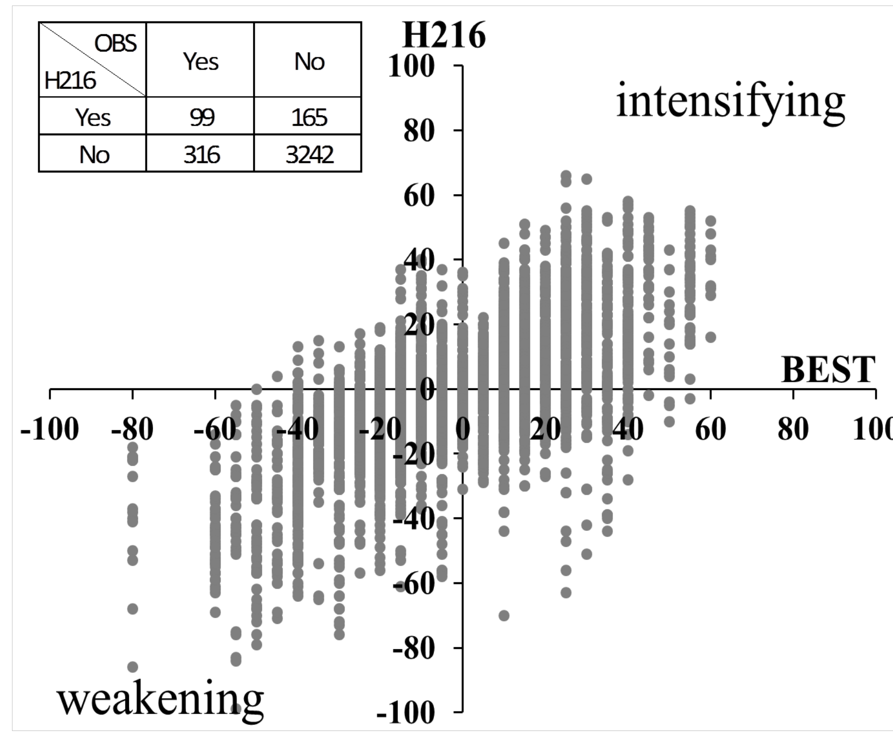
RI Probability of Detection (13-25W2015)

H215 \ OBS	Yes	No
Yes	107	213
No	282	3139



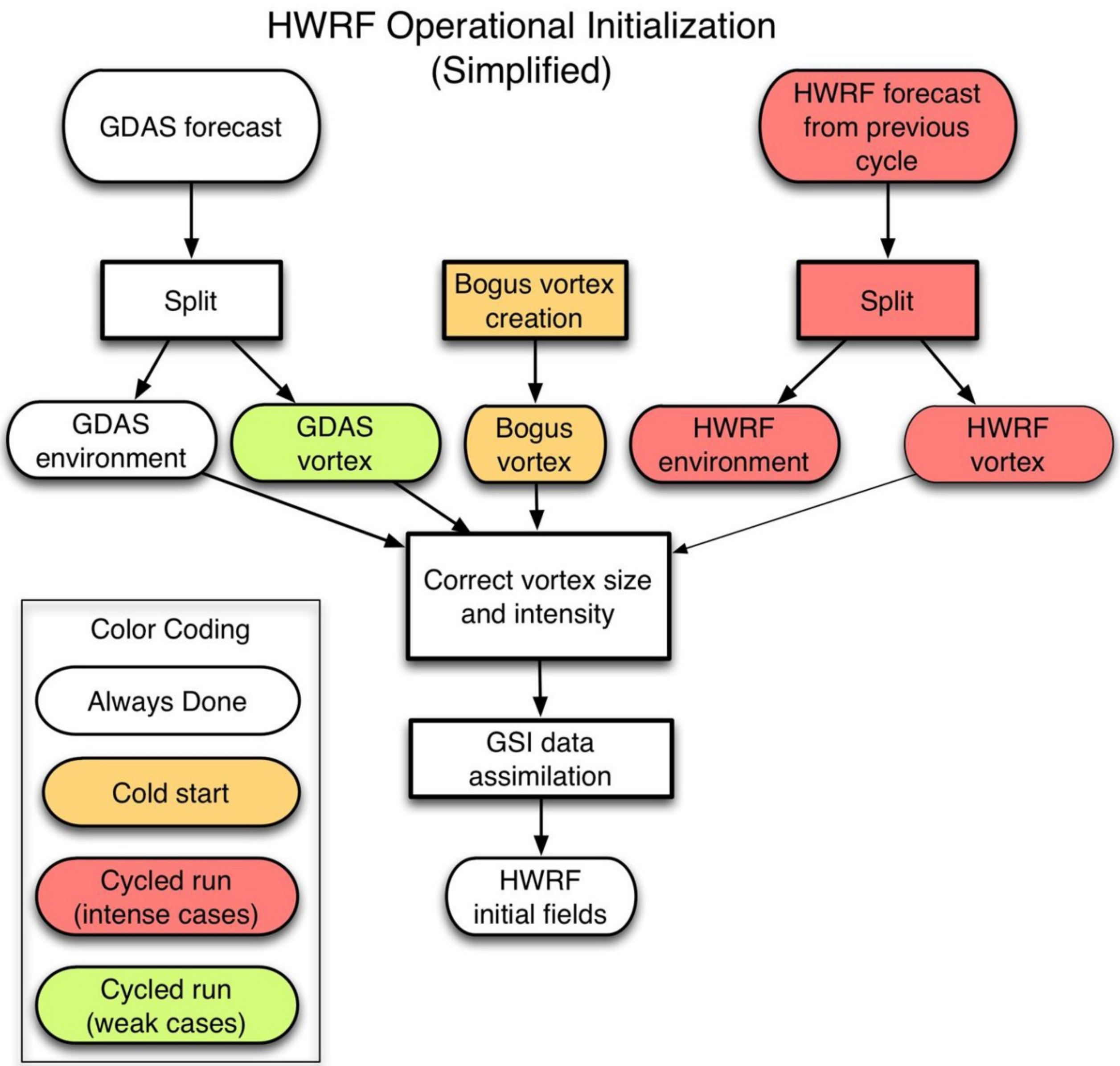
POD = 0.28 FAR = 0.67

H216 \ OBS	Yes	No
Yes	99	165
No	316	3242

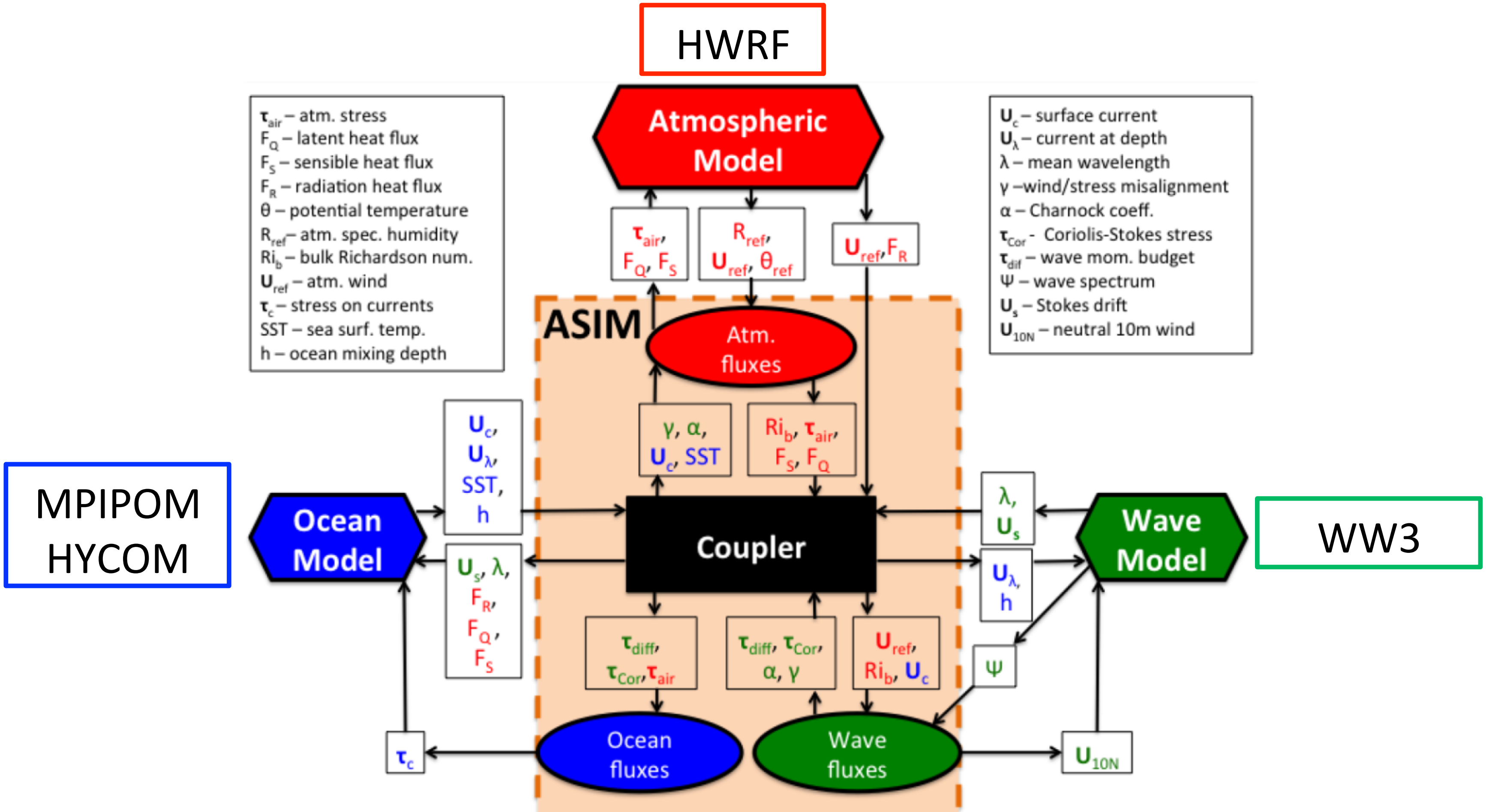


POD = 0.24 FAR = 0.63

HWRF Initialization



Coupled Atmosphere-Wave-Ocean HWRF System



Courtesy to I. Ginis et al. from URI