Operational Hurricane Modeling at NCEP/EMC

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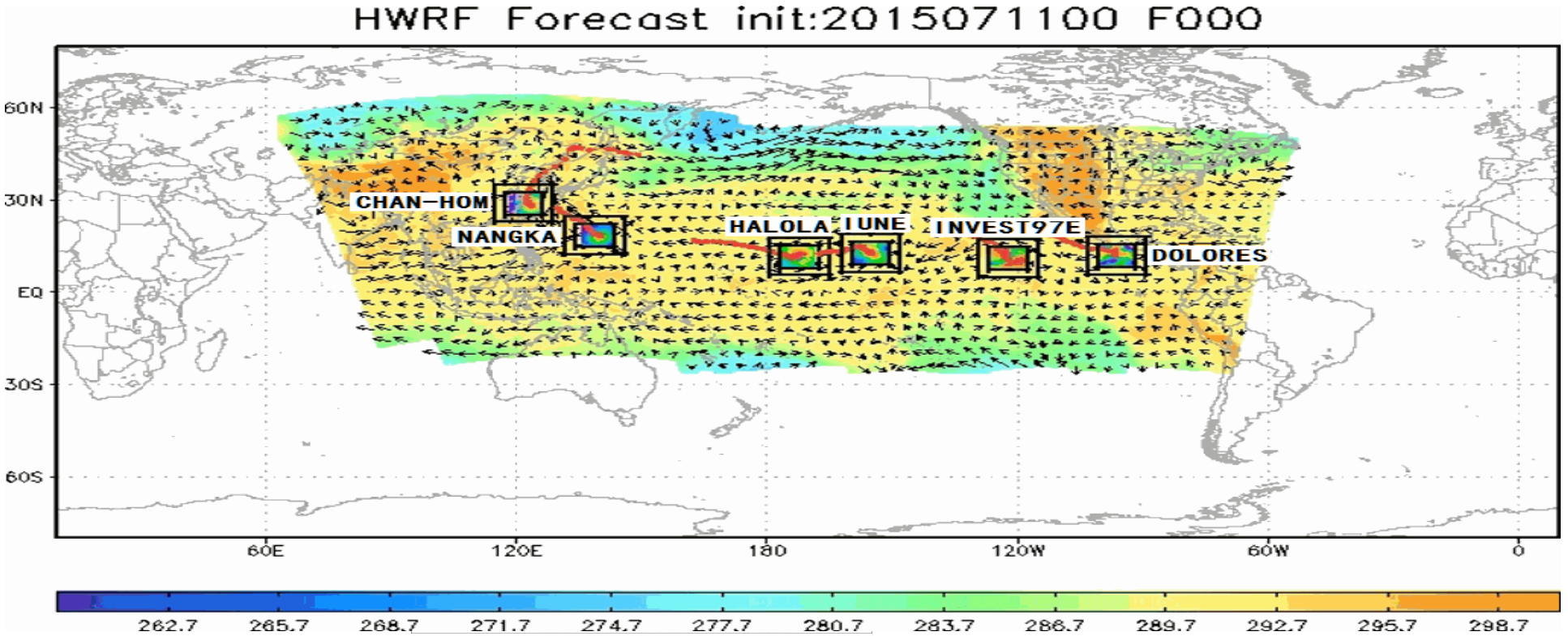
NOAA HURRICANE FORECAST IMPROVEMENT PROJECT

Outline

- HWRF in 2016
- 2016 Performance in Western North Pacific
- HWRF planned upgrades for 2017
- New Hurricane model development (HMON)
- HWRF long term plans
- Future Hurricane modeling plans at NCEP (2018 and beyond)
- Accelerated transition of HFIP/NGGPS supported research to operations; continue community modeling approach.

Expanded High-Resolution Guidance for all Global Tropical Cyclones from HWRF

Seven storm capability to run year-long in all tropical cyclone basins



Scope of FY16 HWRF Upgrades

System & Resolution Enhancements

- T&E with new 2016 4D-Hybrid GDAS/GFS IC/BC
- Upgrade dynamic core from WRF3.6a to WRF3.7.1a (with bug fixes)
- Smaller time step (dt=30 s vs. 38 4/7 s)
- ***Increase the size of nested domains (details on next slide)***
- More products: MAG and AWIPS2

Initialization/Data Assimilation Improvements

- GSI upgrades; ***new data sets for GSI (CrIS, SSMI/S, METOP-B changes)***
- ***Turn on Data Assimilation for all storms in East Pacific and use of ROTFS initialization***

Physics Advancements

- Implement ***new GFS PBL*** (2015 version)
- Upgrade to ***new scale-aware SAS convection scheme*** for all domains
- Update momentum and enthalpy exchange coefficients(Cd/Ch)
- Improved vertical wind profile in the surface and boundary layer

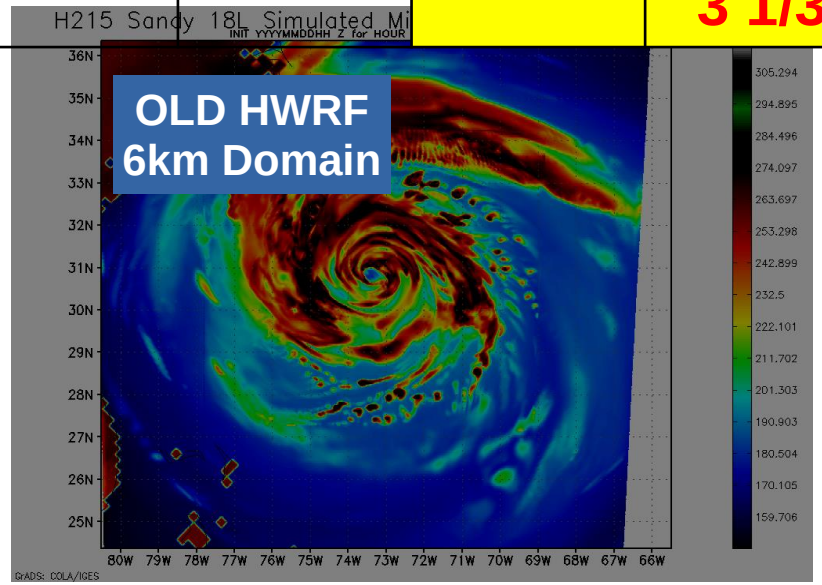
First time in 2016….

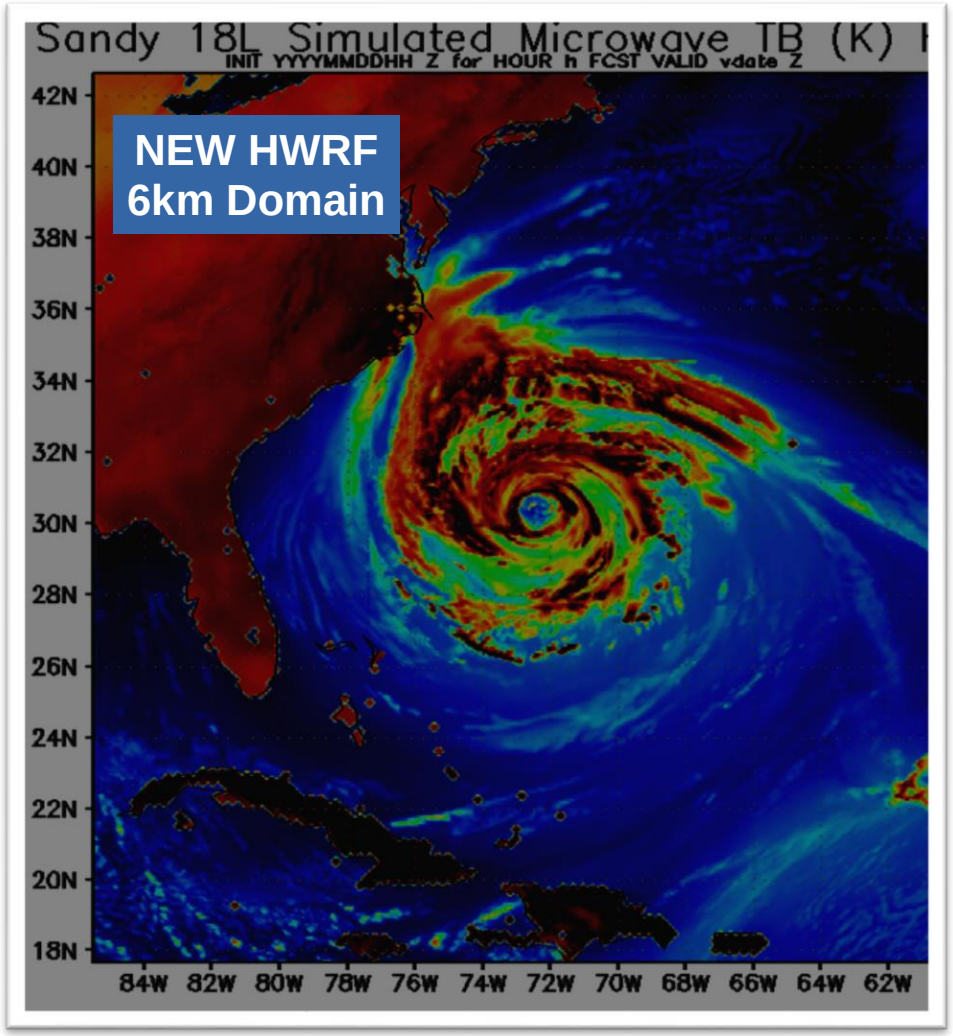
- Implementation on WCOSS Cray
- Ocean coupling for CPAC, WPAC and NIO (all NH basins)
- One-way coupling to wave model (Hurricane Wave Model)
- Use of dev-ecflow for accelerated T2O

Operational HWRF: Larger size nested domains and smaller time steps

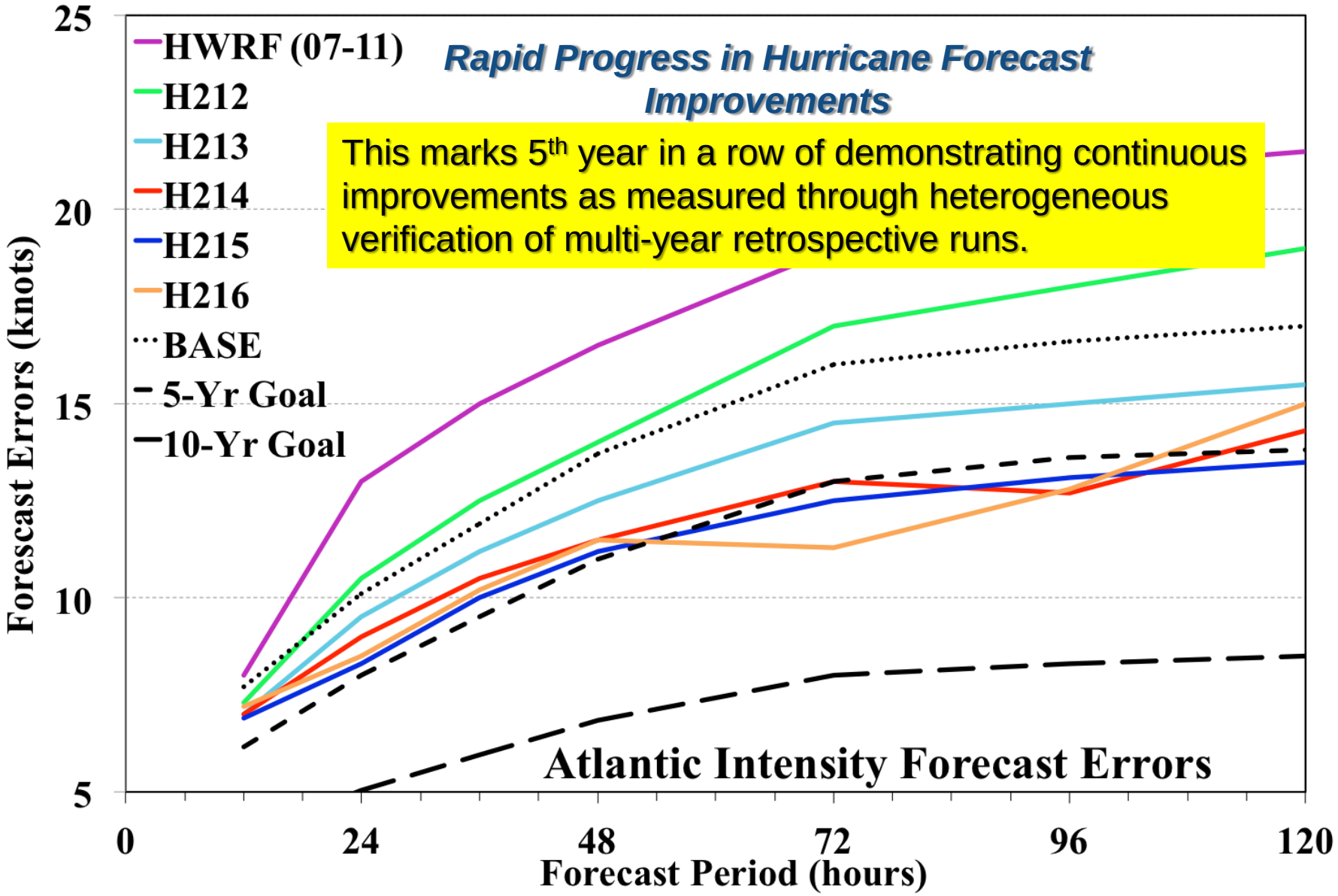
Domain Sizes/Time Steps

(Degrees /Sec)	18 km	6 km	2 km
2015 HWRF	75 x 75 38 4/7	12 x 12 12 6/7	6.5 x 7 4 2/7
2016 HWRF	75 x 75 30	**25 x 25** 10	**8.3** **x8.3** **3 1/3**





2016 HWRF: Continuing the trend of incremental but substantial improvements in NATL intensity forecasts



2016 Operational HWRF in Western North Pacific

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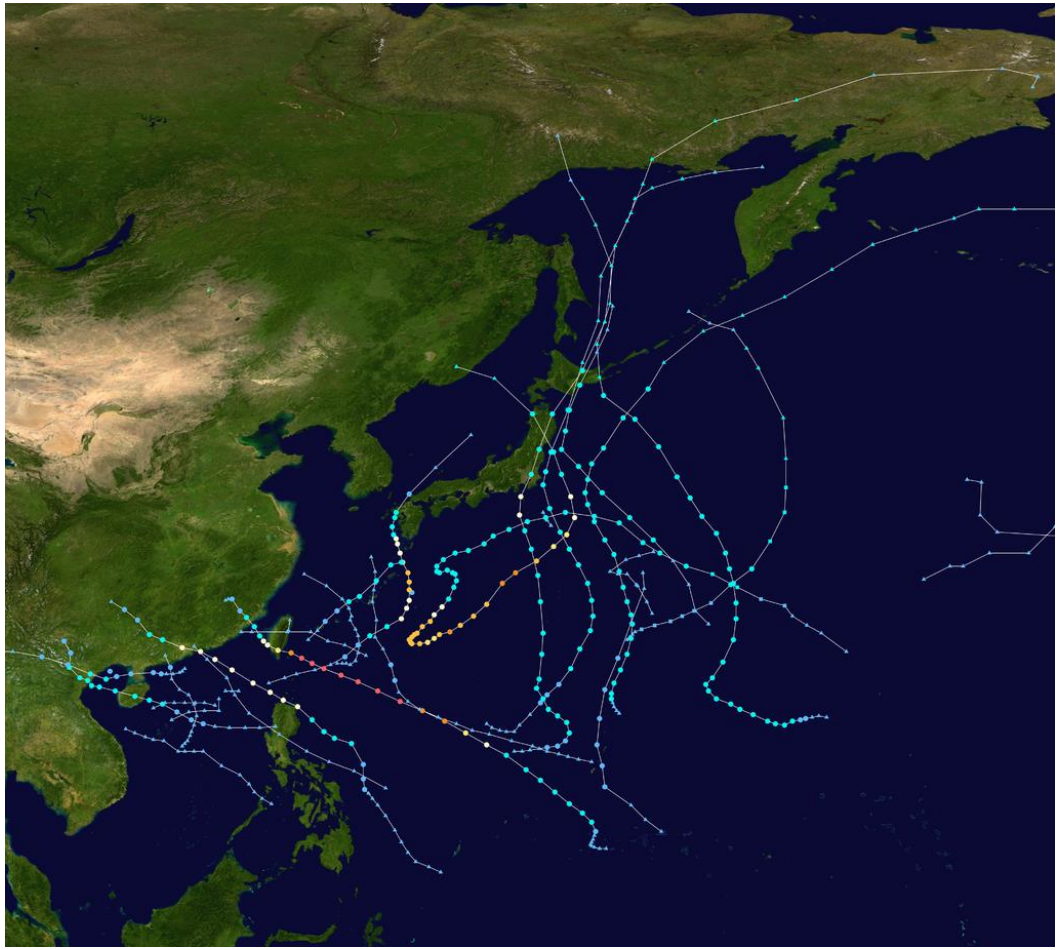
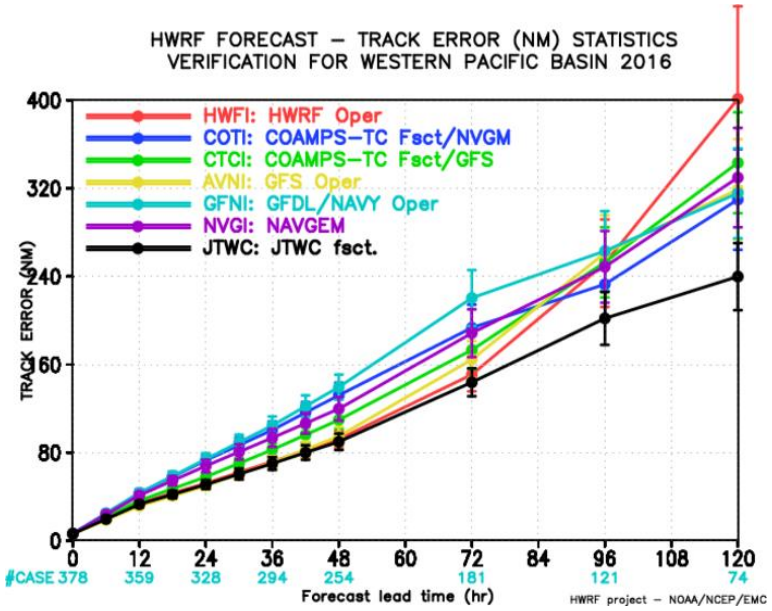
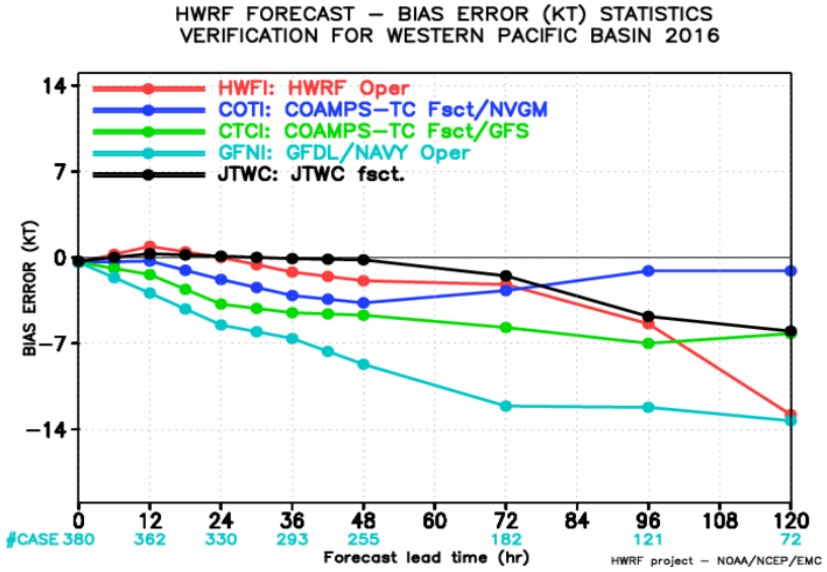
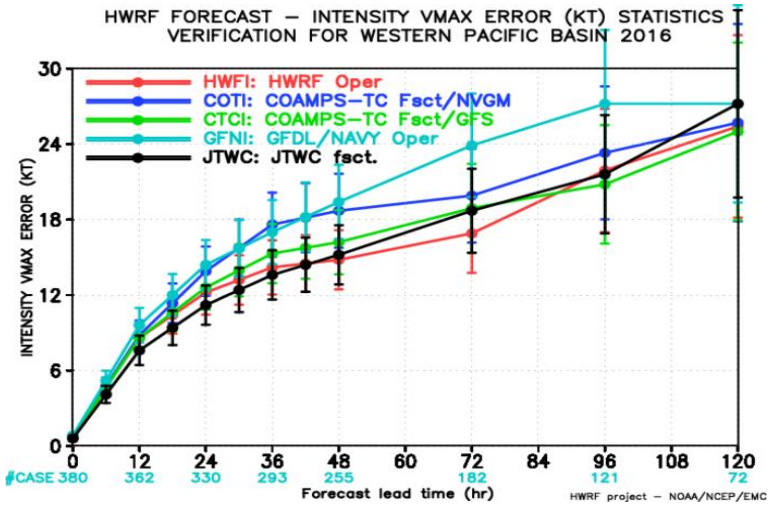


2016 HWRF verification for WPAC: Interpolated Guidance

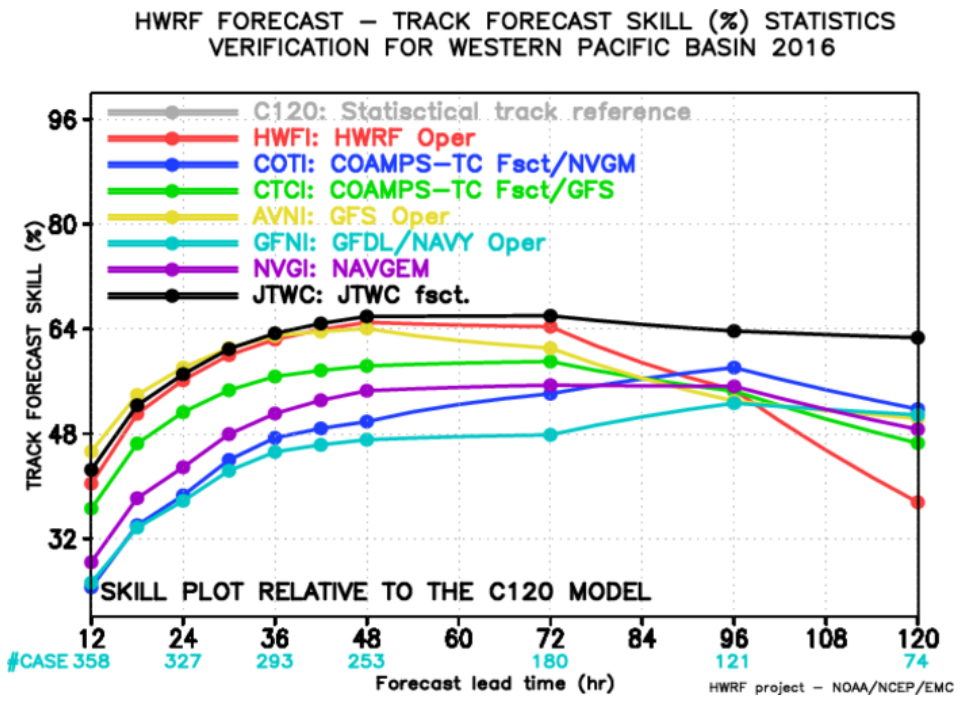


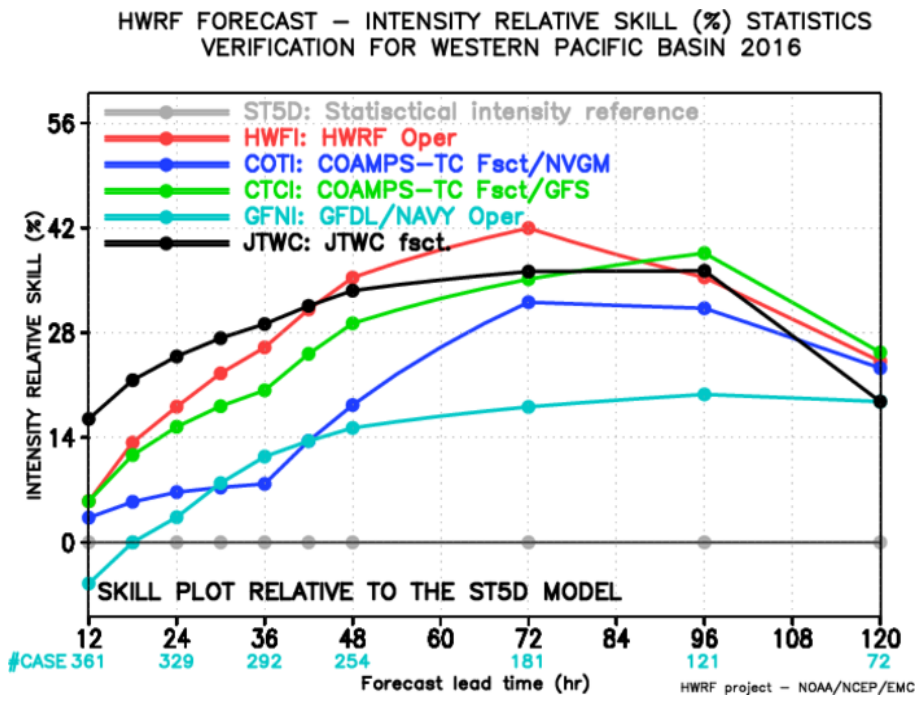




For 2016,HWRF tracks and intensity forecasts show lowest errors for the first 3 days. The intensity errors are lower than JTWC official forecasts from hrs 48-90

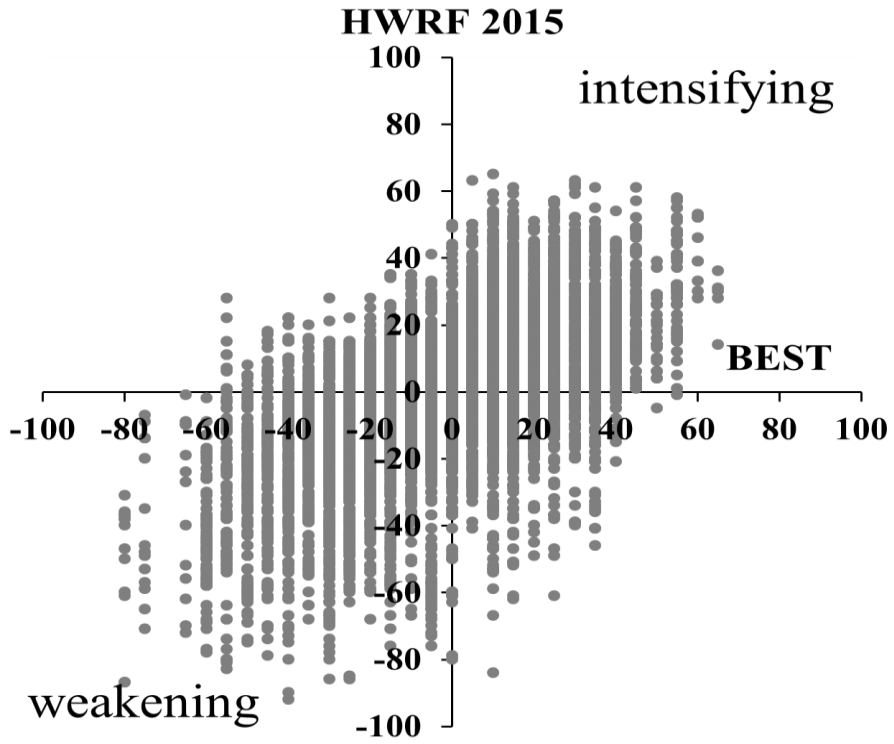
Early models skill plots





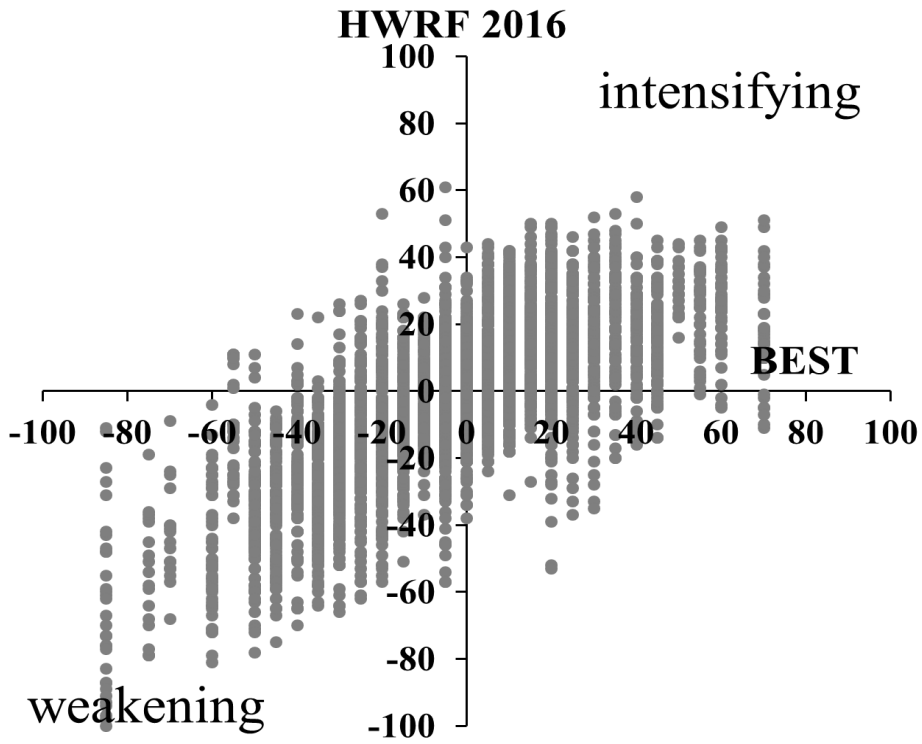
- Track skill drops off after 72 hrs
- Intensity skill best amongst all model up to 84 hrs

RI Probability of Detection for Western North Pacific



OBS / HWRF	Yes	No
Yes	127	415
No	638	7397

POD = 16.8%
FAR = 76.6%



OBS / HWRF	Yes	No
Yes	94	197
No	370	3556

POD = 20.3%
FAR = 67.7%

Scope of FY17 HWRF Upgrades

System & Resolution Enhancements

- T&E with new ***2017 NEMS GFS*** IC/BC
- Upgrade dynamic core from WRF3.7.a to WRF3.8 (with bug fixes)
- Consider storm's meridional movement when determining parent domain center

Initialization/Data Assimilation Improvements

- Improve vortex initialization (new composite storm vortex)
- GSI code upgrades; ***new data sets for GSI (hourly shortwave, clear air water vapor and visible AMV's, GH changes, G –IV TDR data)***
- ***Fully Cycled EnKF two-way hybrid DA when TDR data is available***
- Change in blending threshold (to 65 Kt)
- HDOBS data assimilation

Physics Advancements

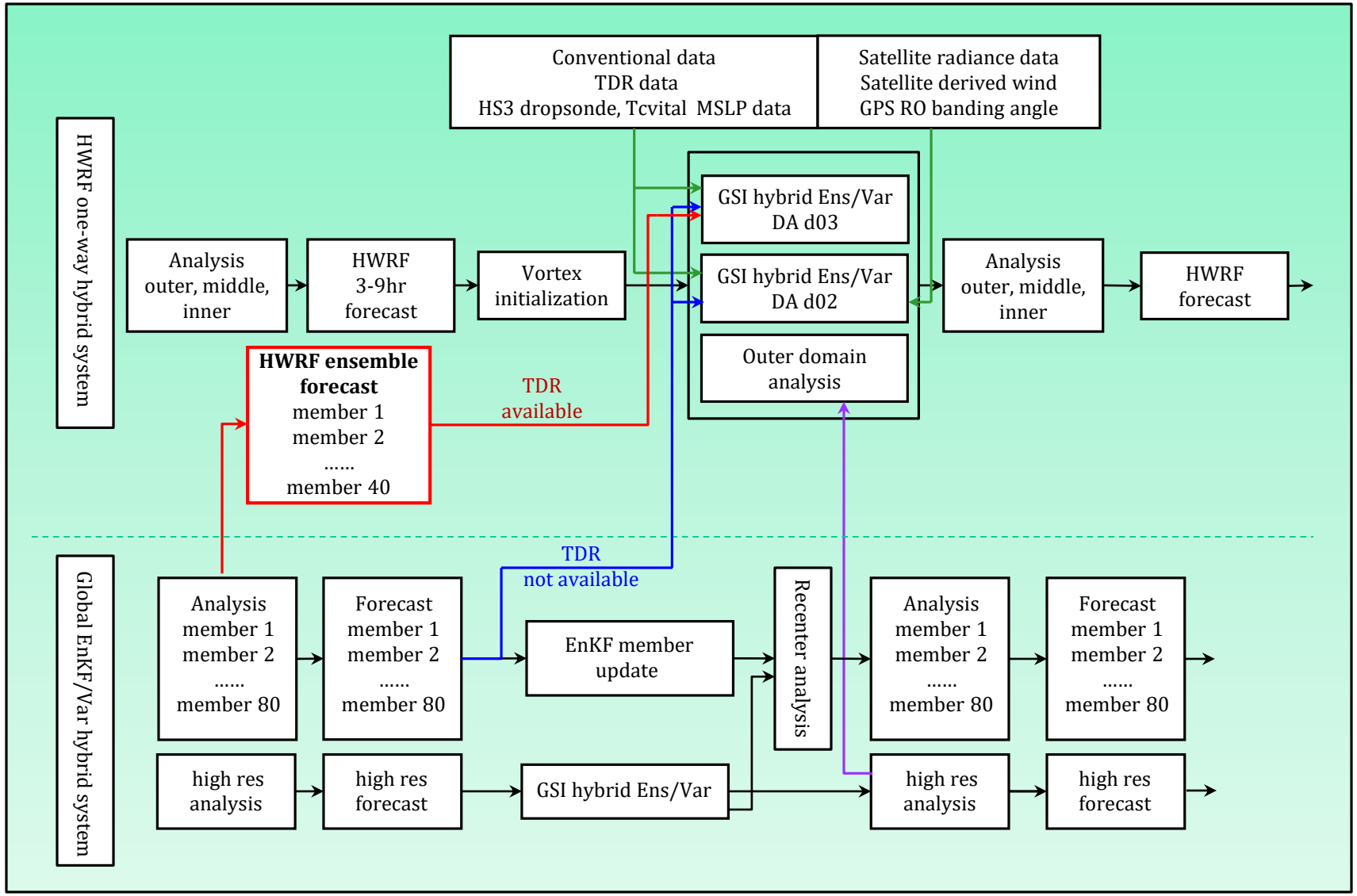
- Update F-A Microphysics
- Updates to mixing in PBL
- Updates to RRTMG (partial cloudiness/cloud overlap)
- Update convection with G-F cumulus scheme

First time in 2017….

- ***Fully Cycled Hybrid EnKF DA***
- ***Use of NEMSIO (IC) and GRIB2 (LBC) files for inputs***
- Reduce coupling time step from 9min to 6 min for both waves and ocean
- Increase vertical resolution from 24 to 40 levels for POM with reduced time step

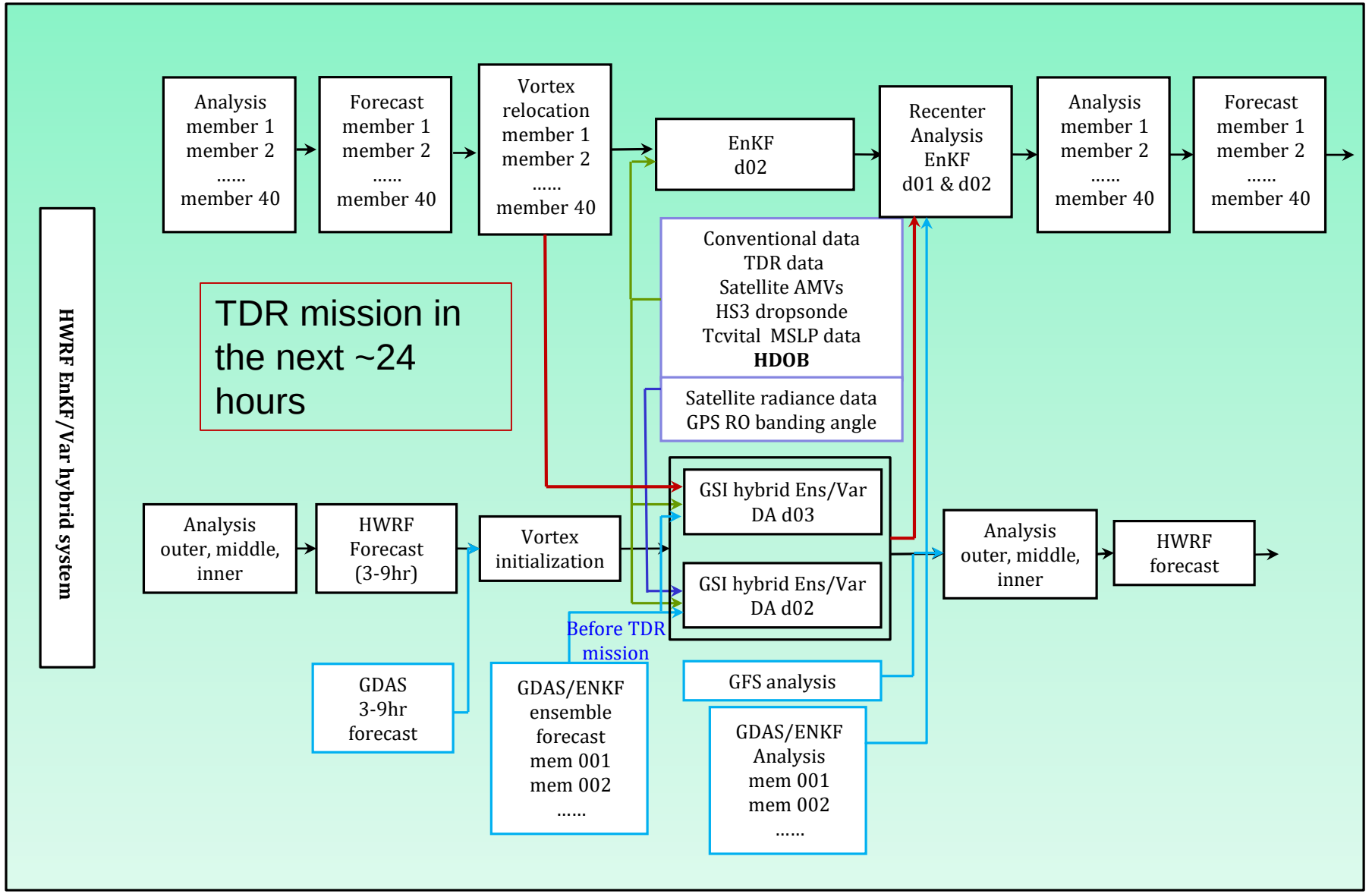
2016 HWRF Hybrid Data Assimilation System

Warm-start HWRF ensemble when TDR available

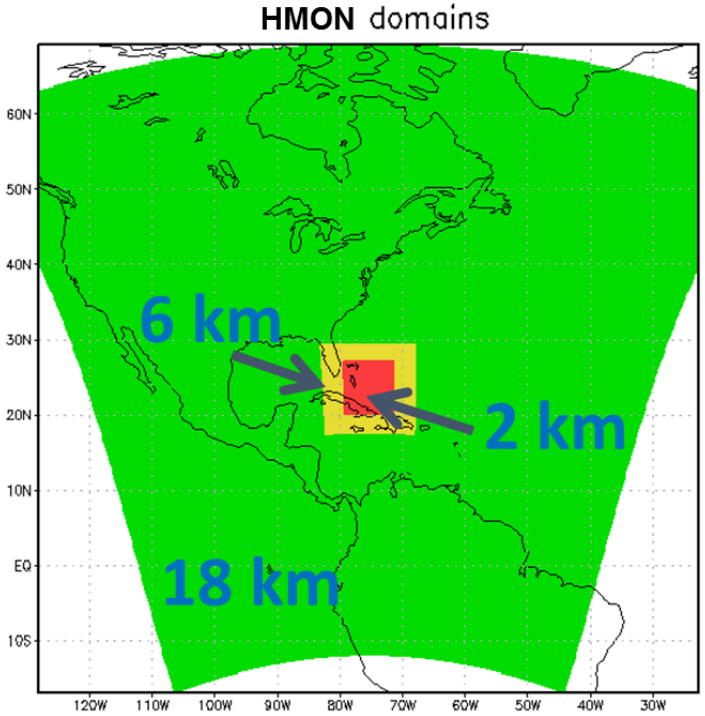


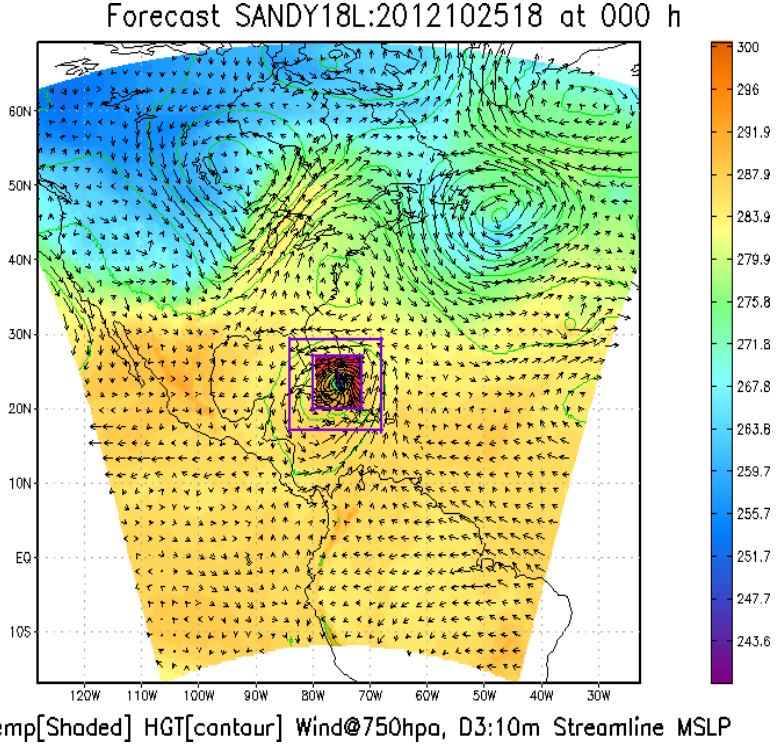
2017 HWRF Hybrid Data Assimilation System

Cycled HWRF EnKF Ensemble Hybrid when TDR available



HMON: A New Operational Hurricane Model at NCEP replacing GFDL Hurricane Model

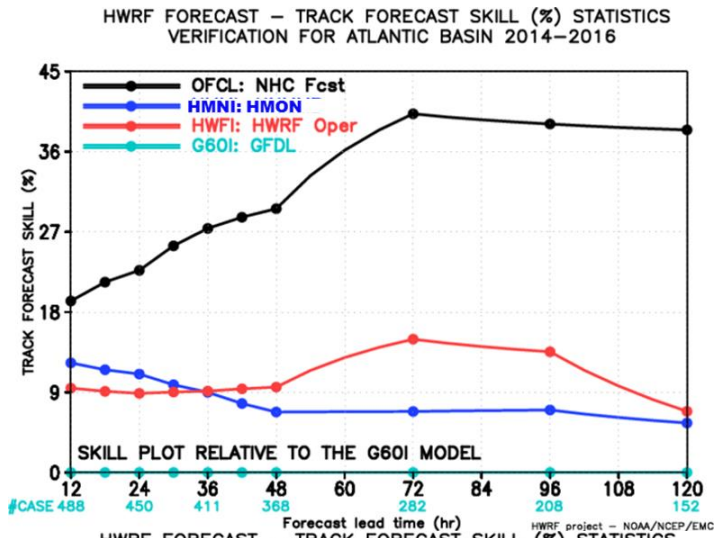


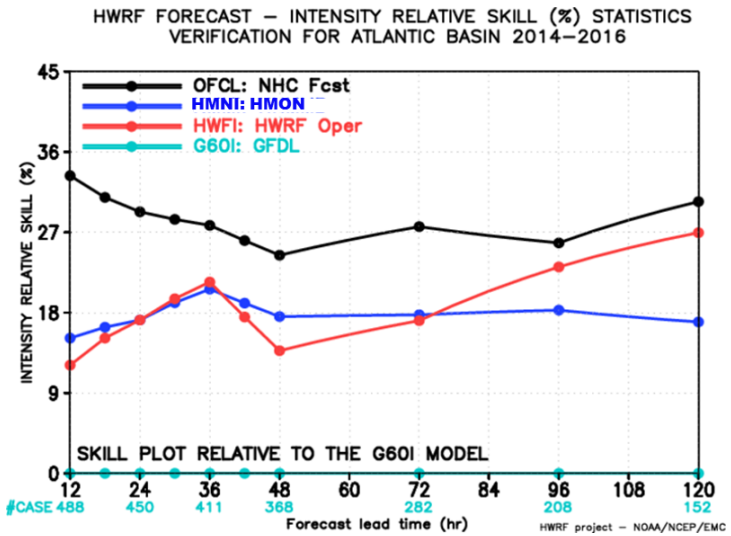


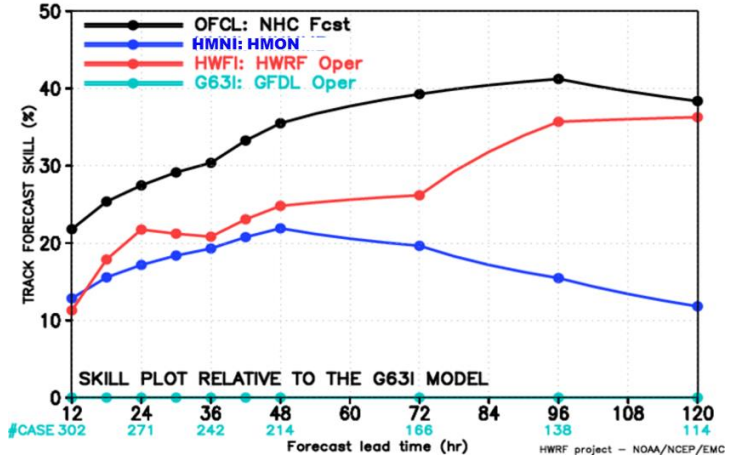
HMON: **H**urricanes in a **M**ulti-scale **O**cean coupled **N**on-hydrostatic model

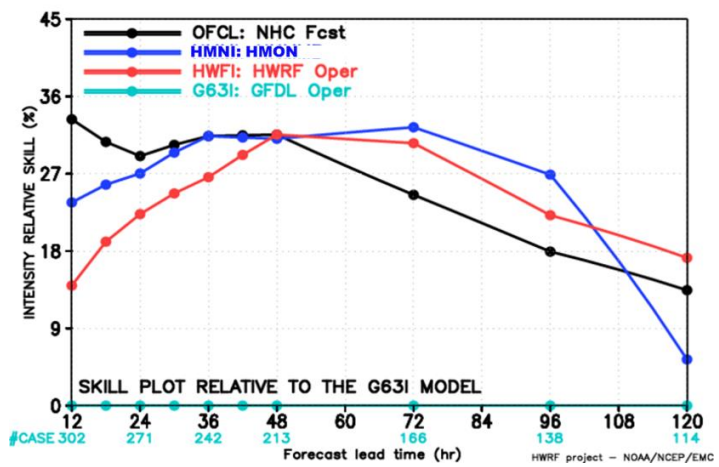
HMON: Implements a long-term strategy at NCEP/EMC for multiple static and moving nests globally, with one- and two-way interaction and coupled to other (ocean, wave, sea ice, surge, inundation, etc.) models using NEMS-NUOPC infrastructure.

HMON: A New Operational Hurricane Model at NCEP





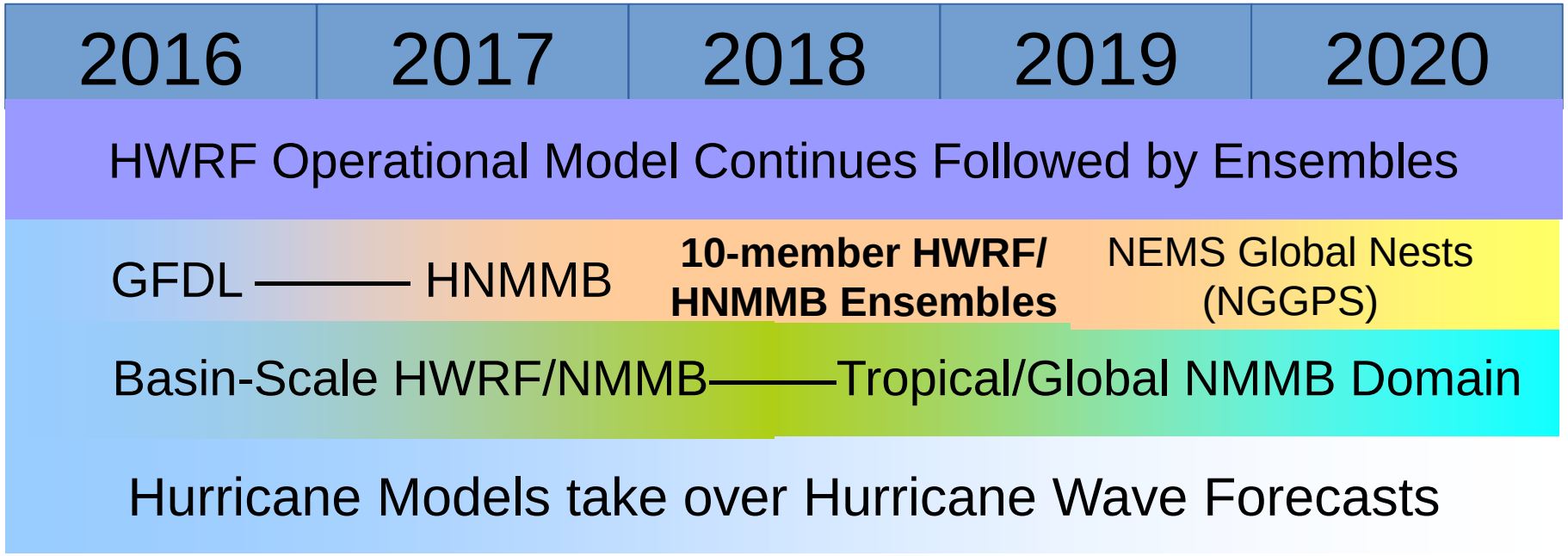




Robust T&E shows HMON has superior results over GFDL and different characteristics than HWRF in North Atlantic and North

- **HMON:** Advanced Hurricane Model using NMMB dynamic core which is currently being used in NCEP's operational NAM and SREF systems.
- Shared infrastructure with unified model development in NEMS. A step closer towards NEMS/FV3 Unified Modeling System for hurricanes
- Much faster, scalable and uses CCPP style physics package
- Development supported by NGGPS, HFIP and HIWPP programs
- Provides high-resolution intensity forecast guidance to NHC along with HWRF (replacing the legacy GFDL hurricane model)

HWRF Long-Term Plans



Development, T&E and Implementation Plans for HWRF (supported by HFIP)

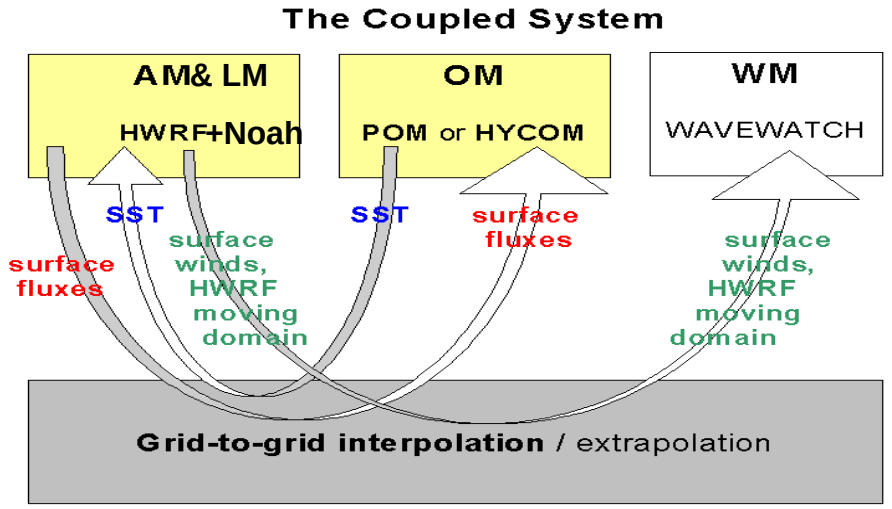
2016 Dec: H217 configuration ready
2017 Jan- Feb: H217 pre-implementation testing
2017 March: EMC CCB and code hand-off
2017 May: H217 Implementation

HWRF-HYCOM-WAVEWATCH III in 2017/2018

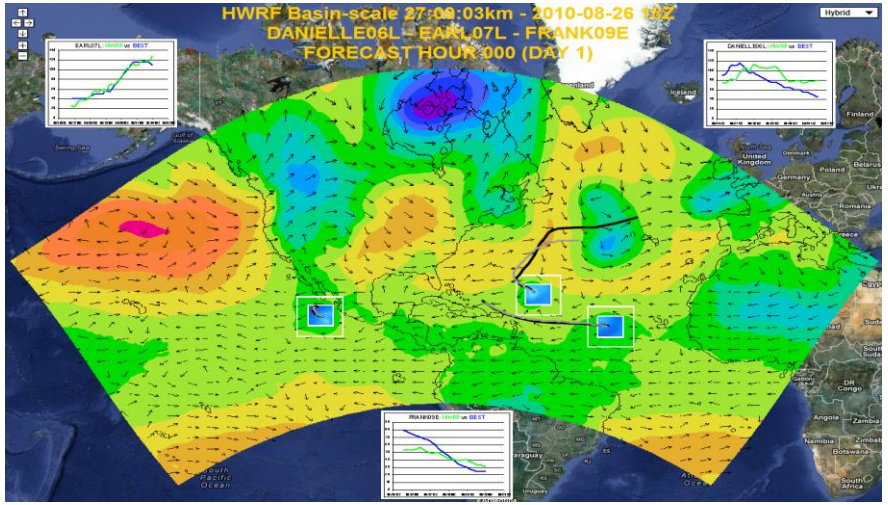
- Three-way coupled system development is in mature stage
- HYCOM for all global tropical storms:
  - Climatology based MPIPOM has exposed the limitations in Eastern Pacific basin in 2015 with strong El-Nino conditions
  - HYCOM with RTOFS initialization has been in the development
  - OMITT helped improve the initialization and physics of HYCOM
  - HYCOM-HWRF tested in 2016 real-time parallels, operational in 2017 (WPAC, NIO basins)
- One-way or three-way coupling with WaveWatch III Hurricane Wave Model
  - Unification of hurricane wave model with HWRF for all tropical cyclones
  - Three-way coupled system expected to enhance the representation of wave impacts on surface layer physics
  - 2017 HWRF upgrade includes one-way coupling, with three-way coupled system planned for 2018

Future Plans: Hurricane Physics

- Align with HFIP and NGGPS Physics Strategy
- Focus on improved air-sea interactions and inner core processes
- Advanced scale-aware and stochastic physics with focus on multi-scale interactions

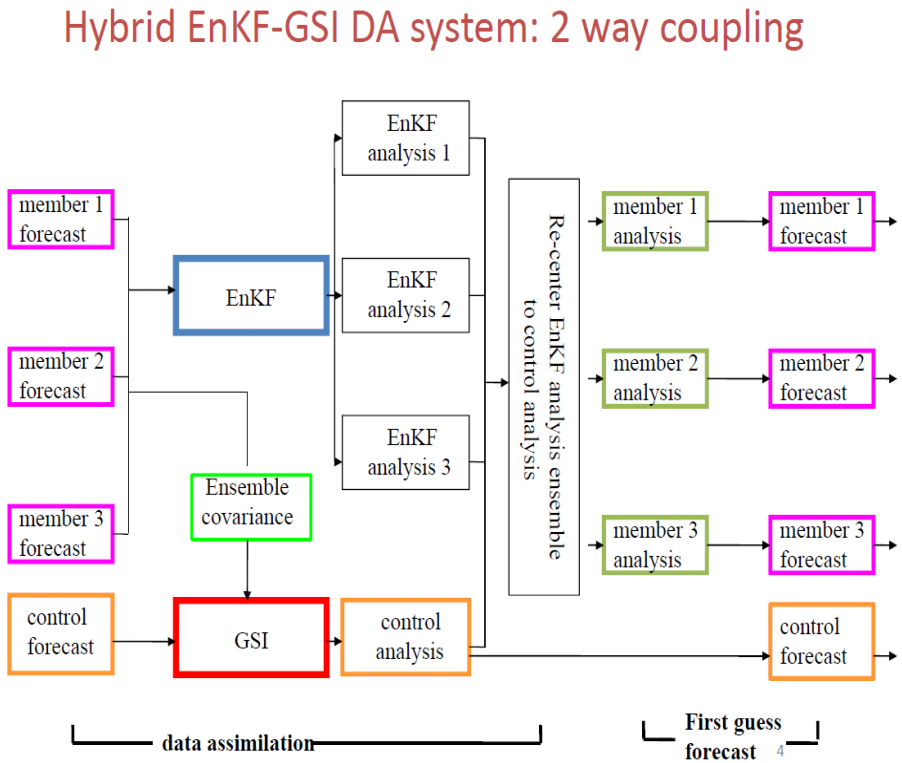


(additional **WM? AM** and **WM? OM** communications in progress)



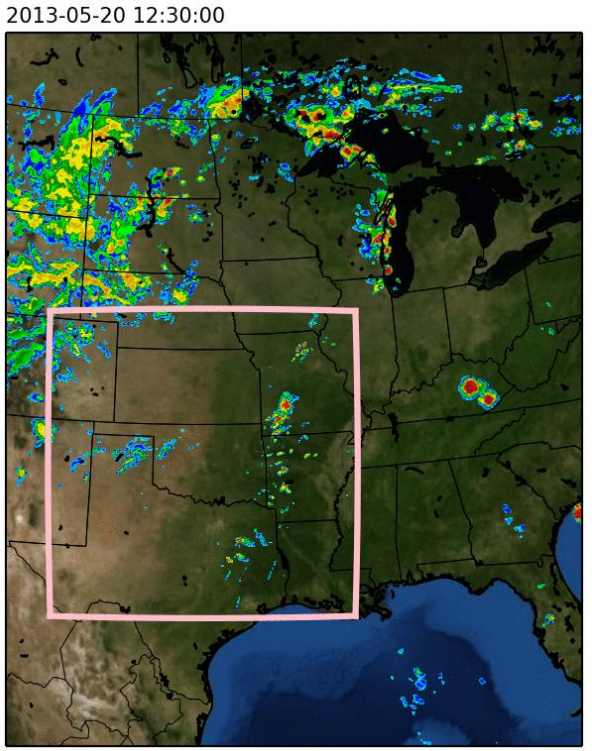
Future Plans: Hurricane Data Assimilation

- Align with HFIP DA Strategy
- Focus on inner core aircraft and all-sky radiance data assimilation
- Advanced self-cycled HWRF EnKF-GSI Hybrid Data Assimilation System (HDAS)
- Vortex relocation and initialization become part of Data Assimilation



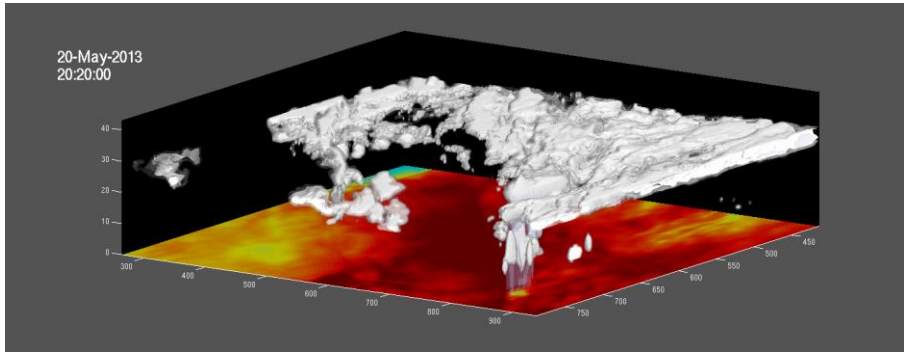
NGGPS/FV3 Plans for Hurricanes (Nesting & Convective Systems)

- Static/Moving
- 1-way/2-way interactive (nests)
- Multiple nests run simultaneously
- Bit reproducible and restartable (static/moving/ 1-way/2-way)
- ***Very fast and efficient!***
- Dynamics, physics and initialization appropriate and applicable for high-resolution nests within the global model



Two-way nests in FV3 designed for simultaneous, consistent, coupled regional and global solutions.

For example: **Three-day HiRAM/FV3 forecasts of severe convection during the Moore, OK tornado outbreak of May 2013, in a simulation nesting down to 1.3 km over the southern plains.**



HWRF as a unique global tropical cyclone model

Operational Real-time forecast guidance for all global tropical cyclones in support of NHC, JTWC and other US interests across the Asia Pacific, North Indian Ocean and Southern Hemisphere ocean basins

Continue the community modeling approach for accelerated transition of research to operations

NOAA HURRICANE FORECAST IMPROVEMENT PROJECT

NATIONAL HURRICANE CENTER

Japan Meteorological Agency

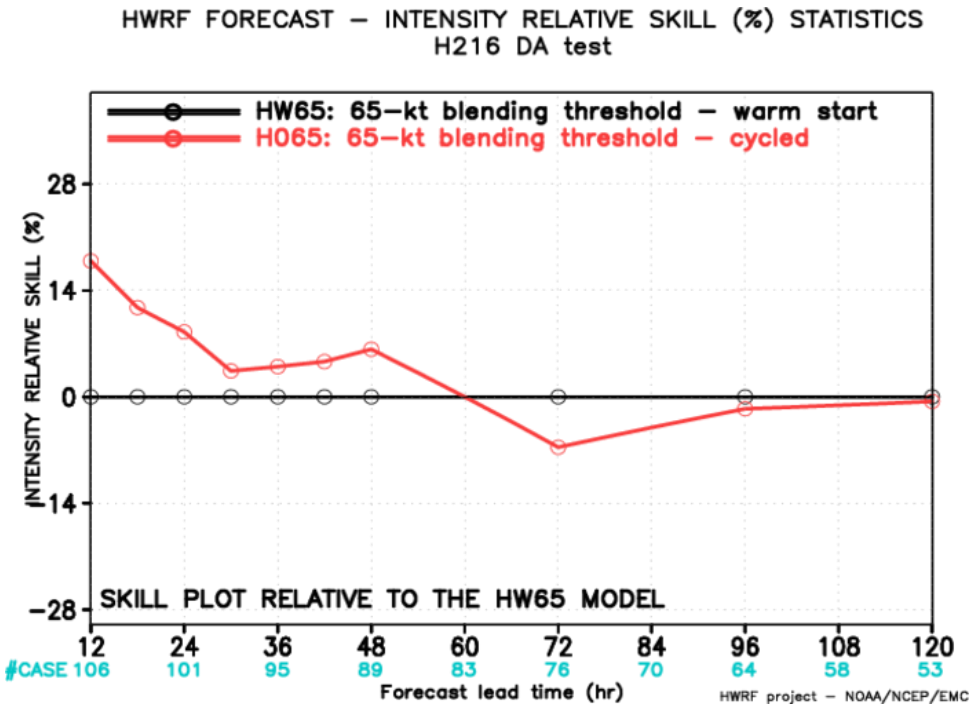
International partnerships for accelerated model development & research

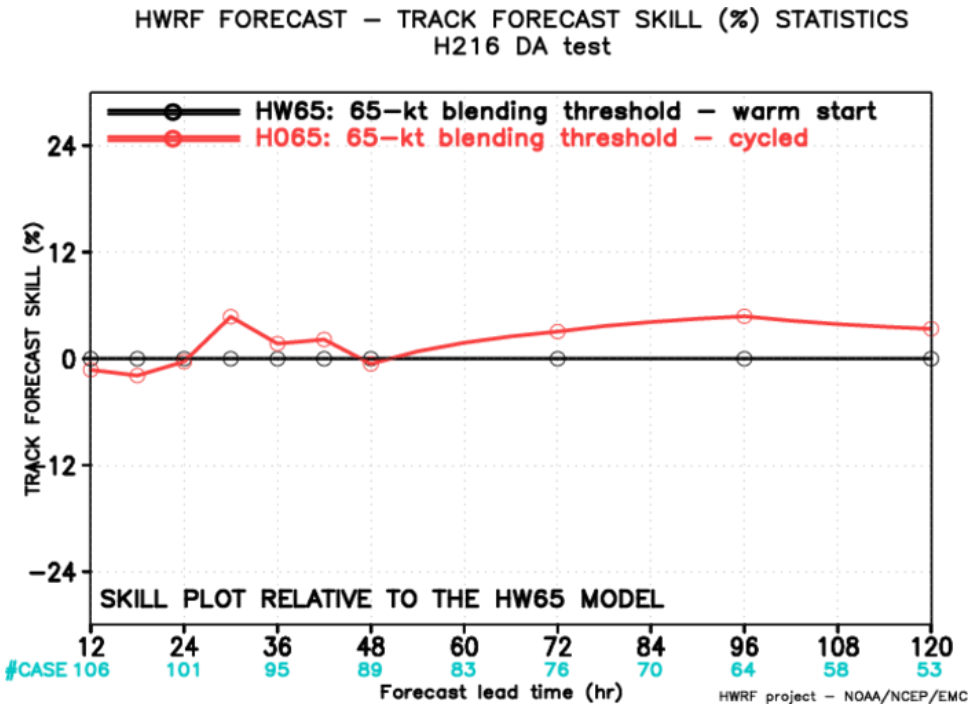
Thank You!

Doumo arigatou!

Supplemental Slides

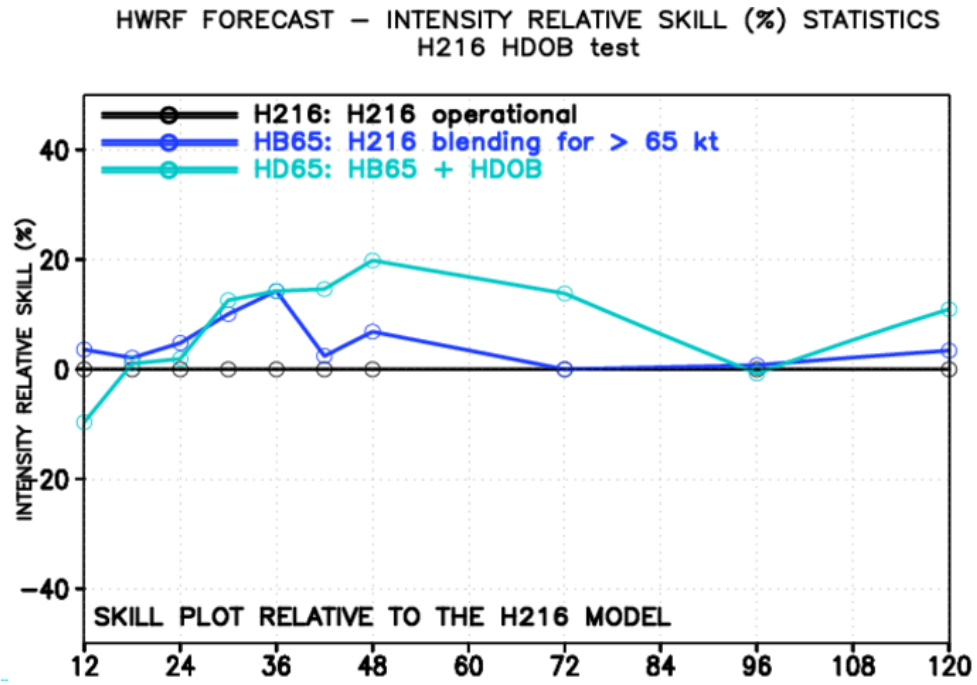
Impact of changes to Blending and cycled DA (2014-2016 Storms)

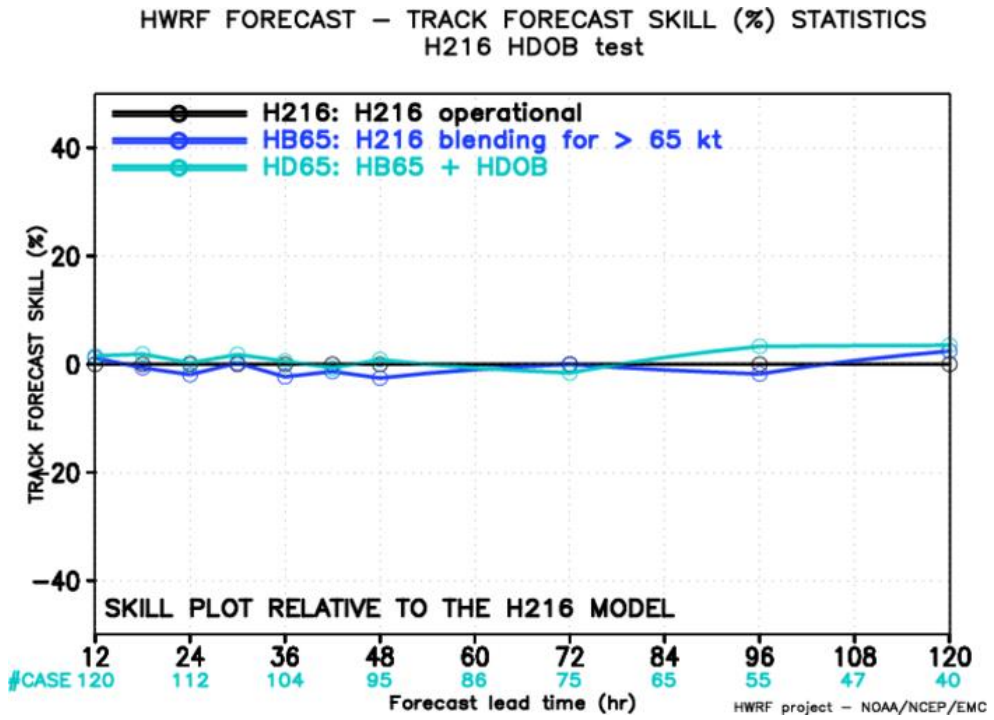




- HO65: Cycled DA results in better intensity forecasts for the first 60 hrs
- HO65: Cycled DA also improves track skill especially at long lead times

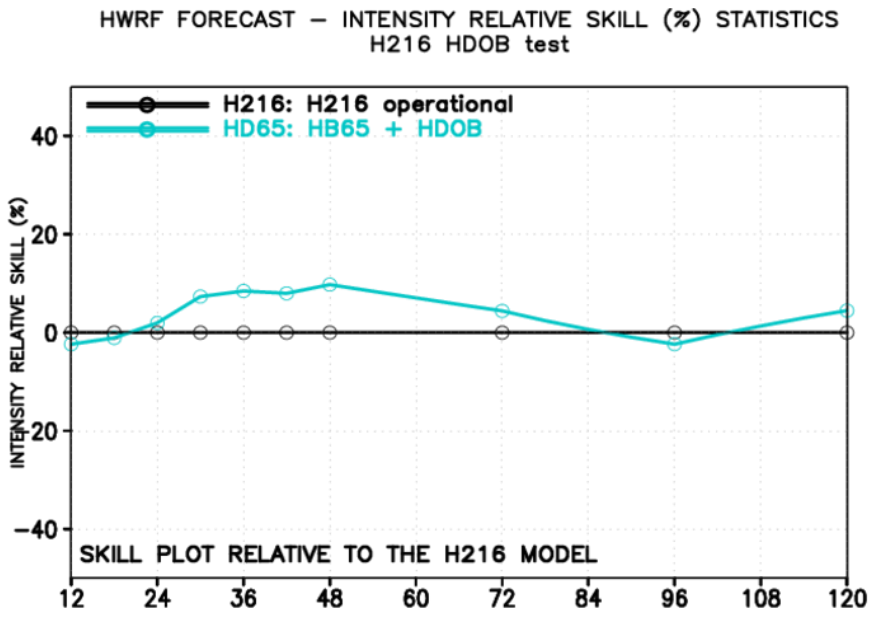
Impact of changes to Blending and HDOBS (2014 Storms)

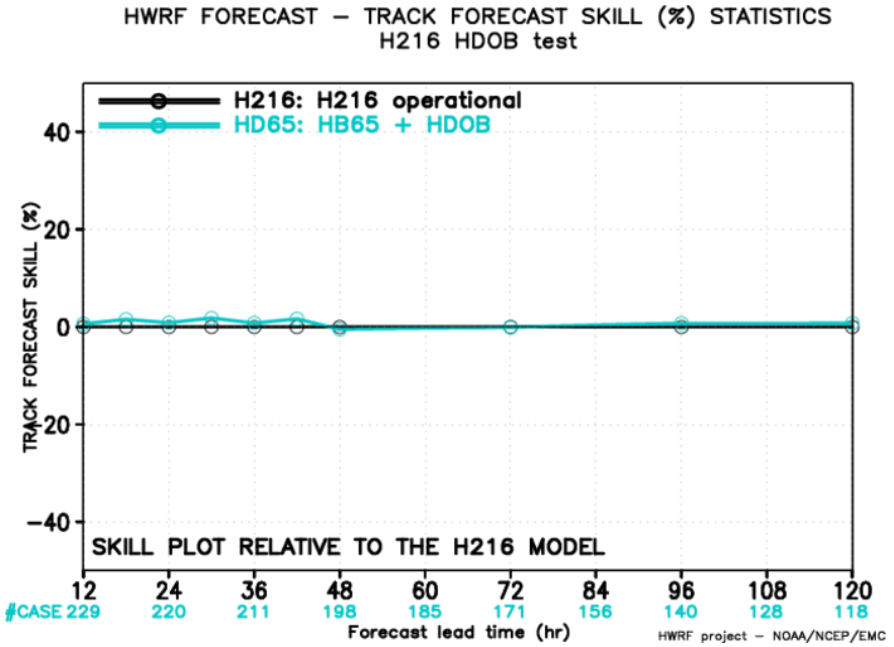




- HB65: Increasing blending threshold results in better intensity forecasts
- HD65: Adding HDOBS significantly improves intensity
- No impact on track

Impact of changes to Blending and HDOBS (2014 & 2016 Storms)





- Expanded sample to include Matthew & Hermine
- Consistent results of significant intensity improvement peaking at 48 h

Ferrier-Aligo Microphysics Changes

Problem / Solution

High reflectivity bias in PBL clouds

→ Added a drizzle parameterization (allows for smaller, more numerous drops)

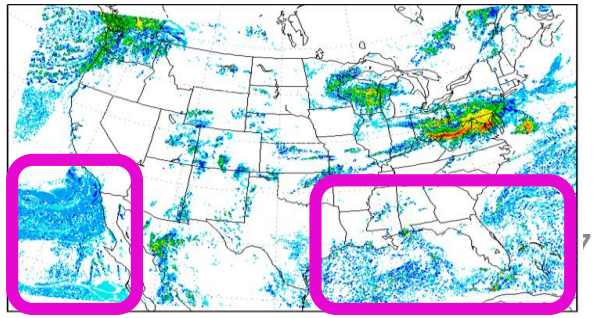
High reflectivity bias at anvil

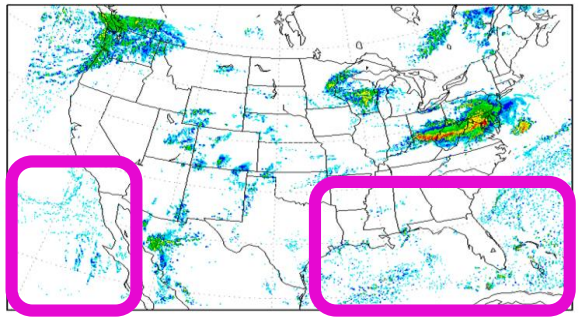
→ Increased largest possible number concentration of snow

Lack of stratiform precipitation

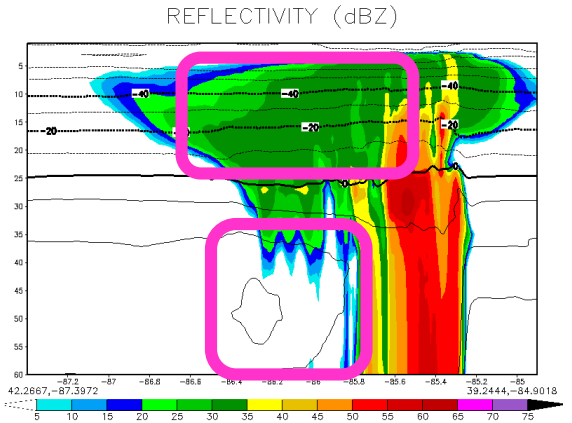
→ Constant rain drop size during rain evaporation (reduces evaporation)

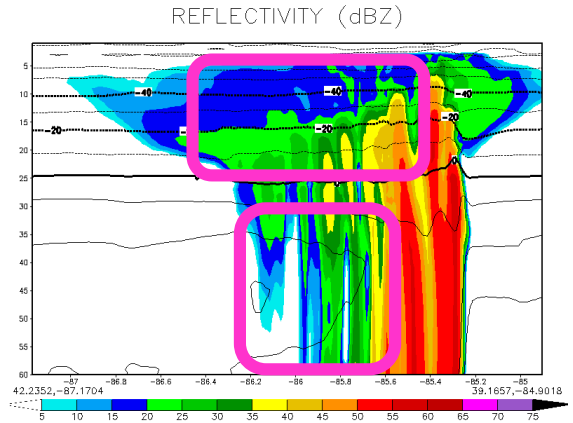
Old | **New**





12Z 23 June 2016



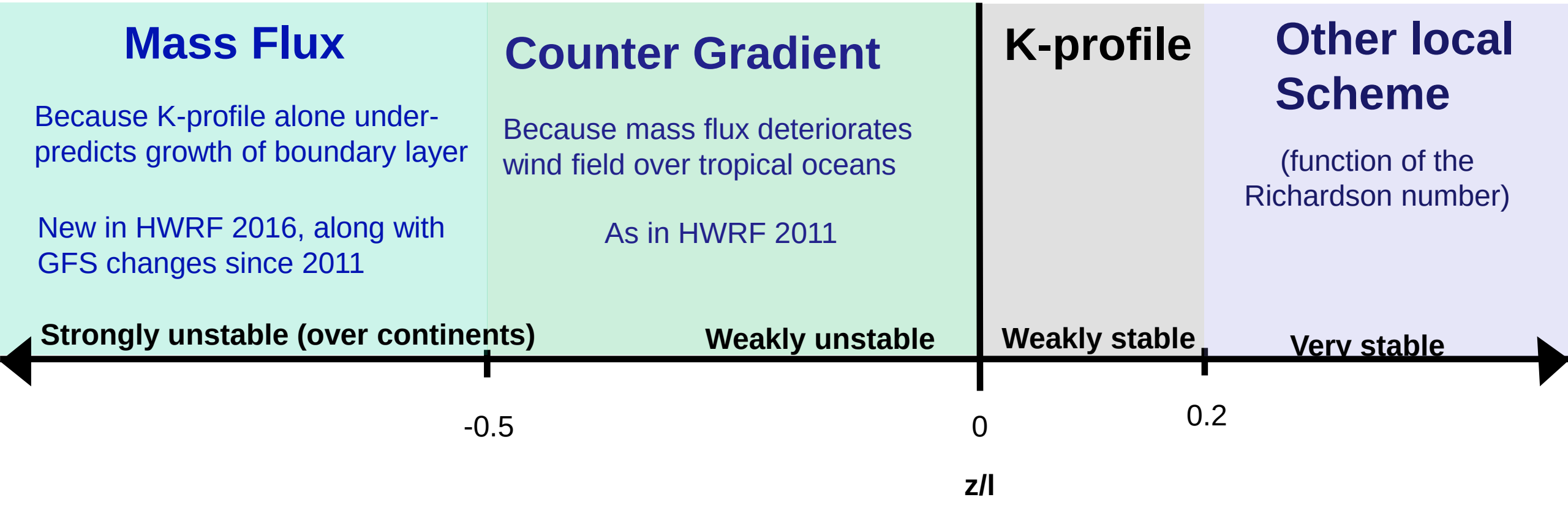


21Z 29 June 2012

HWRF 2016, “Hybrid” PBL

K-profile + other term

Potential change in HWRF 2017:
PBL height increased where vertical velocity w>0.4 ms^{-1}
This is to account for mixing within convective clouds



RRTMG cloud-radiation enhancements

- **Cloud overlap advancements**
- **Exponential-random (ER)** replaces maximum-random (MR) cloud overlap
  - More realistic relative to radar measurements within vertically deep clouds

    MR- Continuous cloud layers overlap as much as possible; blocks of cloud layers with clearing in-between are oriented randomly

    ER -Continuous cloud layers use overlap that transitions exponentially from maximum to random with distance through clouds, blocks of cloud layers and clearing in-between are oriented randomly

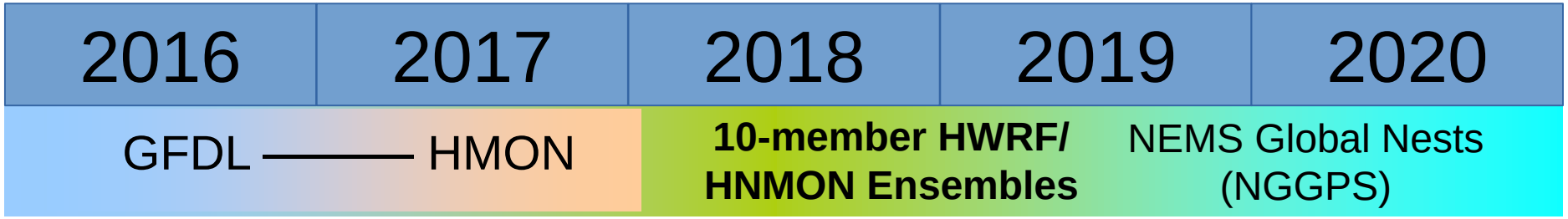
- **Partial cloud modifications**
  - Adjustments to RH threshold methodology
  - Reduction in solar radiation biases over CONUS

DTC physics testing: Grell-Freitas

- Grell-Freitas convective scheme implemented in HWRF by G. Grell and J.-W. Bao (NGGPS project)
  - Scale-aware/Aerosol-aware (Grell and Freitas, 2014)

- G-F scheme is undergoing testing at DTC in HWRF
  - Provided developer support to bring code and subsequent bug fixes into centralized HWRF repository
  - Tests are against baseline 2016 operational HWRF configuration.
  - Initial results in NATL basin show promising results in both track and intensity

High-Resolution HWRF/HMON Ensembles in 2018



HWRF Ensembles have been showing value during the past three years (HFIP Demo).

Surge in computing at NCEP operations allows us to plan for implementing high-resolution HWRF ensembles

Take advantage of ensemble DA, perturbations in physics and IC/BCs

Develop products that directly benefit NHC operations to improve deterministic forecasts

2016/2017: Continue HWRF ensemble HFIP Demo (multi-model regional ensembles); add HMON members to the mix

2016/2017: Develop advanced products for providing guidance on guidance and probabilistic forecasts

2018: 10-member HWRF/HMON ensemble implementation

Basin-Scale Multi-Storm HWRF/HMON in 2018

2016	2017	2018	2019	2020
Basin-Scale HWRF/NMMB———				—Tropical NMMB Domain

Large basin-scale domains that forecast multiple storms at the same time.

Need to show the value (cost vs. benefit)

Primary focus is for NATL/EPAC basins

Seven day forecasts including genesis.

Such large domains are needed for good wave forecasts

HMON could do a “tropical domain”: -60 to +60 latitude, cyclic in longitude; Covers all storms.

2016/2017: HWRF/HMON basin-scale parallels

2018:

- **HWRF/HMON basin-scale operational**
- **HMON tropical domain parallel**

2019: HMON tropical domain operational

2020 onward: develop global nests to replace HMON tropical domain with NGGPS/FV3

Tropical Domain HMON in 2019

2016	2017	2018	2019	2020
Basin-Scale HWRF/NMMB———			**Tropical NMMB Domain**	

2017 Nov: Full DA, basin-scale, system ready.

2018 Jun: HMON with DA operational

- Basin-scale, just like HWRF.
- Upgrade at same time as HWRF.

2018 Nov: “Tropical” domain ready

2019 Jun: “Tropical” HMON model operational

2019 onward:

- **Development switches to global nesting implementation.**
- **Three-way global coupling (wave/ocean/atmos)**
- **Target 2021 for parallel.**
- **Target 2022 for implementation.**
- **Follows the path of NGGPS for hurricanes.**
- **Assists in developing advanced modeling techniques for NGGPS hurricane components**

Summary

- 2017 targets:
  - HWRF improvements to Physics and Data Assimilation
  - HMON with no DA replaces GFDL
  - HWRF produces all standalone hurricane wave outputs
  - Standalone hurricane wave model is retired
- 2018:
  - HWRF/HMON basin-scale with wave forecasts and DA
  - HWRF wave forecasts as good as standalone
  - 10-member HWRF/HMON Ensembles
- 2019:
  - HMON single tropical outer domain for all storms
- 2020 onwards:
  - Development switches to global nests