Operational Tropical Cyclone Modeling Advancements at NCEP: Current Status & Plans for Development of Next Generation Hurricane Analysis and Forecast System

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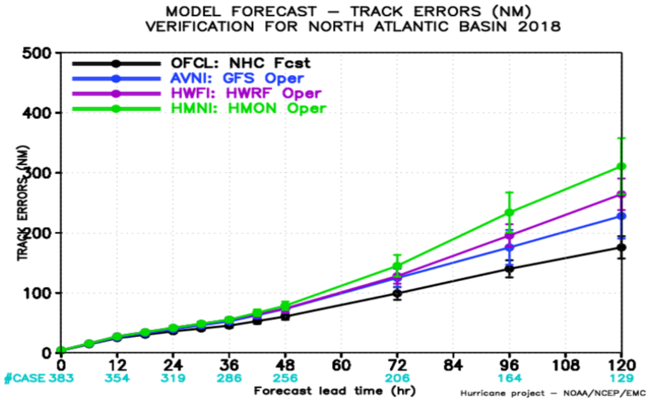
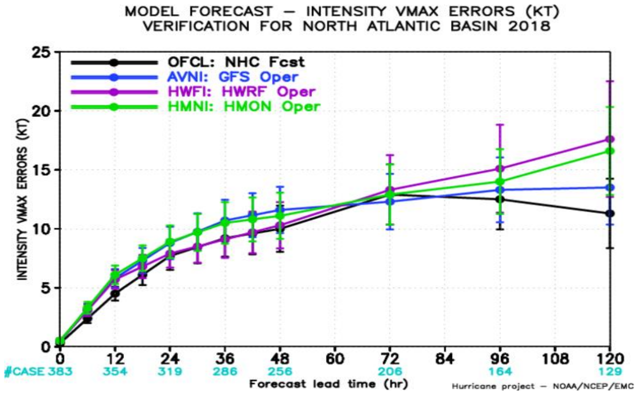
Outline

- FY18 real-time performance
- FV3GFS downstream testing for HWRF and HMON
- FY20 HWRF and HMON potential upgrades
- HWRF/HMON diversity
- Future plans – Hurricane Analysis and Forecast System (HAFS)

North Atlantic Basin 2018

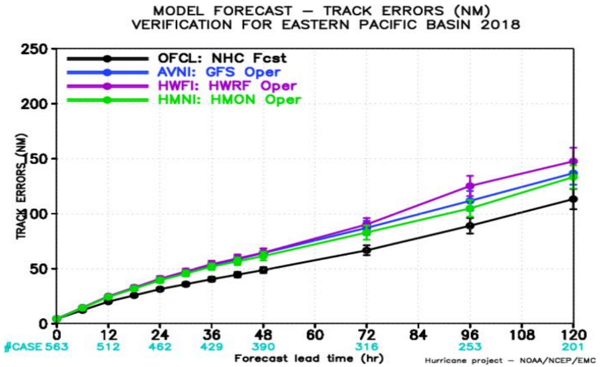


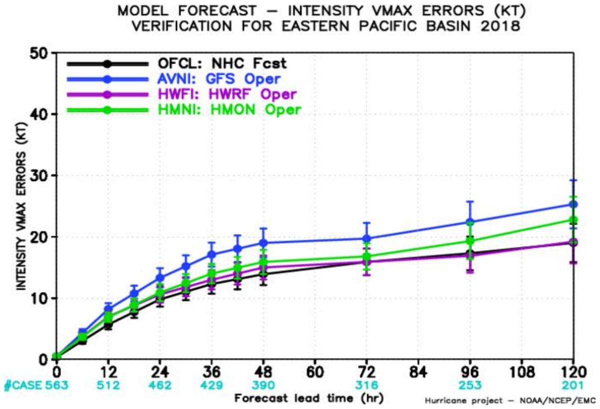


NCEP dynamical models performed very well in the North Atlantic Basin for the 2018 Hurricane season. The Global Forecast System (GFS; in blue) provided forecasts with the lowest track errors (top left panel). It provided the best numerical track guidance for Hurricanes Florence and Michael (not shown).

HWRF (in purple) was the best dynamical model with the lowest intensity errors prior to Day 3 (bottom left panel) when it was comparable to the official forecasts from NHC (in black). After Day 3, GFS (in blue) had the lowest errors.

North East Pacific Basin 2018

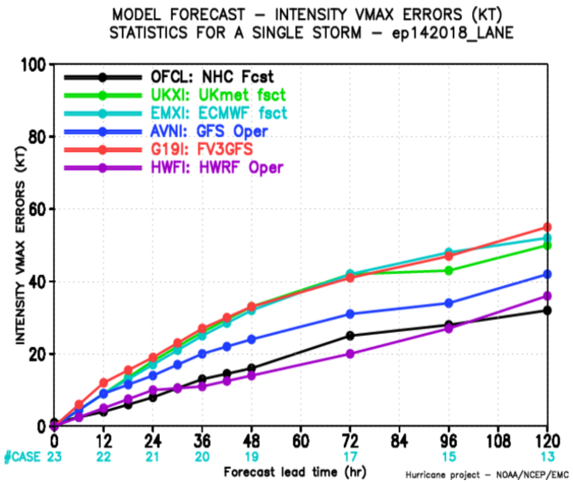


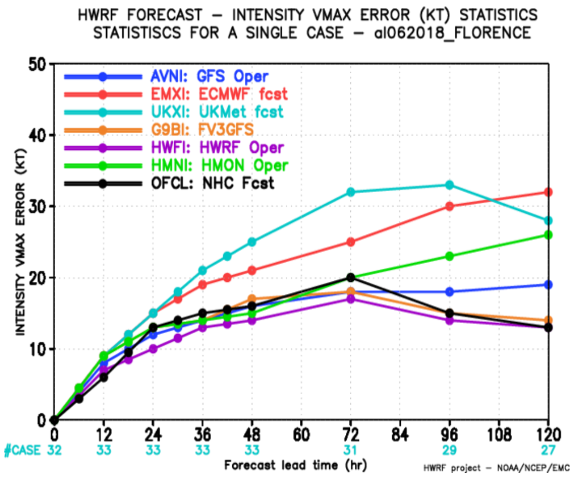


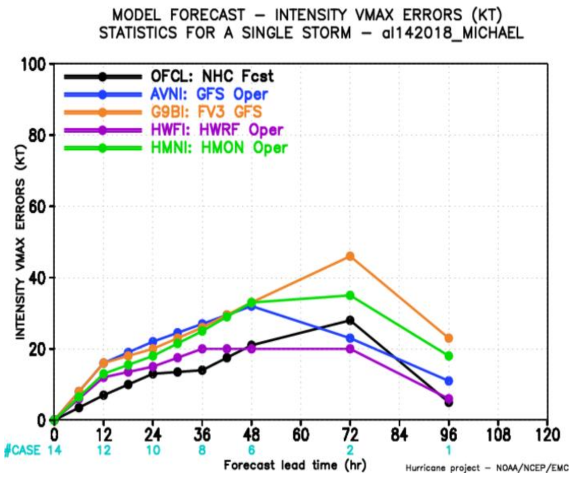
NCEP dynamical models performed very well in the North East Pacific Basin as well for the 2018 Hurricane season. HMON (in green) provided forecasts with the lowest track errors (top left panel). It provided the best track guidance for Hurricane Lane which impacted the islands of Hawaii (not shown).

HWRF (in purple) was the best dynamical model with the lowest intensity errors (bottom left panel). HWRF forecasts were very comparable to the official forecasts from NHC and CPHC (in black).

2018: Hurricanes Florence (AL06); Lane (EP14) and Michael (AL14)







Operational HWRF (in purple) had the best intensity forecast skill for all three storms, with results comparable to NHC/CPHC official forecasts at most of the forecast intervals based on early (interpolated) results.

Downstream Testing with FV3GFS for Priority Storms in NATL and EPAC Basins

HWRF v12.1.0 *

* Approved for implementation with FV3GFS in FY19Q3

HWRF Configurations

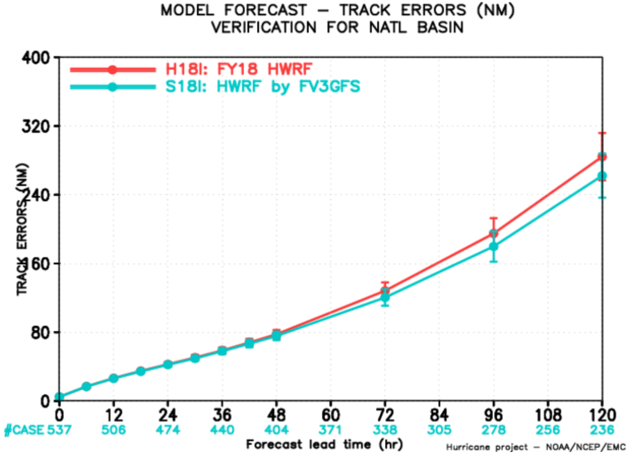
➢ H18I: Interpolated results for FY18 HWRF using 2017 GFS (operational GFS v14) results (2015-2017)

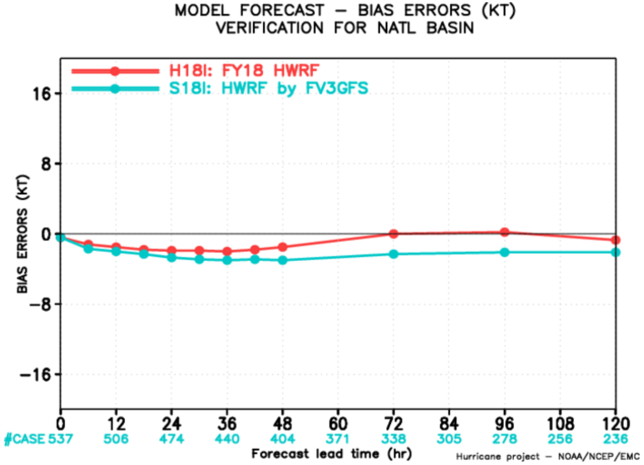
➢ S18I: Interpolated results for FY18 HWRF using FV3GFS (proposed GFS v15) retrospective results (2015-2017)

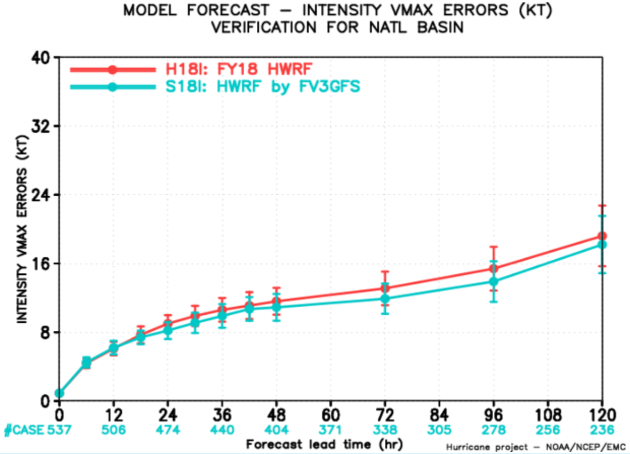
Changes Include:

- ✓ scripts and source code changes in HWRF initialization process to read in FV3GFS GRIB2;
- ✓ scripts and source code change HWRF/GSI for FV3GFS;
- ✓ bug fix for the case when storm moved too far north (> 60N).

HWRF Performance (NATL Basin): Early Model



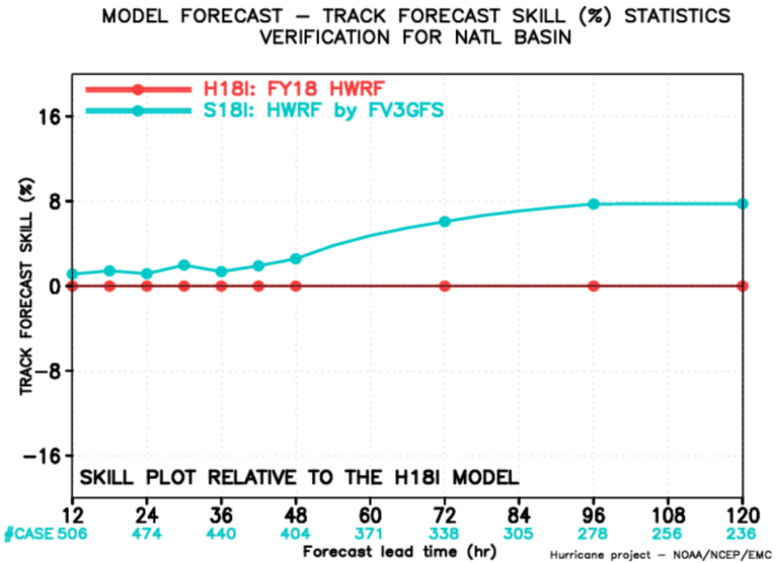


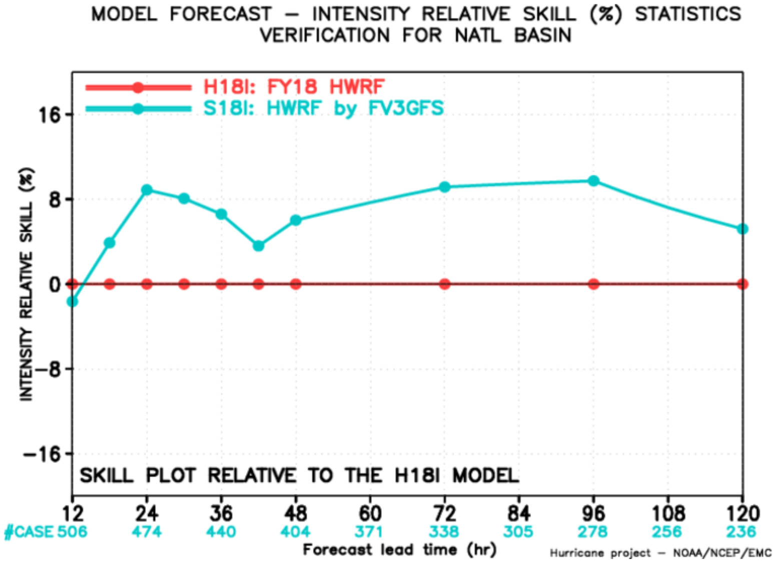


S18I has reduced track errors as compared to H18I (the operational version of HWRF) especially for longer lead times (> 3 days0.

The intensity errors are also smaller for all lead times for S18I but the bias errors are on the negative side.

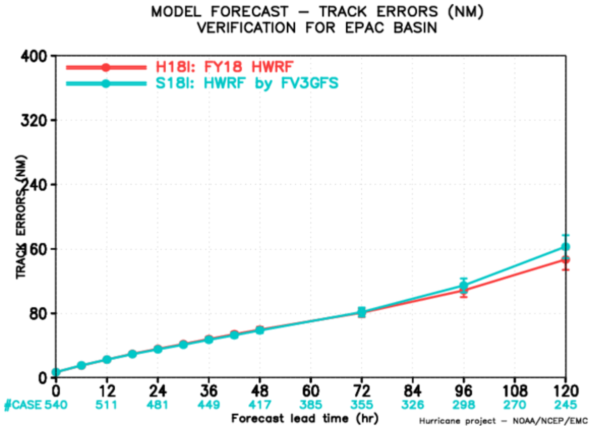
Track and Intensity skill for NATL basin (priority storms)
(Early Model)

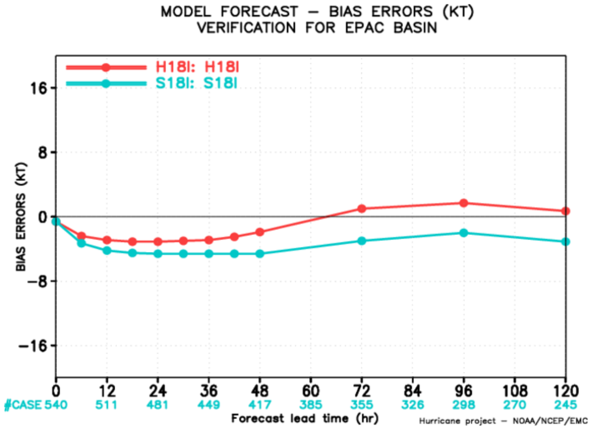


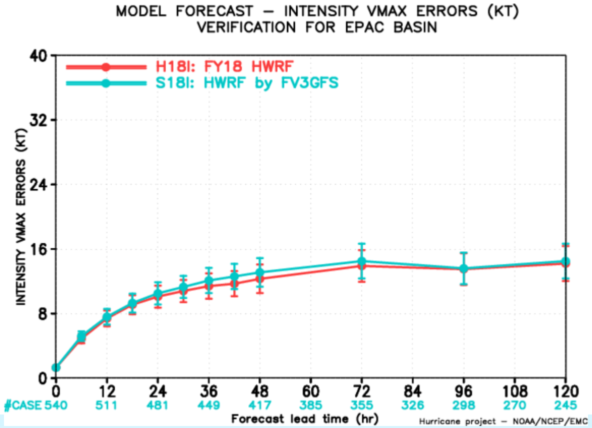


There is good improvement in track skill especially for longer lead times reaching 8% at Days 4 and 5. Intensity skill improvements are evident at all lead times with more than 8% improvements at Day 1 and again at Day 4.

HWRF Performance (EPAC Basin): Early Model



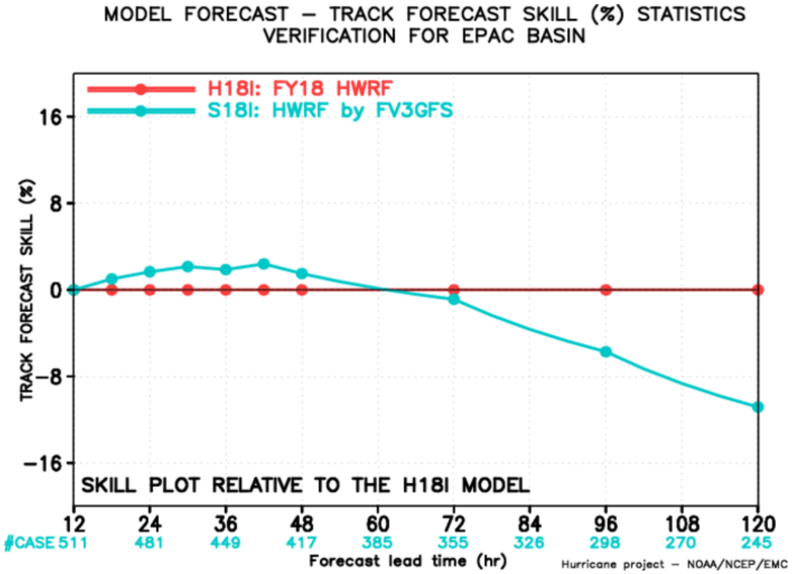


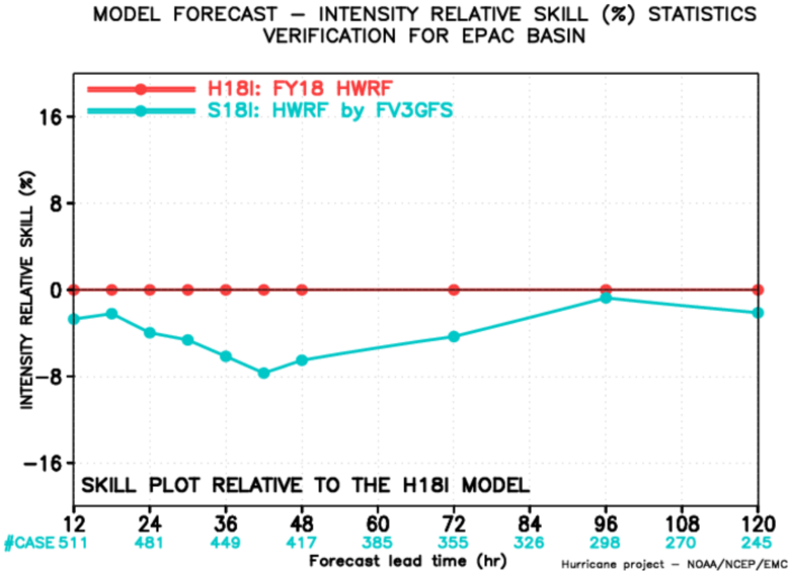


S18I has similar track errors for early lead times up to Day 3 but larger errors for Days 4 and 5 as compared to H18I.

The intensity errors are larger for early lead times but similar for Days 4 and 5. Intensity biases are also larger and negative when compared with H18I.

Track and Intensity skill for EPAC basin (priority storms) (Early Model)





Track forecast skill is improved for the first 2 days and then neutral for Day 3, but behind for Days 4 and 5. Intensity skill, on the other hand, is behind for the first 3 days and then mostly neutral for longer lead times at Days 4 and 5.

Downstream Testing with FV3GFS for Priority Storms in NATL and EPAC Basins

HMON v2.1.0 *

* Approved for implementation with FV3GFS in FY19Q3

HMON Configurations

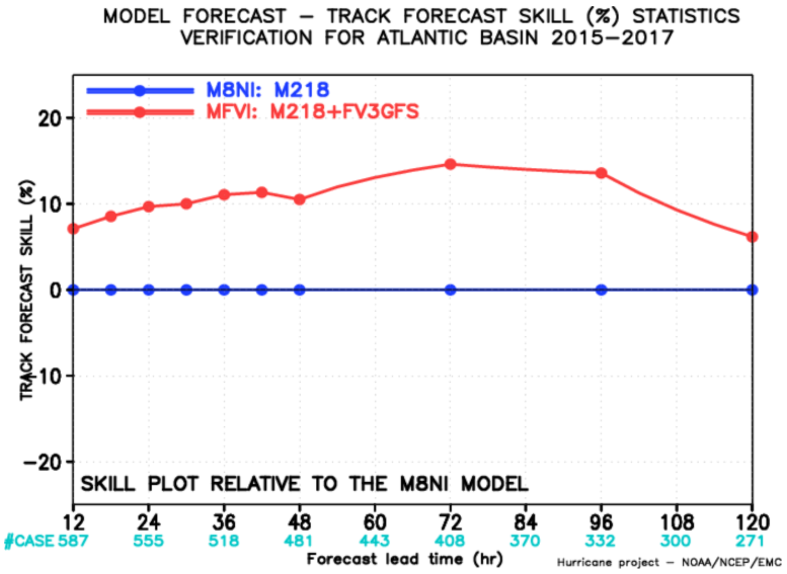
- **M18I**: Interpolated results for FY18 HMON using 2017 GFS (operational GFS v14) results (2015-2017)

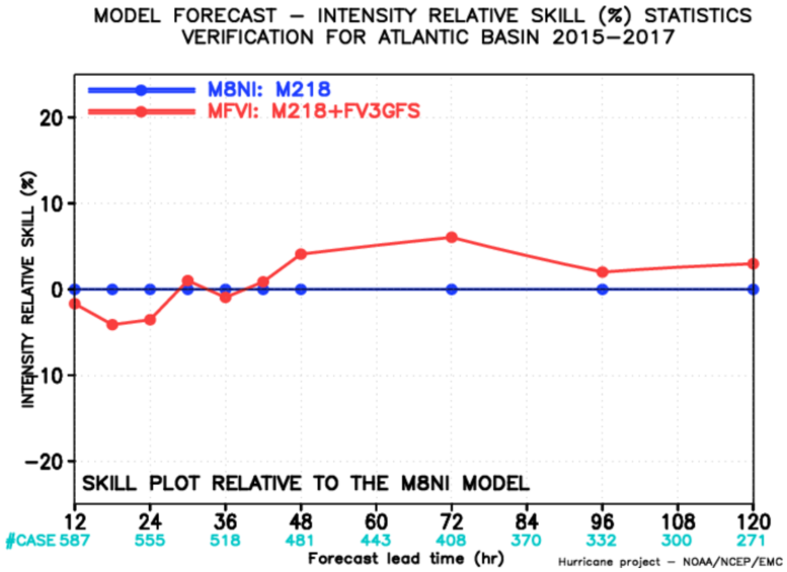
- **MFVI**: Interpolated results for FY18 HMON using FV3GFS (proposed GFS v15) retrospective results (2015-2017)

Changes include:

  - ✓ source and scripts changes in HMON initialization process to read in FV3GFS GRIB2;
  - ✓ bug fix for rain swath product

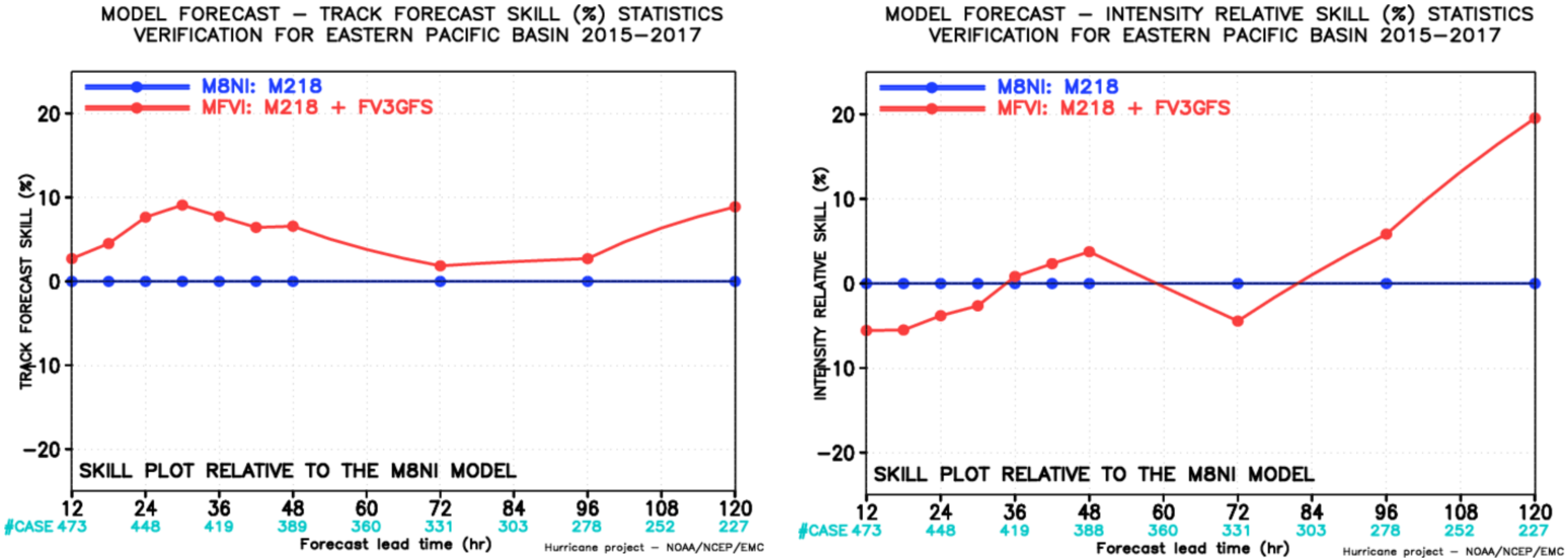
Track and Intensity skill for NATL basin (priority storms) (Early Model)





There is good improvement in track skill for all lead times peaking at around 14 % (at Day 3) while giving an average improvement of 10%. Intensity skill improvements start after Day 2 with 4-6% improvements at Day 2 and 3. There is some degradation at Day 1 but overall its positive.

Track and Intensity skill for EPAC basin (priority storms) (Early Model)



There is good improvement in track skill for early lead times peaking at around 10 % (at hr 30) and once again at Day 5 while giving improvement at all lead times. Intensity relative skills are neutral till Day 3 and significantly positive at Day 4 (6%) and Day 5 (20%).

FY20 HWRF v13.0.0
Potential Upgrades

Scope of FY20 HWRF Upgrades

➢ System & Resolution Enhancements

- Framework upgrade to WRFV4.0 with bug fixes
- T&E with 2019 FV3GFS IC/BC
- **High Resolution land-sea mask**
- Optimize time steps
- Increase vertical resolution

  or
- Increase domain size (d01, d02, d03) incl. basin-scale

➢ Physics Advancements

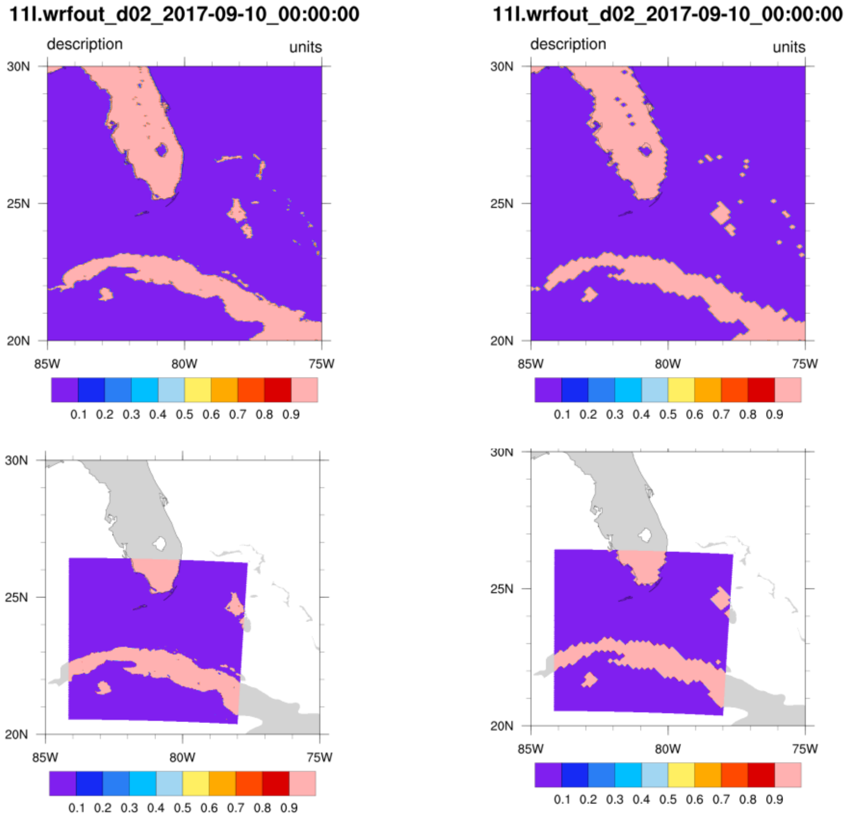
- Updates/options for PBL schemes (MYNN; in-cloud mixing; YSU)
- G-F cumulus scheme (ESRL)
- Consider YSU surface layer scheme (with YSU PBL)
- Radiation, RRTMG- cloud overlap changes (AER/DTC)
- Adjust surface flux exchange coefficients

-- Green: Included in Baseline
-- Orange: Tested separately as an option

Hurricane Irma: Comparison of coastlines for the HWRF nested domains with and without high-resolution mask

D2@4.5 KM

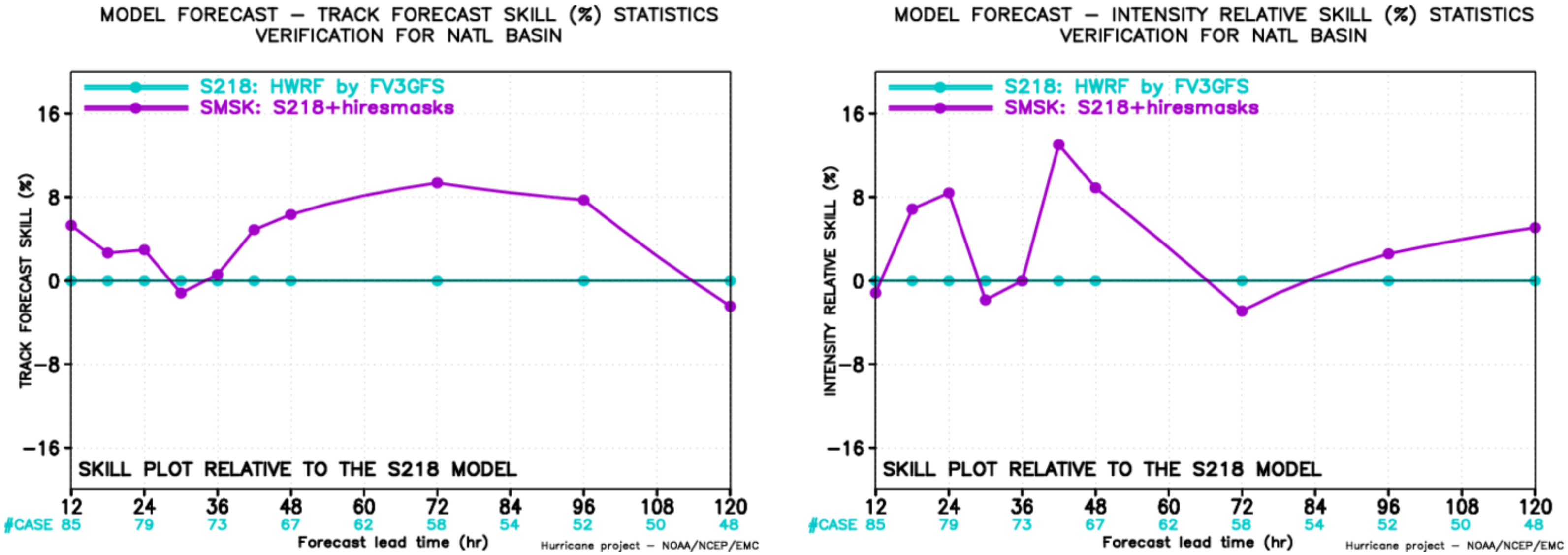
D3@1.5 KM



Using Hurricane Irma (2017) as an example, high-resolution land-sea masks are compared for outer nest domain (D2) (top left panel) with operational HWRF (top right panel) and for inner nest domain with high-resolution mask (bottom left) with operational HWRF (bottom right).

The high-resolution mask provides a much improved representation of coastlines (and orography) for Florida, Cuba and the Bahamas.

HWRF with High-Resolution Mask: Much Improved track and Intensity skill for Hurricanes Irma and Harvey



Based on results for Hurricanes Irma and Harvey, there is good improvement in track skill (left panel) and intensity skill (right panel) when high-resolution mask is introduced in the HWRF configuration.

Scope of FY20 HWRF Upgrades

Initialization/Data Assimilation Improvements

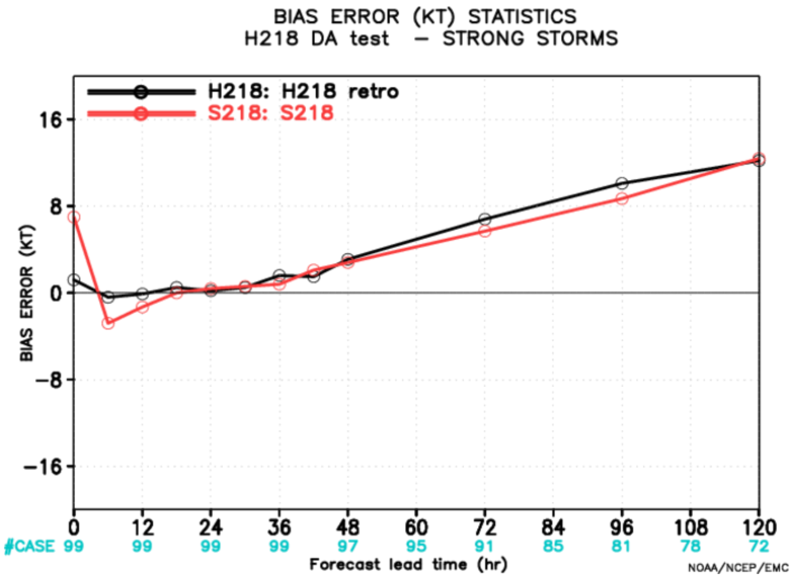
- Extend self-cycled DA to two concurrent storms
- GSI code upgrades (for FV3GFS); add new data sets
- **SFMR observation errors tuning**
- Tuning increments for storms > 120 kt
- Changes to front-end (Relocation, VI, VM), explore fully cycling D02/D03 instead of limited area around vortex
- Satellite background covariance coefficients
- Extend DA to WPAC

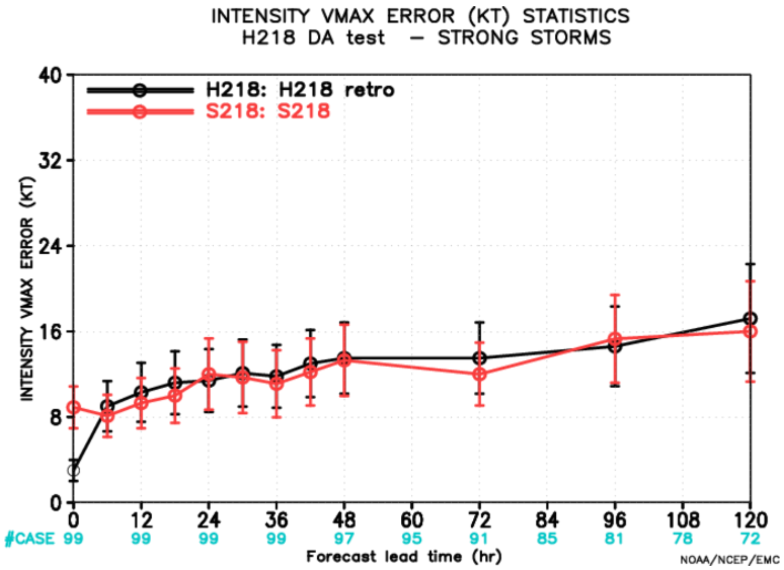
Other Upgrades

- Updated coupler
- POM SST initialization from RTOFS in NATL basin (similar to EPAC and CPAC basins)
- **Adjust damping coefficients**
- Updated tracker
- Graphics included in workflow
- 3-way coupling with waves

-- Green: Included in Baseline
-- Orange: Tested separately as an option

HWRF with tuned error characteristics for dropsondes and SFMR (Late Model)





Changing error characteristics for dropsonde and SFMR data for strong storms (> 64 kt) being assimilated in HWRF leads to somewhat reduced bias and intensity errors.

Scope of FY20 HMON Upgrades

➢ System & Resolution Enhancements

- Upgrade to the latest NMMB dynamic core
- Add vertical levels, revise nest domain sizes

➢ Initialization Improvements

- Updated composite vortex

➢ Physics Advancements

- Update momentum and enthalpy exchange coefficients(Cd/Ch)
- Deep convection (with FV3)
- Use scale aware TKE EDMF PBL scheme
- Use MYNN-EDMF scheme

➢ Coupling Upgrades

- Use updated coupler
- 3-way coupling

-- Green: Included in Baseline/MFVI
-- Orange: Tested separately as an option

HWRF/HMON Configurations (maintain diversity for FY20)

Note: Items in Red are different

	HWRF	HMON
Dynamic core	Non-hydrostatic, NMM-E	Non-hydrostatic, NMM-B
Nesting	13.5/4.5/1.5 km; 77°/18°/6°; 75 vertical levels; Full two-way moving	18/6/2 km; 75°/12°/8°; 51 vertical levels; Full two-way moving
Data Assimilation and Initialization	Vortex relocation & adjustment, Self-cycled hybrid EnKF-GSI with inner core DA (TDR)	Modified vortex relocation & adjustment, no DA
Physics	Updated surface (GFDL), GFS-EDMF PBL, Updated Scale-aware SAS, NOAH LSM, Modified RRTM, Ferrier	Surface (GFDL), GFS-EDMF PBL, Scale-aware SAS, NOAH LSM, RRTM, Ferrier
Coupling	MPIPOM/HYCOM, RTOFS/GDEM, WaveWatch-III	HYCOM, RTOFS/NCODA, No waves
Post-processing	NHC interpolation method, Updated GFDL tracker	NHC interpolation method, GFDL tracker
NEMS/NUOPC	No	Yes with moving nests
Computation cost for forecast job	81 nodes in 98 mins	26 nodes in 95 mins

Ongoing and Future Tasks

- Further improvements to hurricane physics
- Further improvements to vortex initialization and data assimilation
- Increase/change resolution, domain sizes
- Three-way Atmosphere-Ocean-Wave coupling
- 5-10 Member Ensembles for HWRF & HMON
- **HAFS**

Hurricane Analysis and Forecast System (HAFS): A collaborative Project in UFS Framework

Revised HFIP Goals aligned with the Weather Act

1. Reduce forecast guidance errors, including during RI, by 50% from 27
2. Produce 7-day forecast guidance as good as the 27 5-day forecast guidance
3. Improve guidance on pre-formation disturbances, including genesis timing, and track and intensity forecasts, by 20% from 27
4. Improve hazard guidance and risk communication, based on social and behavioral science, to modernize the TC product suite (products, information, and services) for actionable lead-times for storm surge and all other threats

HAFS: Hurricane Analysis and Forecast System

Goals:

- **Develop FV3 based multi-scale model and data assimilation package capable of providing analyses and forecasts of the inner core structure key to improving size and intensity predictions, as well as the large-scale environment that is known to influence the TC's motion.**

- **Provide an advanced Hurricane Analysis and Forecast System for cutting-edge research within the outlined Next Generation Global Prediction System (FV3) plans for the Unified Forecast System.**

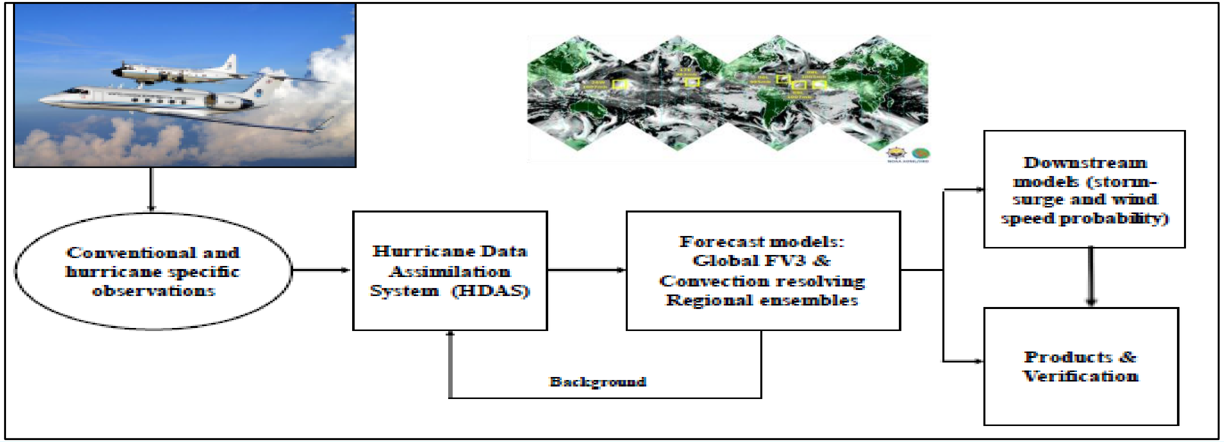
Ongoing Efforts at EMC Towards Simplified Production Suite

Modeling System	Current Status	Proposed Plans in the UFS Context
Global Deterministic	FY19: Transition FV3GFS into operations	Advancement of NGGPS/FV3GFS (biennial upgrades)
Global DA	4D-Hybrid En-Var using GSI	Migrate to JEDI
Global Ensembles (Sub-seasonal)	FV3/NEMS based reanalysis/ reforecasts	FY20: Implement FV3 GEFS for sub-seasonal weather forecasts (35 days)
Global Seasonal Climate	Develop coupled UFS and coupled DA	Implement FV3 SFS for seasonal climate forecasts (MOM6, CICE5, Noah-MP, WWIII, GOCART,JEDI)
Global Aerosols	NGAC V2 (NEMS/GSM + GOCART)	FY20: Merge with FV3 GEFS
Hurricanes	HWRF & HMON	FV3 GFS with multiple moving nests (HAFS)
Waves	Waves Multi2 merged with HWRF	FY20: Merge wave ensembles models with FV3GEFS FY21: Merge deterministic Waves with GFSv16
Ocean	RTOFS/HYCOM	MOM6 + NCODA + Marine JEDI
Meso-Scale	NAM V4 & NMMB frozen	Transition to FV3 CAM, NAM/RAP Parent domains subsumed by FV3GFS?
Short-range ens.	SREF V7.1 frozen	FY20: Replace SREF with FV3GEFS???
HREF	V2: HiRes Window + NAM Nests (SSEO)	FV3 SAR to replace poor performing HREF members
RAP/HRRR	V2/V3	FY20: V3/V4 UFS CAM (RRFS)
Products, V&V	UPP, VSDB/MET, MEG, NAWIPS	UPP+, MET+, MEG+
Collaborative Infrastructure	Various	NEMS/ESMF/NUOPC+; EE2+; CROW; Shared infrastructure and distributed development

HAFS Strategies

1. Advance operational hurricane analysis and forecast system (HAFS)

- R&D for HAFS to advance deterministic and ensemble prediction capabilities
- R&D for fusion of modeling, data assimilation and observations to produce an analysis of record
- R&D for ensemble post-processing to extract guidance and uncertainty information

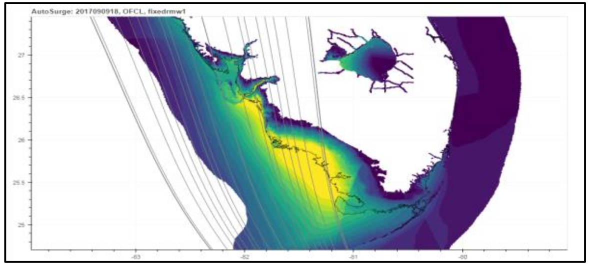


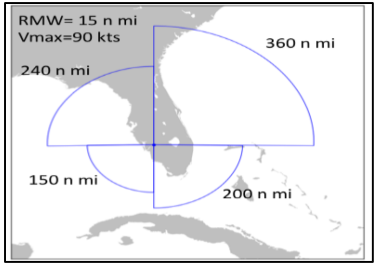
HAFS: Guidance & Products

2. Improve probabilistic guidance

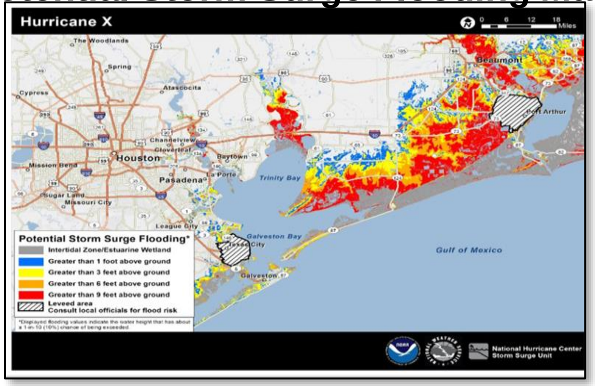
- Calibrate guidance with HAFS
- Incorporate dynamically-based uncertainty into hazard models and products
- R&D for hazard-specific products from HAFS

Planned improvements to P-Surge to Improve the Potential Storm Surge Flooding Map





Potential Storm Surge Flooding Map

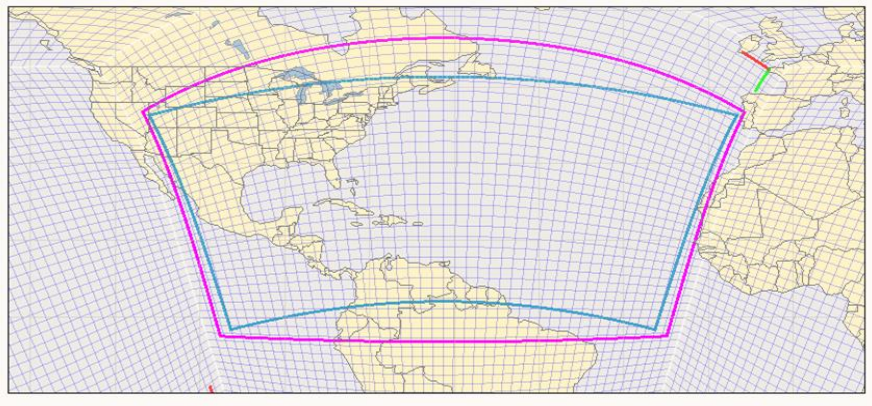


3. Enhance communication of risk and uncertainty

- Evaluate TC products for the effective communication of risk
- Modernize TC products as informed by social and behavioral science

HAFS Experimental Configurations

HAFS domains



Blue: Global with 3km static nest

Purple: 3km Stand-Alone Regional Model

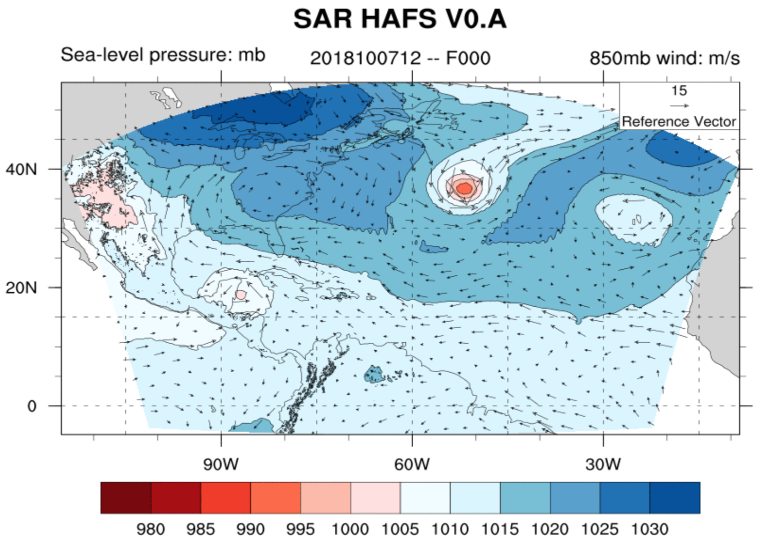
HAFS 0.A:
The NATL basin focused standalone regional domain configuration

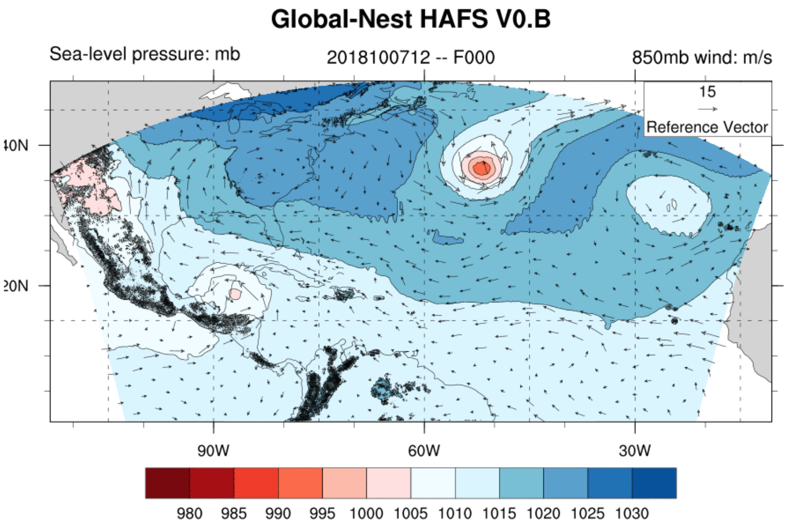
- C768 with a refinement ratio of 4
- the regional domain size: 2880x1920 (~85x56deg)

HAFS 0.B:
The NATL basin focused global-nesting domain configuration

- C768 with a refinement ratio of 4
- the nested domain size of 2880x1536 (~85x45deg)

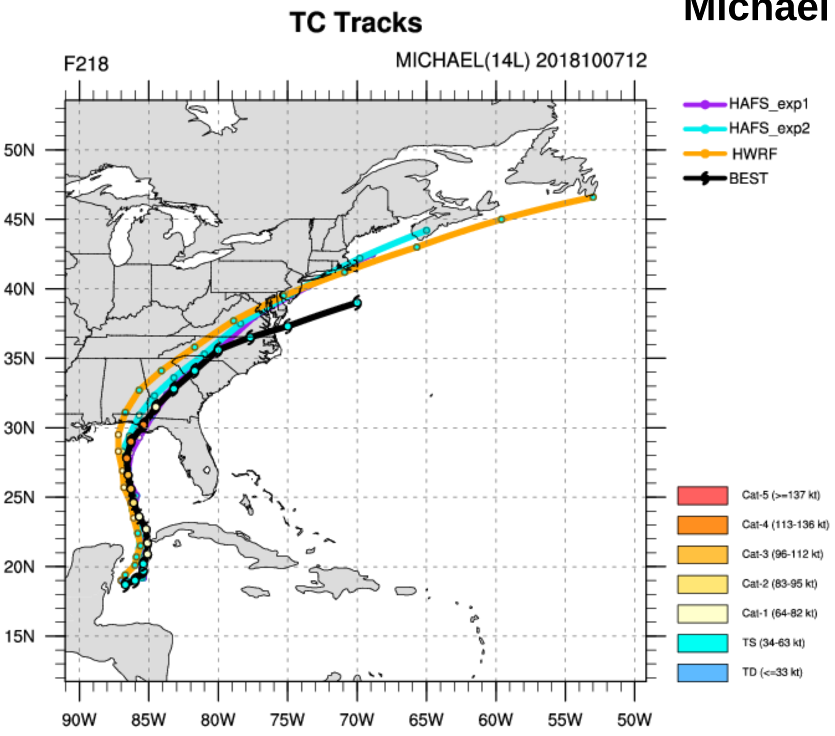
HAFS Experimental Configurations

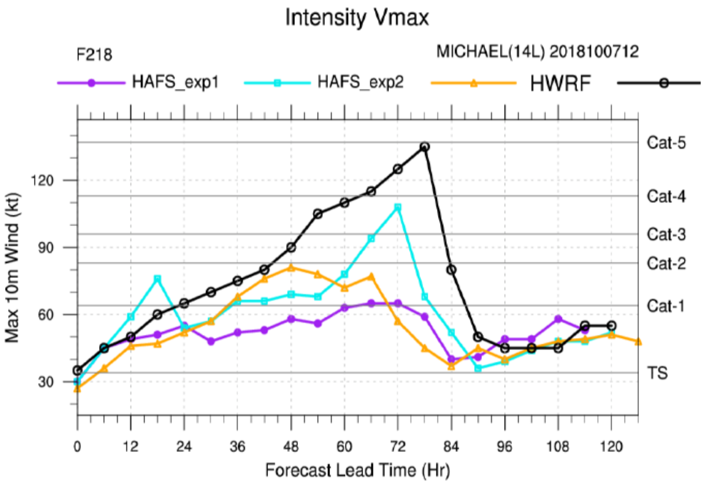




Physics Experiments for HAFS v0.A (SAR)

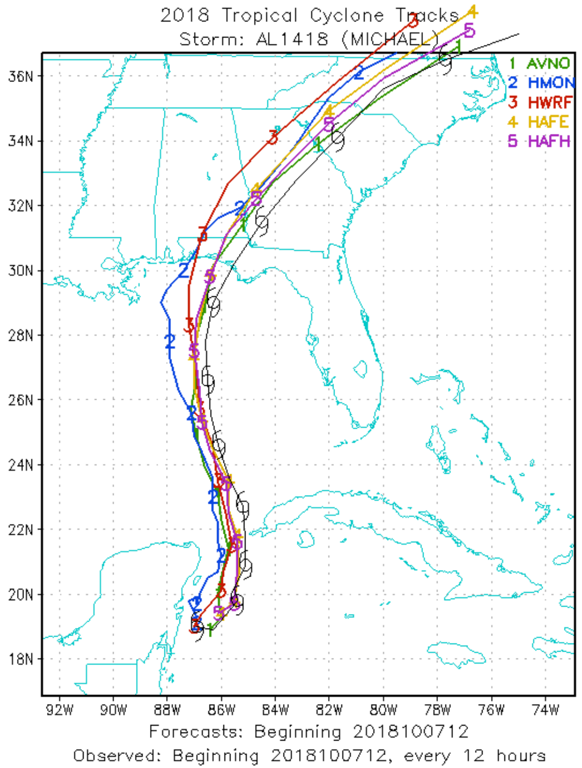
Michael AL14 2018100712Z

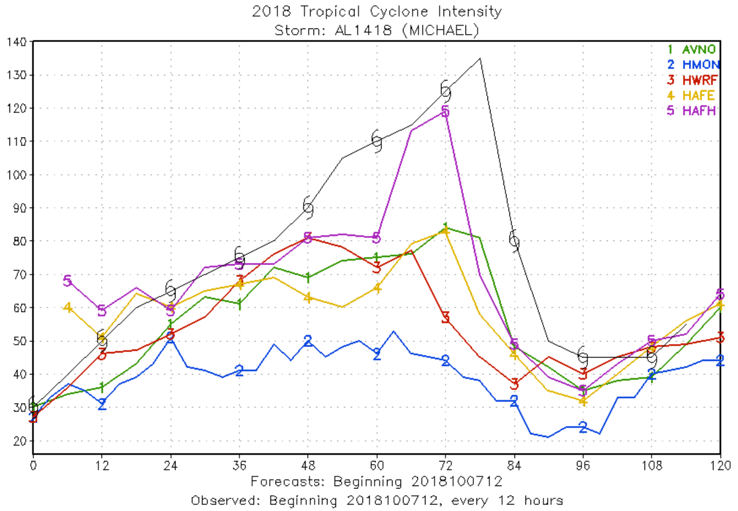




Best is from Official Best Tracks
HWRF is from operational HWRF
HAFS_exp1 is HAFS with the original EDMF/SFC
HAFS_exp2 is HAFS with modified (HWRF) SFC/PBL.

Physics Experiments for HAFS v0.B (Global-with-nest)
Michael AL14 2018100712Z





AVNO is from operational GFS
HMON is from operational HMON
HWRF is from operational HWRF
HAFE is HAFS with the original EDMF/SFC
HAFH is HAFS with modified (HWRF) SFC/PBL.

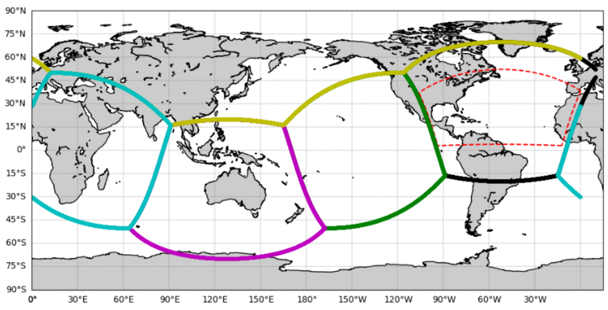
HAFS 0.A—Global FV3GFS Nest Approach

❑ Ongoing Activities

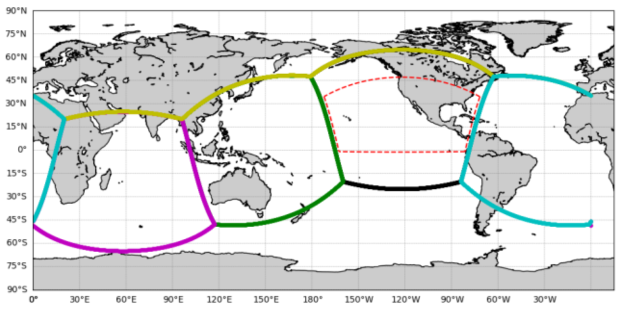
- Real-time FV3GFS global-nest configuration
  - Domain configuration (ATL, EP/CP, WP)
  - Physics tuning based on observation
  - Real-time products
  - Website at HRD
- Multiple static nests
  - Domain configuration
  - Preprocessing
- Code porting and HAFS repository test
  - Jet CentOS transition

Global/Nest Layout

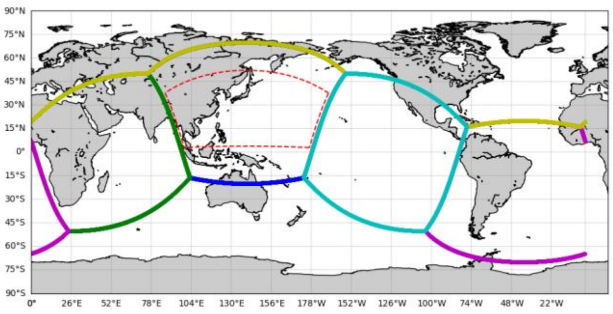
2017-2018 Atlantic Grid



East/Central Pacific Focused

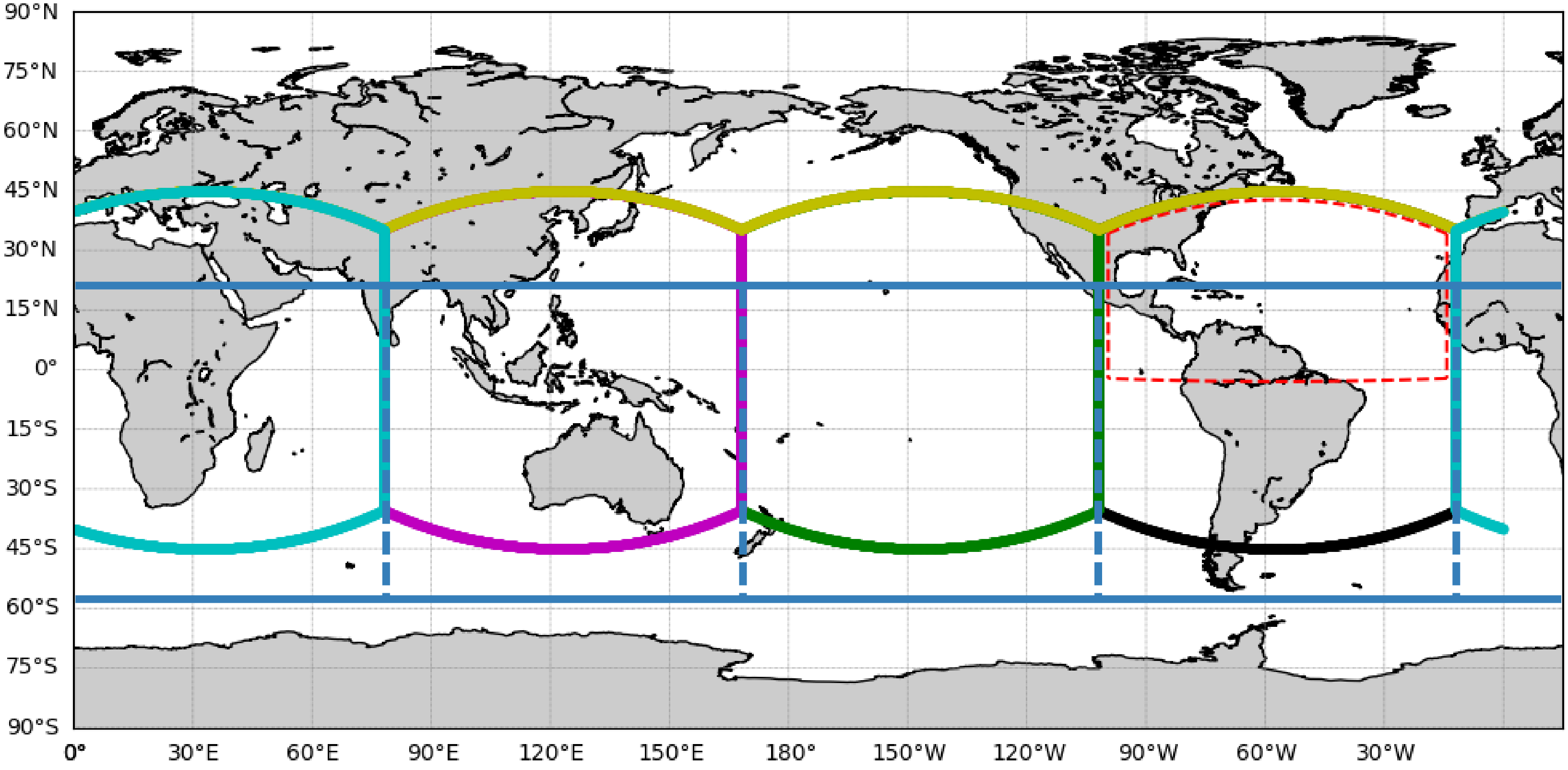


West Pacific Focused



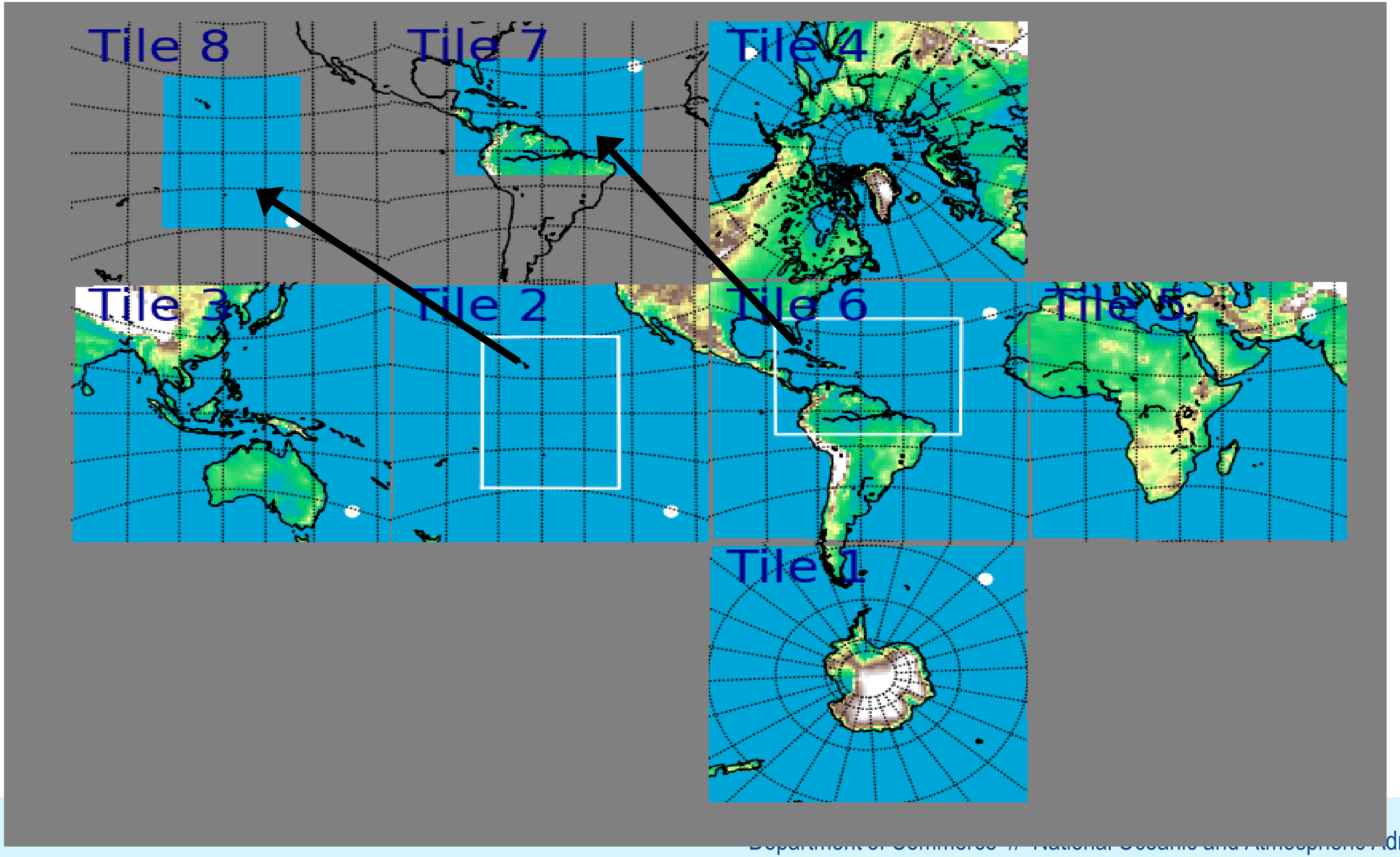
- 2017-2018 real-time Atlantic runs at GFDL were based on a layout with a tile centered at -57W, 25N
- Similar configurations for the EPAC/CPAC/WPAC can be derived by moving the tiles around
- None of these configurations are optimal for these three global-nest configurations (corner points or nest boundaries close to or within the Caribbean and/or Bay of Bengal)

Tropical Channel Configuration



- Layout of the 6 tiles for global TC prediction

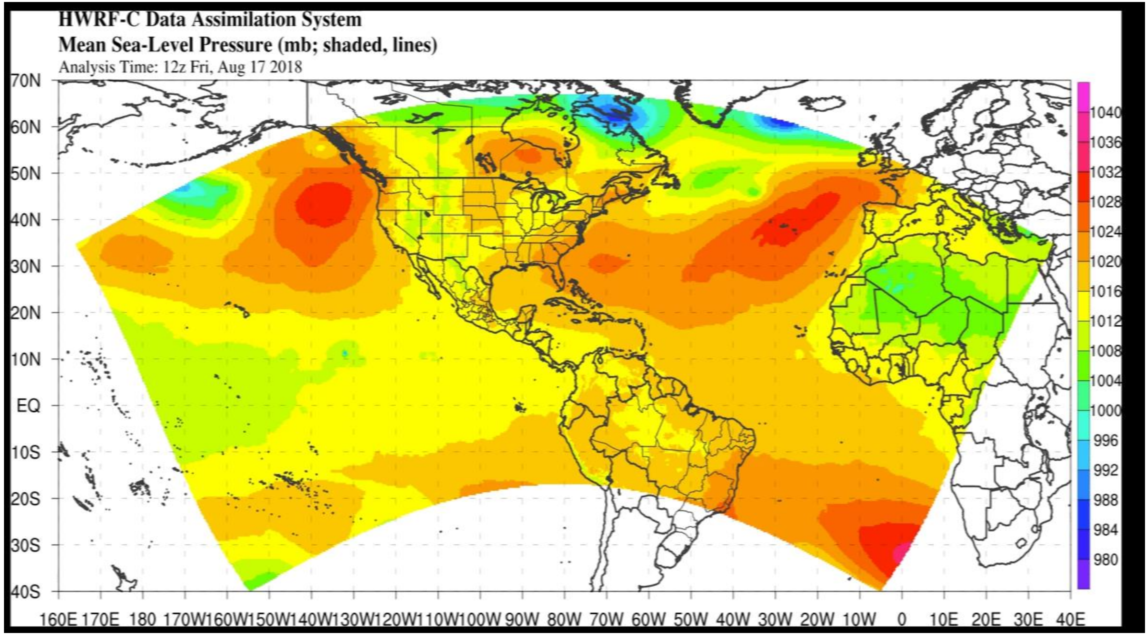
Multiple Static Nests in FV3GFS



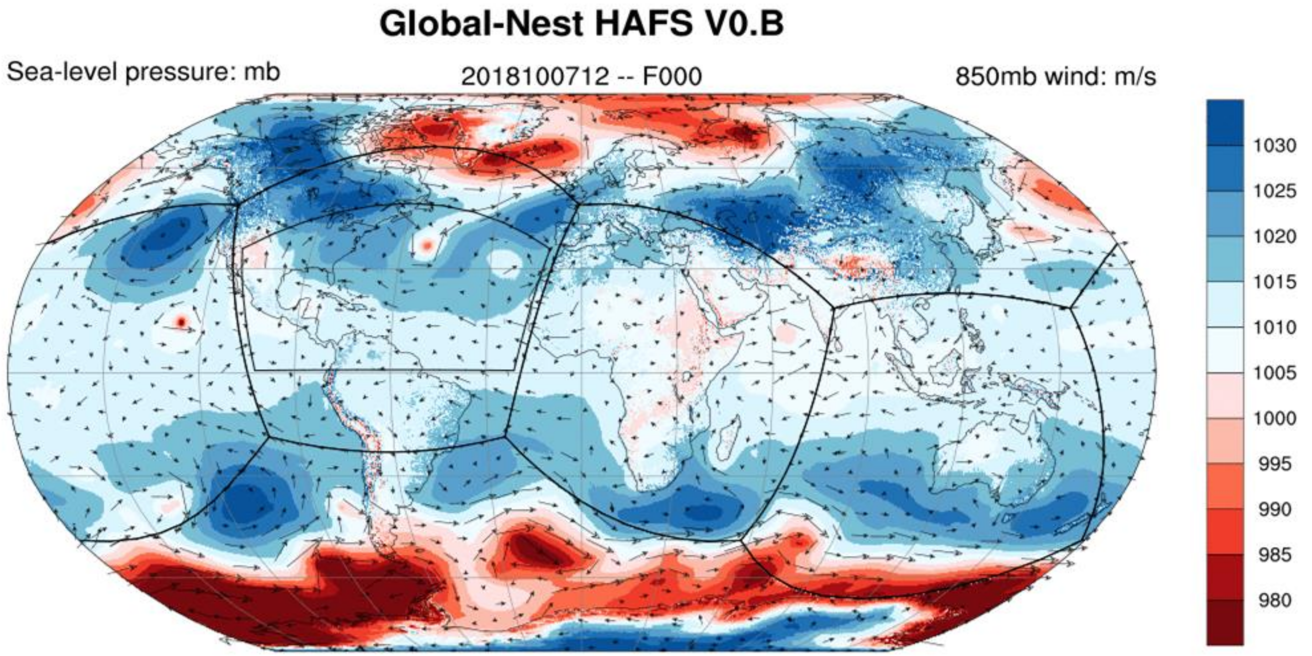
HAFS 0.0—HWRF-C Approach

AOML-UMD-EMC Ensemble System (HWRF-C)

- **Objectives**
  - No model drift
  - 3D hurricane analysis
  - Physics evaluation
- **Configuration**
  - Cycled Data Assimilation System
    - 60 member EnKF
    - Satellite radiances
  - Ensemble Prediction System
    - Up to 20 members for 7 days
    - DA analyses as initial conditions
    - Capacity for high-resolution nests
- **Data**
  - ~2 million obs. per cycle
    - Satellite radiance
    - AMV (derived from satellite obs)
    - Conventional obs
    - Total: 10% assimilated



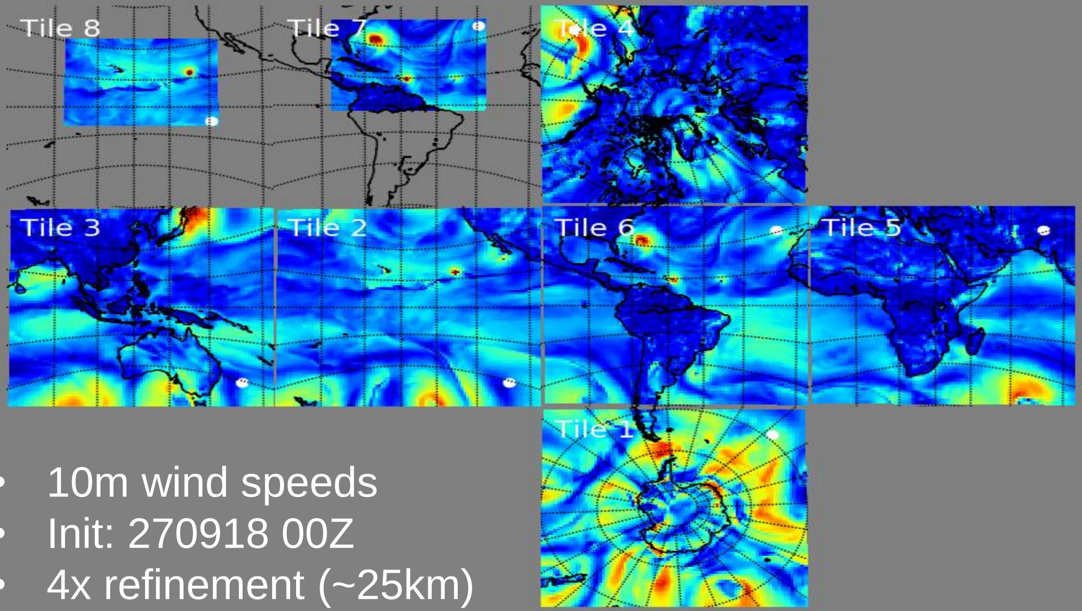
Hurricane Moving Nest
Single 3km Nest on Global Parent



Hurricane Moving Nest
Two Static Nests on Two Tiles

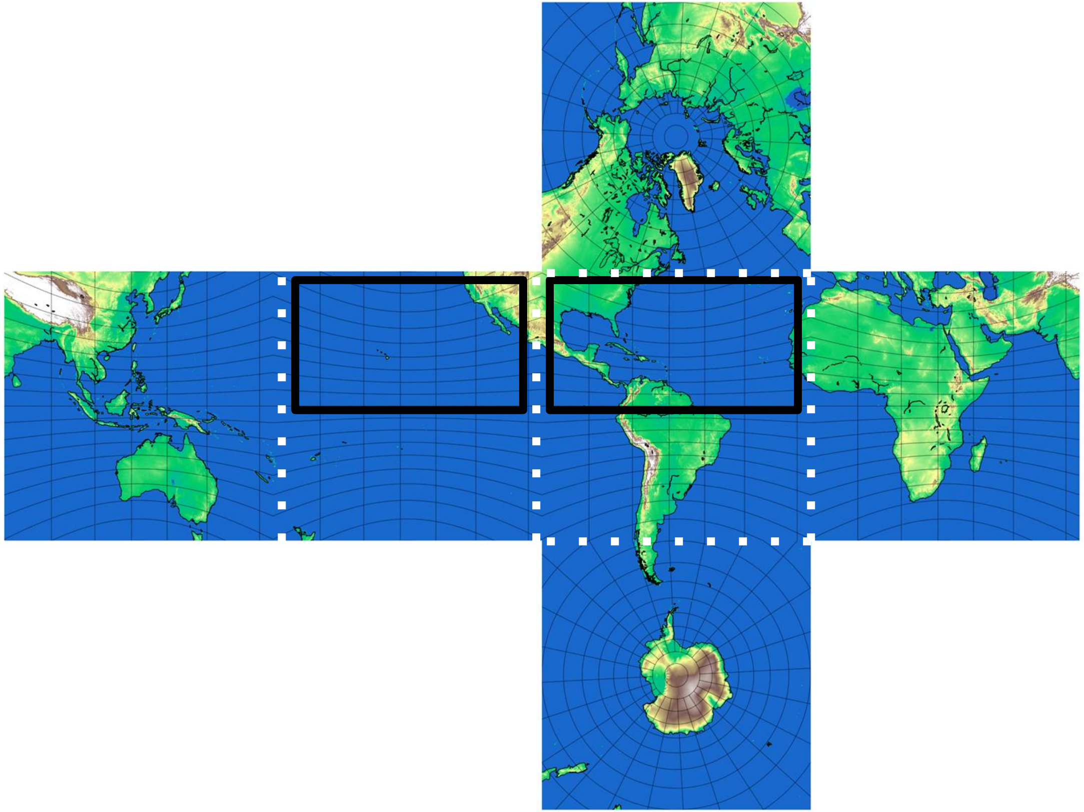
- Stable runs to 96 hours
- Scalable performance
- 24 (12) cores global (nest)
- 1 nest:36 cores: 1:29
- 2 nests:48 cores: 1:32
- Validation underway
- Original single nest results identical
- Multiple nests alter forecast in expected ways

Maria, Jose (NATL) and Otis (EPAC)



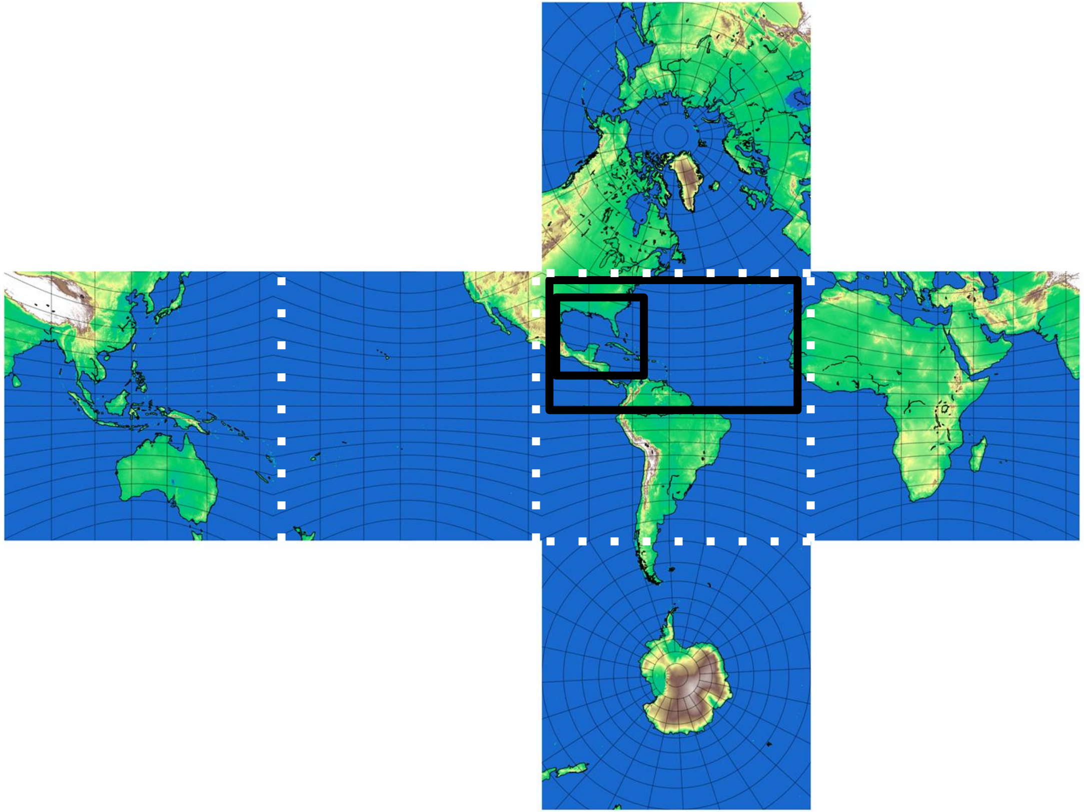
- 10m wind speeds
- Init: 270918 00Z
- 4x refinement (~25km)

Future Directions: Nest Development



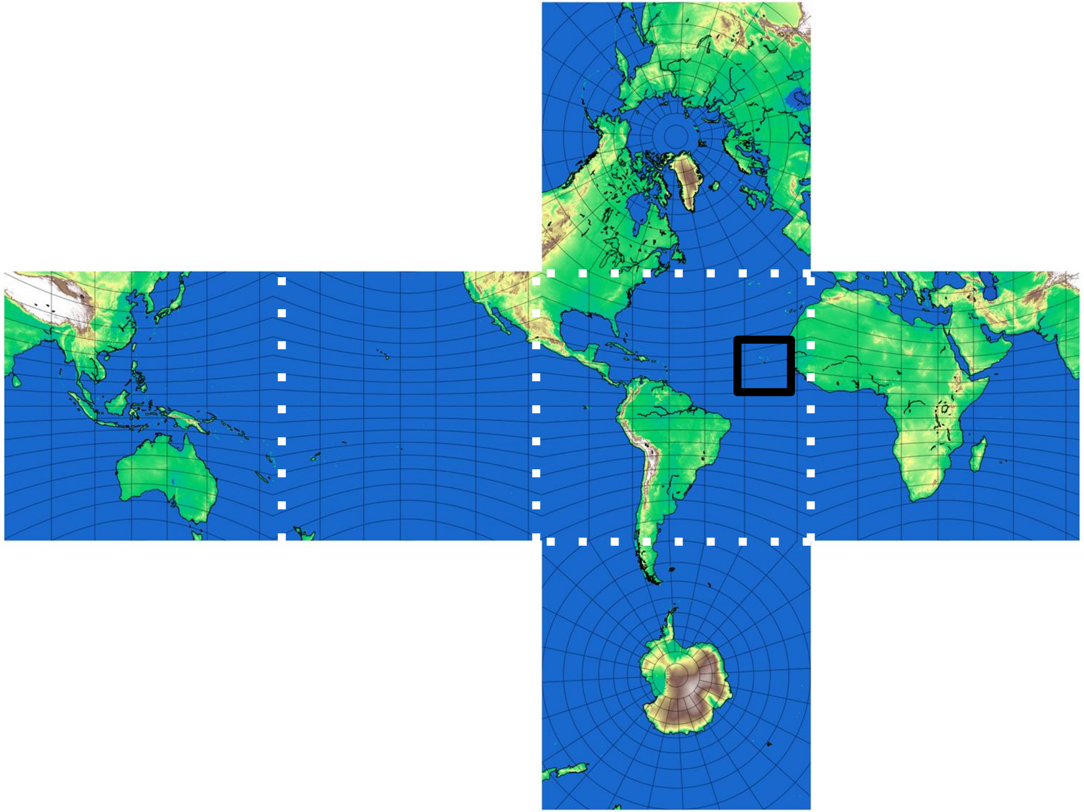
- Incremental approach to nest development:
  - **Two static nests (almost done)**

Future Directions: Nest Development



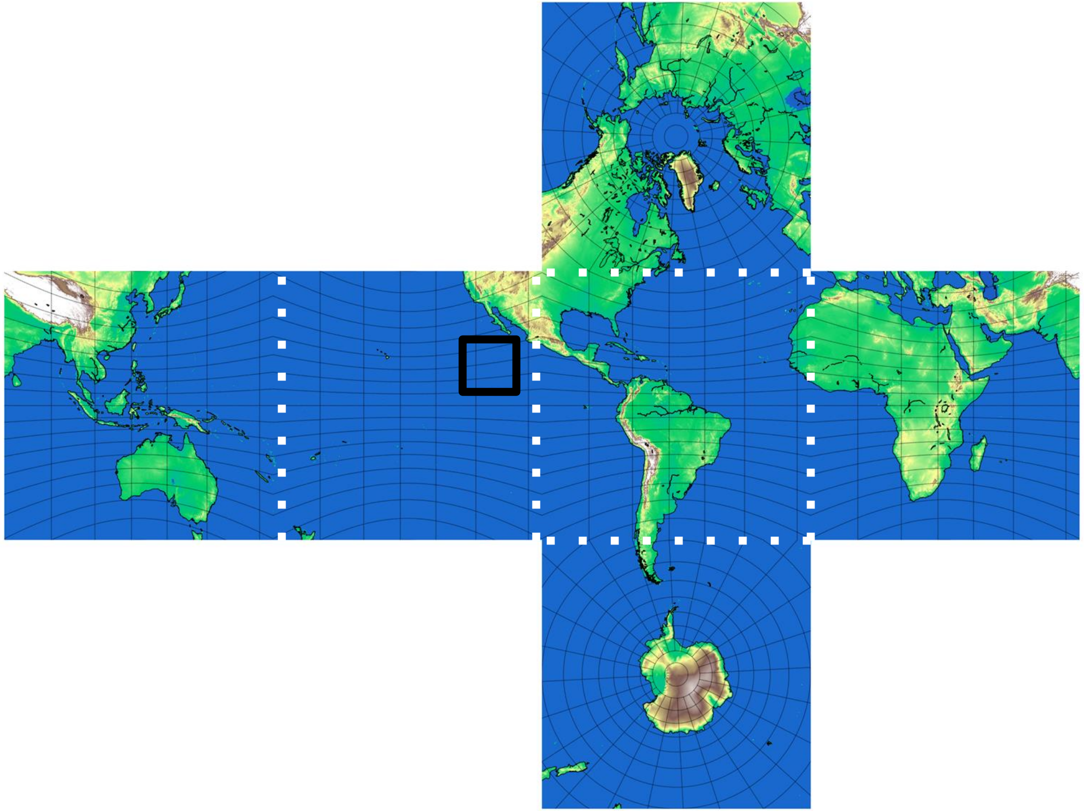
- Incremental approach to nest development:
  - Two static nests (almost done)
  - **Telescoping static nests**

Future Directions: Nest Development



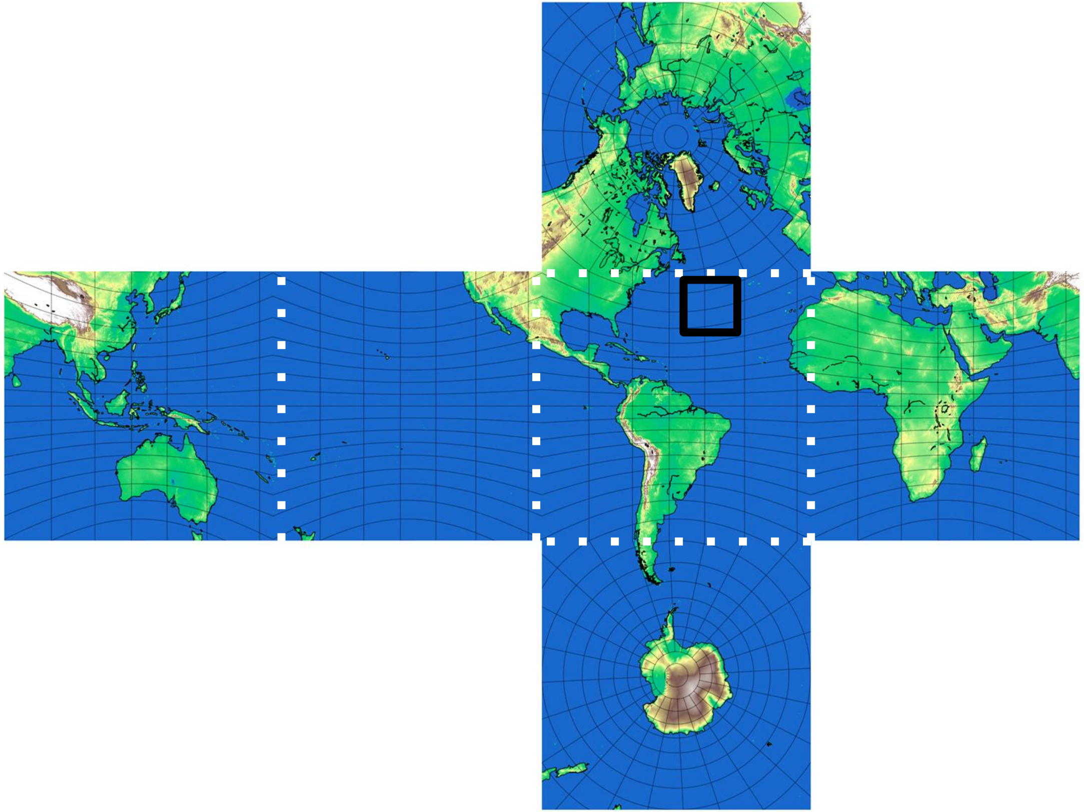
- Incremental approach to nest development:
  - Two static nests (almost done)
  - Telescoping static nests
  - **Nest moving within one tile**

Future Directions: Nest Development



- Incremental approach to nest development:
  - Two static nests (almost done)
  - Telescoping static nests
  - Nest moving within one tile
  - **Nest moving across an edge (likely needed for recurving cases and long tracks)**

Future Directions: Nest Development



- Incremental approach to nest development:
  - Two static nests (almost done)
  - Telescoping static nests
  - Nest moving within one tile
  - Nest moving across an edge (likely needed for recurving cases and long tracks)
  - **Nest crossing a corner (hopefully less frequent but needs to be dealt with)**

HAFS Sub-Projects

- Reproduce HWRF/HMON functionality with FV3 based HAFS
- Accelerate multiple, moving nest implementations in FV3
- FV3 nests coupling to ocean and waves using NEMS/CMEPS NUOPC
- Implement vortex initialization for FV3
- Implement inner-core Hybrid En-VAR DA
- Implement HWRF Physics in FV3 using CCPP
- Coupling advanced LSM, hydrology, inundation and surge models (future)

Major sub-tasks for HAFS in the first year

Task ID	Subtasks	Start Date	Completion Date	Lead	Dependencies	Collaborators	Project
1.1	Implement HWRF physics in FV3 through CCPP	*July 2019*	June 2020	EMC (85K)	None	GMTB/GSD (90K)	3A.2
1.6	DA capability in the regional stand-alone FV3	*June 2019*	May 2020	EMC (170K)	EMC's ongoing regional DA project	AOML	3A.2
1.9	Vortex initialization and storm relocation for FV3	June 2019	May 2020	EMC (170K)	None	AOML	3A.2
1.12	Develop hurricane specific model diagnostic products for HAFS v0.A and v0.B	*July 2019*	June 2020	AOML	None	GFDL, EMC	3A.1
1.18	Advance moving nest framework for existing idealized/semi-idealized vortex (without physics)	*June 2019*	May 2020	AOML	Task 1.7	GFDL, EMC	1A.4
1.20	Prepare and Run HAFSv0.A and HAFSv0.B experiments, document performance and the importance of global parent	*June 2019*	November 2019	EMC (170K)	Tasks 1.1, 1.2 and 1.9	AOML	3A.2

HAFS Development Coordination

- Bi-weekly HAFS Development Meetings (HFIP)
- Published HAFS user/developer guide materials
- **HAFS Developer Guide; Quick Start for HAFS Developers; Quick Start for HAFS Users**
- HSupp activities to gain momentum once funding in place and staff hired
- Need dedicated HPC resources (MSU, Cloud?? Others?)

What do multiple moving nests look like in global model?

06L: Florence; 08L: Helene; 09L: Isaac;
17E: Olivia; 26W: Mangkhut