GFS Development and Transition to Operations

Fanglin Yang
Environmental Modeling Center
National Centers for Environmental Prediction

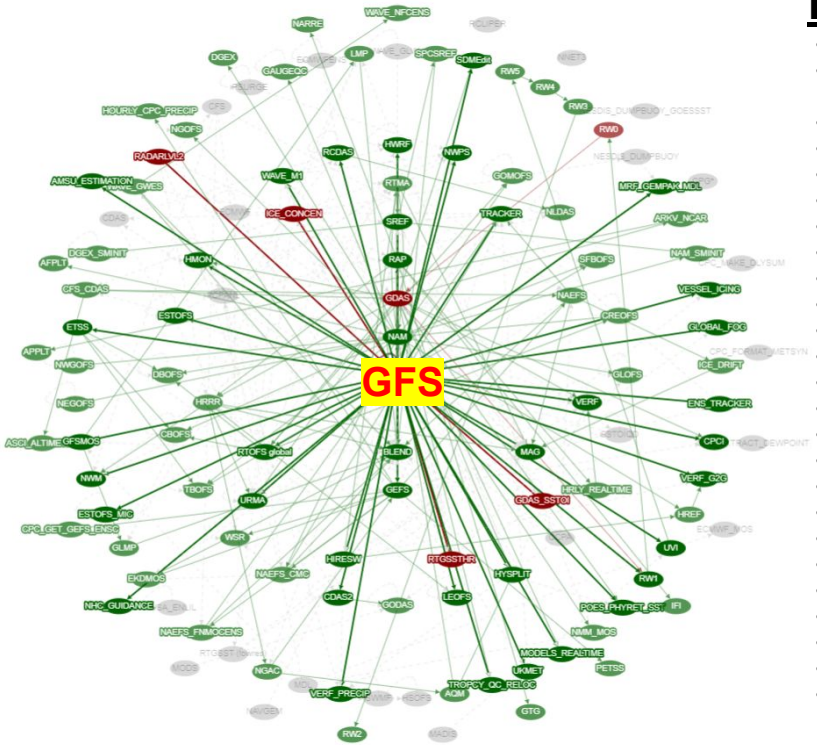
NATIONAL WEATHER SERVICE

Unified Forecast System (UFS) Medium-Range Weather (MRW) Application Users' Training, November 2020

Outline

- History of NCEP Global Forecast System (GFS)
- GFS Performance
- Recent Changes and Upgrades
- The Future

Current NCEP Production Suite (NPS)



Distinct Modeling Systems of NPS:

- AQM: CMAQ North American Air Quality Model (84 hrs)
- CFS: Spectral model coupled to ocean and ice & weakly coupled DA for seasonal forecasts (9 months)
- GDAS/GFS: FV3 based atmospheric model with GSI based DA (16 days, medium range)
- GEFS: Spectral model with 21 member ensemble (16 days)
- HiRes Window: Regional NMMB (72 hrs)
- HREF: Ensembles of WRF ARW and NMMB (72 hrs)
- HRRR/RAP: Regional WRF ARW with ensemble DA (36 hrs)
- HWRF: Regional WRF NMM-E hurricane model coupled to ocean and waves (126 hrs)
- HMON: Regional NMMB hurricane model coupled to ocean (126 hrs)
- HySPLIT: Regional on-demand dust/smoke/volcanic ash prediction
- NAM: NMMB North American Mesoscale Model (84 hrs)
- NAM Nests: High-Resolution NMMB Nests (84 hrs)
- NWPS: SWAN Near Shore Wave Prediction System
- NGAC: Global Spectral Model for Aerosols (5 days)
- NLDAS: Regional Land Data Assimilation System
- NAEFS: North American Ensemble Forecast System (GEFS+Canadian Ensembles)
- NWM: WRF Hydro for Water Prediction (5 days)
- RTMA/URMA: Regional Mesoscale Analysis
- RTOFS: HyCOM Global Ocean Model (5 days)
- SREF: Short Range Ensemble with WRF ARW, NMMB (84 hrs)
- Waves: Global multigrid WaveWatch III Model (10 days)
- Wave Ensembles: Global WaveWatch III Ensembles (10 days)
- Great Lakes: WaveWatch III for great lakes (10 days)
- Space Weather: Global Spectral Whole Atmosphere Model
- Space Weather: WSA EnLil Solar Wind Prediction Model

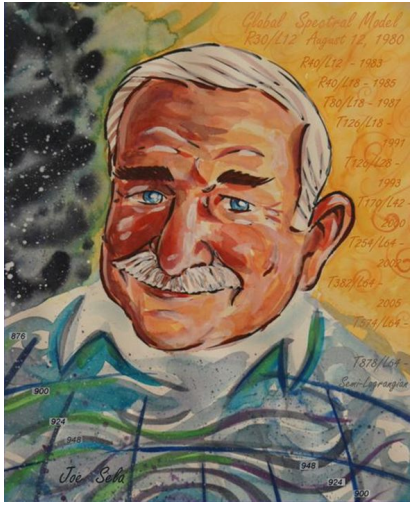
GFS is the center of the universe

26 models

The Birth of NWS Global Forecast Systems

- **NCEP's first global forecast system was implemented in 1974 using the Hough analysis and a 2.5^{o} 9-layer sigma coordinate global primitive equation model** (Shuman, 1989, Flattery, 1971, Stackpole, 1973, 1978).

- In 1980, **Joseph Sela** introduced the spectral model to NCEP operation.



Dr. Joseph Sela created and developed the spectral GFS and worked on improving it from 1975 until his death in 2010.

People Developed the NWP Models at NCEP

Development Division in the early 1990's at the World Weather Building

EMC in the NCWCP Auditorium in 2017
(photo taken by Michiko Masutani)

Change History of GFS Configuration

Mon/Year	Lev	Truncations	Z-cor/dyncore	Major components upgrade
Aug 1980	12	R30 (375km)	Sigma Eulerian	first global spectral model, rhomboidal
Oct 1983	12	R40 (300km)	Sigma Eulerian	
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Jan 2015	64	T1534 (13km)	Hybrid Semi-Lag	SLG; Hybrid EDMF; McICA etc
May2016	64	T1534 (13km)	Hybrid Semi-Lag	4-D Hybrid En-Var DA
Jun2017	64	T1534 (13km)	Hybrid Semi-Lag	NEMS GSM, advanced physics
Jun 2019	64	FV3 (13km)	Finite-Volume	NGGPS FV3 dycore, GFDL MP

Selected Major GFS Changes

- 5/2007
  - **SSI (Spectral Statistical Interpolation) □ GSI (Gridpoint Statistical Interpolation).**
  - **Vertical coordinate changed from sigma to hybrid sigma-pressure**
  - New observations (COSMIC, full resolution AIRS, METOP HIRS, AMSU-A and MHS)

- 2/2009
  - **Flow-dependent weighting of background error variances**
  - **Variational Quality Control**
  - METOP IASI observations added

- 7/2010
  - **Resolution Change: T382L64 □ T574L64 (38 km □ 23 km)**
  - **Major radiation package upgrade (RRTM2 , aerosol, surface albedo etc)**
  - **New mass flux shallow convection scheme; revised deep convection and PBL scheme**
  - **Positive-definite tracer transport scheme to remove negative water vapor**

Selected Major GFS Changes (cont'd)

- **5/22/2012**

  * **GSI Hybrid EnKF-3DVAR** : A hybrid variational ensemble assimilation system is employed. The background error used to project the information in the observations into the analysis is created by a combination of a static background error (as in the prior system) and a new background error produced from a lower resolution (T254) Ensemble Kalman Filter.

- **01/14/2015**

  * **Upgrade to T1534 Semi-Lagrangian (~13km)** : Use Lagrangian instead Hermite vertical interpolation; Use high resolution daily RGT SST and daily sea ice analysis; Extend high resolution forecast from 8 days to 10 days;

  * Use McICA radiation approximation; Reduced drag coefficient at high wind speeds; Hybrid EDMF PBL scheme and TKE dissipative heating

Selected Major GFS Changes (cont'd)

05/11/2016

* **Hybrid EnKF-3DVAR --> 4D Hybrid Ensemble-Variational Data Assimilation.**
* Assimilate **all-sky** (clear and cloudy) **radiances**

07/19/2017

* Implement GSM source code in NOAA Environmental Modeling System (NEMS) framework
* Implement Near Surface Sea Temperature (NSST) for analysis and forecast
* High-resolution MODIS snow-free albedo, soil type and vegetation type.

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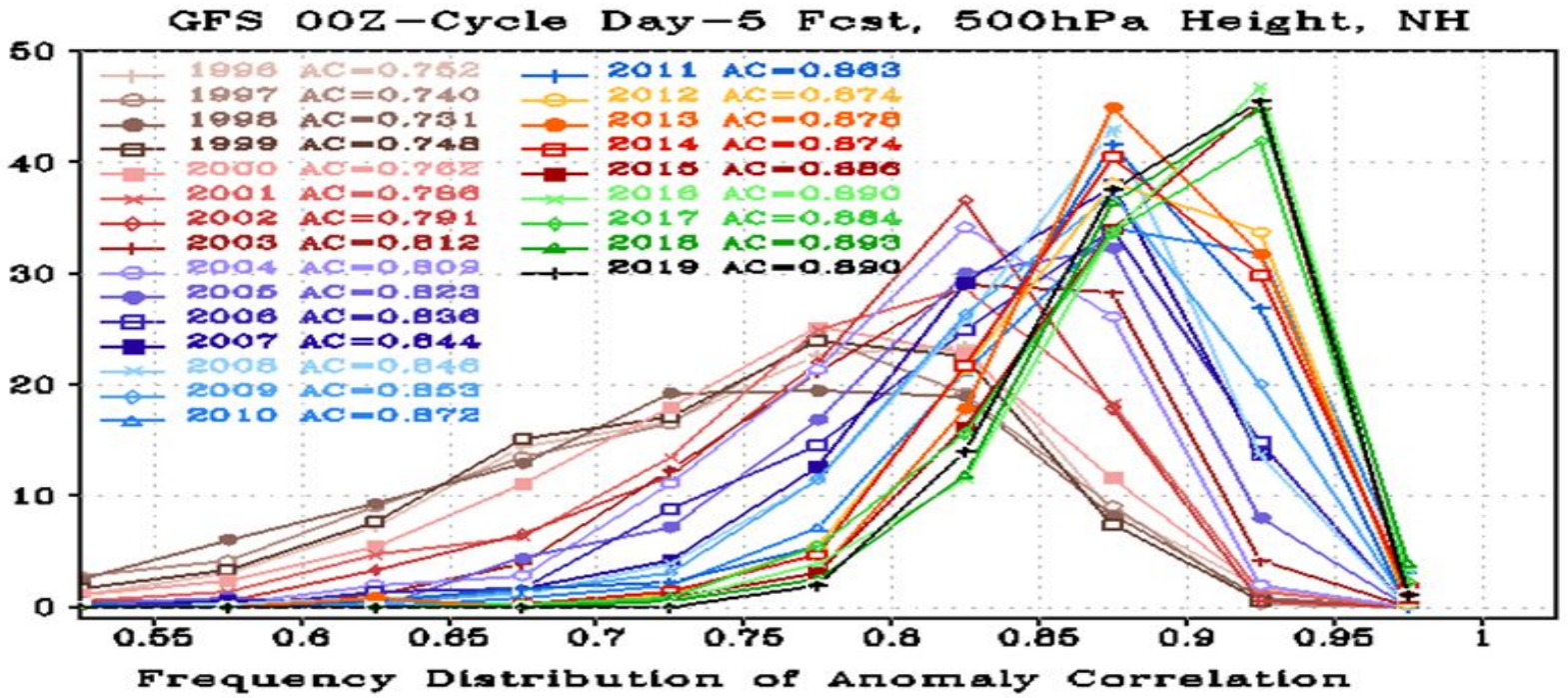
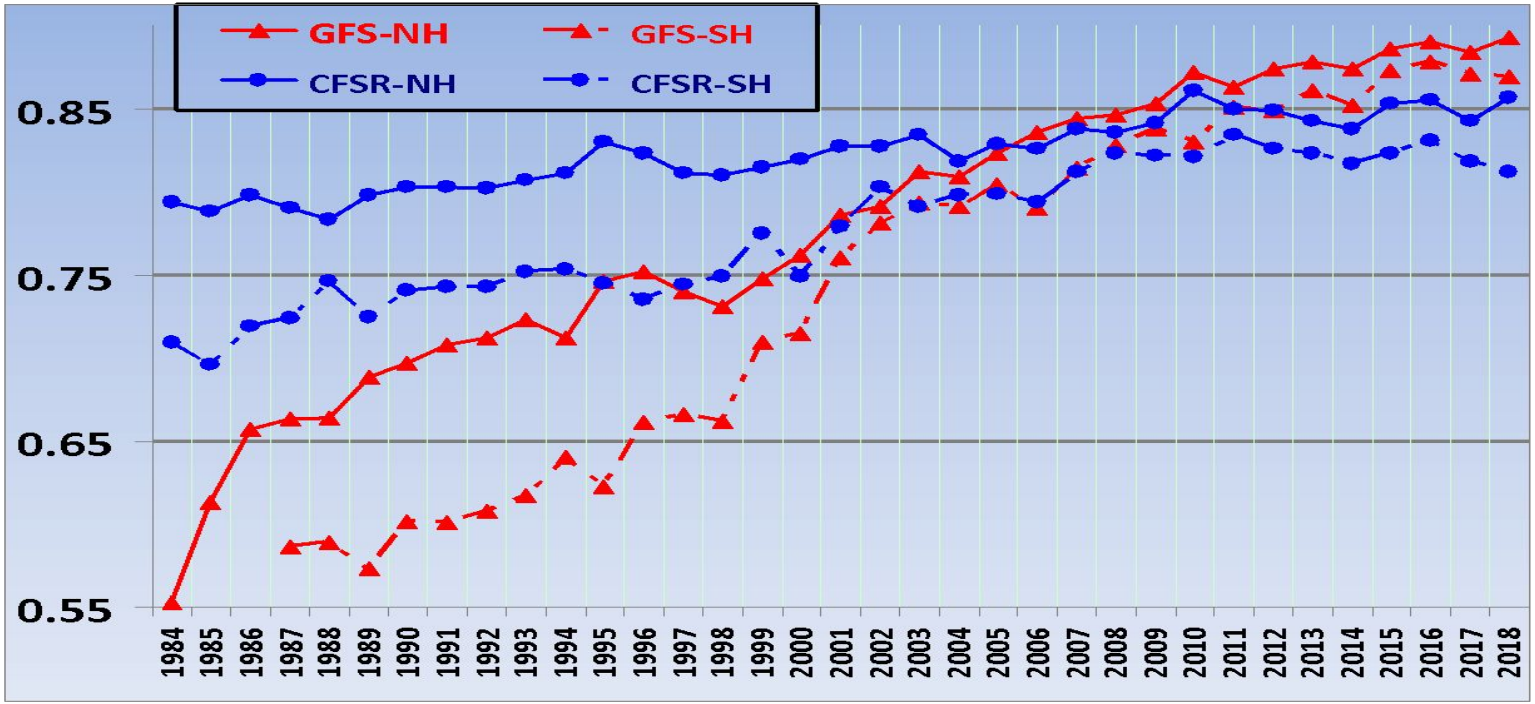
GFS Historical Performance

NH 500-hPa HGT Day-5 ACC Frequency Distribution

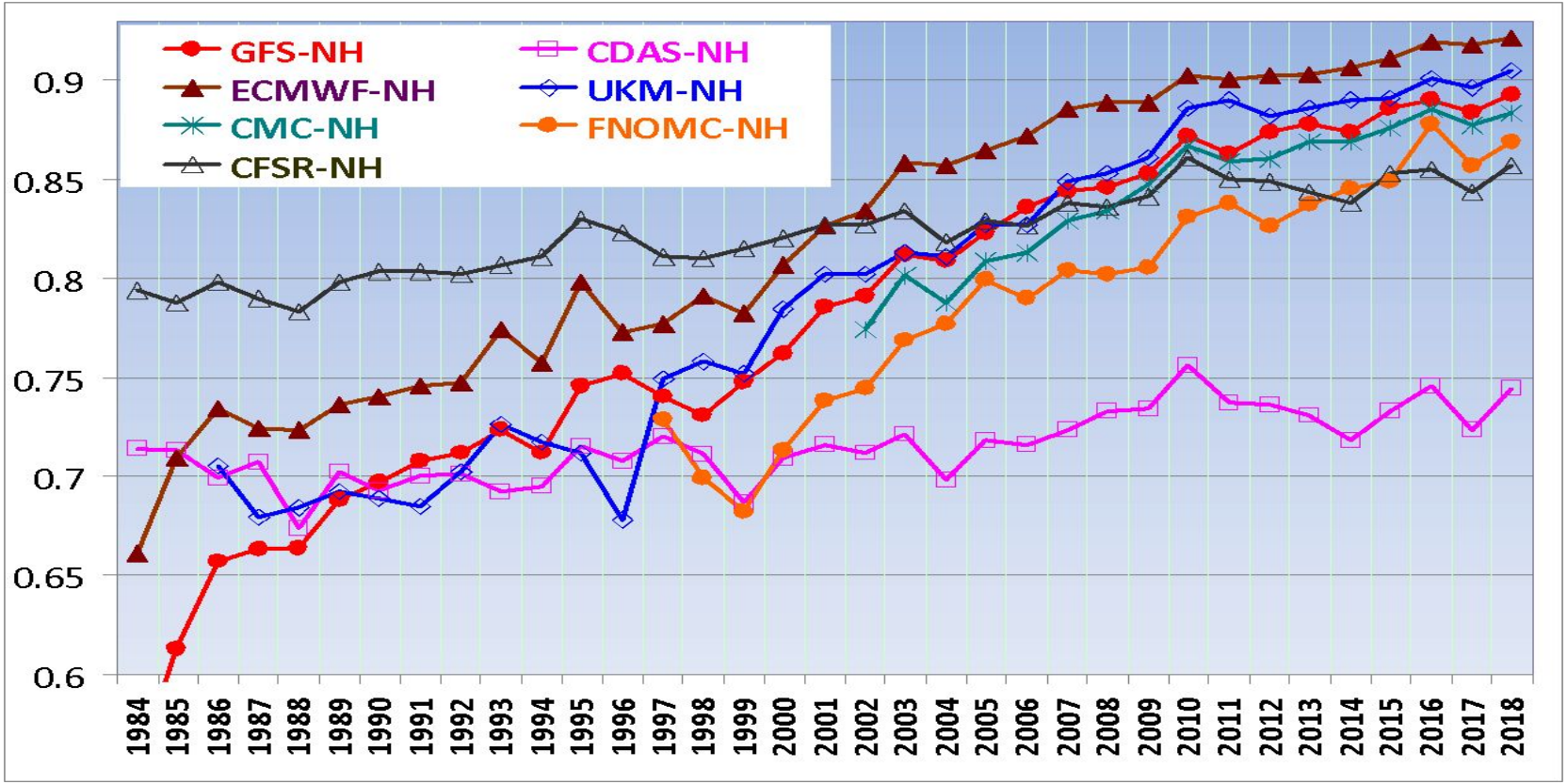


Annual Mean 500-hPa HGT Day-5 Anomaly Correlation

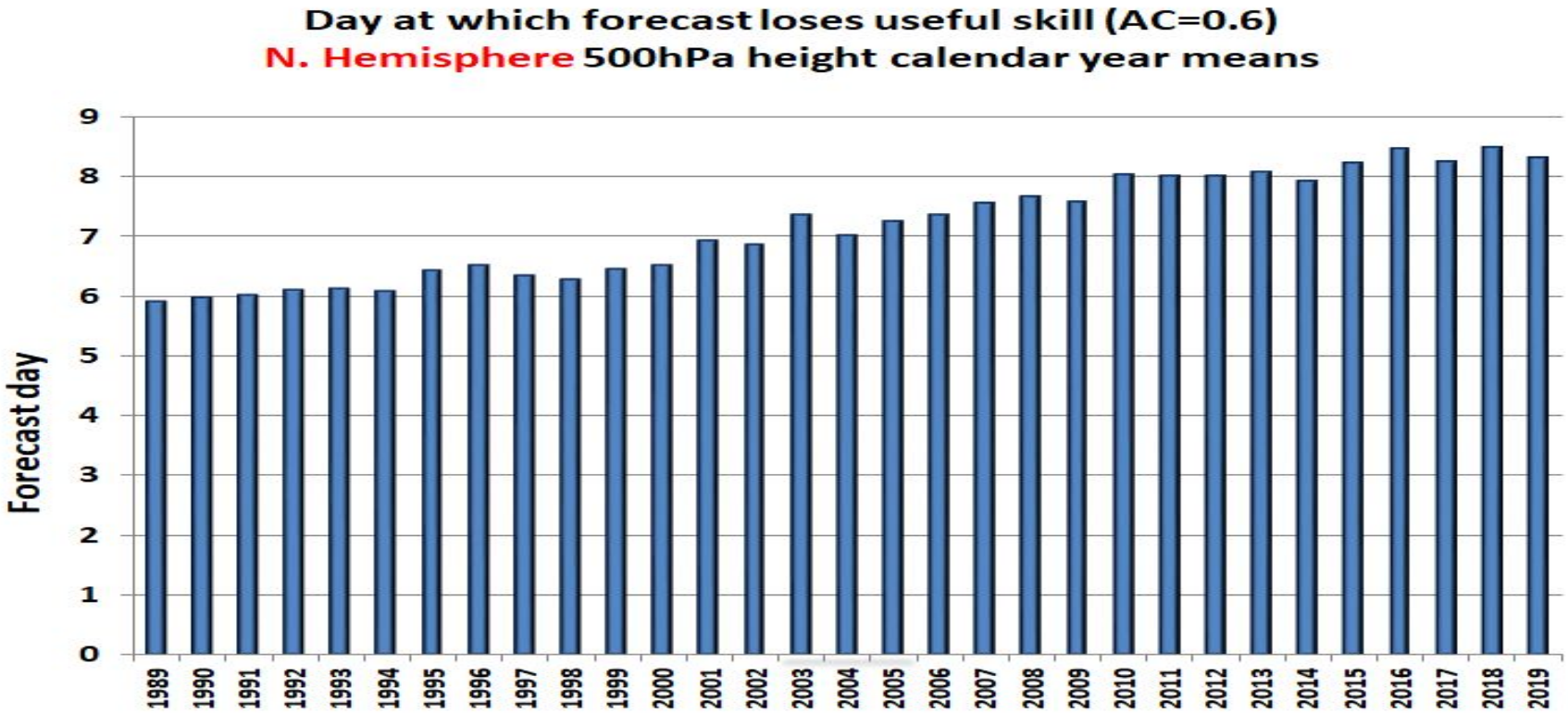


Increase by 0.1 per decade

Annual Mean 500-hPa HGT Day-5 Anomaly Correlation



GFS Historical Performance



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GFS.v15 Transition to Operation

Finite-Volume Cubed-Sphere Dynamical Core (FV3)

Microphysics Scheme with Multiple Prognostic Cloud Hydrometers

In Operation: June 12, 2019

Configuration:

- **High-res: C768 (~13km)**
- **Data Assimilation: C384 (~25km, 80 member ensemble)**
- **64 layer, top at 0.2 hPa**
- **Uniform resolution for all 16 days of forecast**
- **Dycore: FV3, non-hydrostatic, single precision**
- **Physics: GFS Physics + GFDL Cloud Microphysics, double precision**

Model: Infrastructure & Physics Upgrades

- Integrated FV3 dycore into NEMS
- Added IPD in NEMSfv3gfs
- Newly developed write grid component -- write out model history in native cubed sphere grid and Gaussian grid
- Replaced Zhao-Carr microphysics with the more advanced GFDL microphysics
- Updated parameterization of ozone photochemistry with additional production and loss terms
- New parameterization of middle atmospheric water vapor photochemistry
- a revised bare soil evaporation scheme.
- Modify convection schemes to reduce excessive cloud top cooling
- Updated Stochastic physics
- Improved NSST in FV3
- Use GMTED2010 terrain to replace TOPO30 terrain

GFDL FV3 Dycore and Microphysics

GSM

Spectral
Gaussian
Hydrostatic
64-bit precision

GFDL FV3

Finite-volume
Cubed-Sphere
non-hydrostatic
32-bit precision

Physics still runs at 64-bit precision

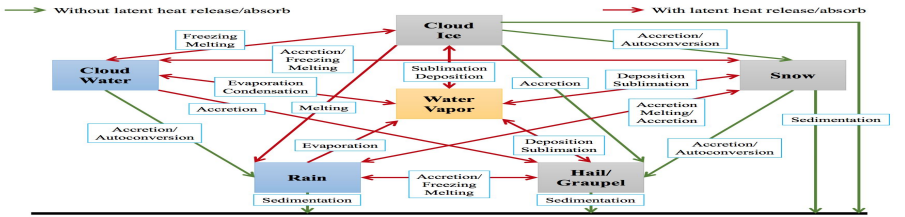
Zhao-Carr MP

Prognostic could species: one
total cloud water

GFDL MP

Prognostics cloud species : five
Liquid, ice, snow, graupel, rain

more sophisticated cloud processes



Updated Ozone Physics in FV3GFS

Funded by NOAA Climate Program Office

Naval Research Laboratory CHEM2D Ozone Photochemistry Parameterization (CHEM2D-OPP, *McCormack et al. (2006)*)

$$\frac{\partial \chi}{\partial t}(P-L) = (P-L)_0 + \left.\frac{\partial (P-L)}{\partial \chi_{O3}}\right|_0 \left(\chi_{O3} - \bar{\chi}_{O3}\right) + \left.\frac{\partial (P-L)}{\partial T}\right|_0 \left(T - \bar{T}\right) + \left.\frac{\partial (P-L)}{\partial c_{O3}}\right|_0 \left(c_{O3} - \bar{c}_{O3}\right)$$

NEMS GSM
Includes reference tendency and dependence on O3 mixing ratio

FV3GFS
Additional dependences on temperature and column total ozone

Reference tendency $(P\text{-}L)_0$ and all partial derivatives are computed from odd oxygen ($Ox \equiv O_3+O$) reaction rates in the CHEM2D photochemical transport model.
CHEM2D is a global model extending from the surface to ~120 km that solves 280 chemical reactions for 100 different species within a transformed Eulerian mean framework with fully interactive radiative heating and dynamics.

χ_{O3} prognostic Ozone mixing ratio
T Temperature
c_{O3} column ozone above

From: Shrivinas Moorthi

Water Vapor Sources and Sinks in the Stratosphere/Mesosphere

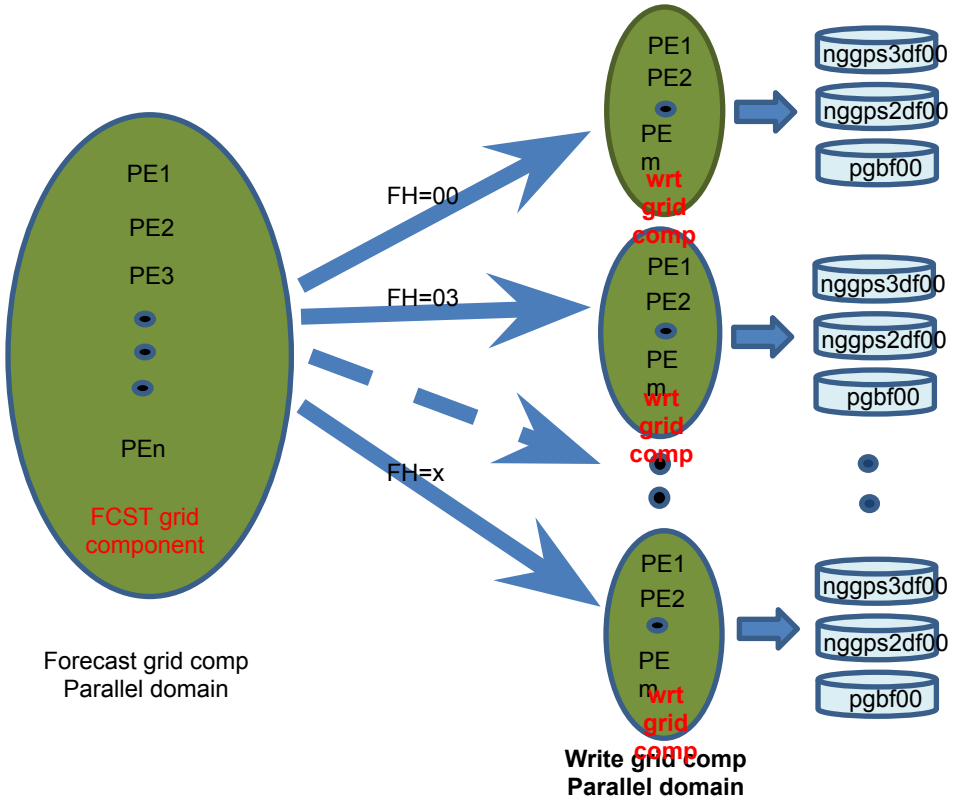
- This new scheme is based on "*Parameterization of middle atmospheric water vapor photochemistry for high-altitude NWP and data assimilation*" by McCormack et al. (2008), from NRL

- Accounts for the altitude, latitude, and seasonal variations in the photochemical sources and sinks of water vapor over the pressure region from 100–0.001hPa (~16–90km altitude)

- Monthly and zonal mean H_2O production and loss rates are provided by NRL based on the CHEM2D zonally averaged photochemical-transport model of the middle atmosphere

From: Shrivinas Moorthi

Parallelized NEMS FV3 Write Grid Component



GFDL FMS writes files in native cubed sphere grid in six tiles, one file for each tile in netcdf format with ***all output times at once***.

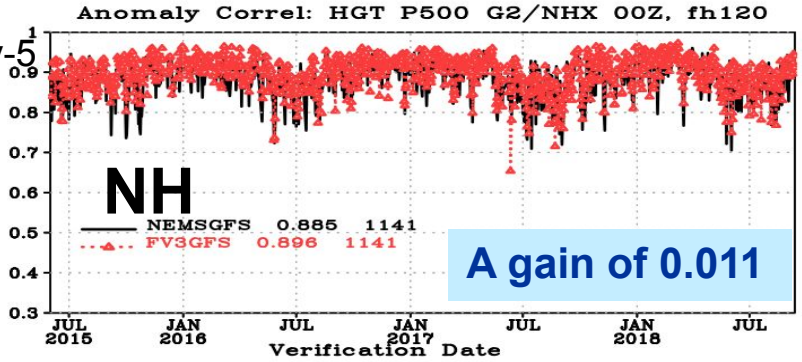
NEMSIO writes

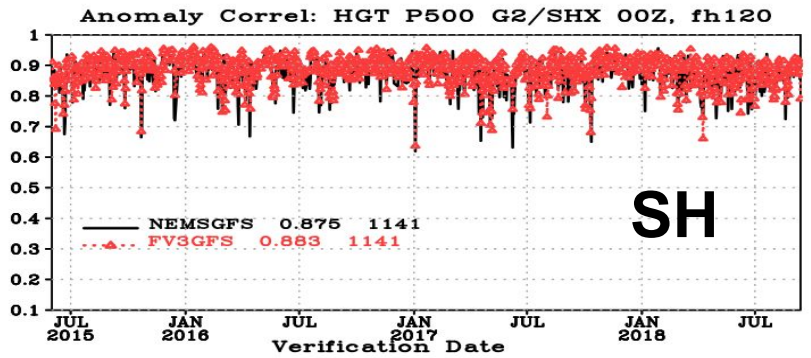
- history files in **cubed sphere grid** in six tiles, one file one tile in netcdf format at a ***specific output time***
- history files in **global Gaussian grid**, one file for global ***at a specific output time*** in either **netcdf** format or **NEMSIO** format

From : Jun Wang

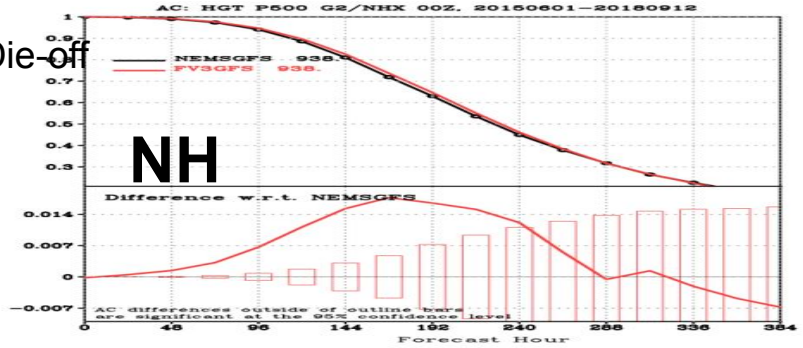
GFS.v15: Improved 500-hPa HGT ACC (2015 ~ 2018)

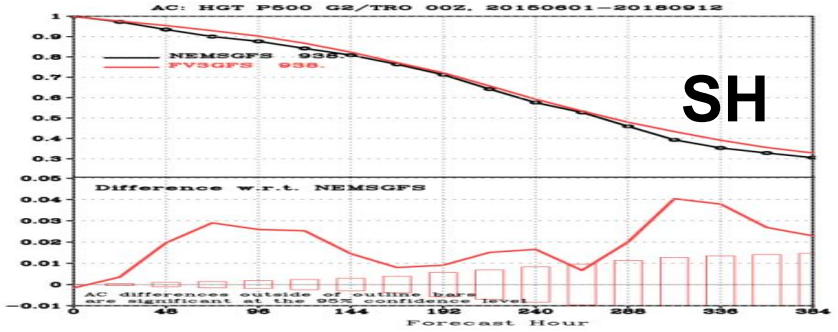
Day-5





Die-off



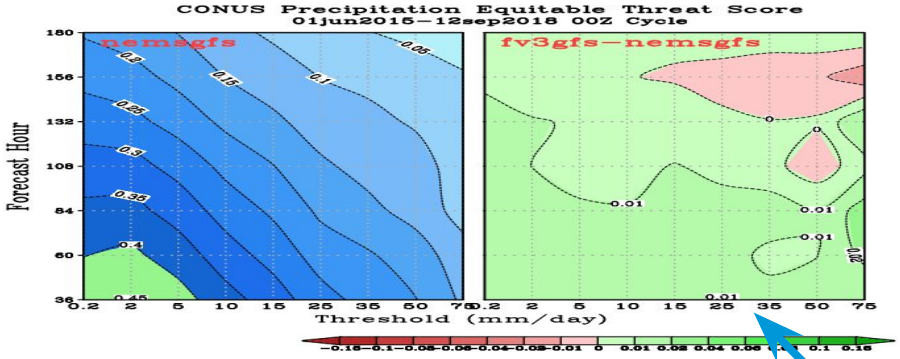


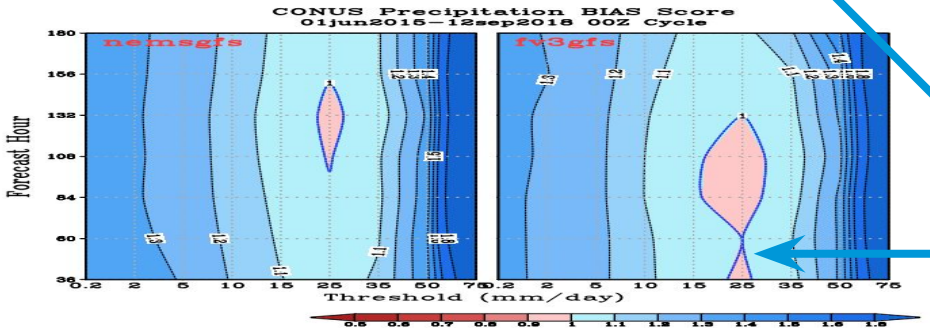
Increase is significant up to day 10

GFS.v15 - Improved Precipitation Forecast

Precip ETS and BIAS SCORES over the Continental US

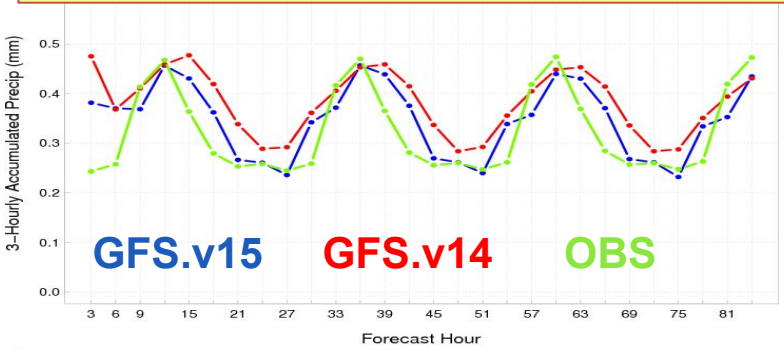
00Z Cycle, verified against gauge data, 20150601~ 20180912





Improved Precipitation Diurnal Cycle

SUMMER 2018 CONUS DOMAIN-AVG PCP

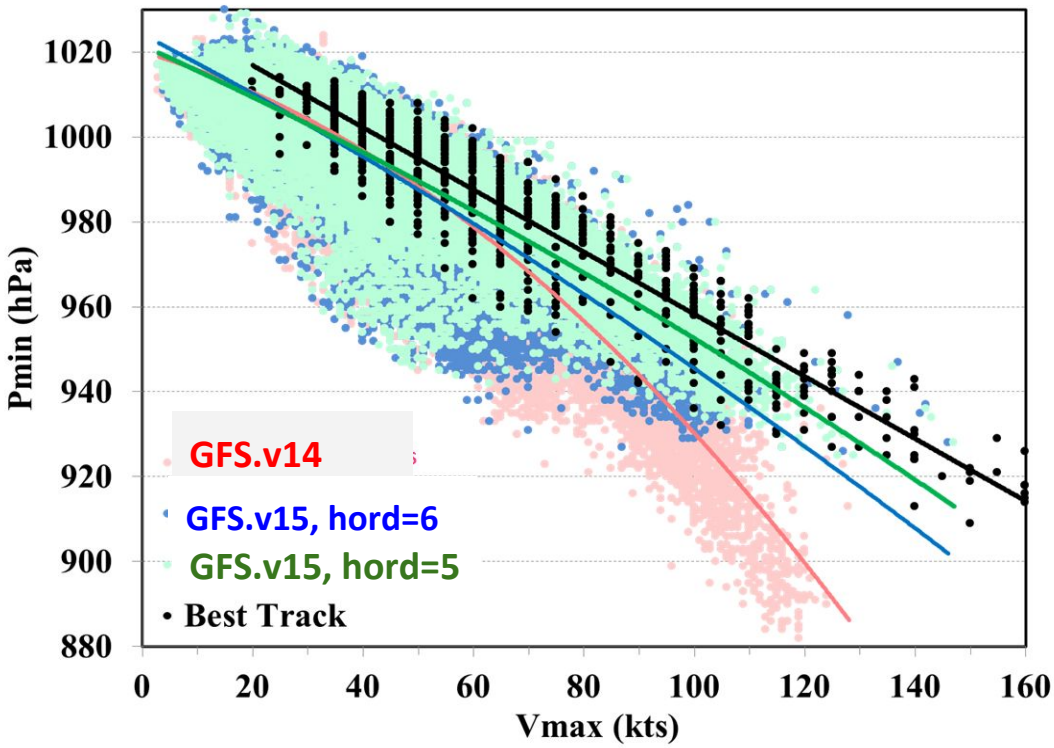


- Improved ETS scores for almost all thresholds and at all forecast length
- Reduced wet bias for light rains
- Slightly worsened dry bias for moderate rainfall categories

GFS.v15 - Improved Wind-Pressure Relationship

GFS.v15 shows a much better wind-pressure relation than GFS.v14 (GSM) for strong storms

Graph made by HWRF group



GFS.v15 -- Systematic Biases to be Addressed in GFS.v16

- Excessive cold bias in the winter season
- Progressive bias for synoptic scale systems
- Less skillful TC track forecasts, especially for stronger storms
- Temperature cold bias in the stratosphere
- Poor representation of boundary layer inversions

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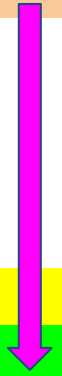
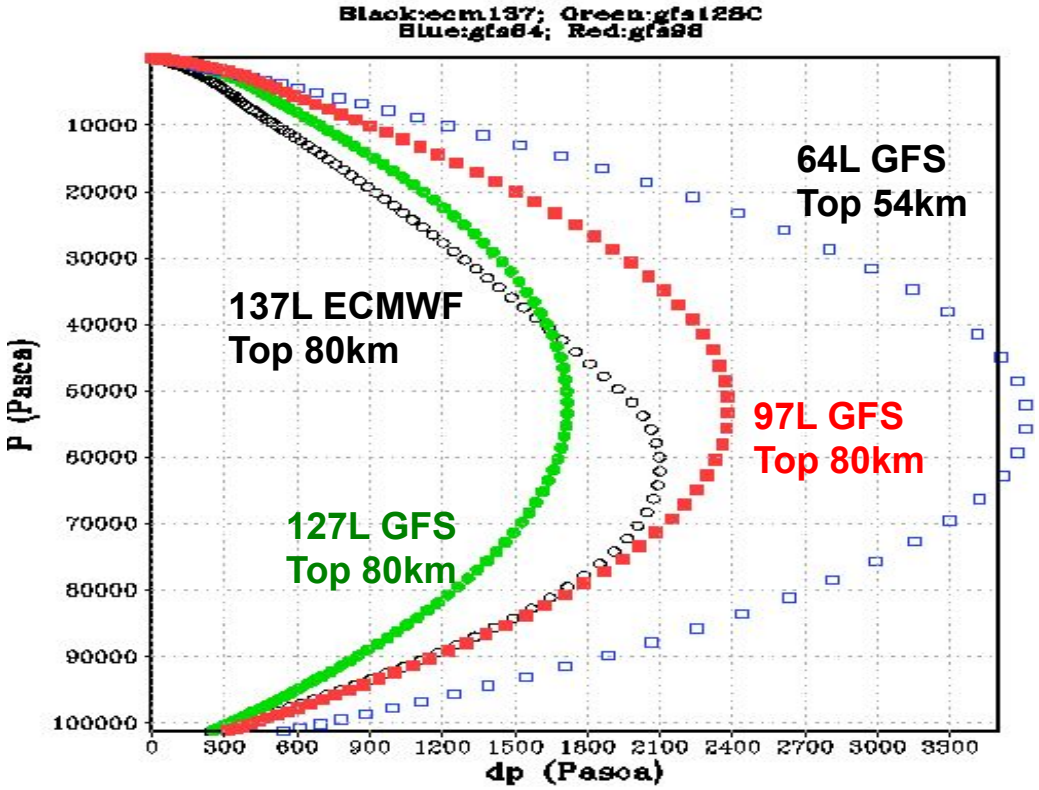
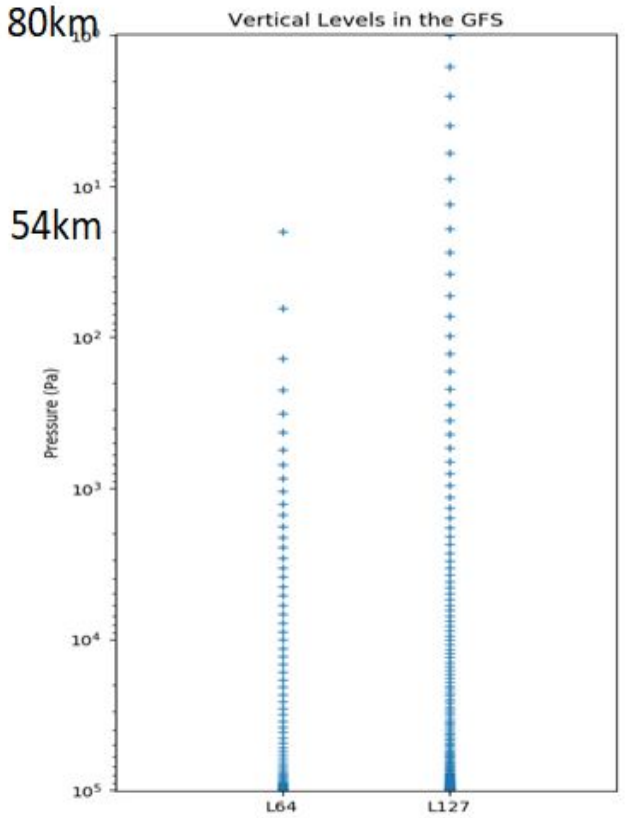
Jun 2019	64	FV3 (13km)	Finite-Volume	NGGPS FV3 dycore, GFDL MP
Feb 2021	127	FV3 (13km)	Finite-Volume	IAU, LETKF, TKE-EDMF, uGWD



18 years !

GFS.v16 Vertical Structure





GFSv16: Major Changes to the Forecast Model

Model resolution:

Increased vertical layers from 64 to 127 & raised model top from 54 km to 80 km

Physics updates:

PBL/turbulence: Replaced K-EDMF with sa-TKE-EDMF (Revised background diffusivity as a stability dependent function)

GWD: Added a parameterization for subgrid scale nonstationary gravity-wave drag

Radiation: Updated calculation of solar radiation absorption by water clouds; Updated cloud overlap assumptions.

Microphysics: Updated GFDL microphysics scheme for computing ice cloud effective radius

Noah LSM: Revised ground heat flux calculation over snow covered surface; Introduced vegetation impact on surface energy budget over urban area

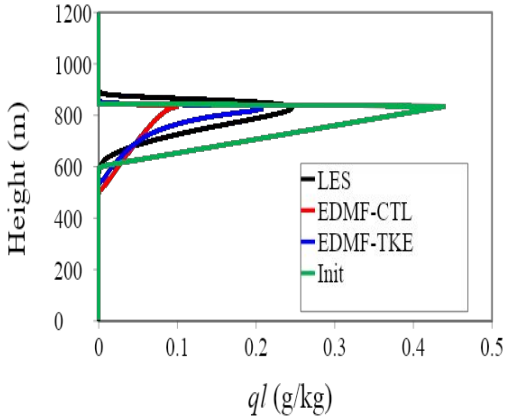
Coupling to Wave Model:

One-way coupling of atmospheric model with Global Wave Model (WaveWatch III, Multi_1)

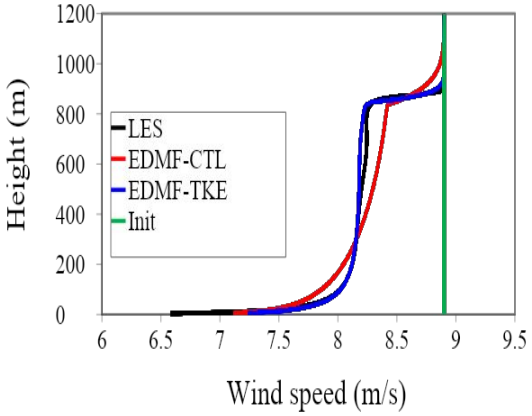
GFSv16: Major Changes to the Forecast Model

New TKE-EDMF PBL:

- **Higher-order accuracy in turbulence representation**, less diffusive than K-EDMF
- Advection of turbulence by the grid-mean flows
- Inclusion of **moist processes**
- Mass-flux representation for the **nonlocal momentum mixing**
- EDMF parameterization for the **stratocumulus-top-driven turbulence mixing**
- **Scale awareness**
- **Interaction of TKE with cumulus convection**



cloud water



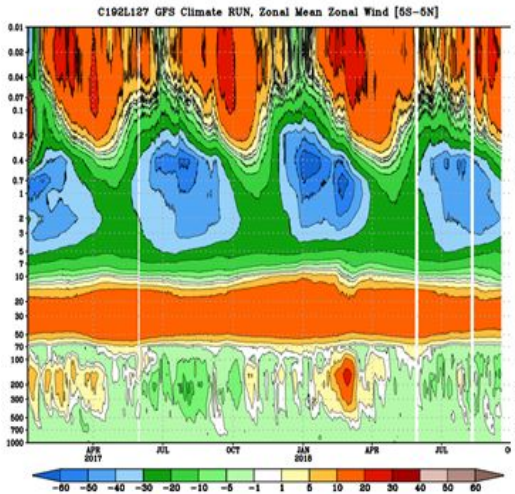
wind speed

GFSv16: Major Changes to the Forecast Model

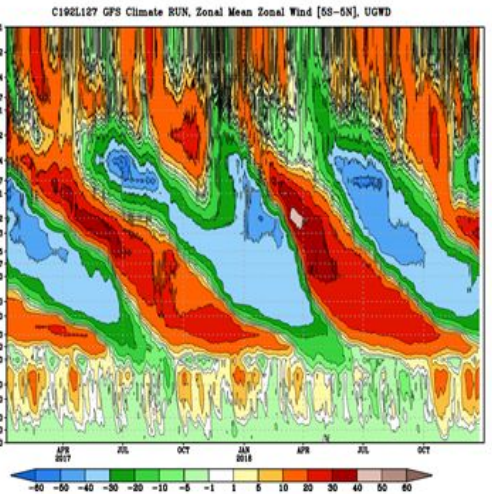
Non-Stationary GWD: Impact on QBO/SAO

In collaboration with CIRES, UCB

CONTROL



W/ non-stationary GWD



Prescribed Forcing (MERRA2 AGCM)

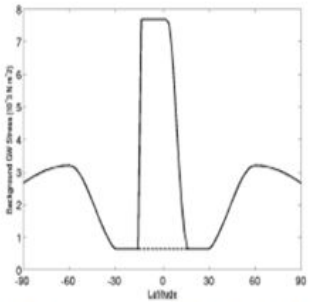
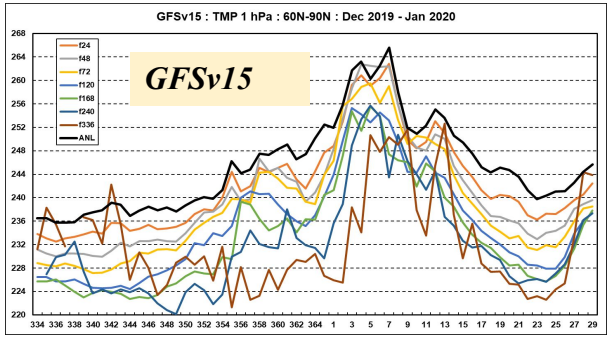


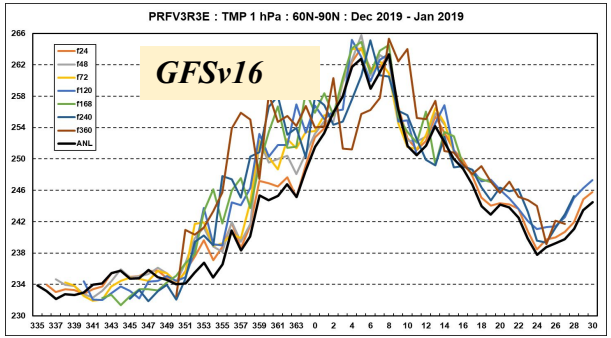
Figure 3. Background non-orographic drag from the MERRA (dashed line) and MERRA2 AGCM (solid line) simulations. The dashed line underlies the solid line outside of the tropics.

- Current operational model cannot simulate the QBO
- A QBO-like feature is captured in GFS.v16 "climate" run with the non-stationary GWD physics included; However, the periodicity is too short, appears to be a downward propagating SAO.

Forecast improvements in the Stratosphere

Improved 1-hPa Temperatures :
60N-90N Dec 2019 – Jan 2020





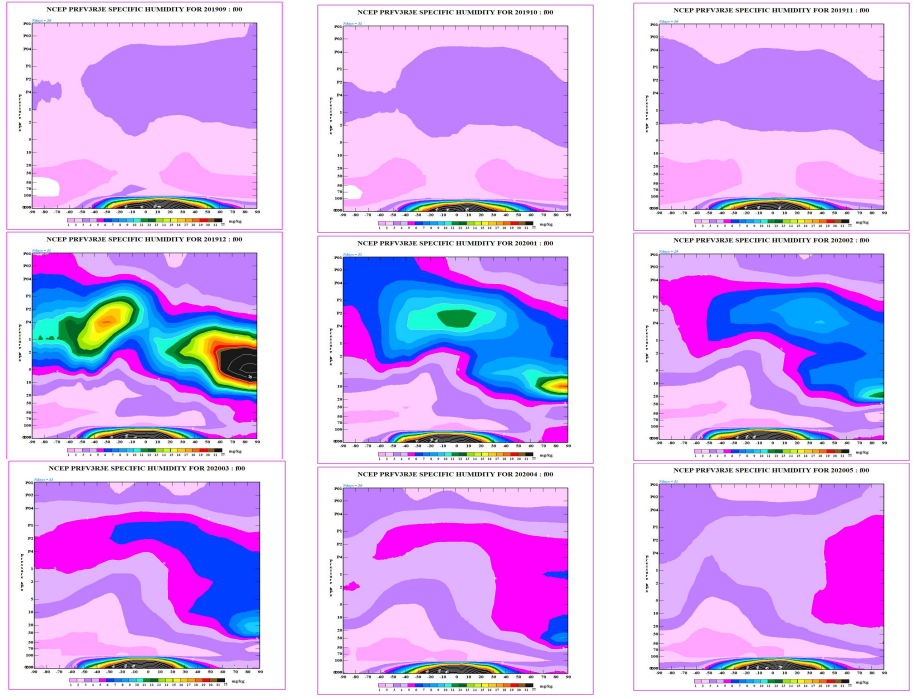
Figures courtesy: Craig Long, CPC

Captured water vapor seasonal cycle in the stratosphere, compares well with UARS HALOE observations (Sept. 2019-May 2020)

09-11/2019

12/2019-02/2020

03-05/2020



One-Way Coupling to Wave Model

Operational Multi_1 (GWMv3)

- Arctic Polar Stereographic
  - 18 km resolution
  - 50°N to 90°N
- Global grid: 30 arc min
- Regional grids: 10 arc min
  - ak_10m; wc_10m; at_10m; ep_10m
- Coastal grids: 4 arc min
  - ak_4m; wc_4m; at_4m
- No ocean current interactions

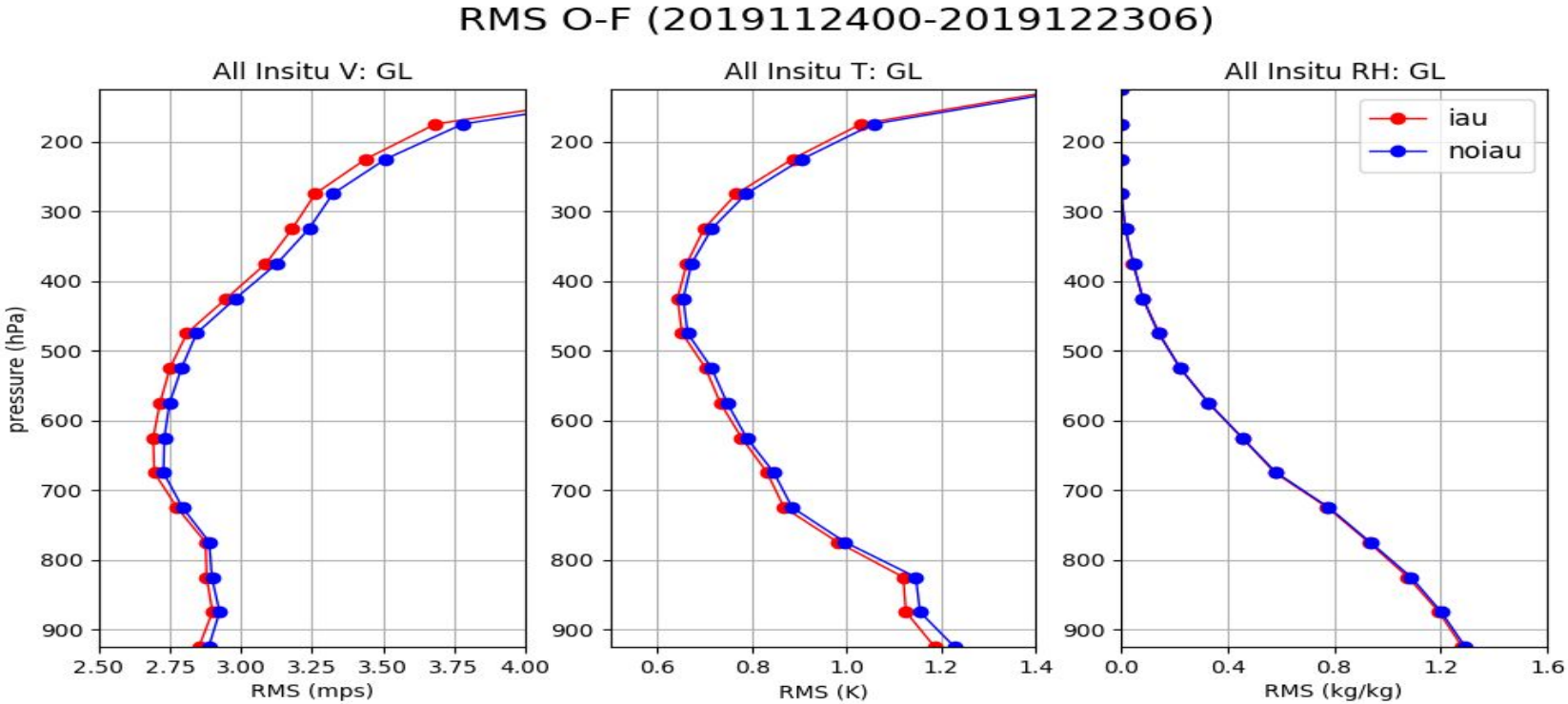
GFSv16-Wave Component

- Arctic Polar Stereographic: 9 km resolution
  - 50°N to 90°N
- Global grid: 16 km (10 arcmin)
  - 15°S to 52.5°N
- Southern Ocean : 25 km (15 arcmin)
  - 10.5°S to 79.5°S
- Removal of regional and coastal grids
- New RTOFS ocean surface current forcing up to 192h
- Forecasts will be extended from 180 hr to 384 hr.
- Improved Wave Physics

Major Upgrades to GDAS

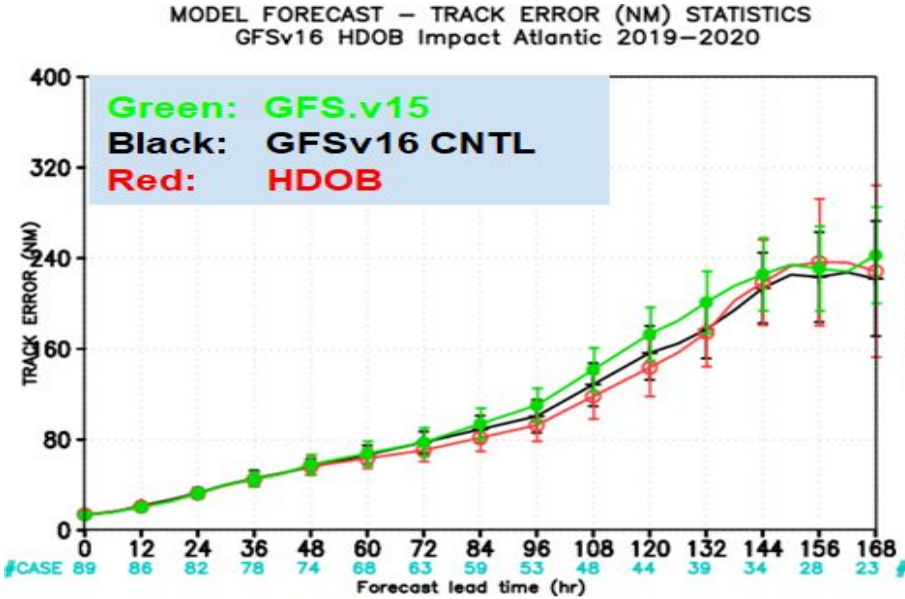
- **Local Ensemble Kalman Filter (LETKF)** with model space localization and linearized observation operator to replace the Ensemble Square Root Filter (EnSRF)
- **4-Dimensional Incremental Analysis Update (4D-IAU)**
- **Turn on SKEB** in EnKF forecasts
- **New variational QC**
- Apply Hilbert curve to aircraft data
- **Correlated observation error** for CrIS over sea surfaces and IASI over sea and land
- Update temperature aircraft bias correction with safeguard
- Assimilate AMSU-A channel 14 and ATMS channel 15 w/o bias correction
- **Assimilate CSR data from ABI_G16, AHI_Himawari8, and SEVIRI_M08; AVHRR** from NOAA-19 and Metop-B for NSST
- **Assimilate additional GPSRO** (add Metop-C GRAS, More Cosmic-2)
- **Assimilate** high-density flight-level wind, temperature, and moisture observations **(HDOBS) in tropical storm environment (first time in operations for GFS)**
- Reduce the distance threshold for inner core dropsonde data to 55km (from 111km or 3*RMW) and add a wind threshold of 32 m/s to **allow more dropsonde data being assimilated**
- **Use CRTM v2.3.0**

4D-Incremental Analysis Update (IAU)

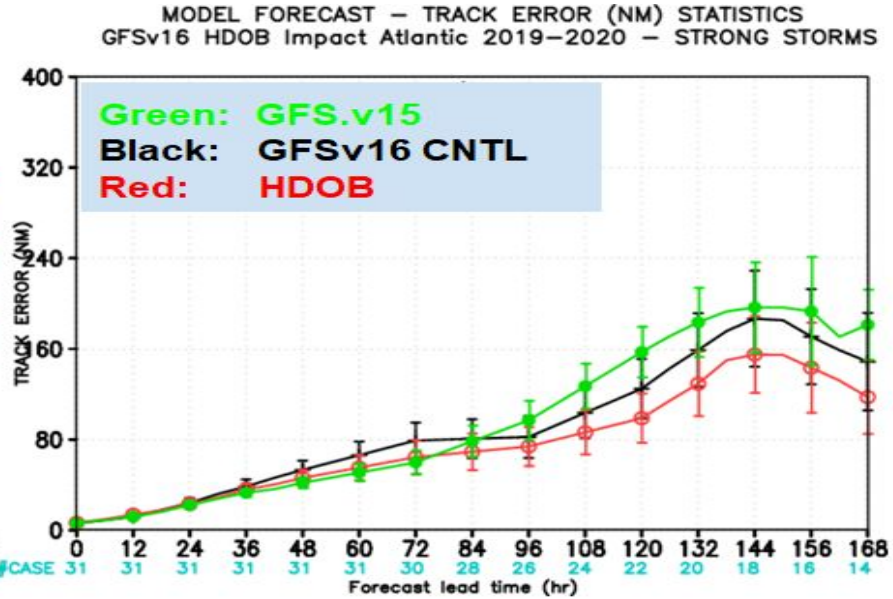


In collaboration with OAR/PSL

New Assimilation of HDOBS



All Storms



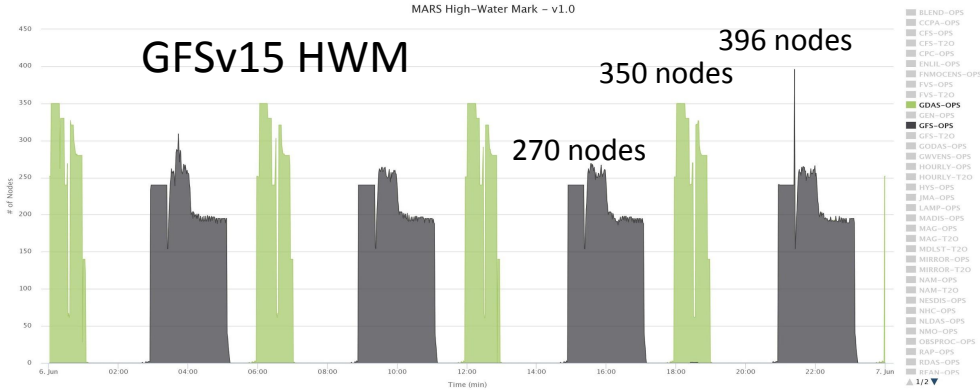
Strong Storms vmax>50kts

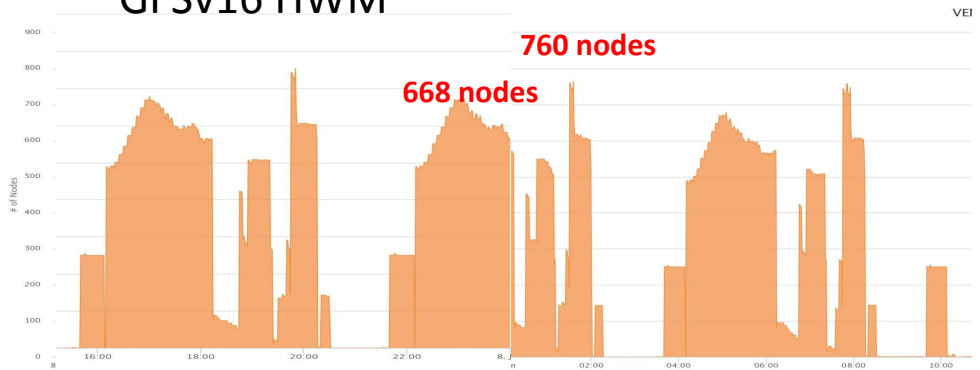
Significant improvements in track forecast errors, especially for strong storms

Infrastructure changes

- **Change the model output format from nemsio to compressed netCDF**
  - A new parallel I/O was developed with updated netCDF and HDF libraries
  - 3D Atmospheric fields will have 5x compression (33.6 GB to 6.7 GB, lossy compression)
  - Surface 2D fields will have 2.5x compression (2.8 GB to 1.1 GB, lossless compression)
- **Pre-Processing Changes**
  - obsproc_global and obsproc_prep was updated to process new satellite observations, high density aircraft observations, and to work with model history files in netCDF format.
- **Inline Post-Processing**
  - Inline post makes use of forecast data saved in memory for post processing, ***reduces I/O activity, and speeds up the entire forecast system.***
  - A Post library was created using the offline post Fortran programs. It can be called by the Write Grid Component within the forecast model.
  - Since lossy compression is applied for writing out forecast history files, ***inline post generates more accurate products*** than the standalone offline post.
  - Simulated satellite radiance and WAFS files are still made by the offline post.

Impact on Computational Resources





	GFS v15 time (min)	GFS v15 nodes	GFS v16 time (min)	GFS v16 nodes
gfs_analysis	28.0 - 28.7	240	28.1 - 29.4	250
gdas_analysis_high	32.2 - 33.0	240	38.2 - 39.3	250
gfs_forecast_high	100.8 - 103.4 (6.38 min/day)	148	122.8 - 124.2 (7.72 m/day)	484
wave_fcst	53.8 - 54	18	122.8 - 124.2	60
gdas_forecast_high	11.5 - 11.7	28	21.10- 21.5	119
enkf_update	6.5 - 6.8	90	25.6 - 26.7	240
enkf_fcst_XX	19.7 - 19.8	14 x 20 = 280	28.5 - 31.5	15 x 40 = 600

Retrospective and Real-Time Parallels

	Machine & Throughput	Period to be covered (total days)	Wave starting Cycle	CAPE/CIN fix starting cycle	Completion Date	Notes
v16retro0e	Mars Dell 3.5 7 cycles/day	05/10/19~05/31/19 (26)	No WAVE	**rerun fcst completed**	July 4	For MEG evaluation of significant weather events.
v16retro1e	Mars Dell 3.5 7 cycles/day	06/1/19~08/31/19 (92)	2019060712	2019081512	July 23	MDL and NCAR need data for JJA 2019
v16retro2e	Mars Dell 3.0 4 cycles/day	09/1/19~11/30/19 (91)	2019090918	2019102712	August 8	
v16retro3e	HERA 7 cycles/day	12/01/19 ~ **05/19/20** (169)	2020013106	2020040112	August 1	MDL and NCAR need data for DJF 2019/20
v16retro5e	Venus Dell 3.5 4 cycles/day	08/31/18~10/12/18 (43)	No Wave	2018091012	August 10	Forecast length is 10 days for all cycles.
v16rt2	**Mars Dell 3.0**	**05/19/20 ~**	**2020051900**	**2020071300**	**Ongoing**	

GFSv16 Evaluation

Carried out by EMC Model Evaluation Group with contributions from GFS.v16 model developers, NWS STI Science Operations Officers (SOO), and community collaborators.

https://www.emc.ncep.noaa.gov/users/meg/gfsv16/

- The GFSv16 official evaluation included analyses of:
  - Retrospectives (5/5/19–5/18/20; added 8/31/18–10/12/18)
    - Statistics
    - 50 Case Studies
  - Real-time Parallel (5/19/20–09/16/20)
    - Statistics
    - Representative examples

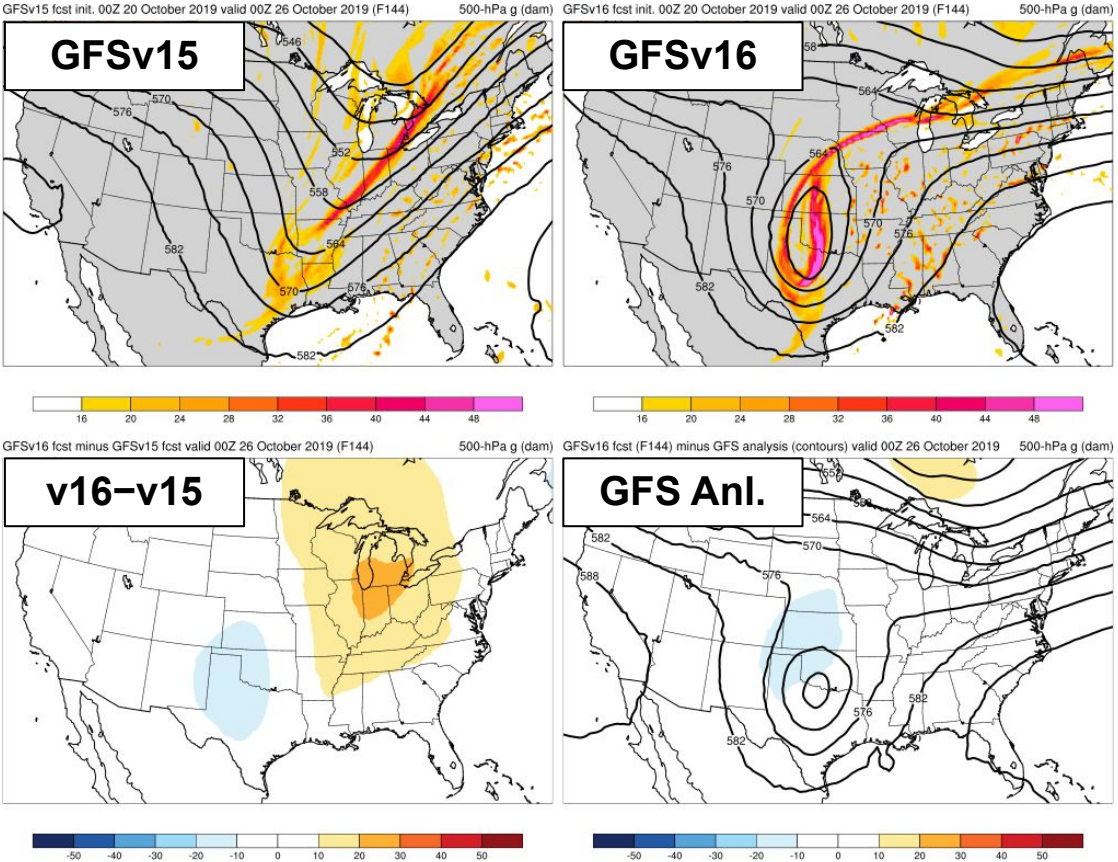
Common Strengths From All Evaluations

- Notable improvements in synoptic-scale performance in the medium-range
  - Progressive bias in GFSv15 appears mitigated with better consistency catching correct solutions earlier
  - Improved frontal positions and QPF
- Improvement in low-level temperature forecasts (mitigation of the winter low-level cold bias)
- Better ability to resolve shallow, cold air masses and some associated cold air damming events
- Improvements to TC intensity and increased lead time for genesis
  - With stronger TCs, GFSv16 has overall better track, size, and intensity

GFSv16 AC Scores (NH 500-hPa Z at Day 5)

	GFSv15 (OPS)	GFSv16 (RETRO)
Fall 2018	0.916	**0.916**
May 2019	0.880	**0.897**
Summer 2019	0.880	**0.888**
Fall 2019	0.897	**0.901**
Winter/Spring 2020	0.909	**0.913**
Real-Time Parallel	0.864	**0.871**
Full Retro Period	0.890	**0.896**

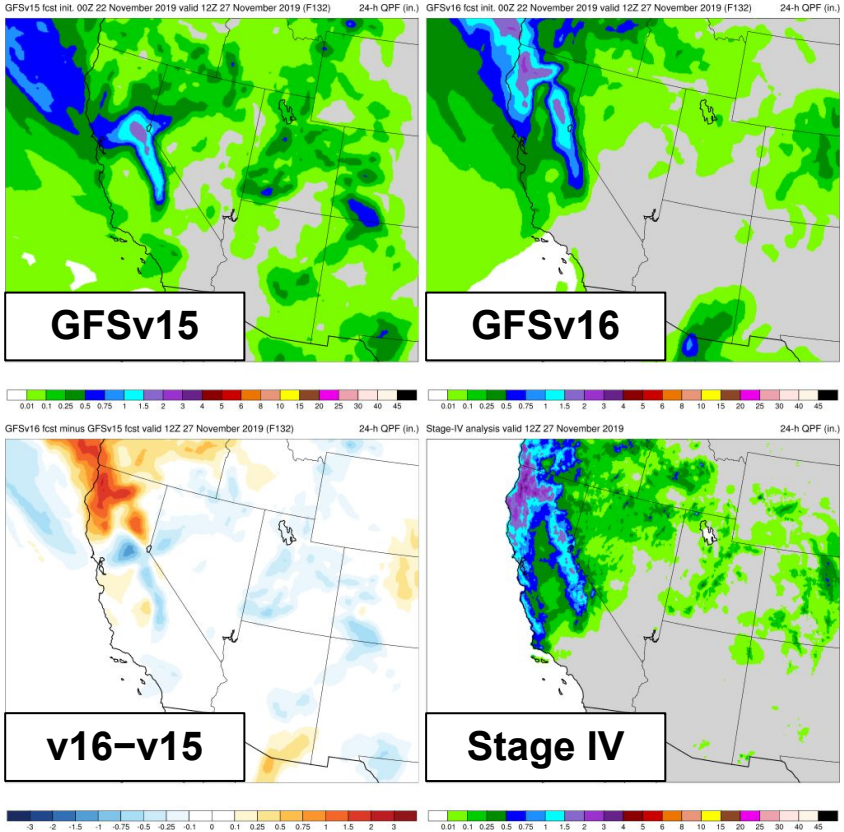
Strengths: Captures Synoptic Pattern Better



TC Olga Case
Fcst: 00z 10/20/20 (F144)
Valid: 00Z 10/26/20

- GFSv16 forecasted the location of this and other cutoff lows earlier and more consistently than GFSv15, with some mitigation of the progressive issue noted in the GFSv15 evaluation
- Several evaluators noted that GFSv16 showed more run-to-run continuity than GFSv15

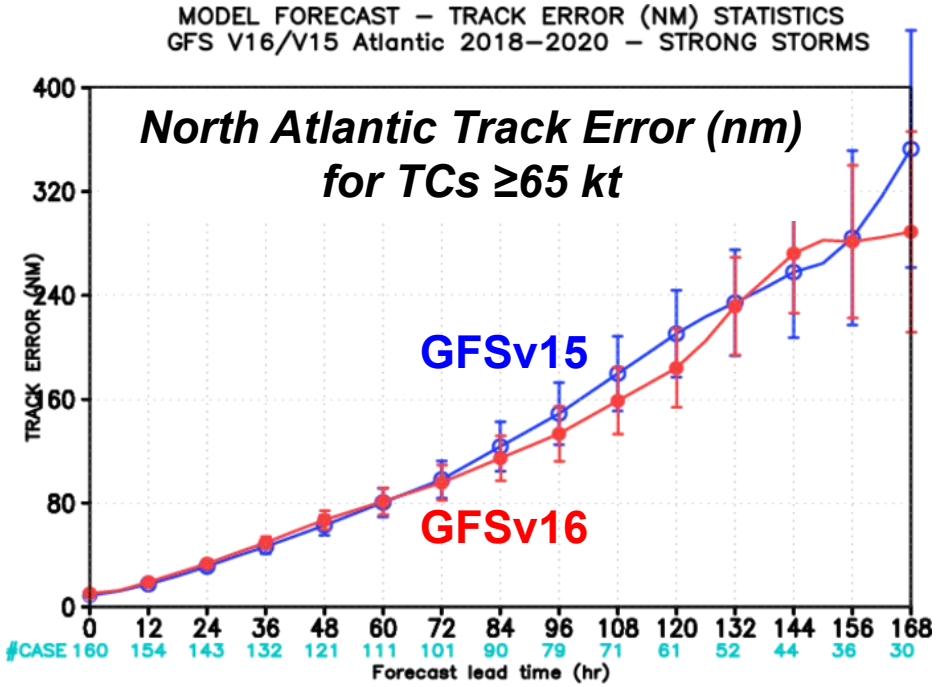
Strengths: Improved QPF ETS and Bias

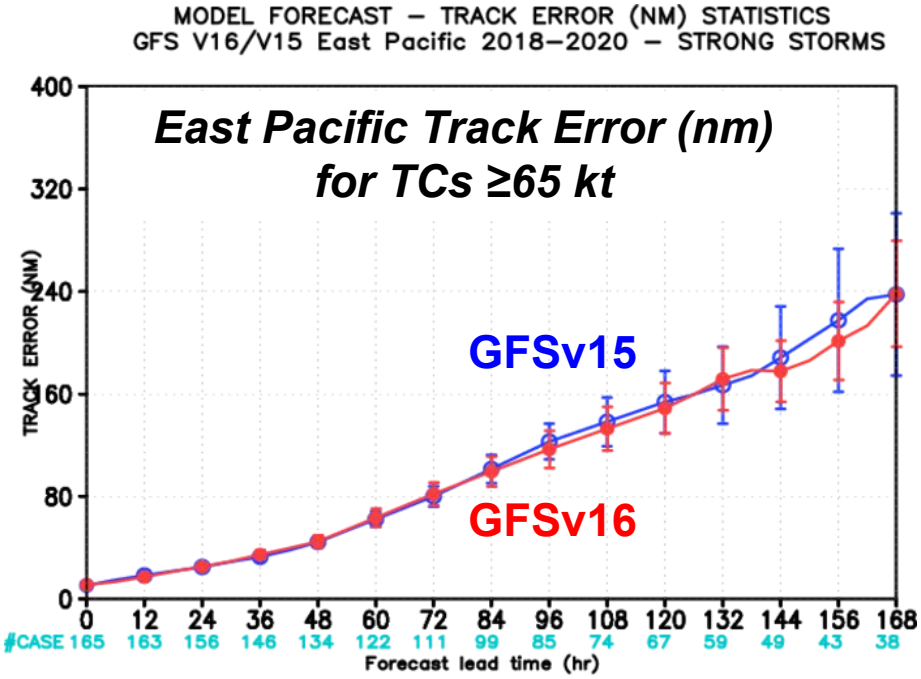


West Coast Bomb Cyclone Case
Fcst: 00z 11/22/19 (F132)
Valid: 12Z 11/27/19

- GFSv16 consistently had (correctly) higher QPF amounts inland over N California and Oregon for this case

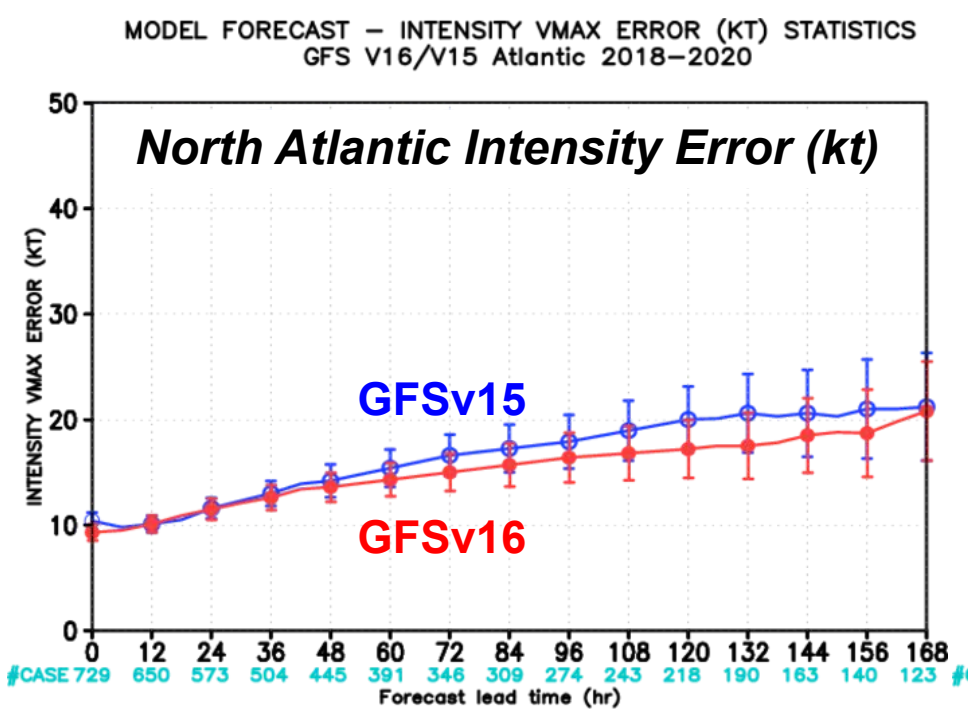
Strengths: Improved Medium-Range Track Error

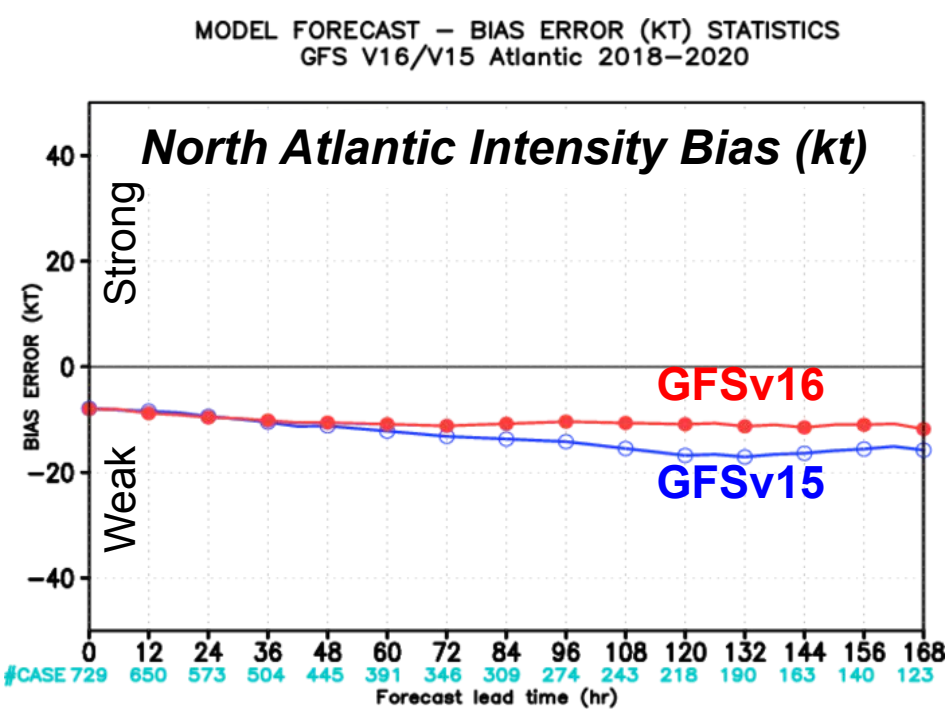




GFSv16 has lower track error than **GFSv15** for strong TCs (≥65 kt) during most of the medium range in both the North Atlantic and East Pacific

Strengths: Improved TC Intensity in N Atlantic





GFSv16 has lower intensity error than **GFSv15** at almost all lead times in the N Atlantic

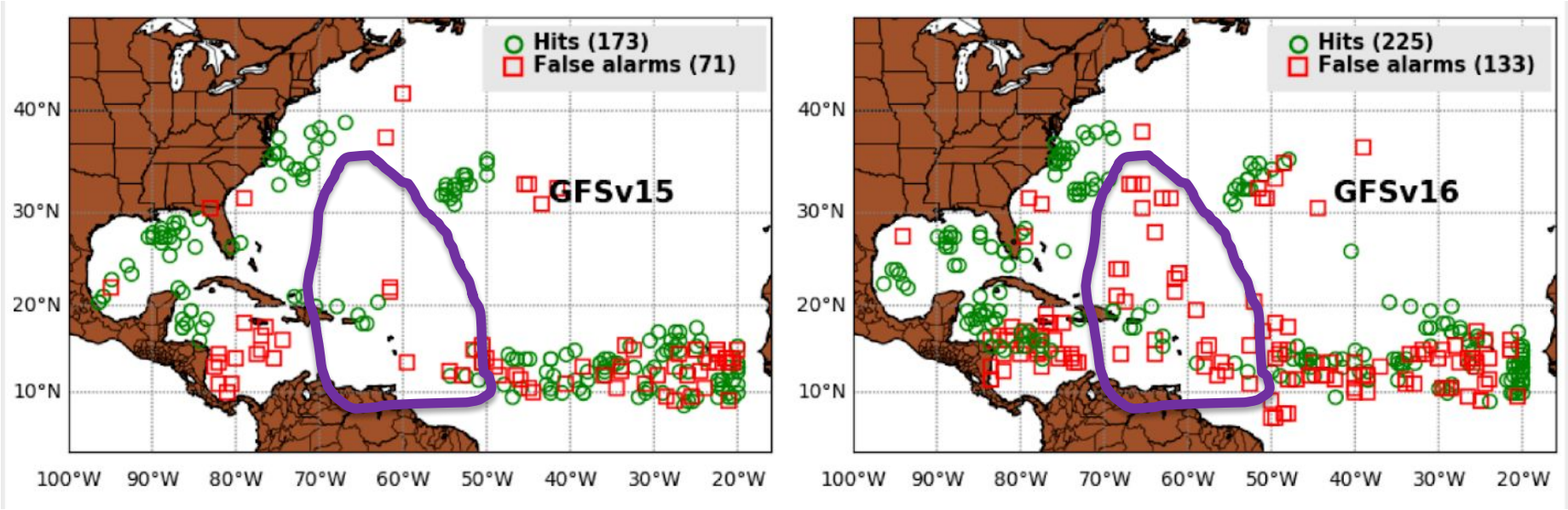
GFSv16 has less of a weak bias than **GFSv15** at longer lead times

Common Concerns Across the Evaluations

- Increased right-of-track bias at longer lead times for North Atlantic TCs
- Larger TC False Alarm Rate (FAR) in the western North Atlantic (70°W–50°W)
- Exacerbation of low instability (i.e., CAPE) bias that already existed in GFSv15, driven largely by dry soil moisture
- Lack of considerable improvement in forecasting radiation inversions

Larger TC False Alarm Rate

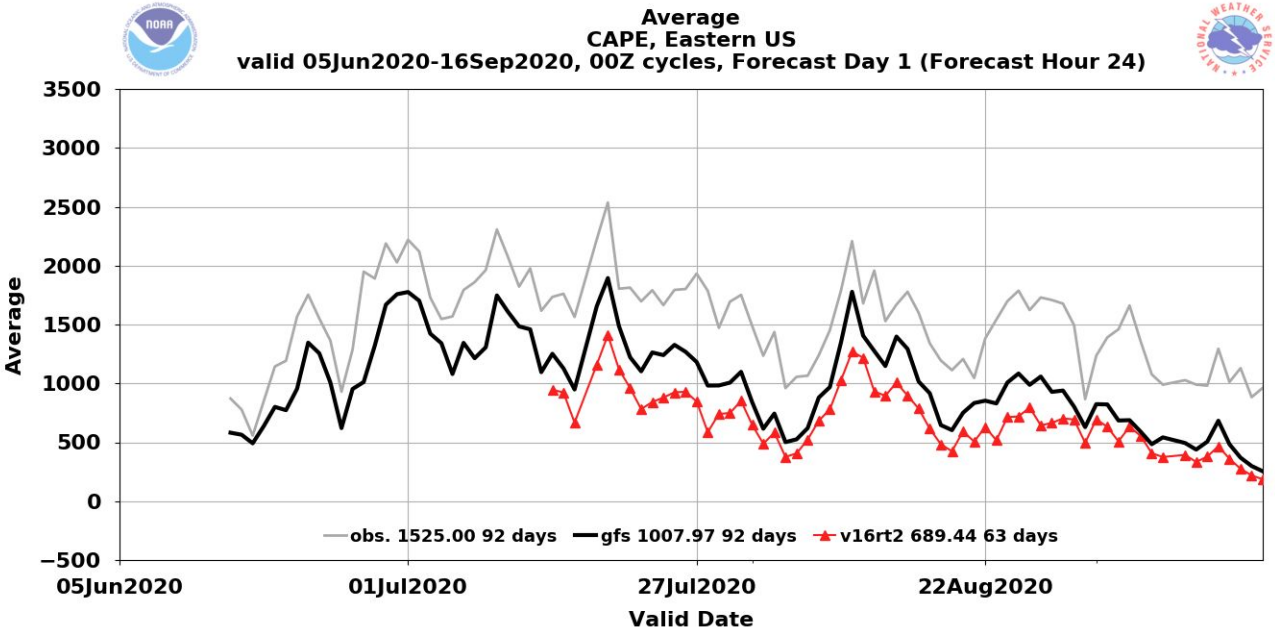
From Dan Halperin, ERAU



Large number of false alarms in GFSv16, relative to v15, between 50º and 70º W

CAPE Magnitudes Are Reduced in GFSv16

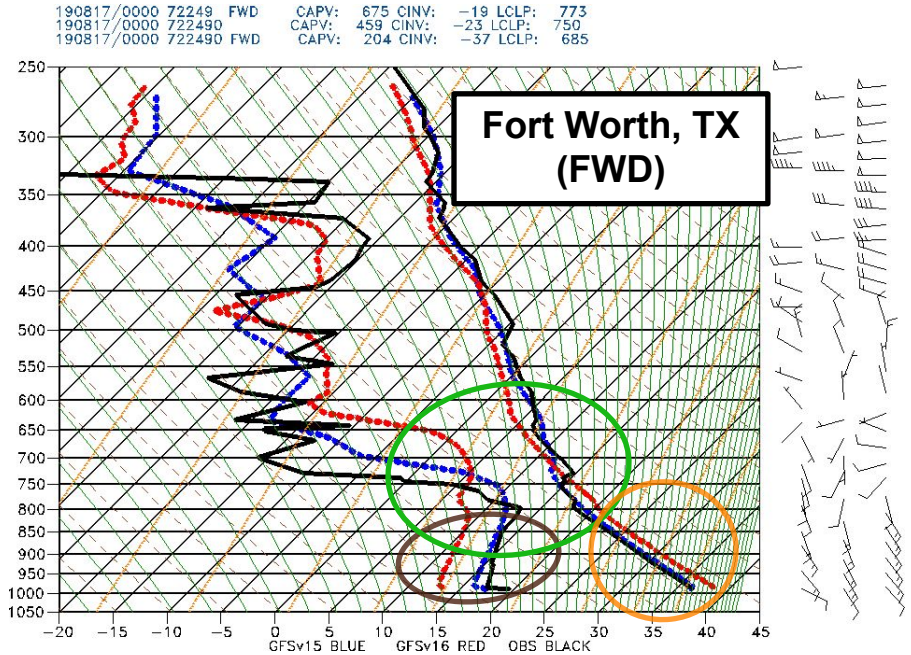
GFSv15
GFSv16
Obs

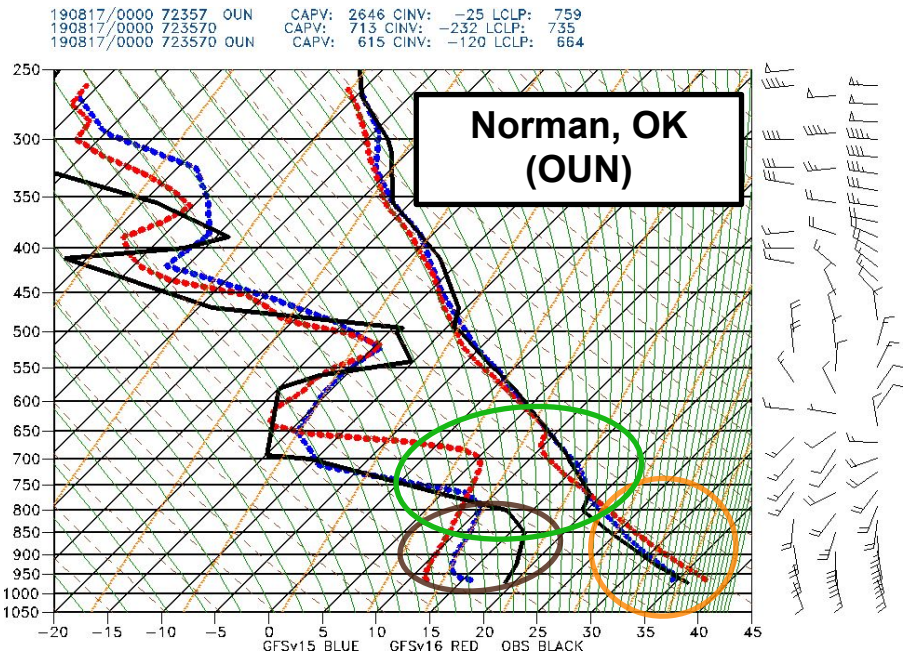


- Operational **GFSv15** CAPE analyses/forecasts are consistently lower than **obs**
- CAPE magnitudes in **GFSv16** analyses/forecasts are consistently lower than those from **GFSv15**

Tendency to Overmix the Boundary Layer

GFSv15 **GFSv16** **Obs**





Init: 12Z 08/16/20 **Valid: 00Z 08/17/20 (F012)**

- **GFSv16** PBL was drier/warmer/deeper than **GFSv15** and **obs** in the unstable air

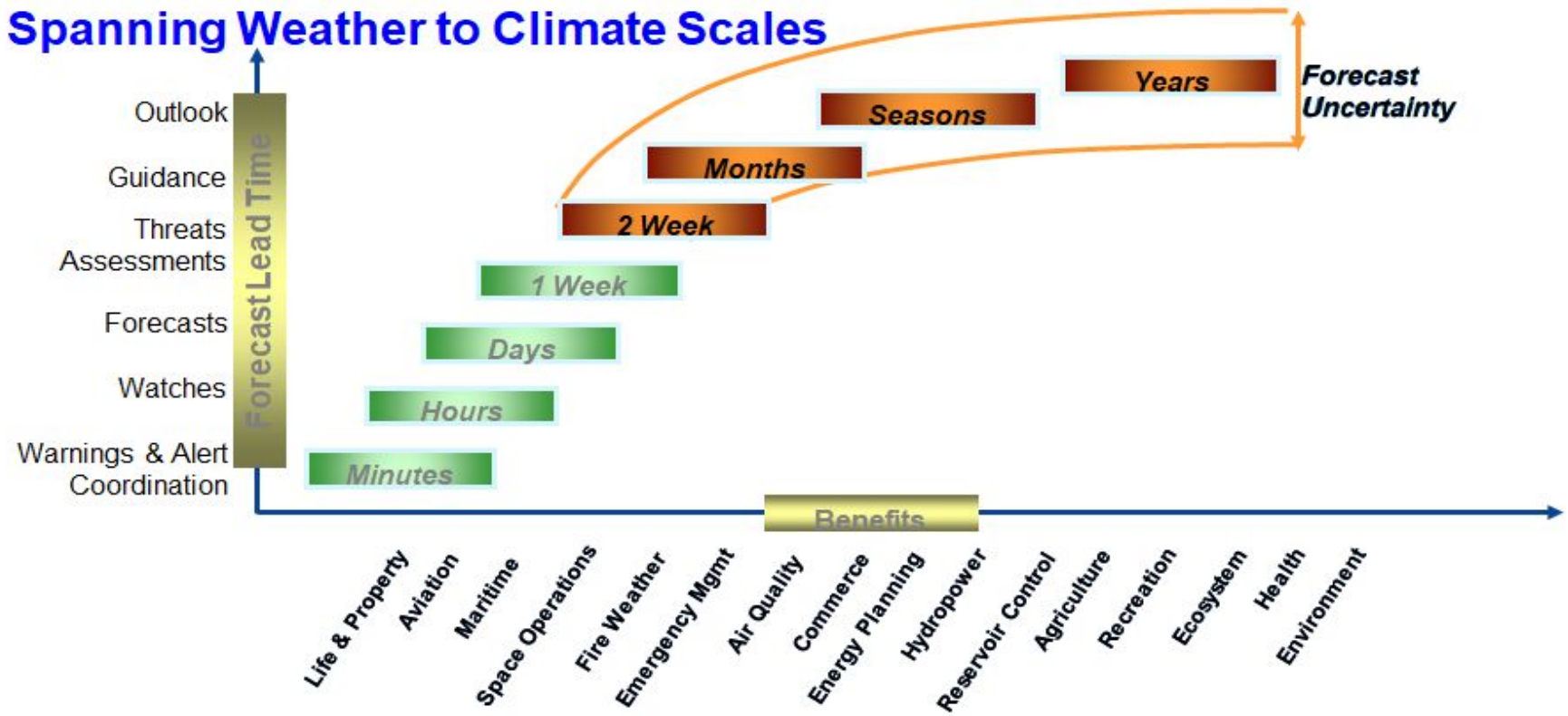
GFSv16 Development and T2O Timeline

- Development started after GFS.v15 implementation – **6/12/2019**
- Project Plan and Charter drafted and approved – **9/5/2019**
- Freeze GFSv16 configuration (including waves) for retrospectives – **5/19/2020**
- Produce full retrospective and real-time experiments: **8/31/2020**
- Deliver PNS to HQ:
- Complete field evaluation: **9/25/2020**
- EMC CCB: **9/30/2020**
- MEG final briefing: **10/1/2020**
- Science briefing to NCEP OD: **10/05/2020**
- **Final IT and EE2 compliance – 10/08/2020**
- Deliver final package to NCO: **10/09/2020**
- Transition to Operations: **02/03/2021 (Planned)**

Outline

- History of NCEP Global Forecast System (GFS)
- GFS Performance
- Recent Changes and Upgrades
- The Future

Scope of NWS Applications



Building a Community Based Unified Forecast System

NOAA NGGPS to UFS Strategic Implementation Plan (FY19-21):

- UFS is a community-based, coupled comprehensive end-to-end Earth system prediction system, including data assimilation.
- UFS applications span local to global domains and sub-hourly analyses to seasonal predictions.
- UFS will support the Weather Enterprise and be the source system for NOAA's operational NWP applications.
- UFS will serve both the R&D and Operational communities engaged in numerical prediction of the Earth System.

Shared Community Infrastructure Support for UFS Development

Infrastructure for data assimilation:
Joint Effort for Data assimilation Integration (**JEDI**)

Infrastructure for coupling models together:

- NOAA Environmental Modeling System (**NEMS**) coupler
- based on the Earth System Modeling Framework (**ESMF**)
- using National Unified Operational Prediction Capability (**NUOPC**) conventions

Infrastructure for interoperable physics:

- Common Community Physics Package (**CCPP**) framework

Infrastructure for Code Management:

- Git based repositories with Gitflow

1. Coupling components
New ESMF/NUOPC mediator (CMEPS/NEMS)

2. Interoperable atmospheric physics
CCPP & CPF frameworks

3. Community-friendly workflow
CIME - CROW unification, CIME Case Control System

4. Hierarchical model development capabilities
Extensions of CIME data models, unit, & system testing

5. Forecast Verification: Comparison to Observations
Extension of MET+

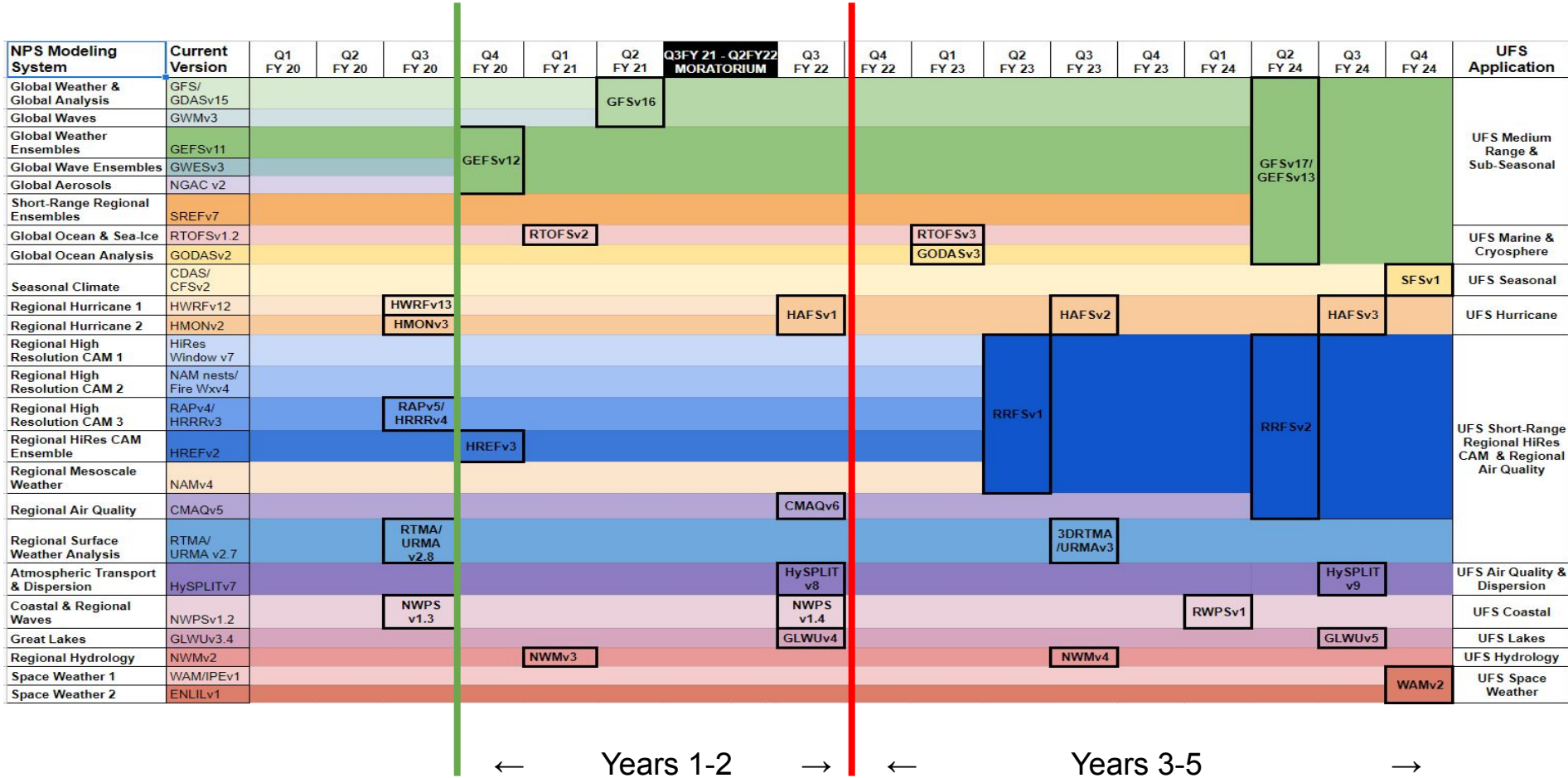
6. Software Repository Management
NCAR manage_externals tool

7. User / Developer Support
DTC and CESM Capabilities

NOAA-NCAR MoA Work Areas

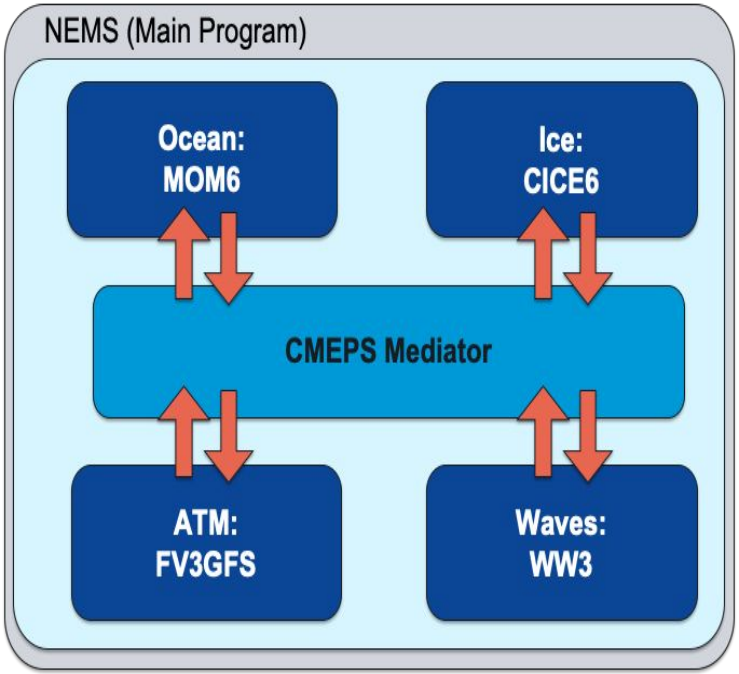
Courtesy of Brian Gross

Operational Models Consolidation Timeline



UFS - the Next Chapter

Fully coupled atm-ocn-ice-wave model for MRW/S2S operation in 2024



NPS Modeling System	Current Version	Q1 FY 20	Q2 FY 20	Q3 FY 20	Q4 FY 20	Q1 FY 21	Q2 FY 21	Q2 FY 24	Q3 FY 24	Q4 FY 24	UFS Application
Global Weather & Global Analysis	GFS/ GDASv15						GFSv16	GFSv17/ GEFSv13			UFS Medium Range & Sub-Seasonal
Global Waves	GWMv3										
Global Weather Ensembles	GEFSv11				GEFSv12						
Global Wave Ensembles	GWESv3										
Global Aerosols	NGAC v2										
Short-Range Regional Ensembles	SREFv7										
Global Ocean & Sea-Ice	RTOFSv1.2					RTOFSv2					UFS Marine & Cryosphere
Global Ocean Analysis	GODASv2										
Seasonal Climate	CDAS/ CFSv2									SFSv1	UFS Seasonal

Thank You