Development and Evaluation of NCEP's Global Forecast System Version 16

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GFSv16 Acknowledgements

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★ A brief review of GFS history

★ Science and infrastructure changes

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★ Benefits and concerns

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
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Aug 1987	18	T80 (150km)	Sigma Eulerian	First triangular truncation; diurnal cycle
Mar 1991	18	T126 (105km)	Sigma Eulerian	
Aug 1993	28	T126 (105km)	Sigma Eulerian	Arakawa-Schubert convection
Jun 1998	42	T170 (80km)	Sigma Eulerian	Prognostic ozone; SW from GFDL to NASA
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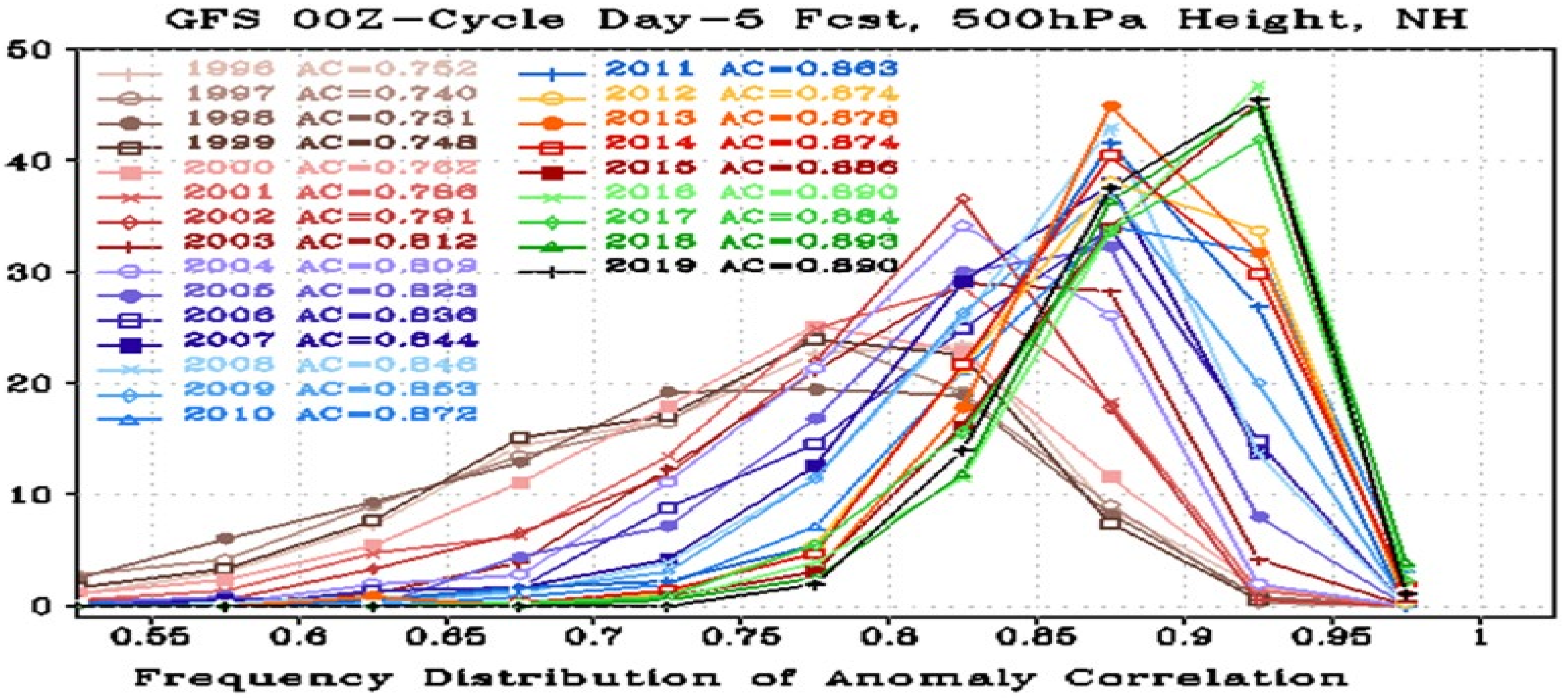
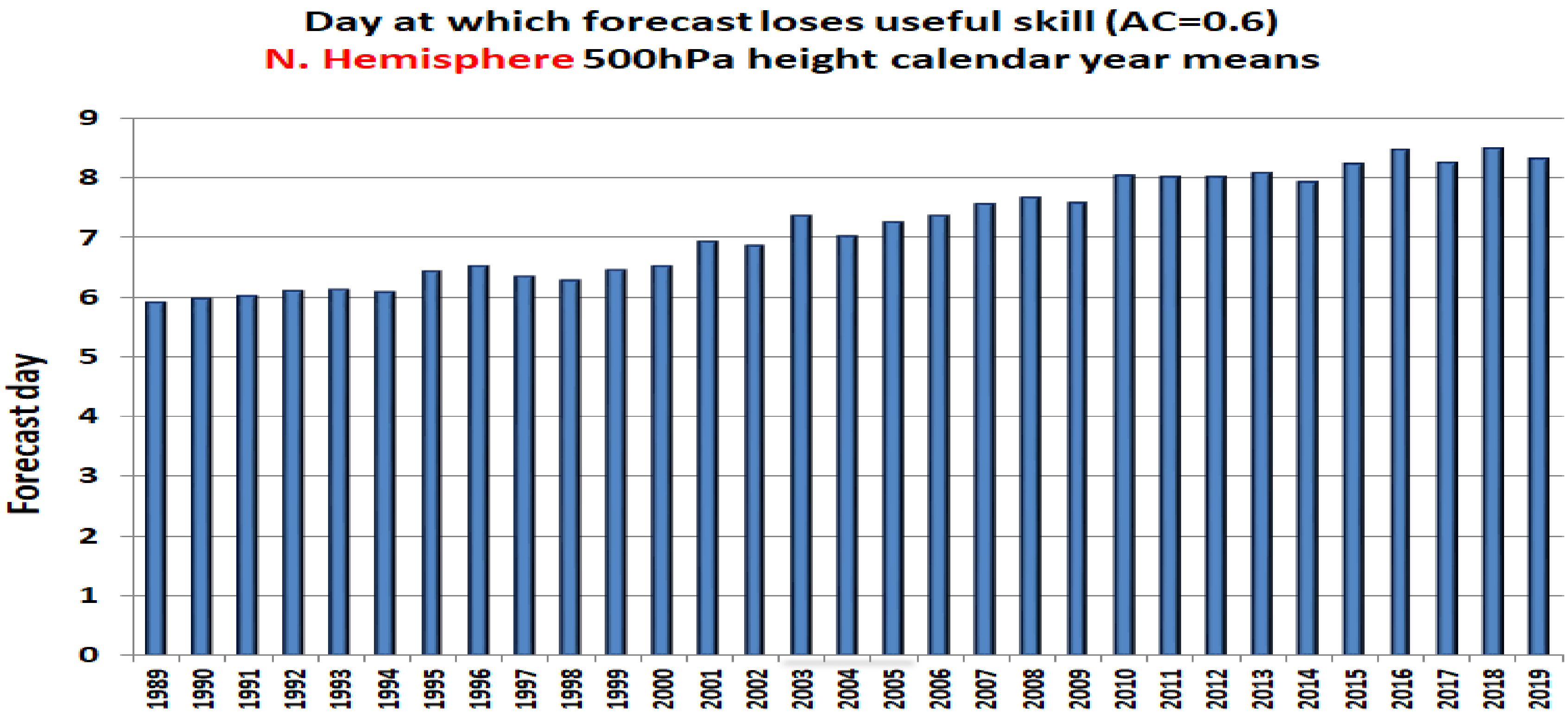
Jan 2000	42	T170 (80km)	Sigma Eulerian	first on IBM
Oct 2002	64	T254 (55km)	Sigma Eulerian	RRTM LW;
May 2005	64	T382 (35km)	Sigma Eulerian	2L OSU to 4L NOAH LSM; high-res to 180hr
May 2007	64	T382 (35km)	Hybrid Eulerian	SSI to GSI
Jul 2010	64	T574 (23km)	Hybrid Eulerian	RRTM SW; New shallow cnvtion; TVD tracer
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
Jul2017	64	T1534 (13km)	Hybrid Semi-Lag	NEMS GSM, advanced physics
Jun 2019	**64**	**FV3 (13km)**	**Finite-Volume**	**NGGPS FV3 dycore**

GFS Historical Performance

NH 500-hPa HGT Day-5 ACC Frequency Distribution



GFS Historical Performance



GFS.v15 Transition to Operation

Finite-Volume Cubed-Sphere Dynamical Core (FV3)

Microphysics Scheme with Multiple Prognostic Cloud Hydrometeers

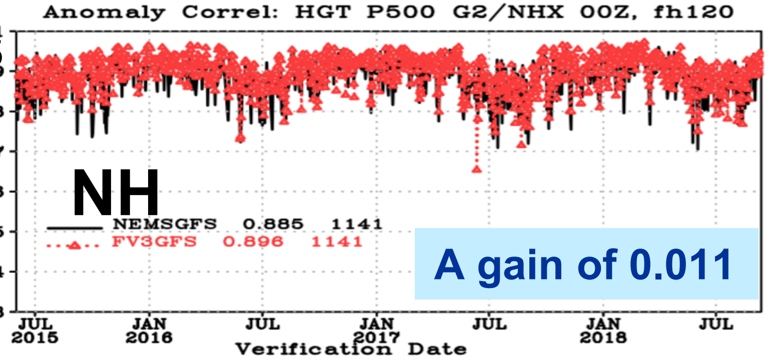
In Operation: June 12, 2019

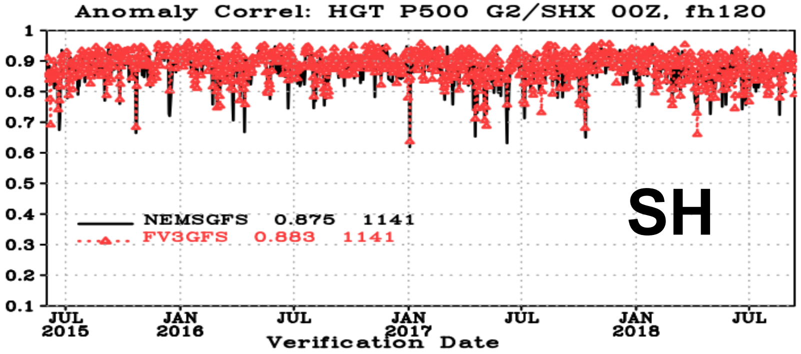
Configuration:

- **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**

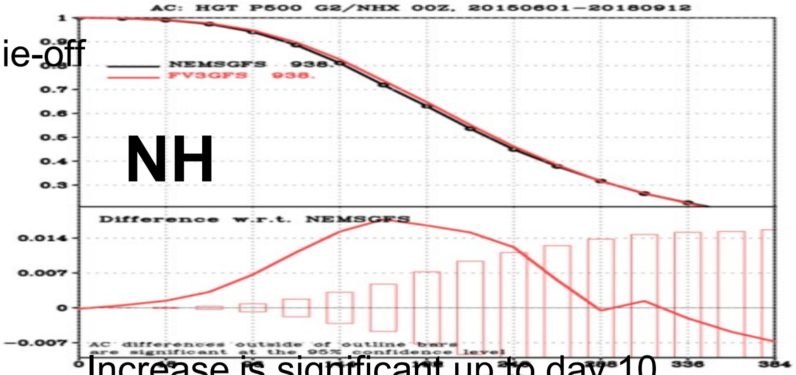
GFS.v15: Improved 500-hPa HGT ACC (2015 ~ 2018)

Day-5

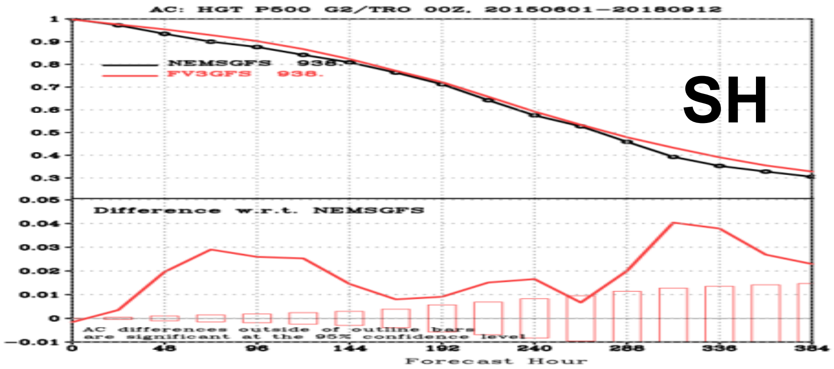




Die-off



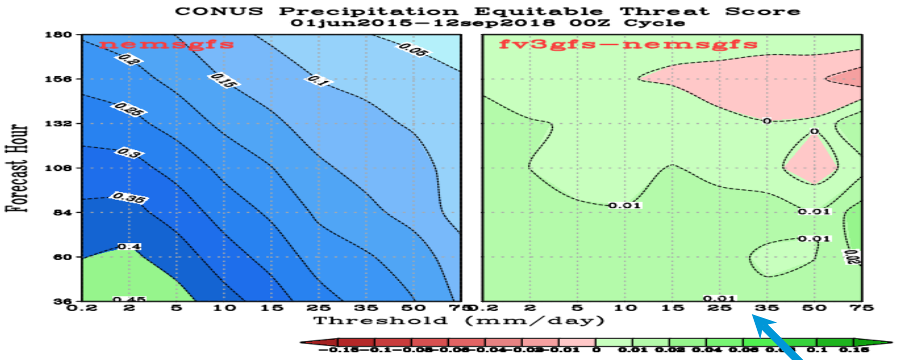
Increase is significant up to day 10

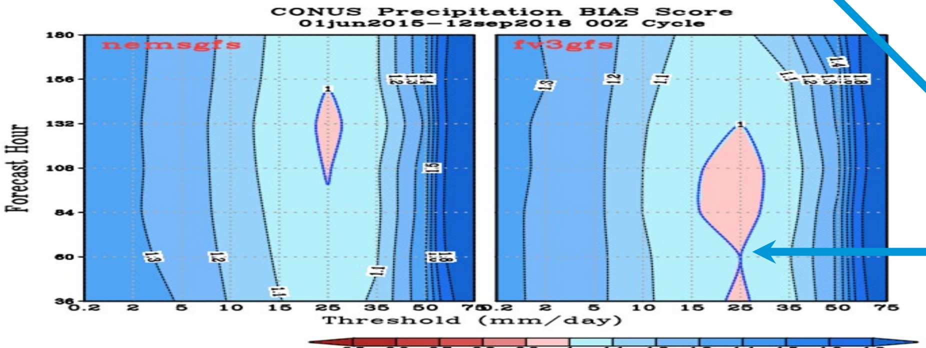


GFS.v15 - Improved Precipitation Forecast

Precip ETS and BIAS SCORES over the Continental US

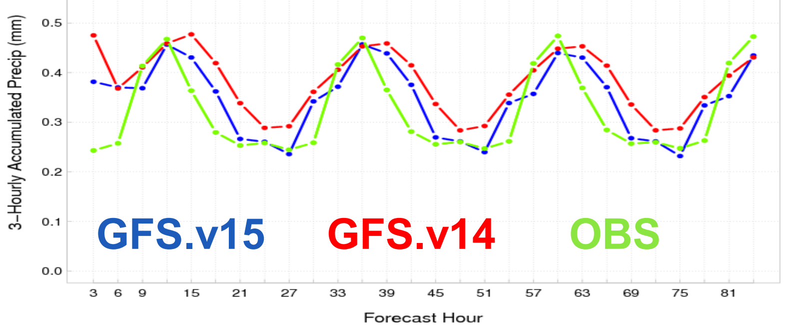
00Z Cycle, verified against gauge data, 20150601~ 20180912





Improved Precipitation Diurnal Cycle

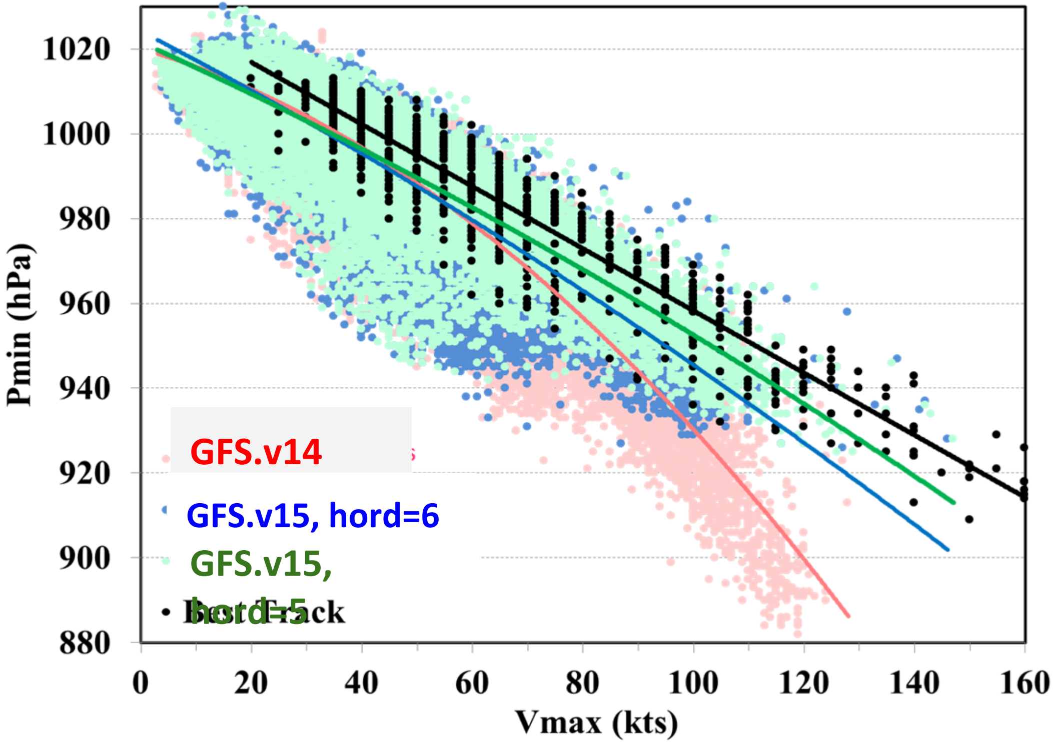
SUMMER 2018 CONUS DOMAIN-AVG PCP



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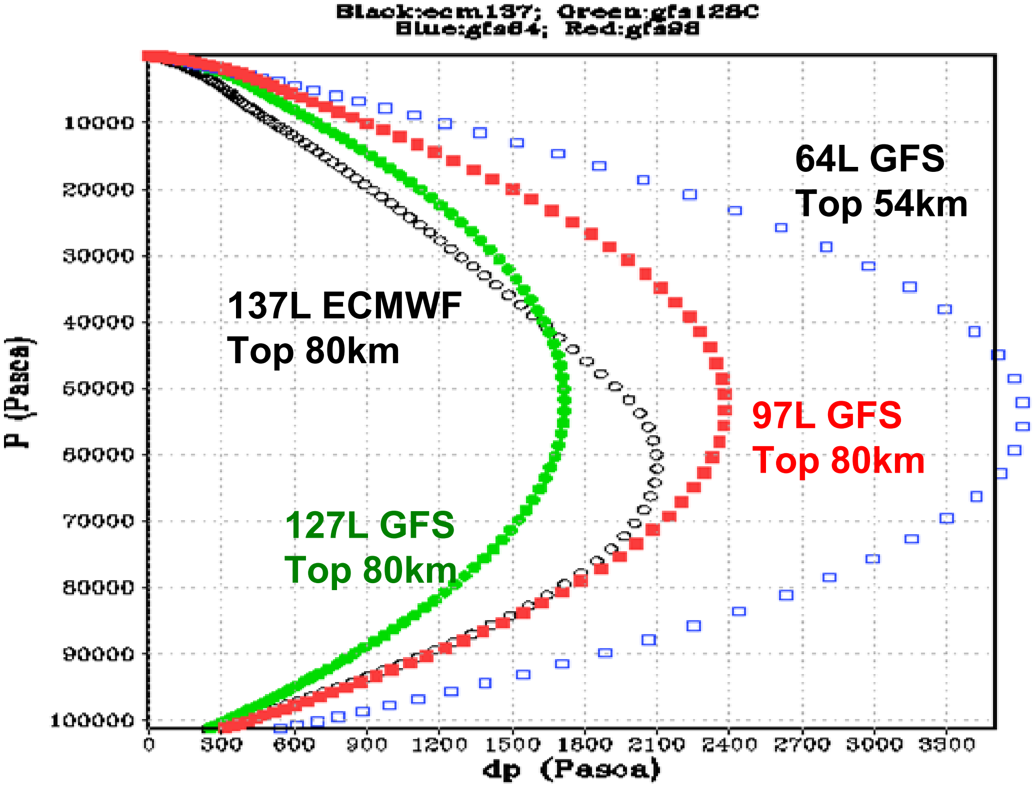
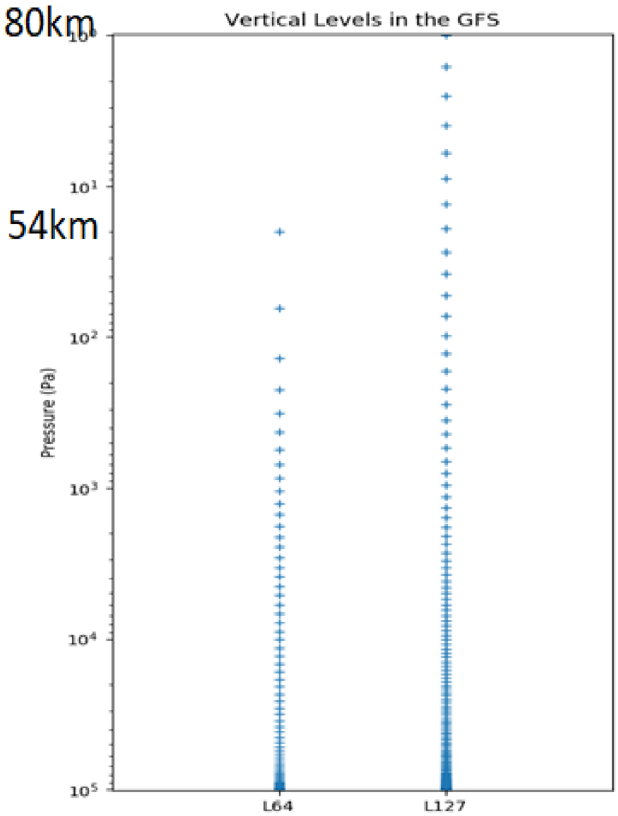
Jun 2019	64	FV3 (13km)	Finite-Volume	NGGPS FV3 dycore, GFDL MP
Feb 2021	127	FV3 (13km)	Finite-Volume	IAU, LETKF, TKE-EDMF, uGWD

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

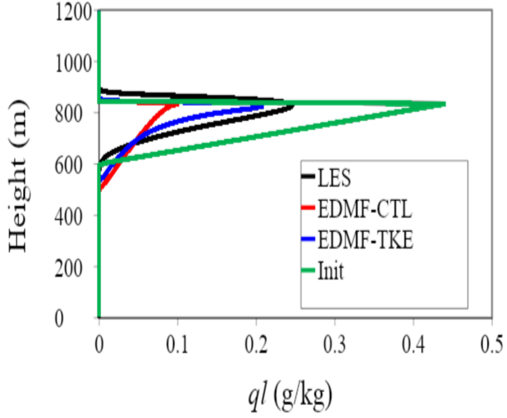
Coupling to Wave Model:

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

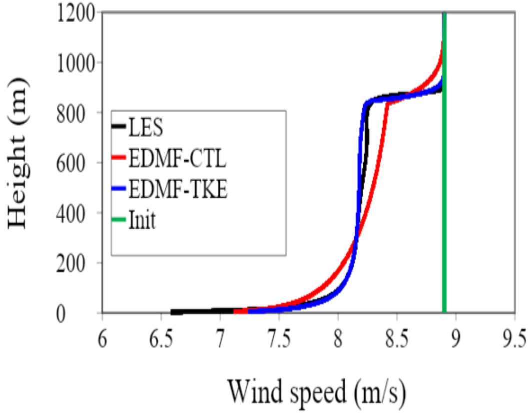
GFSv16: Major Changes to the Forecast Model

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



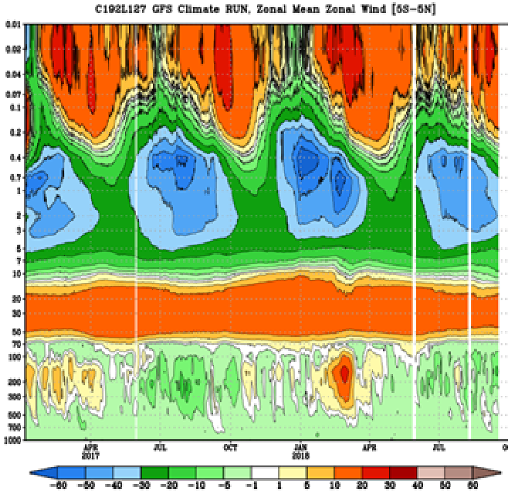
wind speed

GFSv16: Major Changes to the Forecast Model

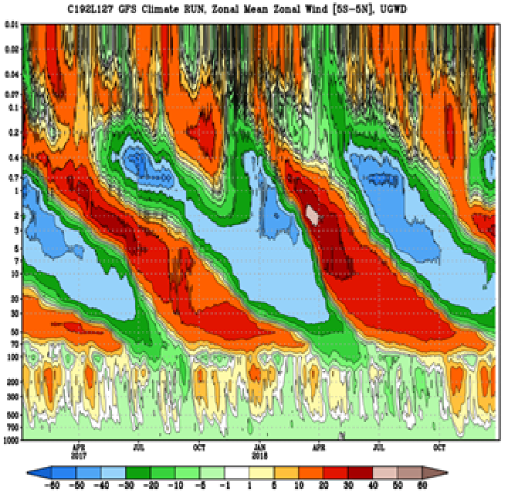
Non-Stationary GWD: Impact on QBO/SAO

In collaboration with CIRES, UCB

CONTROL



W/ non-stationary GWD



Prescribed Forcing (MERRA2 AGCM)

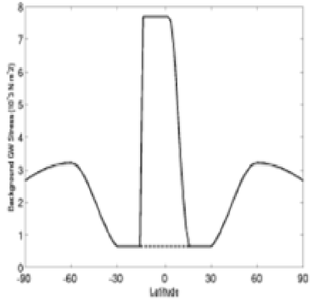


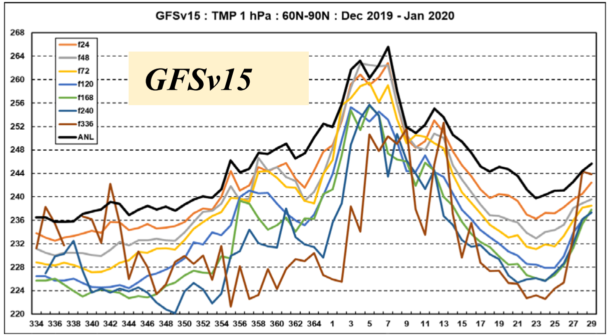
Figure 3. Background non-orographic drag from the MERRA (dashed line) and MERRA2 AGCM (solid line) simulations. The dashed line underlies the solid line outside of the tropics.

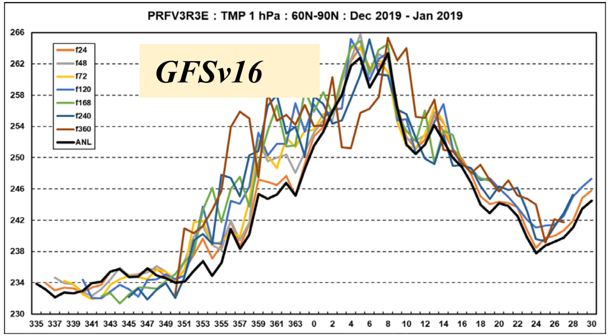
- Current operational model cannot simulate the QBO
- A QBO-like feature is captured in GFS.v16 "climate" run with the non-stationary GWD physics included; However, the periodicity is too short, appears to be a downward propagating SAO.

Forecast improvements in the Stratosphere

Improved 1-hPa Temperatures :

60N-90N Dec 2019 – Jan 2020





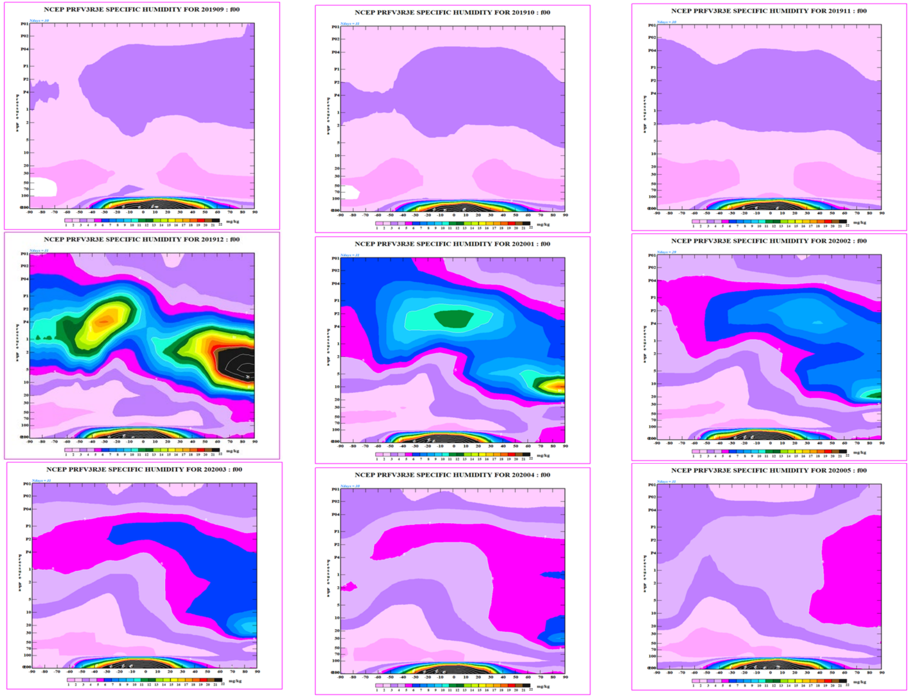
Figures courtesy: Craig Long, CPC

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

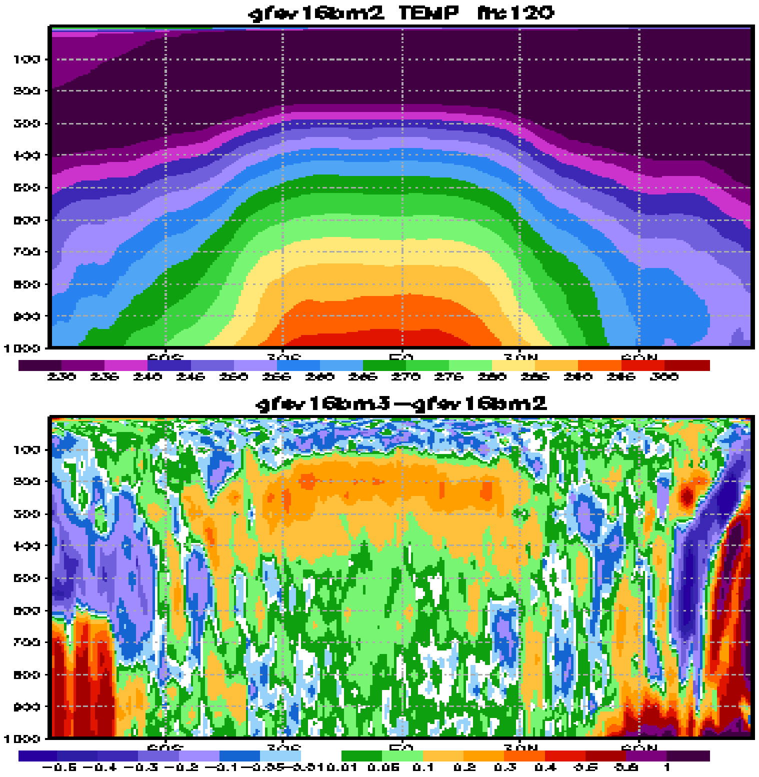
09-11/2019

12/2019-02/2020

03-05/2020

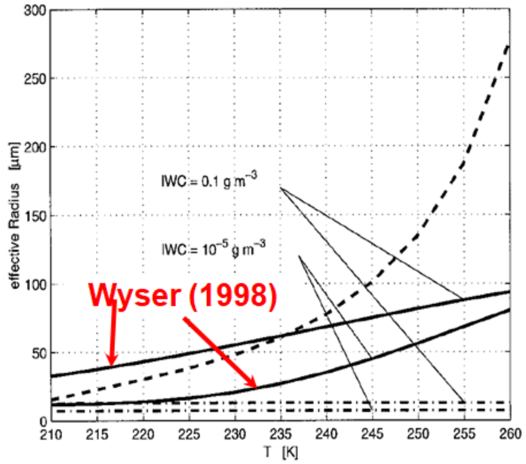


Improved ice cloud – radiation interactions



reduced tropospheric cold bias

Use Wyser (1998) formula to calculate $r_{eff\text{-}ice}$ as a function of q_i and T for q_i > qmin instead of using a constant $r_{eff\text{-}ice}$

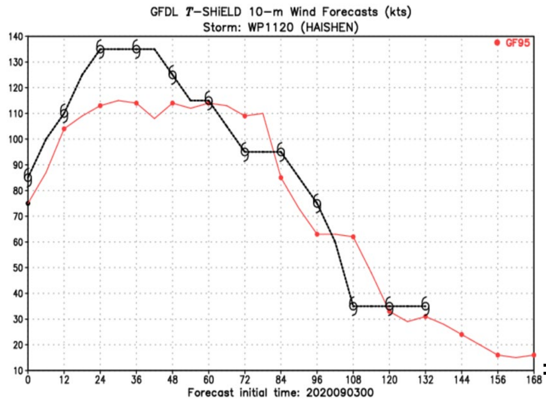


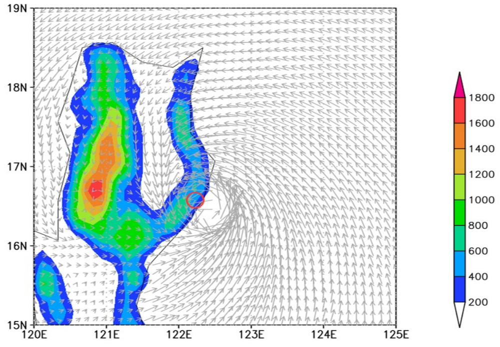
In collaboration with GFDL

Addressing Model Stability Issues

- The GFS.v16 had a few model crashes in early September when a strong typhoon passed over a small island over southern Japan. EMC worked with GFDL to diagnose the cause of the crashes and tested a few options to stabilize the model. All crashed cycles had excessive vertical velocities (>300 m/s) and delp becoming negative.
- The model failures have close resemblance to similar failed cases for GEFSv12, which was addressed by applying the 2dz filter to 100hPa and above (n_sponge=23 instead of 4). However, GFSv16 with similar settings (n_sponge=40) did not recover the failures.
- **After several trials, a solution was implemented by extending the delta-z filter in the vertical from the model top down to the tropopause and increasing the value of a minimum layer thickness parameter which enforces height monotonicity.**

In collaboration with GFDL





=-354m/s at (i,j,k)=(741,558,125)

- **All crashed cases were recovered.**
- **This solution was tested in both forecast-only experiments and a cycled experiment. It has a very small impact on the forecast skills and proved to be efficient in removing the model instability issues.**

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

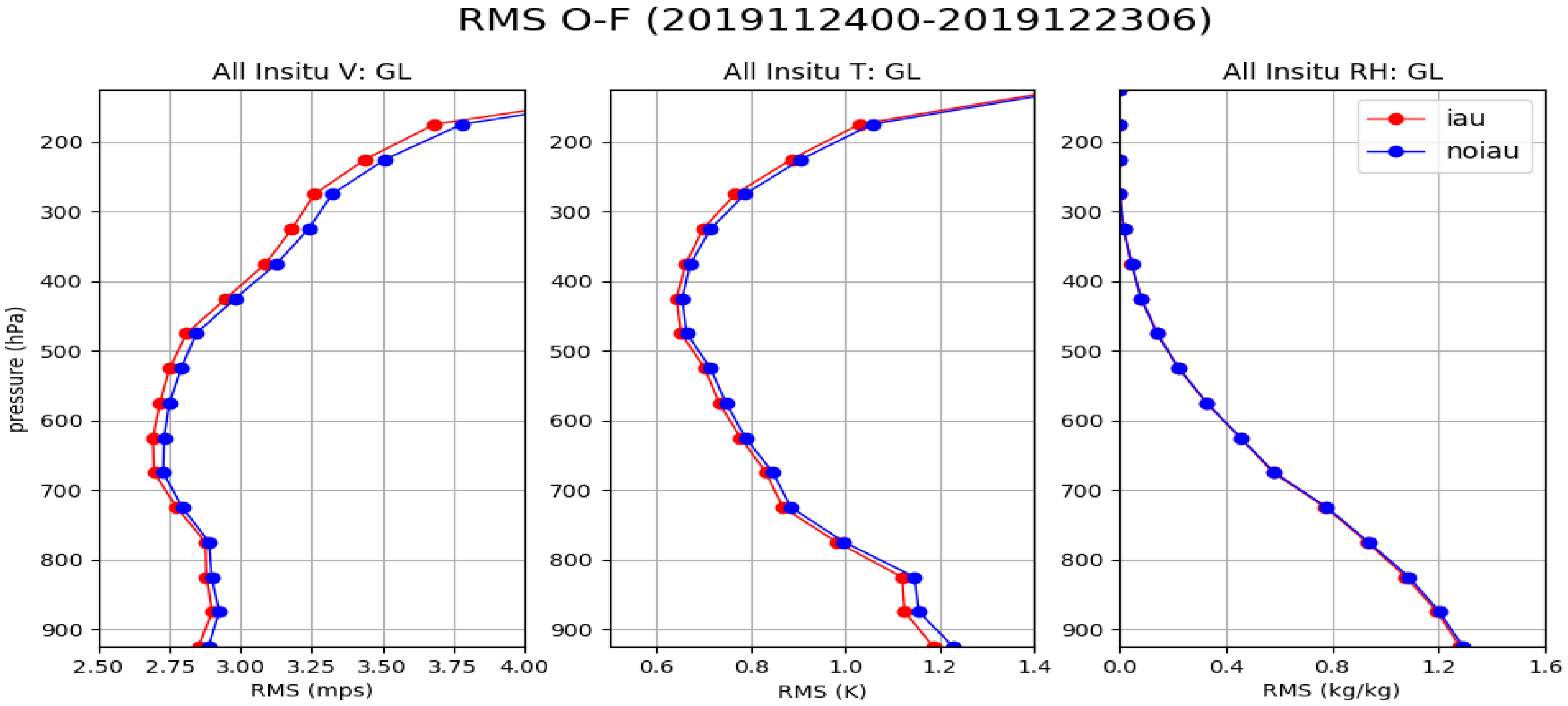
GFSv16-Wave Component

- 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

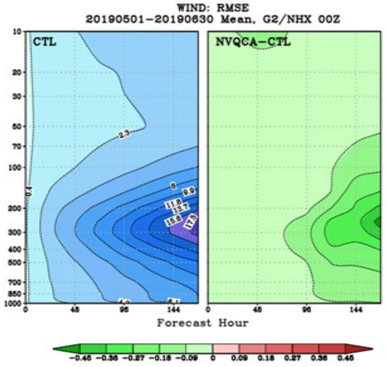
- **Local Ensemble Kalman Filter (LETKF)** with model space localization and linearized observation operator to replace the Ensemble Square Root Filter (EnSRF)
- **4-Dimensional Incremental Analysis Update (4D-IAU)**
- T**urn on SKEB** in EnKF forecasts
- **New variational QC**
- Apply Hilbert curve 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**

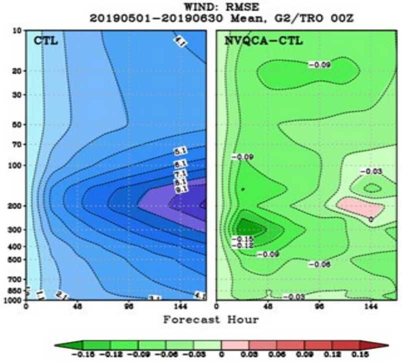
4D-Incremental Analysis Update (IAU)

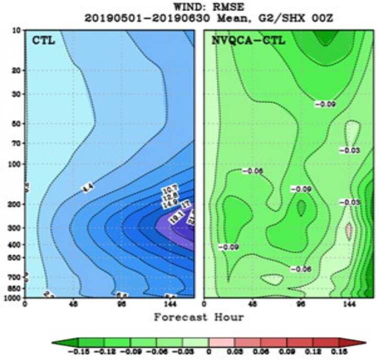


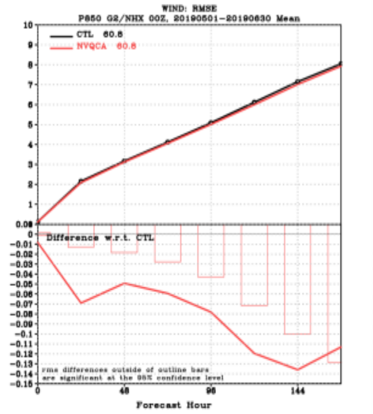
In collaboration with OAR/PSL

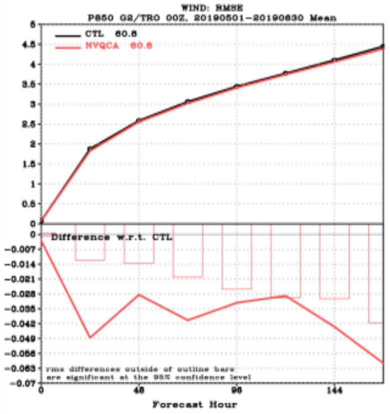
New Variational Quality Control Algorithm

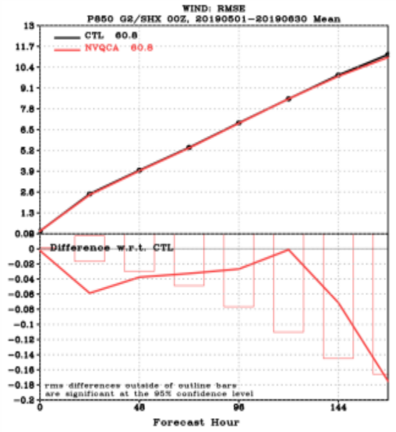






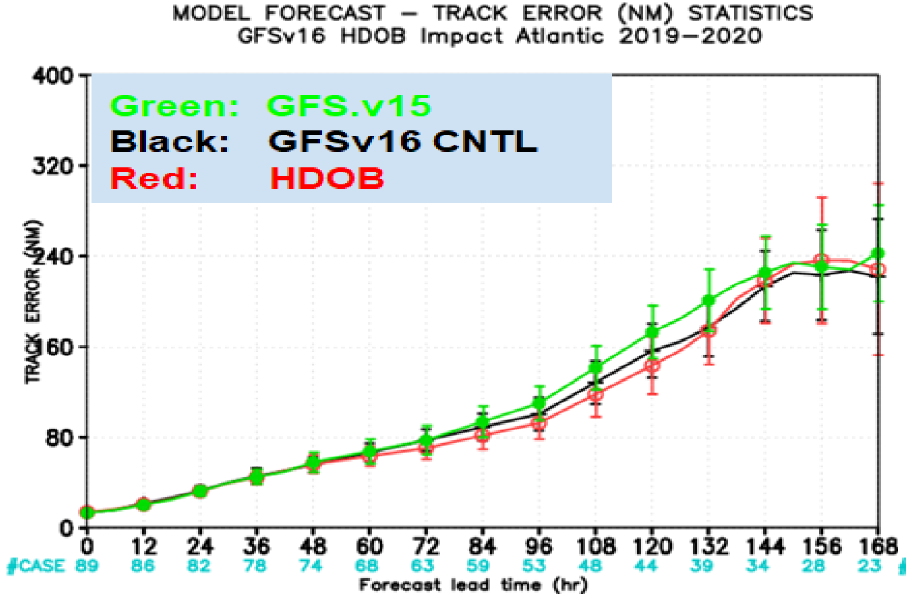




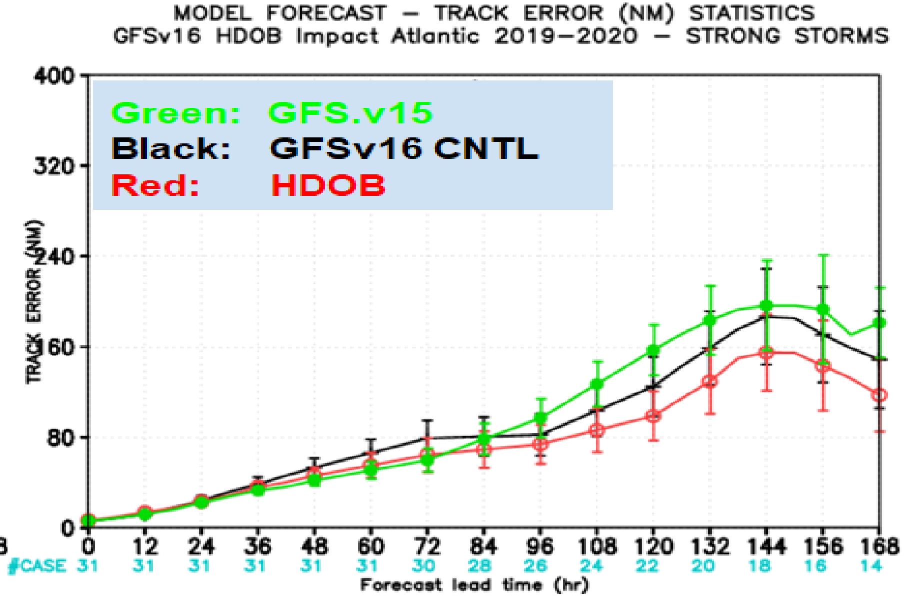


- A **new variational quality control** is applied to **conventional observations**.
- Previous variational quality control could not be applied in the first iterations of minimization due to the possibility of multiple minima in the cost function.
- New probability density function formulation greatly reduces the possibility of multiple minima.
- **Greatest impact in wind RMSE** and in the northern hemisphere.

New Assimilation of HDOBS



All Storms



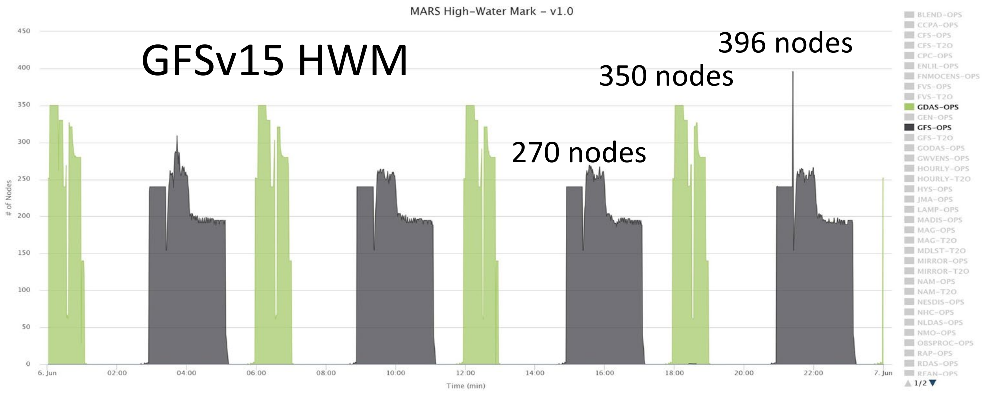
Strong Storms vmax>50kts

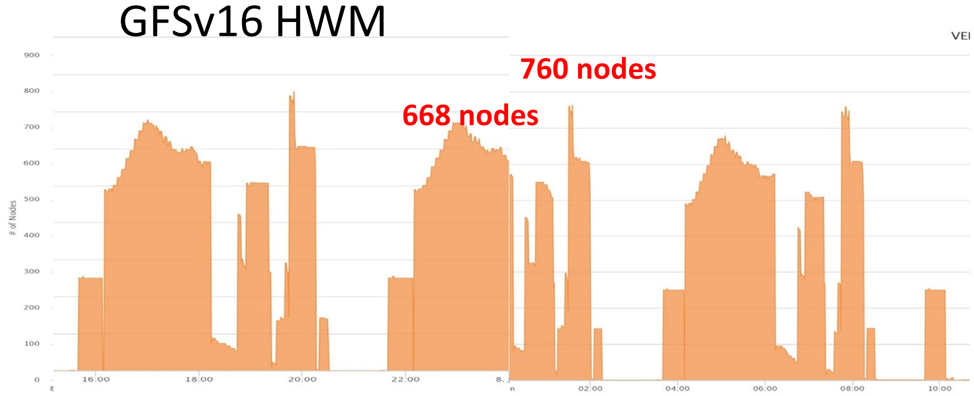
Significant improvements in track forecast errors, especially for strong storms

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

Evaluation of WAVE forecasts is skipped in this presentation

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

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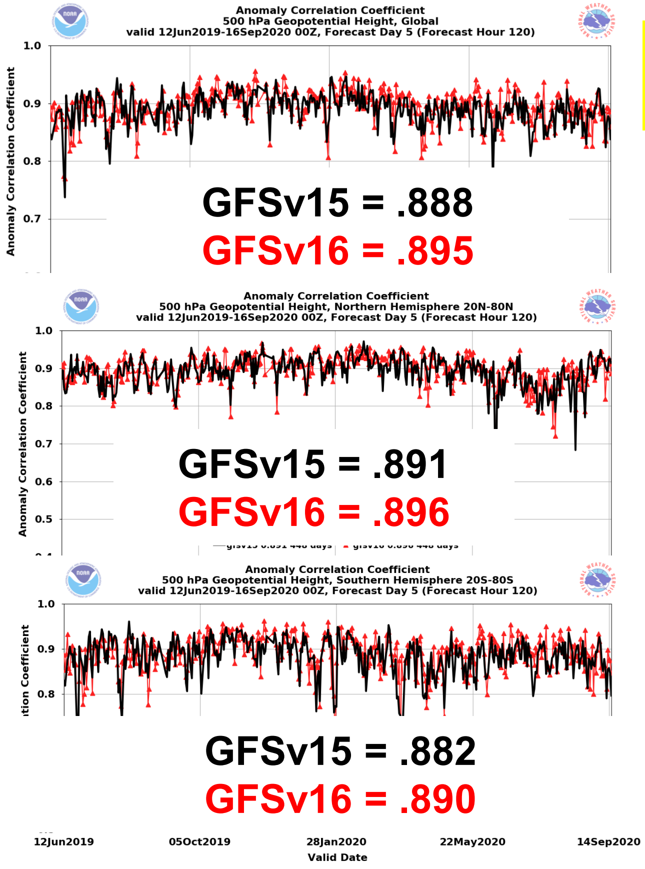
Strengths: 500-hPa AC Scores (Global)

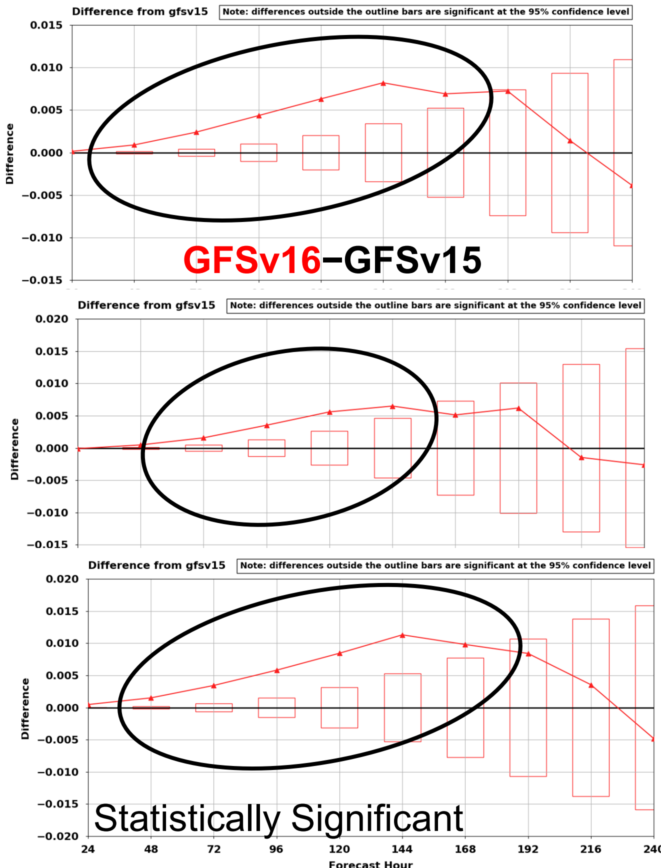


Valid: 6/12/19–9/16/20 (Day 5)

Global

NH

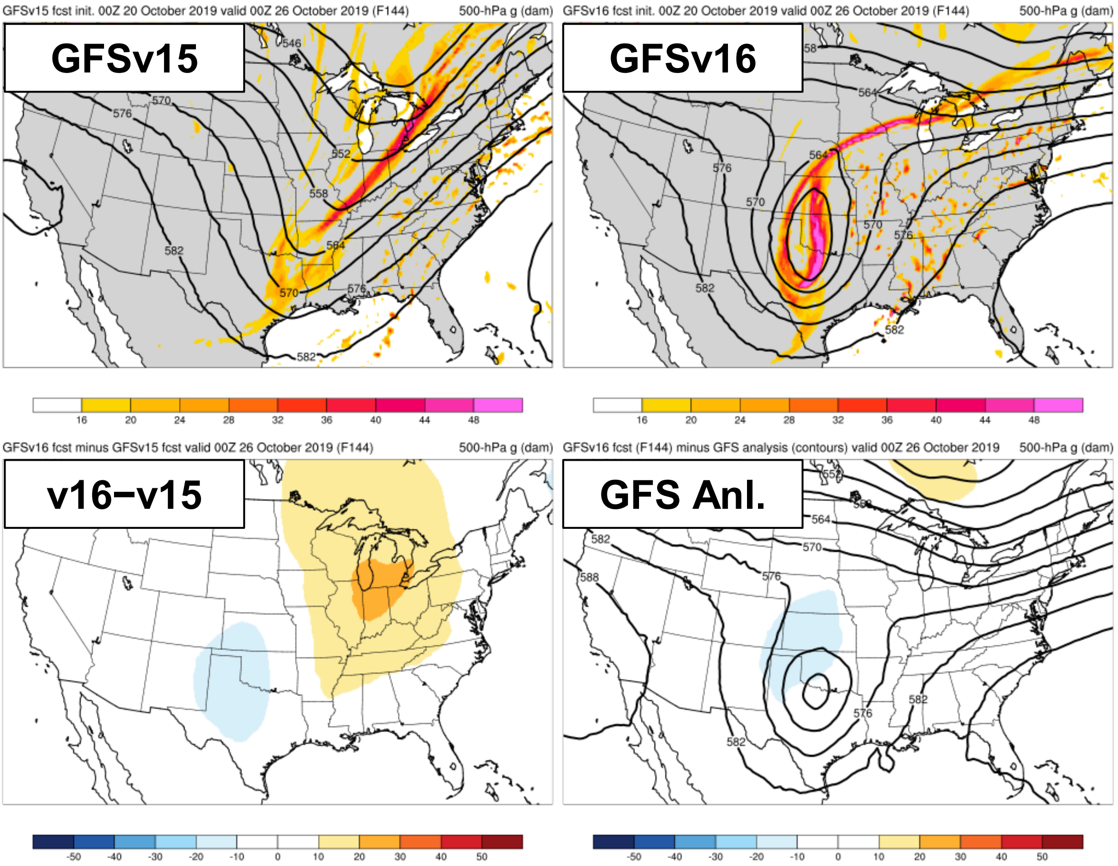
SH



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

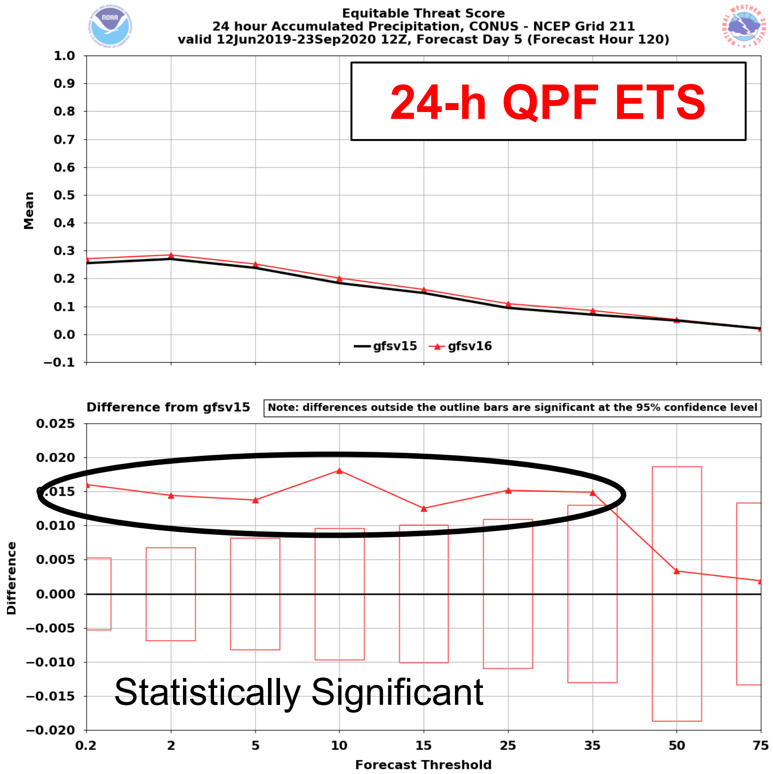


TC Olga Case
Fcst: 00z 10/20/20 (F144)
Valid: 00Z 10/26/20

- 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

Valid: 6/12/19–9/23/20 (F120)

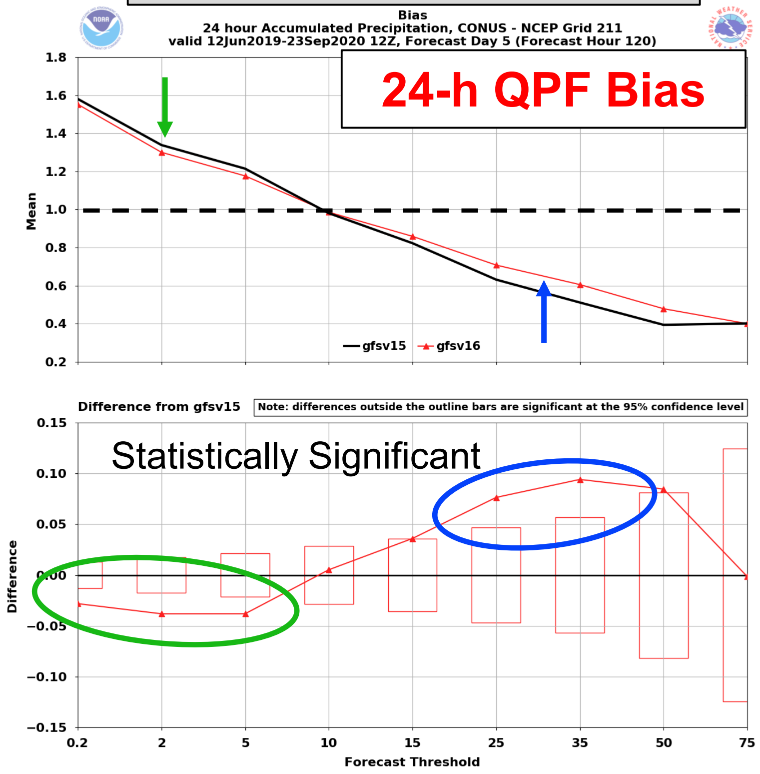


Equitable Threat Score (ETS)

- 24-h QPF improvements appear most pronounced in the medium range, which is consistent w/ improved 500-hPa AC scores
  - **F120:** Statistically significant improvement at 0.2–35 mm thresholds

Strengths: Improved QPF ETS and Bias

Valid: 6/12/19–9/23/20 (F120)



Bias

- 24-h QPF bias improvements also most pronounced in the medium range
- Reduction of the high bias at lower QPF thresholds is statistically significant
- Reduction of the low bias at medium-to-high QPF thresholds is statistically significant
- Overall bias improvement is seen in the short range as well

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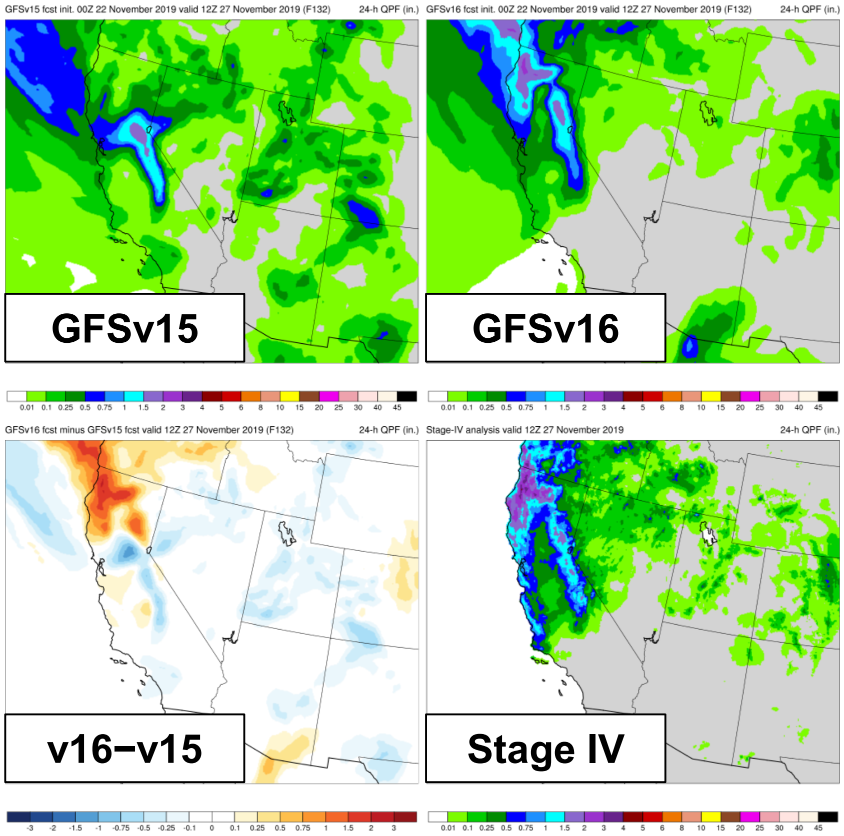
Strengths: Improved QPF ETS and Bias



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

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

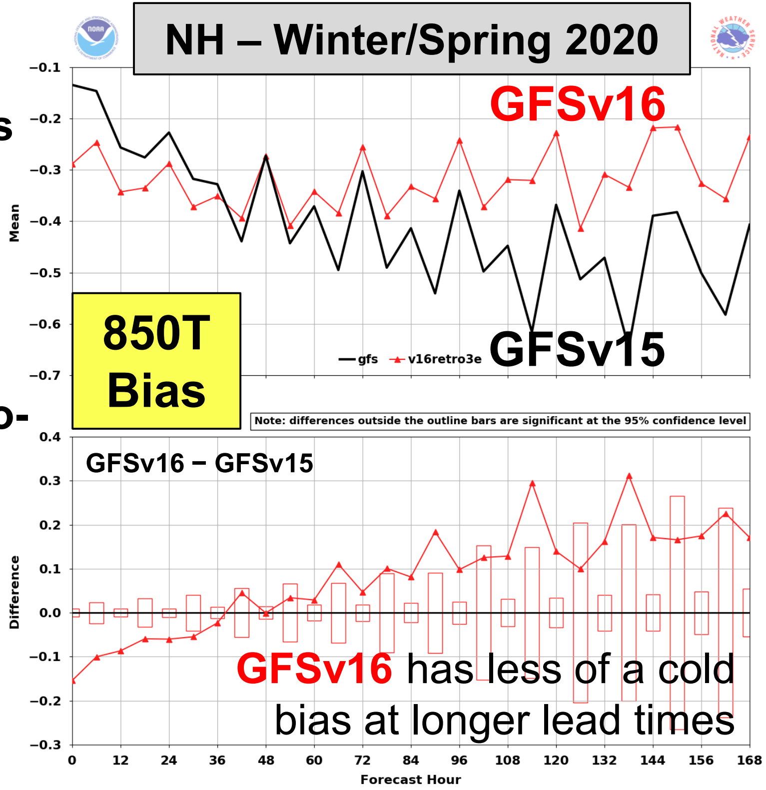
- Improvements to TC intensity and increased lead time for genesis
  - With stronger TCs, GFSv16 has overall better track, size, and intensity

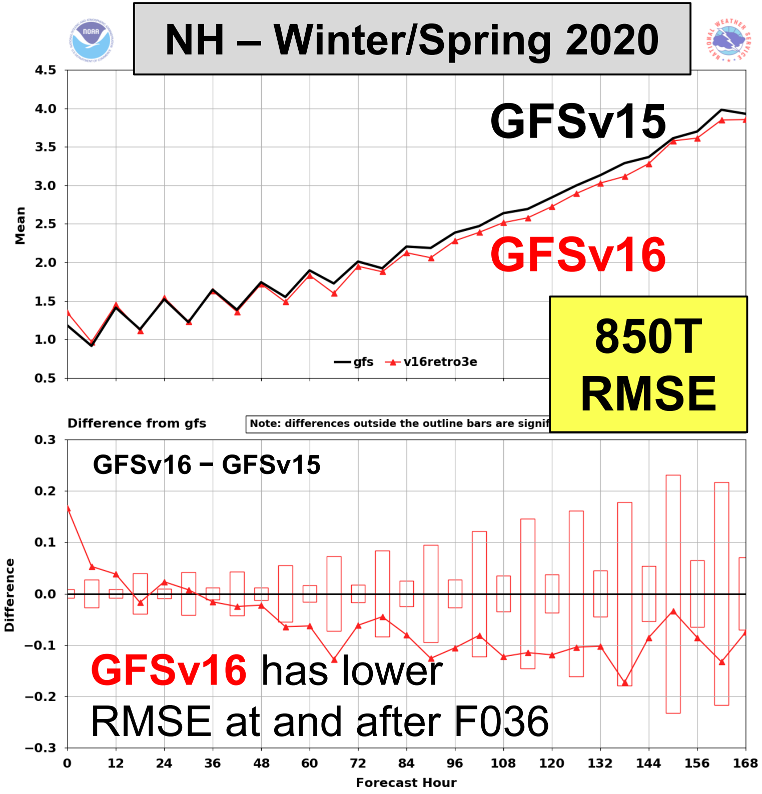
Strengths: Mitigated Low-Level Cold Bias

GFSv15 has a known <u>low-level cold bias</u> that gets worse with lead time

00Z cycles

Grid-to-Obs



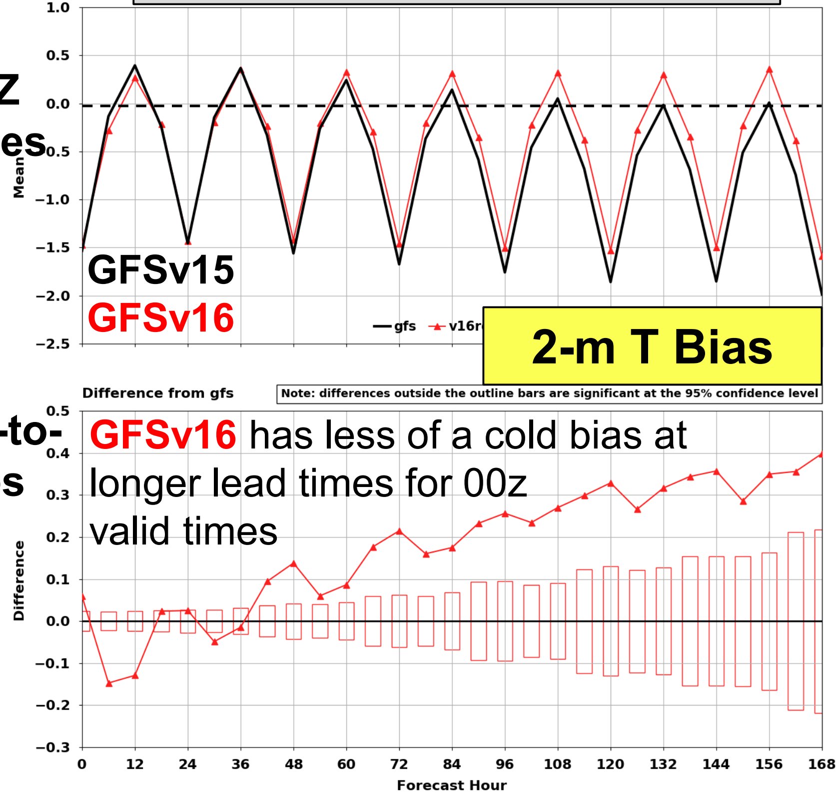


Strengths: Mitigated Low-Level Cold Bias

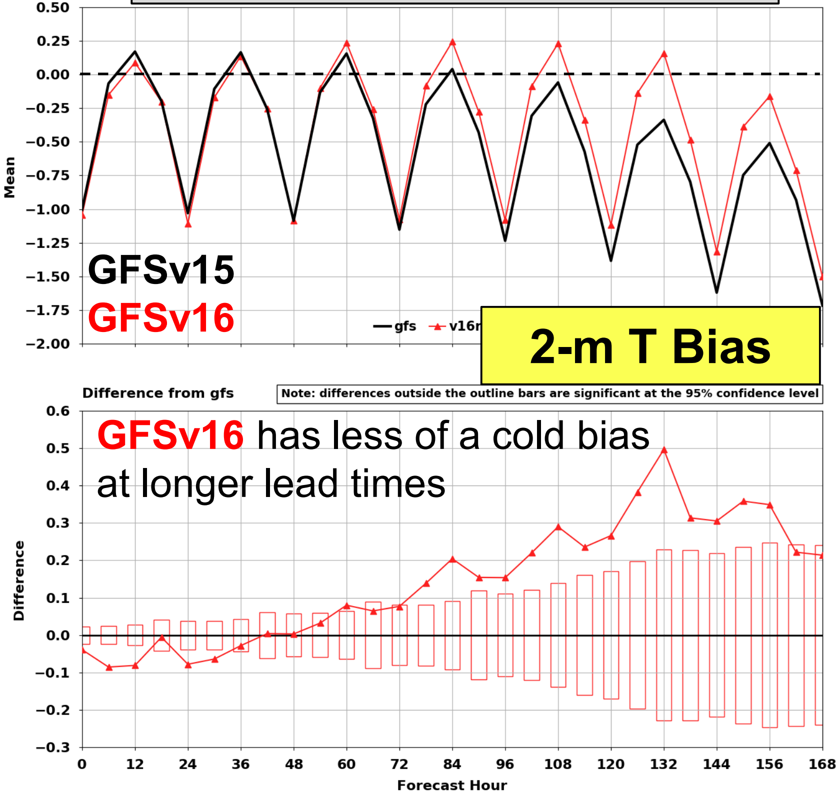
Western US – Winter/Spr. 2020

00Z cycles

Grid-to-Obs



Eastern US – Winter/Spr. 2020



Common Strengths From All Evaluations

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  - Progressive bias in GFSv15 appears mitigated with better consistency, catching correct solutions earlier
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  - With stronger TCs, GFSv16 has overall better track, size, and intensity

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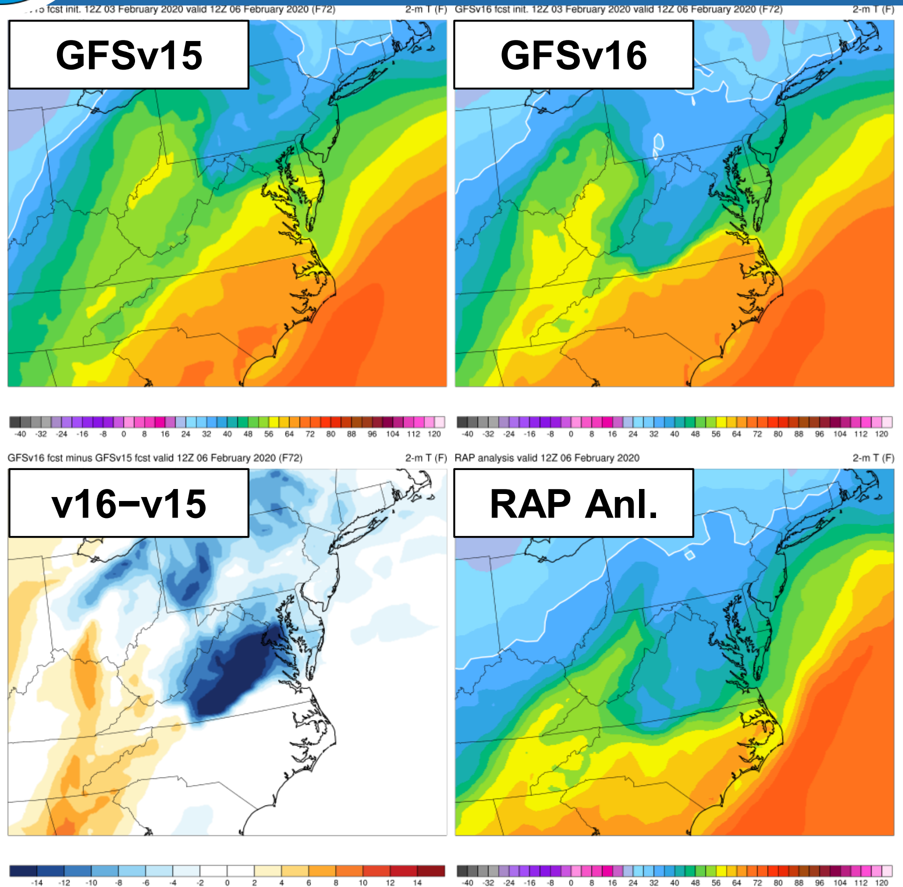
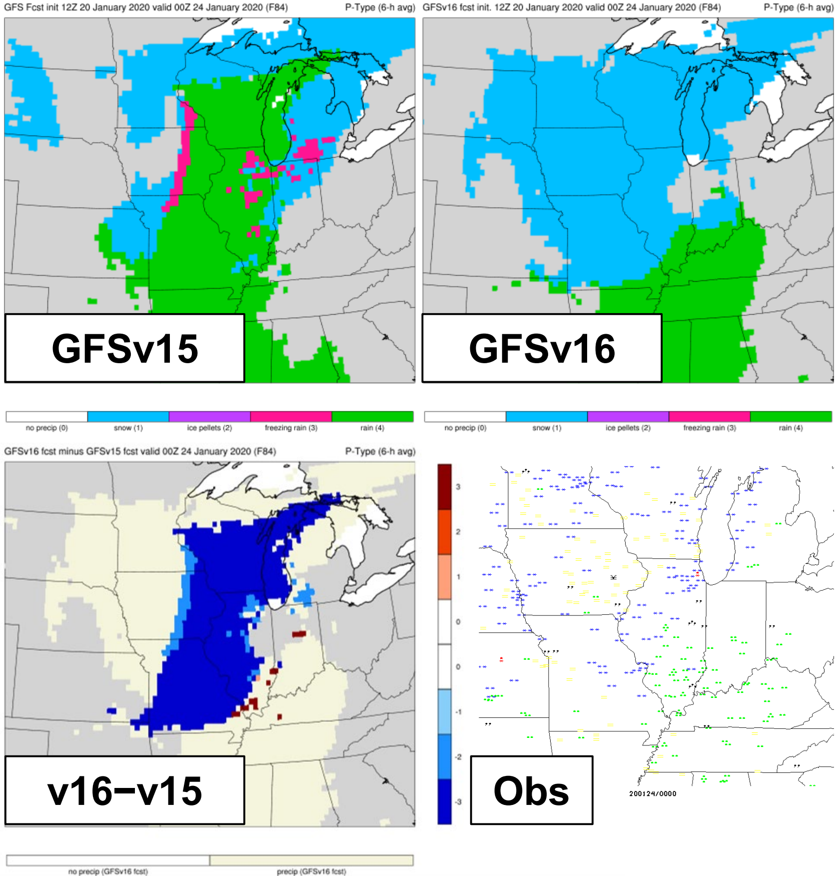
Strengths: Temps in Shallow, Cold Air Masses



Mid-Atlantic Severe Case
Fcst: 12z 02/03/20 (F072)
Valid: 12Z 02/06/20

- GFSv16 was correctly colder than GFSv15 over VA/MD area, where cold air damming is occurring along the eastern Appalachians
- Improved 2-m T forecasts in shallow, cold air masses may be tied to a better handling of low-level clouds
- This is a long-standing GFS issue for which there seems to be some v16 improvement

Strengths: Resolved Low-level Warming Issue



Midwest Ptype Event
Fcst: 12z 01/20/20 (F084)
Valid: 00Z 01/24/20

- An odd GFSv15 low-level warming issue that was seen a few cases last winter in GFSv15 appears to be resolved in GFSv16. In this example, GFSv15 forecasts rain over IA/IL/WI/MO where snow occurred; GFSv16 forecast is much improved

Thanks to Ray Wolf (WFO DVN)

Common Strengths From All Evaluations

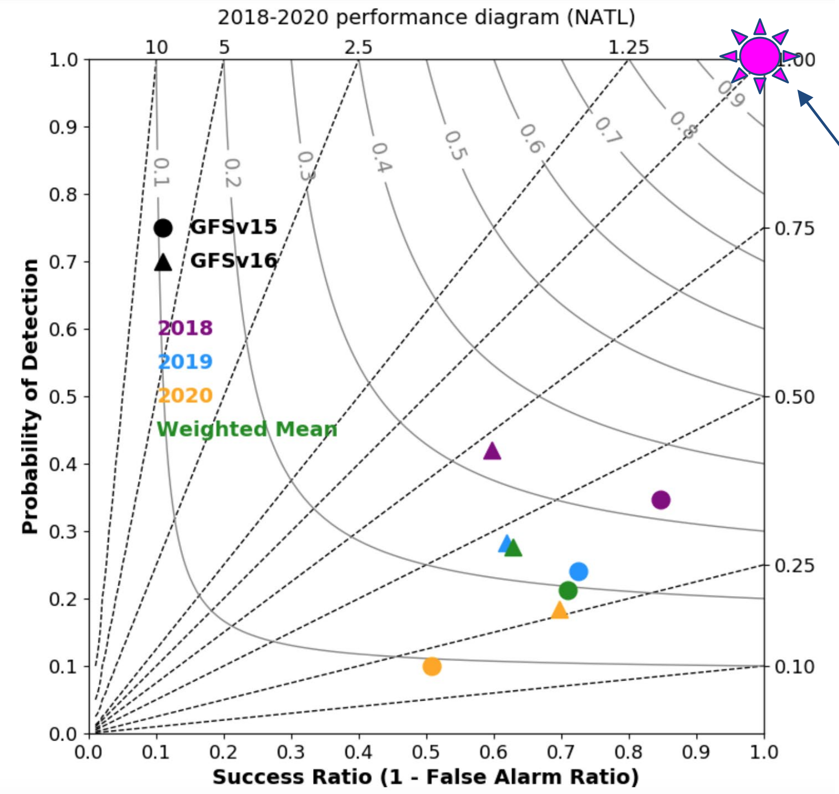
- Notable improvements in synoptic-scale performance in the medium-range
  - Progressive bias in GFSv15 appears mitigated with better consistency catching correct solutions earlier
  - Improved frontal positions and QPF

- 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

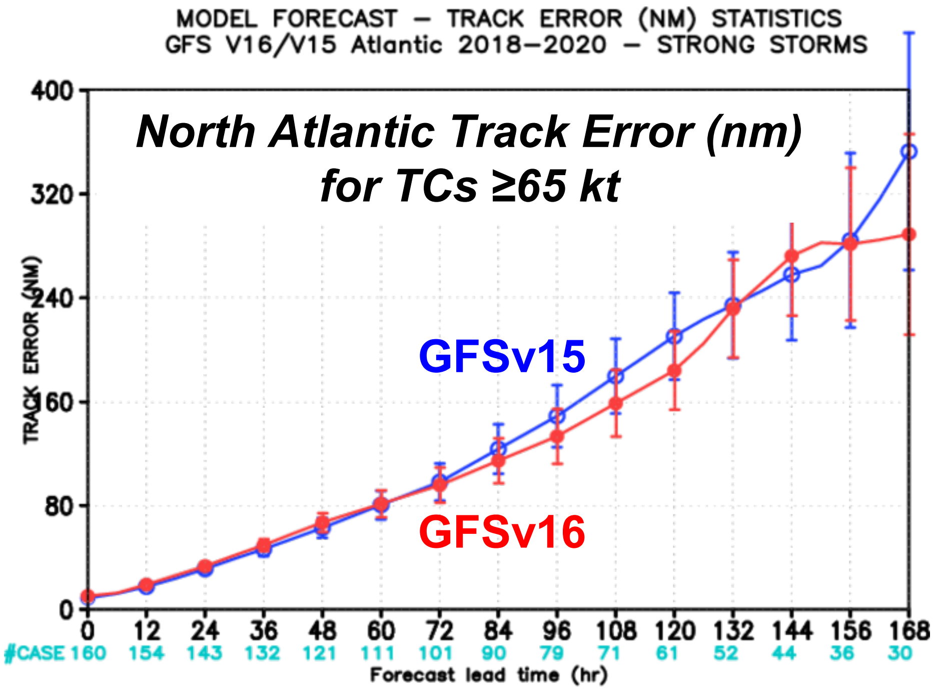
Strengths: Identifies TCs More Often & Earlier

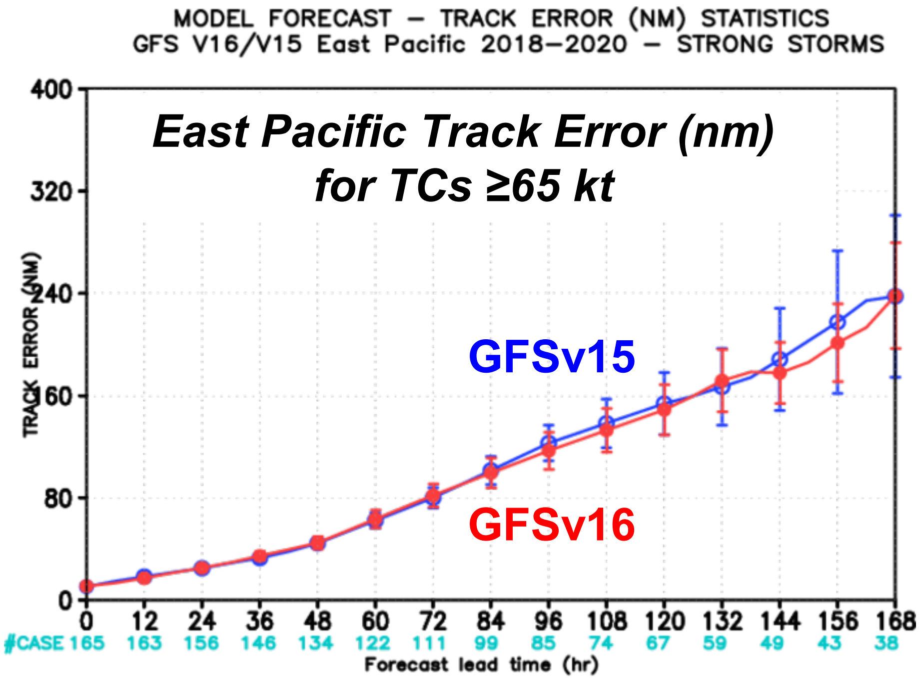


Thanks to Dan Halperin (ERAU)

- **Legend:**
  - x-axis: Success Ratio (1−FAR)
  - y-axis: Probability Of Detection (POD)
  - dashed lines: Frequency Bias
  - solid lines: Critical Success Index (CSI)
- All values would equal 1 in a perfectly performing model
- On average, GFSv16 exhibits:
  - Larger POD and CSI (closer to 1)
  - Frequency Bias is closer to 1
  - Smaller Success Ratio (FAR too high)
- GFSv16 is more cyclogenetic than GFSv15, and it identifies genesis with more lead time

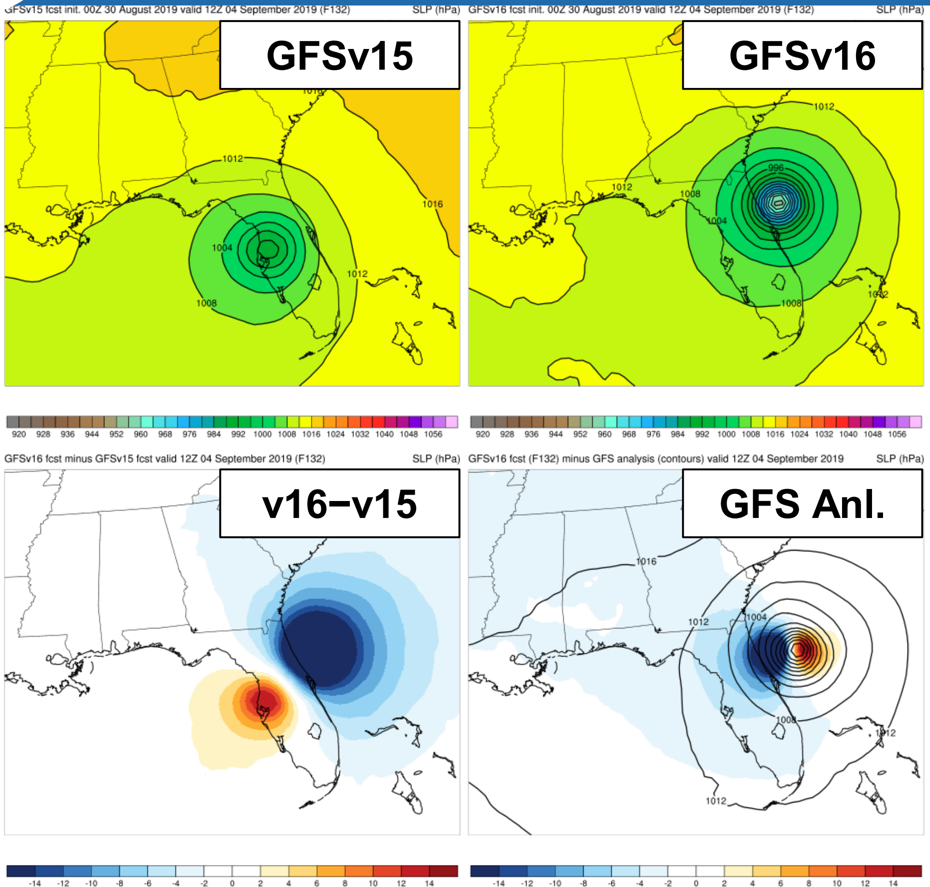
Strengths: Improved Medium-Range Track Error





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

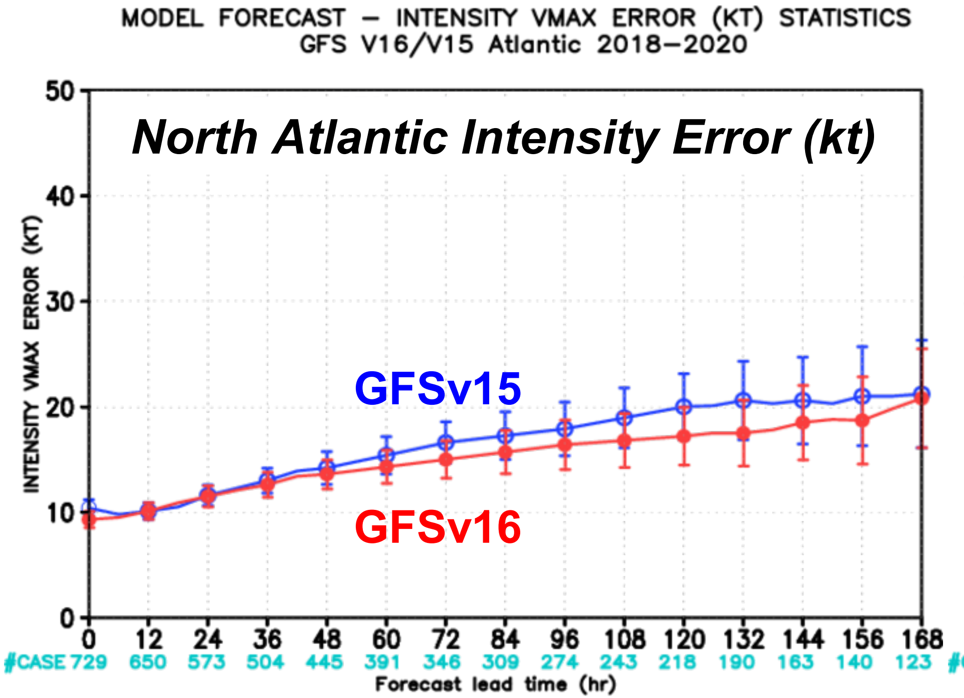
Strengths: Improved Medium-Range Track Error

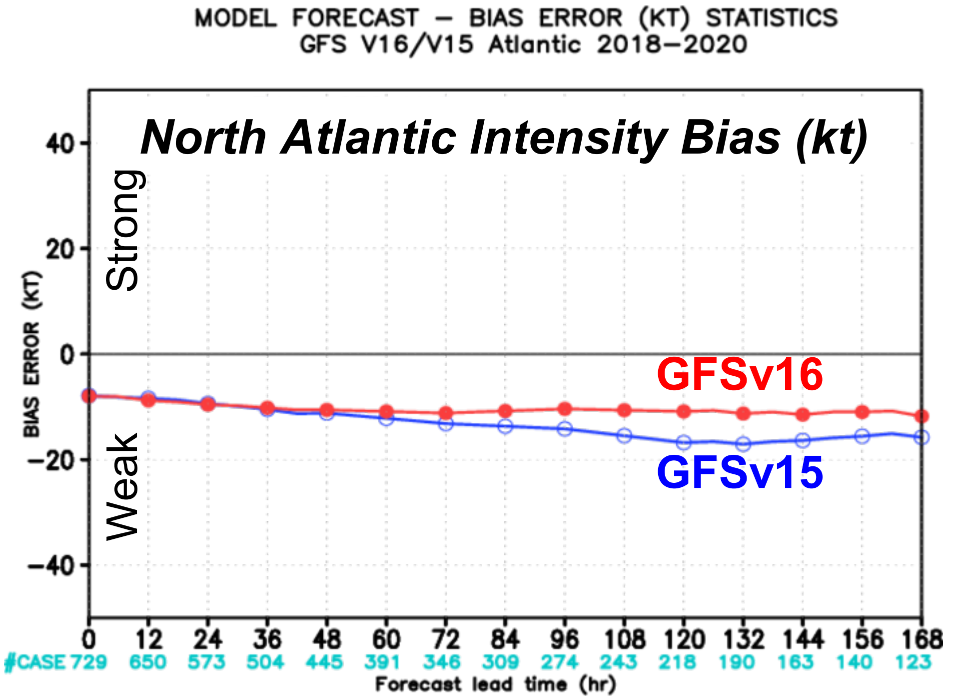


TC Dorian
Fcst: 00z 08/30/19 (F132)
Valid: 12Z 09/04/19

- GFSv16 forecasted Dorian to track north of Puerto Rico more than 24 h earlier than GFSv15 (not shown)
- Shown here, GFSv16 forecasted Dorian to turn right and skim the Florida coast 36 h earlier than GFSv15

Strengths: Improved TC Intensity in N Atlantic

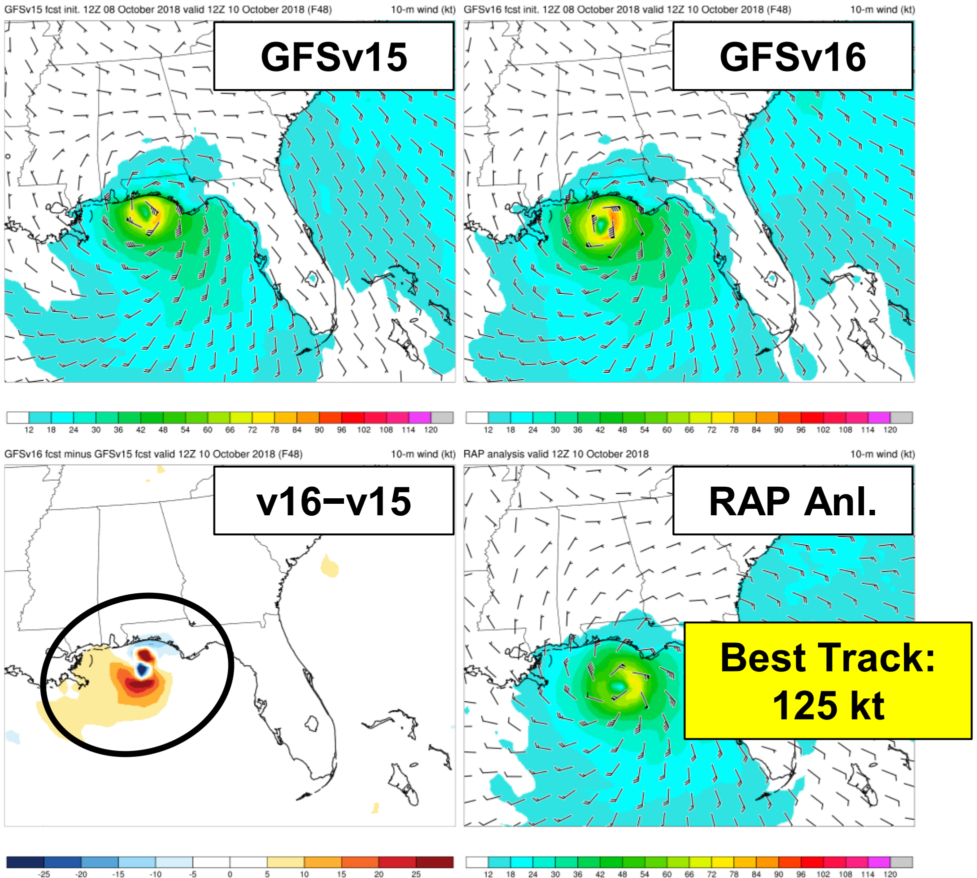




GFSv16 has lower intensity error than **GFSv15** at almost all lead times in the N Atlantic

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

Strengths: Improved TC Intensity in N Atlantic



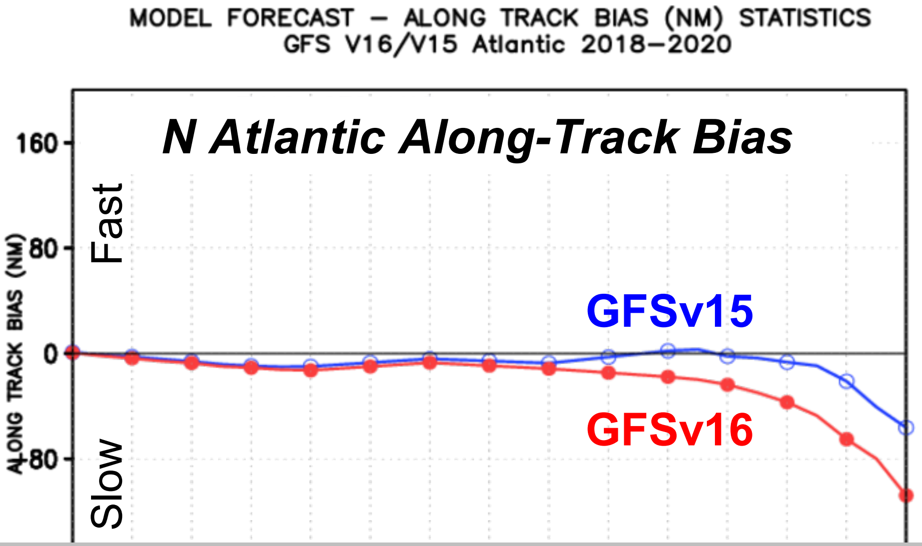
TC Michael
Fcst: 12z 10/08/18 (F048)
Valid: 12Z 10/10/18

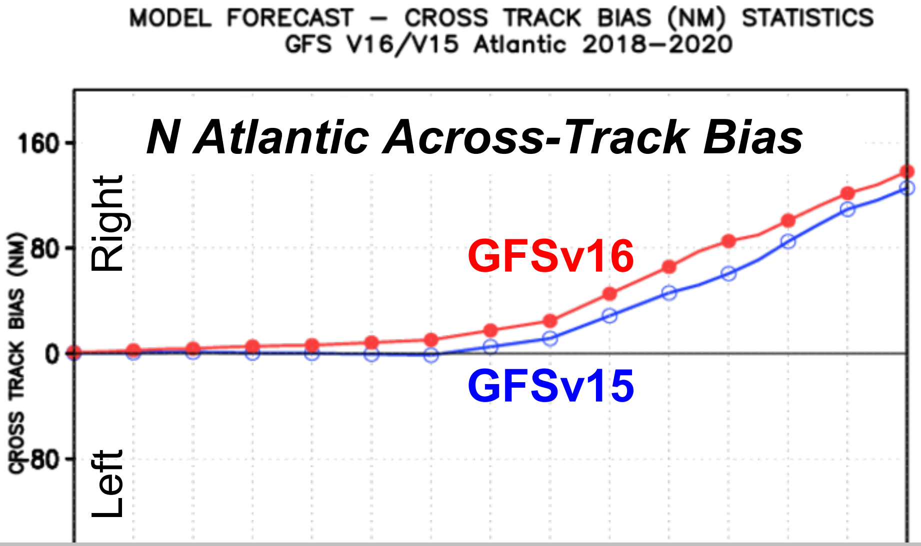
- **Michael:** GFSv16 consistently (and correctly) forecasted a stronger TC than GFSv15

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

Concerns: Increased Right-of-Track Bias





A slower and right-of-track bias at longer lead times suggests that GFSv16 may be recurving TCs earlier than GFSv15

GFSv16 has a larger slow bias than **GFSv15** that grows with forecast length in the N Atlantic

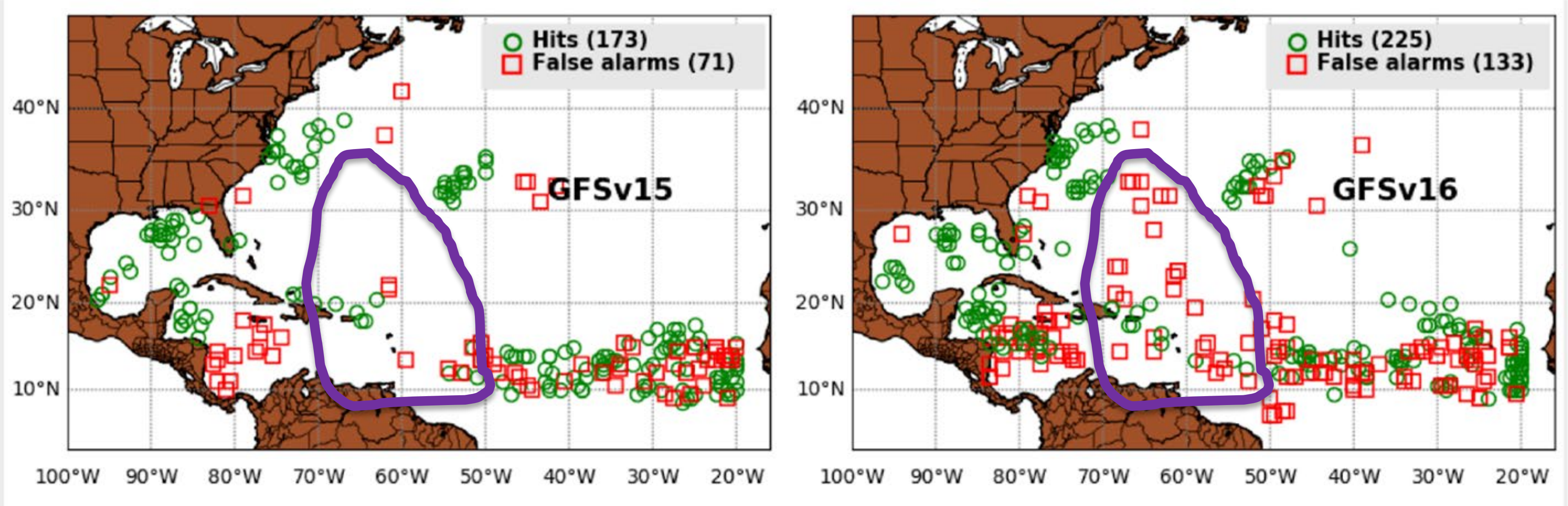
GFSv16 has a larger right-of-track bias than **GFSv15** that is largest at longer lead times

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

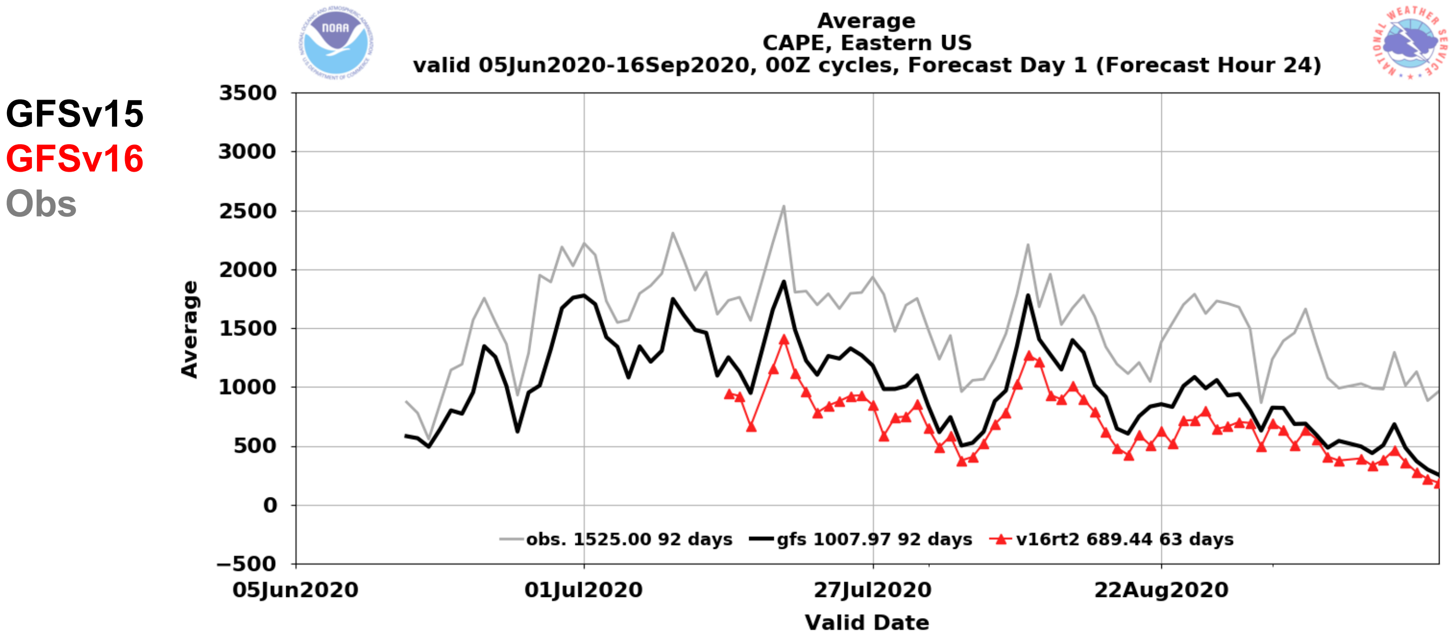


Large number of false alarms in GFSv16, relative to v15, between 50º and 70º W

Common Concerns Across the Evaluations

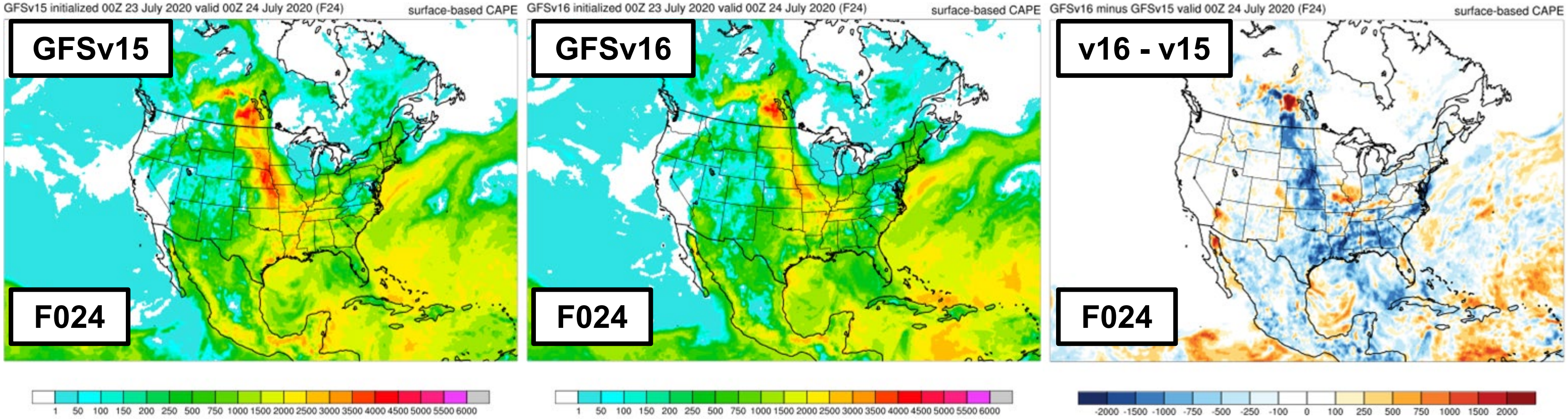
- Increased right-of-track bias at longer lead times for North Atlantic TCs
- Larger TC False Alarm Rate (FAR) in the western North Atlantic (70°W–50°W)
- Worsened low instability (i.e., CAPE) bias that already existed in GFSv15
- Lack of considerable improvement in forecasting radiation inversions

CAPE Magnitudes Are Reduced in GFSv16



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

CAPE Magnitudes Are Reduced in GFSv16



Surface-Based CAPE Forecasts (left and middle) and Forecast Differences (right)
Init: 00Z 07/23/20 Valid: 00Z 07/24/20 (F024)

- GFSv16 CAPE was notably lower across the Northern and Central Plains, as well as over the Gulf Coast region and southeast; smaller reductions over the northeast, Ohio Valley, and Mexico

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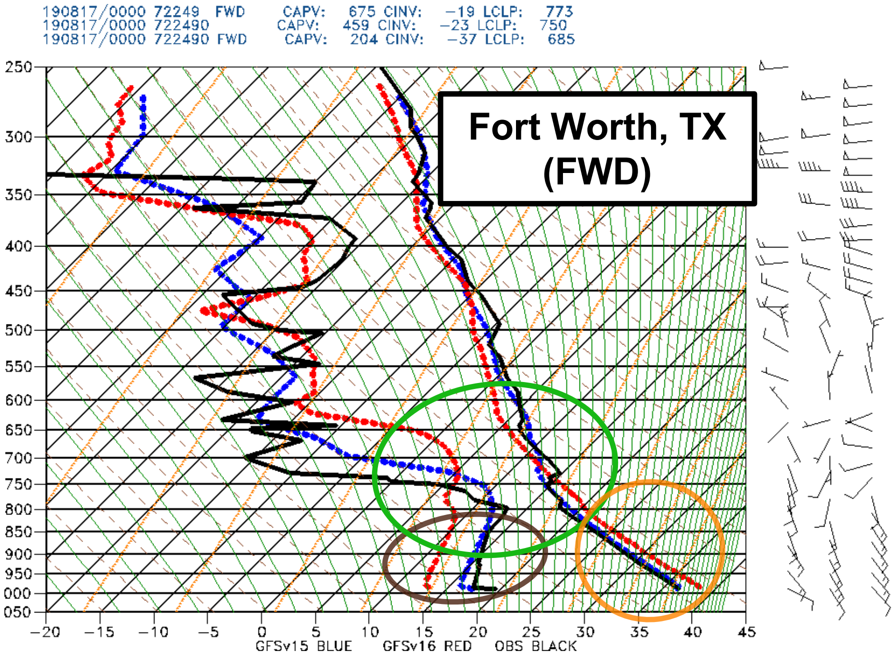
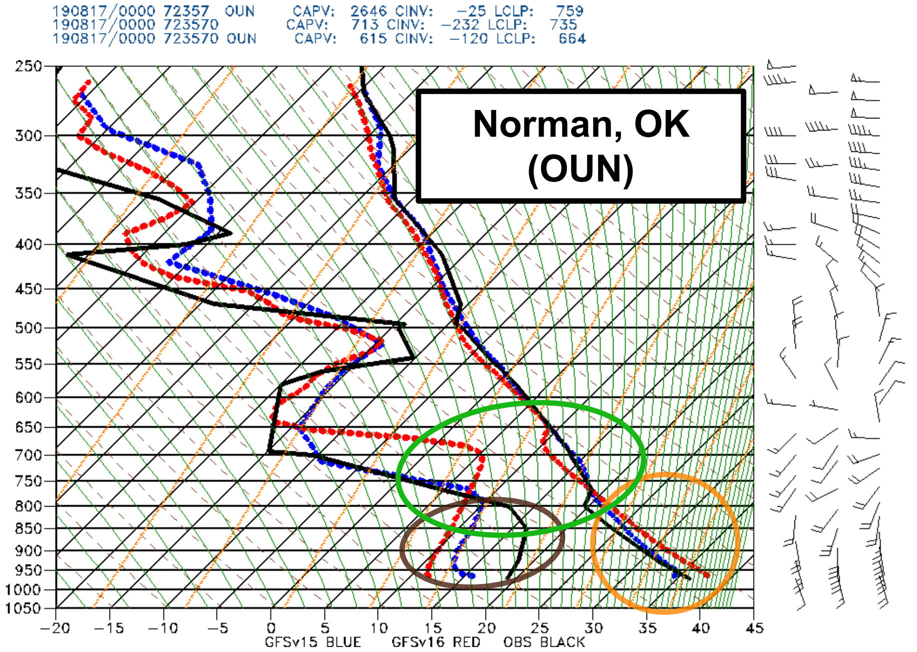
Tendency to Overmix the Boundary Layer

GFSv15 **GFSv16** **Obs**





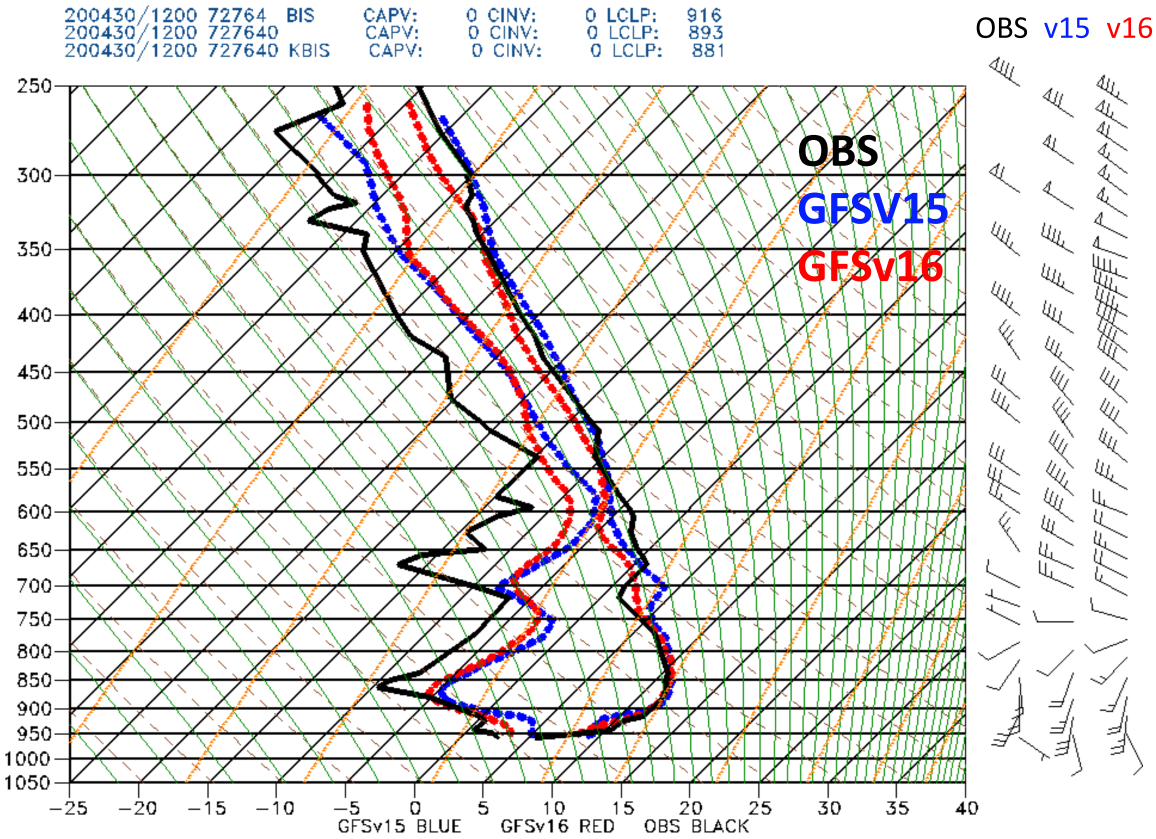
Init: 12Z 08/16/20 **Valid: 00Z 08/17/20 (F012)**

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

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

Inversions - BIS soundings



Bismarck, ND (BIS)

Fcst: 12Z 04/29/20 (F024)
Valid: 12Z 04/30/20

- GFSv15 and v16 both fail to capture the strength of the low-level inversion and end up way too warm at the lowest levels
- GFSv16 shows very modest improvement over v15
- Note how the observed winds are weak at the lowest level; both GFS versions have winds that are too strong

Summary of GFSv16 Objectives

- **Science Changes**: Increase the vertical resolution (from 64 to 127 levels), implementation of advanced physics; Advanced 4D-IAU data assimilation with LETKF, new Variational QC and use of additional satellite and aircraft (HDOBS) data; One-way coupling to deterministic Global Wave Model (WaveWatch III) within the UFS framework towards simplifying the production suite.

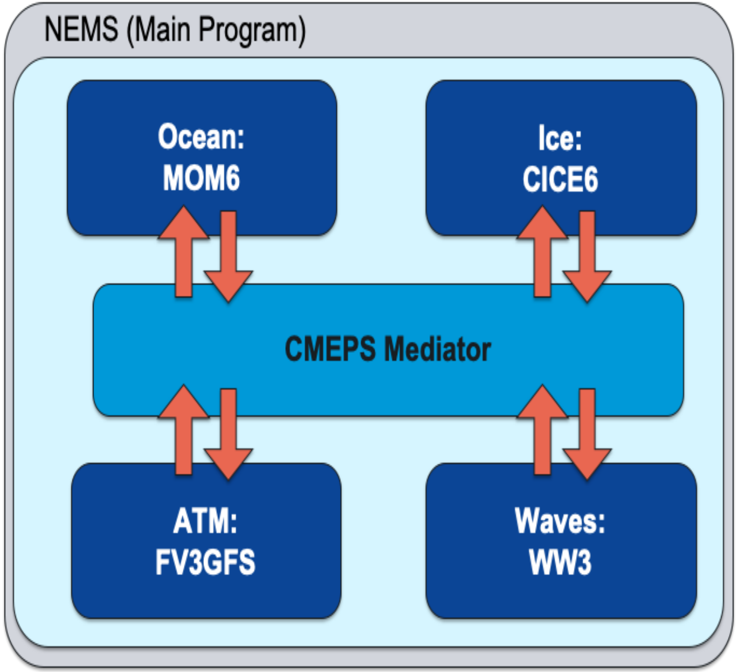
- **Performance Evaluation**
  - Excessive cold bias in the winter season – **mitigated**
  - Progressive bias for synoptic scale systems - **improved**
  - Less skillful TC track forecasts, especially for stronger storms - **improved, especially with HDOBS assimilation**
  - Low bias for stratospheric temperature forecasts - **improved**
  - Precipitation dry bias for moderate rainfall - **improved**
  - Poor representation of boundary layer inversions **–** ***Not much improvement.***

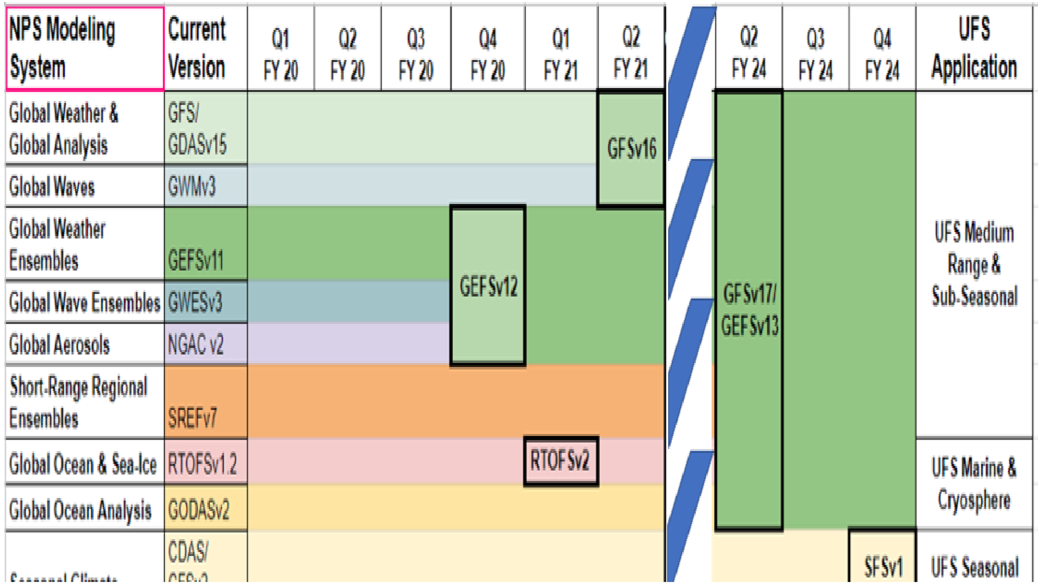
GFSv16 Development and T2O Timeline

- 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)**

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

thanks you