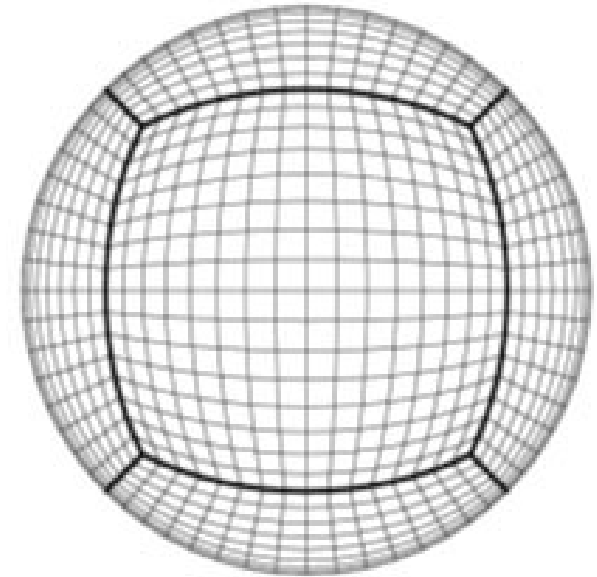
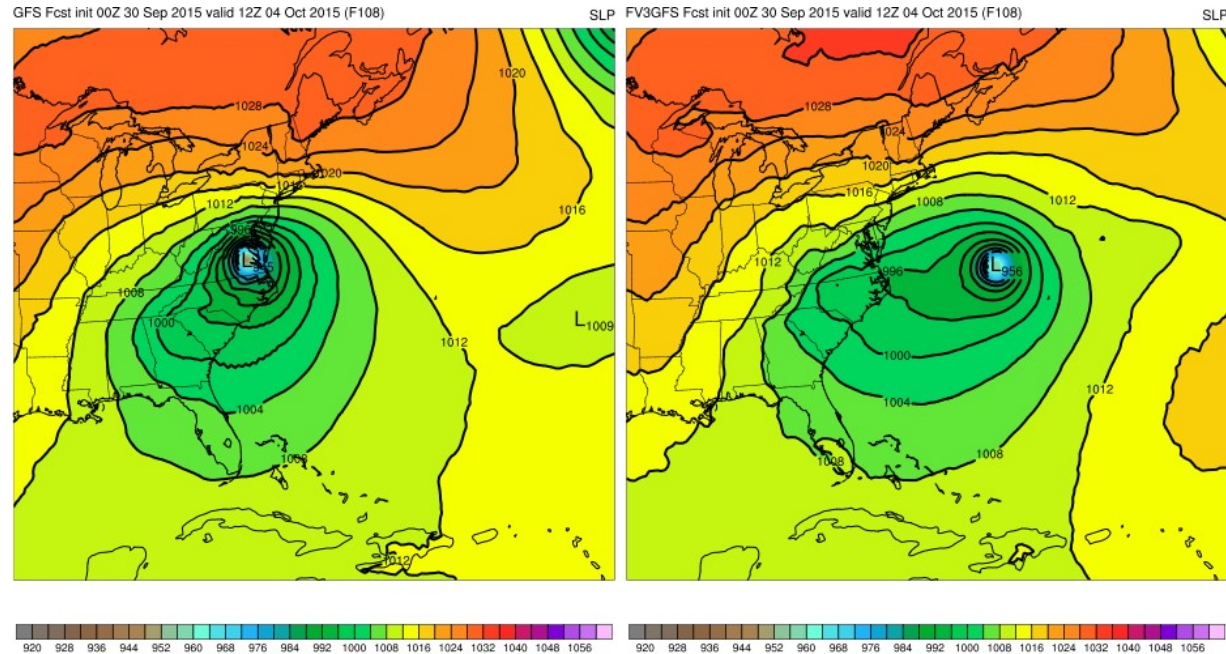
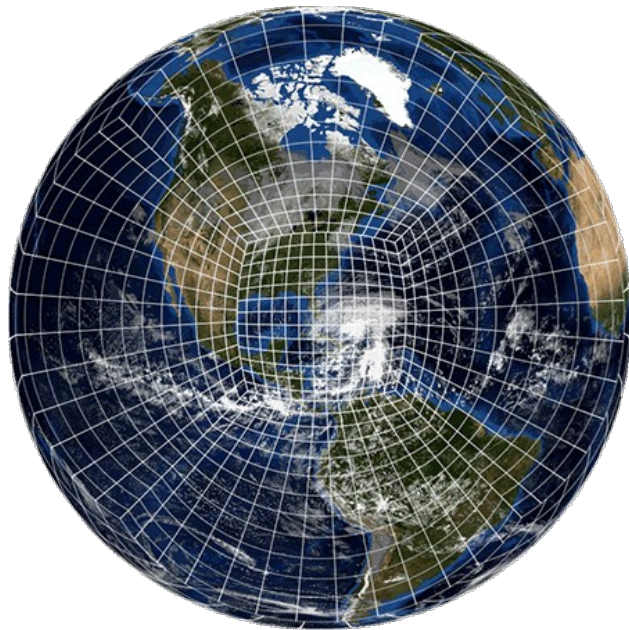


# THE IMPLEMENTATION of GFSv15



**Geoff Manikin, Alicia Bentley, Logan Dawson, Tracey Dorian**  
NCEP/EMC Model Evaluation Group  
13 June 2019

# Official Evaluation Website

<http://www.emc.ncep.noaa.gov/users/meg/fv3gfs>

## TIMELINE

FV3GFS Code Frozen	Parallel Runs Begin	Evaluation Period (Start - End)	Recommendations from Field Due	NCEP Director Briefing	Code Handoff to NCO	IT Test Period (Start - End)	Implementation Date
3/7/18	4/1/18	5/25/18 - 9/10/18	9/24/18	10/1/18	4/5/19	5/3/19 - 6/1/19	6/12/19

## SUMMARY

[FV3GFS MEG Evaluation Summary](#) - Presented by Geoff Manikin (9/20/18 MEG Meeting)  
[NCEP/EMC CCB Presentation](#) - Presented by Fanglin Yang (9/24/18 CCB Meeting)  
[FV3GFS NOAA/NWS Evaluation Summary](#) - Presented by Logan Dawson (9/27/18 MEG Meeting)

## INFORMATION

[FV3 Dynamical Core Information](#) - Developed by GFDL  
[FV3GFS Evaluation Overview](#) - Presented by Geoff Manikin (5/3/18 MEG Meeting)  
[FV3GFS SST Issue and Fix](#) - Presented by Geoff Manikin (5/24/18 MEG Meeting)  
[FV3GFS Soil Moisture, Reflectivity, Visibility](#) - Presented by Geoff Manikin (5/31/18 MEG Meeting)  
[FV3GFS Statistical Update](#) - Presented by Logan Dawson (6/14/18 MEG Meeting)  
[FV3GFS Inst. Precip. Rate, Reflectivity, Visibility](#) - Presented by Alicia Bentley/Logan Dawson (6/28/18 MEG Meeting)  
[MEG Evaluation of FV3GFS Retrospectives](#) - Presented by Logan Dawson (7/19/18 MEG Meeting)  
[FV3GFS Statistical Update](#) - Presented by Alicia Bentley (8/9/18 MEG Meeting)  
[FV3GFS East Coast Winter Storm Retrospectives](#) - Presented by Tracey Dorian/Alicia Bentley/Logan Dawson (8/16/18 MEG Meeting)  
[FV3GFS Tropical Cyclone Status Update](#) - Presented by Vijay Tallapragada (8/16/18 NHC Briefing)  
[FV3GFS North Atlantic/East Pacific TC Retrospectives](#) - Presented by Geoff Manikin (8/23/18 MEG Meeting)  
[FV3GFS Western U.S. Retrospectives](#) - Presented by Alicia Bentley (9/6/18 MEG Meeting)  
[FV3GFS Alaskan Retrospectives](#) - Presented by Tracey Dorian (9/6/18 MEG Meeting)  
[FV3GFS Cold SST Concerns \(e.g., Alaska's Cook Inlet\)](#) - Presented by Logan Dawson (9/6/18 MEG Meeting)  
[FV3GFS Products Update](#) - Presented by Logan Dawson (9/13/18 MEG Meeting)  
[FV3GFS QPF Statistics](#) - Presented by Tracey Dorian (9/13/18 MEG Meeting)  
[FV3GFS QPF Retrospectives](#) - Presented by Alicia Bentley (9/13/18 MEG Meeting)  
[FV3GFS Snowfall Totals and Cold Bias](#) - Presented by Geoff Manikin (2/21/19 MEG Meeting)  
[FV3GFS Snowfall Totals and Cold Bias Update](#) - Presented by Logan Dawson (3/7/19 MEG Meeting)  
[FV3GFS Snowfall Totals, Cold Bias, and Implementation Update](#) - Presented by Alicia Bentley (4/4/19 MEG Meeting)

## DATA

[FV3GFS Data](#) - Available on Para NOMADS  
[List of New Output Parameters](#) - Maintained by Hui-ya Chuang

## REAL-TIME GRAPHICS/OUTPUT

[FV3GFS Analyses and Guidance \(Note: GFS = FV3GFS\)](#) - Maintained by NCEP/NCO  
[GFS vs. FV3GFS Forecast Comparisons](#) - Maintained by Geoff Manikin  
[GFS vs. FV3GFS Plume Comparisons](#) - Maintained by Tracey Dorian  
[GFS vs. FV3GFS Sounding Comparisons](#) - Maintained by Tracey Dorian  
[NAM vs. FV3GFS vs. GFS Comparisons](#) - Maintained by Eric Rogers  
[FV3GFS vs. GFS MOS Comparisons](#) - Maintained by NOAA/NWS/MDL

## VERIFICATION

[NCEP/EMC Model Evaluation Group \(MEG\)](#) - Maintained by Geoff Manikin  
[NCEP/EMC MEG Past Presentations](#) - Available to NOAA email addresses only  
[NCEP/EMC QPF Verification Scores for FV3GFS Runs](#) - Maintained by Ying Lin  
[NCEP/EMC Daily Precipitation Verification \(FV3GFS included\)](#) - Maintained by Ying Lin  
[NCEP/EMC Fit-to-Observations \(Fit2Obs\) for FV3GFS](#) - Maintained by Suranjana Saha and Jack Woollen

[NCEP/EMC Global Model Experimental Forecast Performance Statistics \(Real-time Parallel\)](#) - Maintained by FV3GFS Parallel Execution Group  
[Retrospective Forecast Performance Statistics \[Full Period \(June 2015-September 2018\)\]](#)  
[Retrospective Forecast Performance Statistics \[December 2017-May 2018\]](#)  
[Retrospective Forecast Performance Statistics \[May 2017-November 2017\]](#)  
[Retrospective Forecast Performance Statistics \[December 2016-May 2017\]](#)  
[Retrospective Forecast Performance Statistics \[May 2016-November 2016\]](#)  
[Retrospective Forecast Performance Statistics \[December 2015-May 2016\]](#)  
[Retrospective Forecast Performance Statistics \[May 2015-November 2015\]](#)

## RETROSPECTIVES

[FV3GFS Retrospective Case Studies](#) - Images by NCEP/EMC MEG  
[MEG Evaluation of FV3GFS Retrospectives](#) - Presented by Logan Dawson (7/19/18 MEG Meeting)  
[FV3GFS East Coast Winter Storm Retrospectives](#) - Presented by Tracey Dorian/Alicia Bentley/Logan Dawson (8/16/18 MEG Meeting)  
[FV3GFS North Atlantic/East Pacific TC Retrospectives](#) - Presented by Geoff Manikin (8/23/18 MEG Meeting)  
[FV3GFS Western U.S. Retrospectives](#) - Presented by Alicia Bentley (9/6/18 MEG Meeting)  
[FV3GFS Alaskan Retrospectives](#) - Presented by Tracey Dorian (9/6/18 MEG Meeting)  
[FV3GFS QPF Retrospectives](#) - Presented by Alicia Bentley (9/13/18 MEG Meeting)

## FEEDBACK

[VLAB - FV3 Evaluation Forum](#) - Monitored by NCEP/EMC MEG

Update:

1. If you email [FV3GFS-Feedback.VLab@noaa.gov](mailto:FV3GFS-Feedback.VLab@noaa.gov), a post will appear in the forum and forum subscribers will get an email from [vlab.notifications@noaa.gov](mailto:vlab.notifications@noaa.gov).
  2. If you reply to the email from [vlab.notifications@noaa.gov](mailto:vlab.notifications@noaa.gov), forum subscribers will get an email and your response will appear in the forum.
- Non-VLab members who email the forum will be identified as "Anonymous". If you write to the forum as a non-VLab member, please identify yourself in your email.

# FV3GFS: Infrastructure and Physics Upgrades

- **Integrated FV3 into NEMS**
  - **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**
  - **Remove tropical cyclone vortex relocation**
  - **Revised bare soil evaporation scheme**
  - **Stochastic physics in the data assimilation**
  - **Higher resolution in GDAS (now ~25 km)**
- other minor changes:**
- **correction bugs related to the convective cloud water**
  - **radiation bug fix**
  - **slight modification in scale-aware mass-flux deep or shallow convection schemes**

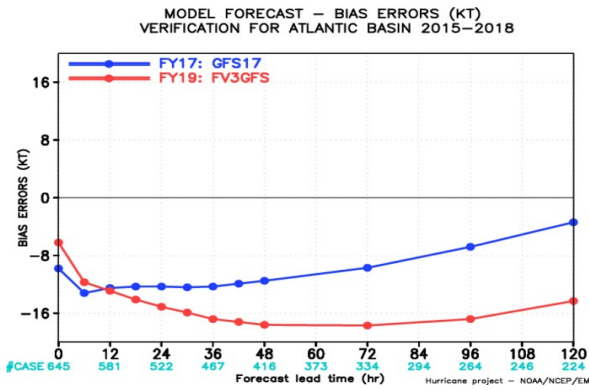
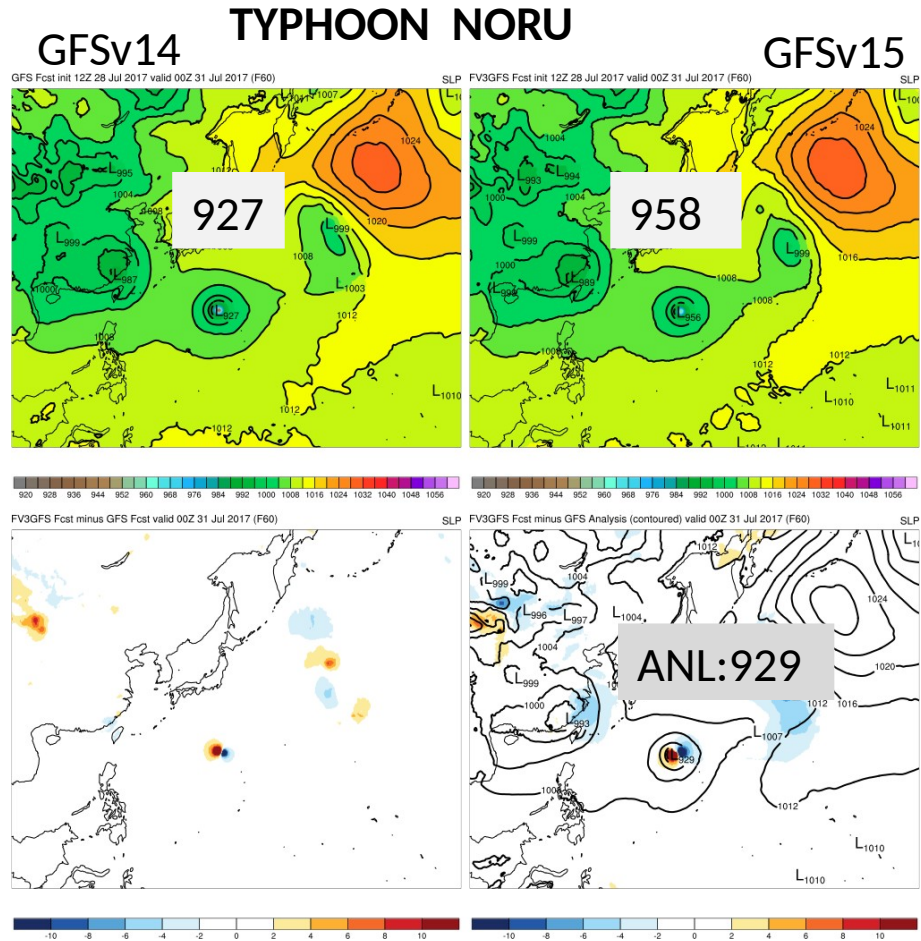
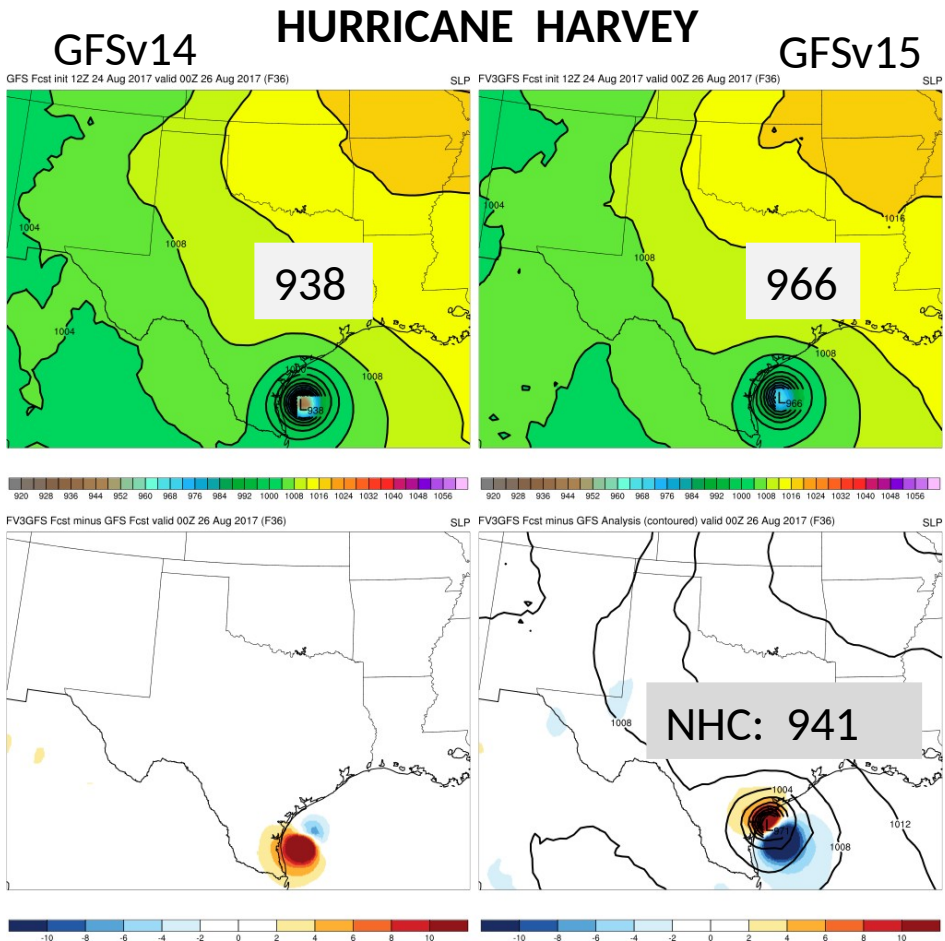
[Service Change Notice](#)

# A Few Key Product Changes

- Non-hydrostatic vertical velocity ( $dz/dt$  in m/s) now available in addition to omega; Omega in gridded output (Pa/s) is now derived using the hydrostatic approximation; VV has now replaced omega in GFS station time series bufr output
- New cloud hydrometeor fields, isobaric (3D cloud fractions), and simulated composite reflectivity now available
- Total and convective accumulated precip now available in addition to 6-hr buckets (although not yet in AWIPS)
- GFS directory structure on NCEP web services now breaks out daily directories by cycle
- 3hrly output now available beyond f240, but there is no decrease in resolution beyond f240 as in GFSv14, so delivery of grids beyond f240 is slower than in GFS v14; f384 delivery time now 20 minutes later than in GFSv14
- GFSv14 still running, with products available in GFS “para” data flow

# A Few Key Model Changes After the Initial Code Freeze

# TROPICAL CYCLONES in the ORIGINAL VERSION of GFSv15 WERE CONSISTENTLY CONSIDERABLY WEAKER THAN IN THE OPS GFS in ALL BASINS



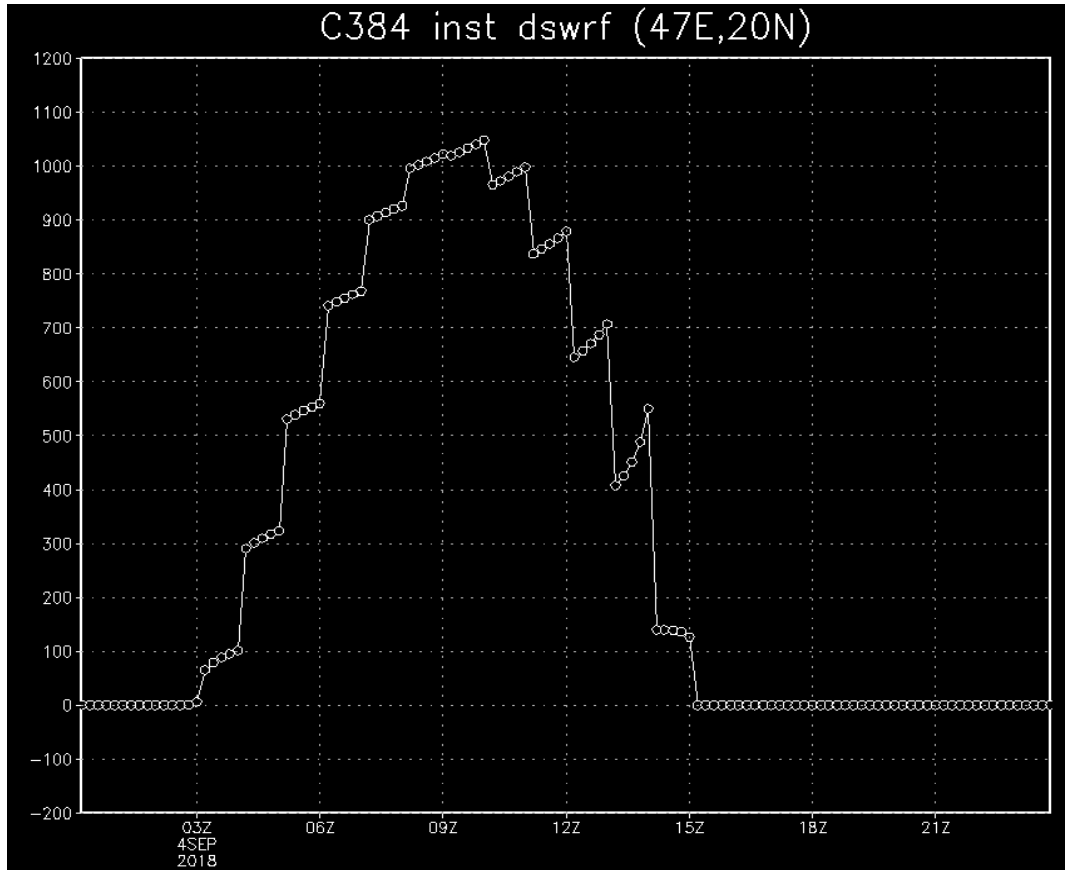
GFDL recommended changing the horizontal advection setting

# JUSTIFICATION FOR HORD=5 CHANGE

- There was a clear improvement with regard to tropical cyclone intensity – almost always yielded a stronger storm than HORD=6 run, and it was usually in the right direction with its forecast of a stronger storm
- Some concern about overdeepening of winter storms but overall impact was far less than on tropical cyclones
- Stats indicated little change on the synoptic scale with this change in any time of year
- NCEP Director Approved changing hord=6 to hord=5 starting with **18Z on August 15, 2018** for real-time parallel

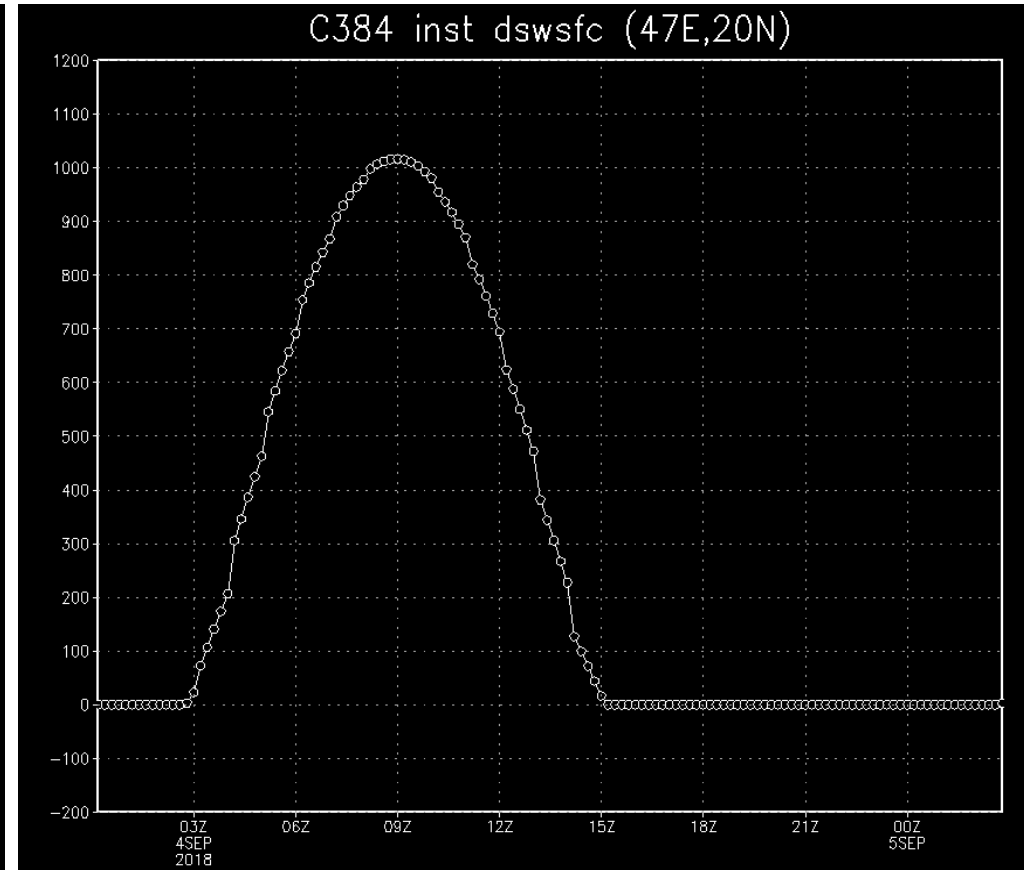
# BUG w DOWNWARD SOLAR RADIATION FOUND AND CORRECTED in FALL 2018

Old version of GFSv15



New version of GFSv15

EXAMPLE from 47E, 20N

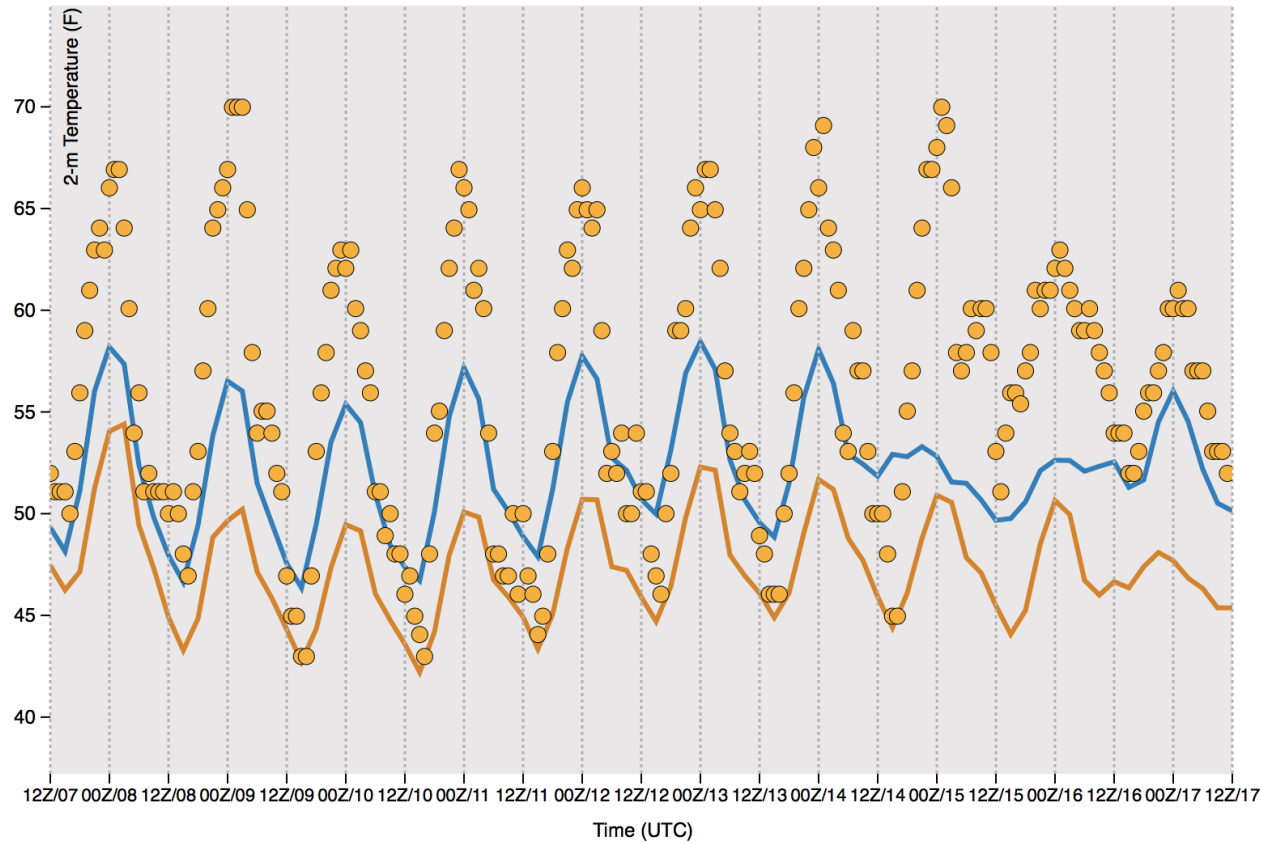


MORE on THIS LATER!

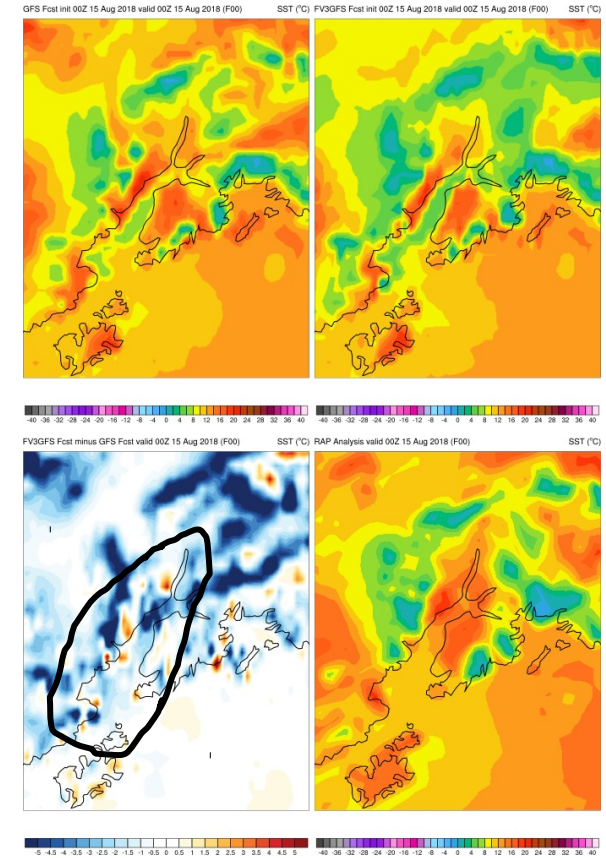


# 2m ALASKA TEMP STATS SHOWED A COLD BIAS in SUMMER 2018, and ANCHORAGE PLUMES CONFIRMED IT

FV3GFS and GFS plumes for: PANC  
12 UTC 07 September 2018 cycle



GFSv14  
GFSv15  
OBS



# CHANGE MADE IN SEPTEMBER 2018 to SST

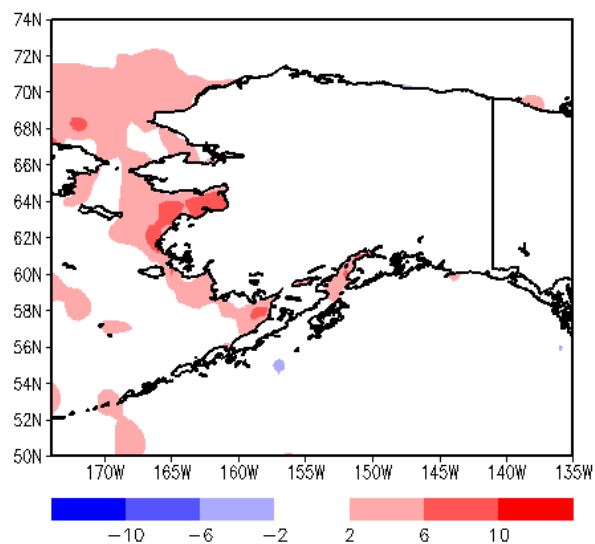
Cycle 2018071600 f24 Valid 2018071700  
Sea Surface Temperatures (°C)

Cycle 2018071600 f24 Valid 2018071700  
2m Temperature [F]

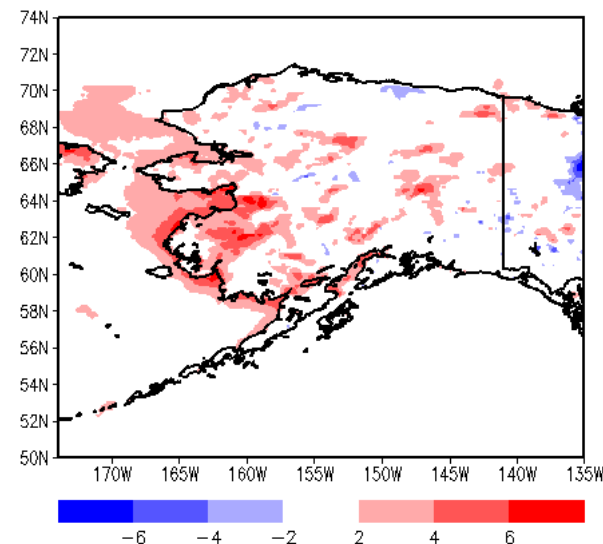
F24 valid 00Z

FV3GFStest-FV3GFSrealtime

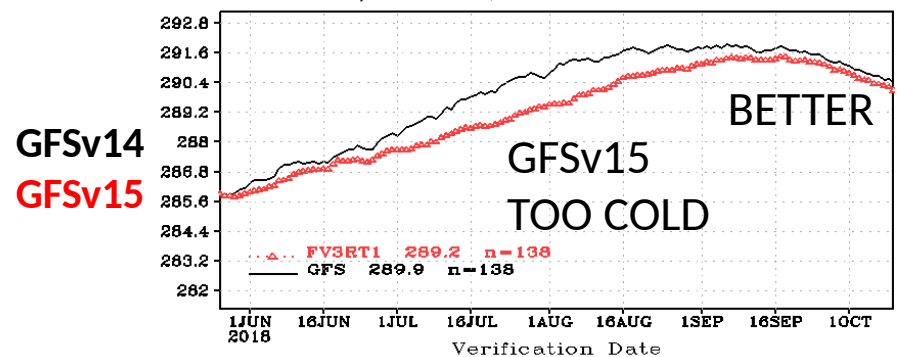
FV3GFStest-FV3GFSrealtime



RED indicates where  
run with new SST  
is warmer



TG G2/NPO 00Z, 20180526-20181010 fh0

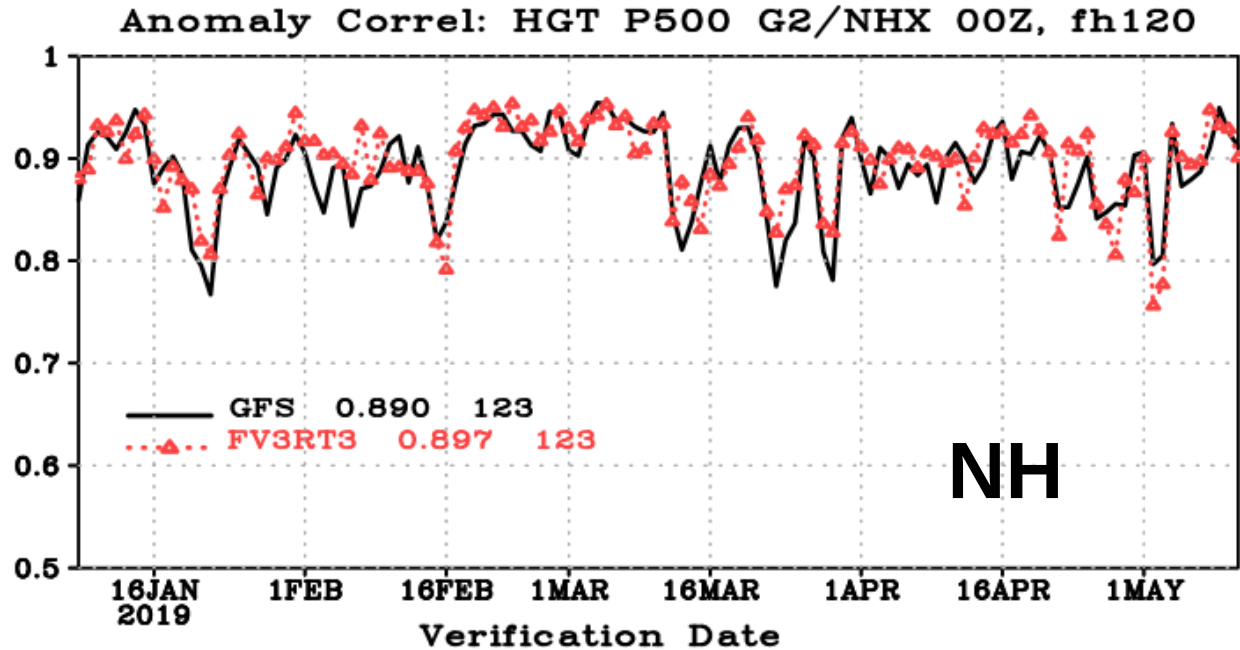


Mean SST in  
North Pacific  
GFSv14 vs v15

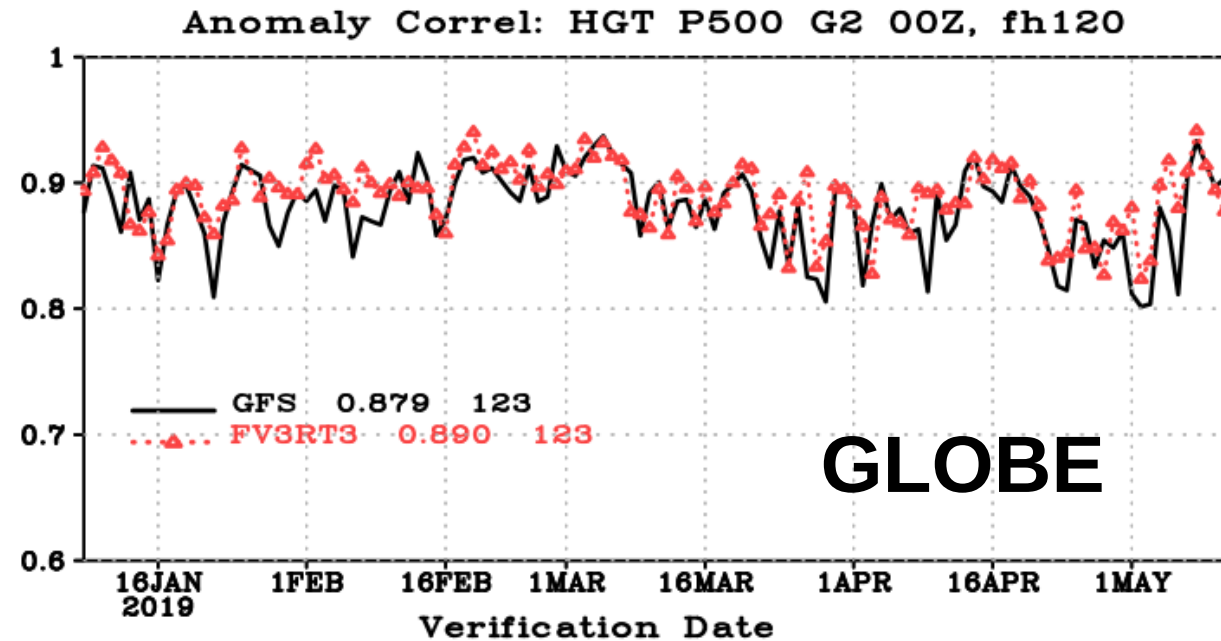
# HIGHLIGHTS OF THE POSITIVES

- 1. 500-MB AC SCORES ARE STATISTICALLY SIGNIFICANTLY BETTER IN GFSv15, AND OTHER SYNOPTIC STATS ARE TYPICALLY AS GOOD AS IN GFSv14, WITH SOME IMPROVEMENT IN DETAILS**
- 2. IMPROVED WARM-SEASON DIURNAL CYCLE OF PRECIPITATION**
- 3. INTENSE TROPICAL DEEPENING NOT SEEN IN GFSv15**
- 4. DOUBLE-LOW CENTERS FOR SINGLE STORM NOT SEEN IN GFSv15 FCTS OR ANL**
- 5. GFSv15 SEEMS TO BE ABLE TO GENERATE MODEST SFC CONVECTIVE COLD POOLS, WITH CORRESPONDING IMPROVEMENT IN WARM SEASON QPF**
- 6. NEW SIMULATED COMPOSITE REFLECTIVITY PARAMETER IS AVAILABLE**

# DAY 5: 500-mb AC SCORES FOR THIS PAST WINTER

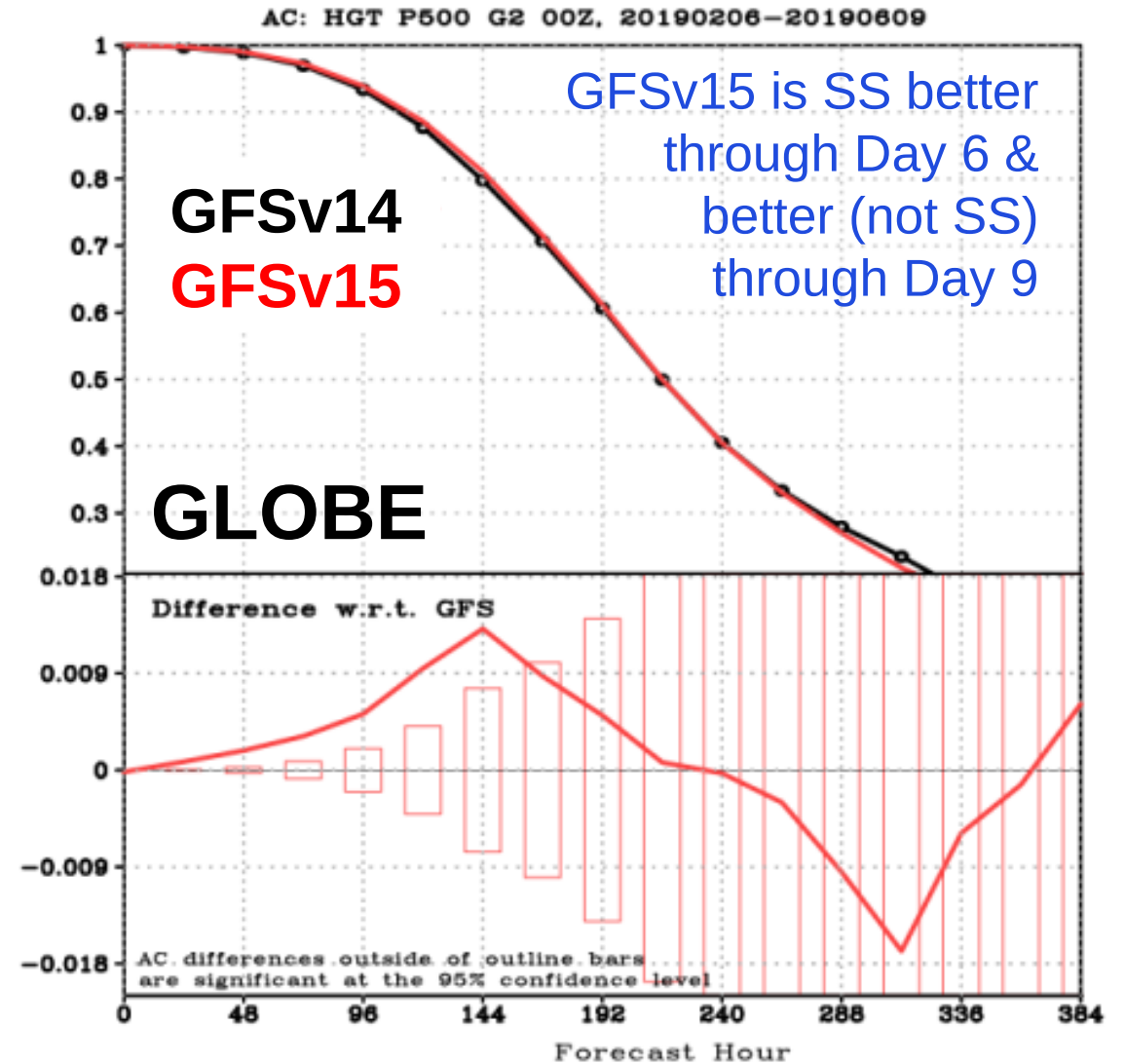
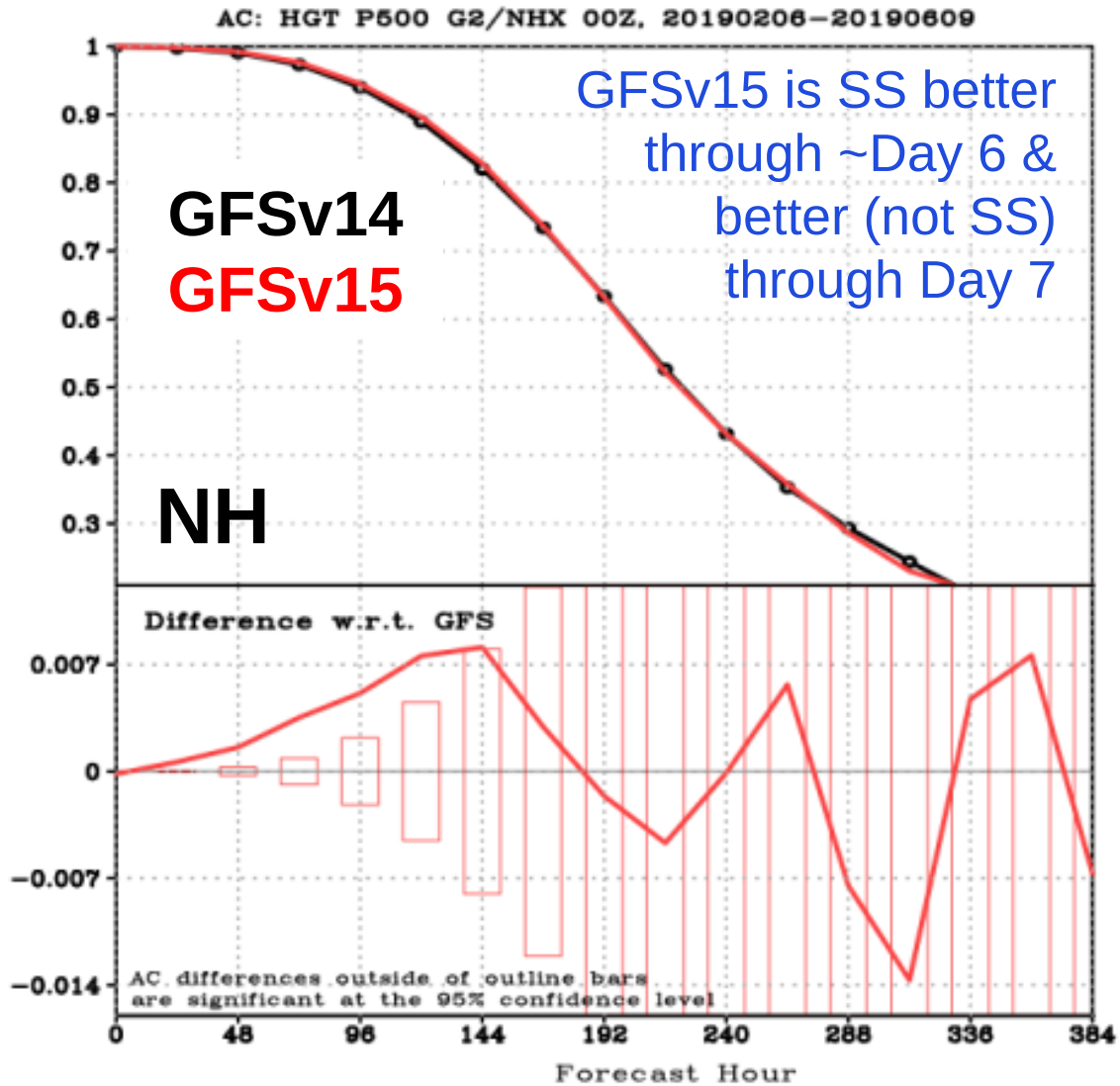


**GFSv14: 0.890**  
**GFSv15: 0.897**



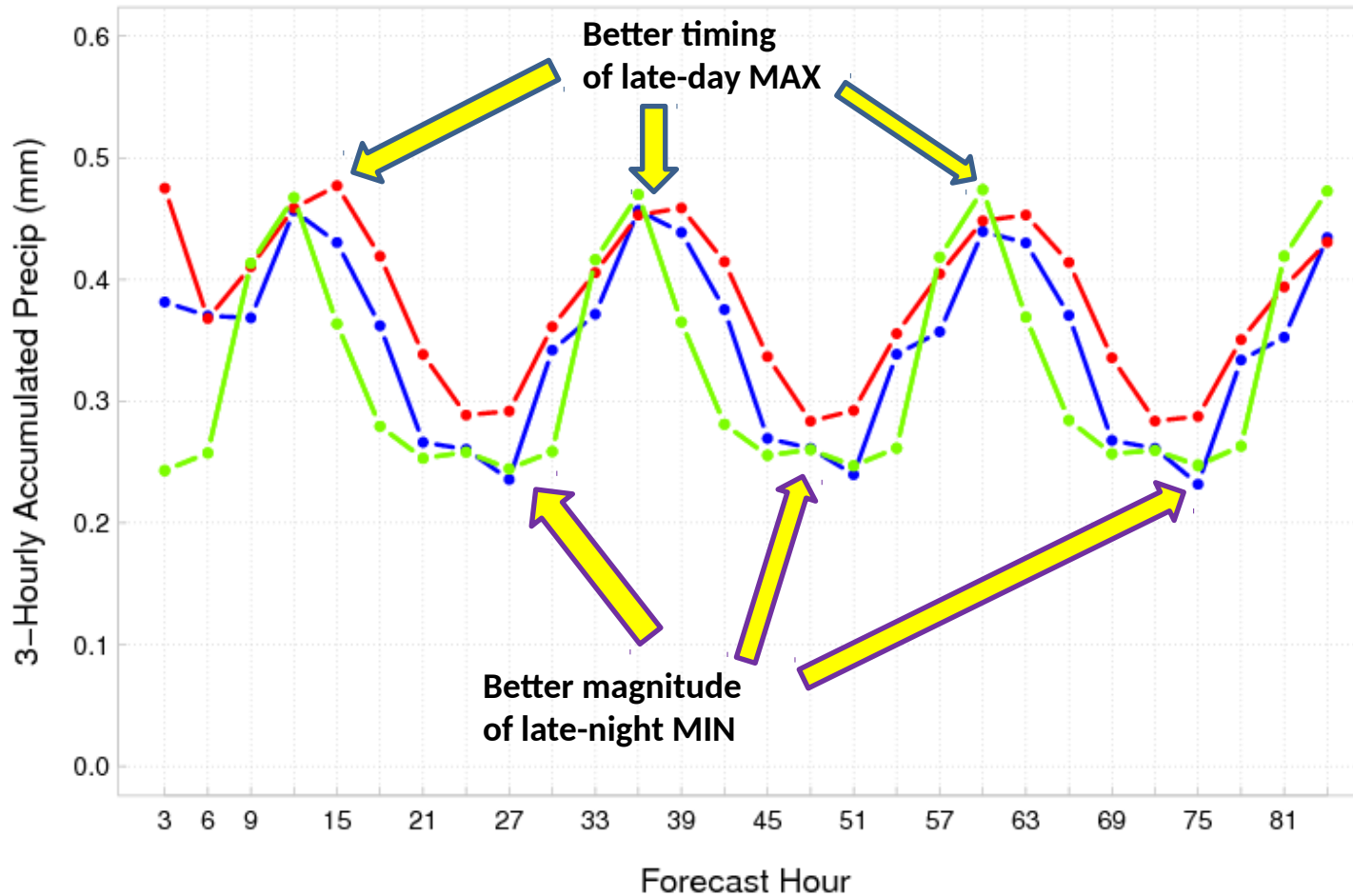
**GFSv14: 0.879**  
**GFSv15: 0.890**

# DIE-OFF : 500-mb AC SCORES FOR THIS SPRING



# SUMMER 2018 CONUS DOMAIN-AVG PCP

FV3GFS/GFS 3-hrly domain-avg APCP Jun-Aug 2018 12z cyc CONUS region



**Considerable improvement in diurnal cycle of warm season precipitation**

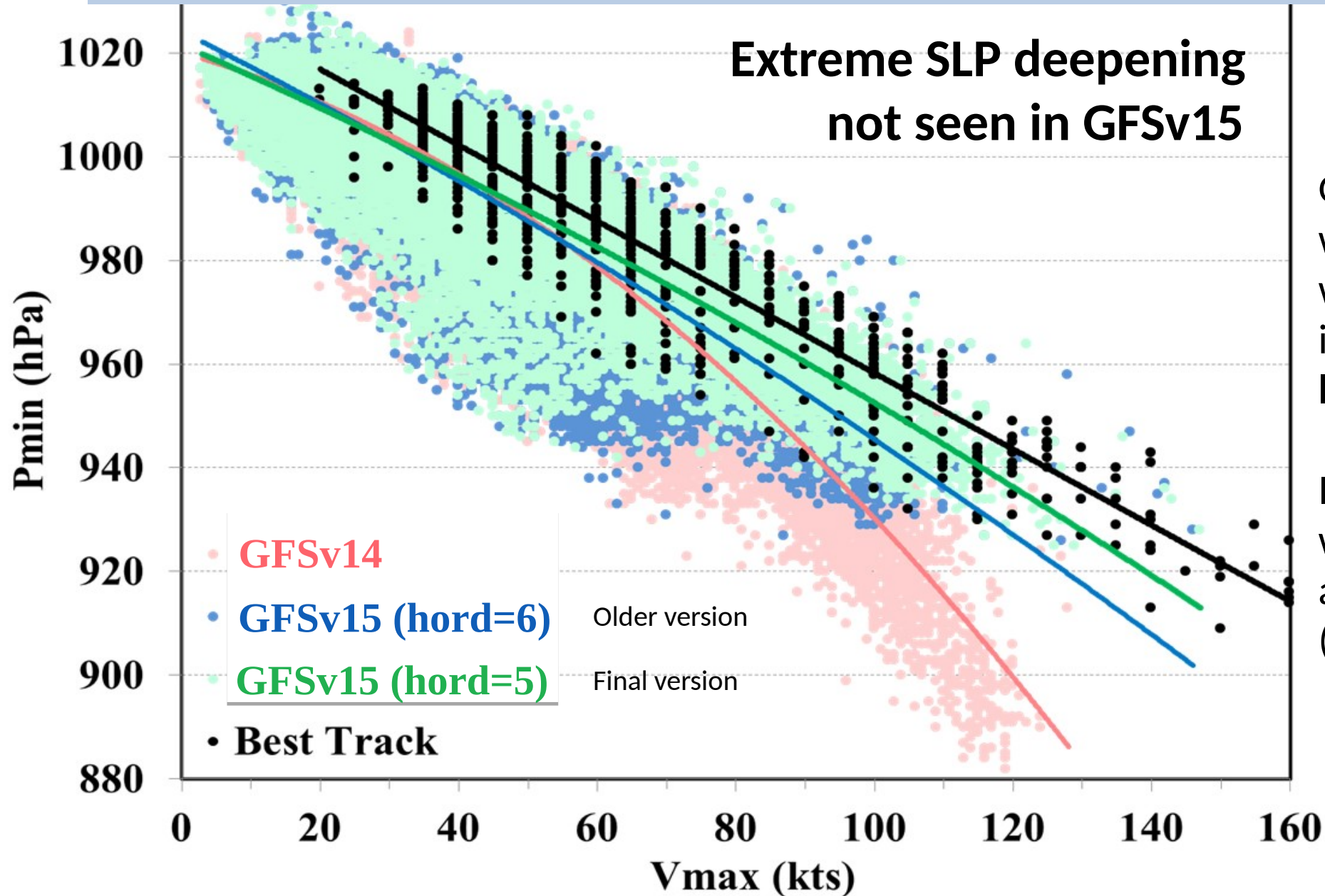
**Improvement in GFSv15 is the most pronounced during overnight hours**

**GFSv15**

**GFSv14**

**OBS**

# TROPICAL CYCLONE WIND-PRESSURE RELATIONSHIP



GFSv14 has a poor wind-pressure relationship, with max wind speeds inconsistent w/ extremely low SLP values

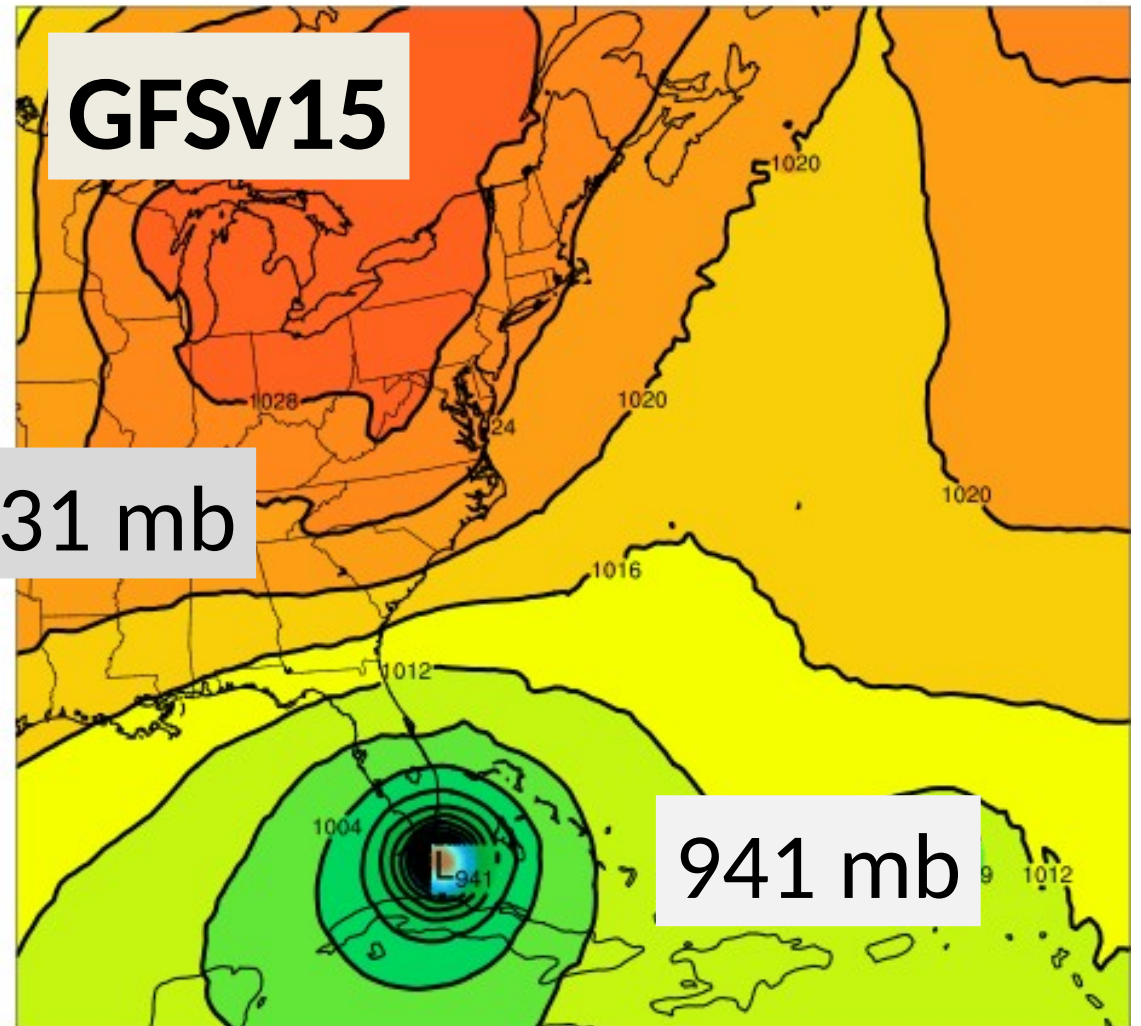
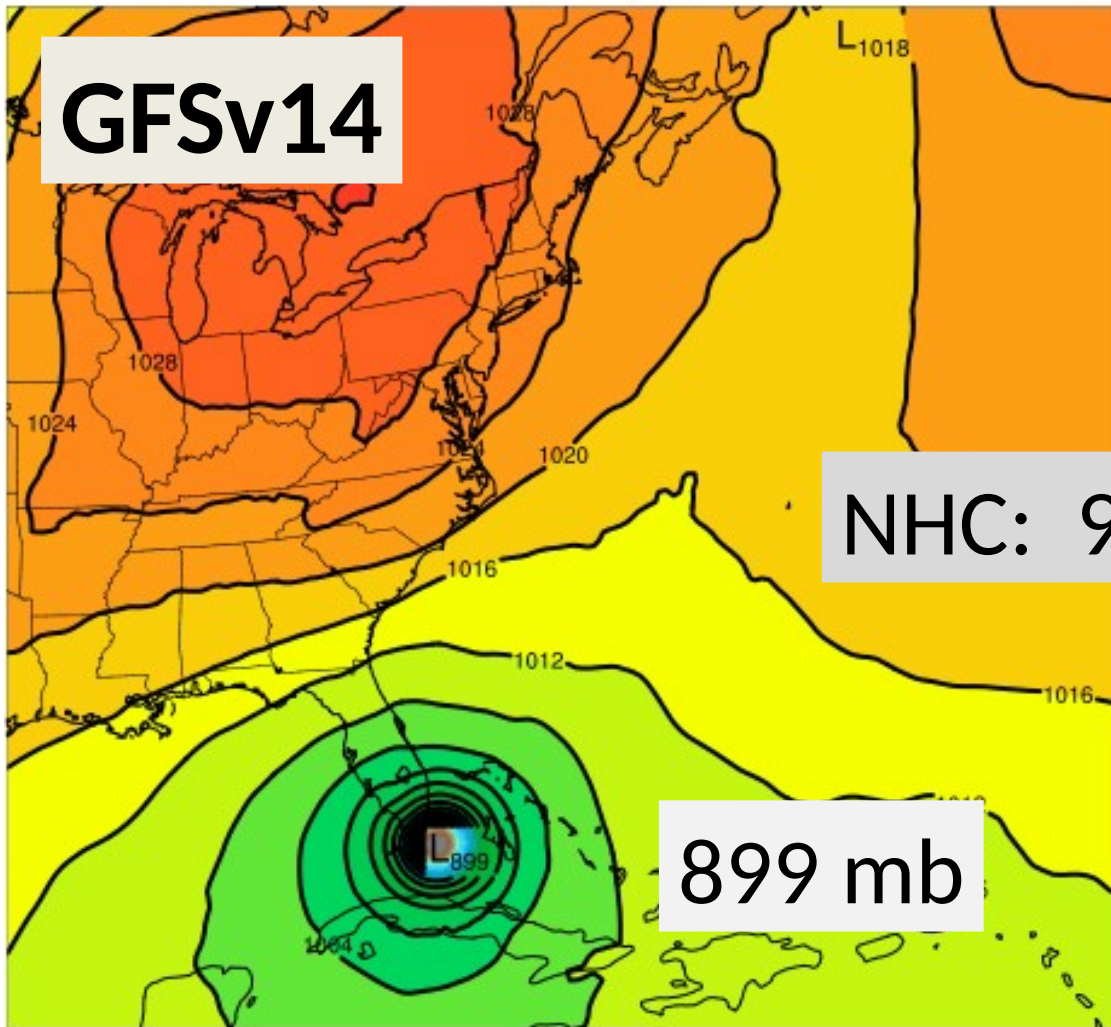
Intensity scores, computed with maximum wind speed, are better in GFSv15 (not shown)

# IRMA 00z 9/8/17 F54

GFS Fcst init 00Z 08 Sep 2017 valid 06Z 10 Sep 2017 (F54)

SLP FV3GFS test Fcst init 00Z 08 Sep 2017 valid 06Z 10 Sep 2017 (F54)

SLP



NHC: 931 mb



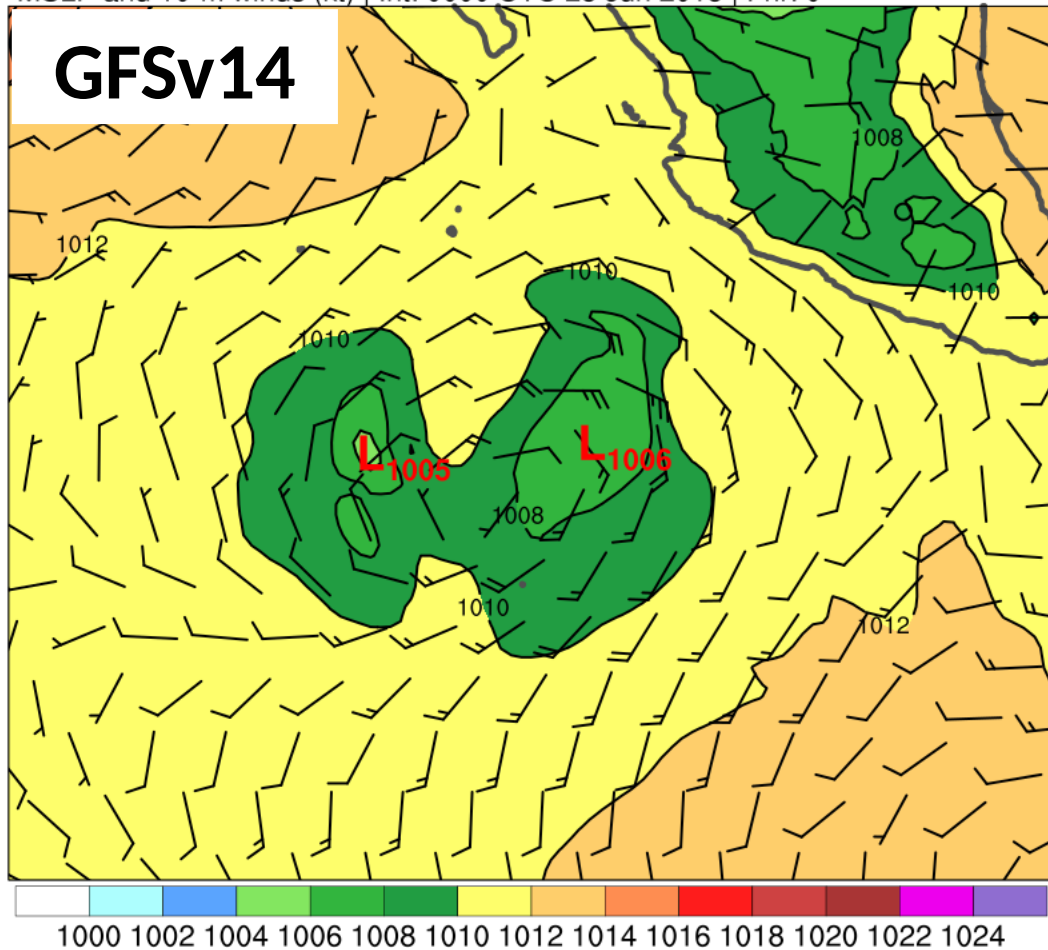
- Higher SLP values in GFSv15 are more consistent w/ nature (wind-pres) & resolution of a global model
- Higher SLP does not mean a weaker tropical cyclone



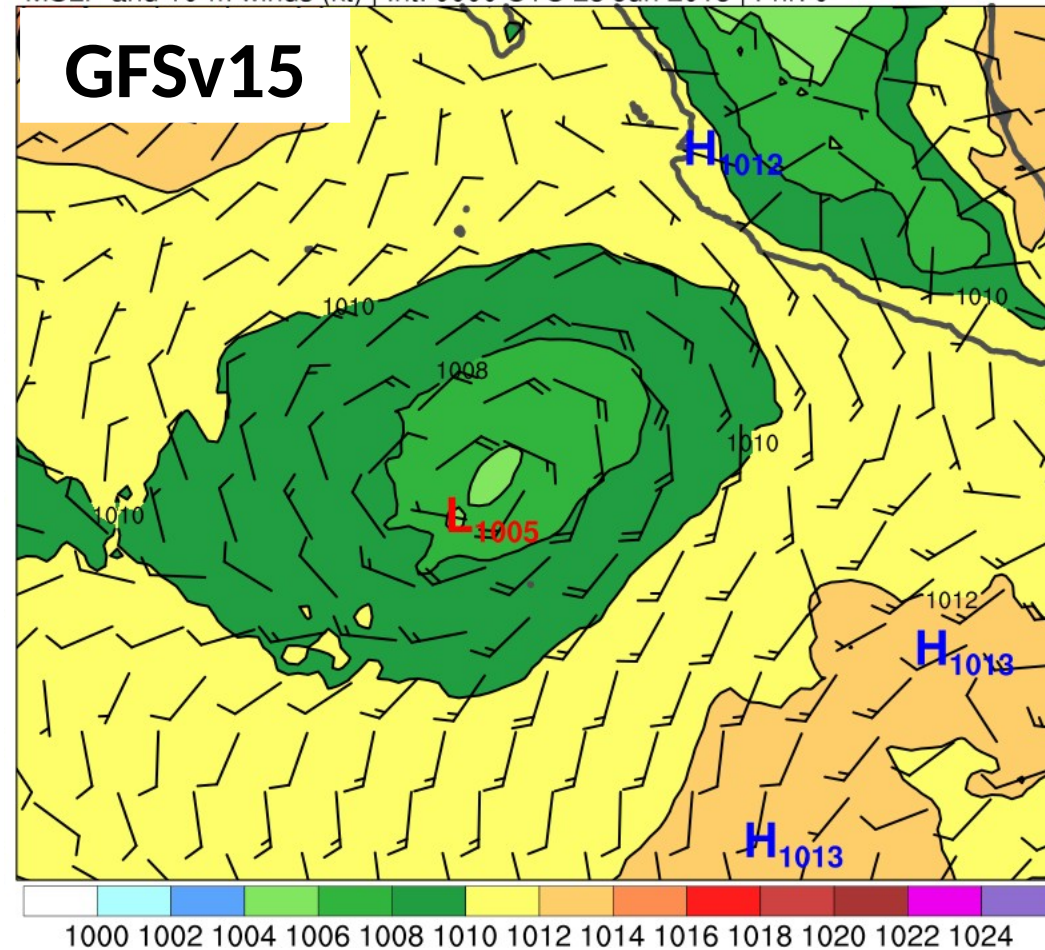
# MULTIPLE TROPICAL CYCLONE CENTERS FOR SINGLE STORM GENERATED BY GFSv14 NOT SEEN IN GFSv15 FORECASTS or ANALYSES

6/28/18 00z F00

MSLP and 10-m winds (kt) | Int: 0000 UTC 28 Jun 2018 | Fhr: 0



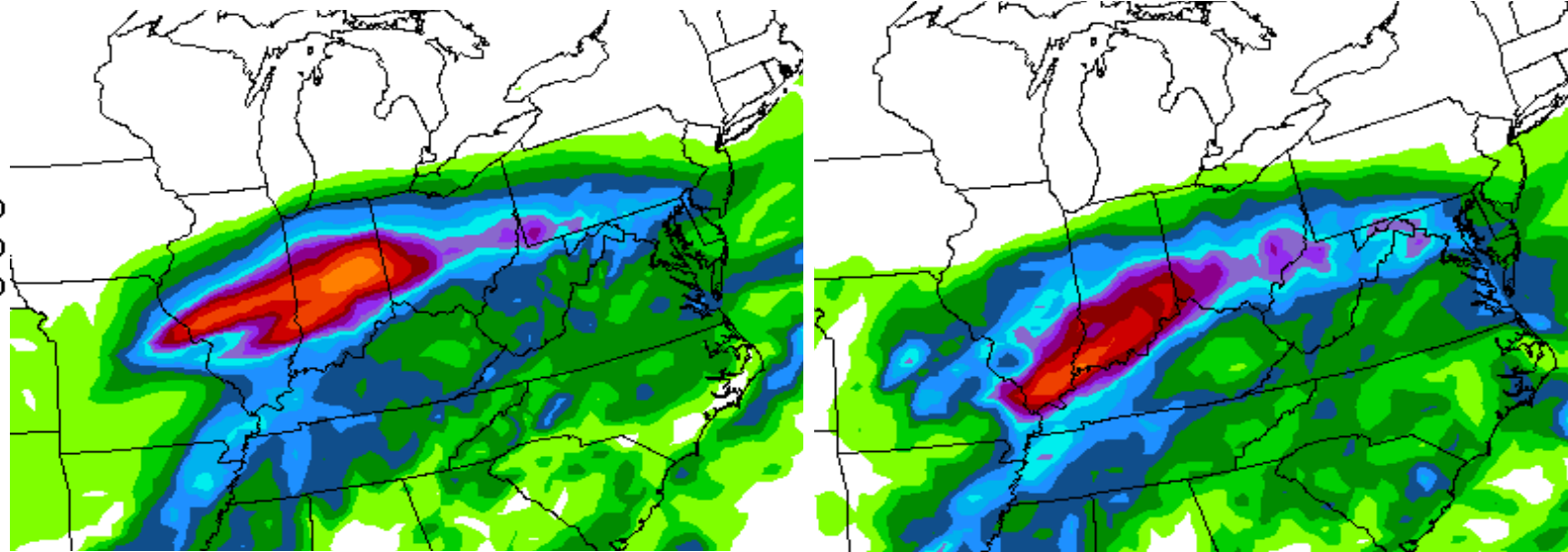
MSLP and 10-m winds (kt) | Int: 0000 UTC 28 Jun 2018 | Fhr: 0



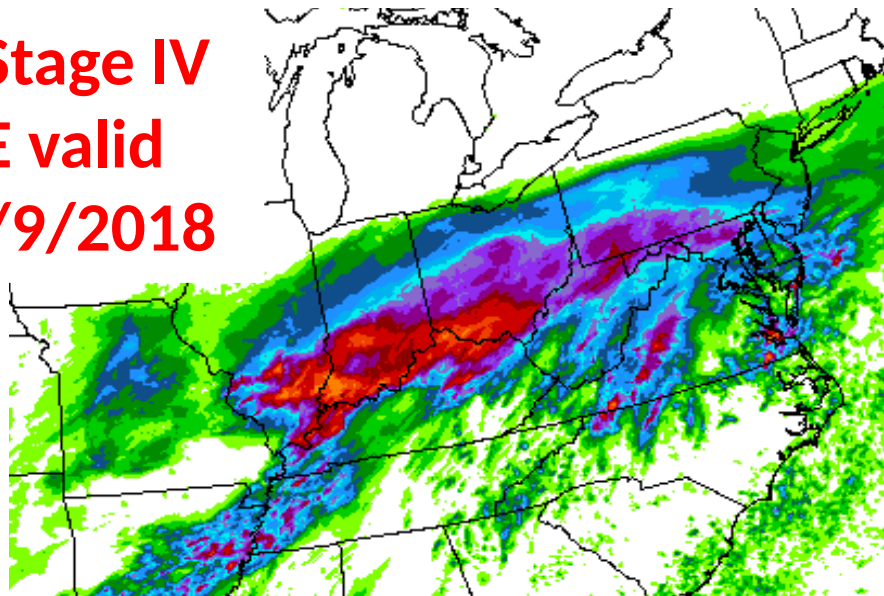
# From the WPC GFSv15 Evaluation

**GFSv14 24-h QPF F60**

**GFSv15 24-h QPF F60**



**24-h Stage IV  
QPE valid  
12Z 9/9/2018**



**SOME REDUCTION IN  
NORTHWARD QPF BIAS,  
POTENTIALLY ASSOCIATED  
WITH ABILITY OF GFSv15 TO  
GENERATE MODEST COLD  
POOLS FROM SIGNIFICANT  
CONVECTION**

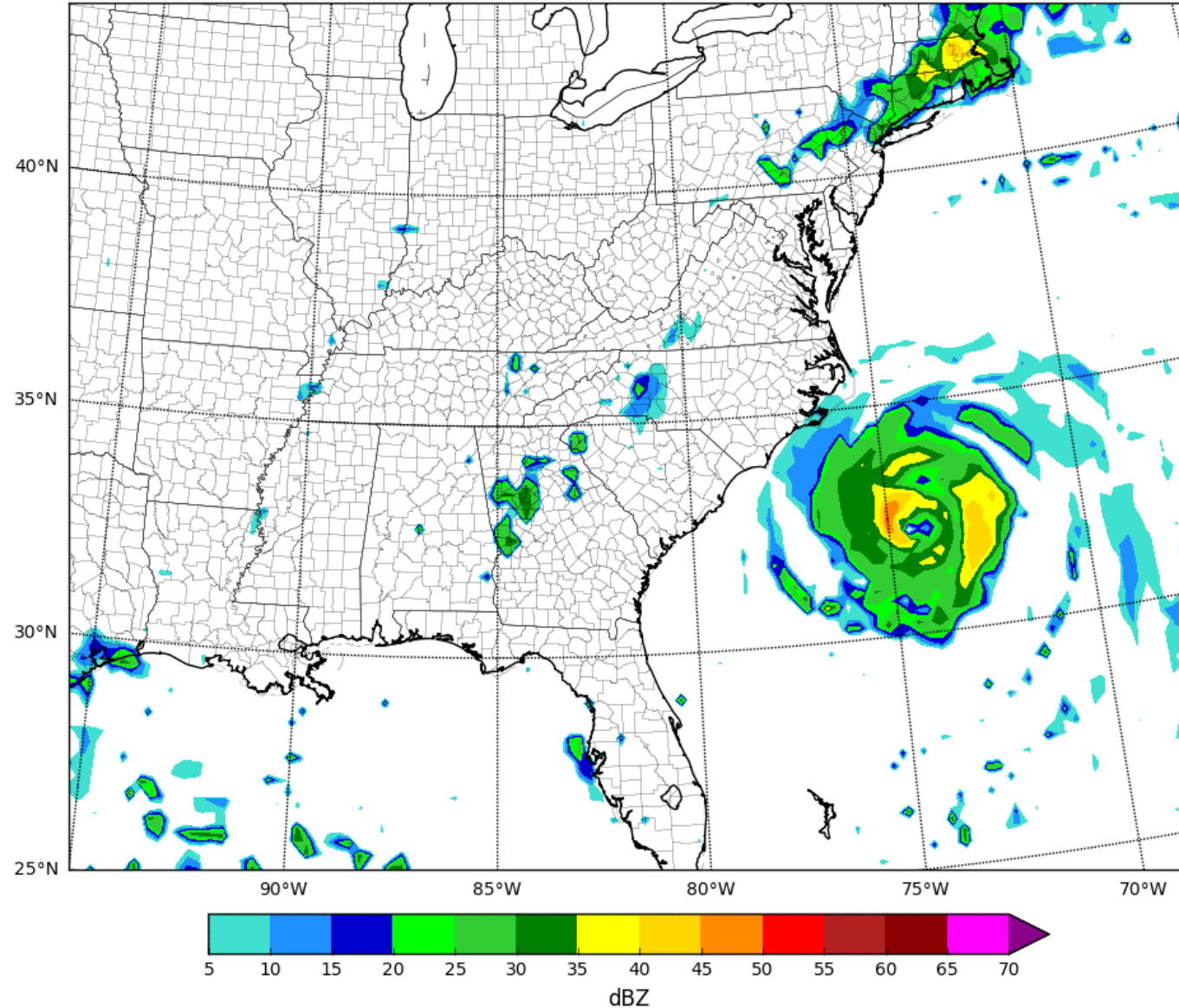
# NEW GFDL MP ALLOWS FOR SIMULATED COMPOSITE REFLECTIVITY

FV3GFS

Init: 00Z 13 Sep 2018

Composite Reflectivity

Valid: 06Z 13 Sep 2018 (F06)



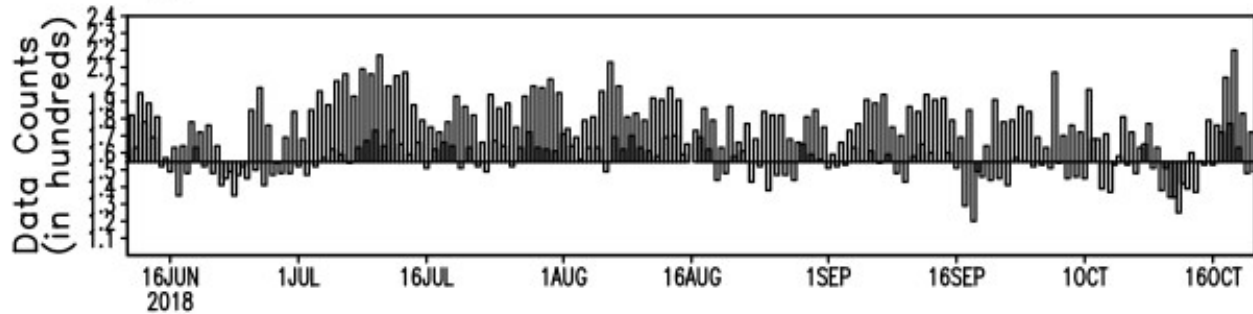
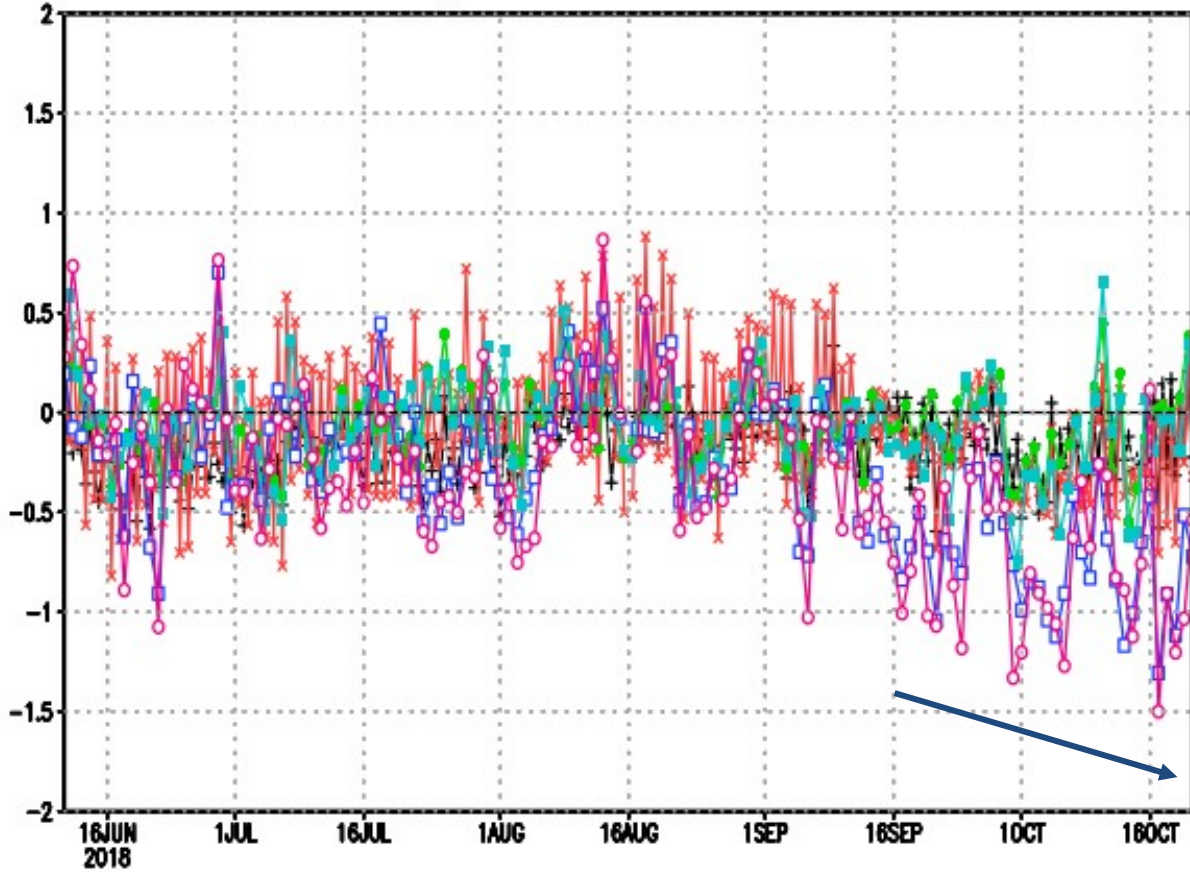
## **SOME CONCERNS**

- 1. LOW-LEVEL COLD BIAS IN THE COLD SEASON, POTENTIALLY LEADING TO EXCESSIVE SNOW FORECASTS**
- 2. FV3GFS CAN BE TOO PROGRESSIVE CLOSED UPPER LOWS RE-ENTERING THE FLOW**
- 3. WARM-SEASON DRY QPF BIAS FOR MID AND UPPER THRESHOLDS**
- 4. CONCERNS WITH FORWARD SPEED OF POLEWARD-MOVING TROPICAL CYCLONES**

prfv3rt1 North America Temperature 1000 MB BIAS f-o to ADPUPA  
00z11jun2018 - 00z21oct2018

prfv3rt1  
-0.32  
-0.07  
-0.29  
-0.05  
-0.08  
-0.17

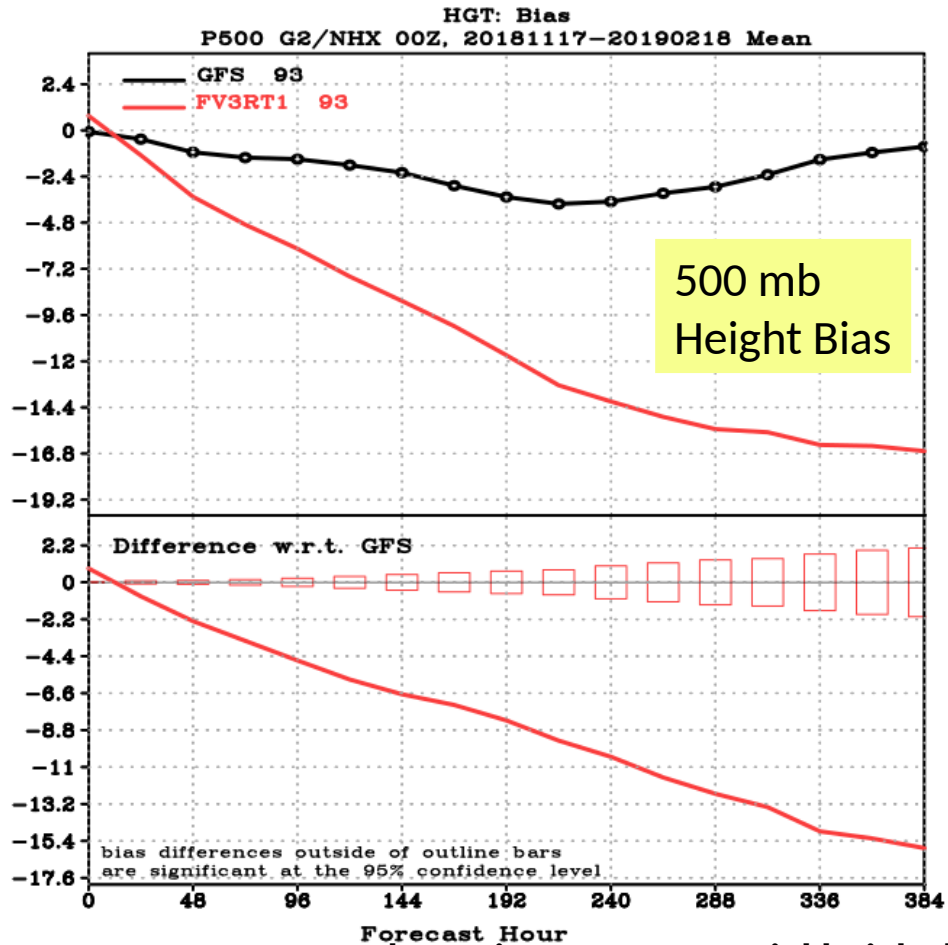
○ 48hr  
■ 36hr  
□ 24hr  
● 12hr  
× Ges  
+ Anl



GFSv15 change @ **18z 9-17-18** to correct radiation error:

**RADIATION DRIVER CORRECTION  
LED TO A SIGNIFICANT  
INCREASE in the LOW-LEVEL  
COLD BIAS**

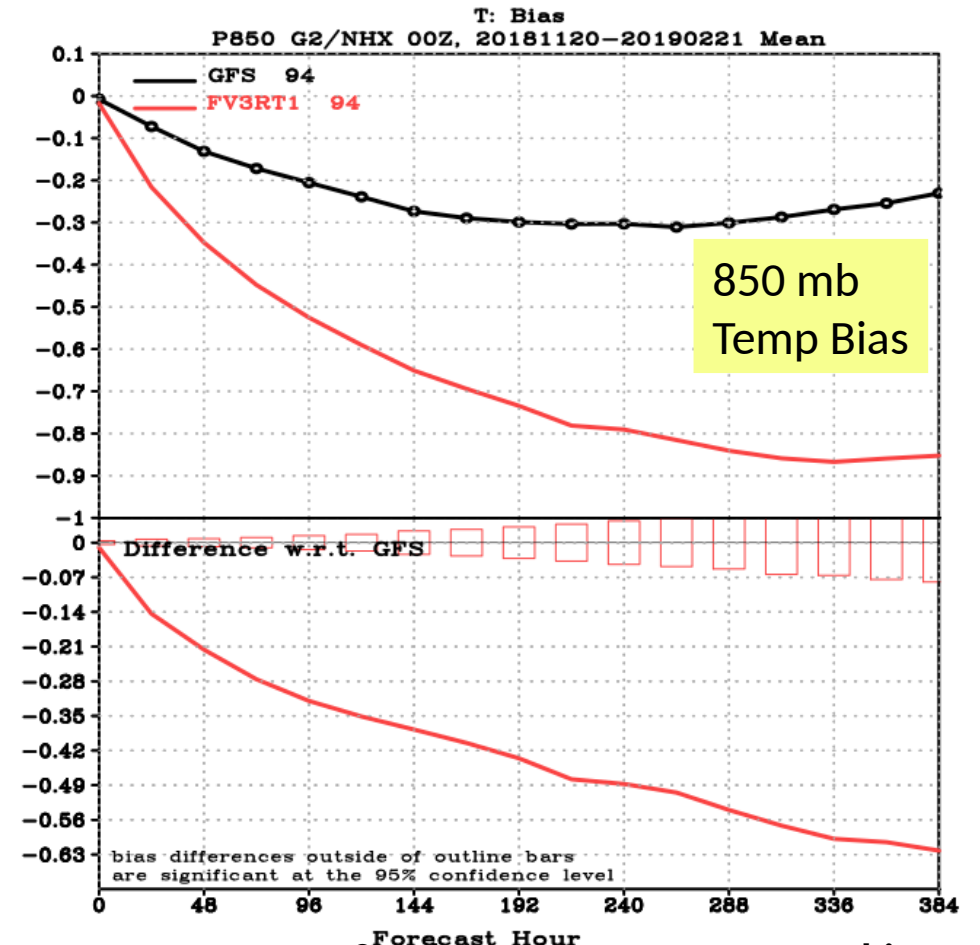
**COLD BIAS WAS EVIDENT IN RETROSPECTIVE RUNS, BUT MAGNITUDE INCREASED SIGNIFICANTLY THIS PAST WINTER**



**Day-10 500-hPa winter geopotential height bias**

- (2015-2016) -4.5 m
- (2016-2017) -5.0 m
- (2017-2018) -3.2 m
- (2018-2019) -14.4 m

**GFSv14**  
**GFSv15**



**Day-10 850-hPa winter temperature bias**

- (2015-2016) -0.27°C
- (2016-2017) -0.35°C
- (2017-2018) -0.23°C
- (2018-2019) -0.77°C

# Mitigation of the cold bias (Late Winter 2019)

## Physics:

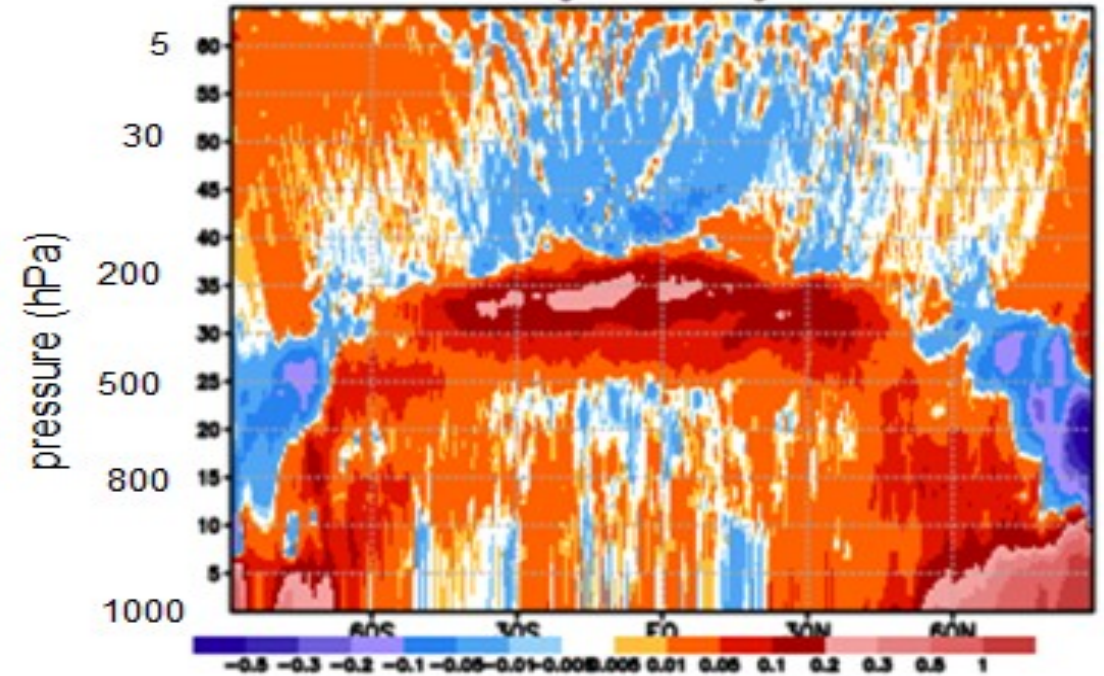
- Adopting an improved cloud radiation interaction in the **new configuration** reduces long-wave cooling in the troposphere, and indirectly increases heating in the PBL and near-surface due to mixing, warming the troposphere.



## Data Assimilation:

- Adjustment to supersaturation constraint in the **new configuration** reduces the cold bias in the polar regions near surface.

Zonal Mean Temperature Difference  
Lat-HGT Cross Section, 24hr Forecast

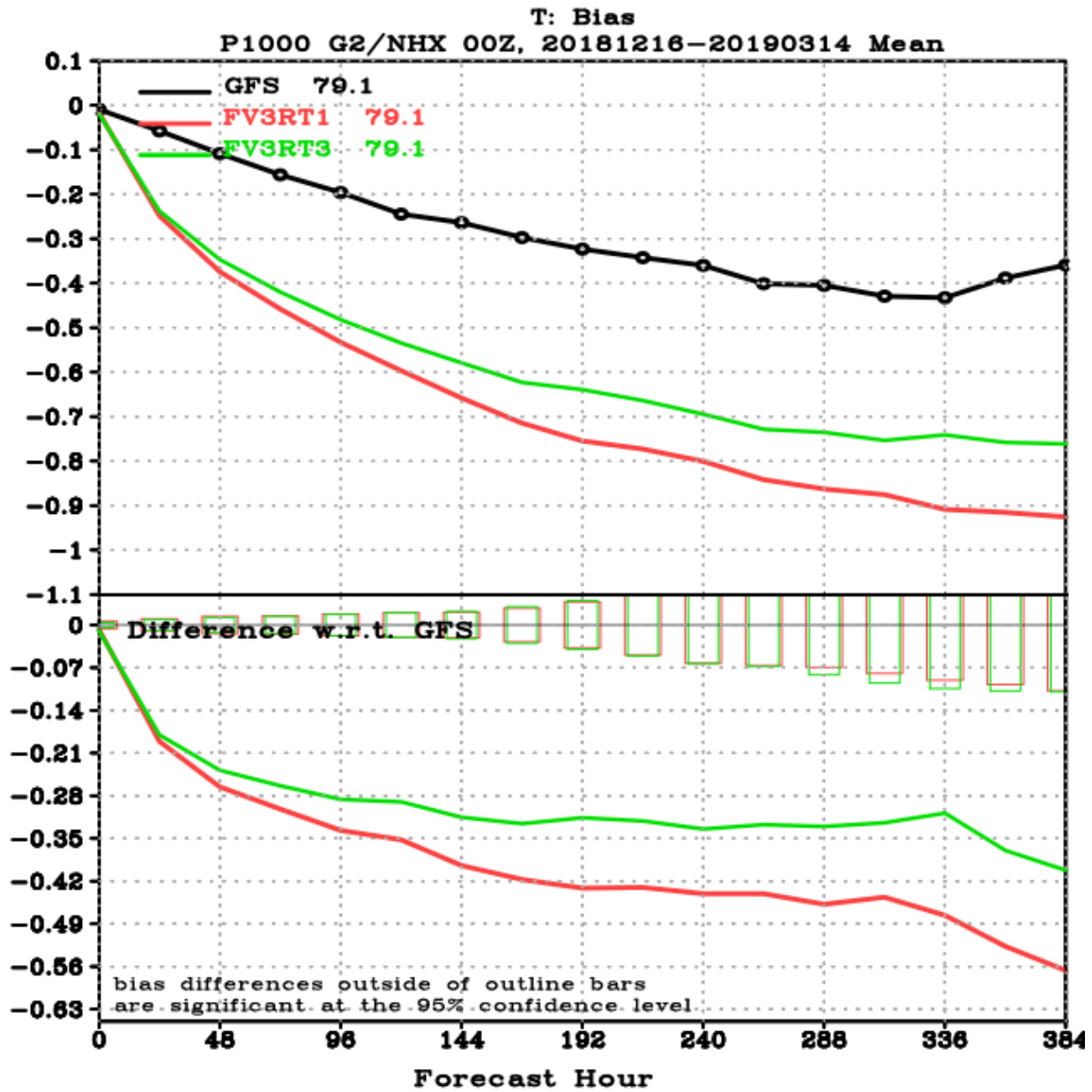
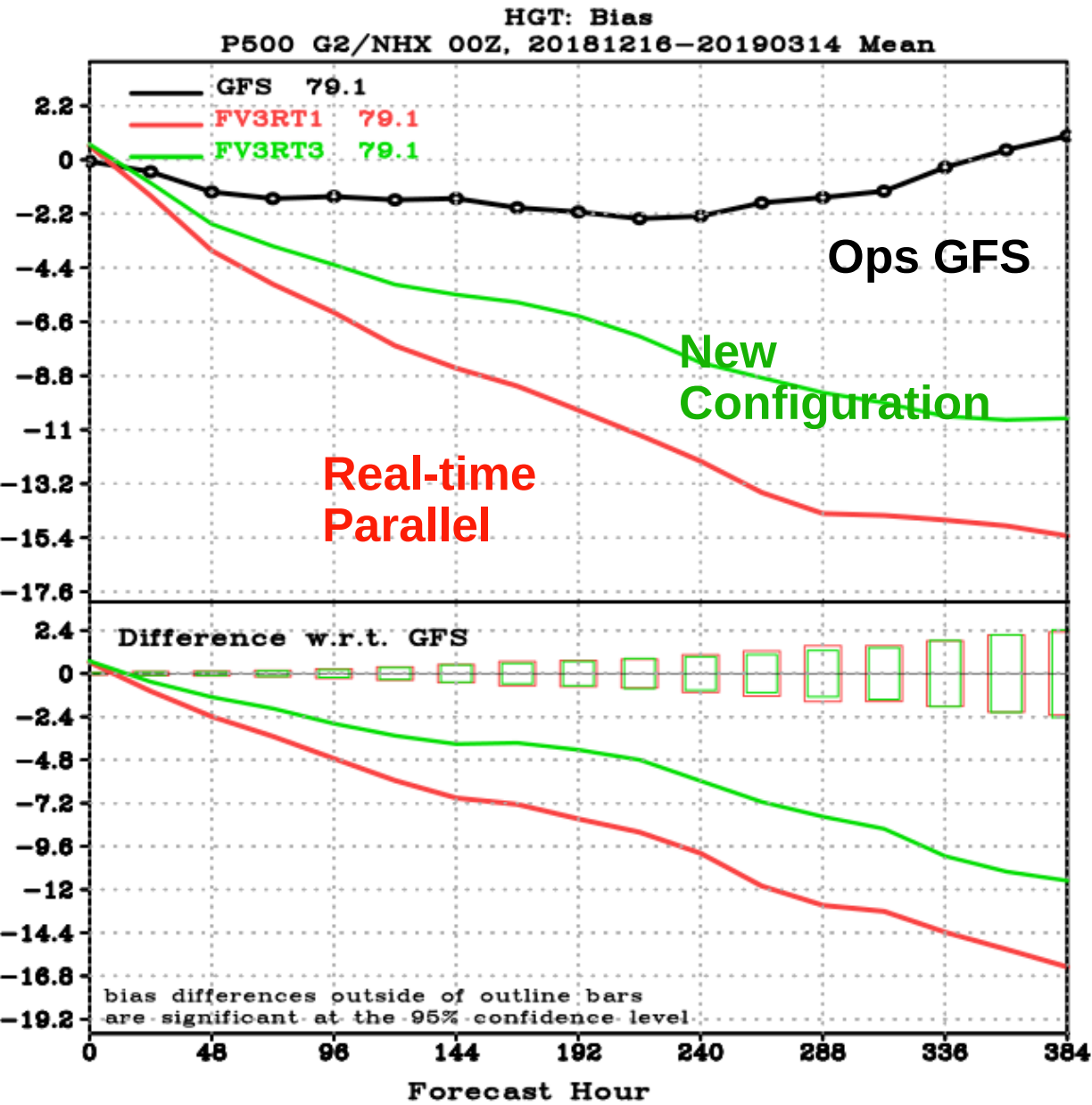


**Impact of improved cloud-radiation interactions: Warm the atmosphere (recovers some of the cold bias in the lower troposphere)**

**GFDL is acknowledged for their contribution to the implementation of the improved cloud-radiation interaction**

500 hPa Height Bias

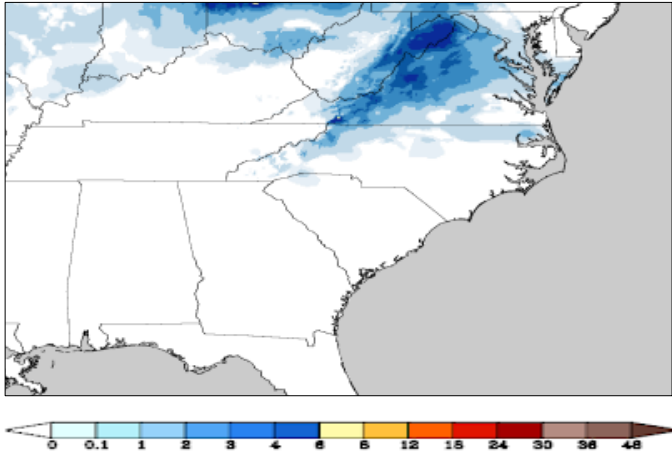
1000 hPa Temp Bias



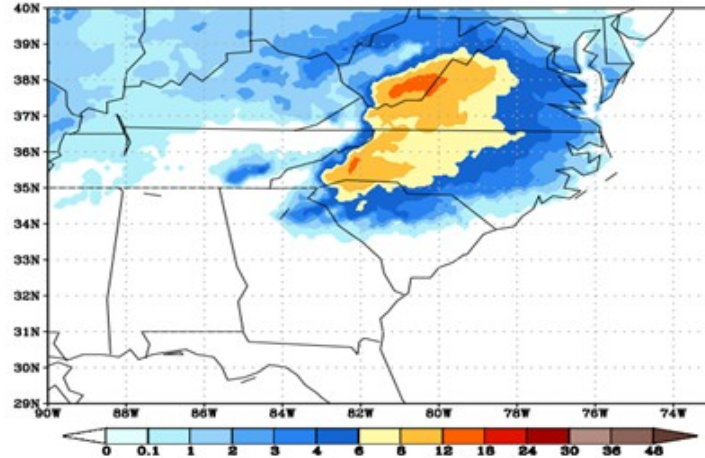


# Excessive 24-h Snowfall Totals in Medium Range (Valid: 12Z 2/20/19)

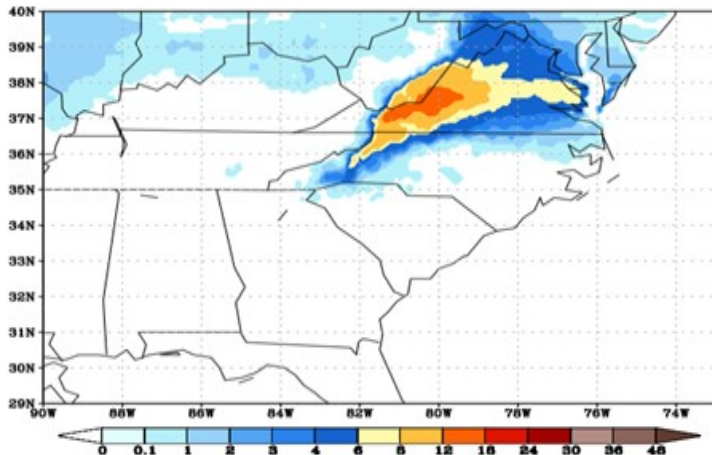
## NOHRSC Analysis



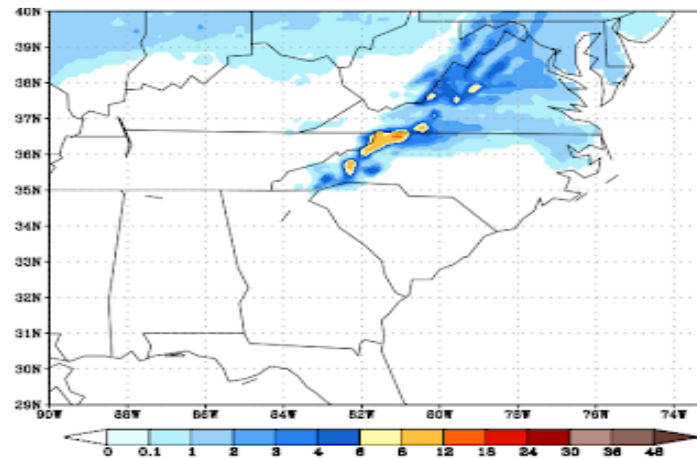
## Previous GFSv15 Version



## Final GFSv15 Configuration



## GFSv14



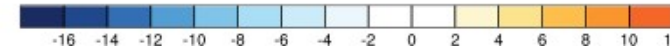
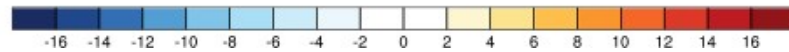
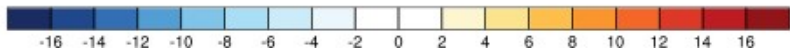
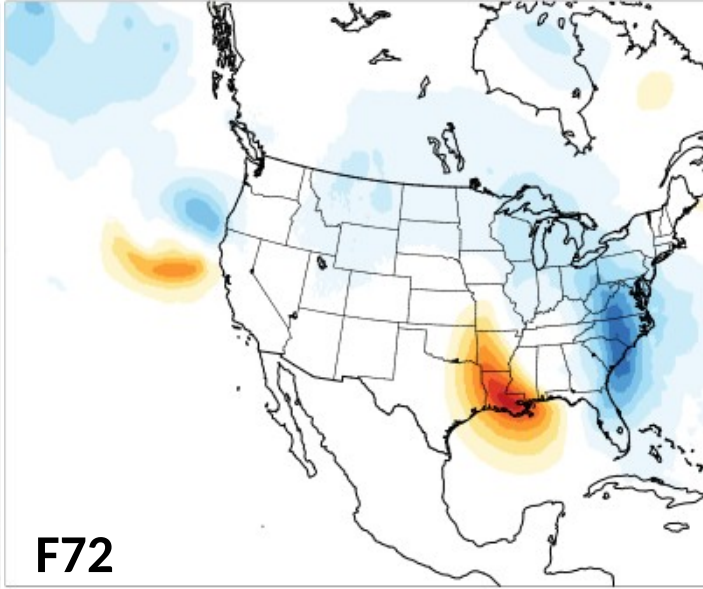
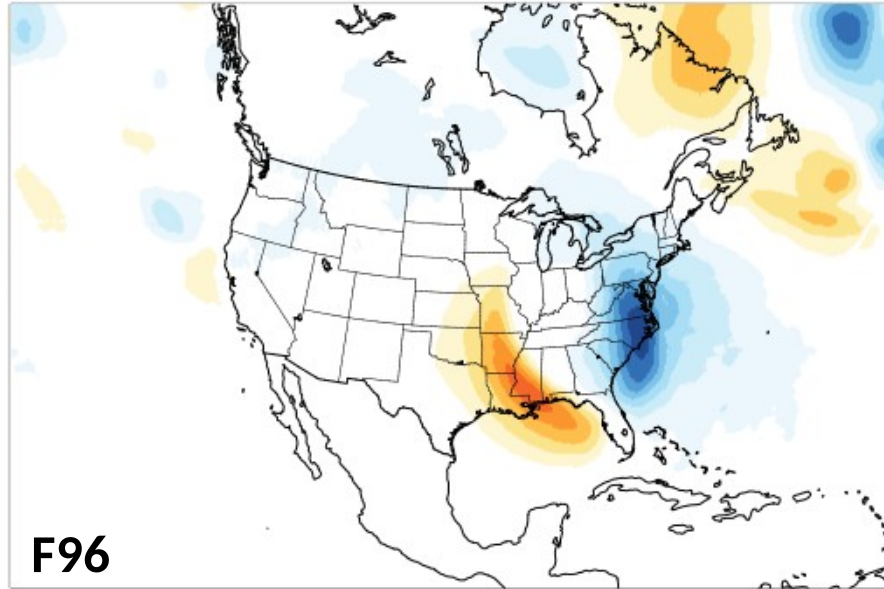
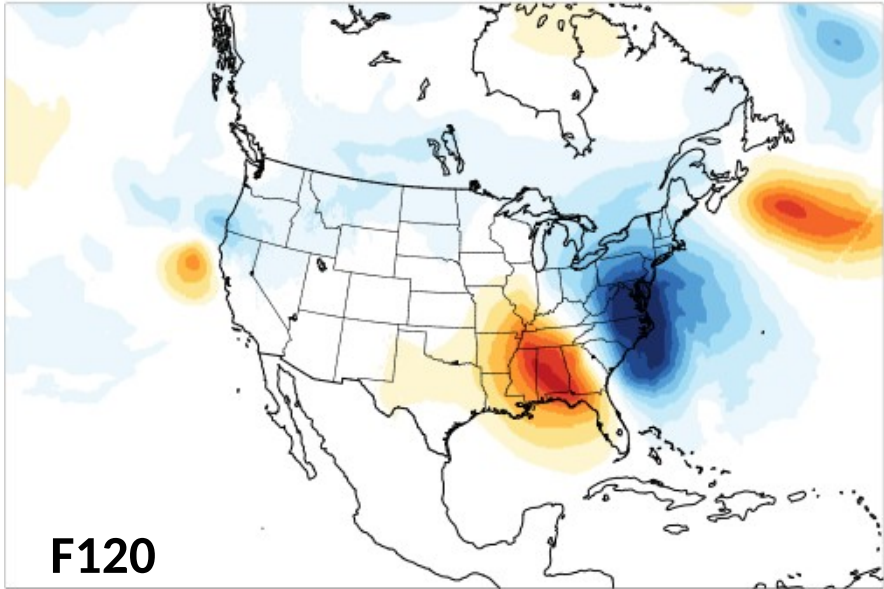
- **Final Configuration** has correct areal coverage of snowfall, and coverage of higher amounts is significantly reduced from the real-time parallel run but are still too high, potentially due to the lingering low-level cold bias

# PROGRESSIVENESS

FV3GFS Fcst minus GFS Fcst valid 00Z 23 Jan 2016 (F120)

500-hPa FV3GFS Fcst minus GFS Fcst valid 00Z 23 Jan 2016 (F96)

500-hPa FV3GFS Fcst minus GFS Fcst valid 00Z 23 Jan 2016 (F72)

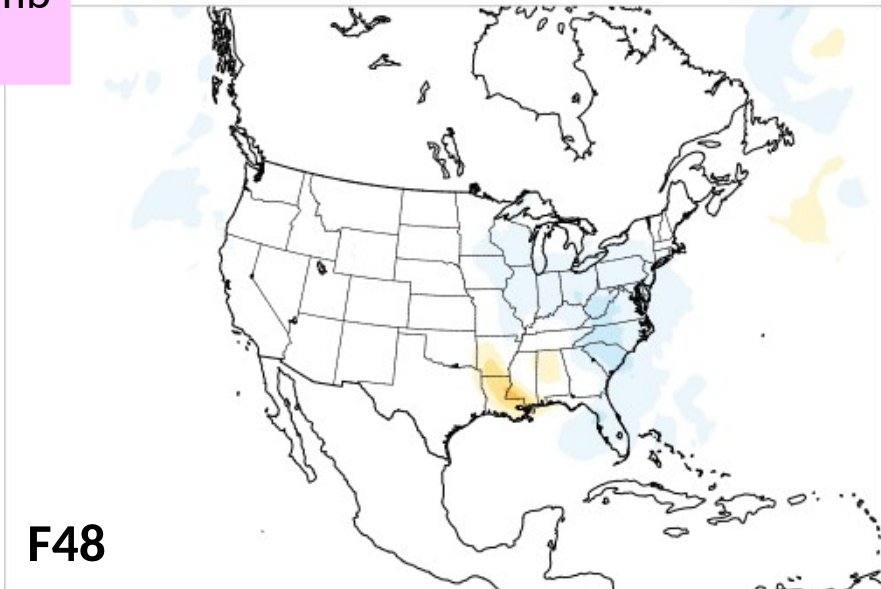


GFSv15 - v14 500mb  
BLIZZARD of 2016

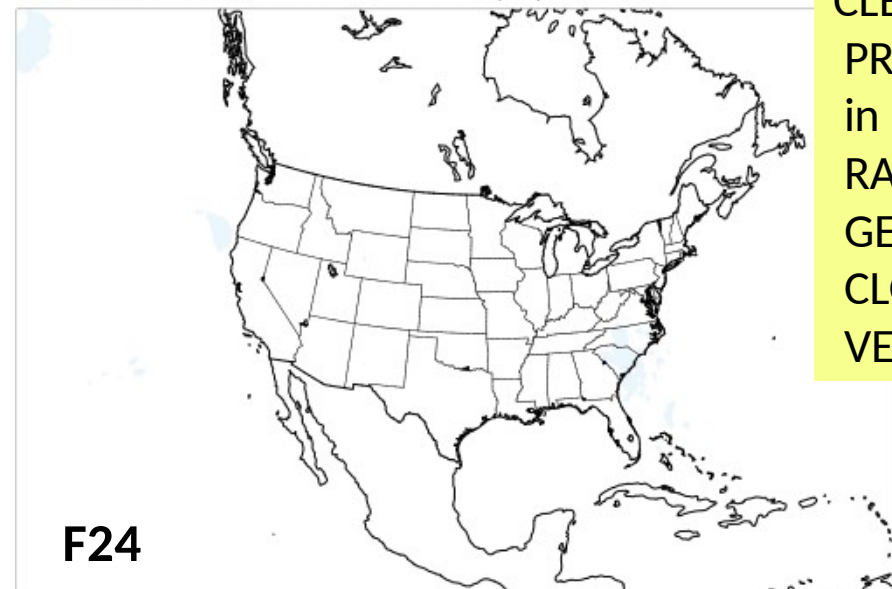
Blue = GFSv15  
has lower  
heights

Red = GFSv15  
has higher  
heights

S Fcst minus GFS Fcst valid 00Z 23 Jan 2016 (F48)

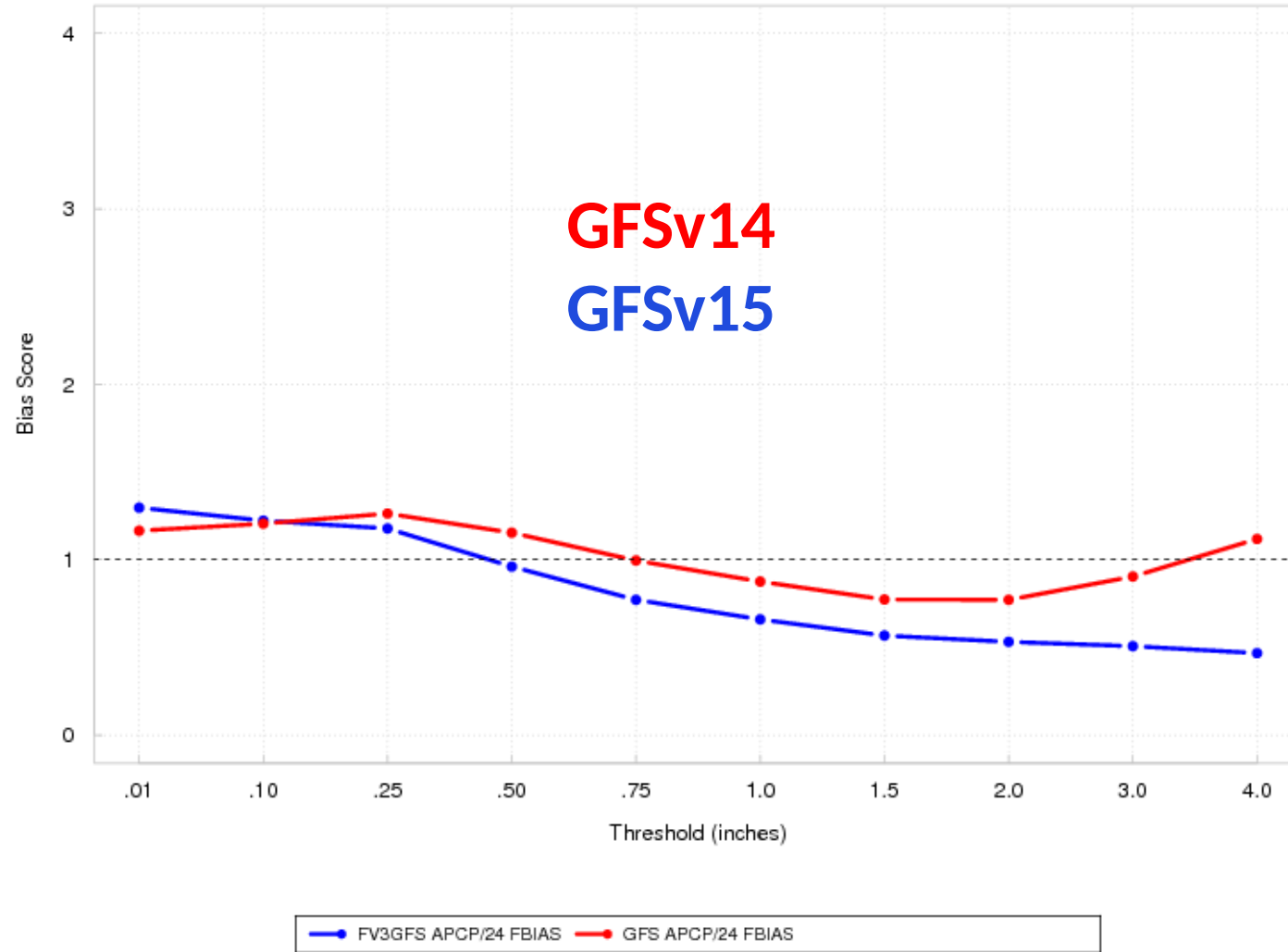


FV3GFS Fcst minus GFS Fcst valid 00Z 23 Jan 2016 (F24)



CLEARLY TOO  
PROGRESSIVE  
in MEDIUM  
RANGE; DIFFS  
GET SMALLER  
CLOSER to  
VERIFYING TIME

GFS vs. FV3GFS (Forecasts: 18Z 25 May to 18Z 10 September 2018)



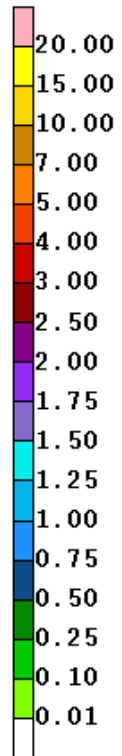
**WARM SEASON DRY BIAS FOR MID AND UPPER-RANGE AMOUNTS**



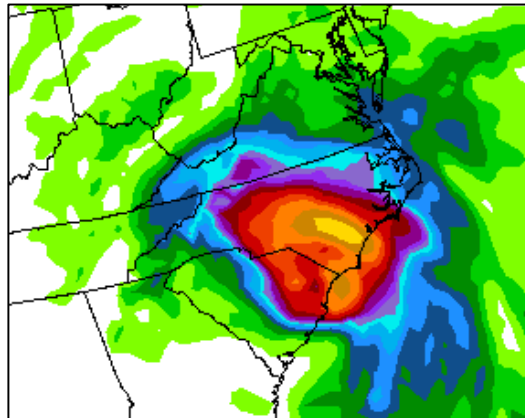
## QPF Evaluation - Concerns

Low bias for higher QPF thresholds

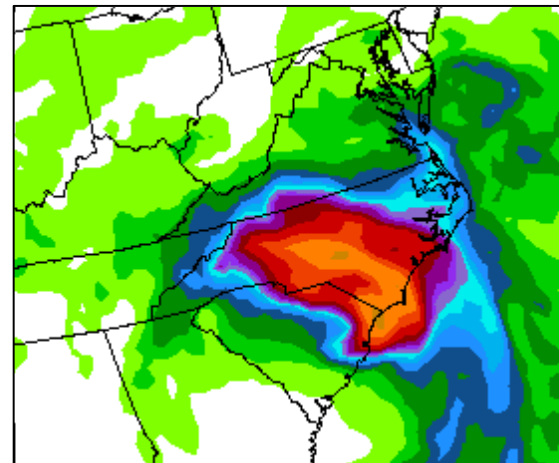
24-hour QPF from the 00Z Sep 14 runs valid 12Z Sep 16 (F060)



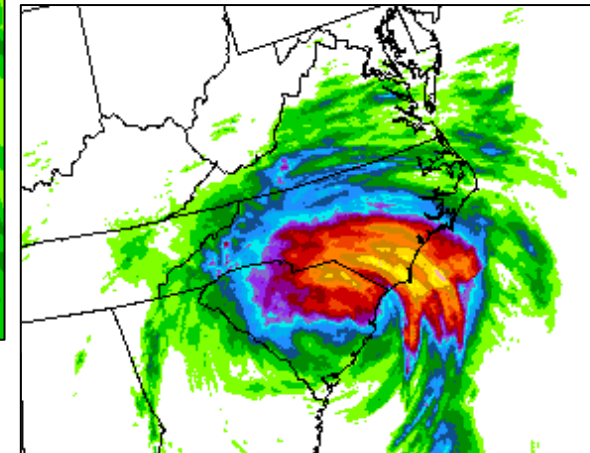
GFSv14



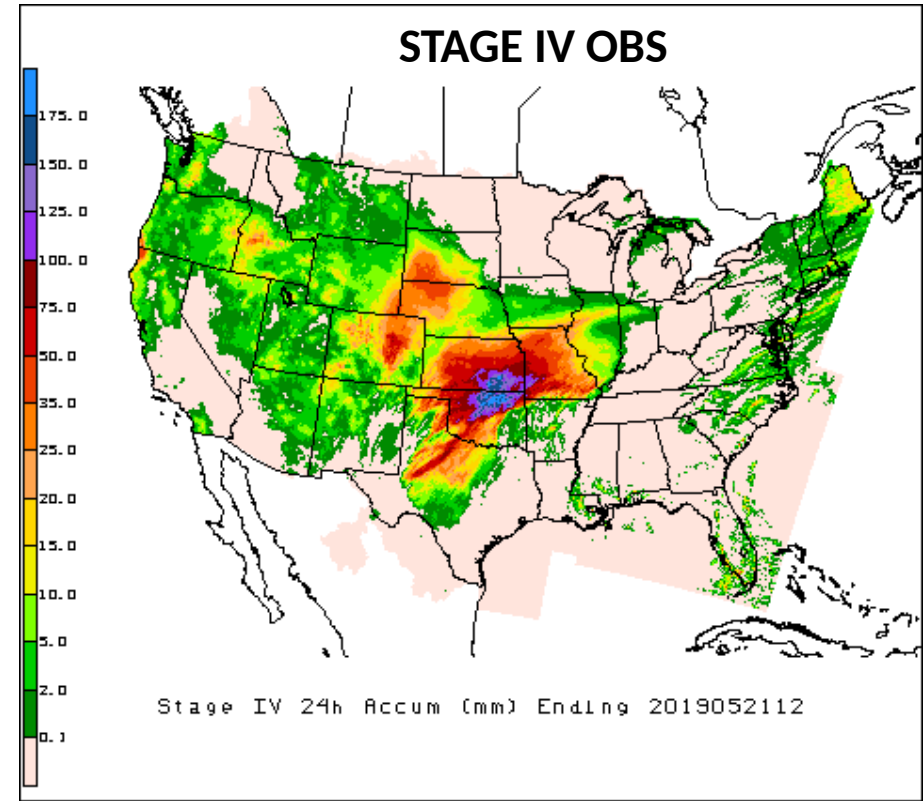
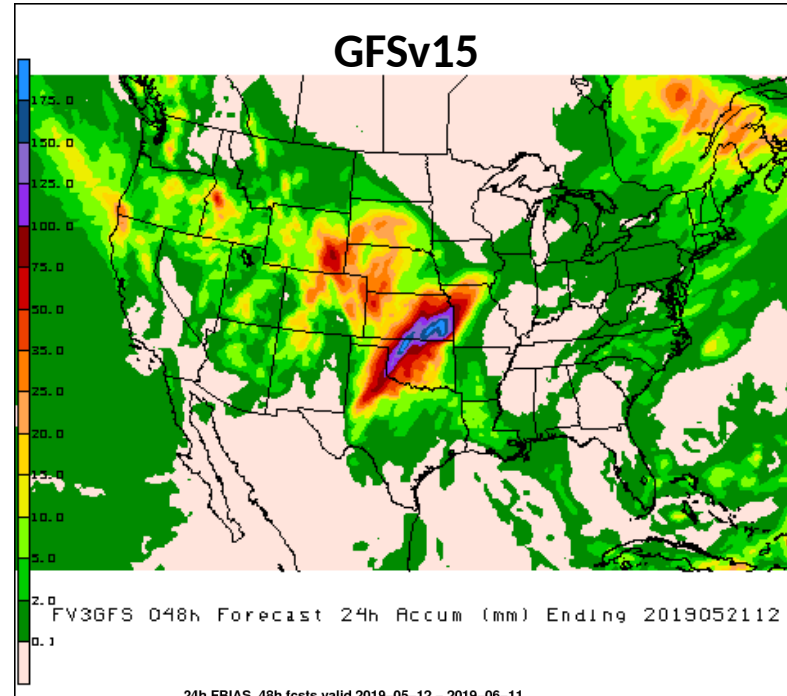
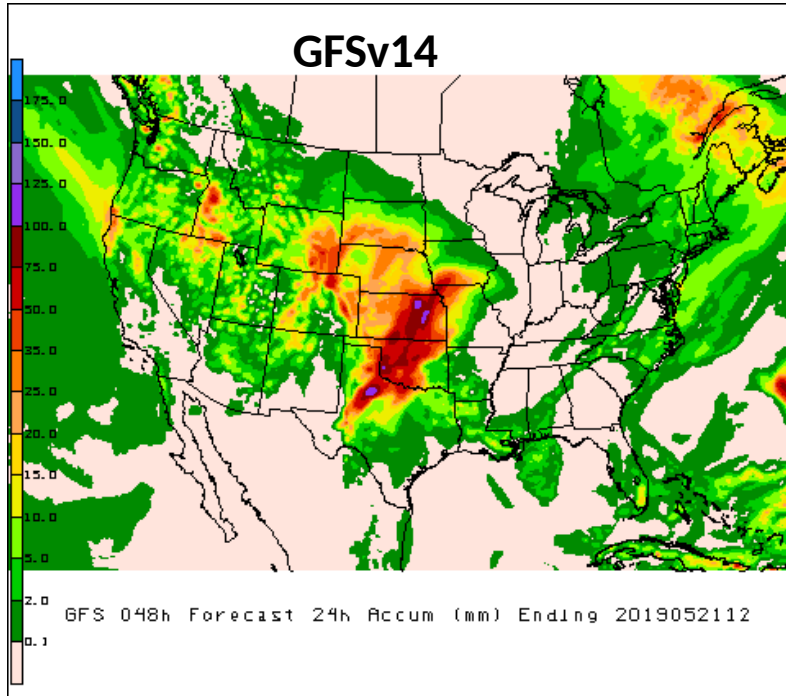
GFSv15



Stage IV QPE

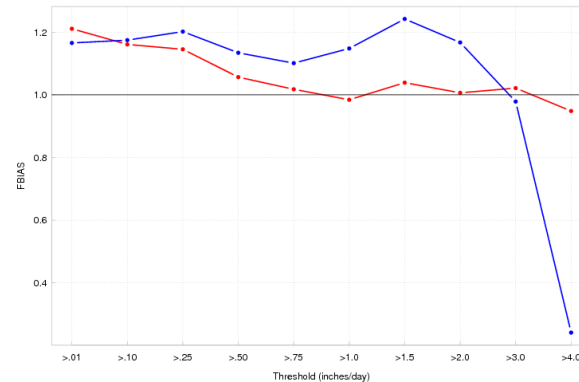


But some evidence this spring of better performance on wetter cases



24h FBIAS, 48h fcsts valid 2019-05-12 - 2019-06-11

Recent  
Bias  
Scores

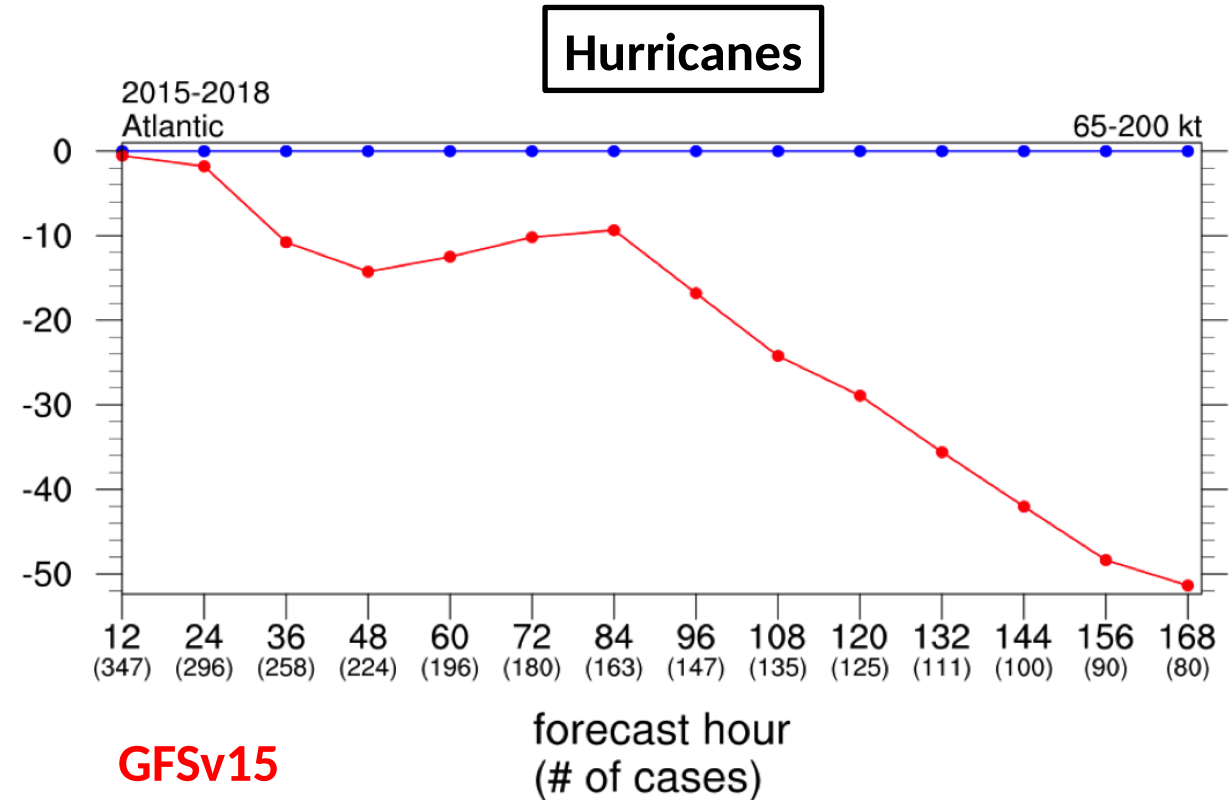
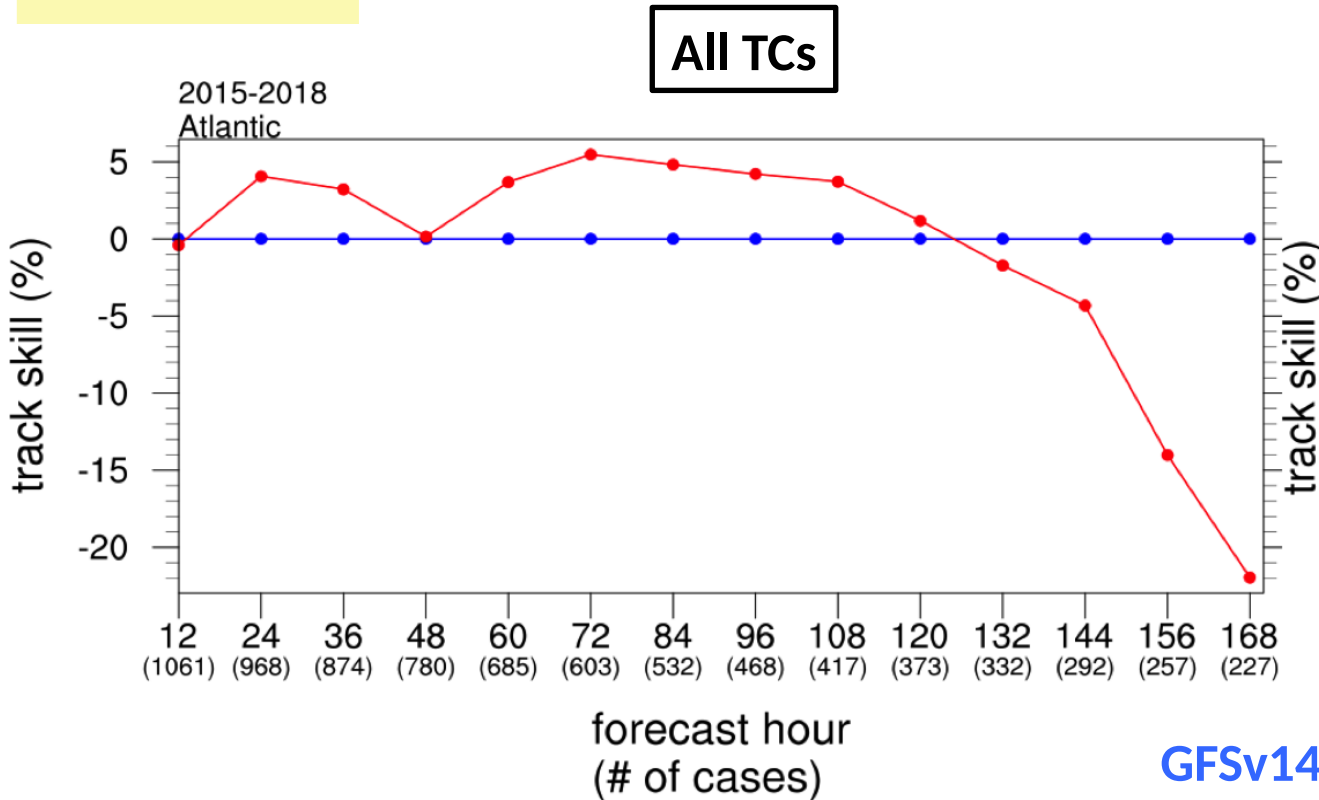


**GFSv14**  
**GFSv15**

— FV3GFS APCP/24 FBIAS — GFS APCP/24 FBIAS

# TROPICAL TRACKS

## GFSv15 Track Skill Relative to Older GFS for 2015-18 Atlantic TCs and Hurricanes From NHC Evaluation of GFSv15



- For all 2015-2018 Atlantic TCs (left), modest improvement in track forecasts through Day 5
- Clear degradation by Day 6 with significant degradation at Day 7
- For all 2015-2018 Atlantic **hurricanes** (right), track forecasts were degraded at all lead times – worst cases seemed to be ones with poleward-moving storms

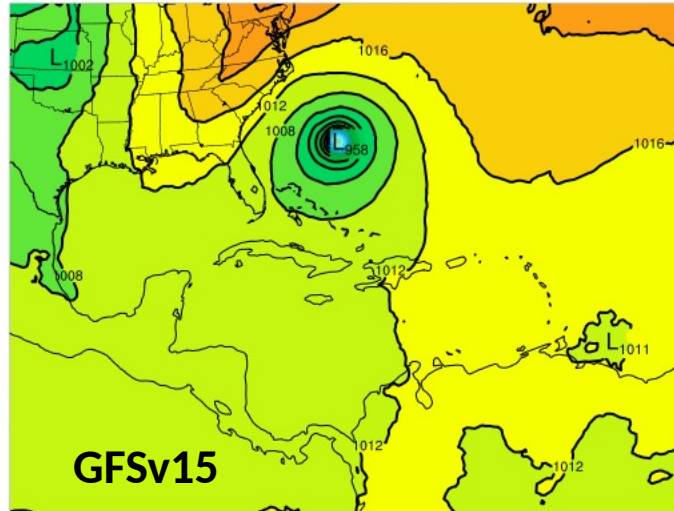
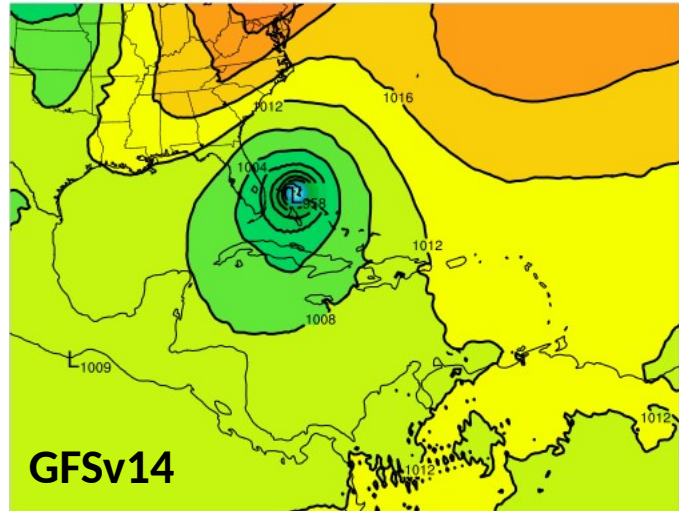
# HURRICANE MATTHEW - 2016

9/30/16 12z F132

GFS Fcst init 00Z 30 Sep 2016 valid 12Z 05 Oct 2016 (F132)

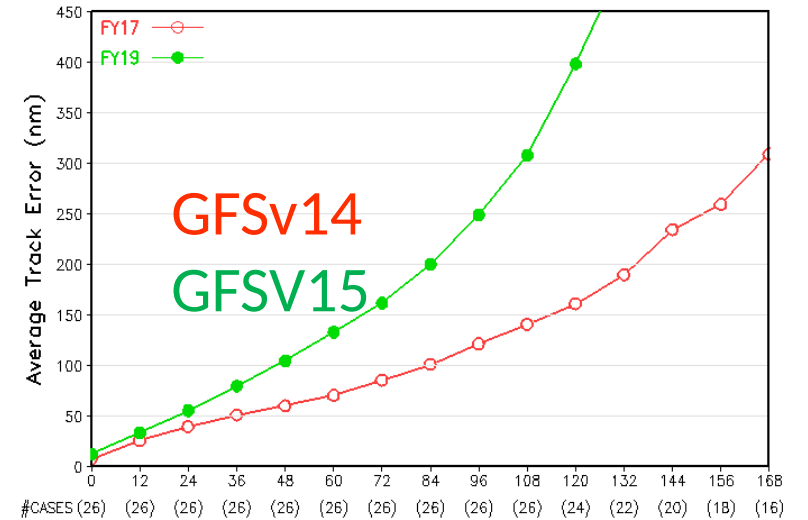
SLP FV3GFS Fcst init 00Z 30 Sep 2016 valid 12Z 05 Oct 2016 (F132)

SLP



## Hurricane Track Errors – Atlantic 2016

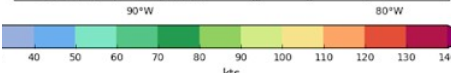
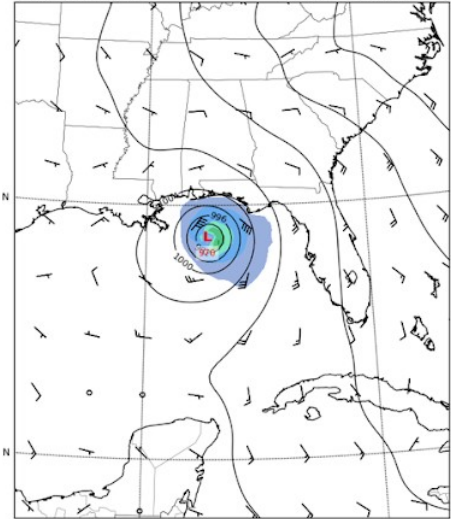
Matthew\_20160928\_20161009\_4cyc



## Confidence Level (%) of Student-t Tests

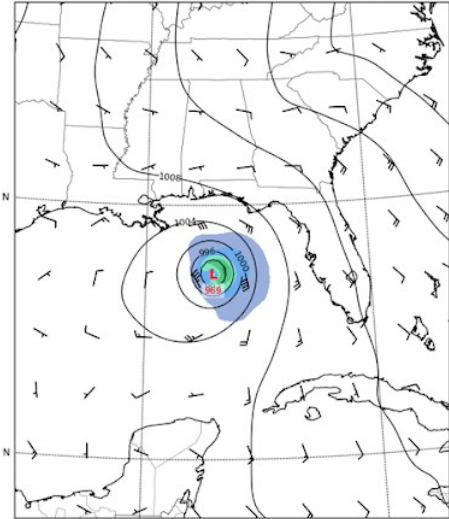
FY17\_FY19 99 98 99 99 99 99 99 99 99 99 99 99 99

FV3GFS Experiment Init: 00Z 07 Oct 2018 Valid: 00Z 10 Oct 2018 (F72)



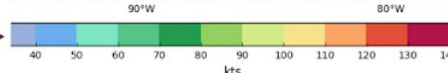
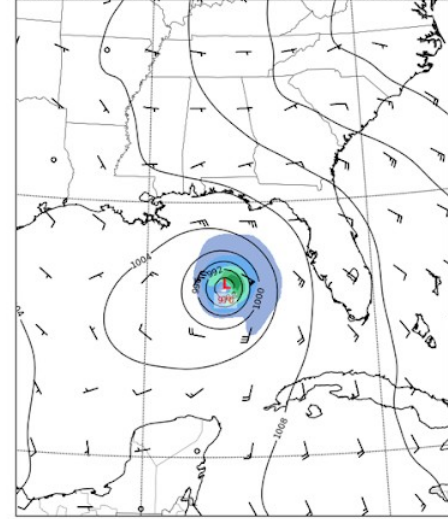
GFSv15

GFS Init: 00Z 07 Oct 2018 Valid: 00Z 10 Oct 2018 (F72)



GFSv14

GFS Init: 00Z 07 Oct 2018 Valid: 00Z 10 Oct 2018 (F00)



GFS ANL

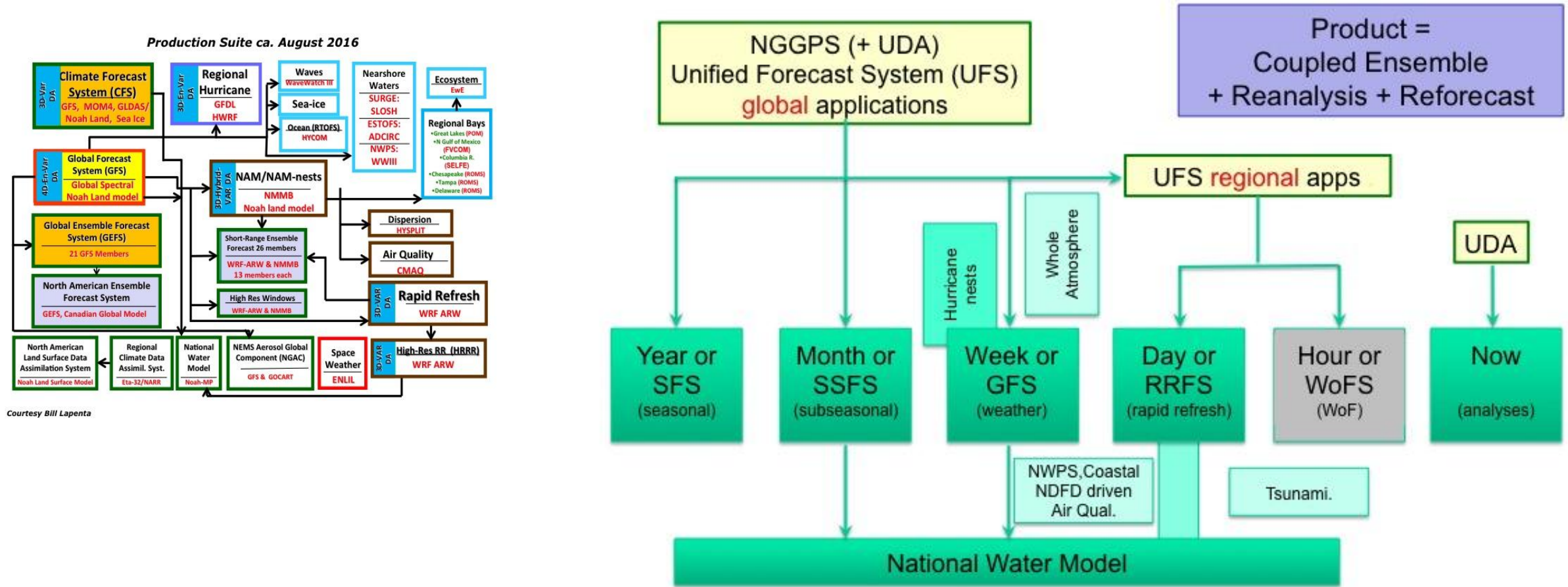
# HURRICANE MICHAEL - 2018

10/7/18 00z F72

**GOING FORWARD**

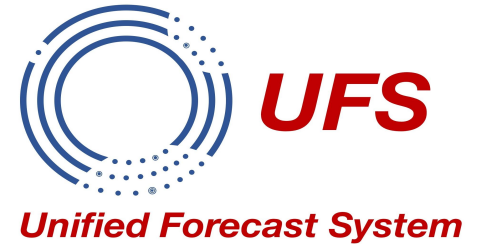


# Target: Simplifying the NCEP Production Suite

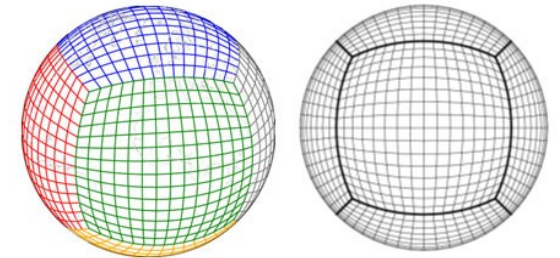


Courtesy Bill Lapenta

# CURRENT PLAN TO SIMPLIFY THE PRODUCTION SUITE

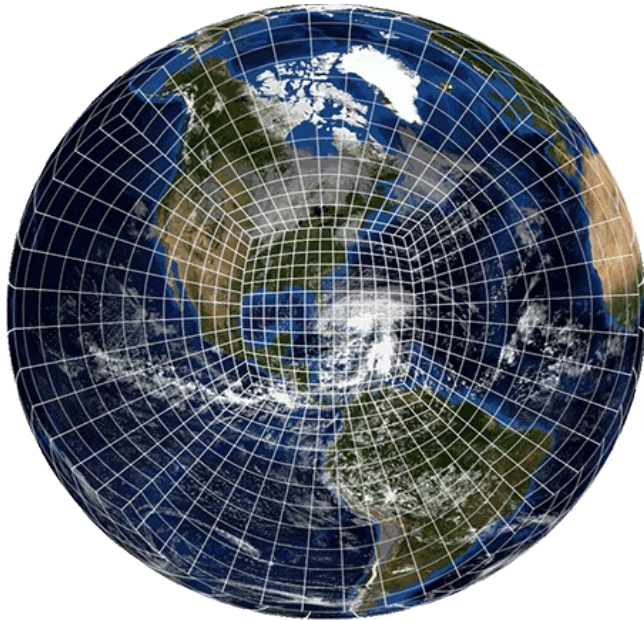


- Move toward the **Unified Forecast System**
- In 2016, the GFDL **finite-volume cubed-sphere (FV3)** dynamical core was selected to be the **cornerstone of future NCEP modeling** efforts
- Allows NCEP to focus development on a **single system**
- Initial work focused on developing the **Next-Generation Global Prediction System (NGGPS)**
- **FV3GFS (GFSv15)**, transition of the Global Forecast System to the FV3 dynamical core, is the first step toward implementing NGGPS



# Sub-Seasonal Forecast System

## *Global Ensemble Forecast System GEFS v12*



- The next step towards the UFS
- Configuration
  - C384L64 (~25km)
  - 31 members, 4 cycles/day
  - Forecast extension to day 35 (1x/day)
- Q2FY19: Start to produce 30 years (1989-2018) reforecast
- Q4FY19: Start to produce retrospective runs (2-3 years)
- Q2FY20: Official evaluation
- **Q4FY20: Implement FV3GEFS operational version (v12)**

## Global Wave Ensemble (GWES) Coupled to GEFS v12

**Coupling to GEFS v12:** Provide initial framework for transition to unified, fully-coupled systems at NCEP,

**New global grids:** Improve overall model skill, and match requirements for inclusion of wave products to NAEFS,

- Global core resolution increased from  $\frac{1}{2}$  degree to  $\frac{1}{4}$  degree,
- Inclusion of Arctic Polar grid with 18km resolution.

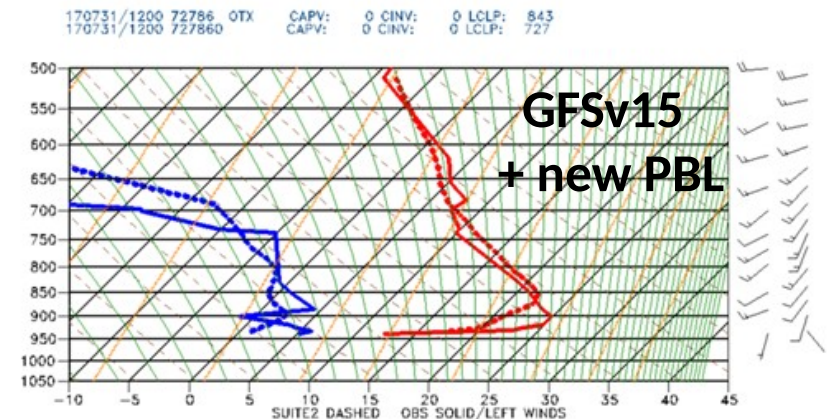
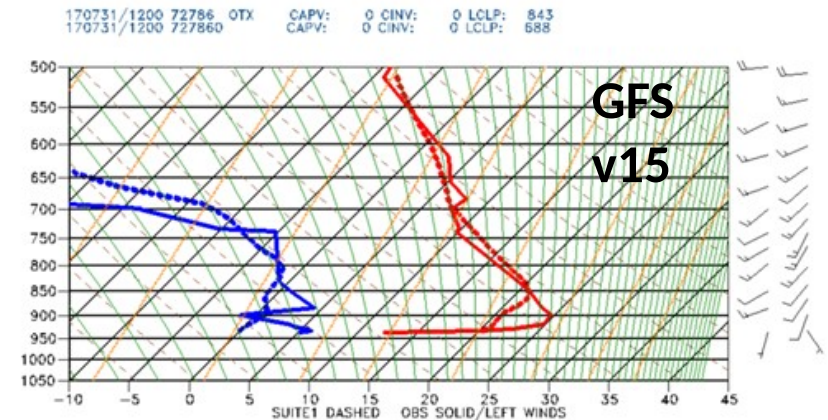
**Objective Physics Retuning:** Reduction of RMS error and bias, adjustment of wave model physics to FV3 forcing.

# GFS V16: Major Upgrades to Deterministic Global Model

- **Model resolution:**
  - Increased vertical resolution from 64 to 127 vertical Levels and raise model top from 54 km to 80 km; Increased horizontal resolution from 13 km to 10 km (depending on operational resources)
- **Dynamics:** New advection algorithms from GFDL
- **Advanced physics chosen from Physics Test Plan:**
  - PBL/turbulence: K-EDMF => sa-TKE-EDMF
  - Land surface: Noah => Noah-MP
  - Gravity Wave Drag: => unified gravity-wave-drag
  - Radiation: updates to cloud-overlap assumptions,
  - Microphysics: Improvements to GFDL MP
- **Coupling to WaveWatchIII**
  - Two-way interactive coupling of atmospheric model with Global Wave Model (GWM)
    - **Evaluation planned for Q3 FY20, with planned for implementation in Q2FY21**
- **Data Assimilation Upgrades:**
  - Local Ensemble Kalman Filter (LETKF), including early cycle updates in support of GEFS
  - 4-Dimensional Incremental Analysis Update (4DIAU)
  - Stochastic Kinetic Energy Backscatter (SKEBS) and land-surface perturbations
  - Stratospheric humidity increments
  - Improved Near Surface Sea Temperature (NSST) analysis
  - Land Data Assimilation
  - Shifting and Lagging Ensemble Members to expand ensemble size
  - Improved cloud analysis
  - Delz increments

# Potential Additional Components of GFSv16

- work ongoing within physics group to understand and further mitigate the low-level cold bias
- New PBL scheme shows promise in slightly mitigating long-standing GFS issues with being too weak with low-level inversions – more testing ongoing



Thank You!      Questions?